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SDDOT Maintenance Decision Support System (MDSS) Operation Plan

Project SD2016-07

Final Report

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DISCLAIMER

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16. Abstract

Maintenance of transportation assets can be complex due to varying weather effects of snow, ice, wind, temperature, and other factors. The goal of DOTs conducting weather event operations and maintenance is to provide safe and clear roadways for motorists. Currently, the South Dakota Department of Transportation (SDDOT) uses the Maintenance Decision Support System (MDSS) for its winter weather maintenance operations. As the lead state for the Pooled Fund Study PF-(054), SDDOT would like a strategic implementation plan to deploy the Pooled Fund MDSS (PFMDSS) and its use further across the state. The goal of this research project is to develop a comprehensive implementation plan for future use of the PFMDSS at SDDOT. To achieve this goal, a rigorous literature review, combined with interviews with SDDOT maintenance staff, discussions and investigations of other state DOTs using the MDSS, and discussions with MDSS vendors were conducted. This process allowed the research team to develop a series of implementation strategies to begin deploying the PFMDSS to more route segments and equipping more trucks with data collection systems and piloting the use of a tablet device as the PFMDSS interface in trucks. The recommended strategies represent the implementation plan for the future use of the PFMDSS. The implementation plan includes adding new route segments into the PFMDSS, equipping more plow trucks with mobile data collectors, use ESS data for weather and road conditions, and pilot the use of the Zonar portable device system. Further, SDDOT should consider hiring dedicated PFMDSS staff to provide expertise and guidance to the agency, adjust and enforce PFMDSS policies, provide training to maintenance staff, conduct post-storm meetings with maintenance staff, integrate plow truck information with public information, explore the use of the PFMDSS for summer use, and consider new and emerging technologies to enhance the PFMDSS . The benefits of implementing the plan include reduced environmental impact, reduced material use, reduced labor costs, reduced fleet maintenance, and safer roadways.

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Acronym	Definition
AVL	Automatic Vehicle Location
AVL/MDC	Automatic Vehicle Location / Mobile Data Collection
BCA	Benefit-Cost Analysis
BHM	Bureau of Highway Maintenance
CANbus	Controller Area Network bus
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communication
ESS	Environmental Sensor Station
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
GPS	Global Positioning System
GUI	Graphical User Interface
HiCAPS	Highway Condition Analysis and Prediction System
HMS	Highway Maintenance Supervisor
HMW	Highway Maintenance Worker
LHMW	Lead Highway Maintenance Worker
I2V	Infrastructure-to-Vehicle
IRIS	Integrated Roadway Information System
MARWIS	Mobile Advanced Road Weather Information System
MDC	Mobile Data Collection
MDSS	Maintenance Decision Support System
MODSS	Maintenance and Operations Decision Support Systems
NCAR	National Center for Atmospheric Research
NWS	National Weather Service
OBD-II	On-Board Diagnostics II
OMB	Office of Management and Budget
PFMDSS	Pooled Fund Maintenance Decision Support System
PFS	Pooled Fund Study
PI	Principal Investigator
QA/QC	Quality Assurance/Quality Control
RCTM	Road Condition and Treatment Module

Acronym	Definition
RWFS	Road Weather Forecast System
RWIS	Road-Weather Information System
SDDOT	South Dakota Department of Transportation
SD	South Dakota
SSI	Storm Severity Index
TPF	Transportation Pooled Fund
US	United States
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
WMI	Winter Mobility Index
WMRI	Winter Maintenance Response Index
WPI	Winter Performance Index
WPM	Winter Performance Measure
WSI	Winter Severity Index

1.0 EXECUTIVE SUMMARY

1.1 Problem Description

Winter maintenance of transportation assets can be complex due to varying weather effects. State department of transportation (DOT) maintenance managers’ process data related to weather and road conditions to make appropriate decisions for roadway treatments. The main goal of any maintenance operation is to ensure the roadway system provides a proper level of service in terms of being clear and safe for motorists. Yet, difficulties exist in analyzing weather and road conditions, and forecasts can be inconsistent and inaccurate at times.

To reduce inefficiencies in roadway winter weather maintenance operations, the Federal Highway Administration (FHWA) initiated the development of a Maintenance Decision Support System (MDSS) Functional Prototype in 2000. Based on the idea of the FHWA MDSS Prototype, the South Dakota Department of Transportation (SDDOT), along with several other state DOTs, created a Transportation Pooled Fund Study, TPF-5(054), to develop a comprehensive and operational MDSS in 2002. The SDDOT has been the lead state for the TPF-(054) Pooled Fund Study since its inception.

Since 2004, SDDOT has used the Pooled Fund MDSS (PFMDSS) to improve the department’s effectiveness and efficiency in maintaining roadways during winter weather events. Currently, the SDDOT has approximately 125 trucks with mobile data collector (MDC) and vehicle location equipment along 232 PFMDSS road segments across 147 routes that totals 3,034-centerline miles of roadway. About 250 SDDOT maintenance employees use the PFMDSS for winter maintenance operations in some manner.

The PFMDSS is a computer-based system that integrates weather, road, and maintenance information to provide scientifically driven treatment options (Hershey, 2011). The PFMDSS is an interactive tool that supports the winter maintenance decision process with information of existing pavement conditions, the physical and chemical characteristics of the pavement, current and forecasted weather conditions, previous treatments used, and available maintenance resources. The PFMDSS considers the number of operators and trucks that a DOT has at its disposal and suggests how to deploy them most efficiently (Peng and Jiang, 2012). The PFMDSS can improve the productivity and cost efficiency of winter maintenance, which translates into improved mobility and safety for traveling motorists. There are three versions of the PFMDSS in use: The MDSS Graphical User Interface (GUI), the MDSS mobile app, and the web-version of the MDSS called WebMDSS.

The PFMDSS includes on-vehicle data systems installed in the cab of plow trucks that maintain PFMDSS route segments. Currently, SDDOT uses an automatic vehicle location/mobile data collector (AVL/MDC) data system mounted in plow trucks that communicates data from the PFMDSS to plow operators to use such as forecast information and maintenance treatment recommendations. The AVL/MDC also communicates actual conditions data that a truck operator enters into the MDC interface in the truck to the PFMDSS to assist with tracking what has occurred, the conditions on a route segment, and forecasting future maintenance actions.

1.2 Research Objective

With SDDOT currently using the established PFMDSS, the research objective of this project is to:

Develop an implementation strategy plan for future use of PFMDSS within SDDOT.

1.3 Task Descriptions

To accomplish the research objective, the research team developed an implementation strategy plan that SDDOT can adopt based on its internal business requirements. To develop the implementation plan, the research team followed the research plan, detailed in chapter 4.0 and listed here:

Task 1: Project kickoff meeting with the technical panel

Task 2: Identify and describe the pooled fund study MDSS

Task 3: Submit Technical Memorandum #1

Task 4: Review MDSS literature from SDDOT and other DOTs

Task 5: Interview SDDOT personnel and staff

Task 6: Submit Technical Memorandum #2

Task 7: Describe the value of the PFMDSS's principal features

Task 8: Describe and compare implementation strategies

Task 9: Submit Technical Memorandum #3

Task 10: Develop a detailed implementation plan

Task 11: Prepare final report

Task 12: Make executive presentation of final report to SDDOT research review board

The research team completed a literature review on the application of the MDSS by collecting information from the FHWA, SDDOT, and other state DOTs. The literature and previous research studies on the MDSS have shown that benefits are possible from the use of an MDSS. The focus of this review was to examine the use and deployment of MDSS for maintenance activities from SDDOT and other state DOTs. Furthermore, the research team engaged with DOTs in the MDSS Pooled Fund Study to gather additional information on their experiences with the MDSS.

Using the information collected in the literature review, the research team developed a pre-interview questionnaire, found in Appendix A, and an interview questionnaire, found in Appendix B. Distribution of the pre-interview questionnaire occurred prior to the interview to collect primary information from maintenance managers and staff, and to shorten the time needed to conduct the interviews. The research team used the data from the pre-interview questionnaire to refine the list of interview questions to ensure that the most useful data would be collected.

The research team then facilitated in-person group interviews in July 2017 with 83 SDDOT maintenance employees. Each interview included at least three SDDOT staff, took between 60 and 90 minutes to complete, and followed the same set of questions. A member of the SDDOT Office of Research monitored all interviews, while the research team conducted the interviews. During the interview week, the research team visited each of the four SDDOT regions to interview the following groups of SDDOT maintenance personnel:

- Area engineers;
- Highway maintenance supervisors (HMSs);
- Lead highway maintenance workers (LHMWs);
- Highway maintenance workers that use a mobile data collector (MDC) (HMWs with MDC); and

- Highway maintenance workers that do not have an MDC (HMWs without MDC).

The research team had detailed discussions with SDDOT personnel on effective practices, benefits, challenges, and other issues related to implementing and using the PFMDSS.

1.4 Findings and Conclusions

While conducting a literature review, collecting responses from the pre-interview questionnaire, interviewing SDDOT maintenance staff in formal group interviews, researching other state DOTs that use an MDSS, and analyzing all SDDOT route segments based on route data provided by SDDOT (presented in Appendices D through G), the research team developed an implementation plan for future PFMDSS use. The plan, listed below and detailed in Section 5.10, provides four strategic components within the implementation plan.

1.4.1 Add New PFMDSS Route Segments

Expanding the PFMDSS to cover more routes statewide can provide better winter weather maintenance management. Currently, the PFMDSS includes 232 route segments. A total of 304 route segments are designated to be added to the PFMDSS as new routes, for a total of 536 PFMDSS route segments across South Dakota.

Based on information provided by SDDOT's Office of Operations Support, a typical installation time for building a route, and sending it to Iteris, Inc. for programming takes about three hours. Deployment should focus on the experience of maintenance shops in the use of the PFMDSS.

1) Shops that currently have at least four PFMDSS route segments should be the focus for immediately adding new route segments. These shops already use the PFMDSS and have plow trucks equipped with MDC units, so the training and startup should be minimal. Each of the 112 new PFMDSS route segments can be programed during the summer of 2019 so they are ready for use during the 2019-2020 winter season.
2) Following the 2019-2020 winter season, the SDDOT can then add new PFMDSS route segments to the maintenance shops that currently have two or three PFMDSS route segments. These shops will have limited experience with the PFMDSS and MDC units, so training will need to take place with these shops and corresponding maintenance staff during the summer of 2019. A total of 109 route segments are to be added across these shops to the PFMDSS. Programming and training are to be completed during summer 2020 to be ready by the beginning of the 2020-2021 winter season.
3) Next, the maintenance shops that currently have one or do not have any PFMDSS route segments will have 83 route segments added to the PFMDSS during summer 2021 for them to be ready for the 2021-2022 season. Training will be necessary during the installation period of the summer 2021 and hands-on guidance should be provided during the 2021-2022 winter maintenance period for these PFMDSS inexperienced maintenance shops.

The costs for the implementation of configuring and programming new PFMDSS route segments is $408,000, which is the total investment SDDOT will need to make over the next five years, as shown in Table 1.

Table 1. Five-year cost summary for adding new PFMDSS route segments

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	$90,000	$88,000	$67,000	$0	$0	$245,000	
Annual Costs	$15,000	$28,000	$40,000	$40,000	$40,000	$163,000	
TOTAL	$105,000	$116,000	$107,000	$40,000	$40,000	$408,000	

With the addition of 304 new route segments, which represents all roadways that SDDOT maintains, more route segments will be available in the PFMDSS for HMSs to use. However, some of the maintenance shops currently have limited or no experience using the MDSS. To train all HMSs, and any LHMWs or HMWs that will use the PFMDSS, PFMDSS GUI training will be need. Iteris, Inc., which is a third-party firm that SDDOT works with in the Pooled Fund Study that provides the technical development and support of the MDSS, can lead the training, as their personnel has firsthand knowledge and are experts in the use of the PFMDSS GUI. SDDOT can conduct GUI training sessions during the summer and fall at regional offices, starting with training the staff at maintenance shops with route segments added for the 2019-2020 winter season, then training staff at maintenance shops with route segments added for the 2020-2021 season, and finally training staff at maintenance shops with route segments added for the 2021-2022 season. Iteris, Inc. and SDDOT should work together to update training materials used in the past. Training should also include the use of the WebMDSS.

Refresher PFMDSS GUI training should be offered to current PFMDSS HMSs users so that SDDOT can build consistency in the use of the PFMDSS by HMSs. The refresher GUI training can be rolled into the full GUI training so that everyone that uses the MDSS has up to date training on the MDSS GUI. In addition, Iteris, Inc. has developed a series of tutorial videos that are quite useful. SDDOT can send out these videos to HMSs via email or other correspondence, with one or two videos sent out on a bi-weekly basis as mini-refreshers.

1.4.2 Deploy the Use of MDCs for Plow Trucks on New PFMDSS Route Segments

In discussions with SDDOT maintenance staff, improving accuracy of forecasts and treatment recommendations can justify the deployment of additional MDC unites to more SDDOT plow trucks. Deploying MDC units to plow trucks will improve consistency of winter weather maintenance processes and procedures throughout the state. MDC deployment will also provide more real-time weather and road condition information, which can improve forecasts and treatment recommendations to maintenance personnel in the field. Of the 304 new PFMDSS route segments programmed and added to the PFMDSS, 188 trucks are to be equipped with MDC units.

The MDC setup for trucks a new system to use for some SDDOT maintenance staff. Therefore, SDDOT needs to provide training to the maintenance shops that are to receive MDC equipped trucks for new PFMDSS route segments. Using a similar deployment method as adding the new PFMDSS route segments, adding MDC to plow trucks includes:

1) Shops that currently have at least four current PFMDSS route segments with MDC unit equipped trucks should be the focus for adding route segments and equipping trucks with AVL systems as soon as possible. A total of 68 trucks are to be equipped for the 2019-2020 winter maintenance season.

2) During summer 2020, trucks to equip with MDC units should focus on the maintenance shops that currently have two or three PFMDSS route segments. Although the these shops will have some experience with the PFMDSS and using MDC units, training will need to take place with these shops and corresponding maintenance staff during the summer of 2020. Seventy new plow trucks are to be equipped in time for the 2020-2021 winter season.
3) Fifty trucks to equip with MDC units will be deployed to shops with limited or no use of trucks with MDC units. Hands-on training will be necessary during the installation period of the summer 2021 and SDDOT will need to provide guidance for the 2021-2022 winter maintenance period to these shops.

A typical installation time for the MDC equipment into a plow truck takes approximately 12 hours, based on information from SDDOT operations support. The installation is to begin in the summer 2019 and continue through summer 2021 with all 188 newly MDC-equipped trucks ready by the 2021-2022 winter season.

Using the deployment schedule and plan, Table 2 outlines the annual costs that SDDOT can expect over the next five years for equipping 188 plow trucks with new MDC units. A discount rate of -0.3% has been applied to values starting with the FY2020 (Office of Management and Budget, 2017). For FY2023 and FY2024, only annual costs are included as the designated number of trucks are to be ready for the winter maintenance season of 2021 – 2022.

Table 2. Five-year cost summary for equipping plow trucks with MDC units

	FY2020	FY2021	FY2022	FY 2023	FY 2024	5-year Total
Capital Costs	$558,000	$576,000	$412,000	$0	$0	$1,546,000
Annual Costs	$118,000	$240,000	$328,000	$328,000	$329,000	$1,343,000
TOTAL	$676,000	$816,000	$740,000	$328,000	$329,000	$2,889,000

Adding MDC units to 188 plow trucks will require MDC training for LHMWs, HMWs, and other maintenance staff that might operate an MDC-equipped truck. The training needed will be MDC training, which can include a classroom session as well as a hands-on training session. SDDOT maintenance staff that use MDC units on a regular basis, such as LHMWs, should conduct the MDC training due to their regular use and experience. In addition, in taking an idea from Indiana DOT, an MDC setup can be brought into the classroom so that trainees can see what it looks like and how it operates before using it.

During the summers of 2019, 2020, and 2021, all maintenance shops that will have newly equipped MDC trucks for each of the upcoming seasons as outlined in the previous section will need to be trained to use the MDC units. This training can be done with LHMWs regionally, using a ½-day classroom session and ½-day hands-on session. Once the LHMWs are trained, they can be responsible to train their HMWs within their shops and this training can take place at their maintenance shop so that the HMWs can be trained locally.

Due to the time needed to install the 188 MDC units and associated equipment, SDDOT will require labor resources for installation. Installation training will need to take place with installers so that they can correctly perform the initial installation and address issues with the equipment once it is in use. Installing technicians need to participate in equipment installation training across each region. Each region can then perform the equipment installation in its fleet. After installation and use, follow up training is to be provided to review the troubleshooting , to answer questions, and collect lessons learned.

1.4.3 Use of Environmental Sensor Stations for Route Conditions

With the addition of new PFMDSS route segments, all roadways that SDDOT is in charge of will be included in the PFMDSS. Therefore, each route segment can use the features of the PFMDSS. To monitor each route segment, collected weather and road conditions information helps to update the PFMDSS for future treatment recommendations. One way to do this is by equipping plow trucks with MDC units, as the previous section detailed. Another way is to use Road Weather Information System (RWIS) and the existing environmental sensor stations (ESSs) located throughout the state that are in close proximity to PFMDSS route segments. The RWIS is a winter observation system comprised of ESSs located throughout a state, a communication system for data transfer, and central systems to collect field data from numerous ESS. The ESSs measure atmospheric, pavement and water level conditions, and other weather and road conditions as designated by the DOT. RWIS hardware and software are used to process observations from ESS and display or disseminate road weather information in a format that can be easily interpreted by a manager. RWIS data are used by DOT maintenance personnel to support decision making (Federal Highway Association, 2017).

The existing ESSs provide real-time conditions at its location along with a camera for maintenance personnel to view the location. To save on the costs and time to equip more plow trucks than the 188 already suggested, SDDOT can consider using the current ESSs in lieu of equipping more trucks. Minnesota DOT uses a similar process with its ESS network and the PFMDSS.

The research team evaluated the location of each ESS and the route segments that are nearest to each ESS. This helped to identify the route segments not already included in the PFMDSS that are close to an ESS location. It was determined that 82 route segments are near an ESS and can use the ESS information for updating route conditions so that an MDC-equipped truck would not be needed on that particular route.

Costs for this component of the implementation plan should be minimal. The ESSs selected are already installed and being used by SDDOT. Also, the route segments close to ESS locations will be added to the PFMDSS as stated in the first component of the implementation plan, so no costs associated with adding the route segments to the MDSS. The difference with this part of the implementation plan is that it is more of a change in processes that requires training for maintenance staff.

To show the savings that SDDOT can experience by using ESSs in lieu of equipping more trucks with MDC units, the cost information provided in Table 3 illustrates that equipping 82 more trucks for 82 route segments would cost SDDOT $1,384,000 over the next five years.

Table 3. Cost savings by not equipping 82 more trucks with MDC units and using existing ESSs

	FY2020	FY2021	FY2022	FY2023	FY2024	5-Year Total
Capital Costs	$672,000	$0	$0	$0	$0	$672,000
Annual Costs	$142,000	$142,000	$142,000	$143,000	$143,000	$712,000

TOTAL	$814,000	$142,000	$142,000	$143,000	$143,000	$1,384,000

Deployment can take place once the new route segments are added to the PFMDSS. The use of ESS data to update the PFMDSS for specific route segments in close proximity to ESS locations can be deployed based on the schedule provided for adding new route segments to the PFMDSS, which is to use a phased schedule over three years.

Although minimal costs will be needed for this component of the implementation plan since no new equipment is being purchased or installed, training will need to be developed and conducted for HMSs and other maintenance staff that might use the PFMDSS with route segments close to ESS locations. The training should focus on the use of data from ESSs and its use with the PFMDSS. Initial training can be done in person to a select group of HMSs per region. Then, the trained HMSs can train the remaining HMSs in their region. In addition, videos are an option for this training in which SDDOT or Iteris, Inc. can develop training videos for distribution to SDDOT maintenance staff.

1.4.4 Pilot the Use of Zonar system for PFMDSS Route Segments

Discussions with SDDOT maintenance staff and managers suggested that SDDOT would like to expand the PFMDSS and equipping more trucks with MDC units, but to consider an alternative to rolling out MDC units to plow trucks. Other state DOTs are investigating moving away from MDC units and other in-cab data systems and interfaces in favor of more portable devices. One option for SDDOT to consider is the use of tablet devices in lieu of the current MDC units used in plow trucks. SDDOT already issues mobile devices to some maintenance staff along with Wi-Fi hotspots for remote Internet connection (e.g., HMSs use laptops or portable devices to access the PFMDSS during a winter weather event).

In addition, SDDOT currently uses mobile devices for specific maintenance activities, such as sign work. A portable device that can access and communicate with the PFMDSS along with other applications for maintenance could allow for more flexibility and better communication of information. Mobile devices can be used in a variety of vehicles, not just plow trucks. SDDOT could assign mobile devices to individual staff rather than certain vehicles to allow portability from one vehicle to another, which is not possible with the current stationary MDC units. A mobile device that a maintenance worker can use daily is more cost-effective than stationary equipment that performs only select functions in select trucks.

Thirteen route segments are suggested to be added to the PFMDSS as Zonar system pilot along with 13 Zonar equipped plow trucks are needed to cover these route segments. The route segments proposed are distributed across the four SDDOT regions so each region can try the Zonar system. The route segments are grouped within maintenance shops so Zonar-equipped trucks can be strategically deployed to cover them. The route segments covered by the Zonar include the remaining interstate route segments not included in the PFMDSS currently as well as US highway route segments in the Aberdeen and Pierre regions.

Since the Zonar system is to be a pilot, the deployment will be contingent on the development and configuration of the Zonar system with the Force America controllers that SDDOT currently uses in its plow trucks. Zonar is in discussions with Force America and several state and local transportation agencies to develop the winter maintenance platform for use by any transportation agency. Once the Zonar and the Force America controllers can be integrated, the pilot can be deployed. In discussions with Zonar, when SDDOT decides to commit to this plan, development of the system for SDDOT can begin as early as the summer of 2020 for deployment to a few route segments. The following suggested timeline will assist with deployment:

1) Initiate discussions with Zonar: June 2019 – August 2019
2) Work with Zonar and Force America to integrate the two systems for SDDOT use: September 2019– July 2020
3) Equip three plow trucks with the Zonar system: July 2020 – October 2020
4) Pilot initial three Zonar equipped trucks on three route segments during the 2020-2021 winter maintenance period: October 2020 – May 2021
5) Depending on the outcome of the initial three pilot route segments and trucks, SDDOT to equip ten more plow trucks with the Zonar system: June 2021 – October 2021
6) Pilot 13 PFMDSS route segments with the 13 Zonar equipped plow trucks during the 2021-2022 winter maintenance season: October 2021 – May 2022
7) Review and discuss pilot results from 2020 – 2021 and 2021 – 2022 winter maintenance seasons to determine if further Zonar deployment is appropriate: June 2022 – August 2022
8) Depending on results of pilot, continue the pilot for another year, discontinue its use, or expand to more route segments at SDDOT's discretion.

Based on this step-by-step process, Table 4 shows the total costs for deploying the Zonar system, starting during the 2020-2021 winter maintenance season. No costs are shown for FY 2020 as deployment will begin during summer 2020 (FY2021) with three trucks and three route segments and then expand to ten more routes and ten more trucks during summer 2021 with use beginning during the 2021-2022 winter maintenance season. A -0.3% discount rate has been applied to years two through five.

Table 4. Five-year cost summary for adding Zonar System to plow trucks

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	$0	$10,300	$32,000	$0	$0	$42,300	
Annual Costs	$0	$4,000	$17,000	$17,000	$17,000	$55,000	
TOTAL	$0	$14,300	$49,000	$17,000	$17,000	$97,300	

Zonar training will need to occur with HMSs, LHMWs, and HMWs. First, SDDOT will need to work with Zonar to develop training materials. Then, Zonar staff can conduct the initial training sessions with the six maintenance shops designated to receive plow trucks equipped with the Zonar system. Training can take place at each maintenance shop and should include a classroom session and a hands-on session within an equipped truck, similar to the MDC training proposed for the second component of the implementation plan. Training will also be needed on the interaction of the PFMDSS with the Zonar system. Training for the three Zonar systems to be installed and used for the 2020-2021 season will need to take place during the summer of 2020. The ten Zonar systems to be installed and used for the 2021-2022 season can be done with SDDOT staff that used the Zonar system during the 2020-2021 season. All Zonar training should be completed by the end of the summer of 2021.

Installation training will also need to occur. As the Zonar system is different from the MDC system, training will need to take place with installers, preferably during the spring of 2020 so that Zonar and SDDOT install the three Zonar systems into three plow trucks before the 2020-2021 season. Then, the remaining ten Zonar systems can be installed prior to the 2021-2022 season, using installers trained during the summer of 2020 and these installers can then train other installers.

1.4.5 Benefits of the Implementation Plan

A summary of the costs for adding new route segments to the PFMDSS, equipping more plow trucks with the MDC system, using ESSs conditions information for route segments in close proximity to them, and piloting the use of the Zonar system for plow trucks are presented in Table 5.

Table 5. Summary of costs for implementation plan

Cost	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
Add Route Segments to PFMDSS	$105,000	$116,000	$107,000	$40,000	$40,000	$408,000
Equip More Plow Trucks with MDC Units	$676,000	$818,000	$740,000	$328,000	$329,000	$2,889,000
Use of ESSs for Route Conditions	$0	$0	$0	$0	$0	$0
Pilot the Use of the Zonar System	$0	$14,000	$49,0000	$17,000	$17,000	$97,000
TOTAL	$781,000	$948,300	$1,337,000	$385,000	$386,000	$3,394,300

Then, the quantified benefits of the implementation plan would be reduced material costs, reduced labor costs, reduced fleet maintenance, and improved level of service for safer travel. The quantified benefits are summarized in Table 6.

Table 6. Summary of benefits for implementation plan

Benefit	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
Reduced Materials	$46,000	$92,000	$138,000	$231,000	$463,000	$970,000
Reduced Labor	$24,000	$47,000	$71,000	$119,000	$238,000	$499,000
Reduced Fleet Maintenance	$131,000	$131,000	$131,000	$131,000	$132,000	$656,000
Safer Travel	$1,138,000	$1,084,000	$1,033,000	$985,000	$938,000	$5,178,000
TOTAL	$1,339,000	$1,354,000	$1,373,000	$1,466,000	$1,771,000	$7,303,000

As the total cost for the implementation plan is $3,394,300 and the quantitative benefits for the implementation plan is $7,303,000, the benefit-cost ratio for the implementation plan is 2.15:1. Also as a comparison, if SDDOT decides to equip 82 more trucks with MDC units instead of using the ESSs, the total cost of the implementation plan would then increase by $1,384,000 to $4,778,300. The potential benefits would be the same, so that the benefit-cost ratio is 1.53:1.

1.5 Recommendations

Recommendations are based on the findings from the literature review, a review of SDDOT other state DOTs that use an MDSS, a pre-interview questionnaire from SDDOT maintenance staff, and the interviews conducted with SDDOT maintenance staff and managers.

1.5.1 Hire dedicated staff in each region for the PFMDSS

Applying practices from other state DOTs, there is a potential for SDDOT to provide dedicated PFMDSS staff within each region to provide timely support, training, and operation of the PFMDSS. Dedicated staff can help substantially improve the effective use of the PFMDSS across state. Other state DOTs (e.g., Minnesota DOT) have hired dedicated staff for their MDSS operations. Dedicated staff, which should include at least one person per SDDOT region, would be responsible for maintaining the PFMDSS as well as the MDC and Zonar equipped trucks. Further, dedicated staff are in charge of conducting training for the PFMDSS, MDC units, and Zonar units.

Dedicated staff will need to be trained in the PFMDSS, the MDC units, and the Zonar system. Once trained, the dedicated staff will have knowledge to use throughout the department that is retained within SDDOT and not from a third party. This then keeps the experience and knowledge in house at SDDOT and makes it easier to pass the knowledge along to other maintenance employees.

1.5.2 Adjust and enforce policies for using the PFMDSS

The interview results found that some HMSs allow HMWs to vary treatment recommendations based on the actual conditions, and their experience and intuition, while other HMSs limit the ability of HMWs to vary the recommendations from PFMDSS as these should be the best option and should not be adjusted. As a result, SDDOT needs to decide when HMWs can vary the treatment recommendations. To obtain consistency, SDODT should have a policy, whether to follow recommendations explicitly, or adjust them based on real-time conditions.

LHMWs and HMWs are to update route conditions in the MDC at the end of each route. Yet, many maintenance staff mentioned that they often forget to perform this task. They stated that it is difficult to find a place to pull over to update conditions since the MDC will not work if the plow truck is moving faster than five miles per hour. The route condition updates are the most real-time information that the PFMDSS can use so updating is vital to the optimal use of the PFMDSS. It is recommended that SDDOT require route condition updates at the end of each route by all maintenance units.

The end of route survey is a simple and quick survey for HMWs to fill out. SDDOT should reinforce the importance of filling out these surveys and sharing the results with staff. Currently, end of route surveys are only filled out occasionally based on the interviews with maintenance personnel. It is important to complete the end of route surveys as the more data collected, the better the PFMDSS performs.

Finally, SDDOT maintenance staff with extensive experience with PFMDSS noted a lack of communication on MDSS operation expectations. Many other maintenance staff hired since the initial deployment could not state the actual expectations for using the PFMDSS. It is then important that SDDOT develop expectations, if they do not already exist, and communicate them to all levels of maintenance staff. Promoting the use of the PFMDSS and any future implementations will require support from high levels of management, and will require buy-in from maintenance workers. Buy-in can be established by developing the expectations that all maintenance staff are to follow.

1.5.3 Provide training to all SDDOT maintenance staff

Many SDDOT maintenance staff noted that training plays an important role for implementing the PFMDSS. They stated that training usually occurs each year for those that want it, but it could be an advantage to provide more in-depth training and require more HMSs, LHMWS, and HMWs to attend. Some SDDOT maintenance staff noted that they are not using the PFMDSS to its fullest potential because they are unsure of what the PFMDSS can do, which means more training would be beneficial. Training was outlined in the implementation plan. Further, SDDOT has a series of YouTube videos that detail various aspects and features of the PFMDSS, found on the Pooled Fund Study website. SDDOT can consider developing additional videos for the MDC units and the Zonar system. Additional videos can be developed for any new features that are added in the future, and for other PFMDSS platforms, which include a mobile app for mobile devices and a web-version that does not require software to use.

In discussions with HMWs with SDDOT, several of the newer employees noted that they received no formal training in using the MDC and never received any guidance or training in using the PFMDSS. It is suggested to provide MDC training to all LHMWs and HMWs, even if they do not use a truck with an MDC system. Further, although the HMWs do not interface with the PFMDSS, HMWs should still receive training on the PFMDSS so that they understand the system better. This may lead to potential benefits that the skeptical staff will begin to see the value of the PFMDSS.

1.5.4 Conduct review sessions after each winter storm event

SDDOT should consider meeting with HMSs, LHMWs, and HMWs after a storm event to discuss the accuracy of forecast and treatment recommendations and share lessons learned to help improve winter weather maintenance. The meeting should include using the PFMDSS and the data collected from the previous storm. The PFMDSS records and store data before, during, and after winter weather events, which then a PFMDSS user can employ the time slider to animate the data. The data that can be animated includes radar, visible satellite, infrared satellite, visible satellite and radar, infrared satellite and radar, air temperature, dew point, relative humidity, wind speed, wind gusts, hourly precipitation, hourly snow, and maintenance truck location and movement. Once the play button is pressed, the map will animate the data (and loop it if the option is selected) within the specified time period. The animation works in time intervals, which can be set to 10, 20, 30, or 60 minutes. The PFMDSS also provides a speed controller for the animation, which allows users to speed up the animation or slow down the animation to view what is happening to the data selected during the time period chosen.

Beyond using the time slider and data for after-storm recap meetings, the time slider and data animation feature can also be used for training maintenance managers and staff. Historical data collected from previous storms can be used to simulate winter storm events so that maintenance personnel can experience real scenarios of a winter storm before using it for an actual storm (Federal Highway Administration, 2012). The PFMDSS can simulate potential impacts of new maintenance practices or different levels of service for various winter weather conditions using the recorded data from previous storms.

1.5.5 Provide performance information on the PFMDSS to maintenance staff demonstrating its usefulness

During the group interviews, SDDOT maintenance staff stated that most maintenance staff do not think the PFMDSS is accurate enough and may not be that useful. To change that perception, it is recommended that SDDOT report performance measures to their staff to show that the PFMDSS works and is accurate when it is used appropriately. Deviating from the PFMDSS plan, such as not entering in road and weather conditions in the truck data system at the end of a route, can result in inaccuracies in the data coming from the PFMDSS. This situation can be shown to maintenance workers using performance metrics and collected and recorded data from previous storms in the PFMDSS to make workers accountable for their actions.

1.5.6 Integrate plow truck information with traveler information systems

The data from MDC and Zonar systems for plow trucks can be integrated with travel websites such as SafeTravelUSA to display images of trucks treating roadways and provide the public a visual of current road conditions. Features to report from the plow trucks could include truck location and direction, real-time road conditions, plow truck camera images, treatments made to a road, and when SDDOT plans to plow a road.

1.5.7 Revise the management reporting tool for the PFMDSS

The PFMDSS includes the winter maintenance response index (WMRI) tool, which provides maintenance managers information on labor, equipment, and material use. The WMRI reports data from the PFMDSS to help make business decisions about the amount of resources needed for winter weather maintenance. The WMRI can also provide reports from previous winter storm events to simulate costs of new practices or to vary the level of service for similar winter weather conditions. However, maintenance managers feel the WMRI tool is not as intuitive as it could be. Some mentioned the difficulty in navigating the tool and finding the information they need. Other maintenance staff mentioned that they normally forget how to use the PFMDSS from one season to the next due to its complexity. SDDOT should consider refining the WMRI tool and other management reporting tools so maintenance managers can generate reports easily and quickly. Further, specific training on the WMRI should be considered on an annual basis.

1.5.8 Explore the use of the PFMDSS for non-winter maintenance operations

The PFMDSS has the potential to be used with summer maintenance activities. A few state DOTs have begun using the PFMDSS for summer maintenance. Minnesota DOT uses the PFMDSS in paint striping and herbicide spraying during summer maintenance operations. Michigan DOT also performed a pilot of the PFMDSS for applying herbicides in summer 2016. Colorado DOT is piloting the PFMDSS application for non-winter operations such as weed spraying, mowing, lane striping, and surface repairs. All these instances are small-scale deployments to determine whether using the PFMDSS for summer maintenance is cost effective and useful.

Indiana DOT uses the PFMDSS not only for winter weather maintenance operations, but also to help with: (1) equipment purchasing, (2) defining and naming support staff, (3) implementation and follow-up training, and (4) a quality assurance/quality control accountability program. Additionally, Indiana DOT used the PFMDSS for chip seal maintenance during the summer of 2015. The PFMDSS was used to identify periods where air temperature was above 60 degrees Fahrenheit and relative humidity was below 70%. A chip seal operation could be scheduled or postponed based on a long-range forecast of humidity and probability of precipitation from the PFMDSS.

Wisconsin DOT has also applied the PFMDSS for summer maintenance. One specific application is using the PFMDSS to help Wisconsin DOT's awareness of ideal conditions for pavement buckling to occur. The Wisconsin DOT has set up alerts within the PFMDSS to provide advanced notice that conditions are right for pavement buckling to potentially develop on roadways. Maintenance managers can then be alerted to possible roadway buckles, and have crews ready to perform repairs if they do in fact occur.

It is recommended that SDDOT explore and evaluate similar PFMDSS uses for summer maintenance before deploying and using it for summer maintenance activities. A full scale study should be considered and a pilot developed for summer use of the PFMDSS.

1.5.9 Consider new and emerging technologies for future PFMDSS integration

The PFMDSS may soon be able to incorporate information from automated vehicles, connected vehicles, and information technology to enhance its abilities and refine its use. For example, new mobile sensors can collect various conditions such as air temperature, road surface condition, surface grip or traction, wind speed and direction, and precipitation rates and amounts. SDDOT will need to advance the PFMDSS functionality to use new technologies such as mobile sensors on the horizon. It is recommended that SDDOT closely follow the various testing and pilot studies (e.g., Indiana DOT’s use of mobile sensors, Wyoming DOT’s connected vehicle pilot along I-80) to further investigate the use of mobile road weather information systems and interconnected vehicles.

2.0 PROBLEM DESCRIPTION

For winter maintenance applications, State department of transportation (DOT) maintenance managers often have to evaluate data related to weather forecasts, weather conditions, and road conditions. DOTs must also deal with multiple tasks continuously throughout the weather event to make appropriate decisions for roadway surface treatments. The main goal of maintenance operations is to ensure that roadway systems provide a proper level of service in terms of clear and safe roadways for the traveling public. However, many factors challenge maintenance managers at state DOTs, including:

- increasing need of motorists to travel all times of the day, every day of the year
- demanding product delivery and travel schedules require higher levels of service
- fixed levels of agency funding and staff
- limited equipment availability
- difficulty in obtaining reliable and timely site-specific road condition reports
- limited road surface condition information, which can vary even on short stretches of roadway
- inaccuracies in weather forecasts or ineffective interpretation of forecasts
- difficulty in forecasting certain weather-related conditions such as fog, frost, blowing and drifting snow
- complex interactions of snow, ice, water, chemical, and traffic at the pavement surface
- capabilities and limitations of new and innovative maintenance treatments are not fully understood
- retirement of experienced maintenance staff (Murphy et al., 2012; Ye et al., 2009; Hart and Osborne, 2003)

To reduce the inefficiencies of roadway clearing operations during severe weather events, the Federal Highway Administration (FHWA) initiated the development of a Maintenance Decision Support System (MDSS) Functional Prototype in 2000. The state transportation departments of Indiana, Minnesota, North Dakota, and South Dakota felt the FHWA MDSS Functional Prototype did not fully meet their maintenance operational needs and created a Transportation Pooled Fund Study, TPF-5(054), to develop a comprehensive and operational MDSS in 2002. The South Dakota Department of Transportation (SDDOT) has been the lead state for the TPF-5(054) Pooled Fund Study since its inception. SDDOT began using the Pooled Fund MDSS (PFMDSS) in 2004 to improve its winter maintenance operations.

Currently, the SDDOT has approximately 125 trucks instrumented for the PFMDSS along 147 PFMDSS routes that 232 PFMDSS route segments, totaling 3,034 miles of roadway. About 250 SDDOT employees use the PFMDSS for winter maintenance operations in some manner. The next phase of deploying the PFMDSS is to develop an implementation strategy plan for future use of the MDSS within SDDOT.

As the development of the PFMDSS continues to advance, the SDDOT can implement a new operation plan for the PFMDSS as the tool for winter weather events and possibly summer maintenance activities. However, it is important to understand the costs of implementation and use, and the potential benefits associated with the use of new technologies, new processes, and the possibility of expanding the PFMDSS to more route segments and more MDC unit equipped plow trucks.

This report includes a summary of the research objective (Section 3.0), the research plan and associated task descriptions (Section 4.0), the findings and results from the research process and collected data (Section 5.0), recommendations (Section 6.0), and benefits of this research (Section 7.0).

3.0 RESEARCH OBJECTIVES

The primary objective of this research project is to develop an implementation strategy plan for future operational use of the PFMDSS within SDDOT. To accomplish this objective, the research team developed an implementation plan, and a list of recommendations, that SDDOT can adopt based on its internal business requirements. The plan components are expected to benefit SDDOT by providing more efficient and effective maintenance operation plans.

3.1 Develop Implementation Strategy

Develop an implementation strategy for future use of PFMDSS within SDDOT.

Using the information collected and investigated through 12 research tasks, the team prepared an implementation strategy plan for SDDOT to effectively implement and operate the PFMDSS for future winter maintenance operations.

4.0 TASK DESCRIPTIONS

To achieve the overall objective, this research project included 12 tasks. The deliverables from this study included three technical memoranda and the final report. The study also provided SDDOT with recommendations for future PFMDSS implementation. Figure 1 shows a flow chart of the work. Each of the 12 tasks is detailed in the following sections.

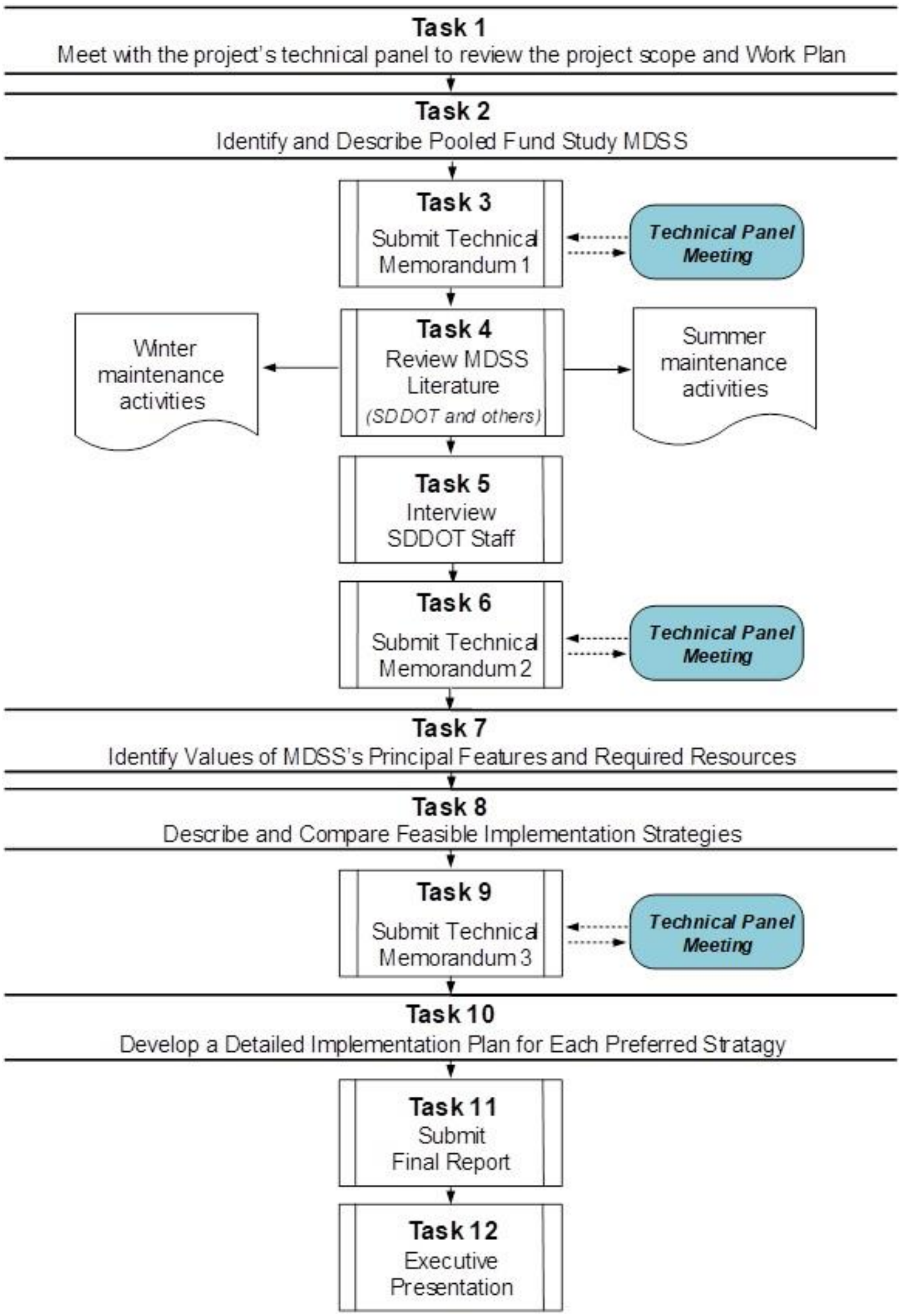

Figure 1. Overview of the research methodology

4.1 Task 1: Project Kickoff Meeting with Technical Panel

Meet with the project's technical panel to review the project scope and work plan.

The objective of this kick-off meeting was to introduce the research team to the technical panel, review the project scope, respond to any questions, and finalize the work plan. The research team worked with SDDOT to schedule the kickoff meeting and provided an agenda for the meeting. Based on the availability of the technical panel members, the kickoff meeting was held in February 2017 at SDDOT's central office in Pierre, SD. The half-day meeting agenda included:

- a review of the project scope, deliverables and responsibilities
- the research team answering questions from the technical panel
- the technical panel answering questions from the research team
- a demonstration of the MDC system in one of SDDOT's plow trucks
- final thoughts and a plan for the research team to move forward with the project

After the meeting, the SDDOT Office of Research reviewed the MDSS Graphical User Interface (GUI) with the research team and set up an account for the research team to download, install, and access the MDSS GUI. Additionally, the research team prepared and distributed meeting minutes to the technical panel for review.

4.2 Task 2: Identify and Describe the Pooled Fund Study MDSS

Identify and describe the principle features of the Pooled Fund Study Maintenance Decision Support System (PFMDSS).

The objective of this task was for the research team to review the MDSS from the Transportation Pooled Fund Study TPF-5(054) to identify and describe features of the PFMDSS. The PFMDSS is an operational tool for weather event maintenance. To develop the PFMDSS and its use, a collection of several state DOTs, led by South Dakota, pooled resources and the Transportation Pooled Fund Study, *TPF-5(054) Development of a Maintenance Decision Support System*, began in 2002. The study has developed, refined, validated, and deployed an operational and sustainable PFMDSS (Pisano et al., 2006). As of 2018, 13 state DOTs are providing funds and resources to continue the development and refinement of the PFMDSS.

After gaining access to the pooled fund study website (mdss.iteris.com/mdss/pfs/), the research team collected documents, reports, summaries, newsletters, proposals, videos, and any other relevant materials. The information provided the research team with the progression of the MDSS from the FHWA MDSS Functional Prototype to the current PFMDSS. The research team described the PFMDSS, its design and development, and on-vehicle data systems and user interfaces. The research team used collected information to develop the questionnaire for the interviews with SDDOT staff.

4.3 Task 3: Submit Technical Memorandum #1

Submit a technical memorandum and meet with the project technical panel to present the results of Tasks 1-2.

The research team developed a technical memorandum with the results from research Tasks 1 and 2 and submitted it to the project technical panel in April 2017. After receiving the comments from the technical panel, the research team revised and resubmitted Technical Memorandum #1 in May 2017. The team then presented findings from Technical Memorandum #1 to the project panel in June 2017.

In addition, the research team submitted a draft list of interview questions for panel review. The interview questionnaire, which was developed based on the information gathered from the MDSS pooled fund study documents and reports, inquired about the PFMDSS and possible improvements from SDDOT maintenance managers and staff. Based on comments and feedback from the panel, the research team revised the interview questionnaire and discussed them with the technical panel during the Technical Memorandum #1 meeting.

Based on the panel's feedback, the research team and the technical panel developed and distributed of a pre-interview questionnaire (see Appendix A). The questionnaire allowed the research team to separate the more straightforward questions from the open-ended questions used in the interviews. The pre-interview questionnaire, distributed electronically to SDDOT maintenance staff via email, was completed before conducting any interviews.

4.4 Task 4: Review MDSS Literature from SDDOT and Other DOTs

Thorough review of published literature and interviews with responsible staff, summarize other agencies' experience regarding deployment and use of MDSS for winter and summer maintenance activities.

The research team completed a literature review on the application of the MDSS by collecting information from the FHWA, SDDOT, the Pooled Fund study, and other state DOTs. Previous studies of the MDSS have shown that its use can generate benefits for maintenance operations in the winter. The focus of this review was to examine the use and deployment of MDSS for maintenance activities in SDDOT and other state DOTs. Documented benefits of implementing the MDSS include:

- reducing costs of labor, materials, and equipment
- improve productivity
- improving public safety
- improving mobility
- realizing a higher level of service for roadways
- maintaining a level of consistency in services
- reducing the impact to the environment
- providing training for both new and experienced DOT personnel
- providing a "one-stop" location for weather and pavement treatment information
- enhancing collaboration between DOT maintenance areas
- providing a way to review maintenance actions from past winter weather events
- better staging of equipment during pre-storm preparations
- ability to better allocate maintenance personnel
- making more informed decisions about the effectiveness of chemicals before, during, and after a weather event (McClellan et al., 2010; Cluett and Jenq, 2007; Dye et al., 2008)

4.5 Task 5: Interview SDDOT Personnel and Staff

Interview selected managers, staff, and other stakeholders within SDDOT regarding awareness, acceptance, extent of use, perceived value, shortcomings, and needed technical and operational improvements related to the implementation of the MDSS.

The research team provided the interview questionnaire to the project technical panel for review and approval via Technical Memorandum #1. After receiving the panel's feedback and comments, the research team revised the questionnaire (See Appendix B). With the assistance of the project technical panel, the research team identified SDDOT maintenance managers and staff who know, understand, and use the PFMDSS. To fully understand the use of PFMDSS in SDDOT, the research team focused interviews with:

- highway maintenance supervisors (HMSs), lead highway maintenance workers (LHMWs), and highway maintenance workers (HMWs)
- Area Engineers
- other SDDOT personnel with knowledge of the PFMDSS, such as the Office of Research and Operations Support

The interviews were set up as in-person interviews of groups rather than individuals to allow the research team to talk with a large number of SDDOT staff. Each interview included at least three SDDOT maintenance managers or staff and took between 60 and 90 minutes. The interviews with SDDOT maintenance staff were conducted by the Principal Investigator (PI) during the last week of July 2017, while a member of the SDDOT Office of Research monitored each interview. During that week, the research team visited each of the four SDDOT regions (Rapid City, Pierre, Aberdeen, and Mitchell) to interview Area Engineers, HMSs, LHMWs, HMWs using a plow truck with an MDC system, and HMWs using a plow truck without an MDC system.

During the interviews, the research team had discussions with SDDOT maintenance managers and staff on effective practices, benefits, challenges, and other relevant issues related to using the PFMDSS. A total of 83 individuals were interviewed, as summarized in Table 7.

Table 7: Breakdown of the SDDOT maintenance staff interviewed about the PFMDSS

Interviewee	Rapid City Region July 24, 2017	Pierre Region July 25, 2017	Aberdeen Region July 26, 2017	Mitchell Region July 27, 2017	Total
HMS	2	3	3	4	12
LHMW	4	6	4	4	18
HMW with MDC	4	4	6	5	19
HMW without MDC	6	4	6	7	23
Area Engineer	5	2	2	2	11
TOTAL	21	19	21	22	83

An additional interview occurred via a webinar in September 2017 with four individuals from Operations Support and two from the Office of Research at the headquarters office in Pierre. The purposes of this interview were to:

- verify and validate the findings from the previous interview of the 83 maintenance managers and staff
- gather feedback from SDDOT support and research staff

4.6 Task 6: Submit Technical Memorandum #2

Submit a technical memorandum and meet with the Technical Panel to present the results of Tasks 2-5.

At the completion of the interviews, the research team prepared Technical Memorandum #2 that summarized the features of MDSS, the deployment and use of MDSS for maintenance activities, and the identified and potential value of PFMDSS at SDDOT. Technical Memorandum #2 was submitted to the project technical panel for review in October 2017. The research team worked with SDDOT staff to schedule a meeting with the technical panel to present the results, which took place in December 2017.

Meeting participants discussed the next steps for this study based on the findings from the literature review, the pre-interview questionnaire, and the group interviews with SDDOT maintenance staff. Additionally, the research panel provided feedback on Technical Memorandum #2 in January 2018. The research team addressed the panel's comments on Technical Memorandum #2.

4.7 Task 7: Describe the Value of MDSS's Principal Features

Based on the documented capabilities of MDSS and the experience of SDDOT and other agencies, describe the realized and potential value of MDSS's principal features and the resources required to provide them.

The research team documented features of the PFMDSS used by either SDDOT staff or other state DOTs by synthesizing literature review findings and results of the interviews. The research team then developed candidate implementation strategies with potential to help SDDOT achieve their maintenance operations expectations from implementing the PFMDSS system. Next, the research team performed an analysis of costs and benefits of each of the components included in the implementation plan. To perform the analysis, the research team estimated the benefits of the PFMDSS candidate strategies as well as the capital and annual costs.

4.8 Task 8: Describe and Compare Implementation Strategies

Describe and critically compare feasible implementation strategies that incorporate features most valuable to SDDOT, in consideration of SDDOT's business needs, discrete MDSS capabilities, technology requirements, deployment and ongoing support costs, training, needed enhancements, and resource needs and constraints.

A total of eight candidate implementation strategies were proposed to SDDOT for future PFMDSS use and implementation. To evaluate the impact of the suggested strategies on the overall goal of providing safe and efficient transportation during winter weather events, the research team analyzed the requirements for the implementation plan based on the following factors:

1) SDDOT's business needs: How does the implementation plan align with SDDOT's business needs and help SDDOT provide a safe and effective public transportation system?
2) Discrete PFMDSS capabilities: How does the implementation plan utilize one or more PFMDSS key features?

3) Technology requirements: What technologies does the implementation plan require which SDDOT does not currently have in possession?
4) Deployment and ongoing support costs: What deployment and ongoing support costs does implementation plan require that are within SDDOT's budget?
5) Training needs: What additional training is required for SDDOT staff for the implementation plan?
6) Required enhancements: What enhancements in SDDOT's current processes, policies, or standards does the implementation plan require?
7) Resource needs: What additional resources does the implementation plan require from SDDOT and are there any constraints within SDDOT that prevent the implementation plan?

4.9 Task 9: Submit Technical Memorandum #3

Submit a technical memorandum and meet with the Technical Panel to present the results of Task 8 and identify preferred candidate implementation strategies.

Building upon the work completed in Task 8, the research team developed the third technical memorandum, which details the findings and results from Tasks 7 and 8. In addition, Technical Memorandum #3 contains information for the preferred candidate strategies that the research team identified in Tasks 6 and 8. The technical memorandum was submitted to the project technical panel for review in January 2018. Based on the availability of SDDOT staff, the panel members, and research team, the Technical Memorandum #3 meeting was held in February 2018 in Sioux Falls, SD. Goals of this meeting were to present the results, discuss any questions or concerns, and determine the preferred implementation candidates, which the research team developed into an implementation plan in subsequent tasks.

4.10 Task 10: Develop a Detailed Implementation Plan

For each preferred candidate implementation strategy, develop a detailed implementation plan proposing tasks, timelines, resource requirements, training, performance measures, and organizational communication and describing advantages and disadvantages of the strategy.

The research team developed an implementation strategic plan around four components that includes adding route segments to the PFMDSS, equipping more trucks with MDC units, using environmental sensor stations (ESSs) for road and weather conditions information in lieu of equipping trucks with MDC units for route segments close to ESS locations, and piloting the use of the Zonar system. The research team included a description, unit and total costs, implementation budget, implementation schedule, and a description of training for each component (See Section 5.10). The research team then provided the potential benefits of implementing the plan (See Section 7.0). The implementation plan allows SDDOT to determine the course of action for future PFMDSS operations.

4.11 Task 11: Prepare Final Report

In conformance with Guidelines for Performing Research for the South Dakota Department of Transportation, prepare a final report summarizing the research methodology, findings, conclusions, and recommendations.

The research team developed the final report by compiling data, findings, and analyses and by addressing panel's comments and feedback. The final report summarizes the research methodology, a recap of the entire research project, findings from the literature review and other state DOTs, pre-interview and interview processes, the implementation plan, recommendations, and research benefits.

4.12 Task 12: Make Executive Presentation of Final Report to SDDOT Research Review Board

Make an executive presentation to the South Dakota Department of Transportation Research Review Board at the conclusion of the project.

The research revised the draft final report to address the comments and feedback from the panel and provided it to the technical panel and the SDDOT Research Review Board prior to making the executive presentation. The research team traveled to South Dakota to present the research, implementation plan, and recommendations.

5.0 FINDINGS AND CONCLUSIONS

The objective of this study was to develop an implementation plan that SDDOT can use to further deploy and use the PFMDSS throughout South Dakota. This section presents findings and conclusions from analyzing data relevant to implementing and using the PFMDSS collected from SDDOT and other state DOTs. The findings and results are based on:

1) A literature review
2) review of other state DOTs using the MDSS
3) the pre-interview (survey) questionnaire
4) in-person group interviews with 83 SDDOT maintenance staff
5) verifying interviews through discussions with six SDDOT employees from the Offices of Research and Operations Support
6) data, maps, and documents provided by SDDOT

5.1 The Maintenance Decision Support System

5.1.1 Overview of MDSS

MDSS is a computer-based tool for winter road maintenance operators that integrates weather, road, and maintenance information to recommend scientifically driven maintenance action options (Hershey, 2011). An MDSS is a decision-support tool, not a decision-making tool, which can assist maintenance personnel to interpret road and weather information and make more informed decisions. MDSS is an interactive tool that supports the maintenance decision process by analyzing existing pavement conditions, the physical and chemical characteristics of the pavement, current and forecasted weather conditions, previous treatments used, and available maintenance resources. The MDSS integrates this information, along with staff, equipment, and material resources available, and uses it to recommend optimal treatments for a specific roadway (Dye, 2008).

The MDSS consists of three primary components, which are the MDSS information system, a graphical user interface (GUI), and on-vehicle data systems (Murphy et al., 2012). The MDSS information system integrates a variety of weather and maintenance data to simulate pavement surface maintenance responses. The MDSS GUI provides the detailed information and data from the MDSS information system, including weather and road surface conditions and forecasts and maintenance treatment recommendations, to MDSS users. The on-vehicle data system collects weather and road conditions for use by the MDSS information system and informs operators of route-specific forecasted conditions and treatment recommendations provided by the MDSS (Murphy et al., 2012).

Operationally, the MDSS provides prediction information along roadways on precipitation type and amount, pavement temperature, and winter material chemical concentrations by addressing two primary functions:

1) Real-time assessment of current and future conditions: The MDSS assess the current road and weather conditions information using time- and location-specific forecasts along specific MDSS routes.

2) Real-time maintenance treatment recommendations: Using the weather and road information assessment information, the MDSS suggests viable maintenance treatment recommendations based on available staff, equipment, and materials (Ye et al., 2009)

The second function provides the specific maintenance actions based on the assessment in the first function, which demonstrates the decision-support advantage of the MDSS. Furthermore, a secondary function of the MDSS is the ability to record and store information from winter weather events. This allows a DOT to use this information for future storms (e.g., historical data and lessons learned) and for training maintenance personnel.

As a decision-assisting tool, the MDSS provides benefits that can enhance the business needs of a state DOT. Some of the benefits recognized in the use of an MDSS include:

- consistent level of service for winter maintenance and traveler safety
- cost savings for treatment materials
- improved treatment recommendations
- improved forecasting capabilities
- improved incident management
- improved operator safety
- improved communications
- improved accountability
- automated reporting capabilities
- improved winter crash analysis
- new operational mapping
- real-time storm management
- summer asset observations (Wisconsin Department of Transportation, 2013).

One of the main steps of initiating the use of the MDSS at state DOTs is implementation and evaluation. The FHWA MDSS Deployment Guide (Dye, 2008) describes the tasks of a typical MDSS implementation plan including:

- acquiring and installing hardware and software
- designing and developing the MDSS system configurations, extensions, and interfaces
- conducting initial testing, training, and piloting
- implementing the system and managing projects, changes, and risks
- performing post-implementation support

During implementation, follow-up evaluation is necessary to confirm that the system is operating as expected. The post-implementation tasks include discussing lessons learned, providing follow-up training to users, addressing any problems or issues, and evaluating MDSS performance.

5.1.2 Development of MDSS Functional Prototype

MDSS research began in 2000 as a cooperative initiative between the FHWA and six national weather-related laboratories (e.g., National Center for Atmospheric Research). Led by the FHWA, and working with state DOTs, the private sector, and academia, the weather-related laboratories combined state-of-the-art weather forecasting capabilities with computerized winter maintenance rules of practice and developed a "Functional Prototype" (Ye et al., 2009). The MDSS Functional Prototype was a decision-tree approach that provided strategic planning decision support for maintenance personnel to keep roads as clear and safe as possible during winter weather events (Dye et al., 2008). Figure 2 shows the data flow and the primary components of the MDSS Functional Prototype.

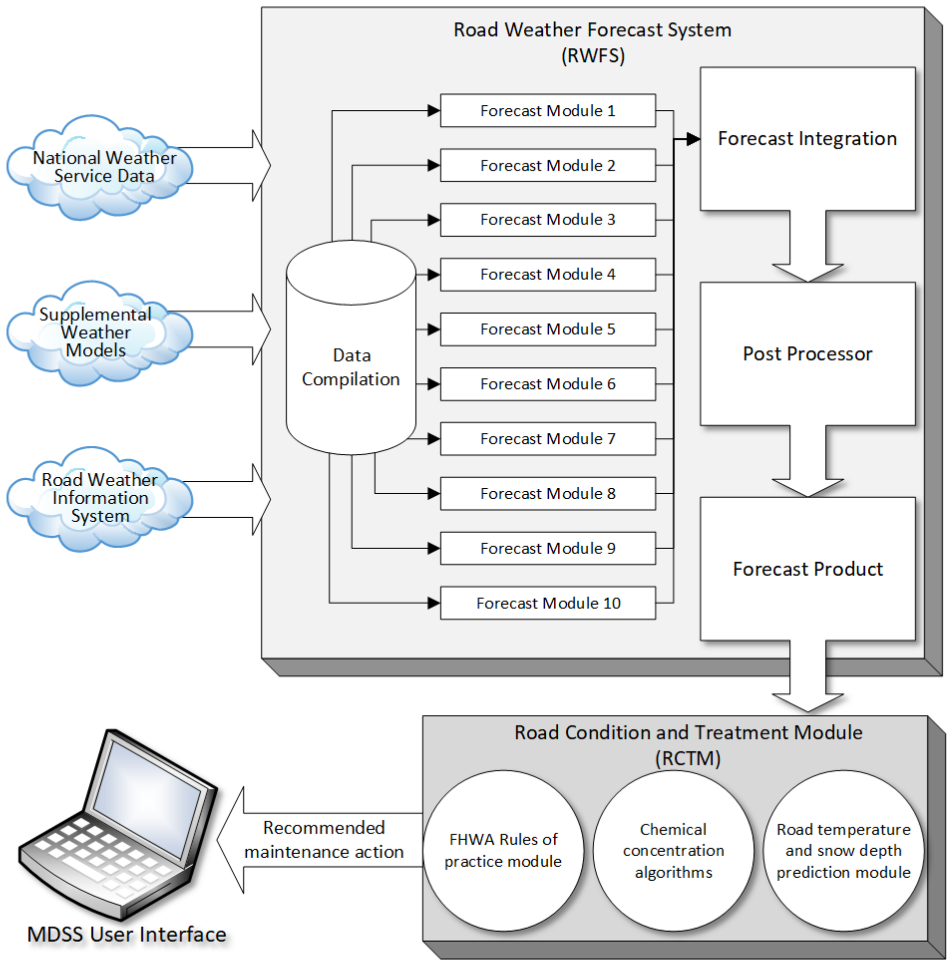

Figure 2. FHWA MDSS Functional Prototype design

Ten weather models and information sources, including the National Weather Service (NWS) and the Federal Aviation Administration (FAA), provide surface weather observations and numerical weather prediction models. Also, Road Weather Information System (RWIS) sends weather and surface conditions information collected from environmental sensor stations (ESSs) located across a state or region to the MDSS. The RWIS is a winter observation system comprised of ESSs located throughout a state, a communication system for data transfer, and central systems to collect field data from numerous ESSs. These stations measure atmospheric, pavement, water level conditions, and other weather and road conditions. RWIS hardware and software are used to process observations from ESS and display or disseminate road weather information in a format that can be easily interpreted by a manager. RWIS data are used by DOT maintenance personnel to support decision making (Federal Highway Administration, 2017).

The information then flows into the Road Weather Forecast System (RWFS) that integrates the weather and surface data. Using specifically developed algorithms, the RWFS processes the data, determines a set of forecast outputs that are considered acceptable, and sends this information to the Road Condition and Treatment Module (RCTM) (Pisano et al., 2006).

The RCTM has another set of algorithms that predict road temperature and accumulation, the probability of blowing snow and road/bridge frost occurring, and chemical concentration and dilution amounts. The models then feed into the rules of practice algorithm. The final output is a set of route-specific weather forecasts, predicted road conditions, and recommended treatments (Pisano et al., 2006).

5.1.3 Design of the PFMDSS

After several demonstrations and pilots of the FHWA MDSS Functional Prototype, DOTs realized that a winter MDSS tool could be a worthy investment. However, several DOTs, including SDDOT, recognized that the FHWA MDSS Functional Prototype did not meet their maintenance operational needs (Ye et al., 2009). A pooled fund study, led by South Dakota, emerged in 2002 to advance the MDSS to a fully functional product. The pooled fund study worked with the private sector to develop customized MDSS related technologies, applications, and equipment to meet their needs. The pooled fund states contracted with Meridian Environmental Technology (now known as and referred to as Iteris, Inc. for the rest of this report) to develop the operational prototype for the pooled fund version of the MDSS (e.g., PFMDSS). While the goal of the TPF-5(054) pooled fund study has been the establishment of an operational MDSS, the project operates as a research project. As such, the PFMDSS is in a process of continuous research, development, and improvement based on user recommendations.

The design of the PFMDSS, which differs from the FHWA MDSS Functional Prototype, considers the physical properties of the roadway and its surrounding environment and simulates actual practices to make the best possible recommendations on maintenance treatments. Figure 3 shows the PFMDSS functional design. The infrastructure of the PFMDSS is a server-client model, in which Iteris, Inc. maintains the server side and the client can be either a single proxy server or individual workstations located at a state DOT. This infrastructure setup was designed to limit investments from DOTs in computer hardware and software (Ye et al., 2009).

The PFMDSS integration and processing system, which is at the center of the PFMDSS system, uses a dynamic modeling technique that considers each weather event as unique, which is different from the FHWA MDSS Functional Prototype that uses rules of practice based on normal maintenance experiences. The recommended actions address the specific conditions created by the existing and forecasted weather conditions, the current pavement surface temperature and condition, and the present state of snow, ice, slush, or water on the roadway surface. The process simulates the balances between what materials and associated heat are added or removed from the roadway surface (Hart and Osborne, 2003).

As a condition of the PFMDSS, roadways are programmed into the system based on parameters such as roadway (segment) length, traffic volume, pavement structure, and environmental information. Resource and service level information is preconfigured for each route segment based upon information collected from maintenance personnel but can be adjusted by maintenance managers as resource availability and practical maintenance limitations change during a storm event. Route segment parameters are adjustable by maintenance managers, which include available maintenance practices (material types, minimum and maximum application rates, and material costs), work shifts, traversal and cycle times, and the within-event and nominal level of service for a route segment (Hart et al., 2004).

The PFMDSS approach simulates the road pavement surface layer, called the contaminant layer. Weather observations from weather services are integrated with RWIS, plow truck observations, and provided to a statistical and heuristic forecasting system. Weather forecasts are then reviewed and modified by expert meteorologists at Iteris, Inc., which is a major difference from the FHWA MDSS Functional Prototype that relied solely on weather service information and was not reviewed by meteorologists. Using current and forecasted weather conditions, as well as road condition and maintenance activities reports, the PFMDSS processes the information and assesses the past and present states of the roadway (Hart and Osborne, 2003). The road condition reports represent the current state of a roadway and the associated current weather conditions collected from plow trucks. The maintenance activities report tracks the maintenance activities (e.g., plowing, patrolling, applying materials) performed on the route.

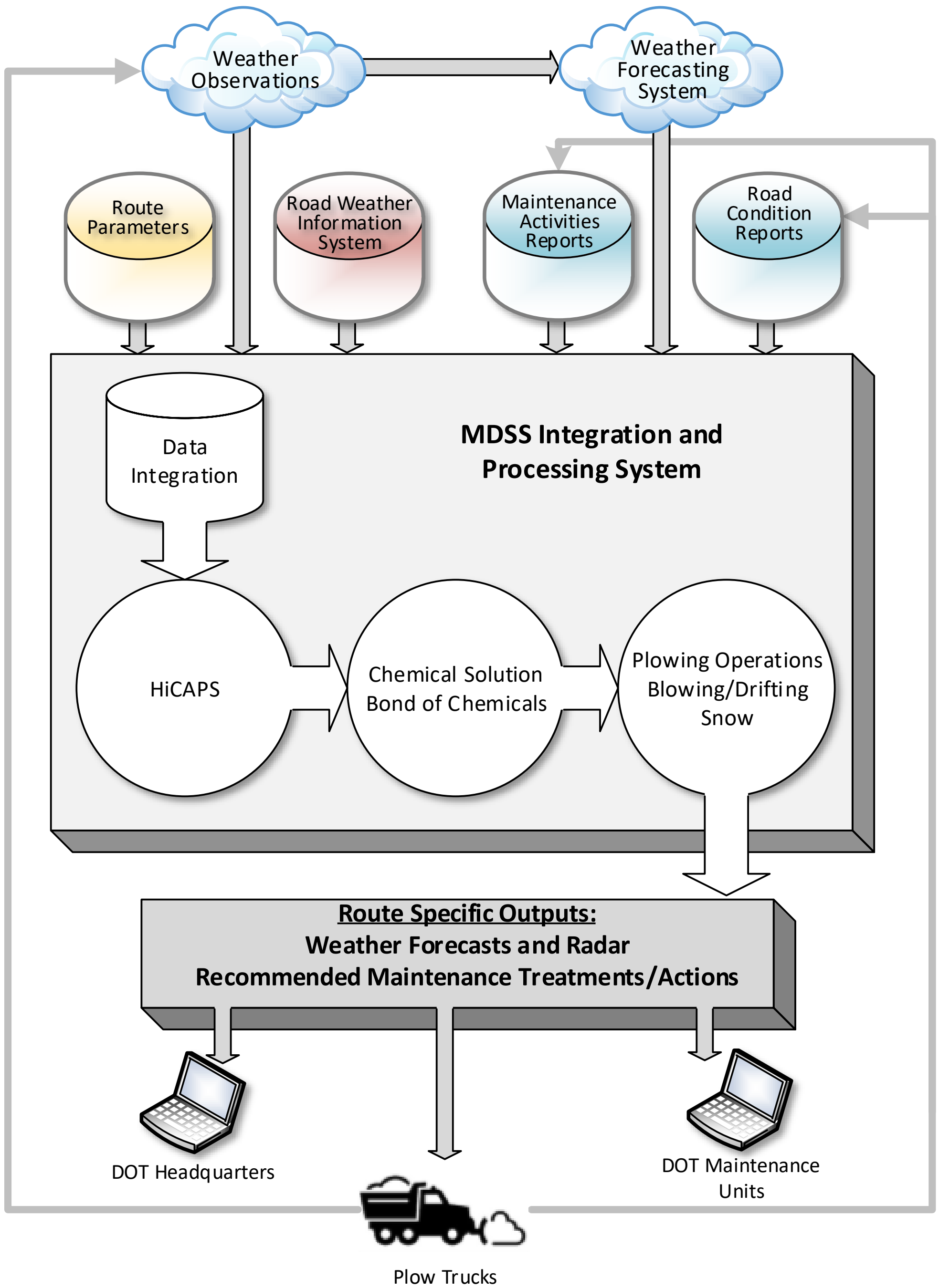

Figure 3. PFMDSS design

An enabling technology for the PFMDSS processing system is Iteris', Inc. proprietary Highway Condition Analysis and Prediction System (HiCAPS) algorithm. HiCAPS is a sophisticated mass and energy balance pavement model algorithm that simulates changing conditions of the roadway contaminant layer and the processes active on the containment layer. Modeling the changes in road surface sensible (temperature) and latent (moisture) heat is performed using thermodynamic formulas. Then, the HiCAPS latent heat flux module accounts for the exchange of energy and mass due to precipitation, condensation and evaporation, heat energy taken and released to the surrounding environment, and phase changes.

Fluctuations in ground heat are modeled using the unsteady heat flow equation. (Hart et al., 2004). Figure 4 illustrates the HiCAPS algorithm model.

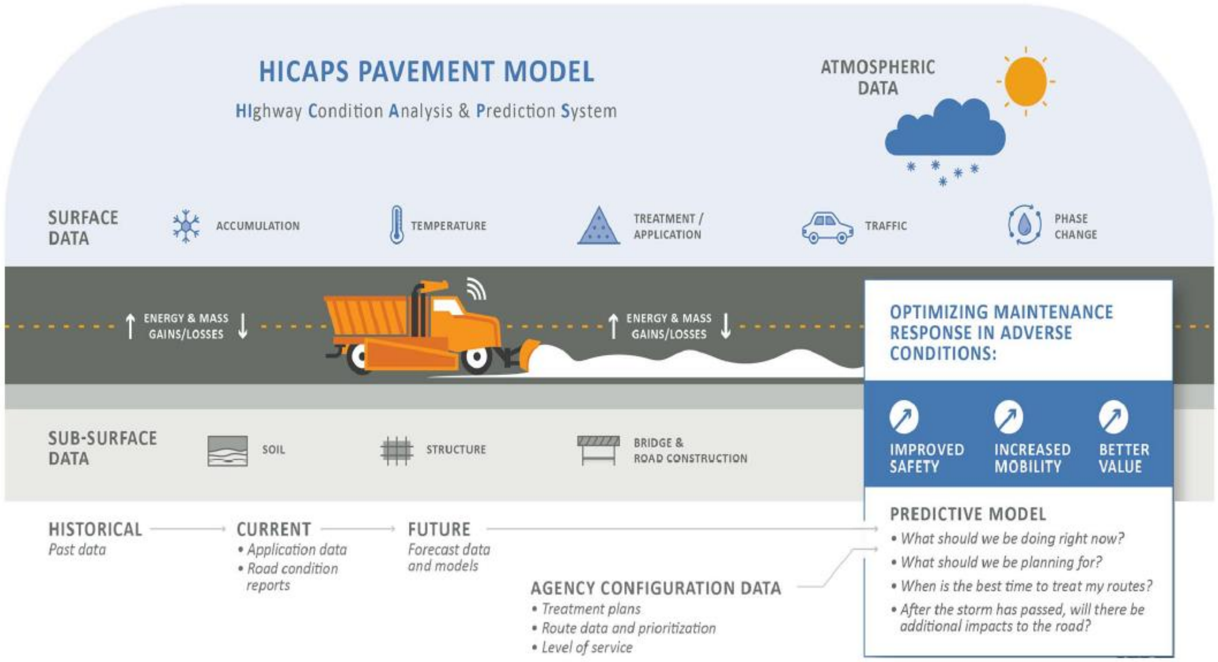

Figure 4. HiCAPS pavement model (Hershey, 2016)

HiCAPS assesses the road conditions for each PFMDSS route segment based on previous roadway conditions, current weather activity, and actual road conditions and treatment activities as reported by maintenance personnel operating maintenance trucks. This process creates a best estimate of the current road conditions, which is used to forecast future road conditions based on projected weather and modifications in the state of snow, ice, and liquid on the roadway surface caused by ongoing changes in pavement temperature, traffic volume, and projected treatments. HiCAPS generates recommendations deems necessary to maintain roads at the level of service desired by SDDOT for that route segment (Hart and Ostermeier 2014).

Modules shown in Figure 3, simulate the impact of chemicals that lower the freeze point based on the conditions of the roadway contaminant layer. Freeze point temperature is dynamically calculated based on the chemicals present on the roadway. The chemical solution module also addresses salt absorbing humidity and precipitation from the air, the reduction in evaporation due to lower vapor pressure of the chemical solution, and the bonding and removal of applied chemical materials due to runoff, traffic, wind, and other maintenance activities (Hart and Osborne, 2003).

The plowing operations and the blowing and drifting snow modules, shown in Figure 3, estimate the depth of snow and ice remaining behind the plow based upon plow type and the road surface conditions. The depth of materials remaining behind the plow is configurable based upon plow type used. To consider density of the roadway surface layer, the module assumes that liquids reside near the bottom of the contaminant layer and are generally removed at a lesser rate than the frozen materials at the top of the layer being plowed from the road (Hart et al., 2004). The plowing operations also considers the possibility of blowing and drifting snow.

The PFMDSS models the effects of traffic based on average daily auto and truck traffic counts by distributing traffic vehicles across the contaminant layer at configurable rates throughout a day. Each traffic vehicle is assigned a lane, tire track, and vehicle width and moisture content within the tire tracks is classified as splattered, sprayed, spread, or compacted depending upon the current conditions of the contaminant layer. Moisture and materials on the roadway contaminant layer are assumed to move laterally and are removed from the roadway depending upon the splatter, spray, and spread widths and the distance from the traffic vehicle tire location and the edge of the roadway (Hart et al., 2004).

Decision support in the PFMDSS is provided on a maintenance route segment basis. A maintenance route is made up of one or more road segments that are to be treated contiguously by a single maintenance vehicle. Each segment within a maintenance route possesses unique weather, construction, traffic, and environmental information. Therefore, the maintenance needs of a single route segment can vary. However, the PFMDSS only presents maintenance action recommendations on the segments of a given roadway that can be practiced with a single vehicle at contiguous times with traversal, cycle, and dead times that are realistic (Hart et al., 2004). Note that although the materials recommended will be similar on all segments of a route, the recommended rates can vary between segments based upon the modeled needs. Roadway information in the PFMDSS is generally displayed on a segment-by-segment basis.

The outputs from the PFMDSS are weather forecasts and recommended treatment applications that can maintain the required level of service for a route segment in the most economical manner based on the available labor, equipment, and material resources.

5.1.4 Maintenance vehicle data systems

The PFMDSS includes on-vehicle data systems installed on plow trucks that maintain PFMDSS route segments. Currently, SDDOT uses an automatic vehicle location/mobile data collector (AVL/MDC) data system mounted in plow trucks that communicates data from the PFMDSS and communicates data from the truck back to the MDSS. However, other truck data system options exist, including different levels of AVL/MDC systems and the portable devices such as the Zonar system. The following sections discuss these options.

5.1.4.1 Automatic vehicle location (AVL)

AVL technology automatically determines and reports the geospatial location of a vehicle using the global positioning system (GPS). For winter maintenance applications, AVL is used for more than location. By connecting sensors and the hydraulic controller system of a plow truck, AVL-equipped vehicles become mobile weather stations and provide operators with real-time weather information to help with winter weather maintenance decisions. Studies show that the use of AVL can increase productivity, quality of work, environmental awareness, and accountability while maintaining or increasing the overall level of service (Fay et al., 2010). AVL systems can also monitor material use and assist with making sound decisions during a winter weather event. Other benefits noted by agencies using AVL technology for winter weather maintenance are:

- improved operator accountability
- improved meteorological data
- in-cab real-time weather information
- in-cab nearby snowplow location information

- more accurate timesheet reporting and end of shift reporting
- material and labor savings
- more accurate audits of material use
- automatic reporting and mapping
- improved real-time storm event management
- improved treatment recommendations (Potter et al., 2016)

The drawbacks to installing AVL systems in a maintenance vehicle are related to cellular data coverage, software issues, training, and privacy concerns (Potter et al., 2016). Losing a signal in “dead spots” on rural area route segments has been a complaint from various operators at transportation agencies. As networks continue to improve coverage and speeds, this issue should lessen. On the software side, malfunctions (commonly due to user error, power supply issues, and the durability of the AVL equipment), and software compatibility are problems when first setting up the AVL system. Training is needed for operators so that they use the AVL effectively. Additionally, when installing the AVL system for the first time, training is needed on the installation and maintenance processes. Finally, and one of the more common concerns, is the issue of operator privacy. With a vehicle location system in the truck, managers can track what their employees are doing. Although this is not the intent of AVL, the perception exists and operators worry about micromanagement of their work (Ravani and Wehage, 2017).

AVL may include basic tracking of a vehicle or a more comprehensive setup that adds camera imagery, material use, and an in-cab interface (Schneider et al., 2017). Table 8 summarizes the levels of technologies associated with their benefits and drawbacks. Primarily, the AVL system collects various real-time information about the vehicle such as truck location, speed, and direction of travel, which is a Level 1 AVL system. The addition of a camera provides imagery of actual conditions where the truck is located, which is then a Level 2 AVL system. With the addition of collecting data on the truck’s winter operational applications through integration of sensors and the truck’s hydraulic controller system, including plow position, material use, application rates, air temperature, and road surface temperature, the AVL is a Level 3 system. To allow for interaction with the system from the truck operator, a user interface can be installed in the truck and the AVL can be set up to include operator inputs such as lane indicator, road and weather conditions, and material type and application rates. This is called a Level 4 AVL, which is equivalent to SDDOT’s current MDC system. Note that the more complex the setup is, the higher the cost for the system.

Table 8. Levels of technology and advantages/disadvantages for AVL setups

Level	Description	Equipment	Advantages	Disadvantages
1	Truck tracking and visualization	• Cellular/GPS modem • Antenna	• Low cost of implementation • Low cost of maintenance • Managers can track and know what route segments are being treated	• No material tracking • No road conditions
2	Truck tracking and camera interface	• Cellular/GPS modem • Antenna	• Real time view of route segments and conditions	• Maintenance of system • Increased data bandwidth needed

		• Camera	• Road conditions can be stored as photos	
3	Truck tracking, camera interface, and material use	• Cellular/GPS modem • Antenna • Camera • Sensors and cables	• Automated material use reports • Managers can track route segments being treated and the amount of material being used • Road conditions can be stored as photos	• Maintenance of the system • Sensors need calibration • Increased data bandwidth needed
4	Tracking, camera interface, material use, real-time communication	• Cellular/GPS modem • Antenna • Camera • Sensors and cables • In-cab interface controller	• Automated material use reports • Managers can track route segments being treated and the amount of material being used • Road conditions can be stored as photos • Real-time route optimization • Interface for drivers showing weather conditions, treatment recommendations, and material use	• Highest cost • Maintenance of the system • Sensors need calibration • Increased data bandwidth needed • Distracted driving issues • A mobile data collector system

5.1.4.2 Mobile data collection (MDC)

The MDC system, which is a Level 4 AVL data system, combines AVL, GPS, and mobile data collection into a tracking and reporting tool. An in-cab touchscreen interface that connects with the PFMDSS to provide real time data to the operator and collects data from the vehicle's sensors and equipment and information provided by the truck operator. An MDC unit can connect to various sensors, on-board diagnostics II (OBD-II) ports, the hydraulic controller system, and other equipment such as cameras, which can then be programmed to collect user-specified data. Data collected by an MDC unit typically include:

- vehicle location, speed, direction, and lane indicator
- odometer reading, fuel use, and tire pressure
- engine compression rate, idle time, on/off
- type and amount of material hauled and used
- camera images
- warnings and alarms
- air and road temperature (Delcan Technologies, 2016)

Plow truck operators can interact with the PFMDSS through the touchscreen interface in the truck. The operator can view information from the PFMDSS that includes the local and regional radar, weather forecast, road and weather conditions, road surface temperature, ambient air temperature, and the PFMDSS treatment recommendations based on route segment, lane, and timing of the treatment. The operator can then send information, such as the current lane being plowed on a multi-lane highway and the observed weather and road conditions for a particular route segment, back to the MDC. SDDOT plow truck drivers manually enter actual weather and road conditions at the end of each route into the MDC.

This information is then transmitted to the PFMDSS to adjust treatment recommendations. Specific weather and road conditions inputs and associated choices that operators must choose from include:

- snow accumulation for occupied and adjacent roadway: none, under 2”, 2-4”, 4-6” over 6”
- precipitation: none, drizzle, rain, sleet, hail, snow flurries, snow, unknown
- visibility: clear, fog, smoke, blowing snow
- visibility distance: near zero, under 1/4 mile, over 1/4 mile
- wind (mph): calm (under 10), light (10-20), medium (20-30), strong (over 30)
- road conditions: dry, damp, wet, frost, snow, drifted snow, slush, ice

Currently, SDDOT has installed MDC units in 125 of its 468 plow trucks (26.7%). SDDOT’s current MDC truck configuration, shown as the gray shaded area in Figure 5, is the Parsons MDC-004, which consists of the touchscreen interface located in the cab of the truck, a Sierra Wireless Raven XC or RV50 modem, a Garmin R4 GPS and modem antenna, and a Vaisala surface control system infrared temperature sensor. The setup also includes an ambient air temperature sensor, typically mounted on the mirror of the truck, mercury switches to detect the position of the front, wing, and underbody plows, and cameras attached to the front of the truck (Ravani and Wehage, 2017).

The MDC system integrates with the plow truck hydraulic controller system, which is from Force America. This setup allows the MDC unit to record once a minute the vehicle location, material application rates for solid and liquid materials, plow blade position, lane being plowed or treated, road temperature, and air temperature and transmit the information to a Parsons Data Management Center, which then immediately transfers the data to the Iteris Weather Center. At the Iteris Weather Center, the MDC collected data is incorporated into the road weather database and is also passed to the PFMSS processing component and ultimately to the PFMDSS user (Hart and Ostermeier, 2015).

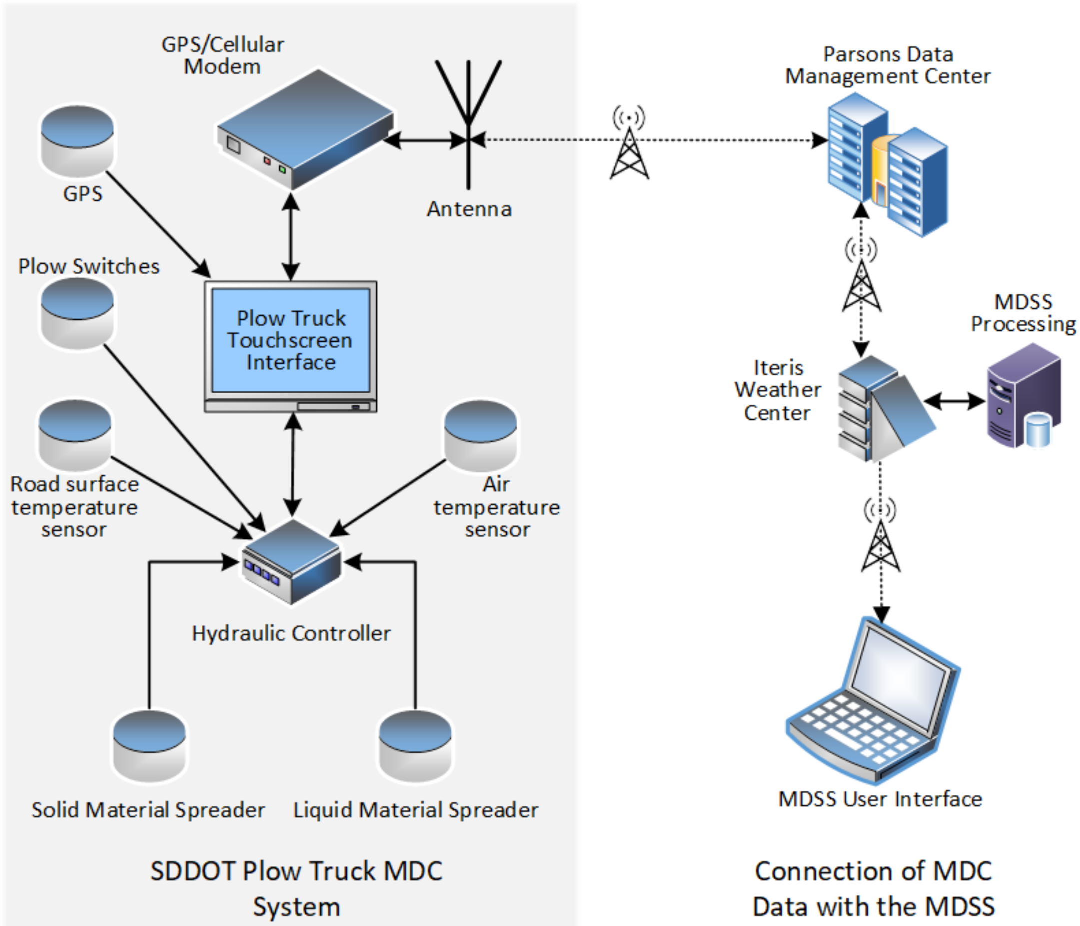

Figure 5. Diagram of the MDC truck setup and connection to the PFMDSS

With the vast amounts of data collected by the MDC units, the PFMDSS provides an MDC and AVL data management interface called the AVL/MDC Report that collects GPS-tagged information of plow truck activities. The data is organized into reports and spreadsheets to assist maintenance managers with fleet and material resources. The interface provides metadata, reported data, and maintenance action summaries. The metadata is the basic information about the maintenance vehicles that are included in the PFMDSS and defines the material type and applications. Reported data includes selecting a time period (a single day up to an entire winter season), selecting if the information should be provided as daily or hourly, and selecting if the data is displayed as a table or a map. The user can then run the AVL/MDC report, which is sorted by segment or truck and provides time-stamped information on plow use, material use, and application amounts. The maintenance action summaries allow users to filter specific data based on time and date, route segment, plow position, road temperature, and specific maintenance actions such as patrol or plow. The maintenance action summaries then provide the data requested as a spreadsheet. Maintenance managers can then use the AVL/MDC Reports to make informed decisions about resources and practical activities for winter weather events.

5.1.4.3 Zonar system

Another type of AVL/MDC system, the Zonar system, is a portable tablet device. The purpose of the Zonar system is to provide an electronic logging device for fleet management and electronically verified inspections along with the ability to interact with the PFMDSS in the cab of a plow truck. The Zonar system uses radio frequency identification (RFID) technology in which the Zonar tablet can scan the RFID tags located on the truck to identify maintenance requirements for the truck. The Zonar offers fleet managers two-way communication, pre- and post-trip inspections, navigation assistance, robust vehicle diagnostic programs, and fuel management (Ravani and Wehage, 2017). It can also monitor driving habits of operators related to acceleration, braking, cornering, land handling, and speeding. Currently, the Colorado Department of Transportation uses the Zonar System.

Zonar has begun working in the AVL/MDC realm of winter maintenance. Figure 6 shows the Zonar 2020, an Android-based Samsung Tab-E portable tablet device. The tablet can access Iteris, Inc. radar and weather, and the PFMDSS for messaging, treatment recommendations, and road conditions. It can be set up to provide PFMDSS reports that detail the maneuvers and locations of trucks and the type and quantity of materials used. Custom maintenance applications can be added by using the Zonar software development kit.

Figure 6. Zonar 2020 Tablet

5.1.5 PFMDSS User Interfaces

Table 9 shows the four PFMDSS user interface platforms. Two of the platforms are the mobile applications for iPhone and iPad mobile devices and Android-based mobile devices. These mobile platforms provide easy access to a variety of PFMDSS features. The newest platform is the Internet version called WebMDSS, which is still in the development stage. The current WebMDSS version performs most of the same functions as the MDSS GUI. The web-based version does not require the installation or update of software.

Table 9: PFMDSS platforms

MDSS Platform Versions
MDSS Graphical User Interface (GUI) Software Program – Version 13.0
MDSS iOS Mobile Application for iPhone and iPad devices
MDSS Android OS Mobile Application for Android devices
WebMDSS: www.webmdss.com

5.1.5.1 MDSS Graphical User Interface

The PFMDSS graphical user interface (GUI) is in its 13th version and is currently the most used platform at SDDOT. It is a client-side interface that is installed on users' computers. The GUI can support a wide variety of features, which are customizable to focus on issues that impact the evolution of the road surface due to weather, traffic, maintenance actions, and other critical factors. The GUI uses a three-panel layout, with the upper left Alert Panel, the lower left Support Panel, and the Primary Panel. The primary panel contains most of the PFMDSS functionality and provides four different views 1) map view, 2) route segment view, 3) RWIS/ESS view, and 4) FAA/NWS view (Hart et al., 2016; Ye et al., 2009). Each of the views provides various PFMDSS information to users depending on what they are looking for.

The MDSS GUI includes many features and applications (Hart et al., 2016; Ye et al., 2009) such as dynamic overlays, time slider and loop controls, camera views, truck views and information, weather observations and forecasts, and detailed PFMDSS route segment information. Navigating the MDSS GUI for the first time can be difficult for a new user as there are many different tools and ways to view the PFMDSS data. Providing training and allowing all maintenance staff, both supervisors and plow truck operators, to use the MDSS GUI can provide a better understanding of the PFMDSS and how it works.

5.1.5.2 Mobile App

The mobile MDSS app, which is a scaled-down but user-friendly version of the MDSS GUI has been available since 2012. Approximately one-half of the SDDOT maintenance staff in the interview process were aware of the MDSS app, but only about one-third have used it. Most agreed that the MDSS app is useful but the small screen size and lack of normal features found in the MDSS GUI have partly limited its use. Some staff mentioned that the MDSS app often crashed and occasionally does not perform well. Overall, the mobile MDSS app is currently not the best platform to view and use the MDSS but it provides the necessary information when it is the only platform available (e.g., when patrolling during winter weather events).

5.1.5.3 Web-Based MDSS

The web-based MDSS system provides access to the PFMDSS through a web browser and the same features and layout as the MDSS GUI. The Pooled Fund Study is refining the WebMDSS as the natural progression from the MDSS GUI. The advantage of the web-based MDSS over the MDSS GUI is the ability to access the PFMDSS from any Internet-connected device. The web-based system does not need software updates and support can be provided through the website. Maintenance managers can track road conditions and receive treatment recommendations for winter weather events on the road when using the WebMDSS. The web-based PFMDSS also provides:

- continuous alert monitoring send messages to email accounts, cell phones, and other communication tools
- access to making and viewing reports
- access to view other States' live data as well as previous storms
- a recent tab to look back 72 hours

Figure 7 provides a screenshot of the WebMDSS. The WebMDSS version is relatively new and is still in development, which explains why when discussing the WebMDSS with SDDOT that only a few maintenance staff were aware of it and even fewer have used it. SDDOT maintenance staff using the WebMDSS indicated that it is easier to navigate and has a better layout with radar much improved over the MDSS GUI. As SDDOT continues the development of the WebMDSS, SDDOT needs to inform its maintenance staff of this platform. Employing web-based and cloud-based systems allows for more flexibility and wider use than current client-based software applications.

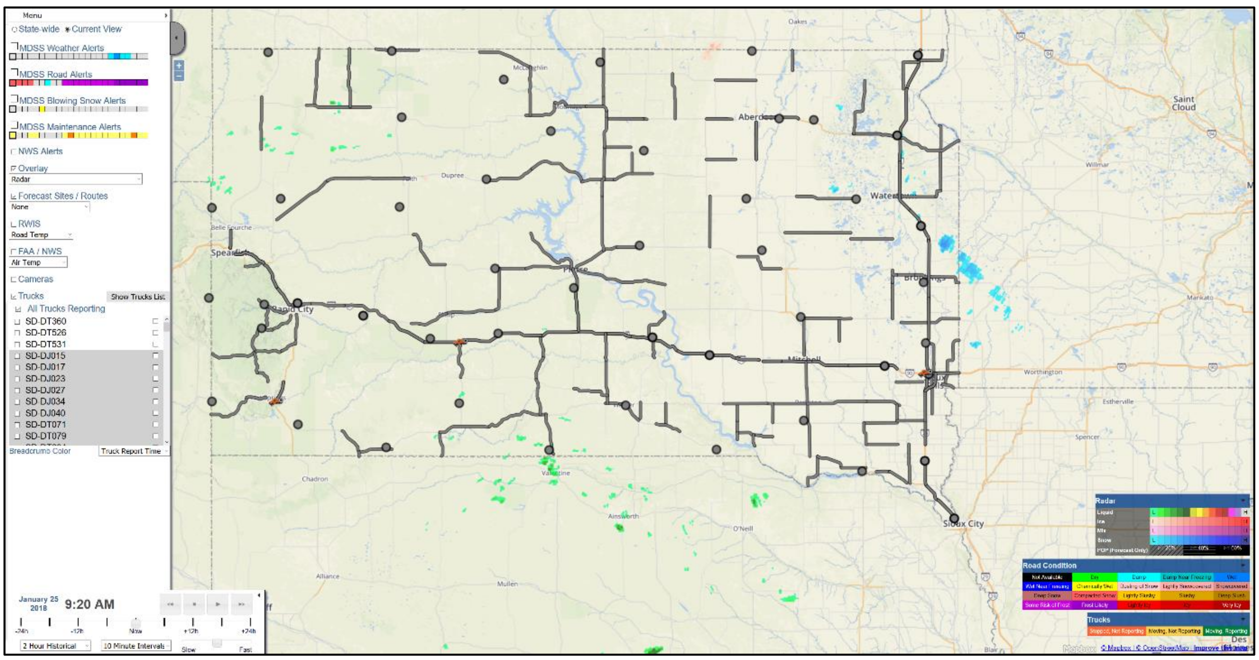

Figure 7. Screenshot of the WebMDSS

5.2 PFMDSS features

The PFMDSS is an interactive decision-support system that combines information on existing pavement conditions, current and forecasted weather conditions, physical and chemical behavior of pavement surfaces, past maintenance treatments, and available resources to present recommendations on the most effective treatments to apply, and the timing of the treatment, specifically for each route segment in the PFMDSS. PFMDSS users have access to a range of tools and features that gives users current road weather information and detailed guidance regarding future road conditions for any route segments that are a part of the PFMDSS (Hart and Ostermeier 2014). The PFMDSS is a customizable tool that can be set up with various functions and tools. As stated by Chambers and Hershey (2012), the PFMDSS is a "one-stop-shop" that provides information on:

- Weather forecasts such as the NWS,

- Weather conditions collected from RWIS,
- Camera images from traffic cameras and maintenance vehicles,
- Weather and pavement forecasts that are tailored to a specific route segment's requirements, and
- Automated vehicle location and mobile data collection from maintenance trucks.

A summary of features associated with the PFMDSS are discussed below.

5.2.1 Interactive Maps

The interactive maps feature in the PFMDSS allows users to view data icons, dynamic overlays (e.g., NWS observations, PFMDSS route segments), FAA/NWS and RWIS locations, maintenance truck locations, and route segments or counties related to the alerts shown in the alert panel. Clicking on any of the icons displays additional information about that particular item in the PFMDSS. Figure 8 shows an example of an interactive map during a winter storm event and the various icons that can be clicked by a user to see additional information.

Typically, the information provided when clicking on an item on the map is an extension of the information available from the icon at the time selected. For example, while displaying air temperatures from FAA/NWS RWIS/ESS, clicking on one of the observations will result in a pop-up window that displays additional weather variables for a specified time. The procedure is the same whether looking at current, past, or future data. However, for alert information, clicking on a route, or county for NWS alerts, will display details about all alerts for all times for that route segment or county (Hart et al 2016).

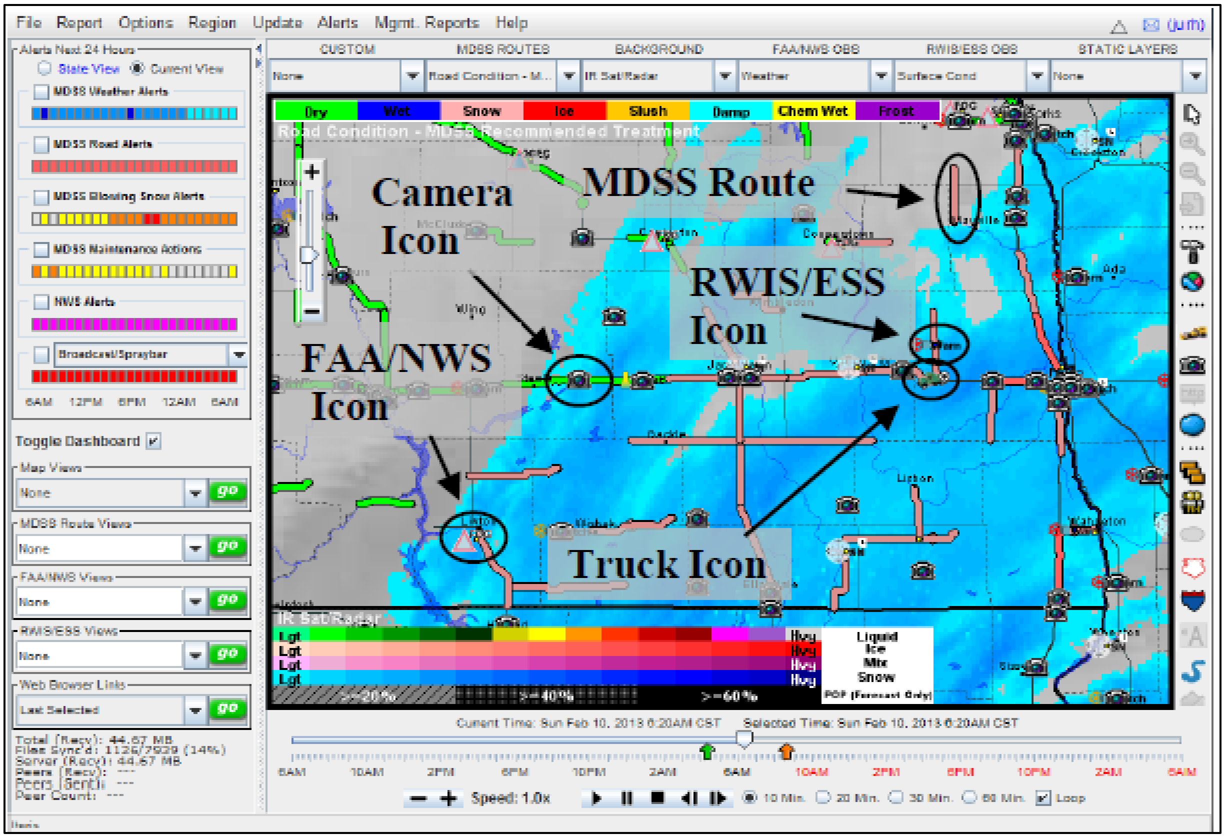

Figure 8. Screen shot of the interactive map view from the PFMDSS GUI (Hart et al 2016).

Dynamic overlays are another feature of the interactive maps that brings the maps to life. Dynamic overlays, controlled by six drop-down menus at the top of the interactive map, display a variety of information in a geospatially-referenced manner for a specified time, which can be in the past, current, or in the future. The six dynamic overlays are:

- Custom: Provides default and user-defined shortcuts to specific information
- PFMDSS Route Segments: Displays one of four conditions along PFMDSS route segments (Road temperature, road condition, mobility index, and percent ice)
- Background: Allows users to view one variable to be displayed in the background of the map. The variables include radar, visible satellite, infrared satellite, visible satellite and radar, infrared satellite and radar, air temperature, dew point, relative humidity, wind speed, wind gusts, hourly precipitation, and hourly snow.
- FAA/NWS Observations: displays weather observations from airports (FAA) or NWS offices. Observations can display air temperature, dew point, relative humidity, wind speed, wind gusts, wind direction, weather (precipitation type and intensity, fog, blowing snow), visibility, and cloud cover.
- RWIS/ESS Observations: Shows data that is available from ESSs from across the state. The data displayed includes surface/pavement conditions, atmospheric conditions, and road sensor location as either pavement only, bridge deck only, or both.

- Static Layers: Displays to the user future 24- and 48-hour weather risks based on the current time. This dynamic overlay can also display the previous 24 hours of observed accumulations (Hart et al 2016).

5.2.2 Alerts

The purpose of the PFMDSS weather alerts feature is to provide quick access to PFMDSS users to access near-term weather conditions and threats that have the potential to impact operations (NCAR, 2009). Weather alerts are generated in the PFMDSS using the current and forecast weather and road conditions information that results in a weather status that more than likely impacts maintenance operation for each route segment in the PFMDSS.

Weather alerts are shown in real-time in the alert panel. Figure 9 shows an example of the weather alert panel, which maintenance personnel use to monitor alerts for three different locations, which are the current view, state view, or custom defined view. The alert panel provides users with an hourly assessment of the following:

- MDSS Weather conditions,
- MDSS Road conditions,
- MDSS Blowing snow conditions,
- MDSS Recommended maintenance, and
- NWS alerts for the upcoming 24 hours.

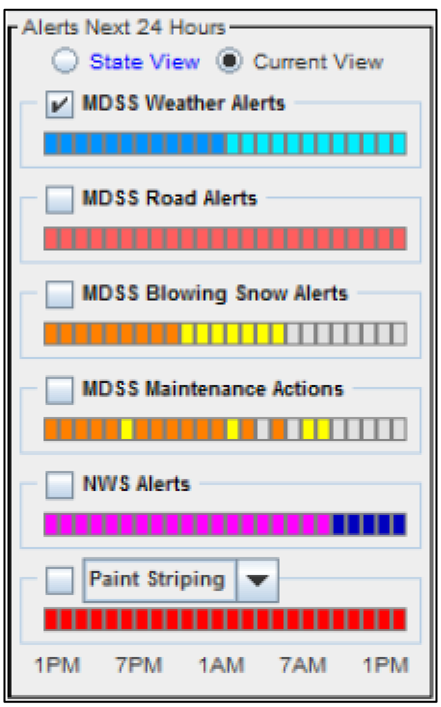

Figure 9. Example weather alert panel provided in the PFMDSS

The weather conditions, road conditions, blowing snow conditions, and recommended maintenance are applicable to specific PFMDSS route segments, while the NWS alerts and applicable on a county-by-county basis (Hart et al 2016).

The alert bars are composed of 24 color-coded boxed and each box in the alert rows represents one hour of time, showing the current hour first. The color-coding designates the level of conditions forecasted for the monitored area for that hour. When clicking on any of the boxes in an alert bar, the map view automatically shows the time selected so that a user can see the forecast for that particular time.

The last alert bar in the alert panel represents the Maintenance and Operations Decisions Support Systems (MODSS). The MODSS bar allows users to monitor specific maintenance operations that can only be completed based on certain weather criteria. Once a user selects a specific operation, such as spraying or paint striping, the bar displays whether or not conditions are favorable for that operation on a specific route (Hart et al 2016).

5.2.3 Past, Present, and Future Weather Conditions

PFMDSS provides past and current weather conditions, and can predict route- and time-specific weather from four to six hours in the short-term, and up to 24 to 48 hours in the long-term. In the PFMDSS, users can select a desired FAA, NWS, or RWIS observation to obtain specific weather data for a particular location. By clicking on an observation location, a pop-up menu displays all available weather variables from the selected observation at a specified time. The pop-up menu also describes the observation location, the time the observation was taken, and the age of the observation compared to the time selected. Further information is displayed in a table format that details all observed weather variables for the past 24 hours (Hart et al 2016).

PFMDSS considers both current and recent past weather conditions (e.g., air temperature, dew point, wind speed and direction, precipitation type and rate, presence of blowing or drifting snow, cloud cover, and visibility) that may affect the road surface. The PFMDSS includes weather radars that can loop the previous weather conditions with current conditions (Minnesota Department of Transportation, 2013). Previous and current weather conditions as provided by the PFMDSS notifies maintenance personnel of approaching storm conditions.

5.2.4 Route Information

The PFMDSS can predict current roadway temperature, bridge temperature, bridge frost potential, blowing snow potential, moisture type and depth, and chemical concentration (Murphy, 2012). Therefore, the PFMDSS route information is one of the primary functions as the PFMDSS provides route-specific weather and road condition forecasts at various time intervals (Federal Highway Administration, 2012). The MDSS provides a route view, which provides a detailed-level of real-time information relevant to the winter maintenance activities on a route-by-route basis (Hart et al. 2016). The route information can be viewed in the MDSS map or in a table based on how the user wants to see the data.

Within the MDSS, a pulldown menu provides users with a list of MDSS route segment numbers and the associated highway number and description (Interstate, US Highway, or State Highway), and the pulldown menu is searchable to find routes easily. When a user selects an MDSS route, the analysis and forecast data of that MDSS route is available for a specific time that the user selects. The MDSS route data ~~displayed depends on what MDSS route data is shown on the map. For example, if an MDSS alert panel~~

box is checked, then the 24 hour-by-hour forecast for each type of alert selected are displayed for that MDSS route. When selecting an MDSS route segment in the MDSS routes dynamic overlay menu, then a variety of information can be displayed, which includes:

- Model analysis or forecasts: Road temperature, road condition, percent ice, mobility index, snow depth, liquid depth, and ice depth
- Last maintenance action reported: Vehicle ID, plow position, maintenance action icon, maintenance action description, start time, midpoint time, and end time
- Last condition reported: Vehicle ID, road condition, and time reported.

5.2.5 Maintenance Vehicle Locations

Maintenance vehicles and trucks equipped with MDC units can be located and displayed within the PFMDSS, which allows maintenance managers to know 1) where a truck is currently located, 2) where it was previously and when it was there, and 3) the maintenance actions it has taken (Minnesota Department of Transportation, 2013). Using the map view in the PFMDSS, the truck data icon can be activated. Once ready, the truck icons will appear showing the exact location of maintenance trucks. The trucks are color-coded, with green truck icons representing a maintenance truck equipped with an MDC system that is moving and reporting the required weather and road conditions, and materials. A yellow truck icon means a maintenance truck is moving, but not reporting data or not meeting the required amount of data specified for the region/shop. A red truck icon means a maintenance truck is not moving and may or may not be reporting data (Hart et al 2016). Further, each truck icon may include a white-outlined black dot, which represents that the maintenance truck is equipped with a camera.

Each truck icon in the PFMDSS can be clicked to show a pop-up menu that includes the trace route segment feature, the storm report feature, and the camera-view feature if a truck is equipped with a camera. When using the trace route feature, varying sized dots are placed on the PFMDSS map showing ten-minute intervals that shows the previously reported truck locations, with the most recent location shown as large dots and the older locations shown with small dots. The storm report tool provides information for a truck, including date and time, PFMDSS segment, direction of travel, speed, blade position, materials being applied and the application rate, weather conditions, road conditions, pavement temperature, and air temperature. Further, the storm report tool allows PFMDSS users to see previous reports (e.g., End of Shift and Event Summary reports) from a specific maintenance truck or PFMDSS route, which then provides a good indication of how reports are being mapped from the active trucks to the PFMDSS. The camera-view feature allows maintenance managers to view the camera image from the truck associated with the selected time (Hart et al 2016).

5.2.6 Maintenance Treatment Recommendations

The goal of the PFMDSS recommendations is to provide the most efficient treatment (in terms of application materials, rates, and timing) for maintaining the required level of service on a specific route during winter storm events (Hart et al 2016). The PFMDSS incorporates a collection of information to provide recommendations that fit within a DOT's maintenance requirements and level of service for a specific PFMDSS route or segment. The recommendations use past, present, and future weather and road conditions. The recommendations also account for specific weather impacts such as temperature, wind and gusts, humidity and dew point, and precipitation type and amount, bridge frost potential, and blowing snow potential (Dye, 2008). Further, recommendations consider the previously conducted maintenance operations on a route (as long as the previous maintenance operations have been reported by MDC-equipped trucks or through manual reporting), along with budget, personnel, material, and equipment limitations (Chambers and Hershey, 2012). The PFMDSS communicates treatment recommendations to maintenance managers and to truck operators that have access to the PFMDSS in the truck via an MDC. Once the recommended treatments are applied to a roadway, the PFMDSS records the actual treatments used and uses this information to modify future treatment recommendations for that route.

5.2.7 Time Slider and Data Animation

The PFMDSS records and stores data before, during, and after winter weather events, which then a user can employ the time slider to animate the data in the PFMDSS. The time slider can be set at the bottom of the map view in the PFMDSS to a start time and a finish time. The data that can be animated is any of the options listed under the background dynamic overlay menu (radar, visible satellite, infrared satellite, visible satellite and radar, infrared satellite and radar, air temperature, dew point, relative humidity, wind speed, wind gusts, hourly precipitation, and hourly snow) as well as other data such as maintenance truck location and movement. Once the play button is pressed, the map will animate the data (and loop it if the option is selected) within the specified time period. The animation works in time intervals, which can be set to 10, 20, 30, or 60 minutes. The PFMDSS also provides a speed controller for the animation, which allows users to speed up the animation or slow down the animation to view what is happening to the data selected during the time period chosen.

The use of the time slider and looping data in the PFMDSS allows a user to animate previous observations as well as future forecasts. Previous observation data can be animated in an event playback to view what happened during a storm. Using data from previous storms allows maintenance managers to evaluate the reliability of the PFMDSS forecasts and treatment recommendations and the overall effectiveness of applied treatments for the road and weather conditions experienced during a storm (Iteris, Inc. 2014a). Evaluating the reliability and effectiveness of the PFMDSS helps the DOT to improve its efforts for future storms and associated maintenance operations.

Forecast data can also be animated to see what future weather will be and how a storm may progress from its status and location. The ability to animate forecasts helps maintenance managers to see where a storm is and where it is headed. Maintenance managers can then take tactical actions to prepare for the incoming storm in terms of the resources and materials needed to perform the maintenance operations.

The time slider and data animation feature can also be used for training maintenance personnel. Historical data collected from previous storms can be used to simulate winter storm events so that maintenance personnel can experience real scenarios of a winter storm before using it for an actual storm (Federal Highway Administration 2012). The PFMDSS can also simulate potential impacts of new maintenance practices or different levels of service for various winter weather conditions using the historical data from previous storms.

5.2.8 "What if" Scenarios for Various Conditions and Treatments

The PFMDSS includes a "What-if" tool that maintenance managers can use to enter up to three different maintenance actions over a 24-hour period. The tool then can model the response to the user-selected alternative actions. One of the alternative actions can be the "None" mode, which means no maintenance will take place. Within the PFMDSS user interfaces, a graph is provide for maintenance managers to assess the effects of the alternative maintenance actions to see what the results may be. Each of the “What-if” maintenance actions allows the user to select the treatment material (chemical or grit), amount of material (in pounds), if the plow blade is up or down, and the time the maintenance action should be applied. Once the simulation is run using the “What-if” alternative maintenance actions, the results are displayed for evaluation by maintenance managers (Hart et al 2016). It is important to note that the results displayed do not affect any of the PFMDSS functions as the “What-if” tool is designed for users to test and try out different practices and materials.

5.2.9 Resource Management

The PFMDSS uses physical properties of the roadway and its environment to make recommendations on optimal treatment decisions. These decisions would be constrained by the chemicals, materials, and equipment available to a DOT for a specific PFMDSS roadway (Ye et al 2009). Then, the PFMDSS has the ability to record the use of resources for maintenance activities, such as the amount of material used and where it was used, blade wear, spreader functionality, and labor or overtime used (Chambers and Hershey, 2012).

In addition, during the period of 12-48 hours ahead of a storm, strategic planning can take place to prepare the personnel, materials, and equipment resources that will be required for the storm. Then, just before and during a storm (0-12 hours), the PFMDSS helps maintenance managers make tactical decisions to relay information from areas of a state that has experienced the storm to areas of the state about to be hit by the storm so that resources can be managed and moved accordingly (Murphy, 2012; Dye, 2008).

5.2.10 Summer Maintenance

Summertime applications of PFMDSS can be used to help crews stay ahead of their summertime roadway maintenance, with PFMDSS supporting a wide variety of summer maintenance activities, which includes chip sealing, concrete repair, crack sealing and hand spray applications, and other activities. Even some non-roadway actions, such as controlled burns, mowing, and pesticide spraying, can use the PFMDSS.

For each of these supported summertime maintenance activities, certain atmospheric criteria must be met or the PFMDSS provides an alert that criteria are not right for the work proposed. These criteria often relate to potential precipitation, precipitation rates and amounts, wind, relative humidity, and road conditions. While the criteria changes depending on the desired maintenance operation, the PFMDSS removes the alert for the appropriate hours, thus highlighting the most optimal time to perform the maintenance activity.

While PFMDSS can provide valuable information on its own, some users are also receiving additional services relating to summertime hazards from the Iteris Weather Operations Center. These services relate to the more frequent summertime hazards of flooding and severe thunderstorms. In both instances, forecasters provides alert when there is an elevated risk of flooding or severe thunderstorms in an area of a state. The PFMDSS sends updates as long as the threat persists. These severe forecast alerts provide those in decision-making positions the ability to assess the situation and make appropriate staffing adjustments to handle the potential threat. In the most severe cases, such as flooding from a powerful thunderstorm or a widespread damaging wind event, these forecasts are necessary to coordinate with other agencies on how to begin the maintenance cleanup process (Urh, 2018)

5.3 Use of the MDSS in Other State DOTs

Many state DOTs have reported on the effectiveness of using an MDSS for their maintenance operations. The following sections summarize the relevant findings of the use of the MDSS from 11 state DOTs. Although some state DOTs have more experience with MDSS than others, and MDSS use varies from state to state, the three primary components of the MDSS (the MDSS information system, a computer graphical user interface, and on-vehicle data system) are used in each state as summarized below.

5.3.1 Colorado Department of Transportation

The Colorado DOT, responsible for over 9,000 centerline miles of roadways, uses the MDSS to use maintenance resources effectively, and to increase safety, reliability, and mobility along roadways. Colorado DOT uses the PFMDSS system to provide maintenance crews with suggested treatments based on real-time conditions (e.g., road and ambient temperature, type of snow removal materials, and the material application rate) and comparison of up to 15 weather reports. The suggested treatment can be applied, or the operator can override the system (Colorado Department of Transportation 2017). Colorado DOT has deployed the PFMDSS application on roadway segments in all Colorado DOT Regions. PFMDSS road condition information is incorporated into the Colorado Transportation Management Center (Colorado Department of Transportation 2008).

Colorado DOT began using an AVL data system in plow trucks with the PFMDSS during the 2005-2006 winter season. Then in 2016, Colorado DOT began investigating other AVL systems from various providers (e.g., Network Fleet, Infusion, Ameritrak, Delcan, and Zonar) and ultimately chose the Zonar system (Lester et al. 2017). Colorado DOT uses both Force America (older trucks) and Certified Cirus (newer trucks) controllers. As of 2017, AVL reporting from the Zonar system fully integrates with Certified Cirus controllers, but only partially integrated with Force America controllers (Lester et al., 2017).

Initially, Colorado DOT focused on efficient preparation for winter weather events. However, Colorado DOT identified several examples of poor resource utilization, such as trucks idling for 24 hours. In December 2014, Colorado DOT started focusing on operator oversight and equipment maintenance (Lester et al., 2017). Operator oversight includes monitoring hard braking, idle time, lost power, odd-hour operation, speed, and other vehicle sensor data. Since implementing its operator oversight program, Colorado DOT realized that using the AVL data system reduces costs, idle times, fuel consumption, vehicle down time, and response time. The reduction in idle time is valued at approximately $2 million a year (Lester et al., 2017). In addition to winter weather events, Colorado DOT is piloting the PFMDSS application for non-winter operations such as weed spraying, mowing, lane striping, and surface repairs (Colorado Department of Transportation, 2017).

5.3.2 Idaho Transportation Department

The Idaho Transportation Department, responsible for about 5,000 centerline miles of state roadways, was a member state of TPF-5(054) from 2009 until 2012. After leaving the MDSS Pooled Fund Study, the Idaho Transportation Department embarked on developing a winter weather maintenance performance measures program to measure how quickly snow and ice on the surface of a roadway are reduced and whether good grip or traction on the surface is restored. Using their winter weather performance measures, shown in Table 10, Idaho Transportation Department can determine the effectiveness of the deicing process (Koeberlein et al., 2015). Figure 10 illustrates the scaled that Idaho Transportation

Department uses to evaluate the storm performance in terms of maintenance and improving grip on roadways affected by winter storms.

Table 10. Idaho Transportation Department winter weather performance measures (Jensen and Koeberlein, 2015)

Performance Measure	Description	Calculation	Goal
Winter Mobility Index (WMI)	Percentage of time safe grip (> 0.60) maintained during winter storm events	RWIS stations measures the percentage of time a roadway has precipitation on it in liquid form when temperatures are below 32°F	Maintain at least 55% unimpeded mobility during winter events
Winter Performance Index (WPI)	Duration of time that the grip is below safe levels (< 0.60) divided by the storm severity index	$WPI = \frac{Ice\ Up\ time\ (hrs)}{Storm\ Severity\ Index}$ Ice Up Time = Duration of the event when grip is below 0.60 for more than 30 minutes	A WPI of 0.20 or less, as this indicates that crews had significant success in accelerating the elimination of adverse conditions
Storm Severity Index (SSI)	SSI derived from the winter weather conditions, ranging from 10 to 100	$SSI = Wind\ Speed\ (mph)$ $+ Water\ Equivalent\ Layer\ (mm)$ $+ \frac{300}{Min\ Surface\ Temp\ (°F)}$	Range of 10-80 is light to normal events. Severe cold and high winds can result in a SSI as high as 500
RWIS Uptime	Percentage of time valid data is provided from RWIS	Comparison of received polling data from individual sensor transfers from the RWIS sites to the expected data at the RWIS sites	90% uptime 24/7/365

Prior to the implementation of the winter performance measures program, Idaho Transportation Department lacked guidance on basic winter weather maintenance practices (e.g, crews would respond on an ad hoc basis). The PFMDSS initially seemed to predict precipitation amounts higher than the actual amounts, which affected the Idaho Transportation Department's treatment recommendations and maintenance timing. With maintenance staff training, the Idaho Transportation Department noticed increases in the reliability of the data from RWIS ESSs (an algorithm is used to determine grip coefficient from ESS sensor data), and they then created the winter performance measures program. Idaho Transportation Department has realized that winter weather maintenance operations are now structured storm responses, driven by the data from the RWIS and the calculated performance measures (Jensen and Bala, 2013). In terms of accountability, Idaho Transportation Department has integrated the winter performance measures into the rating factors used for annual employee reviews. Transportation technician positions are linked to the winter performance measures as a part of determining any pay increases. Further, each Idaho Transportation Department maintenance manager has at least one RWIS site that can generate the performance measures. Highly performing maintenance individuals are recognized by Idaho Transportation Department (Jensen and Koeberlein, 2015).

0	Successfully treated
0.00 – 0.30	Significantly accelerated grip recovery
0.31 – 0.49	Some success at grip recovery
0.50 – 0.69	Very little success at deicing
0.70 –	Limited maintenance or no deicer success
	Observation data/parameter missing or temperature is below threshold

Figure 10. Storm Performance Index scale used by Idaho Transportation Department (Jensen and Bala, 2013)

The Idaho Transportation Department winter performance measures program relies on sensors such as automated traffic recorders and avalanche detection alarms and, more recently, AVL data system with cameras for trucks. The Idaho Transportation Department has installed more than 125 ESS sites throughout the state, using non-invasive pavement sensors to measure surface grip and atmospheric parameters. Each ESS provides polled data every 15 minutes throughout a winter weather event. The data is then fed automatically into the winter mobility index, winter performance index, and the RWIS uptime performance metrics to produce performance reports (Koeberlein et al., 2015). The winter performance indices provide the Idaho Transportation Department with a quantitative process to understand winter weather operations and incorporate changes to improve the efficiency of the system.

Each season, the Idaho Transportation Department sets statewide goals for each performance measure tracked on each route segment. Based on the results of the performance measures, the Idaho Transportation Department can provide regions that need improvement with additional training and resources. Overall, the Idaho Transportation Department has steadily improved from year to year. Table 11 shows the improvements that the Idaho Transportation Department has experienced in winter weather maintenance with the implementation of the winter performance measures during the evaluation period from 2010 to 2015. The results show a decrease in total winter maintenance costs and winter weather related accidents and an increase in mobility, meaning that WPM helped to make the Idaho Transportation Department's winter maintenance operations more efficient and resulted in safer roadways.

Table 11. Idaho Transportation Department winter maintenance performance from 2010 to 2015 (Koeberlein et al., 2015)

Season	Winter Performance Measures Used	Winter Maintenance Cost	Winter Mobility Index	Number of Winter Accidents

2010-2011	No	$30+ million	28%	1962
2011-2012	Yes	$30.0 million	47%	834
2012-2013	Yes	$25.5 million	54%	972
2013-2014	Yes	$21.4 million	59%	930
2014-2015	Yes	$15.1 million	73%	856

5.3.3 Indiana Department of Transportation

The Indiana DOT, one of the first states to test out an MDSS with its involvement with the FHWA MDSS Functional Prototype, rolled out a statewide MDSS initiative in 2009. Indiana DOT uses the PFMDSS to manage winter weather maintenance operations based on observations, forecasts, and data collected from on-vehicle AVL/MDC data systems. Indiana DOT's main objective in using the PFMDSS is to provide guidance to make informed decisions and achieve more efficiency in the use of maintenance resources. Indiana DOT recorded that one load of salt was approximately $500 in materials. With more than 1,100 snow trucks in the Indiana DOT fleet, one extra trip per event would cost more than $500,000 in materials (McClellan et al., 2010). Until recently, Indiana DOT incurred approximately $1.57 million annually in damages due to weather-related crashes, and a quarter of those accidents occurred on slick pavements or adverse winter weather (Kinion and Coulter, 2017).

Implementation of the PFMDSS required changes to Indiana DOT maintenance operations. To address the changes to operations based on use of the PFMDSS statewide, Indiana DOT provides a formalized training program to its staff. The Indiana DOT training program includes:

1) Graphical User Interface (GUI) Training: Iteris, Inc. personnel led the PFMDSS GUI training, which provided a hands-on experience for maintenance personnel. Indiana DOT PFMDSS personnel helped answer questions and insured trainees kept up with the material. Trainees noted experiencing circumstances comparable to those faced in their everyday use of PFMDSS during the hands-on training sessions.
2) QA/QC Training: The Quality Assurance/Quality Control plan was developed to help ensure that the system was being used, understood, and to achieve buy in. A series of QA/QC forms were developed and Indiana DOT personnel were trained in the QA/QC form completion so that no matter what time of day or who was working, these quality monitoring checks could be maintained.
3) Drivers Classroom AVL/MDC Training: Indiana DOT plow truck drivers that potentially could operate a truck with AVL/MDC equipment attended training to gain an overview of the system. Drivers had the opportunity to use AVL/MDC equipment, which Indiana DOT mounted on a portable board for the training sessions.
4) Drivers Hands-On AVL/MDC Training: This training expanded upon the classroom AVL/MDC training sessions. To train the large group of drivers a "train the trainer" session was held with each district, using an AVL/MDC unit mounted in a van and personnel from each district were trained on the use of the equipment.
5) Mechanics Training: Indiana DOT Mechanic technicians participated in equipment installation training across each district. Each district then performed the equipment installation in its fleet.

After installation and use, follow up training was provided to review the troubleshooting tips document and to answer questions.

6) Refresher GUI Training: This training reinforces major elements of the initial GUI training and provides the user the opportunity to learn new features of the system. Probabilities in weather forecasting and specific saved storms were used to illustrate how the system should be used. The refresher training was part of a change management process used for PFMDSS implementation. (McClellan et al., 2010)

In 2016, Indiana DOT introduced the use of Mobile Advanced Road Weather Information Sensors (MARWIS), a real-time mobile collection tool (Bunnell et al., 2016). The MARWIS can be mounted on the front, rear or the side of the vehicle to collect temperature, relative humidity, dew point and road conditions (e.g., dry, damp, wet, ice/snow, chemical wet). From the collected data, MARWIS determines ice percentages and can calculate weather-related surface friction. The MARWIS collects 100 measurements per second, which are transferred to a cloud database and then to a central office for processing. From there, the information is passed along via a server to Indiana DOT district offices.

Indiana DOT use the PFMDSS not only for winter weather maintenance operations, but also to help with: (1) equipment purchasing, (2) defining and naming support staff, (3) implementation and follow-up training and (4) a quality assurance/quality control accountability program. Additionally, Indiana DOT used the PFMDSS for chip seal maintenance during the summer of 2015. The PFMDSS was used to identify periods where air temperature was above 60 degrees Fahrenheit and relative humidity was below 70%. A chip seal operation could be scheduled or postponed based on a long-range forecast of humidity and probability of precipitation from the PFMDSS. The use of the PFMDSS proved to be accurate and assisted Indiana DOT maintenance with performing chip sealing during optimal times.

5.3.4 Michigan Department of Transportation

The Michigan DOT began installing AVL devices in its winter road maintenance equipment in 2013. Michigan DOT feeds that information with additional road and weather data and forecasts into its PFMDSS. As of 2015, Michigan DOT had 130 MDSS routes with 267 snowplows equipped with AVL data systems in six regions (Croze, 2015). The combination of AVL and the PFMDSS has helped Michigan DOT reduce salt consumption, material costs, and the impact of salt and chemicals on the environment (Weingarten, 2016).

Michigan DOT spends on average $30 million on salt material during the winter maintenance season. Using the PFMDSS with AVL equipped trucks has helped improve salt application practices. Even modest reductions in salt save a substantial amount for the state (Weingarten 2016). With the PFMDSS, Michigan DOT reduces their average winter operation costs by nearly 15% annually and provides accurate operating reports of equipment and materials, road conditions, and maintenance actions (Porrett, 2016). Specifically, maintenance supervisors can view road condition predictions for specific snow routes, using the real-time reports available from the PFMDSS, to optimize staff and resource deployment.

Michigan DOT recognized that it takes time to gain trust in the PFMDSS treatment recommendations (Croze, 2015) and that training is critical to gaining this trust. The Michigan DOT PFMDSS implementation team was provided comprehensive training and web-based access of reported data from the AVL equipped trucks (Porrett, 2016). Michigan DOT suggests the following tactics to implement the PFMDSS:

(1) gather data inputs from all relevant areas; and (2) hold weekly accountability meetings with staff and vendors to ensure they are held accountable for their tasks and deliverables.

In addition to using the PFMDSS for winter operations, Michigan DOT recently began to use the PFMDSS for summer maintenance activities. For example in a pilot project, Michigan DOT deployed the PFMDSS with five trucks in summer 2016 to collect and analyze data related to wind speed, precipitation, and alerts (Howe, 2016). The features of these trucks for summer maintenance include:

- In-cab touchscreen interface to display location of the trucks and known locations of invasive and endangered species.
- electronic spray log and flow meter recording to track spray locations, time of spraying, materials used, amount of materials used, and to monitor the spraying history of herbicides and associated location

The non-winter features of the PFMDSS used by Michigan DOT in this Pilot include:

- sustained and gust wind speed and direction
- precipitation probability and predicted amounts and rates
- timing of forecasted weather
- alerts of impending severe weather events (Howe, 2016)

Figure 11 shows an example of the PFMDSS non-winter alerts feature used in Michigan DOT. The next steps of implementing the PFMDSS for non-winter maintenance activities in Michigan DOT involve monitoring progress and collecting feedback, developing customized reports, and mapping spray locations (Howe, 2016).

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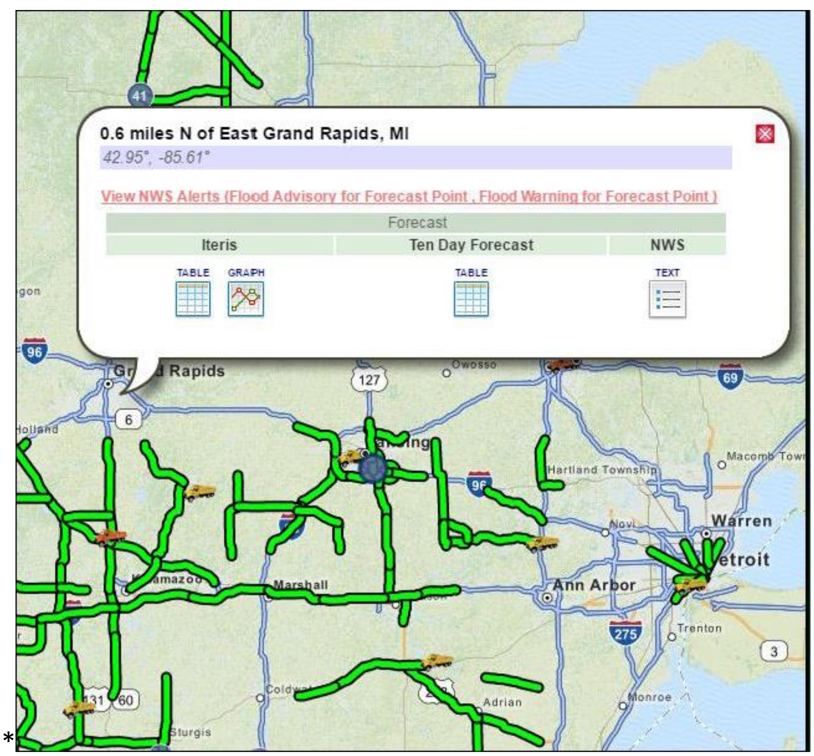

Figure 11. Non-winter alerts feature of the MDSS at Michigan DOT (Howe, 2016)

5.3.5 Minnesota Department of Transportation

The Minnesota DOT uses the PFMDSS to access road conditions through on-vehicle AVL data systems, in-pavement sensors, and manual entry of observations. Continuously updated weather forecasts are uploaded in The Minnesota DOT PFMDSS to help assess past and present weather conditions and predict short- and long-term storm weather. The Minnesota DOT showed that the PFMDSS has the potential to significantly reduce salt use and lessen environmental impacts while still meeting or exceeding performance targets (Minnesota Department of Transportation, 2010).

Minnesota DOT demonstrated that combining the PFMDSS with AVL data systems substantially improves the effectiveness of maintenance activities. AVL/GPS provides operators on-demand access to PFMDSS features including treatment recommendations, radar view and playback loops, route specific weather forecasts and nearby snowplow locations, and forces accountability by tracking maintenance actions (Minnesota Department of Transportation, 2013). As of 2018, The Minnesota DOT has 843 plow trucks in which 668 are equipped with AVL systems. Further, the Minnesota DOT equipped 226 snowplow trucks with dash and ceiling mounted cameras and integrated the cameras into the AVL system already installed in the plow trucks (Hirt and Petersen, 2017). The Minnesota DOT noted that the PFMDSS helps them achieve their strategic goals. Specifically, the PFMDSS:

- provides consistent levels of safety
- enhances movement of freight and people
- provides maintenance operators the tools they need to make informed decisions and lessen the risk involved
- helps to transparently document operation information and make it available to the public (Minnesota Department of Transportation, 2013)

The Minnesota DOT also uses RWIS data for its PFMDSS system. Environmental sensor stations (ESSs) collect air temperature, type and amount of precipitation, visibility, dew point, relative humidity, wind speed and direction, pavement temperature, subsurface temperature, surface condition (dry, wet, frozen), amount of deicing chemical on the roadway, and freezing point of the road surface. As of 2017, Minnesota DOT has 98 active ESS sites (Bjorkquist, 2017).

The Minnesota DOT uses the PFMDSS for summer maintenance operations, but on a much smaller scale than in winter. In 2010, Minnesota DOT started using the forecast-based recommendation feature in the PFMDSS to determine whether certain summertime operations should be restricted due to weather conditions. For example, Minnesota Department of Transportation uses the forecast feature to guide decisions on operations such as cold mix patching, concrete repair, and micro-surfacing. The Minnesota DOT also uses the AVL system in maintenance vehicles to mark potholes and weed patches, applications of pavement markings and herbicides, accident investigations, and serving as a proof of response or actions in complaints and lawsuits (Minnesota Department of Transportation, 2013). Trucks equipped with AVL were able to provide the maintenance crew with weather information needed for summer activities (e.g., site-specific radar, current wind speed, and precipitation forecast). Another pilot project by the Minnesota DOT T fitted 30 mowing tractors with an AVL system to provide mowing operations in the Minneapolis-St. Paul Metro District.

5.3.6 Nebraska Department of Transportation

The Nebraska DOT is responsible for maintaining 9,942 centerline miles of roads. The Nebraska DOT uses the PFMDSS to reduce the use of snow and ice removal materials, which is a significant part of Nebraska DOT's winter maintenance budget. The Nebraska DOT joined the MDSS Pooled Fund Study in 2006 and started using Level 4 AVL systems in 2010. Although the system performed well at recording vehicle location and weather data, large amounts of PFMDSS data could not be used because of missing data on the type and amount of materials used during the winter event (Gerbino-Bevins and Tuan, 2011). Further development of the MDSS was needed to improve its use and Nebraska DOT stopped using the MDSS. Then 2016, Nebraska DOT invested $6 million in a new five-year contract with Parsons to modernize the state's road clearing operations with the use of the PFMDSS (Nebraska Department of Transportation, 2018) as the development of the PFMDSS had been much improved and enhanced since the mid 2000s. As of 2018, Nebraska DOT has installed level 4 AVL systems in 629 plow trucks across the eight districts within Nebraska. Table 6 shows a breakdown of the equipped plow trucks in each district.

Table 12. Nebraska DOT breakdown of plow trucks equipped with AVL/MDC systems (Adapted from Nebraska DOT, 2017)

District	Plows
1	93
2	68
3	101
4	97
5	89
6	74
7	51
8	56
TOTAL	629

Each Nebraska DOT snowplow truck now has three integrated parts: (1) AVL system; (2) a touchscreen MDC interface integrated with the spreader controller that monitors truck movements and the amount and application rate of salt and other snow and ice removal; and (3) a dashboard truck camera, which takes a snapshot of the roadway every minute and automatically uploads them to a server.

5.3.7 New Hampshire Department of Transportation

The New Hampshire DOT has used an MDSS since 2006. The New Hampshire DOT showed interest in the PFMDSS to improve the efficiency of highway maintenance and reduce the use of salt and abrasives and their negative impacts on the environment. For example, the I-93 widening project between the towns of Salem and Manchester resulted in an environmental impact statement stipulating that New Hampshire DOT use an MDSS to reduce salt use by more precisely timing the application of materials (New Hampshire Department of Transportation, 2012).

The PFMDSS provides route-specific weather forecasts up to 36 hours ahead of a storm for highway segments along the I-93 corridor. Using forecasting services, ESSs with pavement sensors, AVL systems in maintenance vehicles, and observations by maintenance supervisors, the PFMDSS determines the best course of action for clearing roadways (New Hampshire Department of Transportation, 2014). The PFMDSS is used for guidance (e.g., a tool to help maintenance supervisors make informed decisions) rather than as a directive by New Hampshire DOT management (New Hampshire Department of Transportation, 2012).

5.3.8 North Dakota Department of Transportation

The North Dakota DOT, responsible for the maintenance of 8,500 centerline miles of roads, was one of the state DOTs to initiate the TPF-5(054) Pooled Fund Study in 2002. The PFMDSS supports North Dakota DOT mainly in snow and ice management with accurate predictions of weather conditions (North Dakota Department of Transportation, 2015). The PFMDSS provides daily reports related to the use of materials for snow and ice control management. In addition, the PFMDSS addresses environmental issues and helps reduce the total road maintenance cost for North Dakota DOT. For instance, using the PFMDSS saved North Dakota DOT more than $160,000 in the 2015-16 winter maintenance budget (Beise, 2017). Other advantages in using the PFMDSS are improved productivity of maintenance staff and accountability of the actions performed (North Dakota State University, 2016).

North Dakota DOT uses AVL/MDC data system technologies to collect data on road and weather conditions, which maintenance managers' use and feed into the PFMDSS. As of 2015, North Dakota DOT has 33 AVL/MDC units installed in maintenance vehicles across the state. North Dakota DOT realized several benefits of using AVL/MDC systems, including:

- assist with seamless route conditions across the different North Dakota DOT districts
- more informed snow and ice control decisions
- improve accuracy of MDSS weather forecasts and maintenance recommendations
- truck tracking to address risk management issues, public complaints, and efficient storm response
- camera images that support decision making and could be made available to the public
- assist with tracking and scheduling truck maintenance
- more easily create End of Shift Reports and Material Tracking Reports (North Dakota Department of Transportation, 2015)

5.3.9 Pennsylvania Department of Transportation

The Pennsylvania DOT committed to implementing the PFMDSS since 2010, when it joined the Pooled Fund Study. Pennsylvania DOT has a snowplow fleet of 2,250 trucks that cover 96,000 snow-lane miles across the state (Ravani and Wehage, 2017).

The Pennsylvania DOT uses AVL systems to provide situational awareness of weather and road conditions, and operator actions. Therefore, Pennsylvania DOT sees each equipped truck as a mobile mini-RWIS unit. The Pennsylvania DOT can compare vehicle speeds, road conditions, and treatments in real time from the data conveyed from the trucks. The data from the trucks can also be compared with grip data that is collected at stationary RWIS sites. Using the PFMDSS with AVL in addition to the RWIS system helps

Pennsylvania DOT with cost savings in route optimization, paperwork reduction, and labor savings collecting data (Ravani and Wehage, 2017).

Currently, more than 2,500 maintenance fleet vehicles have been equipped with three different types of AVL technologies (Ravani and Wehage, 2017). The first AVL is the Advanced Tracking System (ATS) from Certified Power, which is the preferred equipment setup, but the Pennsylvania DOT only installs this system if it is compatible with the spreader controller on the trucks. The ATS transmits data via cellular signal and has internal storage in case the cellular signal is lost. The ATS also provides location information to the 511pa.com vendor for public use on Pennsylvania DOT's traveler website. The ATS system is a level 3 AVL.

The second AVL system is the WT10X system from WebTech Wireless, which is used when the Certified Power ATS is not compatible with the spreader controller software or when no spreader control is present. The WT10X system provides data over cellular signals. Further, the WT10X units can connect to a vehicle's controller area network bus (CANbus) or OBD-II port, but Pennsylvania DOT has only used them for their GPS location function. The location of trucks can then be provided to the public (Ravani and Wehage, 2017). The WT10X is a level 2 AVL.

In the case when Pennsylvania DOT uses seasonal rental vehicles for winter maintenance operations, a third system used is the WT2250 system from WebTech Wireless, which transmits GPS location data via cellular wireless signals. Pennsylvania DOT ultimately chose the WT2250 due to its quick installation and plug-and-play abilities with a variety of vehicles. However, the WT2250 does not include internal storage of data in cellular signal is lost (Ravani and Wehage, 2017). The WT2250 setup is equivalent to a level 1 AVL system.

Another method used by Pennsylvania DOT to collect actual conditions is with the use of cellphones to collect and transmit data to the PFMDSS system. Pennsylvania DOT has developed various cellphone apps that include an app for taking photos of routes and uploading them to a server, and an app that can identify the location of the cellphone and the associated maintenance vehicle, which then transmits the location data to Pennsylvania DOT maintenance shops (Petersen, 2017).

5.3.10 Wisconsin Department of Transportation

The Wisconsin DOT's Bureau of Highway Maintenance (BHM) works with the five Wisconsin DOT regions (Northwest, North Central, Southwest, Northeast, and Southeast) to maintain 34,620 lane miles. The Wisconsin DOT contracts with 72 state county highway maintenance departments to maintain roadways, including winter operations (Wisconsin Department of Transportation, 2017). Wisconsin DOT began using the MDSS in 2009 and participating in the Pooled Fund Study TPF-(054) in 2010. Initial deployment of the PFMDSS occurred in 2009, focusing on Interstate highways. Then, during 2010 and 2011, the Wisconsin DOT added four to five representative routes to the PFMDSS for each county so that county highway maintenance departments could use the PFMDSS on a regular basis for accurate forecasts and treatment recommendations. The Wisconsin DOT BHM then added the remainder of state roadways in to the PFMDSS, but these routes are for AVL/MDC data tracking (Wisconsin Department of Transportation, 2017).

Wisconsin DOT has implemented the PFMDSS with and without the integration of AVL systems. Table 13 lists the differences between deployment with and without the use of AVL systems as observed by Wisconsin DOT maintenance personnel.

Table 13. Differences in PFMDSS deployment with and without AVL at Wisconsin DOT (Adams, 2013)

With AVL	Without AVL
• Data collected from vehicles go directly to the MDSS • Treatment recommendations updated based upon real-time treatments done to routes. • Higher operation cost • More vehicle maintenance required • Longer implemented time	• Lower operation cost • Quicker deployment • Less technology involved • No vehicle feedback goes directly to the MDSS system • Treatment recommendations not based upon real-time information

As the owner and operator of state highways, Wisconsin DOT has the responsibility to use the most efficient and effective means for making system and operational management decisions involving vehicle equipment and data collection devices. Wisconsin DOT identifies the following benefits of the PFMDSS:

- consistent high level of service for winter maintenance and traveler safety
- cost savings for materials (salt, liquid, sand, etc.)
- improved treatment recommendations
- improved forecasting capabilities
- improved incident management
- improved operator safety
- improved communications
- improved accountability
- automated reporting capabilities
- improved winter crash analysis
- new operational mapping
- real-time storm management
- summer asset observations (Adams, 2013)

The Wisconsin DOT noted that training plays a critical role in the PFMDSS deployment. Recently, Wisconsin DOT has focused PFMDSS user training on the transition to the web-based MDSS and the mobile MDSS application. The Wisconsin DOT BHM worked closely with Iteris, Inc. to develop a training plan. Additionally, Wisconsin DOT continues implementing the improved reporting capabilities of PFMDSS and investigating the use of PFMDSS data, including the development of a new winter severity index based on PFMDSS data (Wisconsin Department of Transportation, 2017).

Wisconsin DOT has also applied the PFMDSS for summer maintenance. Wisconsin DOT has realized the benefit of using the PFMDSS to determine best times to perform short-term road maintenance. One specific application is using the PFMDSS to help Wisconsin DOT be aware of ideal conditions for pavement buckling. The Wisconsin DOT has set up alerts within the PFMDSS, along with a Module in the MODSS, to provide advanced notice that conditions are right for pavement buckling to occur. Maintenance managers can then be alerts to possible roadway buckles, and then have crews ready to perform repairs if they do in fact occur (Urh, 2018).

5.3.11 Wyoming Department of Transportation

The Wyoming DOT has several PFMDSS routes, mostly along Interstates I-25, I-80, and I-90 that use information gathered from ESSs, cameras, and patrols to determine the best option for snow removal procedures. However, lack of funding has limited the deployment of the PFMDSS to other roadways throughout the state as Wyoming DOT contributed to the TPF-(054) Pooled Fund Study, but only through 2013.

To advance maintenance of roadways, Wyoming DOT is one of three states involved in the FHWA's connected vehicle pilot deployment program, which focuses on improving road safety, mobility, and efficiency (National Center for Atmospheric Research, 2017). The heavily traveled 402-mile I-80 corridor through Wyoming is mostly rural and is subject to winter weather conditions that adversely affect travel. The I-80 corridor averages more than 32 million tons of freight movement each year, and a lack of alternate routes in Wyoming means that truck volumes can reach 70% during peak seasons (Wyoming Department of Transportation, 2017). The connected vehicles pilot study is deploying dedicated short-range communication (DSRC) technology for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V) connectivity to improve monitoring and reporting not of winter road and weather conditions, but also fog and wind in the summer. A total of 75 roadside units are being deployed along the I-80 corridor to receive and broadcast messages to motorists DSRC-equipped vehicles.

Additionally, Wyoming DOT is equipping 400 fleet vehicles with DSRC-connected in-cab units that can broadcast safety messages, alerts, and advisories and collect weather conditions and roadway data using mobile weather stations (Wyoming Department of Transportation, 2017). The connected vehicle pilot will communicate forward collision warnings, work zone warnings, distress notifications, weather impact warnings, and situational awareness information to traveling motorists in real time. The findings from this pilot program should provide data and results that can be applied towards the development of enhanced features for future PFMDSS versions.

5.4 PFMDSS Expectations

This section presents the overall expectations of implementing the PFMDSS in SDDOT based on the findings from the interviews conducted with 83 SDDOT maintenance personnel across the four SDDOT regions that took place in July 2017. No SDDOT staff could explicitly state the department's clear expectations of the PFMDSS for winter maintenance. Some maintenance staff mentioned that they were unsure of the department's expectations. Others thought SDDOT expects the PFMDSS to be the "end-all be-all" tool that will provide error-free information. Even others believed the PFMDSS is just another tool in the toolbox. Table 14 synthesizes typical common findings from SDDOT staff in terms of SDDOT's expectations as well as their own individual expectations of implementing the PFMDSS. Overall, the PFMDSS is a decision-support tool that provides weather and road data to help maintenance staff plan and execute snow removal and road clearing during winter weather events.

Table 14. Comments from SDDOT staff on the expectations of the PFMDSS

	Area Engineers	Highway Maintenance Supervisors	Lead Highway Maintenance Workers	Highway Maintenance Workers with MDC Units	Highway Maintenance Workers without MDC Units
SDDOT Expectations of the PFMDSS	"Not really sure" "SDDOT expects the MDSS to be a decision assistance tool for winter maintenance"	"The 'Bible' of winter weather maintenance" "Very high expectations from upper management" "Cost savings tool"	"The 'Bible' of winter weather maintenance" "Another tool in the toolbox" "Not sure expectations were communicated to us"	"The 'Bible' of winter weather maintenance" "Useful tool for winter weather maintenance"	"The 'Bible' of winter weather maintenance" "Not sure expectations were ever communicated"
Individual Expectations of the PFMDSS	"Provide some degree of certainty and trust" "A useful tool, a starting point" "Provide accurate forecasts and give good recommendations to follow"	"Useful tool, but not the only tool" "Provide accurate forecasts and treatment recommendations being somewhat accurate" "A good starting point"	"Forecast and treatment recommendations being correct" "Correct predictions of the weather and what materials to use, how much, and when"	"Useful tool, but needs to be more accurate" "Forecast and treatment recommendations being correct"	"Forecasts and treatment recommendations need to be accurate" "Another tool in the toolbox to help with our job"

In terms of individual expectations of the PFMDSS, many staff mentioned that the PFMDSS and associated components are effective tools to assist with winter maintenance but it does not replace human experience and intuition. The consensus finding obtained from the interviews is that most SDDOT staff view the PFMDSS as a tool using weather and road conditions to help them make better decisions based on PFMDSS forecasts and treatment recommendations.

5.4.1 SDDOT perception of PFMDSS information

Table 15 outlines the importance of PFMDSS information as perceived by SDDOT maintenance staff, based on responses to the pre-interview questionnaire (See Appendix A). Although almost all information generated from PFMDSS is important, a few items vary among the levels of SDDOT maintenance staff. For instance, the HMWs without MDCs noted a lower level of importance for each piece of information from the PFMDSS than the rest of the maintenance staff. This could be attributed to the fact that these HMWs do not interface with the PFMDSS or the MDC. Instead, they use the information provided by their supervisor. These HMWs typically rely on their experience and intuition to maintain the route segments.

Table 15. Importance of information provided by the PFMDSS

	Area Engineers	Highway Maintenance Supervisors	Lead Highway Maintenance Workers	Highway Maintenance Workers with MDC Units	Highway Maintenance Workers without MDC Units
Radar	Very important	Very important	Very important	Important	Slightly important
Treatment recommendations	Important	Moderately important	Moderately important	Moderately important	Not important
Current road surface conditions	Important	Moderately important	Important	Important	Slightly important
Current wind conditions	Very important	Important	Important	Important	Slightly important
Forecasted road surface conditions	Important	Moderately important	Moderately important	Important	Slightly important
Forecasted wind conditions	Very important	Important	Very important	Important	Slightly important
Forecasted precipitation rate	Very important	Important	Important	Important	Slightly important
Start time of storm event	Very important	Important	Important	Important	Slightly important
End time of storm event	Moderately important	Moderately important	Very important	Moderately important	Not important
Truck mounted cameras	Important	Slightly important	Slightly important	Slightly important	Slightly important
RWIS Cameras	Very important	Important	Important	Moderately important	Slightly important
AVL/Truck movements	Moderately important	Not important	Slightly important	Not important	Not important
Management reports	Important	Slightly important	Slightly important	Slightly important	Not important

Another area of information showing differences among levels of maintenance staff is the importance of truck mounted cameras, the cameras mounted on RWIS ESSs, AVL truck movements, and management reports. Based in the importance rating information, Area Engineers rated the importance of truck mounted cameras, RWIS cameras, AVL truck movements, and management reports higher than the rest of the maintenance staff. Part of the reason may be that during a winter weather event, Area Engineers do not travel the route segments as often as other maintenance staff. In fact, the Area Engineers rely on the cameras on the trucks, the RWIS cameras, and the location of the trucks to analyze a winter weather event. Further, some of the lead highway maintenance workers (LHMWs) and HMWs indicated that "the AVL truck movements just provide a way for supervisors to micro-manage their work by knowing where they are at all the time".

Finally, the interview results showed that management reports are more important to Area Engineers than the other levels of maintenance staff. However, Area Engineers expressed difficulty in accessing and understanding the management reports. PFMDSS accuracy expectations

Although many agreed the PFMDSS is a useful tool in the toolbox, most SDDOT staff noted that the accuracy of the PFMDSS is not meeting their own expectations. Most maintenance workers interviewed expect the PFMDSS to "provide accurate forecasts and treatment recommendations most of the time" while Area Engineers and HMSs want to see accurate forecasts and treatment recommendations all the time. A few HMWs stated that they see the PFMDSS as never correct and so they do not use it, which results in some staff turning the MDC unit off in their truck.

PFMDSS accuracy expectations can be further explained based on questions posed to SDDOT staff about the accuracy of PFMDSS treatment recommendations. More than half of the maintenance staff interviewed believe the treatment recommendations are only accurate some of the time, or less than half of the time. In follow up discussions, both HMSs and LHMWs agreed that the treatment recommendations are accurate less than 50% of the time. Area Engineers and HMWs with and without MDC units agreed that treatment recommendations are "only as good as the forecast". If the forecast is off, then the treatment recommendations will be incorrect. Further, HMWs with and without MDC units agreed that pre-treatment recommendations do not work well and perceived pre-treatment as a waste of time.

The maintenance staff was asked to rate the accuracy of weather forecasts, predicted road conditions, and treatment recommendations (Table 16). Most SDDOT staff believe the weather forecasts and predicted road conditions are more accurate than the treatment recommendations.

Table 16. Rating the accuracy of weather forecasts, predicted road conditions, and treatment recommendations of the PFMDSS

	Area Engineers	Highway Maintenance Supervisors	Lead Highway Maintenance Workers	Highway Maintenance Workers with MDC Units	Highway Maintenance Workers without MDC Units
Accuracy of weather forecasts	Accurate	Moderately accurate	Moderately accurate	Moderately accurate	Slightly accurate
Accuracy of predicted road conditions	Moderately accurate	Moderately accurate	Moderately accurate	Moderately accurate	Not accurate
Accuracy of treatment recommendations	Moderately accurate	Slightly accurate	Slightly accurate	Slightly accurate	Not accurate

5.4.2 Expectations of the impact of the PFMDSS on winter maintenance

Table 17 summarizes the perception of SDDOT maintenance staff on the impact of the PFMDSS on maintenance costs, amount of material used, efficient use of staff, and level of service. Area Engineers perceived that the PFMDSS has a positive influence in that the PFMSS makes more efficient use of materials and resources. However, Area Engineers noted that the current performance measures for material use were developed and implemented at the same time as the PFMDSS, so making comparisons to material use before implementing the PFMDSS is difficult. In contrast to the Area Engineers, HMSs, LHMWs, and HMWs with MDC units did not observe much of an impact on any of the factors discussed.

Finally, the HMWs who do not have an MDC and do not interact directly with the PFMDSS seem to think the PFMDSS has made winter weather maintenance worse.

Table 17. Rating the impact of the PFMDSS on costs, resources, and level of service

	Area Engineers	Highway Maintenance Supervisors	Lead Highway Maintenance Workers	Highway Maintenance Workers with MDC Units	Highway Maintenance Workers without MDC Units
Maintenance Costs	Better	No change	No change	No change	Much worse
Amount of materials used	Better	No change	No change	No change	Worse
Efficient use of SDDOT staff	Better	No change	No change	No change	Worse
Level of service	Better	No change	Worse	No change	Worse

Some HMSs indicated the PFMDSS has a little impact on costs, resources, and level of service because they did not notice much change in the amount of materials and resources used. However, a few HMSs mentioned that less materials were used. More importantly, they believed the PFMDSS makes HMSs accountable on where and how much the materials are applied. In contrast, some maintenance staff mentioned that more materials and resources were used due to the inaccuracy of the PFMDSS treatment recommendations. Additionally, the maintenance workers were unsure how the PFMDSS impacts their winter maintenance.

Based on the perception of PFMDSS information, accuracy expectations, and the impact of the PFMDSS on winter maintenance operations, SDDOT needs to consider communicating more specific information about the PFMDSS to all SDDOT maintenance staff so that they understand the positive impacts of the PFMDSS on their maintenance operations during winter weather events. Establishing and sharing objective performance measures to maintenance staff across the department will help to educate and quantitatively show that the PFMDSS is a tool that can make maintenance operations more effective and treatments more efficient. Increasing the understanding and knowledge of the PFMDSS by proving its actual performance should advance the overall perception of the PFMDSS and lead to more maintenance staff using the PFMDSS more consistently.

5.5 Deployment of the PFMDSS for South Dakota

South Dakota is the 17th largest state in size in the United States and has a 2016 population of approximately 860,000. South Dakota maintains 7,808 miles of highways to provide a level of service that the travelling public demands. Many areas within the state can experience different weather conditions and events.

Operations within SDDOT during winter events vary. Most of the SDDOT regions do not operate overnight during winter storms, except on urban Interstate highways in Rapid City and Sioux Falls. Currently, SDDOT has 125 plow trucks that have MDC units out of 468 total plow trucks for a total deployment rate of 26.7%. 147 road segments are included the PFMDSS for a total of 3,034 centerline miles or 38.8% of mileage. As the level of service demanded by the public during a winter event continues to increase, SDDOT needs to consider expanding the PFMDSS deployment to more route segments and equipping more trucks with MDC systems.

Discussions during the interview process with different levels of SDDOT maintenance staff provide insight into the level of PFMDSS deployment needed. Table 18 summarizes the level of deployment that SDDOT maintenance staff believe is viable for the PFMDSS. In general, the Area Engineers interviewed noted the need for more route segments covering more lane miles and equipping more plow trucks with MDC units. Most Area Engineers stated that all route segments should be a part of the PFMDSS and all plow trucks should be equipped with MDC units or similar in-cab data systems. However, the Area Engineers agreed that increasing the deployment of the PFMDSS to more route segments and installing additional MDC units or similar equipment could potentially be expensive.

Table 18. Level of deployment based on SDDOT maintenance staff input

	Area Engineers	Highway Maintenance Supervisors	Lead Highway Maintenance Workers	Highway Maintenance Workers with MDC Units	Highway Maintenance Workers without MDC Units
The percentage of route segments that should be included in the PFMDSS	75-99%	25-49%	25-49%	25-49%	Less than 25%
The percentage of plow trucks that should have MDC units	75-99%	25-49%	25-49%	25-49%	Less than 25%

Responses from lead highway maintenance workers (LHMWs) and highway maintenance workers (HMWs) reveal a different opinion on the deployment of the PFMDSS. Table 18 shows that HMSs, LHMWs, and the HMWs with MDC units agreed that less than half of the SDDOT route segments should be a part of the PFMDSS and less than half of all plow trucks need an MDC installed. In general, the HMSs, the LHMWs, and HMWs with MDC units think that the current PFMDSS deployment is acceptable and no further deployment is necessary.

Further, the HMWs without MDC units agreed that less than a quarter of all route segments and all plow trucks need to be included in the PFMDSS and equipped with an MDC unit respectively. This finding is understandable since these HMWs do not interact with the MDC or the PFMDSS. They often receive input from their HMS, and use instructions provided by their HMS along with experience to perform winter storm maintenance operations. As a result, HMWs without MDC units believe that there is little advantage to expanding the deployment of the PFMDSS to more route segments and adding MDC units or other data systems to more trucks.

The interview results also indicated the variation of using MDC and PFMDSS between experienced and less-experienced HMWs. Most experienced HMWs noted that they do not want the MDC in their truck because they tend to rely on their own intuition and experience rather than using the PFMDSS's recommendations. On the other hand, newer HMWs (e.g., less than 5 years of experience) are more accepting of the PFMDSS and the MDCs in their trucks. Newer HMWs have always used the PFMDSS and MDC units.

In summary, based on the information from the interviews and the use of the PFMDSS in other states, SDDOT will need to be strategic in expanding the deployment of the PFMDSS. Specifically, it is important to identify roadways that should be included in the PFMDSS. Then, SDDOT can strategize the deployment of MDC units to plow trucks. Further, SDDOT will need to educate and train maintenance personnel to increase acceptability of the PFMDSS and its use.

5.6 Policy and Guidance for using the PFMDSS in South Dakota

Policies and guidelines help staff make decisions and perform tasks. Adopting specific policies and guidance for the PFMDSS will help SDDOT improve the consistency in use of PFMDSS and control how the PFMDSS should be used. Many SDDOT maintenance staff noted the PFMDSS and MDC units are not difficult to use. Most staff believed only limited additional guidance is needed on the PFMDSS and the MDC data system now. However, many staff indicated that a refresher on PFMDSS guidance and additional PFMDSS training would help to make sure staff uses the PFMDSS correctly and consistently from season to season. As noted by an Area Engineer from the Aberdeen region, the most difficult part of using the PFMDSS involves remembering how to use it from one winter season to the next.

As for the functions associated with the PFMDSS, SDDOT may consider the following policy revisions to improve the PFMDSS and its use during winter storm events:

- clarifying the ability to be flexible in applying PFMDSS treatment recommendations
- clarifying the frequency for updating road conditions while on a route
- training for HMWs with MDC and HMWs without MDC on the PFMDSS and the MDC units
- training for all maintenance staff to use the PFMDSS
- enforcing the completion of end of route surveys
- hiring dedicated PFMDSS staff for each SDDOT region
- holding review and lessons learned sessions after each winter weather event

5.7 Other Maintenance Uses of the PFMDSS

Although the development and use of the PFMDSS is for winter maintenance, it has potential for use with non-winter maintenance operations. Several state DOTs, such as Indiana, Michigan, and Minnesota (which are described in Section 5.3), have begun to use the PFMDSS for year-round maintenance activities. Summer maintenance activities may include patching and paving, weed control and mowing, paint striping, and various other activities.

SDDOT's MDSS GUI includes options for maintenance activities beyond winter weather events. Current maintenance activities options in the PFMDSS include chip and crack sealing, concrete joint sealing, epoxy chip sealing, hot mix paving and patching, pavement markings, and weed spraying. Although these options are available in the PFMDSS, many maintenance staff mentioned during the interviews that they were unaware of them. SDDOT may need to communicate these options to maintenance staff if SDDOT decides to use the PFMDSS for summer maintenance activities. In discussions with the SDDOT maintenance staff, some of the options that might be beneficial to use the PFMDSS are:

- weed spraying
- chip seals and flash seals
- striping and pavement painting
- paving work for construction activities
- tracking of maintenance work being performed

However, several SDDOT staff did not see value in using the PFMDSS for summer activities as the costs to operate the PFMDSS may exceed the value of the work that is performed. For example, HMWs noted that because weather apps on phones and tablets can provide the same information as the PFMDSS in the summer, the costs of using the PFMDSS are unneeded. Maintenance staff in one region (Aberdeen) mentioned that some of their summer maintenance is contracted out to a third party, so it may not make sense to use PFMDSS for some of the summer maintenance activities. Another issue is that weather conditions may need to be updated more frequently and be more accurate for summer maintenance activities as slight changes in wind speed and velocity can compromise some maintenance activities associated with spraying and sealing.

In summary, several state DOTs showed the success of using PFMDSS for various summer maintenance activities. However, it is recommended to SDDOT to conduct a full-scale research project to explore and possibly pilot a few activities for summer maintenance using PFMDSS in the near future. It is important to note that no state DOT has fully deployed the PFMDSS for summer maintenance and determining the overall costs and benefits of use during the summer is a work in progress.

5.8 Integrating the PFMDSS with other SDDOT Information Systems

The PFMDSS can provide detailed road and weather conditions and forecasts, which can be useful information for the 511 telephony system, the SafeTravelUSA website, and winter weather performance measures.

5.8.1 SafeTravelUSA website and 511 telephony system

SDDOT uses SafeTravelUSA website and the 511 telephony system to provide travel information to the roadway users. Figure 12 displays a screenshot of the SafeTravelUSA website for South Dakota. SafeTravelUSA real-time road conditions, weather forecasts showing potential threats that could affect road conditions, commercial vehicle restrictions, construction work zones, and road closures. The threats feature integrates the PFMDSS's road condition forecasting capability.

Currently, SafeTravelUSA uses PFMDSS forecasts of future road conditions and current road conditions are supplied by SDDOT maintenance staff with inputs into the integrated roadway information system (IRIS). Yet, SDDOT has the option to integrate additional features of the PFMDSS into the SafeTravelUSA information. This could improve the overall information that the website provides as well as offering additional information to the traveling public on current and future conditions.

PFMDSS features to consider for integration with SafeTravelUSA would be plow truck locations, plow truck camera images, treatments made to road segments, and predictions of when a road segment will be plowed. Other state DOTs, such as the Minnesota DOT, already provide plow truck locations and truck camera views to the traveling public to show plow locations and where the plows will be heading.

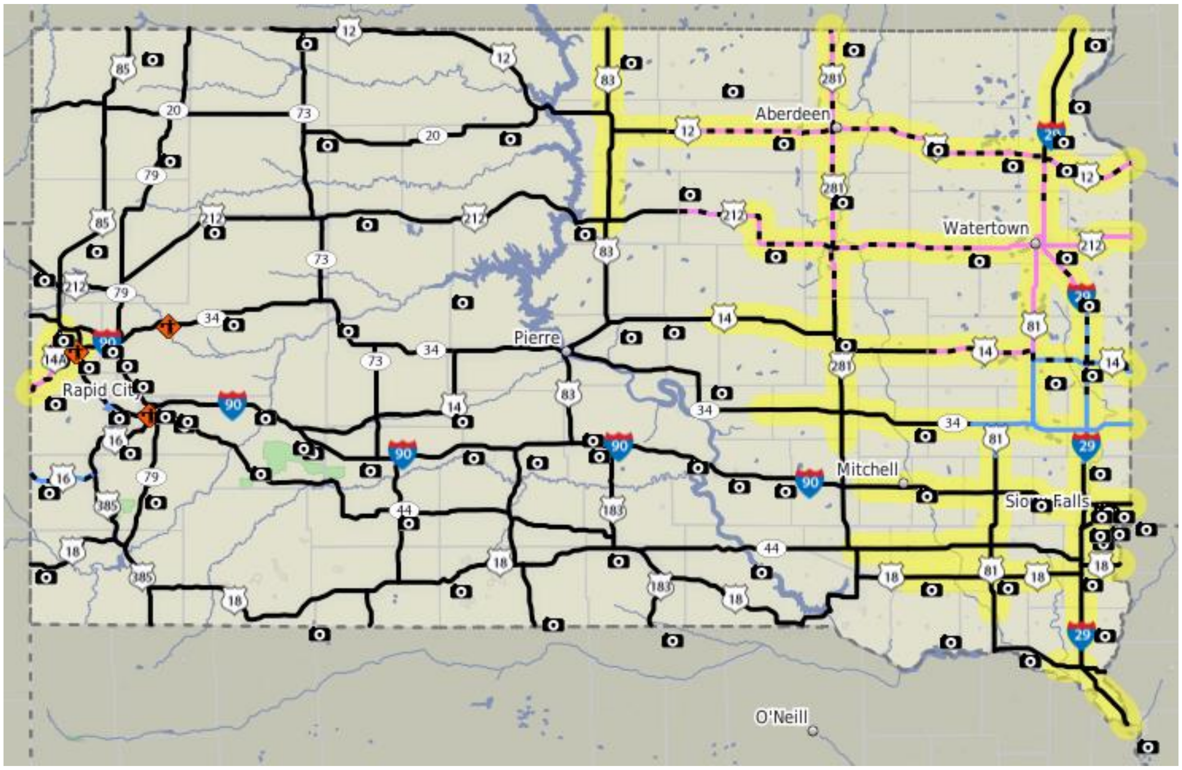

Figure 12. SafeTravelUSA road condition map of South Dakota showing scattered ice and slippery conditions on roadways in pink and threats of worsening conditions in yellow (www.safetravelusa.com/sd/)

5.8.2 Winter weather performance measures

One of the findings from the maintenance staff interviews concerns the performance measures process for winter weather events. Some HMSs and LHMWs suggested that performance measures be tracked through the MDC units in the trucks. This suggestion could work, but only approximately 25% of the plow trucks at SDDOT have MDC units now. The remaining 75% of HMWs without an MDC could not track performance measures in this manner. A more automatic performance measures system could potentially make work easier for the plow drivers and produce more accurate measures.

SDDOT should consider this approach so all plow truck drivers can use the same performance measures system. This will improve consistency and accuracy in the measures and provide cost savings with more efficient use of resources and materials. To do this, more if not all plow trucks would need to be equipped with AVL data systems.

5.9 Developing the Implementation Plan for Future Use of the PFMDSS

This section describes the implementation plan for future use of the PFMDSS in SDDOT. The strategy plan was developed based on findings from the literature review, investigating other state DOT and their use of an MDSS, results of the pre-interview questionnaire, and the group interviews with SDDOT maintenance staff.

5.9.1 Process for conducting an analysis of costs and benefits

In review of MDSS and road weather management documents and reports, studies completed over the last 15 years included benefit-cost analyses of specific aspects of road weather management. According to Lawrence et al. (2017), a benefit-cost analysis (BCA) attempts to capture the benefits and costs that accrue to society (in this case the traveling public) from a project or some sort of action, regardless of the party or parties that realize the benefits or costs, or what are the costs and benefits.

The process used in this research to conduct the BCA followed the guidelines outlined by the US Department of Transportation (2003) and used in a variety of MDSS and winter weather maintenance management studies (Lawrence et al., 2017). The steps followed include:

1) *Establish objectives.* A clear understanding of the BCA's objectives is essential to reducing the number of alternates to consider. The objectives of the BCA for the implementation plan for future PFMDSS use at SDDOT include:
    - Determine capital and annual costs for each component of the implementation plan based on information from SDDOT, literature review, and other state DOTs using the PFMDSS
    - Describe potential research benefits that align with savings realized in maintenance operations as well as benefits that adhere to SDDOT's goal of providing a safe and effective transportation system.
2) *Identify constraints and specify assumptions.* Constraints can be policy, legal, natural, or other. Based on the potential constraints, assumptions will need to be made. Specific constraints and assumptions are provided as needed for each implementation strategy.
3) *Define base case and identify alternatives.* A base case can be established as a minimum alternative. In this study, the base case is the current PFMDSS and road weather management system in place at SDDOT with no additions or changes. The baseline is then considered as $0 to compare to the total costs of the implementation plan and the associated expansion of the PFMDSS.
4) *Set the analysis period.* To ensure that alternatives can be compared evenly, an analyst period must be set to show the life-cycle costs and benefits of all alternatives. In this study, an analysis period of five years (2019 to 2024) was used based on an expected technological equipment usable life span.
5) *Estimate benefits and costs relative to the base case.* The capital and annual costs, and the tangible and intangible benefits are calculated using scientific methods, such as engineering economics, along with cost and benefit data from SDDOT and reliable sources recently published. For simplicity of the BCA and due to the lack of specific cost data from SDDOT for all components of the BCA, the base case for the current PFMDSS at SDDOT is considered zero. Dollar values are then assigned to each cost and benefit along with the use of a discount rate to provide the net present value amount for each of the five years used for the analysis period. The U.S. Office of Management and Budget (OMB) Circular A-94 states a five-year discount rate of -0.3% for cost-effectiveness analyses. (https://www.gpo.gov/fdsys/pkg/FR-2017-01-10/pdf/2017-00209.pdf).

5.9.2 Analysis of SDDOT route segments

South Dakota's current PFMDSS setup includes 147 routes across 232 road segments that cover 3,034 centerline miles of SDDOT-maintained roadways. To cover the remaining miles of SDDOT maintained roadways, the PFMDSS will need to include additional route segments and all 69 maintenance shops. Additional route segments in the PFMDSS will allow SDDOT to maintain many more miles of roadways more efficiently during winter weather events as the MDSS can then be the "one-stop-shop" for information on route segments across South Dakota. The PFMDSS will be able to provide forecasts and treatment recommendations for more SDDOT route segments, which can help to reduce material use and labor costs.

To evaluate the remaining route segments, SDDOT Operations Support provided a detailed list of all Interstate, US, and South Dakota highway segments, which includes the PFMDSS route number (only for route segments currently in the PFMDSS), the beginning and ending mile marker, and the annual average daily traffic (AADT) volume for every route that SDDOT maintains.

To analyze the route data provided by SDDOT, the following criteria were used:

- The research team reviewed all the route segments (current PFMDSS and non-PFMDSS route segments) and sorted each road as Interstate (I-90, I-29, I-190, and I-229), US highway (e.g., US12, US14, and US212), or South Dakota state highway (e.g., SD34, SD47, and SD50).
- Each current and non-PFMDSS route segment was then corresponded to a maintenance unit, shop, and shop number using shop information and a shop boundary map provided by SDDOT (See Figure 13). This allowed the researchers to compare similar route segments within a maintenance shop area and to see which shops already have MDC equipped trucks along current PFMDSS route segments. The shops that currently have multiple route segments and MDC equipped trucks were prioritized as shops to receive more route segments and MDC equipped trucks sooner than shops with limited or no PFMDSS route segments or MDC equipped trucks.
- The list of highways was then separated as either a current PFMDSS route segment or a non-PFMDSS route segment. This allowed the research team to focus on the non-PFMDSS route segments.
- The research team investigated the annual average daily traffic (AADT) of non-PFMDSS route segments to determine the new route segments that have high volumes of traffic. High traffic volume route segments were then determined to need an MDC equipped truck while very low volume roads (route segments with AADT less than 200 vehicles) are to use radio communication and existing ESS locations as a means of communicating and gathering information. By not equipping trucks used on low volume roads, SDDOT can save costs and focus on the route segments that handle high traffic and require more attention to provide the level of service warranted in a winter storm event.
- For each route segment, SDDOT provided the beginning and ending mileage, which was used to calculate the length of each segment. Segments can be adjusted based on the specific conditions and constraints and can be combined into specific PFMDSS route segments based on the practices of each maintenance shop.
- The full route analysis is provided in Appendices D-G, divided up by the four SDDOT regions.

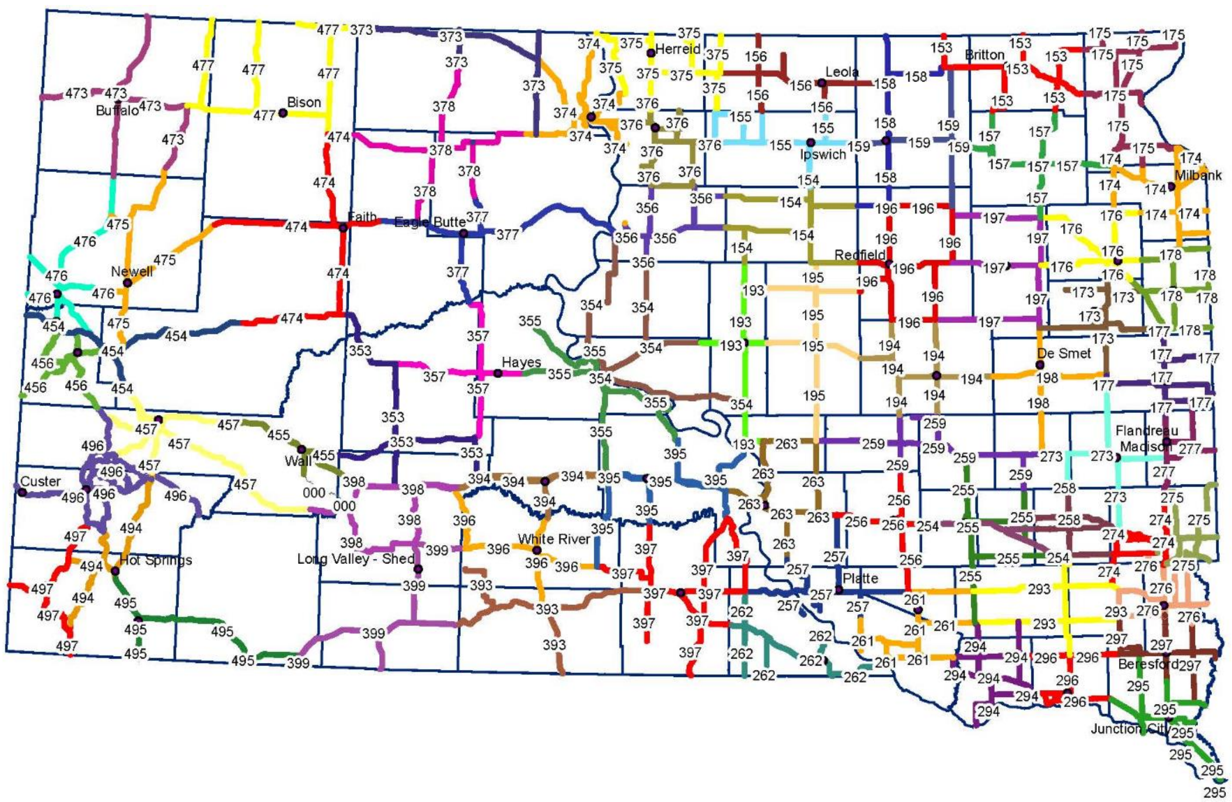

Figure 13. SDDOT Maintenance shops and corresponding route segments

Based on the criteria, Table 19 summarizes the number of new PFMDSS route segments, and the miles added for each region based on the trucks to be equipped. The total miles added to the PFMDSS would more than double the current miles of roadway covered by the PFMDSS. Appendices D through G list route segments by SDDOT region and distinguish existing and new route segments. Each appendix displays whether new route segments should have an MDC unit or the Zonar tablet, and whether route segments are in close proximity to ESSs and do not need trucks equipped with MDC units or Zonar.

Table 19. Number of new PFMDSS route segments and lane miles by region

	Aberdeen	Mitchell	Pierre	Rapid City	Total
No. of new PFMDSS Route Segments	91	81	66	66	304
Lane Miles for New PFMDSS Route Segments	1,467.63	1,056.42	1,266.77	1,013.24	4,804.06
Number of MDC Equipped trucks	66	56	31	35	188
Lane Miles for MDC Equipped Trucks	961.04	683.99	595.64	448.19	2,688.86
Number of Route Segments Covered by ESSs	18	20	23	21	82
Lane Miles for Route Segments Covered by ESSs	424.99	316.38	414.86	421.05	1,577.28
Number of Zonar Equipped Trucks	2	3	2	6	13
Lane Miles for Zonar Equipped Trucks	19.60	35.31	39.37	60.40	154.68

Number of Route Segments with Low AADT (No truck equipment)	5	2	11	4	22
Lane Miles for Route Segments with Low AADT (No truck equipment)	62.00	20.74	216.90	83.60	383.24

5.10 PFMDSS Implementation Plan

This section details the implementation plan for use by SDDOT. The plan includes four strategic components, which include adding new PFMDSS route segments, equipping more plow trucks with MDC units, using ESSs information in lieu of MDC units, and equipping trucks with the Zonar system for piloting. Each section provides the costs to implement and a schedule to implement each part. The benefits that SDDOT may realize from using this plan is included in Section 7.0.

5.10.1 Add New PFMDSS Route Segments

Expanding the PFMDSS to cover more route segments statewide can provide better winter maintenance management. Table 20 summarizes the requirements of adding new route segments throughout South Dakota to the PFMDSS.

Table 20. Requirements for adding new road segments to the PFMDSS

Factor	Response
SDDOT's business needs: How does the implementation plan align with SDDOT's business needs and help SDDOT provide a safe and effective public transportation system?	Yes, potential to provide safer travel on more roadways throughout the state and the ability to manage material and human resources more efficiently and consistently. The PFMDSS has proven in the past with SDDOT and other states that savings can be realized when the PFMDSS provides detailed information for specific route segments.
Discrete PFMDSS capabilities: How does the implementation plan utilize one or more PFMDSS key features?	Each of the new PFMDSS route segments will have the ability to access all the PFMDSS features once they are programmed into the PFMDSS. This will provide more detailed and exact information for each route, which maintenance personnel currently have for the 232 route segments already in the PFMDSS.
Technology requirements: What technologies does the implementation plan require which SDDOT does not currently have in possession?	Adding new route segments to the PFMDSS does not require any new technology as this part of the implementation plan is to program new route segments, which SDDOT has done in the past, and does not require any new technologies.
Deployment and ongoing support costs: What deployment and ongoing support costs does implementation plan require that are within SDDOT's budget?	This component of the implementation plan uses the PFMDSS system and additional costs will be realized for adding route segments to the PFMDSS, first for programming route segments into the PFMDSS and providing maintenance during operation of the PFMDSS.
Training needs: What additional training is required for SDDOT staff for the implementation plan?	This part of the implementation plan is to be deployed to maintenance shops that already have PFMDSS route segments and MDC equipped trucks first so that the PFMDSS can be expanded to those shops first. The shops with limited route segments or no route segments will require MDSS GUI training on the use of the PFMDSS, focusing mostly on maintenance managers.

Required enhancements: What enhancements in SDDOT's current processes, policies, or standards does the implementation plan require?	No enhancements are needed to current processes as the addition of route segments will use the current maintenance practices that maintenance shops use. The additional route segments in the PFMDSS will provide maintenance managers the ability to use the PFMDSS features with all route segments.
Resource needs: What additional resources does the implementation plan require from SDDOT and are there any constraints within SDDOT that prevent the implementation plan?	This part of the implementation Plan will require SDDOT resources to add the 304 new PFMDSS route segments. Based on information from operations support, each route segment takes three hours to be built before it can be sent to Iteris, Inc. for programming into the PFMDSS. To meet the schedule of adding all remaining SDDOT route segments to the PFMDSS by 2022, resources will be needed from Operations Support as well as Iteris, Inc. to help build the route segments.

5.10.1.1 Cost for Adding New PFMDSS Route Segments

Currently, the PFMDSS includes 232 route segments. A total of 304 route segments are designated to be added to the PFMDSS, for a total of 536 PFMDSS route segments. Table 21 shows the costs for adding route segments to the PFMDSS. The capital costs include the labor to plan, build, and program new route segments. Annual costs include support and administrative costs.

Table 21. Unit cost information for adding new PFMDSS route segments

Item and Description	Equipment Cost	Labor Cost	Unit	Quantity
		Capital Costs		
Build route segment		$300	Per route segment	304
Route configuration and programming by Iteris, Inc.		$500	Per route segment	304
		Annual Costs		
Route programming maintenance and support		$50	Per route segment	304
Administrative costs		10%	Of capital costs	

The cost information includes information provided by SDDOT and other BCA reports for similar studies, while the quantities are based on the route analysis.

- The cost to build a route segment was calculated using the average time to program a route segment into the PFMDSS by SDDOT at three hours at a cost of $100 per hour. Route configuration and programming costs were found in Lawrence et al. (2017).
- Route segment programming maintenance and support, provided by SDDOT, is $50 per route segment that Parsons charges for troubleshooting and providing updates as needed.
- Administrative costs are 10% of capital costs, which is commonly used with BCAs (Lawrence et al., 2017). Administrative costs cover necessary overhead and administration in implementing, deploying, and maintaining the additional route segments on an annual basis.

5.10.1.2 Deployment of Adding New PFMDSS route segments

The deployment is to add new route segments into the current PFMDSS used by SDDOT. Based on information provided by SDDOT's Operations Support, a typical installation time for building a route, and sending it to Iteris, Inc. for programming takes about three hours. Deployment should focus on the experience of maintenance shops in the use of the PFMDSS. Shops that currently have at least four existing PFMDSS route segments should be the focus for immediately adding route segments. These shops already use the PFMDSS and have plow trucks equipped with MDC units, so the training and startup should be minimal. Table 22 outlines the maintenance shops that currently have at least four PFMDSS route segments and the number of route segments to add to that shop. Each of the 112 new PFMDSS route segments can be programed during the summer of 2019 so they are ready for use during the 2019-2020 winter season.

Table 22. Maintenance shops with four or more current PFMDSS route segments

Region	Shop	Current PFMDSS Route Segments	New PFMDSS Route Segments
Aberdeen	Milbank	5	3
Aberdeen	Sisseton	6	4
Aberdeen	Brookings	6	4
Aberdeen	Clear Lake	4	8
Mitchell	Plankinton	6	3
Mitchell	Salem	4	5
Mitchell	Armour	6	5
Mitchell	Chamberlain	4	4
Mitchell	Sioux Falls (274)	7	4
Mitchell	Sioux Falls (275)	8	0
Mitchell	Lennox	5	6
Mitchell	Menno	4	4
Mitchell	Junction City	10	5
Pierre	Pierre (354)	5	2
Pierre	Pierre (355)	5	2
Pierre	Gettysburg	6	1
Pierre	Selby	6	5
Pierre	Murdo	5	2
Pierre	Presho	13	4
Pierre	Winner	6	6
Pierre	Kadoka	5	4

Rapid City	Sturgis	4	6
Rapid City	Rapid City	8	5
Rapid City	Belle Fourche	4	6
Rapid City	Bison	5	3
Rapid City	Custer	8	11
TOTAL		155	112

Following the 2019-2020 winter season, the SDDOT can then add new PFMDSS route segments to the maintenance shops that currently have two or three PFMDSS route segments. Table 23 shows the shops with two or three current PFMDSS route segments. These shops will have limited experience with the PFMDSS and MDC units, so training will need to take place with these shops and corresponding maintenance staff during the summer of 2019. A total of 109 route segments are to be added across these shops to the PFMDSS. Programming and training are to be completed during summer 2020 to be ready by the beginning of the 2020-2021 winter season.

Table 23. Maintenance shops with two or three current PFMDSS route segments

Region	Shop	Current PFMDSS Route Segments	New PFMDS Route Segments
Aberdeen	Ipswich	2	4
Aberdeen	Webster	3	3
Aberdeen	Aberdeen (158)	2	3
Aberdeen	Aberdeen (159)	2	3
Aberdeen	Watertown	3	3
Aberdeen	Clark	2	3
Mitchell	Mitchell (254)	2	2
Mitchell	Mitchell (255)	2	4
Mitchell	Platte	2	4
Mitchell	Woonsocket	2	6
Mitchell	Bonesteel	2	5
Mitchell	Madison	3	4
Mitchell	Flandreau	3	2
Mitchell	Tyndall	3	3
Mitchell	Yankton	3	7
Mitchell	Beresford	2	8
Pierre	Phillip	3	3
Pierre	Hayes	2	2

Pierre	McIntosh	2	4
Pierre	Mobridge	3	6
Pierre	Mound City	2	7
Pierre	Eagle Butte	2	3
Pierre	Mission	2	2
Pierre	White River	2	3
Pierre	Martin	2	4
Rapid City	Wall	2	2
Rapid City	Hot Springs	3	4
Rapid City	Oelrichs	3	5
TOTAL		66	109

Next, Table 24 shows the maintenance shops that currently have one or do not have any PFMDSS route segments. Training will be necessary during the installation period of the summer 2021 and perhaps some hands-on guidance should be provided during the 2021-2022 winter maintenance period for these PFMDSS inexperienced maintenance shops.

Table 24. Maintenance shops with only one or no current PFMDSS route segments

Region	Shop	Current PFMDSS Route Segments	New PFMDSS Route Segments
Aberdeen	Britton	1	5
Aberdeen	Faulkton	1	5
Aberdeen	Leola	1	5
Aberdeen	Hayti	1	6
Aberdeen	Highmore	0	7
Aberdeen	Huron	1	6
Aberdeen	Miller	1	6
Aberdeen	Redfield	0	9
Aberdeen	DeSmet	0	4
Pierre	Isabel	0	6
Rapid City	Deadwood	1	8
Rapid City	Buffalo	1	5
Rapid City	Faith	1	4
Rapid City	Newell	1	4
Rapid City	Edgemont	1	3

TOTAL	11	83

Table 25 outlines the deployment, broken down by fiscal year, region, and deploying to maintenance shops with four or more route segments first, shops with two or three current route segments second, and lastly to shops with currently one or no PFMDSS route segments.

Table 25. Deployment schedule for adding new PFMDSS route segments

	Region	No. of new Route Segments	SDDOT Worker-hours for Installation	Start Installation	Complete Installation
FY2020	Aberdeen	19	57	July 2019	July 2019
FY2020	Mitchell	36	108	July 2018	August 2019
FY2020	Pierre	26	78	August 2019	September 2019
FY2020	Rapid City	31	93	September 2019	October 2019
FY2021	Aberdeen	19	57	June 2020	June 2020
FY2021	Mitchell	45	135	July 2020	September 2020
FY2021	Pierre	34	102	September 2020	October 2020
FY2021	Rapid City	11	33	October 2020	October 2020
FY 2022	Aberdeen	53	159	June 2021	August 2021
FY 2022	Pierre	6	18	August 2021	August 2021
FY 2022	Rapid City	24	72	September 2021	October 2021

In following the deployment schedule, Table 26 outlines the annual costs that SDDOT can expect over the next five years. The unit cost information from Table 21 was used along with the quantities that are based on the deployment plan. A discount rate of -0.3% has been applied to values starting with FY2020 (Office of Management and Budget, 2017). For FY2021, FY2022, and FY2023, only annual costs are presented as the designated number of new route segments will be completed before the beginning of the 2021-2022 winter season.

Table 26. Five-year cost summary for adding new PFMDSS route segments

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	Build route segment	$34,000	$33,000	$25,000	$0	$0	$92,000
Capital Costs	Route configuration and programming by Iteris, Inc.	$56,000	$55,000	$42,000	$0	$0	$153,000
Annual Costs	Route programming maintenance and support	$6,000	$11,000	$15,000	$15,000	$15,000	$62,000
Annual Costs	Administrative costs	$9,000	$18,000	$25,000	$25,000	$25,000	$102,000
TOTAL		$105,000	$116,000	$107,000	$40,000	$40,000	$408,000

5.10.1.3 Training for Maintenance Personnel

With the addition of 304 new route segments, which represents all roadways that SDDOT maintains, more route segments will be available in the PFMDSS for HMSs to use. However, some of the maintenance shops currently have limited or no experience using the MDSS. To train all HMSs, and any LHMWs or HMWs that will use the PFMDSS, PFMDSS GUI training will be need. Iteris, Inc., which is a third-party firm that SDDOT works with in the Pooled Fund Study that provides the technical development and support of the MDSS, can lead the training, as their personnel has firsthand knowledge and are experts in the use of the PFMDSS GUI. SDDOT can conduct GUI training sessions during the summer and fall at regional offices, starting with training the staff at maintenance shops with route segments added for the 2019-2020 winter season, then training staff at maintenance shops with route segments added for the 2020-2021 season, and finally training staff at maintenance shops with route segments added for the 2021-2022 season. Iteris, Inc. and SDDOT should work together to update training materials used in the past. Training should also include the use of the WebMDSS.

Refresher PFMDSS GUI training should be offered to current PFMDSS HMSs users so that SDDOT can build consistency in the use of the PFMDSS by HMSs. The refresher GUI training can be rolled into the full GUI training so that everyone that uses the MDSS has up to date training on the MDSS GUI. In addition, Iteris, Inc. has developed a series of tutorial videos that are quite useful. SDDOT can send out these videos to HMSs via email or other correspondence, with one or two videos sent out on a bi-weekly basis as mini-refreshers.

5.10.2 Deploy the Use of MDCs for Plow Trucks on New PFMDSS Route Segments

In discussions with SDDOT maintenance staff, improving accuracy of forecasts and treatment recommendations can justify the deployment of additional MDC unites to more SDDOT plow trucks. Deploying MDC units to plow trucks will improve consistency of winter weather maintenance processes and procedures throughout the state. MDC deployment will also provide more real-time weather and road condition information, which can improve forecasts and treatment recommendations to maintenance personnel in the field. The requirements are shown in Table 27.

Table 27. Requirements for adding MDC units to trucks on new PFMDSS route segments

Factor	Response
SDDOT's business needs: How does the implementation plan align with SDDOT's business needs and help SDDOT provide a safe and effective public transportation system?	MDC units provides SDDOT with the ability to track the maintenance operations and collect actual conditions data from route segments for use with the PFMDSS, which allows maintenance managers to more efficiently deploy trucks and use materials as needed, while providing an improved level of service. The MDC when used with the PFMDSS provides a more efficient snow removal process, which makes the transportation system safer for motorists.
Discrete PFMDSS capabilities: How does the implementation plan utilize one or more PFMDSS key features?	By installing MDC units in more trucks, more maintenance workers can access PFMDSS features in the cab of their truck. The PFMDSS information provides plow operators with route-specific information to treat roadways and see what is coming via forecasts.
Technology requirements: What technologies does the implementation plan require which	The installation and use of MDC units is the same as what SDDOT has used for equipping their current plow trucks. The technology is to be the same as the most current truck setups that SDDOT has installed.

SDDOT does not currently have in possession?	
Deployment and ongoing support costs: What deployment and ongoing support costs does implementation plan require that are within SDDOT's budget?	Deployment costs will require purchasing the MDC equipment and the labor to install and test the equipment before use. Annual costs include maintenance for the MDC equipment, Wi-Fi connection for the truck to communicate between the MDC and the PFMDSS, remote configuration support from Iteris, Inc., and administrative costs to operate the equipment.
Training needs: What additional training is required for SDDOT staff for the implementation plan?	MDC training will be required for LHWs, HMWs, and any other maintenance staff that will use a plow truck equipped with an MDC. Training can include classroom training as well as hands-on training using an MDC equipped truck.
Required enhancements: What enhancements in SDDOT's current processes, policies, or standards does the implementation plan require?	SDDOT will need to promote the use of the PFMDSS and MDC units throughout all maintenance shops since all shops will now have PFMDSS route segments and MDC equipped trucks. By promoting and emphasizing the use of the MDC units to plow operators, SDDOT can gain buy-in from maintenance staff, which then allows for winter weather maintenance operations to be consistent throughout South Dakota.
Resource needs: What additional resources does the implementation plan require from SDDOT and are there any constraints within SDDOT that prevent the implementation plan?	New MDC units and associated equipment will be needed. Then, SDDOT will need to provide labor for installation of the MDC unit and associated equipment. Each MDC setup takes about 12 hours to install. With 188 trucks at 12 hours, that equates to 2,256 hours needed for install over a three year period as outlined below.

5.10.2.1 Cost for Equipping More Trucks with MDC Units on New PFMDSS Route Segments

Of the 304 new PFMDSS route segments to be programmed and added to the PFMDSS, 188 trucks are to be equipped with MDC units. Table 28 lists the unit cost of deploying MDC units to more plow trucks for new PFMDSS route segments. The capital costs include purchasing and installing the MDC unit and associated equipment into plow trucks. The recurring annual costs include annual maintenance, remote configuration support, Wi-Fi or cellular connection, and administrative costs.

Table 28. Unit cost information for equipping plow trucks with new MDC units

Item and Description	Equipment Cost	Labor Cost	Unit	Quantity
		Capital Costs		
MDC Equipment	$4,900	$2,500	Per truck	188
MDC software	$300	Incl. above	Per truck	188
Plow up/down sensor	$200	Incl. above	Per truck	188
GPS equipment and antenna	$150	$50	Per truck	188
Truck-mounted camera	$50	$50	Per truck	188
		Annual Costs		
Annual maintenance		$360	Per truck	188
Remote configuration support		$200	Per truck	188
Wi-Fi or cellular network		$350	Per truck	188
Administrative cost		10%	of capital cost	

The cost information includes information provided by SDDOT and other BCA reports for similar studies, while the quantities are based on the route analysis conducted.

- The labor and equipment costs for the MDC equipment, MDC software, GPS equipment and antenna, plow up/down sensor, and the truck mounted camera were provided by SDDOT Operations Support. The labor total is based on SDDOT operations support stating it takes about 12 hours to install the MDC unit and associated equipment for each truck.
- SDDOT Operations Support provided the total maintenance cost for the 2017-2018 winter season as $45,000. This was divided across the current fleet of MDC equipped plow trucks to find a maintenance cost per truck of $360 per year.
- Remote configuration support cost was also provided by SDDOT, which is a $200 fee per truck that Parsons charges to upload firmware and updates, and allows SDDOT to access truck equipment remotely for troubleshooting.
- Wi-Fi or cellular network is calculated as $50 per month per truck. The winter season is taken as seven months in length, which equates to $350 per truck annually.
- Administrative costs are taken as 10% of capital costs, which is commonly used with BCAs (Lawrence et al., 2017). Administrative costs cover necessary overhead and administration in implementing, deploying, and maintaining the MDC equipped trucks.

5.10.2.2 Deployment of Equipping More Trucks with MDC Units on New PFMDSS Route Segments

The newly added MDC units are a new system for some SDDOT maintenance personnel to use with the PFMDSS. SDDOT will need to provide training to the maintenance shops that are to receive MDC equipped trucks for new PFMDSS route segments. Using a similar deployment method as adding the new PFMDSS route segments, SDDOT can focus the first MDC-equipped route segments to shops with more than four current PFMDSS route segments. These shops will have a quicker learning curve and can begin using the MDC trucks on the new PFMDSS route segments as soon as the 2019-2020 winter maintenance season.

Shops that currently have at least four current PFMDSS route segments with MDC unit equipped trucks should be the focus for adding route segments and equipping trucks with AVL systems as soon as possible. Table 29 outlines the maintenance shops per region that currently have at least four current PFMDSS route segments and the number of trucks to equip with MDC units. A total of 68 trucks are to be equipped for the 2019-2020 winter maintenance season.

Table 29. Maintenance shops with four or more current PFMDSS route segments and the number of new MDC equipped trucks

Region	Shop	New MDC Equipped trucks
Aberdeen	Milbank	3
Aberdeen	Sisseton	4
Aberdeen	Brookings	4
Aberdeen	Clear Lake	8
Mitchell	Plankinton	1
Mitchell	Salem	3
Mitchell	Armour	4
Mitchell	Chamberlain	3
Mitchell	Sioux Falls (274)	2
Mitchell	Sioux Falls (275)	0
Mitchell	Lennox	4
Mitchell	Menno	2
Mitchell	Junction City	5
Pierre	Pierre (354)	0
Pierre	Pierre (355)	0
Pierre	Gettysburg	0
Pierre	Selby	3
Pierre	Murdo	1
Pierre	Presho	1
Pierre	Winner	3
Pierre	Kadoka	1
Rapid City	Sturgis	1

Rapid City	Rapid City	2
Rapid City	Belle Fourche	3
Rapid City	Bison	0
Rapid City	Custer	10
TOTAL		68

During the summer 2020, trucks to equip with MDC units should focus on the maintenance shops that currently have two or three PFMDSS route segments. Table 30 shows the shops with two or three current PFMDSS route segments and the number of plow trucks to equip with MDC units per shop. Although the these shops will have some experience with the PFMDSS and using MDC units, training will need to take place with these shops and corresponding maintenance staff during the summer of 2020. Seventy new plow trucks are to be equipped in time for the 2020-2021 winter season.

Table 30. Maintenance shops with two or three current PFMDSS route segments and the number of new MDC equipped trucks

Region	Shop	New MDC Equipped trucks
Aberdeen	Ipswich	2
Aberdeen	Webster	2
Aberdeen	Aberdeen (158)	2
Aberdeen	Aberdeen (159)	3
Aberdeen	Watertown	2
Aberdeen	Clark	1
Mitchell	Mitchell (254)	1
Mitchell	Mitchell (255)	4
Mitchell	Platte	1
Mitchell	Woonsocket	5
Mitchell	Bonesteel	3
Mitchell	Madison	3
Mitchell	Flandreau	2
Mitchell	Tyndall	2
Mitchell	Yankton	7
Mitchell	Beresford	4
Pierre	Phillip	2
Pierre	Hayes	1
Pierre	McIntosh	3

Region	Shop	New MDC Equipped trucks
Pierre	Mobridge	3
Pierre	Mound City	3
Pierre	Eagle Butte	1
Pierre	Mission	2
Pierre	White River	2
Pierre	Martin	1
Rapid City	Wall	2
Rapid City	Hot Springs	2
Rapid City	Oelrichs	4
TOTAL		70

Table 31 shows the maintenance shops that currently have only one or do not have any PFMDSS route segments or MDC equipped trucks. The 50 trucks to equip with MDC units will be deployed to shops with limited or no use of trucks with MDC units. Hands-on training will be necessary during the installation period of the summer 2021 and SDDOT will need to provide guidance for the 2021-2022 winter maintenance period to these shops.

Table 31. Maintenance shops with only one or no current PFMDSS route segments and the number of new MDC equipped trucks

Region	Shop	New MDC Equipped trucks
Aberdeen	Britton	3
Aberdeen	Faulkton	2
Aberdeen	Leola	3
Aberdeen	Hayti	4
Aberdeen	Highmore	6
Aberdeen	Huron	5
Aberdeen	Miller	2
Aberdeen	Redfield	8
Aberdeen	DeSmet	3
Pierre	Isabel	3
Rapid City	Deadwood	5
Rapid City	Buffalo	0
Rapid City	Faith	2
Rapid City	Newell	3

Rapid City	Edgemont	1
TOTAL		50

Table 32 outlines the deployment, broken down by each region and deploying to maintenance shops with four or more current PFMDSS route segments first, then shops with two or three current PFMDSS route segments second and finally shops with currently only one or no PFMDSS route segments third. A typical installation time for the MDC equipment into a plow truck takes approximately 12 hours. The installation is to begin in the summer 2019 and continue through summer 2021 with all 188 trucks equipped with MDC units by the 2021-2022 winter season.

Table 32. Schedule for equipping plow trucks with MDC units

	Region	No. of Trucks to equip	Worker-hours for Installation	Start Installation	Complete Installation
FY2020	Aberdeen	19	228	July 2019	August 2019
FY2020	Mitchell	23	276	August 2019	September 2019
FY2020	Pierre	9	108	September 2019	October 2019
FY2020	Rapid City	17	204	October 2019	November 2019
FY 2021	Aberdeen	12	144	April 2020	May 2020
FY 2021	Mitchell	32	384	May 2020	August 2020
FY 2021	Pierre	18	216	September 2020	October 2020
FY 2021	Rapid City	8	96	October 2020	October 2020
FY 2022	Aberdeen	36	432	April 2021	July 2021
FY 2022	Pierre	3	36	July 2021	July 2021
FY 2022	Rapid City	11	132	August 2021	August 2021

Using the deployment schedule and plan, Table 33 outlines the annual costs that SDDOT can expect over the next five years for equipping 188 plow trucks with new MDC units. The unit cost information from Table 28 was used along with the quantities that are based on the deployment plan. A discount rate of -0.3% has been applied to values starting with the FY2020 (Office of Management and Budget, 2017). For FY2023 and FY2024, only annual costs are included as the designated number of trucks are to be ready for the winter maintenance season of 2021 – 2022.

Table 33. Five-year cost summary for equipping plow trucks with MDC units

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	MDC equipment	$503,000	$520,000	$372,000	$0	$0	$1,395,000
Capital Costs	MDC software	$20,000	$21,000	$15,000	$0	$0	$56,000

Capital Costs	Plow up/down sensor	$14,000	$14,000	$10,000	$0	$0	$38,000
Capital Costs	GPS equipment and antenna	$14,000	$14,000	$10,000	$0	$0	$38,000
Capital Costs	Truck-mounted camera	$7,000	$7,000	$5,000	$0	$0	$19,000
Annual Costs	Truck maintenance costs	$24,000	$50,000	$68,000	$68,000	$68,000	$278,000
Annual Costs	Remote configuration support	$14,000	$28,000	$38,000	$38,000	$38,000	$156,000
Annual Costs	Wi-Fi or cellular network	$24,000	$48,000	$66,000	$66,000	$67,000	$271,000
Annual Costs	Administrative costs	$56,000	$114,000	$156,000	$156,000	$156,000	$638,000
TOTAL		$676,000	$816,000	$740,000	$328,000	$329,000	$2,889,000

5.10.2.3 Training for Maintenance Personnel

Adding MDC units to 188 plow trucks will require MDC training for LHMWs, HMWs, and other maintenance staff that might operate an MDC-equipped truck. The training needed will be MDC training, which can include a classroom session as well as a hands-on training session. SDDOT maintenance staff that use MDC units on a regular basis, such as LHMWs, should conduct the MDC training due to their regular use and experience. In addition, in taking an idea from Indiana DOT, an MDC setup can be brought into the classroom so that trainees can see what it looks like and how it operates before using it.

During the summers of 2019, 2020, and 2021, all maintenance shops that will have newly equipped MDC trucks for each of the upcoming seasons as outlined in the previous section will need to be trained to use the MDC units. This training can be done with LHMWs regionally, using a ½-day classroom session and ½-day hands-on session. Once the LHMWs are trained, they can be responsible to train their HMWs within their shops and this training can take place at their maintenance shop so that the HMWs can be trained locally.

Due to the time needed to install the 188 MDC units and associated equipment, SDDOT will require labor resources for installation. Installation training will need to take place with installers so that they can correctly perform the initial installation and address issues with the equipment once it is in use. Installing technicians need to participate in equipment installation training across each region. Each region can then perform the equipment installation in its fleet. After installation and use, follow up training is to be provided to review the troubleshooting , to answer questions, and collect lessons learned.

5.10.3 Use of Environmental Sensor Stations for Route Conditions

With the addition of new PFMDSS route segments, all roadways that SDDOT is in charge of will be included in the PFMDSS. Therefore, each route segment can use the features of the PFMDSS. To monitor each route segment, collected conditions information helps to update the PFMDSS for future treatment recommendations. One way to do this is by equipping plow trucks with MDC units, as the previous section detailed. Another way is to use the existing ESSs located throughout the state that are in close proximity to PFMDSS route segments. The existing ESS locations provide real-time conditions at its location along with a camera for maintenance personnel to view the location. To save on the costs and time to equip more plow trucks than the 188 already included in this plan, SDDOT can consider using the current ESSs in lieu of equipping more trucks. Minnesota DOT uses a similar process with its ESS network and the PFMDSS. Table 34 summarizes the requirements.

Table 34. Requirements for using ESSs for Route Conditions in the PFMDSS

Factor	Response
SDDOT's business needs: How does the implementation plan align with SDDOT's business needs and help SDDOT provide a safe and effective public transportation system?	By adding all remaining route segments into the PFMDSS, SDDOT will have the opportunity to use the PFMDSS features to provide a safer transportation system during winter weather events. To enhance the PFMDSS, conditions information is needed from the roadway locations. Since ESSs collect weather and road conditions data, SDDOT can use the ESS data from ESS locations that are in close proximity to new route segments. This can eliminate the need to equip all plow trucks with MDC units, which can be costly.
Discrete PFMDSS capabilities: How does the implementation plan utilize one or more MDSS key features?	Each of the route segments near ESSs will be added as new route segments into the PFMDSS. Therefore, each of these route segments can access the PFMDSS features, which helps HMSs make better decisions. The addition of actual weather and road conditions from ESSs can enhance the forecasting of PFMDSS and decisions being made by HMSs.
Technology requirements: What technologies does the implementation plan require which SDDOT does not currently have in possession?	SDDOT currently has the technologies to do this as the RWIS communicates with the PFMDSS. No new technologies should be necessary.
Deployment and ongoing support costs: What deployment and ongoing support costs does implementation plan require that are within SDDOT's budget?	Deployment costs should be minimal since there is no new equipment to install. Annual costs will also be minimal since the plan is to modify current processes to use ESSs in lieu of equipping more trucks with MDC units.
Training needs: What additional training is required for SDDOT staff for the implementation plan?	Training will be needed to show maintenance staff how to use ESS information with the PFMDSS. SDDOT will need to develop and provide the training to maintenance staff that will use the PFMDSS and ESS, which will be HMSs and some LHMWs.
Required enhancements: What enhancements in SDDOT's current processes, policies, or standards does the implementation plan require?	A new process will need to be developed to outline the standard operating procedure that maintenance staff will use to incorporate ESS information into the PFMDSS.
Resource needs: What additional resources does the implementation plan require from SDDOT and are there any constraints within SDDOT that prevent the implementation plan?	No new equipment or materials are needed. However, training will be required and an assessment of how well the PFMDSS works when using ESS data needs to be done so that SDDOT knows the accuracy of the information being used from ESSs for route segments located near ESSs.

To determine the locations of ESSs in South Dakota, an ESS location map supplied by SDDOT, dated November 2017, was overlaid onto the SDDOT maintenance shops and corresponding route segment locations map. This map is found in Figure 14. There are 86 ESSs with cameras that were considered in this analysis.

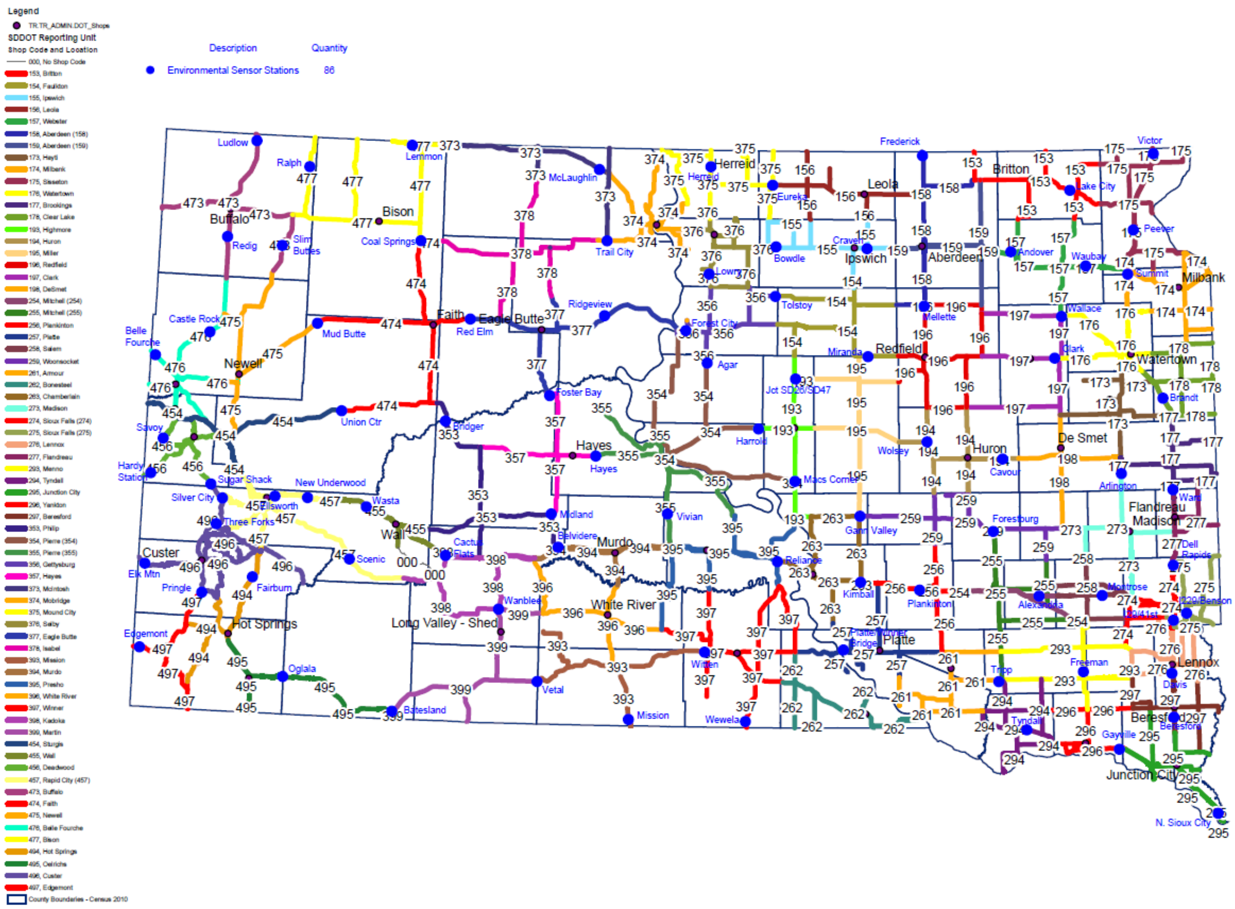

Figure 14. SDDOT Maintenance Shops and Corresponding Route Segments with ESS Locations

Using the map, the research team evaluated the location of each ESS and the route segments that are nearest to each ESS. This helped to identify the route segments not already included in the PFMDSS that are close to an ESS location. It was determined that 82 route segments are near an ESS and can use the ESS for information and an MDC-equipped plow truck would not be needed. A list of the new PFMDSS route segments that are in close proximity to an ESS are shown in Table 35.

Table 35. New PFMDSS route segments near existing ESS locations

Region	Shop	Hwy	Beginning MRM	End MRM	ESS Location
Aberdeen	Britton	SD 10	349.70	361.70	Lake City
Aberdeen	Britton	SD 25	212.26	230.40	Lake City
Aberdeen	Faulkton	SD 20	267.50	296.70	Tolstoy
Aberdeen	Faulkton	US 212	244.90	266.70	Miranda
Aberdeen	Faulkton	US 212	266.70	297.00	Miranda
Aberdeen	Ipswich	SD 45	159.30	176.70	Craven

Region	Shop	Hwy	Beginning MRM	End MRM	ESS Location
Aberdeen	Ipswich	US 12	233.36	262.60	Bowdle
Aberdeen	Leola	SD 10	225.20	259.44	Eureka
Aberdeen	Webster	SD 25	164.80	182.17	Wallace
Aberdeen	Aberdeen (158)	US 281	194.20	229.20	Frederick
Aberdeen	Watertown	SD 20	372.80	398.40	Wallace
Aberdeen	Watertown	US 212	355.60	375.30	Clark
Aberdeen	Highmore	US 14	262.00	278.00	Harrold
Aberdeen	Huron	US 14	345.00	363.30	Cavour
Aberdeen	Miller	SD 45	81.10	111.50	Gann Valley
Aberdeen	Redfield	SD 20	321.60	344.60	Mellette
Aberdeen	Clark	SD 25	131.80	148.90	Clark
Aberdeen	Clark	SD 25	149.80	164.80	Wallace
Aberdeen	DeSmet	US 14	363.50	378.70	Cavour
Mitchell	Mitchell (254)	SD 262	356.02	373.57	Alexandria
Mitchell	Plankinton	US 281	48.58	71.48	Plankinton
Mitchell	Plankinton	US 281	71.48	87.13	Plankinton
Mitchell	Platte	SD 44	273.42	294.46	Platte/Winner
Mitchell	Platte	SD 44	295.46	305.83	Platte/Winner
Mitchell	Platte	SD 50	257.00	273.42	Platte/Winner
Mitchell	Salem	SD 38	317.99	332.28	Montrose
Mitchell	Salem	SD 38	332.28	348.91	Montrose
Mitchell	Woonsocket	SD 34	365.01	373.12	Forestburg
Mitchell	Armour	US 18	348.90	355.87	Tripp
Mitchell	Chamberlain	SD 45	56.74	81.10	Kimball
Mitchell	Madison	US 81	119.10	139.00	Arlington
Mitchell	Sioux Falls (274)	SD 38	348.91	364.26	I-29/41st
Mitchell	Lennox	SD 44	395.83	406.32	Lennox
Mitchell	Lennox	SD 44	406.32	411.87	Lennox
Mitchell	Menno	US 18	355.87	373.94	Freeman
Mitchell	Menno	US 18	373.94	402.77	Freeman
Mitchell	Tyndall	SD 52	315.00	327.32	Tyndall

Region	Shop	Hwy	Beginning MRM	End MRM	ESS Location
Mitchell	Beresford	SD 46	351.00	365.14	Beresford
Mitchell	Beresford	SD 46	365.14	382.58	Beresford
Pierre	Phillip	SD 63	83.36	96.93	Belvidere
Pierre	Pierre	SD 34	257.04	274.80	Macs Corner
Pierre	Gettysburg	SD 20	253.87	267.52	Tolstoy
Pierre	Hayes	SD 63	119.12	144.83	Foster Bay
Pierre	McIntosh	US 12	159.32	181.52	McLaughlin
Pierre	Mobridge	SD 20	141.10	171.00	Trail City
Pierre	Mound City	SD 10	203.22	225.26	Eureka
Pierre	Mound City	SD 47	248.28	260.38	Eureka
Pierre	Selby	SD 144	188.00	190.92	Lowry
Pierre	Eagle Butte	SD 63	144.83	167.54	Foster Bay
Pierre	Eagle Butte	US 212	127.10	154.00	Red Elm
Pierre	Isabel	SD 20	83.00	103.00	Coal Springs
Pierre	Isabel	SD 20	103.00	111.20	Trail City
Pierre	Isabel	SD 20	111.25	141.10	Trail City
Pierre	Presho	SD 248	238.72	262.57	Reliance
Pierre	Winner	SD 53	10.98	26.98	Witten
Pierre	Kadoka	SD 240	162.38	165.85	Cactus Flats
Pierre	Kadoka	SD 248	143.56	162.44	Cactus Flats
Pierre	Kadoka	SD 248	162.44	175.41	Belvidere
Pierre	Martin	SD 44	155.35	172.54	Wanblee
Pierre	Martin	SD 73	25.11	51.09	Wanblee
Pierre	Martin	US 18	120.99	150.00	Batesland
Rapid City	Sturgis	SD 34	56.30	82.00	Union Center
Rapid City	Deadwood	US 14A	29.10	35.60	Savoy
Rapid City	Deadwood	US 385	102.30	116.20	Sugar Shack
Rapid City	Deadwood	US 85	0.00	16.29	Hardy Station
Rapid City	Rapid City	SD 44	54.30	107.50	Scenic
Rapid City	Buffalo	SD 79	151.00	179.00	Slim Buttes
Rapid City	Buffalo	US 85	78.00	101.00	Redig

Region	Shop	Hwy	Beginning MRM	End MRM	ESS Location
Rapid City	Buffalo	US 85	127.00	154.60	Ludlow
Rapid City	Faith	SD 34	81.10	115.60	Union Center
Rapid City	Faith	US 212	114.00	127.10	Red Elm
Rapid City	Newell	SD 168	25.00	31.60	Castle Rock
Rapid City	Belle Fourche	US 212	0.00	13.10	Belle Fourche
Rapid City	Belle Fourche	US 212	13.10	28.80	Belle Fourche
Rapid City	Belle Fourche	US 85	56.50	78.00	Castle Rock
Rapid City	Bison	SD 73	213.00	241.50	Coal Springs
Rapid City	Bison	SD 73	252.26	252.96	Lemmon
Rapid City	Bison	SD 79	176.00	199.10	Ralph
Rapid City	Hot Springs	SD 79N	43.00	61.68	Fairburn
Rapid City	Hot Springs	SD 79S	43.00	61.68	Fairburn
Rapid City	Oelrichs	US 18	61.80	88.50	Oglala
Rapid City	Custer	SD 89	58.50	64.50	Pringle

5.10.3.1 Costs of Using ESSs for Route Conditions

Costs for this component of the implementation plan should be minimal. The ESSs selected are already installed and being used by SDDOT, so no new ESSs are to be located, procured, and installed. Also, the route segments close to ESS locations will be added to the PFMDSS as stated in the first section of the implementation plan, so no costs associated with adding the route segments to the PFMDSS. The difference with this part of the implementation plan is that it is more of a change in processes that requires training for maintenance staff.

To show the savings that SDDOT can experience by using ESSs in lieu of equipping 82 more trucks with MDC units to match the route segments shown in Table 35, the cost information provided in Table 36 illustrates that equipping 82 more trucks would cost SDDOT $1,384,000 over the next five years.

Table 36. Cost savings by using ESSs for 82 new PFMDSS routes instead of equipping 82 more plow trucks with MDC units

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	MDC equipment	$607,000	$0	$0	$0	$0	$607,000
Capital Costs	MDC software	$25,000	$0	$0	$0	$0	$25,000
Capital Costs	Plow up/down sensor	$16,000	$0	$0	$0	$0	$16,000

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	GPS equipment and antenna	$16,000	$0	$0	$0	$0	$16,000
Capital Costs	Truck-mounted camera	$8,000	$0	$0	$0	$0	$8,000
Annual Costs	Truck maintenance costs	$30,000	$30,000	$30,000	$30,000	$30,000	$150,000
Annual Costs	Remote configuration support	$16,000	$16,000	$16,000	$16,000	$16,000	$80,000
Annual Costs	Wi-Fi or cellular network	$29,000	$29,000	$29,000	$29,000	$29,000	$145,000
Annual Costs	Administrative costs	$67,000	$67,000	$67,000	$68,000	$68,000	$337,000
TOTAL		$814,000	$142,000	$142,000	$143,000	$143,000	$1,384,000

5.10.3.2 Deployment of Using ESSs for Route Conditions

Deployment can take place once the new route segments are added to the PFMDSS. The use of ESS data to update the PFMDSS for specific route segments in close proximity to ESS locations can be deployed based on the schedule provided for the first component of the implementation plan, which is to add new PFMDSS route segments using a phased schedule over three years.

5.10.3.3 Training Maintenance Personnel

Although minimal costs will be needed for this component of the implementation plan since no new equipment is being purchased or installed, training will need to be developed and conducted for HMSs and other maintenance staff that might use the PFMDSS with route segments close to ESS locations. The training should focus on the use of data from ESSs and its use with the PFMDSS. Initial training can be done in person to a select group of HMSs per region. Then, the trained HMSs can train the remaining HMSs in their region. In addition, videos are an option for this training in which SDDOT or Iteris, Inc. can develop training videos for distribution to SDDOT maintenance staff.

5.10.4 Pilot the Use of Zonar system for PFMDSS route segments

Discussions with SDDOT maintenance staff and managers suggested that SDDOT would like to expand the PFMDSS but consider an alternative to rolling out MDC units to more plow trucks. Other state DOTs are investigating moving away from MDC units and other in-cab data systems and interfaces in favor of more portable devices. One option for SDDOT to consider is the use of tablet devices in lieu of the current MDC units used in plow trucks. SDDOT already issues mobile devices to some maintenance staff along with Wi-Fi hotspots for remote Internet connection (e.g., HMSs use laptops or portable devices to access the PFMDSS during a winter weather event).

In addition, SDDOT currently uses mobile devices for specific maintenance activities, such as sign work. A portable device that can access and communicate with the PFMDSS along with other applications for maintenance could allow for more flexibility and better communication of information. Mobile devices can be used in a variety of vehicles, not just plow trucks. SDDOT could assign mobile devices to individual staff rather than certain vehicles to allow portability from one vehicle to another, which is not possible with the current MDC units. A mobile device that a maintenance worker can use daily is more cost-effective than stationary equipment that performs only select functions in select trucks. Table 37 summarizes the requirements for piloting the Zonar system for winter weather maintenance. The mobile device proposed is the Android-based Zonar tablet (see Figure 6), which is a Samsung Tab E model tablet device that Colorado DOT currently uses. As discussed in Section 5.1.4, the Zonar can communicate with the PFMDSS and other maintenance applications and provide maintenance management of fleet vehicles.

Table 37. Requirements for equipping trucks with the Zonar System

Factor	Response
SDDOT's business needs: How does the implementation plan align with SDDOT's business needs and help SDDOT provide a safe and effective public transportation system?	The Zonar system provides SDDOT with the ability to track the maintenance operations and collect actual conditions data from route segments for use with the PFMDSS, which allows maintenance managers to more efficiently deploy trucks and use materials as needed, while providing an improved level of service. The Zonar system, when used with the PFMDSS, provides a more efficient snow removal process, which makes the transportation system safer for motorists. In addition, since the Zonar tablet is portable, the Zonar can be assigned to an operator rather than a truck so that it can be interchangeably used.
Discrete PFMDSS capabilities: How does the implementation plan utilize one or more PFMDSS key features?	Using mobile devices, such as the Zonar tablet, moves the current PFMDSS from stationary locations (CPUs, MDCs) to a more mobile application. All PFMDSS features will be available in the Zonar tablet, including features that may or may not already be included in using MDC units.
Technology requirements: What technologies does the implementation plan require which SDDOT does not currently have in possession?	New Zonar tablets and associated equipment will be needed. SDDOT operations support noted that they have the ability to use the Zonar system with plow trucks that are equipped with newer spread controllers, which communicate with the Zonar.
Deployment and ongoing support costs: What deployment and ongoing support costs does implementation plan require that are within SDDOT's budget?	Deployment costs will include the purchase of the Zonar system equipment, plow position sensor (if the plow does not already have this), GPS and antenna, and truck-mounted cameras. Annual costs will include ongoing support for troubleshooting and equipment updates from Zonar, maintenance costs for the plow trucks, Wi-Fi connection, and administrative costs to operate the system.
Training needs: What additional training is required for SDDOT staff for the implementation plan?	New training will need to be developed collaboratively between SDDOT and Zonar will need to collaboratively develop the Zonar training. Then, the Zonar training, conducted by Zonar staff, will need to take place with HMSs, LHMWs, and HMWs at each of the six maintenance shops selected to pilot the Zonar system. Also, training will be needed for operations support staff for installation of the Zonar system and equipment into the 13 plow trucks.
Required enhancements: What enhancements in SDDOT's current processes, policies, or standards does the implementation plan require?	SDDOT will need to develop processes for using the Zonar system as it will have a different user interface than the MDC units. The training mentioned above can incorporate the new processes into the training sessions.
Resource needs: What additional resources does the implementation plan require from SDDOT and are there any constraints	Resources will be needed to work with Zonar to establish the initial relationship and develop the system that will work for SDDOT. Then, resources from operations support will need to install the Zonar system and associated equipment to the 13 trucks. Resources will also be needed to develop training materials and to train maintenance staff to use the Zonar correctly.

within SDDOT that prevent the implementation plan?	

5.10.4.1 Cost of Piloting the Zonar System

Thirteen route segments are suggested to be added to the PFMDSS as Zonar System pilot route segments, as shown in Table 38. As a result, 13 Zonar equipped plow trucks are needed to cover these route segments. The route segments proposed are distributed across the four SDDOT regions so each region can try the Zonar. The route segments are grouped within maintenance shops so Zonar-equipped trucks can be strategically deployed to cover them. The route segments covered by the Zonar include the remaining interstate route segments not included in the PFMDSS currently as well as US highway route segments in the Aberdeen and Pierre regions.

Table 38. Proposed new PFMDSS route segments for piloting Zonar system

Region	Shop	Hwy	Beginning MRM	End MRM
Aberdeen	Hayti	US 81	159.10	161.60
Aberdeen	Hayti	US 81	139.00	156.10
Mitchell	Beresford	I-29N	38.32	47.30
Mitchell	Beresford	I-29S	38.32	47.30
Mitchell	Sioux Falls (274)	I-90	379.63	396.98
Pierre	Winner	US 183	0.00	19.57
Pierre	Winner	US 183	19.57	39.57
Rapid City	Sturgis	I-90W	0.00	14.00
Rapid City	Sturgis	I-90E	0.00	14.00
Rapid City	Sturgis	I-90E	30.00	44.70
Rapid City	Sturgis	I-90W	30.00	44.70
Rapid City	Rapid City	I-190S	0.00	1.50
Rapid City	Rapid City	I-190N	0.00	1.50

The unit cost information for implementing this option is shown in Table 39. The cost information includes information provided by SDDOT and other BCA reports for similar studies, while the quantities are based on the route analysis.

- The labor and equipment costs for the Zonar tablet, controller, and software were obtained from discussions with representative with Zonar Systems, Inc. The costs for the GPS equipment and antenna, plow up/down sensor, and the truck mounted camera were provided by SDDOT Operations Support.
- SDDOT operations support provided the current total maintenance for the 2017-18 season as $45,000. This was divided across the current fleet of MDC equipped plow trucks to find a maintenance cost per truck of $360.

- The service fee is for Zonar to provide support for configuration and troubleshooting, which is $200 per truck annually and covers support for the general Zonar fleet management system and the PFMDSS integration.
- Wi-Fi or cellular network is calculated as $50 per month per truck. The winter season is taken as seven months in length, which equates to $350 per truck annually.
- Administrative costs are taken as 10% of capital costs, which is commonly used with BCAs (Lawrence et al., 2017). Administrative costs cover necessary overhead and administration in implementing, deploying, and maintaining the Zonar system.

Table 39. Unit cost information for equipping trucks with the Zonar system

Item and Description		Equipment Cost	Labor Cost	Unit	Quantity
		Capital Costs			
Zonar Tablet		$450	$1,500	trucks	13
Zonar telematics controller and components		$250	Incl. above	trucks	13
Zonar software		$250	Incl. above	trucks	13
Plow up/down sensor		$200	$50.00	trucks	13
GPS equipment and antenna		$150	$50.00	trucks	13
Truck-mounted cameras	$50	$50.00	trucks	13	
		Annual Costs			
Service fee			$200	trucks	13
Maintenance costs			$360	trucks	13
Wi-Fi or cellular network			$350	trucks	13
Administrative costs			10%	of total capital cost	

5.10.4.2 Deployment of the Zonar System

Since the Zonar system is to be a pilot, the deployment will be contingent on the development and configuration of the Zonar system with the Force America controllers that SDDOT currently uses in its plow trucks. Zonar is in discussions with Force America and several state and local transportation agencies to fully develop the winter maintenance platform for use by any transportation agency. When the Zonar and the Force America controllers can be integrated the pilot can be deployed. In discussions with Zonar, when SDDOT decides to commit to this plan, development of the system for SDDOT can begin as early as the summer of 2020 for deployment to a few route segments. The following suggested timeline will assist with deployment:

1) Initiate discussions with Zonar: June 2019 – August 2019

2) Work with Zonar and Force America to integrate the two systems for SDDOT use: September 2019– July 2020
3) Equip three plow trucks with the Zonar system: July 2020 – October 2020
4) Pilot initial three Zonar equipped trucks on three route segments during the 2020-2021 winter maintenance period: October 2020 – May 2021
5) Depending on the outcome of the initial three pilot route segments and trucks, SDDOT to equip ten more plow trucks with the Zonar system: June 2021 – October 2021
6) Pilot 13 PFMDSS route segments with the 13 Zonar equipped plow trucks during the 2021-2022 winter maintenance season: October 2021 – May 2022
7) Review and discuss pilot results from 2020 – 2021 and 2021 – 2022 winter maintenance seasons to determine if further Zonar deployment is appropriate: June 2022 – August 2022
8) Depending on results of pilot, continue the pilot for another year, discontinue its use, or expand to more route segments at SDDOT's discretion.

Based on this step-by-step process, Table 40 shows the total costs for deploying the Zonar system, starting during the 2020-2021 winter maintenance season. No costs are shown for FY 2020 as deployment will begin during summer 2019 with three trucks and three route segments and then expand to ten more route segments and ten more trucks during summer 2021 with use beginning during the 2021-2022 winter maintenance season. A -0.3% discount rate has been applied to years two through five.

Table 40. Five-year cost summary for adding Zonar System to plow trucks

		FY2020	FY2021	FY2022	FY2023	FY2024	TOTAL
Capital Costs	Zonar tablet	$0	$6,000	$20,000	$0	$0	$26,000
Capital Costs	Zonar telematics controller and components	$0	$1,000	$3,000	$0	$0	$4,000
Capital Costs	Zonar software	$0	$1,000	$3,000	$0	$0	$4,000
Capital Costs	Plow up/down sensor	$0	$1,000	$3,000	$0	$0	$4,000
Capital Costs	GPS equipment and antenna	$0	$1,000	$2,000	$0	$0	$3,000
Capital Costs	Truck mounted cameras	$0	$300	$1,000	$0	$0	$1,300
Annual Costs	Truck maintenance costs	$0	$1,000	$5,000	$5,000	$5,000	$16,000
Annual Costs	Zonar service/support fee	$0	$1,000	$3,000	$3,000	$3,000	$10,000
Annual Costs	Wi-Fi or cellular network	$0	$1,000	$5,000	$5,000	$5,000	$16,000
Annual Costs	Administrative costs	$0	$1,000	$4,000	$4,000	$4,000	$13,000

TOTAL	$0	$14,300	$49,000	$17,000	$17,000	$97,300

5.10.4.3 Training for Maintenance Personnel

Zonar training will need to occur with HMSs, LHMWs, and HMWs. First, SDDOT will need to work with Zonar to develop training materials. Then, Zonar staff can conduct the initial training sessions with the six maintenance shops designated to receive plow trucks equipped with the Zonar system. Training can take place at each maintenance shop and should include a classroom session and a hands-on session within an equipped truck, similar to the MDC training proposed for the second component of the implementation plan. Training should be minimal since only three plow trucks are to receive the Zonar system for the 2020-2021 season. Training for the 10 Zonar systems to be installed and used for the 2021-2022 season can be done with SDDOT staff that used the Zonar system during the 2020-2021 season. All Zonar training should be completed by the end of the summer of 2021.

Installation training will also need to occur with Operations Support staff. As the Zonar system is different from the MDC system, training will need to take place with installers, preferably during the spring of 2020 so that the three Zonar systems can be installed into the plow trucks before the 2020-2021 season. Then, the remaining 10 Zonar systems can be installed prior to the 2021-2022 season, using installers trained during the spring of 2020 and these installers can then train other installers.

6.0 RECOMMENDATIONS

This section presents the recommendations related to the future use of the PFMDSS for SDDOT. These recommendations were developed based on the findings from Section 5.0. The data used for these recommendations were collected from literature of the PFMDSS, relevant MDSS documents and reports from other state DOTs, and interviews with SDDOT maintenance staff.

6.1 Hire dedicated staff in each region for the PFMDSS

Consider employing internal maintenance staff with dedicated employees for the PFMDSS.

Applying practices from other state DOTs, there is a potential for SDDOT to provide dedicated PFMDSS staff within each region to provide timely support, training, and operation of the PFMDSS. Dedicated staff can help substantially improve the effective use of the PFMDSS across state. Other state DOTs (e.g., Minnesota DOT) have hired dedicated staff for their MDSS operations. Dedicated staff, which should include at least one person per SDDOT region, would be responsible for maintaining the PFMDSS as well as the MDC and Zonar equipped trucks. Further, dedicated staff are in charge of conducting training for the PFMDSS, MDC units, and Zonar units.

Dedicated staff will need to be trained in the PFMDSS, the MDC units, and the Zonar system. Once trained, the dedicated staff will have knowledge to use throughout the department that is retained within SDDOT and not from a third party. This then keeps the experience and knowledge in house at SDDOT and makes it easier to pass the knowledge along to other maintenance employees.

6.2 Adjust and Enforce Polices for Using the PFMDSS

Ensure that maintenance staff consistently follows PFMDSS policies in regard to following treatment recommendations, updating route conditions, and completing the end of route surveys.

The interview results found that some HMSs allow HMWs to vary treatment recommendations based on the actual conditions, and their experience and intuition, while other HMSs limit the ability of HMWs to vary the recommendations from PFMDSS as these should be the best option and should not be adjusted. As a result, SDDOT needs to decide when HMWs can vary the treatment recommendations. To obtain consistency, SDODT should have a policy, whether to follow recommendations explicitly, or adjust them based on real-time conditions.

LHMWs and HMWs are to update route conditions in the MDC at the end of each route. Yet, many maintenance staff mentioned that they often forget to perform this task. They stated that it is difficult to find a place to pull over to update conditions since the MDC will not work if the plow truck is moving faster than five miles per hour. The route condition updates are the most real-time information that the PFMDSS can use so updating is vital to the optimal use of the PFMDSS. It is recommended that SDDOT require route condition updates at the end of each route by all maintenance units.

The end of route survey is a simple and quick survey for HMWs to fill out. SDDOT should reinforce the importance of filling out these surveys and sharing the results with staff. Currently, end of route surveys are only filled out occasionally based on the interviews with maintenance personnel. It is important to complete the end of route surveys as the more data collected, the better the PFMDSS performs.

Finally, SDDOT maintenance staff with extensive experience with PFMDSS noted a lack of communication on MDSS operation expectations. Many other maintenance staff hired since the initial deployment could not state the actual expectations for using the PFMDSS. It is then important that SDDOT develop expectations, if they do not already exist, and communicate them to all levels of maintenance staff. Promoting the use of the PFMDSS and any future implementations will require support from high levels of management, and will require buy-in from maintenance workers. Buy-in can be established by developing the expectations that all maintenance staff are to follow.

6.3 Provide Training for all SDDOT Maintenance Staff

Develop and provide a consistent and annual training program on the PFMDSS and for the in-cab equipment systems. Training should be provided to all maintenance staff for both the PFMDSS and in-cab equipment systems.

Many SDDOT maintenance staff noted that training plays an important role for implementing the PFMDSS. They stated that training usually occurs each year for those that want it, but it could be an advantage to provide more in-depth training and require more HMSs, LHMWS, and HMWs to attend. Some SDDOT maintenance staff noted that they are not using the PFMDSS to its fullest potential because they are unsure of what the PFMDSS can do, which means more training would be beneficial. Training was outlined in the implementation plan. Further, SDDOT has a series of YouTube videos that detail various aspects and features of the PFMDSS, found on the Pooled Fund Study website. SDDOT can consider developing additional videos for the MDC units and the Zonar system. Additional videos can be developed for any new features that are added in the future, and for other PFMDSS platforms, which include a mobile app for mobile devices and a web-version that does not require software to use.

In discussions with HMWs with SDDOT, several of the newer employees noted that they received no formal training in using the MDC and never received any guidance or training in using the PFMDSS. It is suggested to provide MDC training to all LHMWs and HMWs, even if they do not use a truck with an MDC system. Further, although the HMWs do not interface with the PFMDSS, HMWs should still receive training on the PFMDSS so that they understand the system better. This may lead to potential benefits that the skeptical staff will begin to see the value of the PFMDSS.

6.4 Conduct Review Session after Each Winter Storm Event

Collect information and lessons learned about the activities and treatments used to clear roadways after a winter weather event occurs.

SDDOT should consider meeting with HMSs, LHMWs, and HMWs after a storm event to discuss the accuracy of forecast and treatment recommendations and share lessons learned to help improve winter weather maintenance. The meeting should include using the PFMDSS and the data collected from the previous storm. The PFMDSS records and store data before, during, and after winter weather events, which then a PFMDSS user can employ the time slider to animate the data. The data that can be animated includes radar, visible satellite, infrared satellite, visible satellite and radar, infrared satellite and radar, air temperature, dew point, relative humidity, wind speed, wind gusts, hourly precipitation, hourly snow, and maintenance truck location and movement. Once the play button is pressed, the map will animate the data (and loop it if the option is selected) within the specified time period. The animation works in time intervals, which can be set to 10, 20, 30, or 60 minutes. The PFMDSS also provides a speed controller for the animation, which allows users to speed up the animation or slow down the animation to view what is happening to the data selected during the time period chosen.

Beyond using the time slider and data for after-storm recap meetings, the time slider and data animation feature can also be used for training maintenance managers and staff. Historical data collected from previous storms can be used to simulate winter storm events so that maintenance personnel can experience real scenarios of a winter storm before using it for an actual storm (Federal Highway Administration, 2012). The PFMDSS can simulate potential impacts of new maintenance practices or different levels of service for various winter weather conditions using the recorded data from previous storms.

6.5 Provide Performance Information on the PFMDSS to Maintenance Staff Demonstrating its Usefulness

Collect and report PFMDSS performance measures to maintenance staff to illustrate the power and usefulness of the PFMDSS for winter weather maintenance operations.

During the group interviews, SDDOT maintenance staff stated that most maintenance staff do not think the PFMDSS is accurate enough and may not be that useful. To change that perception, it is recommended that SDDOT report performance measures to their staff to show that the PFMDSS works and is accurate when it is used appropriately. Deviating from the PFMDSS plan, such as not entering in road and weather conditions in the truck data system at the end of a route, can result in inaccuracies in the data coming from the PFMDSS. This situation can be shown to maintenance workers using performance metrics and collected and recorded data from previous storms in the PFMDSS to make workers accountable for their actions.

6.6 Integrate Plow Truck Information with Traveler Information Systems

Incorporate plow truck data such as location, treatments made, and road and weather conditions with traveler information systems such as SafeTravelUSA and the 511 telephony system.

The data from MDC and Zonar systems for plow trucks can be integrated with travel websites such as SafeTravelUSA to display images of trucks treating roadways and provide the public a visual of current road conditions. Features to report from the plow trucks could include truck location and direction, real-time road conditions, plow truck camera images, treatments made to a road, and when SDDOT plans to plow a road.

6.7 Revise the Management Reporting Tool for the PFMDSS

Refine the Winter Maintenance Response Index (WMRI) reporting tool to make it easier to use and run useful reports for management.

The PFMDSS includes the winter maintenance response index (WMRI) tool, which provides maintenance managers information on labor, equipment, and material use. The WMRI reports data from the PFMDSS to help make business decisions about the amount of resources needed for winter weather maintenance. The WMRI can also provide reports from previous winter storm events to simulate costs of new practices or to vary the level of service for similar winter weather conditions. However, maintenance managers feel the WMRI tool is not as intuitive as it could be. Some mentioned the difficulty in navigating the tool and finding the information they need. Other maintenance staff mentioned that they normally forget how to use the PFMDSS from one season to the next due to its complexity. SDDOT should consider refining the WMRI tool and other management reporting tools so maintenance managers can generate reports easily and quickly. Further, specific training on the WMRI should be considered on an annual basis.

6.8 Explore the use of the PFMDSS for Non-Winter Maintenance Operations

Determine the usefulness of the PFMDSS for non-winter maintenance operations.

The PFMDSS has the potential to be used with summer maintenance activities. A few state DOTs have begun using the PFMDSS for summer maintenance. Minnesota DOT uses the PFMDSS in paint striping and herbicide spraying during summer maintenance operations. Michigan DOT also performed a pilot of the PFMDSS for applying herbicides in summer 2016. Colorado DOT is piloting the PFMDSS application for non-winter operations such as weed spraying, mowing, lane striping, and surface repairs. All these instances are small-scale deployments to determine whether using the PFMDSS for summer maintenance is cost effective and useful.

Indiana DOT uses the PFMDSS not only for winter weather maintenance operations, but also to help with: (1) equipment purchasing, (2) defining and naming support staff, (3) implementation and follow-up training, and (4) a quality assurance/quality control accountability program. Additionally, Indiana DOT used the PFMDSS for chip seal maintenance during the summer of 2015. The PFMDSS was used to identify periods where air temperature was above 60 degrees Fahrenheit and relative humidity was below 70%. A chip seal operation could be scheduled or postponed based on a long-range forecast of humidity and probability of precipitation from the PFMDSS.

Wisconsin DOT has also applied the PFMDSS for summer maintenance. One specific application is using the PFMDSS to help Wisconsin DOT's awareness of ideal conditions for pavement buckling to occur. The Wisconsin DOT has set up alerts within the PFMDSS to provide advanced notice that conditions are right for pavement buckling to potentially develop on roadways. Maintenance managers can then be alerted to possible roadway buckles, and have crews ready to perform repairs if they do in fact occur.

It is recommended that SDDOT explore and evaluate similar PFMDSS uses for summer maintenance before deploying and using it for summer maintenance activities. A full scale study should be considered and a pilot developed for summer use of the PFMDSS.

6.9 Consider New and Emerging Technologies for Future PFMDSS Integration

Investigate new and emerging technologies that can enhance the PFMDSS and its use in the future.

The PFMDSS may soon be able to incorporate information from automated vehicles, connected vehicles, and information technology to enhance its abilities and refine its use. For example, new mobile sensors can collect various conditions such as air temperature, road surface condition, surface grip or traction, wind speed and direction, and precipitation rates and amounts. SDDOT will need to advance the PFMDSS functionality to use new technologies such as mobile sensors on the horizon. It is recommended that SDDOT closely follow the various testing and pilot studies (e.g., Indiana DOT's use of mobile sensors, Wyoming DOT's connected vehicle pilot along I-80) to further investigate the use of mobile road weather information systems and interconnected vehicles.

7.0 RESEARCH BENEFITS

The purpose of this research is to provide SDDOT with an implementation plan for future operations of the PFMDSS. Based on the implementation of the plan and recommendations, some of the expected benefits, as stated in previous MDSS studies, are presented in Table 41 and summarized below.

Table 41. Benefits from this research project

Benefits for SDDOT	Benefits for Motorists
Reduced environmental impact	Improved level of service
Reduced material costs	Safer travel
Improved productivity of maintenance staff	Reduced delays due to adverse weather
Reduced fleet maintenance	Real-time road condition information
Decrease in infrastructure damage	Reduced corrosion to vehicles

This section summarizes the benefits that SDDOT should experience when the implementation plan is deployed across the state. SDDOT can focus on more effective use of materials, people, and fleet vehicles to create more efficient winter weather maintenance operations. More efficient winter weather maintenance operations will produce a better and sustainable level of service for motorists and help SDDOT save costs and achieve the goal of providing clear and safe roadways to users.

Previous studies have shown that savings can occur in these areas by using the PFMDSS. McClellan et al. (2010) noted that Indiana DOT illustrated a three-year average savings of 14.7%. A study by Cluett and Gopalakrishna (2009), noted that the City and County of Denver noted savings of 37% in overtime costs with the use of the MDSS, which the City and County of Denver used to justify the investment into the MDSS. The Minnesota DOT showed that the PFMDSS has the potential to significantly reduce salt use and lessen environmental impacts while still meeting or exceeding performance targets (Minnesota Department of Transportation, 2010). Colorado DOT realized approximately $2 million per year in savings due to reducing idle time of plow trucks by using the PFMDSS (Lester et al., 2017). Each of these studies are used as a basis for the quantified benefits discussed below.

7.1 Reduced Environmental Impact

The PFMSS integrates pavement surface temperatures and current conditions from truck equipment and forecasted temperatures from weather to provide the best treatment recommendation available. The informed decision process allows maintenance managers to direct plow truck operators to use the PFMDSS and efficiently lay materials on roadways.

Using and applying chemical and liquid snow and ice removal materials on roadways more efficiently can reduce their environmental impact. Salt materials are a major reason that many fresh water streams, rivers, and lakes show high levels of salt contents, which damage ecosystems, plant life, and drinking water supplies. Approximately 55% of salt used for winter maintenance ends up in waterways while sand and abrasive materials add sediments, impacting fish and aquatic habitats (Zachos, 2018). Making more efficient use of materials only saves costs, but also protects the environment. Further, less materials used results in less corrosion (which can cause additional environmental concerns) to vehicles.

7.2 Reduced Materials Costs

With the addition of more road segments into the PFMDSS and equipping more plow trucks with MDC units, and the Zonar system, SDDOT should experience a reduction in materials costs. The added road and weather condition information that the trucks can provide allows the PFMDSS to process more efficient treatment tactics for more roadways across South Dakota.

SDDOT spent $14.8M on winter maintenance during the 2017-18 winter season, an increase of 10% from 2015-16 winter maintenance costs. Materials use alone accounts for $4.6M of that total, or 31% of the total winter weather maintenance costs for 2017-18. Table 42 summarizes the cost of materials for each region during the 2017-18 winter maintenance season. Salt is the most used material and represents the majority of the materials cost that SDDOT expended for winter weather across the state.

Table 42. Summary of roadway treatment materials cost for 2017-18 winter season

	Salt	Abrasive	Brine	Magnesium Chloride	Total
Aberdeen	$635,320	$12,910	$76,650	$0.00	$724,880
Mitchell	$1,387,270	$61,395	$192,635	$0.00	$1,641,060
Pierre	$470,350	$10,040	$2,360	$140,060	$622,810
Rapid City	$1,104,980	$95,580	$45,980	$334,550	$1,581,090
TOTAL	$3,597,920	$179,925	$317,625	$474,610	$4,569,840

Table 43 presents the cost savings. As SDDOT deploys the implementation plan, the cost savings from materials should increase over time. During the first year, SDDOT may not experience cost savings as the implementation is just being deployed. However, SDDOT should focus efforts to reduce materials cost by 1% in year 1, 2% in year 2, 3% in year 3, 5% in year 4, and 10% in year 5. Lack of data from SDDOT's material use prior to using the PFMDSS did not allow a straight comparison to know if these savings are already occurring. SDDOT should be able to achieve the targets and save $970,000 over the next five years.

Table 43. Cost savings for reducing winter weather treatment materials use

Region	FY 2020 1% Material Savings	FY 2021 2% Material Savings	FY 2022 3% Material Savings	FY 2023 5% Material Savings	FY 2024 10% Material Savings	Five-Year Material Savings
Aberdeen	$7,000	$15,000	$22,000	$37,000	$73,000	$154,000
Mitchell	$16,000	$33,000	$50,000	$83,000	$166,000	$348,000
Pierre	$6,000	$12,000	$19,000	$31,000	$63,000	$131,000
Rapid City	$16,000	$32,000	$48,000	$80,000	$160,000	$336,000
TOTAL	$46,000	$92,000	$138,000	$231,000	$463,000	$970,000

7.3 Reduced Labor Costs

Using PFMDSS for winter weather operations can help DOTs improve the productivity and cost efficiency of winter maintenance, which translates into improved mobility and safety on roadways for traveling motorists. For example, the PFMDSS considers the number of operators and trucks that a DOT has at its disposal and suggests how to deploy them efficiently (Peng and Jiang, 2012). SDDOT should realize improved productivity with the addition of more PFMDSS route segments and equipping plow trucks with data systems.

As shown in Table 44, SDDOT spent $2,500,900 on labor during the 2017-18 winter maintenance period from October to April, which is an increase of 13% from two years ago. Although some of the increase in cost can be attributed to the differences in the amount and intensity of winter weather events experienced in each season, SDDOT can become more efficient with labor resources with use of the implementation plan provided in this report.

Table 44. Comparing labor costs for winter maintenance at SDDOT

Region	2015-16	2017-18	Average
Aberdeen	$463,850	$478,500	$471,175
Mitchell	$826,400	$845,200	$835,800
Pierre	$467,400	$513,200	$490,300
Rapid City	$447,900	$664,000	$555,950
TOTAL	$2,205,550	$2,500,900	$2,353,225

To correlate with the reduction in material costs, labor can be reduced by 10% over the next 5 years. The labor savings are reported in Table 45.

Table 45. Labor savings from using the PFMDSS across the state

Region	FY 2020 1% Labor Savings	FY 2021 2% Labor Savings	FY 2022 3% Labor Savings	FY 2023 5% Labor Savings	FY 2024 10% Labor Savings	Five-Year Labor Savings
Aberdeen	$5,000	$9,000	$14,000	$24,000	$48,000	$100,000
Mitchell	$8,000	$17,000	$25,000	$42,000	$85,000	$177,000
Pierre	$5,000	$10,000	$15,000	$25,000	$50,000	$105,000
Rapid City	$6,000	$11,000	$17,000	$28,000	$56,000	$118,000
TOTAL	$24,000	$47,000	$71,000	$119,000	$238,000	$499,000

7.4 Reduced Fleet Maintenance

SDDOT can more efficiently use its maintenance vehicles by implementing the plan provided. Table 46 shows total mileage traveled and cost of maintenance for SDDOT fleet plow trucks based on SDDOT for the 2017-18 winter maintenance season. Each mile of travel is multiplied by its mileage rate of $3.00 per mile, which is the cost SDDOT provided for operating plow trucks.

Table 46. Total miles and maintenance costs for plow trucks for 2017-18 winter maintenance

Region	Total Miles Traveled	Cost per Mile	Total Truck Maintenance Cost
Aberdeen	473,610	$3.00	$1,420,820
Mitchell	680,685	$3.00	$2,042,055
Pierre	403,025	$3.00	$1,209,075
Rapid City	512,375	$3.00	$1,537,120
TOTAL	2,069,695		$6,209,070

Although the total mileage traveled to clear roadways during the winter maintenance season will vary based on the number and severity of winter weather events, SDDOT can use the PFMDSS and MDC information to deploy plow trucks more efficiently. This approach will optimize the time that a plow truck is needed. By taking one less pass on each route segment during each winter storm event, SDDOT can save 8,686 miles for each storm event, as shown in Table 47.

Table 47. Current and new PFMDSS route segment lane miles with an MDC or Zonar equipped truck

Region	Current PFMDSS Route Segment Lane Miles with MDC Trucks	New PFMDSS Route Segment Lane Miles	Total PFMDSS Route Segment Lane Miles
Aberdeen	783	1,468	2,251
Mitchell	1,124	1,056	2,180
Pierre	1,206	1,267	2,473
Rapid City	768	1,013	1,782
TOTAL	3,882	4,804	8,686

The total PFMDSS route segment lane miles would be the miles for one pass on each route across each region. A total of 8,685.66 miles would be in the PFMDSS and at $3.00 per mile, SDDOT could save approximately $26,000 for each pass reduced on every route segment in the PFMDSS. Using an average of five storms per season, the SDDOT can save $656,000 over the next five years. Additionally, less materials would be used with one less pass, translating into material savings. Table 48 provides the cost savings information.

Table 48. Cost savings for truck maintenance

Region	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Five-Year Truck Maintenance Savings
Aberdeen	$34,000	$34,000	$34,000	$34,000	$34,000	$170,000
Mitchell	$33,000	$33,000	$33,000	$33,000	$33,000	$165,000
Pierre	$37,000	$37,000	$37,000	$37,000	$38,000	$186,000
Rapid City	$27,000	$27,000	$27,000	$27,000	$27,000	$135,000
TOTAL	$131,000	$131,000	$131,000	$131,000	$132,000	$656,000

7.5 Improved Level of Service for Safer Travel

The research team collected accident information from the South Dakota Department of Public Safety and their annual Motor Vehicle Traffic Crash Summary Facts Book. The data collected consisted of accidents associated with snow, slush, ice, and frost (e.g., winter conditions) from 2008 through 2017. Unit costs of accidents, taken from the National Safety Council (2015), are based on lost wages and productivity, medical expenses, administrative expenses, motor vehicle property damage, and uninsured costs. Table 50 summarizes the number of accidents that occurred in 2008 to 2017 due to winter conditions and the cost of the accidents.

Table 49. Total number of accidents due to winter conditions in South Dakota since 2013

Accident Conditions	2013	2014	2015	2016	2017	5 –Year Total
Snow	1,637	1,878	1,564	1,439	1,323	7,841
Slush	375	270	192	246	161	1,244
Ice	1,431	1,335	1,016	965	916	5,663
Frost	121	121	88	79	71	480
TOTAL	3,564	3,604	2,860	2,729	2,471	15,228

The accident rate each year decreases from 2013 to 2017, which can be attributed to the SDDOT strategic safety goal of reducing the fatal and serious injury crash rate by 15% (South Dakota Department of Transportation, 2014). The use of the PFMDSS increased across more route segments during this time, which also helped reduce the accident rate. The rate of accidents due to winter weather conditions decreased by 4.5% from 2016 to 2017 and 9.5% from 2017 to 2018.

A summary of the five-year average accidents due to winter conditions is shown in Table 50. The accident rate per year for snow, slush, ice, and frost conditions is 3,170 accidents, with 11 of those causing a fatality, 637 causing some type of injury, and 2,522 accidents that only caused property damage.

Table 50. Summary of 5-year average of accidents due to winter conditions in South Dakota

Accident Conditions	Fatal	Injury	Property Damage Only	Total Accidents
Snow	4	266	1,298	1,568
Slush	1	55	193	249
Ice	5	239	889	1,132
Frost	1	28	67	96
TOTAL	11	588	2,448	3,046

With improved level of service from increasing the number of route segments in the PFMDSS, equipping more trucks with MDC units, and piloting the Zonar system, SDDOT has the potential to provide clearer roadways and an appropriate level of service more consistently. This in turn will make travel safer and reduce the number and severity of accidents. SDDOT should focus on improving the level of service on more roadways. The implementation plan can also contribute to the SDDOT strategic safety goal. Table 45 outlines the savings due to reduction in accidents due to winter weather. A 5% decrease was used for each year, which is a conservative estimate since the average reduction in winter weather accidents is 8.4%. The cost of a fatal accident is $1,000,000, while the cost of an injury accident costs $20,000.

Table 51. Savings associated with reducing fatal and serious crashes due to winter weather

	FY2020	FY2021	FY2022	FY2023	FY 2024	Total
Fatal Accidents	$550,000	$524,000	$499,000	$476,000	$453,000	$2,502,000
Injury Accidents	$588,000	$560,000	$534,000	$509,000	$485,000	$2,676,000
TOTAL	$1,138,000	$1,084,000	$1,033,000	$985,000	$938,000	$5,178,000

7.6 Benefits and Costs of Implementation Plan

The costs for each part of the implementation plan was shown in the Section 5.10. A summary of these costs are presented in Table 52.

Table 52. Summary of costs for implementation plan

Cost	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
Add Route Segments to PFMDSS	$105,000	$116,000	$107,000	$40,000	$40,000	$408,000
Equip More Plow Trucks with MDC Units	$676,000	$818,000	$740,000	$328,000	$329,000	$2,889,000
Use of ESSs for Route Conditions	$0	$0	$0	$0	$0	$0
Pilot the Use of the Zonar System	$0	$14,000	$49,0000	$17,000	$17,000	$97,000
TOTAL	$781,000	$948,300	$1,337,000	$385,000	$386,000	$3,394,300

Then, the quantified benefits of the implementation plan would be reduced material costs, reduced labor costs, reduced fleet maintenance, and improved level of service for safer travel. The quantified benefits are summarized in Table 53.

Table 53. Summary of benefits for implementation plan

Benefit	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
Reduced Materials	$46,000	$92,000	$138,000	$231,000	$463,000	$970,000
Reduced Labor	$24,000	$47,000	$71,000	$119,000	$238,000	$499,000
Reduced Fleet Maintenance	$131,000	$131,000	$131,000	$131,000	$132,000	$656,000
Safer Travel	$1,138,000	$1,084,000	$1,033,000	$985,000	$938,000	$5,178,000
TOTAL	$1,339,000	$1,354,000	$1,373,000	$1,466,000	$1,771,000	$7,303,000

As the total cost for the implementation plan is $3,394,300 and the potential quantitative benefits for the implementation plan is $7,303,000, the benefit-cost ratio for the implementation plan is 2.15:1. Also as a comparison, if SDDOT decides to equip 82 more trucks with MDC units instead of using the ESSs, the total cost of the implementation plan would then increase by $1,384,000 to $4,778,300. The potential benefits would be the same, so that the benefit-cost ratio is 1.53:1.

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APPENDIX A: MDSS Operation Plan Pre-Interview Questionnaire

The goal of this study is to develop an implementation strategy for future use of MDSS within the South Dakota Department of Transportation. The SDDOT began using the MDSS in 2004 and started using mobile data collectors (MDCs) in snowplows in 2005. Currently, SDDOT has approximately 110 trucks instrumented on approximately 135 MDSS routes totaling more than 3,200 centerline miles of highway. More than 250 SDDOT staff use MDSS in some manner. The objective of this questionnaire is to better understand your expertise and experience regarding the use of MDSS in SDDOT. This pre-interview questionnaire contains five sections:

- Section 1 – General Overview
- Section 2 – MDSS Information
- Section 3 – MDSS/MDC Technology and Equipment
- Section 4 – Expectations of the MDSS/MDC
- Section 5 – MDSS Training

The survey should take approximately 15-20 minutes and it is recommended that you complete the survey all at once. Your participation is voluntary and all of your responses will be kept confidential. If you have any questions or concerns about this survey or this research project, please contact Christofer Harper (Louisiana State University) at 225-578-0131 or by email at charper@lsu.edu. Based on your input, the research team will follow-up with more detailed questions via an in person interview in July 2017. Your expertise and experience is critical to the success of this project. We thank you in advance for your time and thoughtful consideration.

GENERAL OVERVIEW

1) Please provide the following information (optional):

Name: ____

Date: ____

Email/Phone Number: _______________________________________

2) What is your role at SDDOT?

☐ Regional engineer	☐ Lead highway maintenance worker
☐ Regional operations engineer	☐ Highway maintenance worker
☐ Area engineer	☐ Research
☐ Engineer supervisor	☐ Operations Support
☐ Highway maintenance supervisor	☐ Other: ___________________________

3) In which SDDOT region do you work?

☐ Aberdeen ☐ Mitchell ☐ Pierre ☐ Rapid City ☐ Central Office

MDSS INFORMATION

4) How soon before a storm do you often consult the MDSS for weather forecasts, road conditions, and treatment recommendations (Select all that apply)?

☐ 0-12 hours ☐ 12-24 hours ☐ 24-36 hours ☐ 36-48 hours ☒ More than 48 hours ☐ Not sure

5) How often do you use the MDSS treatment recommendations?

☐ Always ☐Most Often ☐ Sometimes ☐ Rarely ☐ Never ☐ Not sure

6) Please rate the following information provided by the MDSS using the following scale: 5 = Very Important, 4 = Important, 3 = Moderately Important, 2 = Slightly Important, 1 = Not Important, DK = Don't Know.

MDSS Information		5	4	3	2	1	DK
Radar		☐	☐	☐	☐	☐	☐
Treatment Recommendations		☐	☐	☐	☐	☐	☐
Current road surface conditions		☐	☐	☐	☐	☐	☐
Forecasted road surface conditions		☐	☐	☐	☐	☐	☐
Current weather conditions	Air temperature	☐	☐	☐	☐	☐	☐
	Wind	☐	☐	☐	☐	☐	☐
	Precipitation amount	☐	☐	☐	☐	☐	☐
	Precipitation rate	☐	☐	☐	☐	☐	☐
Forecasted weather conditions	Air temperature	☐	☐	☐	☐	☐	☐
	Wind	☐	☐	☐	☐	☐	☐
	Precipitation amount	☐	☐	☐	☐	☐	☐
	Precipitation rate	☐	☐	☐	☐	☐	☐
Start time of storm event		☐	☐	☐	☐	☐	☐
End of storm event		☐	☐	☐	☐	☐	☐
Truck mounted cameras		☐	☐	☐	☐	☐	☐

RWIS Cameras (Safe Travel USA Cameras)	☐	☐	☐	☐	☐	☐
AVL/Truck movements	☐	☐	☐	☐	☐	☐
Management Reports (e.g., Winter Maintenance Response Index Tool)	☐	☐	☐	☐	☐	☐
Other: ____	☐	☐	☐	☐	☐	☐
Other: ____	☐	☐	☐	☐	☐	☐

MDSS/MDC TECHNOLOGY AND EQUIPMENT

7) In your unit, how many routes and plow trucks should be required to use the MDSS?

☐ 100% ☐ 99-75% ☐ 74%-50% ☐ 49%-25% ☐ Less than 25% ☐ Not sure

In your unit, how many plow trucks should have MDCs?

☐ 100% ☐ 99-75% ☐ 74%-50% ☐ 49%-25% ☐ Less than 25% ☐ Not sure

EXPECTATIONS OF MDSS/MDC

8) Based on your experience, please rate the impact of the MDSS on the following metrics during winter weather events (Scale: 5 = Much Better; 4 = Better; 3 = No Change; 2 = Worse; 1 = Much Worse; DK = Don't Know)

Metrics	5	4	3	2	1	DK
Maintenance costs	☐	☐	☐	☐	☐	☐
Use of materials	☐	☐	☐	☐	☐	☐
Use of SDDOT staff	☐	☐	☐	☐	☐	☐
Level of service	☐	☐	☐	☐	☐	☐

9) Please rate the accuracy of MDSS outputs listed below using the following scale: 5 = Very Accurate, 4 = Accurate, 3 = Moderately Accurate, 2 = Slightly Accurate, 1 = Not Accurate, DK = Don't Know.

MDSS Output	5	4	3	2	1	DK
Weather Forecasts	☐	☐	☐	☐	☐	☐
Predicted Road Conditions	☐	☐	☐	☐	☐	☐
Treatment Recommendations	☐	☐	☐	☐	☐	☐

10) How easy is the MDC to use during a winter weather event?

☐ Very Easy ☐ Easy ☐ Neither easy nor difficult ☐ Difficult ☐ Very Difficult ☐ Not sure

MDSS TRAINING

11) How much MDSS/MDC training do you receive?

☐ Too much ☐ Enough ☐ Not enough ☐ None ☐ Not sure

12) How useful are the MDSS training videos on YouTube to you?

☐ Very useful ☐ Useful ☐ Moderately Useful ☐ Slightly Useful ☐ Not Useful ☐ Did not know they existed

13) How useful are the forecast videos provided from Iteris to you?

☐ Very useful	☐ Useful	☐ Moderately Useful	☐ Slightly Useful	☐ Not Useful	☐ Did not know they existed

14) How often do you use the forecast videos from Iteris?

☐ Always ☐ Very Often ☐ Sometimes ☐ Rarely ☐ Never ☐ Did not know they existed

APPENDIX B: MDSS Operation Plan Interview Questionnaire

SDDOT Project SD2016-07

Thank you for your input on the pre-interview questionnaire. We have successfully analyzed the data and would like to discuss with you further on some questions. The main objectives of this interview are to (1) supplement and validate the findings from the literature, and other agencies; (2) obtain specific examples of awareness, acceptance, perceived value, shortcomings, and needed technical and operational improvements related to implementation of MDSS; and (3) identify resources requirements, benefits and challenges of feasible implementation strategies.

As mentioned previously, the goal of this study is to develop an implementation strategy for future use of MDSS within the South Dakota Department of Transportation (SDDOT). SDDOT began using the MDSS in 2004 and started using mobile data collectors (MDCs) in snowplows in 2005. Currently, SDDOT has approximately 110 trucks instrumented on approximately 135 MDSS routes totaling more than 3200 centerline miles of highway. More than 250 SDDOT staff use MDSS in some manner.

Your participation is voluntary and all of your responses will be kept confidential. If you have any questions or concerns about this interview or this research project, please contact Christofer Harper (Louisiana State University) at 225-578-0131 or by email at charper@lsu.edu. Your expertise and experience is critical to the success of this project. We thank you in advance for your time and thoughtful consideration.

Interviewee group: ____

Time and Date: ____

Location: ____

A. GENERAL OVERVIEW
   1) What are your roles and responsibilities for using MDSS? What do you use the MDSS for (Operations/Analysis/Supervision)?
   2) How do your co-workers use the MDSS?
   3) Please explain the impact that the MDSS has had on the amount of winter maintenance materials, staff, and other resources needed for a winter weather event.
   4) How do you assess the accuracy of the MDSS treatment recommendations?
   5) Please explain the process of completing the MDSS MDC route evaluation survey. How easy is this process to follow?
   6) MDSS/MDC TECHNOLOGY AND EQUIPMENT

B. What are some other systems such as maintenance management and traveler information that the MDSS could support?
   7) For plow trucks that do not have MDC units, how would GPS locations of these trucks in the MDSS help with winter weather operations?

8) What benefits or drawbacks do you see from having MDC units in Supervisor or Lead Worker pickup trucks to load road conditions directly into the MDSS to determine treatment recommendations?
9) How important is it to communicate information from the MDSS to the MDC?
10) Please explain any issues you have had with the truck-mounted MDCs.
11) EXPECTATIONS OF MDSS
12) What are your expectations of using the MDSS/MDC?
13) What are the department's expectations of the MDSS as you understand them? Explain.
14) What would make MDSS easier or more useful for you?
15) What other uses are possible/important for the MDSS?
16) Please explain other information or features that you would like to include in MDSS for future use.
17) What is your perception of the MDSS app and WebMDSS?

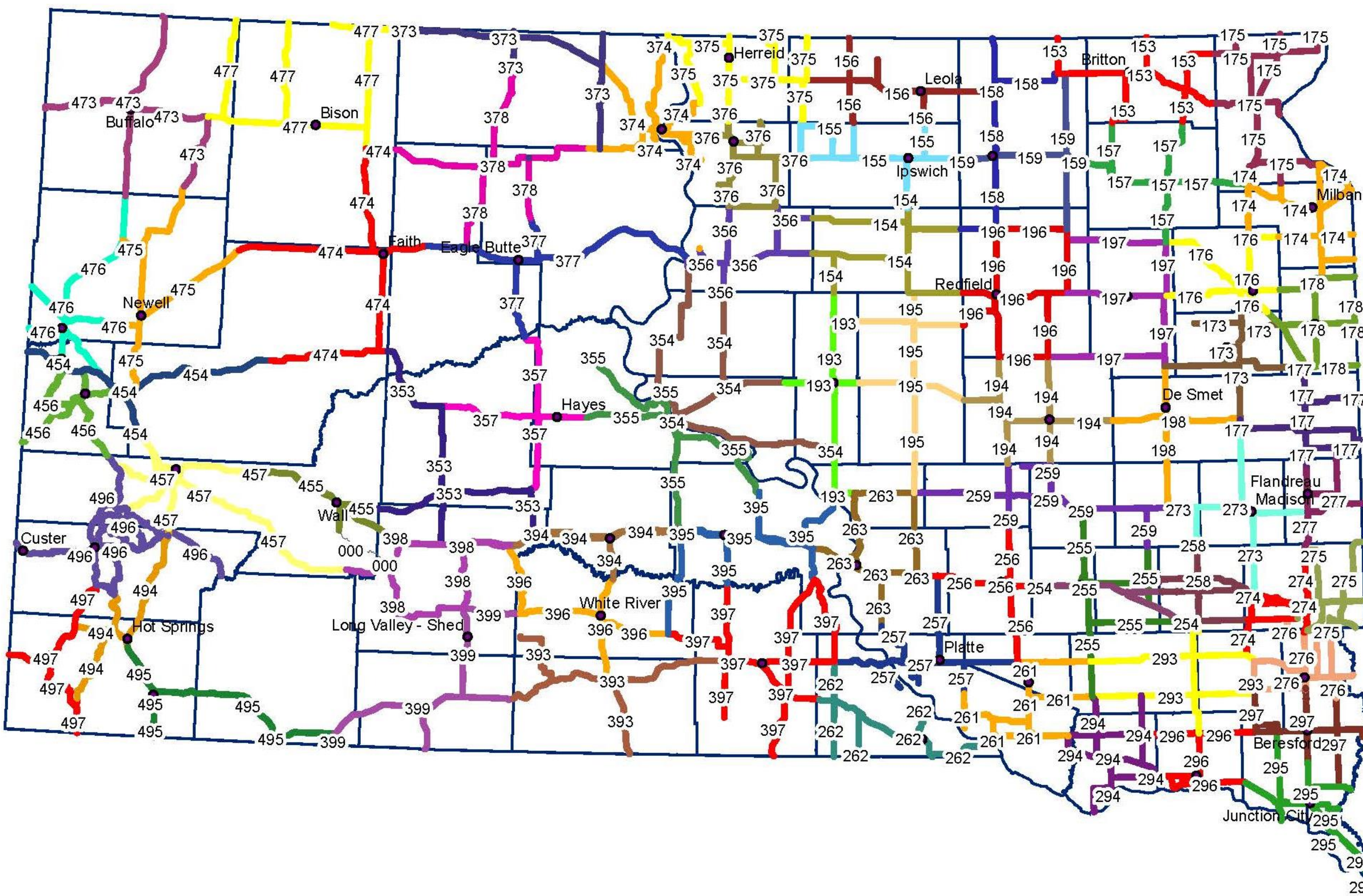
C. MDSS GUIDANCE AND TRAINING

18) What guidance, if any, do you think SDDOT should adopt regarding the use of MDSS and MDC?
19) What types of training does SDDOT provide for its employees to use the MDSS and MDC?
20) How does training help you to use the MDSS effectively? What other training would you like to have?
21) What could have SDDOT done differently to implement the MDSS?
22) SUMMER MAINTENANCE

D. How do you think the MDSS can be used for summer maintenance activities?

23) Please explain potential summer maintenance activities that may be suitable for MDSS. Examples of some potential summer maintenance activities to use the MDSS are pesticide applications, paint striping, pothole repair, etc.

APPENDIX C: Maintenance Shops and Corresponding Routes



APPENDIX D: Route Analysis for Aberdeen Region

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 10			321.20	349.80	28.60	NO	930		Aberdeen	Britton	153	MDC	
SD 10			349.70	361.70	12.00	NO	2,412		Aberdeen	Britton	153	ESS	Lake City
SD 25			212.26	230.40	18.14	NO	282		Aberdeen	Britton	153	ESS	Lake City
SD 27			213.00	230.70	17.70	NO	663		Aberdeen	Britton	153	MDC	
SD 27			236.60	246.60	10.00	NO	557		Aberdeen	Britton	153	MDC	
SD 37			233.51	243.63	10.12	YES	664	SD-125-1	Aberdeen	Britton	153	MDC	
SD 20			267.50	296.70	29.20	NO	281		Aberdeen	Faulkton	154	ESS	Tolstoy
SD 20			296.77	311.66	14.89	YES	717	SD-126-1	Aberdeen	Faulkton	154	MDC	
SD 45			148.60	159.30	10.70	NO	1,033		Aberdeen	Faulkton	154	MDC	
SD 47			162.90	173.90	11.00	NO	279		Aberdeen	Faulkton	154	MDC	
US 212			244.90	266.70	21.80	NO	716		Aberdeen	Faulkton	154	ESS	Miranda
US 212			266.70	297.00	30.30	NO	786		Aberdeen	Faulkton	154	ESS	Miranda
SD 247			170.00	192.53	22.53	YES	146	SD-124-1	Aberdeen	Ipswich	155	MDC	
SD 253			172.90	190.90	18.00	NO	176		Aberdeen	Ipswich	155	NA	
SD 45			159.30	176.70	17.40	NO	755		Aberdeen	Ipswich	155	ESS	Craven
SD 47			224.60	235.00	10.40	NO	466		Aberdeen	Ipswich	155	MDC	
US 12			233.36	262.60	29.24	NO	1,936		Aberdeen	Ipswich	155	ESS	Bowdle
US 12			262.60	276.00	13.40	YES	3,585	SD-110-1	Aberdeen	Ipswich	155	MDC	
SD 10			225.20	259.44	34.24	NO	716		Aberdeen	Leola	156	ESS	Eureka
SD 10			259.44	279.30	19.86	YES	667	SD-123-1	Aberdeen	Leola	156	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 10			282.30	302.10	19.80	NO	380		Aberdeen	Leola	156	MDC	
SD 239			187.90	195.30	7.40	NO	54		Aberdeen	Leola	156	NA	
SD 45			182.60	201.70	19.10	NO	378		Aberdeen	Leola	156	MDC	
SD 45			224.00	236.10	12.10	NO	217		Aberdeen	Leola	156	MDC	
SD 25			164.80	182.17	17.37	NO	1,228		Aberdeen	Webster	157	ESS	Wallace
SD 25	N		182.17	212.26	30.09	YES	749	SD-85-1	Aberdeen	Webster	157	MDC	
SD 27			198.00	213.00	15.00	NO	483		Aberdeen	Webster	157	MDC	
US 12			309.20	343.73	34.53	NO	2,878		Aberdeen	Webster	157	MDC	
US 12	E	Driving	343.73	366.01	22.28	YES	1,141	SD-75-1	Aberdeen	Webster	157	MDC	
US 12	E	Passing	343.73	366.01	22.28	YES	303	SD-75-2	Aberdeen	Webster	157	MDC	
SD 10			302.10	321.20	19.10	NO	994		Aberdeen	Aberdeen	158	MDC	
SD 20			311.60	321.60	10.00	NO	518		Aberdeen	Aberdeen	158	MDC	
US 281	N	Driving	172.98	191.71	18.73	YES	1,167	SD-118-1	Aberdeen	Aberdeen	158	MDC	
US 281	N	Passing	172.98	191.71	18.73	YES	397	SD-118-2	Aberdeen	Aberdeen	158	MDC	
US 281			194.20	229.20	35.00	NO	2,388		Aberdeen	Aberdeen	158	ESS	Frederick
SD 37			184.40	208.40	24.00	NO	942		Aberdeen	Aberdeen	159	MDC	
SD 37			208.40	231.50	23.10	NO	941		Aberdeen	Aberdeen	159	MDC	
US 12			276.00	294.75	18.75	NO	3,466		Aberdeen	Aberdeen	159	MDC	
US 12	E	Driving	294.75	308.81	14.06	YES	2,257	SD-72-1	Aberdeen	Aberdeen	159	MDC	
US 12	E	Passing	294.75	308.81	14.06	YES	600	SD-72-2	Aberdeen	Aberdeen	159	MDC	
SD 21			122.00	131.60	9.60	NO	616		Aberdeen	Hayti	173	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 22			333.40	348.80	15.40	NO	722		Aberdeen	Hayti	173	MDC	
SD 22			348.80	360.60	11.80	NO	1,088		Aberdeen	Hayti	173	MDC	
SD 28			319.90	341.00	21.10	YES	1,102	SD-127-1	Aberdeen	Hayti	173	MDC	
US 81			139.00	156.10	17.10	NO	3,211		Aberdeen	Hayti	173	Zonar	
US 81			159.10	161.60	2.50	NO	1,256		Aberdeen	Hayti	173	Zonar	
I-29		Driving	193.00	207.30	14.30	YES	2,448	SD-76-1	Aberdeen	Milbank	174	MDC	
I-29		Passing	193.00	207.30	14.30	YES	651	SD-76-2	Aberdeen	Milbank	174	MDC	
SD 109			153.50	165.70	12.20	NO	857		Aberdeen	Milbank	174	MDC	
SD 123			173.00	183.50	10.50	NO	241		Aberdeen	Milbank	174	MDC	
SD 15			155.30	174.04	18.74	YES	1,683	SD-160-1	Aberdeen	Milbank	174	MDC	
SD 15			175.04	187.48	12.44	YES	1,468	SD-109-1	Aberdeen	Milbank	174	MDC	
SD 158			439.20	448.40	9.20	NO	262		Aberdeen	Milbank	174	MDC	
US 12			366.01	399.74	33.73	YES	4,140	SD-162-1	Aberdeen	Milbank	174	MDC	
I-29		Driving	207.30	232.00	24.70	YES	2,010	SD-52-1	Aberdeen	Sisseton	175	MDC	
I-29		Passing	207.30	232.00	24.70	YES	535	SD-52-2	Aberdeen	Sisseton	175	MDC	
I-29		Driving	232.00	252.70	20.70	YES	2,181	SD-51-1	Aberdeen	Sisseton	175	MDC	
I-29		Passing	232.00	252.70	20.70	YES	580	SD-51-2	Aberdeen	Sisseton	175	MDC	
SD 10			361.70	371.60	9.90	NO	1,362		Aberdeen	Sisseton	175	MDC	
SD 106			332.50	337.70	5.20	NO	569		Aberdeen	Sisseton	175	MDC	
SD 127			213.92	234.39	20.47	YES	961	SD-140-1	Aberdeen	Sisseton	175	MDC	
SD 127			234.39	251.17	16.78	YES	671	SD-140-2	Aberdeen	Sisseton	175	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 15			187.48	207.70	20.22	NO	864		Aberdeen	Sisseton	175	MDC	
SD 25			230.40	241.50	11.10	NO	583		Aberdeen	Sisseton	175	MDC	
I-29		Driving	170.20	193.00	22.80	YES	2,681	SD-69-1	Aberdeen	Watertown	176	MDC	
I-29		Passing	170.20	193.00	22.80	YES	712	SD-69-2	Aberdeen	Watertown	176	MDC	
SD 20			372.80	398.40	25.60	NO	1,833		Aberdeen	Watertown	176	ESS	Wallace
SD 20			416.40	425.30	8.90	NO	733		Aberdeen	Watertown	176	MDC	
US 212			355.60	375.30	19.70	NO	3,018		Aberdeen	Watertown	176	ESS	Clark
US 212			377.32	398.31	20.99	YES	3,624	SD-103-1	Aberdeen	Watertown	176	MDC	
I-29		Driving	121.80	150.90	29.10	YES	3,868	SD-73-1	Aberdeen	Brookings	177	MDC	
I-29		Passing	121.80	150.90	29.10	YES	1,028	SD-73-2	Aberdeen	Brookings	177	MDC	
SD 13			120.99	128.10	7.11	NO	1,026		Aberdeen	Brookings	177	MDC	
SD 28			341.00	361.60	20.60	NO	980		Aberdeen	Brookings	177	MDC	
SD 30			357.00	374.10	17.10	NO	672		Aberdeen	Brookings	177	MDC	
SD 324			357.50	366.10	8.60	NO	1,112		Aberdeen	Brookings	177	MDC	
US 14	W		400.99	404.52	3.53	YES	1,883	SD-83-1	Aberdeen	Brookings	177	MDC	
US 14			404.52	414.21	9.69	YES	4,260	SD-83-2	Aberdeen	Brookings	177	MDC	
US 14	W		414.21	422.44	8.23	YES	3,381	SD-83-3	Aberdeen	Brookings	177	MDC	
US 14	E		422.40	439.70	17.30	YES	2,473	SD-83-4	Aberdeen	Brookings	177	MDC	
US 14B			418.10	423.20	5.10	NO	6,227		Aberdeen	Brookings	177	MDC	
I-29		Driving	150.90	170.20	19.30	YES	2,868	SD-80-1	Aberdeen	Clear Lake	178	MDC	
I-29		Passing	150.90	170.20	19.30	YES	722	SD-80-2	Aberdeen	Clear Lake	178	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 101			85.50	88.70	3.20	NO	530		Aberdeen	Clear Lake	178	MDC	
SD 15			128.20	140.40	12.20	NO	1,429		Aberdeen	Clear Lake	178	MDC	
SD 15			140.40	150.50	10.10	NO	1,668		Aberdeen	Clear Lake	178	MDC	
SD 20			425.30	439.20	13.90	NO	750		Aberdeen	Clear Lake	178	MDC	
SD 20			446.20	455.70	9.50	NO	287		Aberdeen	Clear Lake	178	MDC	
SD 22			360.60	370.60	10.00	NO	1,785		Aberdeen	Clear Lake	178	MDC	
SD 22			370.60	383.90	13.30	NO	970		Aberdeen	Clear Lake	178	MDC	
SD 28			361.60	377.10	15.50	NO	927		Aberdeen	Clear Lake	178	MDC	
US 212			398.31	402.82	4.51	YES	3,010	SD-103-2	Aberdeen	Clear Lake	178	MDC	
US 212			402.82	412.40	9.58	NO	1,785		Aberdeen	Clear Lake	178	MDC	
SD 249			73.10	74.00	0.90	NO	530		Aberdeen	Highmore	193	MDC	
SD 34			274.84	291.83	16.99	NO	467		Aberdeen	Highmore	193	MDC	
SD 47			88.10	90.80	2.70	NO	1,274		Aberdeen	Highmore	193	MDC	
SD 47			118.20	137.20	19.00	NO	543		Aberdeen	Highmore	193	MDC	
SD 47			137.20	162.90	25.70	NO	296		Aberdeen	Highmore	193	MDC	
US 14			262.00	278.00	16.00	NO	1,772		Aberdeen	Highmore	193	ESS	Harrold
US 14			278.00	285.00	7.00	NO	1,270		Aberdeen	Highmore	193	MDC	
SD 37			114.90	125.20	10.30	NO	1,809		Aberdeen	Huron	194	MDC	
SD 37			128.70	145.80	17.10	NO	1,696		Aberdeen	Huron	194	MDC	
US 14			316.38	342.84	26.46	YES	2,101	SD-82-1	Aberdeen	Huron	194	MDC	
US 14			332.20	345.00	12.80	NO	2,899		Aberdeen	Huron	194	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
US 14			345.00	363.30	18.30	NO	2,220		Aberdeen	Huron	194	ESS	Cavour
US 281			105.10	124.20	19.10	NO	1,566		Aberdeen	Huron	194	MDC	
US 281			124.20	136.40	12.20	NO	1,224		Aberdeen	Huron	194	MDC	
SD 26			230.10	236.90	6.80	NO	105		Aberdeen	Miller	195	NA	
SD 26			236.90	252.80	15.90	NO	109		Aberdeen	Miller	195	NA	
SD 26			253.80	267.70	13.90	NO	198		Aberdeen	Miller	195	NA	
SD 45			81.10	111.50	30.40	NO	562		Aberdeen	Miller	195	ESS	Gann Valley
SD 45	N		112.35	137.72	25.37	YES	733	SD-67-1	Aberdeen	Miller	195	MDC	
US 14			285.00	301.00	16.00	NO	1,775		Aberdeen	Miller	195	MDC	
US 14			301.00	316.30	15.30	NO	1,542		Aberdeen	Miller	195	MDC	
SD 20			321.60	344.60	23.00	NO	645		Aberdeen	Redfield	196	ESS	Mellette
SD 26			267.70	279.60	11.90	NO	415		Aberdeen	Redfield	196	MDC	
SD 28			270.00	283.90	13.90	NO	366		Aberdeen	Redfield	196	MDC	
SD 37			145.80	164.00	18.20	NO	582		Aberdeen	Redfield	196	MDC	
SD 37			169.40	184.40	15.00	NO	502		Aberdeen	Redfield	196	MDC	
US 212			297.00	306.50	9.50	NO	1,112		Aberdeen	Redfield	196	MDC	
US 212			306.50	327.30	20.80	NO	1,538		Aberdeen	Redfield	196	MDC	
US 281			136.40	153.30	16.90	NO	1,874		Aberdeen	Redfield	196	MDC	
US 281			153.70	173.40	19.70	NO	2,451		Aberdeen	Redfield	196	MDC	
SD 20			344.60	372.70	28.10	NO	545		Aberdeen	Clark	197	MDC	
SD 25			131.80	148.90	17.10	NO	928		Aberdeen	Clark	197	ESS	Clark

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	Current MDSS Segment	Region	Shop	Shop Code	Truck Equipment	ESS Location
SD 25			149.80	164.80	15.00	NO	425		Aberdeen	Clark	197	ESS	Wallace
SD 28			283.99	316.92	32.93	YES	546	SD-169-1	Aberdeen	Clark	197	MDC	
US 212			327.30	355.50	28.20	YES	1,657	SD-89-1	Aberdeen	Clark	197	MDC	
SD 25			82.83	114.90	32.07	NO	1,039		Aberdeen	DeSmet	198	MDC	
SD 25			114.90	128.80	13.90	NO	1,341		Aberdeen	DeSmet	198	MDC	
US 14			363.50	378.70	15.20	NO	1,620		Aberdeen	DeSmet	198	ESS	Cavour
US 14			378.70	400.99	22.29	NO	2,224		Aberdeen	DeSmet	198	MDC	

APPENDIX E: Route Analysis for Mitchell Region

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-90	E		319.43	335.43	16.00	YES	5,139	SD-154-1	Mitchell	252	Mitchell	254	MDC	
I-90	W		319.43	335.43	16.00	YES	5,139	SD-154-2	Mitchell	252	Mitchell	254	MDC	
SD 262			356.02	373.57	17.55	NO	1,052		Mitchell	252	Mitchell	254	ESS	Alexandria
SD 42			333.06	347.04	13.98	NO	1,556		Mitchell	252	Mitchell	254	MDC	
SD 25			55.72	71.89	16.17	NO	521		Mitchell	252	Mitchell	255	MDC	
SD 37			41.63	72.35	30.72	YES	2,681	SD-132-1	Mitchell	252	Mitchell	255	MDC	
SD 37			77.00	95.64	18.64	YES	2,923	SD-131-1	Mitchell	252	Mitchell	255	MDC	
SD 38			301.08	317.99	16.91	NO	1,925		Mitchell	252	Mitchell	255	MDC	
SD 42			301.85	327.78	25.93	NO	430		Mitchell	252	Mitchell	255	MDC	
SD 42			327.78	333.06	5.28	NO	1,462		Mitchell	252	Mitchell	255	MDC	
I-90	E		284.36	296.00	11.64	YES	4,687	SD-56-1	Mitchell	253	Plankinton	256	MDC	
I-90	W		284.36	296.00	11.64	YES	632	SD-56-2	Mitchell	253	Plankinton	256	MDC	
I-90	E		296.00	307.00	11.00	YES	3,671	SD-163-1	Mitchell	253	Plankinton	256	MDC	
I-90	W		296.00	307.00	11.00	YES	3,671	SD-163-2	Mitchell	253	Plankinton	256	MDC	
I-90	E		307.00	319.43	12.43	YES	4,642	SD-155-1	Mitchell	253	Plankinton	256	MDC	
I-90	W		307.00	319.43	12.43	YES	4,687	SD-155-2	Mitchell	253	Plankinton	256	MDC	
SD 258			276.93	279.48	2.55	NO	725		Mitchell	253	Plankinton	256	MDC	
US 281			48.58	71.48	22.90	NO	1,455		Mitchell	253	Plankinton	256	ESS	Plankinton
US 281			71.48	87.13	15.65	NO	1,206		Mitchell	253	Plankinton	256	ESS	Plankinton
SD 44			273.42	294.46	21.04	NO	603		Mitchell	251	Platte	257	ESS	Platte/Winner

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 44			295.46	305.83	10.37	NO	1,339		Mitchell	251	Platte	257	ESS	Platte/Winner
SD 44			305.83	327.89	22.06	YES	1,525	SD-90-1	Mitchell	251	Platte	257	MDC	
SD 45			27.00	51.69	24.69	NO	1,063		Mitchell	251	Platte	257	MDC	
SD 50			257.00	273.42	16.42	NO	176		Mitchell	251	Platte	257	ESS	Platte/Winner
SD 50			290.12	299.24	9.12	YES	660	SD-107-1	Mitchell	251	Platte	257	MDC	
I-90	E		335.43	354.00	18.57	YES	4,991	SD-57-1	Mitchell	252	Salem	258	MDC	
I-90	W		335.43	354.00	18.57	YES	4,991	SD-57-2	Mitchell	252	Salem	258	MDC	
I-90	E		354.00	379.63	25.63	YES	4,649	SD-58-1	Mitchell	252	Salem	258	MDC	
I-90	W		354.00	379.63	25.63	YES	4,649	SD-58-2	Mitchell	252	Salem	258	MDC	
SD 38			317.99	332.28	14.29	NO	921		Mitchell	252	Salem	258	ESS	Montrose
SD 38			332.28	348.91	16.63	NO	1,064		Mitchell	252	Salem	258	ESS	Montrose
US 81			49.31	61.58	12.27	NO	1,945		Mitchell	252	Salem	258	MDC	
US 81			61.58	70.63	9.05	NO	1,784		Mitchell	252	Salem	258	MDC	
US 81			70.63	81.65	11.02	NO	1,345		Mitchell	252	Salem	258	MDC	
SD 224			288.11	296.17	8.06	NO	753		Mitchell	253	Woonsocket	259	MDC	
SD 25			71.89	82.83	10.94	YES	450	SD-60-2	Mitchell	253	Woonsocket	259	MDC	
SD 34			318.62	328.25	9.63	NO	1,124		Mitchell	253	Woonsocket	259	MDC	
SD 34			328.25	341.20	12.95	NO	1,645		Mitchell	253	Woonsocket	259	MDC	
SD 34			341.20	365.01	23.81	YES	1,143	SD-60-1	Mitchell	253	Woonsocket	259	MDC	
SD 34			365.01	373.12	8.11	NO	2,165		Mitchell	253	Woonsocket	259	ESS	Forestburg
SD 37			105.80	114.88	9.08	NO	1,342		Mitchell	253	Woonsocket	259	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 281			87.13	105.11	17.98	NO	1,366		Mitchell	253	Woonsocket	259	MDC	
SD 1804			86.01	89.82	3.81	YES	118	SD-59-3	Mitchell	251	Armour	261	MDC	
SD 44			330.53	348.60	18.07	YES	1,353	SD-91-1	Mitchell	251	Armour	261	MDC	
SD 46			277.14	297.27	20.13	NO	2,382		Mitchell	251	Armour	261	MDC	
SD 46			297.27	305.60	8.33	NO	778		Mitchell	251	Armour	261	MDC	
SD 50			299.24	314.14	14.90	YES	597	SD-59-2	Mitchell	251	Armour	261	MDC	
SD 50			323.86	329.16	5.30	NO	1,427		Mitchell	251	Armour	261	MDC	
US 18			320.78	332.90	12.12	NO	978		Mitchell	251	Armour	261	MDC	
US 18			332.90	339.04	6.14	YES	1,371	SD-59-1	Mitchell	251	Armour	261	MDC	
US 18			339.04	348.90	9.86	YES	1,363	SD-59-4	Mitchell	251	Armour	261	MDC	
US 18			348.90	355.87	6.97	NO	1,182		Mitchell	251	Armour	261	ESS	Tripp
US 281			35.81	48.58	12.77	YES	1,613	SD-91-2	Mitchell	251	Armour	261	MDC	
SD 1806			15.68	25.75	10.07	NO	150		Mitchell	251	Bonesteel	262	NA	
SD 1806			37.88	48.55	10.67	NO	133		Mitchell	251	Bonesteel	262	NA	
SD 47			0.00	12.56	12.56	NO	411		Mitchell	251	Bonesteel	262	MDC	
SD 47			20.66	31.67	11.01	YES	1,062	SD-130-2	Mitchell	251	Bonesteel	262	MDC	
US 18			263.34	286.03	22.69	YES	1,504	SD-130-1	Mitchell	251	Bonesteel	262	MDC	
US 18			286.03	306.34	20.31	NO	1,032		Mitchell	251	Bonesteel	262	MDC	
US 18			306.34	320.78	14.44	NO	848		Mitchell	251	Bonesteel	262	MDC	
I-90	E	Driving	251.60	265.85	14.25	YES	3,224	SD-133-1	Mitchell	253	Chamberlain	263	MDC	
I-90	W	Driving	251.60	265.85	14.25	YES	3,224	SD-133-2	Mitchell	253	Chamberlain	263	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-90	E		265.85	284.06	18.21	YES	3,394	SD-153-1	Mitchell	253	Chamberlain	263	MDC	
I-90	W		265.85	284.06	18.21	YES	3,394	SD-153-2	Mitchell	253	Chamberlain	263	MDC	
SD 34			291.83	318.62	26.79	NO	810		Mitchell	253	Chamberlain	263	MDC	
SD 45			56.74	81.10	24.36	NO	773		Mitchell	253	Chamberlain	263	ESS	Kimball
SD 50			211.77	235.27	23.50	NO	1,473		Mitchell	253	Chamberlain	263	MDC	
SD 50			241.50	257.00	15.50	NO	216		Mitchell	253	Chamberlain	263	MDC	
SD 19			73.73	96.94	23.21	NO	1,443		Mitchell	272	Madison	273	MDC	
SD 34			386.16	391.80	5.64	NO	6,795		Mitchell	272	Madison	273	MDC	
SD 34			391.80	406.53	14.73	YES	3,869	SD-66-1	Mitchell	272	Madison	273	MDC	
US 81			81.65	94.71	13.06	NO	2,358		Mitchell	272	Madison	273	MDC	
US 81			94.77	112.00	17.23	YES	1,703	SD-136-1	Mitchell	272	Madison	273	MDC	
US 81			112.00	116.72	4.72	YES	1,315	SD-136-2	Mitchell	272	Madison	273	MDC	
US 81			119.10	139.00	19.90	NO	2,312		Mitchell	272	Madison	273	ESS	Arlington
I-29	N		73.38	83.37	9.99	YES	5,000	SD-165-1	Mitchell	271	Sioux Falls	274	MDC	
I-29	S		73.38	83.37	9.99	YES	5,000	SD-165-2	Mitchell	271	Sioux Falls	274	MDC	
I-29		Driving	83.37	98.77	15.40	YES	5,531	SD-61-1	Mitchell	271	Sioux Falls	274	MDC	
I-29		Passing	83.37	98.77	15.40	YES	4,173	SD-61-2	Mitchell	271	Sioux Falls	274	MDC	
I-90			379.63	396.98	17.35	NO	6,982		Mitchell	271	Sioux Falls	274	Zonar	
I-90	E		396.98	412.52	15.54	YES	8,045	SD-62-1	Mitchell	271	Sioux Falls	274	MDC	
I-90	W		396.98	412.52	15.54	YES	8,047	SD-62-2	Mitchell	271	Sioux Falls	274	MDC	
SD 19			54.17	64.49	10.32	NO	1,301		Mitchell	271	Sioux Falls	274	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 19			65.50	72.68	7.18	NO	628		Mitchell	271	Sioux Falls	274	MDC	
SD 38			348.91	364.26	15.35	NO	3,021		Mitchell	271	Sioux Falls	274	ESS	I-29/41st
SD 42			347.04	361.06	14.02	YES	3,775	SD-134-1	Mitchell	271	Sioux Falls	274	MDC	
I-229	N	Driving	0.00	10.83	10.83	YES	9,156	SD-116-1	Mitchell	271	Sioux Falls	275	MDC	
I-229	N	Passing	0.00	10.83	10.83	YES	6,907	SD-116-2	Mitchell	271	Sioux Falls	275	MDC	
I-229	S	Driving	0.00	10.84	10.84	YES	9,066	SD-116-3	Mitchell	271	Sioux Falls	275	MDC	
I-229	S	Passing	0.00	10.84	10.84	YES	6,838	SD-116-4	Mitchell	271	Sioux Falls	275	MDC	
SD 11			74.71	80.87	6.16	YES	5,712	SD-65-2	Mitchell	271	Sioux Falls	275	MDC	
SD 11			80.87	102.55	21.68	YES	3,208	SD-138-1	Mitchell	271	Sioux Falls	275	MDC	
SD 115			89.86	104.00	14.14	YES	4,397	SD-64-1	Mitchell	271	Sioux Falls	275	MDC	
SD 42			371.31	378.17	6.86	YES	5,687	SD-65-1	Mitchell	271	Sioux Falls	275	MDC	
I-29	N		59.33	73.34	14.01	YES	11,620	SD-63-1	Mitchell	271	Lennox	276	MDC	
I-29	S		59.33	73.34	14.01	YES	11,644	SD-63-2	Mitchell	271	Lennox	276	MDC	
SD 11			49.00	54.48	5.48	NO	1,189		Mitchell	271	Lennox	276	MDC	
SD 11			55.43	70.86	15.43	NO	3,092		Mitchell	271	Lennox	276	MDC	
SD 115			67.39	86.86	19.47	YES	5,000	SD-164-1	Mitchell	271	Lennox	276	MDC	
SD 19			43.26	51.26	8.00	YES	1,130	SD-139-2	Mitchell	271	Lennox	276	MDC	
SD 44			395.83	406.32	10.49	NO	1,272		Mitchell	271	Lennox	276	ESS	Lennox
SD 44			406.32	411.87	5.55	NO	1,626		Mitchell	271	Lennox	276	ESS	Lennox
US 18			420.81	435.29	14.48	YES	1,179	SD-139-1	Mitchell	271	Lennox	276	MDC	
US 18			438.16	441.72	3.56	NO	4,386		Mitchell	271	Lennox	276	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 18			441.72	451.88	10.16	NO	4,821		Mitchell	271	Lennox	276	MDC	
I-29	N		98.77	121.83	23.06	YES	6,847	SD-117-1	Mitchell	272	Flandreau	277	MDC	
I-29	S		98.77	121.83	23.06	YES	6,848	SD-117-2	Mitchell	272	Flandreau	277	MDC	
SD 13			105.00	120.99	15.99	NO	959		Mitchell	272	Flandreau	277	MDC	
SD 32			414.14	422.82	8.68	NO	2,379		Mitchell	272	Flandreau	277	MDC	
SD 34			406.53	422.54	16.01	YES	1,688	SD-135-1	Mitchell	272	Flandreau	277	MDC	
SD 44			348.60	377.89	29.29	YES	1,233	SD-01-1	Mitchell	292	Menno	293	MDC	
SD 44			377.89	395.83	17.94	YES	1,837	SD-02-1	Mitchell	292	Menno	293	MDC	
US 18			355.87	373.94	18.07	NO	557		Mitchell	292	Menno	293	ESS	Freeman
US 18			373.94	402.77	28.83	NO	798		Mitchell	292	Menno	293	ESS	Freeman
US 18			402.77	420.81	18.04	YES	853	SD-03-2	Mitchell	292	Menno	293	MDC	
US 81			15.34	27.18	11.84	YES	1,695	SD-03-1	Mitchell	292	Menno	293	MDC	
US 81			27.18	38.13	10.95	NO	2,221		Mitchell	292	Menno	293	MDC	
US 81			38.13	49.31	11.18	NO	1,635		Mitchell	292	Menno	293	MDC	
SD 25			7.50	27.00	19.50	NO	670		Mitchell	292	Tyndall	294	MDC	
SD 37			0.00	20.44	20.44	YES	1,057	SD-08-1	Mitchell	292	Tyndall	294	MDC	
SD 37			24.44	41.63	17.19	YES	1,083	SD-07-1	Mitchell	292	Tyndall	294	MDC	
SD 46			305.60	318.50	12.90	NO	658		Mitchell	292	Tyndall	294	MDC	
SD 50			355.81	369.78	13.97	YES	2,207	SD-156-1	Mitchell	292	Tyndall	294	MDC	
SD 52			315.00	327.32	12.32	NO	891		Mitchell	292	Tyndall	294	ESS	Tyndall
I-29	N		0.00	4.35	4.35	YES	9,265	SD-102-1	Mitchell	291	Junction City	295	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-29	S		0.00	4.35	4.35	YES	9,225	SD-102-2	Mitchell	291	Junction City	295	MDC	
I-29	N		4.35	15.79	11.44	YES	6,199	SD-54-1	Mitchell	291	Junction City	295	MDC	
I-29	S		4.35	15.79	11.44	YES	6,198	SD-54-2	Mitchell	291	Junction City	295	MDC	
I-29	N		15.79	26.70	10.91	YES	5,781	SD-106-1	Mitchell	291	Junction City	295	MDC	
I-29	S		15.79	26.70	10.91	YES	5,783	SD-106-2	Mitchell	291	Junction City	295	MDC	
I-29	N		26.70	38.32	11.62	YES	6,177	SD-158-1	Mitchell	291	Junction City	295	MDC	
I-29	S		26.70	38.32	11.62	YES	6,177	SD-158-2	Mitchell	291	Junction City	295	MDC	
SD 19			0.00	4.99	4.99	NO	1,590		Mitchell	291	Junction City	295	MDC	
SD 19			4.99	25.27	20.28	YES	903	SD-137-1	Mitchell	291	Junction City	295	MDC	
SD 48			371.80	384.24	12.44	NO	1,029		Mitchell	291	Junction City	295	MDC	
SD 50			396.04	406.00	9.96	YES	2,410	SD-157-1	Mitchell	291	Junction City	295	MDC	
SD 50			406.00	410.81	4.81	NO	5,591		Mitchell	291	Junction City	295	MDC	
SD 50			410.81	416.67	5.86	NO	5,118		Mitchell	291	Junction City	295	MDC	
SD 50			416.67	426.36	9.69	NO	1,159		Mitchell	291	Junction City	295	MDC	
SD 153			1.25	3.62	2.37	NO	738		Mitchell	292	Yankton	296	MDC	
SD 314			378.45	382.11	3.66	NO	1,438		Mitchell	292	Yankton	296	MDC	
SD 46			318.50	334.58	16.08	NO	775		Mitchell	292	Yankton	296	MDC	
SD 46			334.58	350.64	16.06	YES	2,197	SD-159-1	Mitchell	292	Yankton	296	MDC	
SD 50			337.66	355.81	18.15	NO	1,635		Mitchell	292	Yankton	296	MDC	
SD 50			369.78	382.96	13.18	YES	3,547	SD-115-1	Mitchell	292	Yankton	296	MDC	
SD 50			383.82	388.24	4.42	NO	7,943		Mitchell	292	Yankton	296	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 50			388.24	396.04	7.80	YES	2,504	SD-09-1	Mitchell	292	Yankton	296	MDC	
SD 52			332.24	342.46	10.22	NO	3,703		Mitchell	292	Yankton	296	MDC	
US 81			2.57	15.34	12.77	NO	3,626		Mitchell	292	Yankton	296	MDC	
I-29	N		38.32	47.30	8.98	NO	6,097		Mitchell	291	Beresford	297	Zonar	
I-29	S		38.32	47.30	8.98	NO	6,097		Mitchell	291	Beresford	297	Zonar	
I-29	N		47.30	59.33	12.03	YES	7,836	SD-55-1	Mitchell	291	Beresford	297	MDC	
I-29	S		47.30	59.33	12.03	YES	7,836	SD-55-2	Mitchell	291	Beresford	297	MDC	
SD 11			9.04	14.10	5.06	NO	887		Mitchell	291	Beresford	297	MDC	
SD 11			23.46	49.00	25.54	NO	754		Mitchell	291	Beresford	297	MDC	
SD 19			31.26	43.26	12.00	NO	1,258		Mitchell	291	Beresford	297	MDC	
SD 19A			25.28	33.44	8.16	NO	371		Mitchell	291	Beresford	297	MDC	
SD 46			351.00	365.14	14.14	NO	2,931		Mitchell	291	Beresford	297	ESS	Beresford
SD 46			365.14	382.58	17.44	NO	2,365		Mitchell	291	Beresford	297	ESS	Beresford

APPENDIX F: Route Analysis for Pierre Region

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 34			115.67	141.65	25.98	YES	431	SD-98-1	Pierre	352	Phillip	353	MDC	
SD 63			83.36	96.93	13.57	NO	295		Pierre	352	Phillip	353	ESS	Belvidere
SD 73			78.07	92.93	14.86	NO	814		Pierre	352	Phillip	353	MDC	
SD 73			92.93	117.60	24.67	NO	481		Pierre	352	Phillip	353	MDC	
US 14			123.14	142.57	19.43	YES	941	SD-142-1	Pierre	352	Phillip	353	MDC	
US 14			142.57	168.37	25.80	YES	824	SD-143-1	Pierre	352	Phillip	353	MDC	
SD 1804			112.13	120.16	8.03	NO	128		Pierre	351	Pierre	354	NA	
SD 34			234.00	257.04	23.04	YES	538	SD-32-2	Pierre	351	Pierre	354	MDC	
SD 34			257.04	274.80	17.76	NO	778		Pierre	351	Pierre	354	ESS	Macs Corner
US 14			246.63	253.03	6.40	YES	2,315	SD-141-1	Pierre	354	Pierre	354	MDC	
US 14			253.03	263.29	10.26	YES	2,065	SD-141-2	Pierre	354	Pierre	354	MDC	
US 83		Passing	87.24	119.79	32.55	YES	959	SD-28-1	Pierre	351	Pierre	354	MDC	
US 83		Driving	87.24	119.79	32.55	YES	3,611	SD-29-1	Pierre	351	Pierre	354	MDC	
SD 1806			138.45	180.05	41.60	NO	166		Pierre	351	Pierre	355	NA	
SD 1806			186.46	221.05	34.59	YES	336	SD-95-2	Pierre	351	Pierre	355	MDC	
SD 204			178.00	180.13	2.13	NO	836		Pierre	351	Pierre	355	MDC	
SD 34			212.52	234.00	21.48	YES	1,086	SD-32-1	Pierre	351	Pierre	355	MDC	
US 14			203.40	227.74	24.34	YES	1,630	SD-95-1	Pierre	351	Pierre	355	MDC	
US 14			230.39	246.63	16.24	YES	3,000	SD-30-2	Pierre	351	Pierre	355	MDC	
US 83			138.73	166.22	27.49	YES	1,385	SD-30-1	Pierre	351	Pierre	355	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 20			253.87	267.52	13.65	NO	384		Pierre	351	Gettysburg	356	ESS	Tolstoy
SD 47			189.91	199.94	10.03	YES	500	SD-26-3	Pierre	351	Gettysburg	356	MDC	
US 212			208.11	220.20	12.09	YES	920	SD-146-1	Pierre	351	Gettysburg	356	MDC	
US 212			220.20	225.00	4.80	YES	1,376	SD-26-2	Pierre	351	Gettysburg	356	MDC	
US 212			225.00	244.94	19.94	YES	944	SD-26-1	Pierre	351	Gettysburg	356	MDC	
US 83			166.22	174.10	7.88	YES	1,288	SD-146-2	Pierre	351	Gettysburg	356	MDC	
US 83			175.14	191.26	16.12	YES	1,368	SD-26-4	Pierre	351	Gettysburg	356	MDC	
SD 34			141.65	170.45	28.80	NO	467		Pierre	352	Hayes	357	MDC	
SD 63			119.12	144.83	25.71	NO	412		Pierre	352	Hayes	357	ESS	Foster Bay
US 14			168.37	190.03	21.66	YES	819	SD-25-1	Pierre	351	Hayes	357	MDC	
US 14			190.03	203.40	13.37	YES	1,075	SD-144-1	Pierre	351	Hayes	357	MDC	
SD 63			227.58	251.78	24.20	YES	422	SD-27-2	Pierre	372	McIntosh	373	MDC	
SD 65			223.00	231.81	8.81	NO	200		Pierre	372	McIntosh	373	MDC	
SD 65			232.34	233.61	1.27	NO	244		Pierre	372	McIntosh	373	MDC	
US 12			101.68	131.42	29.74	NO	448		Pierre	372	McIntosh	373	MDC	
US 12			131.42	159.32	27.90	YES	398	SD-27-1	Pierre	372	McIntosh	373	MDC	
US 12			159.32	181.52	22.20	NO	954		Pierre	372	McIntosh	373	ESS	McLaughlin
SD 1804			292.34	303.33	10.99	NO	225		Pierre	371	Mobridge	374	MDC	
SD 1804			307.66	311.97	4.31	NO	201		Pierre	371	Mobridge	374	MDC	
SD 1804			339.15	351.63	12.48	NO	156		Pierre	371	Mobridge	374	NA	
SD 1806			359.75	363.43	3.68	NO	116		Pierre	371	Mobridge	374	NA	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 1806			364.61	386.83	22.22	NO	472		Pierre	371	Mobridge	374	MDC	
SD 20			141.10	171.00	29.90	NO	696		Pierre	371	Mobridge	374	ESS	Trail City
SD 20			170.13	193.61	23.48	YES	721	SD-99-1	Pierre	371	Mobridge	374	MDC	
US 12			181.52	187.36	5.84	YES	1,680	SD-99-2	Pierre	371	Mobridge	374	MDC	
US 12			187.36	198.00	10.64	YES	2,455	SD-92-1	Pierre	371	Mobridge	374	MDC	
SD 10			182.37	193.21	10.84	NO	459		Pierre	371	Mound City	375	MDC	
SD 10			203.22	225.26	22.04	NO	540		Pierre	371	Mound City	375	ESS	Eureka
SD 1804			355.50	373.00	17.50	NO	254		Pierre	371	Mound City	375	MDC	
SD 1804			373.00	401.56	28.56	NO	172		Pierre	371	Mound City	375	NA	
SD 271			189.91	203.70	13.79	NO	92		Pierre	371	Mound City	375	NA	
SD 47			235.14	247.27	12.13	NO	367		Pierre	371	Mound City	375	MDC	
SD 47			248.28	260.38	12.10	NO	155		Pierre	371	Mound City	375	ESS	Eureka
US 83			216.56	234.00	17.44	YES	1,131	SD-100-1	Pierre	391	Mound City	375	MDC	
US 83			234.00	240.71	6.71	YES	1,178	SD-100-2	Pierre	391	Mound City	375	MDC	
SD 130			193.00	200.08	7.08	NO	429		Pierre	371	Selby	376	MDC	
SD 144			188.00	190.92	2.92	NO	160		Pierre	371	Selby	376	ESS	Lowry
SD 1804			250.56	292.34	41.78	NO	758		Pierre	371	Selby	376	MDC	
SD 20			240.83	253.87	13.04	YES	173	SD-81-1	Pierre	371	Selby	376	MDC	
SD 271			162.44	173.74	11.30	NO	134		Pierre	371	Selby	376	NA	
SD 47			203.62	217.63	14.01	NO	397		Pierre	371	Selby	376	MDC	
US 12			198.00	209.82	11.82	YES	1,979	SD-93-1	Pierre	371	Selby	376	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 12			209.82	231.53	21.71	YES	1,534	SD-94-1	Pierre	371	Selby	376	MDC	
US 12			231.53	233.36	1.83	YES	1,534	SD-94-2	Pierre	371	Selby	376	MDC	
US 83			191.26	205.90	14.64	YES	1,045	SD-81-2	Pierre	371	Selby	376	MDC	
US 83			212.51	216.56	4.05	YES	1,125	SD-93-2	Pierre	371	Selby	376	MDC	
SD 63			144.83	167.54	22.71	NO	545		Pierre	372	Eagle Butte	377	ESS	Foster Bay
SD 63			173.67	186.38	12.71	NO	693		Pierre	372	Eagle Butte	377	MDC	
US 212			127.10	154.00	26.90	NO	1,249		Pierre	372	Eagle Butte	377	ESS	Red Elm
US 212			154.80	178.00	23.20	YES	822	SD-101-1	Pierre	372	Eagle Butte	377	MDC	
US 212			178.00	208.11	30.11	YES	569	SD-101-2	Pierre	372	Eagle Butte	377	MDC	
SD 20			83.00	103.00	20.00	NO	445		Pierre	372	Isabel	378	ESS	Coal Springs
SD 20			103.00	111.20	8.20	NO	117		Pierre	372	Isabel	378	ESS	Trail City
SD 20			111.25	141.10	29.85	NO	200		Pierre	372	Isabel	378	ESS	Trail City
SD 63			186.38	204.91	18.53	NO	513		Pierre	372	Isabel	378	MDC	
SD 65			164.00	190.03	26.03	NO	569		Pierre	372	Isabel	378	MDC	
SD 65			193.47	223.00	29.53	NO	304		Pierre	372	Isabel	378	MDC	
SD 63			26.71	47.69	20.98	NO	418		Pierre	392	Mission	393	MDC	
US 18			176.08	208.92	32.84	YES	1,432	SD-145-1	Pierre	392	Mission	393	MDC	
US 18			208.92	242.54	33.62	NO	1,690		Pierre	392	Mission	393	MDC	
US 83			0.00	22.15	22.15	YES	2,275	SD-129-1	Pierre	392	Mission	393	MDC	
I-90		Driving	170.31	192.64	22.33	YES	2,199	SD-19-1	Pierre	391	Murdo	394	MDC	
I-90		Passing	170.31	192.64	22.33	YES	585	SD-19-2	Pierre	391	Murdo	394	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-90		Driving	192.64	212.80	20.16	YES	2,298	SD-20-1	Pierre	391	Murdo	394	MDC	
I-90		Passing	192.64	212.80	20.16	YES	611	SD-20-2	Pierre	391	Murdo	394	MDC	
SD 248			175.41	203.87	28.46	NO	88		Pierre	391	Murdo	394	NA	
SD 248			203.87	225.34	21.47	NO	231		Pierre	391	Murdo	394	MDC	
US 83			55.62	67.87	12.25	YES	1,683	SD-14-1	Pierre	391	Murdo	394	MDC	
I-90		Driving	212.80	226.39	13.59	YES	2,566	SD-21-1	Pierre	391	Presho	395	MDC	
I-90		Passing	212.80	226.39	13.59	YES	682	SD-21-2	Pierre	391	Presho	395	MDC	
I-90	E	Driving	226.39	239.00	12.61	YES	2,449	SD-22-1	Pierre	391	Presho	395	MDC	
I-90	E	Passing	226.39	239.00	12.61	YES	650	SD-22-2	Pierre	391	Presho	395	MDC	
I-90	W	Driving	226.39	239.00	12.61	YES	2,449	SD-22-3	Pierre	391	Presho	395	MDC	
I-90	W	Passing	226.39	239.00	12.61	YES	651	SD-22-4	Pierre	391	Presho	395	MDC	
I-90	E	Driving	239.00	251.08	12.08	YES	2,489	SD-23-1	Pierre	391	Presho	395	MDC	
I-90	E	Passing	239.00	251.08	12.08	YES	661	SD-23-2	Pierre	391	Presho	395	MDC	
I-90	W	Driving	239.00	251.08	12.08	YES	2,489	SD-23-3	Pierre	391	Presho	395	MDC	
I-90	W	Passing	239.00	251.08	12.08	YES	661	SD-23-4	Pierre	391	Presho	395	MDC	
SD 248			225.34	238.72	13.38	NO	188		Pierre	391	Presho	395	NA	
SD 248			238.72	262.57	23.85	NO	193		Pierre	391	Presho	395	ESS	Reliance
SD 273			61.25	74.00	12.75	NO	470		Pierre	391	Presho	395	MDC	
SD 47			57.89	67.77	9.88	YES	650	SD-121-1	Pierre	391	Presho	395	MDC	
SD 47			67.77	88.10	20.33	YES	721	SD-120-1	Pierre	391	Presho	395	MDC	
SD 53			49.98	83.32	33.34	NO	83		Pierre	391	Presho	395	NA	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 183			61.38	75.17	13.79	YES	553	SD-16-1	Pierre	391	Presho	395	MDC	
SD 44			172.54	197.21	24.67	NO	364		Pierre	392	White River	396	MDC	
SD 44			200.74	220.60	19.86	NO	307		Pierre	392	White River	396	MDC	
SD 63			54.00	76.28	22.28	NO	80		Pierre	392	White River	396	NA	
US 83			25.13	44.26	19.13	YES	1,911	SD-12-1	Pierre	392	White River	396	MDC	
US 83			44.26	55.62	11.36	YES	1,914	SD-13-1	Pierre	392	White River	396	MDC	
SD 44			220.60	240.40	19.80	YES	287	SD-105-1	Pierre	392	Winner	397	MDC	
SD 44			253.56	274.48	20.92	NO	774		Pierre	392	Winner	397	MDC	
SD 47			31.67	57.89	26.22	NO	309		Pierre	392	Winner	397	MDC	
SD 49			18.14	27.50	9.36	YES	204	SD-33-1	Pierre	392	Winner	397	MDC	
SD 49			27.50	53.52	26.02	NO	523		Pierre	392	Winner	397	MDC	
SD 53			10.98	26.98	16.00	NO	133		Pierre	392	Winner	397	ESS	Witten
US 18			242.54	249.33	6.79	YES	2,783	SD-96-1	Pierre	392	Winner	397	MDC	
US 18	E		249.33	252.74	3.41	YES	2,783	SD-96-2	Pierre	392	Winner	397	MDC	
US 18			252.70	263.34	10.64	YES	1,903	SD-97-1	Pierre	392	Winner	397	MDC	
US 183			0.00	19.57	19.57	NO	481		Pierre	392	Winner	397	Zonar	
US 183			19.57	39.37	19.80	NO	481		Pierre	392	Winner	397	Zonar	
US 183			39.37	61.38	22.01	YES	680	SD-15-1	Pierre	392	Winner	397	MDC	
I-90		Driving	130.30	150.19	19.89	YES	2,222	SD-17-1	Pierre	391	Kadoka	398	MDC	
I-90		Passing	130.30	150.19	19.89	YES	590	SD-17-2	Pierre	391	Kadoka	398	MDC	
I-90		Driving	150.19	170.31	20.12	YES	2,199	SD-18-1	Pierre	391	Kadoka	398	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-90		Passing	150.19	170.31	20.12	YES	585	SD-18-2	Pierre	391	Kadoka	398	MDC	
SD 240			162.38	165.85	3.47	NO	797		Pierre	391	Kadoka	398	ESS	Cactus Flats
SD 248			143.56	162.44	18.88	NO	108		Pierre	391	Kadoka	398	ESS	Cactus Flats
SD 248			162.44	175.41	12.97	NO	237		Pierre	391	Kadoka	398	ESS	Belvidere
SD 44			107.53	155.35	47.82	NO	558		Pierre	391	Kadoka	398	MDC	
SD 73			51.09	71.41	20.32	YES	701	SD-148-1	Pierre	391	Kadoka	398	MDC	
SD 391			0.00	3.37	3.37	NO	740		Pierre	392	Martin	399	MDC	
SD 44			155.35	172.54	17.19	NO	406		Pierre	392	Martin	399	ESS	Wanblee
SD 73			0.00	12.62	12.62	YES	400	SD-113-1	Pierre	392	Martin	399	MDC	
SD 73			25.11	51.09	25.98	NO	556		Pierre	392	Martin	399	ESS	Wanblee
US 18			120.99	150.00	29.01	NO	1,176		Pierre	392	Martin	399	ESS	Batesland
US 18			150.00	176.08	26.08	YES	751	SD-114-1	Pierre	392	Martin	399	MDC	

APPENDIX G: Route Analysis for Rapid City Region

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
I-90	W		0.00	14.00	14.00	NO	4,654		Rapid City	451	Sturgis	454	Zonar	
I-90	E		0.00	14.00	14.00	NO	4,656		Rapid City	451	Sturgis	454	Zonar	
I-90	E	Driving	14.00	30.26	16.26	YES	4,361	SD-43-1	Rapid City	451	Sturgis	454	MDC	
I-90	E	Passing	14.00	30.26	16.26	YES	1,160	SD-43-2	Rapid City	451	Sturgis	454	MDC	
I-90	W	Driving	14.00	30.26	16.26	YES	4,360	SD-43-3	Rapid City	451	Sturgis	454	MDC	
I-90	W	Passing	14.00	30.26	16.26	YES	1,159	SD-43-4	Rapid City	451	Sturgis	454	MDC	
I-90	E		30.00	44.70	14.70	NO	8,933		Rapid City	451	Sturgis	454	Zonar	
I-90	W		30.00	44.70	14.70	NO	8,934		Rapid City	451	Sturgis	454	Zonar	
SD 34			36.50	56.30	19.80	NO	1,130		Rapid City	451	Sturgis	454	MDC	
SD 34			56.30	82.00	25.70	NO	811		Rapid City	451	Sturgis	454	ESS	Union Center
I-90	E	Driving	110.40	130.30	19.90	YES	2,245	SD-38-1	Rapid City	452	Wall	455	MDC	
I-90	W	Driving	110.40	130.30	19.90	YES	2,247	SD-38-2	Rapid City	452	Wall	455	MDC	
SD 240			126.20	134.40	8.20	NO	1,009		Rapid City	452	Wall	455	MDC	
US 14			112.50	123.10	10.60	NO	1,038		Rapid City	452	Wall	455	MDC	
US 14A			8.70	29.10	20.40	NO	1,661		Rapid City	451	Deadwood	456	MDC	
US 14A			29.10	35.60	6.50	NO	1,281		Rapid City	451	Deadwood	456	ESS	Savoy
US 14A			35.60	41.70	6.10	NO	6,594		Rapid City	451	Deadwood	456	MDC	
US 14A			41.07	51.05	9.98	YES	5,442	SD-42-1	Rapid City	451	Deadwood	456	MDC	
US 385			102.30	116.20	13.90	NO	1,889		Rapid City	451	Deadwood	456	ESS	Sugar Shack
US 385	S		116.20	122.00	5.80	NO	1,889		Rapid City	451	Deadwood	456	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 385	N		116.20	122.00	5.80	NO	2,133		Rapid City	451	Deadwood	456	MDC	
US 85			0.00	16.29	16.29	NO	491		Rapid City	451	Deadwood	456	ESS	Hardy Station
US 85			29.10	36.90	7.80	NO	6,042		Rapid City	451	Deadwood	456	MDC	
I-190	S		0.00	1.50	1.50	NO	9,264		Rapid City	452	Rapid City	457	Zonar	
I-190	N		0.00	1.50	1.50	NO	9,284		Rapid City	452	Rapid City	457	Zonar	
I-90	E	Passing	44.66	58.00	13.34	YES	10,855	SD-168-1	Rapid City	452	Rapid City	457	MDC	
I-90	W	Passing	44.66	58.00	13.34	YES	10,855	SD-168-2	Rapid City	452	Rapid City	457	MDC	
I-90	E/W	Driving	58.00	66.60	8.60	YES	11,178	SD-37-1	Rapid City	492	Rapid City	457	MDC	
I-90	E/W	Passing	66.60	84.20	17.60	YES	1,071	SD-151-1	Rapid City	452	Rapid City	457	MDC	
I-90	E/W	Passing	84.20	110.40	26.20	YES	1,071	SD-152-1	Rapid City	452	Rapid City	457	MDC	
SD 231			82.90	87.00	4.10	NO	7,784		Rapid City	452	Rapid City	457	MDC	
SD 44			26.90	40.17	13.27	YES	2,401	SD-39-1	Rapid City	452	Rapid City	457	MDC	
SD 44			54.30	107.50	53.20	NO	1,213		Rapid City	452	Rapid City	457	ESS	Scenic
SD 79	E/W	Driving	61.68	74.70	13.02	YES	2,094	SD-40-1	Rapid City	452	Rapid City	457	MDC	
SD 79	E/W	Passing	61.68	74.70	13.02	NO	4,346		Rapid City	452	Rapid City	457	MDC	
US 16	E/W	Passing	50.60	64.10	13.50	YES	4,672	SD-161-1	Rapid City	452	Rapid City	457	MDC	
SD 20			0.00	28.70	28.70	NO	142		Rapid City	471	Buffalo	473	NA	
SD 20			28.70	51.70	23.00	NO	177		Rapid City	471	Buffalo	473	NA	
SD 79			151.00	179.00	28.00	NO	411		Rapid City	471	Buffalo	473	ESS	Slim Buttes
US 85			78.00	101.00	23.00	NO	1,209		Rapid City	471	Buffalo	473	ESS	Redig
US 85			101.00	127.00	26.00	YES	1,672	SD-45-1	Rapid City	471	Buffalo	473	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 85			127.00	154.60	27.60	NO	1,456		Rapid City	471	Buffalo	473	ESS	Ludlow
SD 34			81.10	115.60	34.50	NO	651		Rapid City	472	Faith	474	ESS	Union Center
SD 73			146.10	174.30	28.20	NO	613		Rapid City	472	Faith	474	MDC	
SD 73			177.50	207.40	29.90	NO	489		Rapid City	472	Faith	474	MDC	
US 212			7.00	114.00	107.00	YES	594	SD-112-1	Rapid City	472	Faith	474	MDC	
US 212			114.00	127.10	13.10	NO	1,069		Rapid City	472	Faith	474	ESS	Red Elm
SD 168			25.00	31.60	6.60	NO	278		Rapid City	471	Newell	475	ESS	Castle Rock
SD 79			111.20	129.70	18.50	NO	1,923		Rapid City	471	Newell	475	MDC	
SD 79			132.70	151.00	18.30	NO	732		Rapid City	471	Newell	475	MDC	
US 212			28.80	40.00	11.20	NO	1,734		Rapid City	471	Newell	475	MDC	
US 212			40.00	73.00	33.00	YES	567	SD-46-1	Rapid City	471	Newell	475	MDC	
SD 34			0.00	10.30	10.30	NO	1,515		Rapid City	471	Belle Fourche	476	MDC	
SD 34			10.30	27.50	17.20	NO	3,931		Rapid City	471	Belle Fourche	476	MDC	
US 212			0.00	13.10	13.10	NO	2,078		Rapid City	471	Belle Fourche	476	ESS	Belle Fourche
US 212			13.10	28.80	15.70	NO	1,805		Rapid City	471	Belle Fourche	476	ESS	Belle Fourche
US 85	N	Driving	44.87	53.69	8.82	YES	3,089	SD-44-1	Rapid City	471	Belle Fourche	476	MDC	
US 85	N	Passing	44.87	53.69	8.82	YES	821	SD-44-2	Rapid City	471	Belle Fourche	476	MDC	
US 85	S	Driving	44.87	53.69	8.82	YES	3,089	SD-44-3	Rapid City	471	Belle Fourche	476	MDC	
US 85	S	Passing	44.87	53.69	8.82	YES	821	SD-44-4	Rapid City	471	Belle Fourche	476	MDC	
US 85			54.00	56.50	2.50	NO	11,129		Rapid City	471	Belle Fourche	476	MDC	
US 85			56.50	78.00	21.50	NO	1,491		Rapid City	471	Belle Fourche	476	ESS	Castle Rock

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
SD 20			51.74	73.92	22.18	YES	527	SD-166-1	Rapid City	472	Bison	477	MDC	
SD 20			73.92	83.00	9.08	YES	583	SD-167-1	Rapid City	472	Bison	477	MDC	
SD 73			213.00	241.50	28.50	NO	661		Rapid City	472	Bison	477	ESS	Coal Springs
SD 73			252.26	252.96	0.70	NO	256		Rapid City	472	Bison	477	ESS	Lemmon
SD 75			213.60	242.90	29.30	YES	286	SD-49-1	Rapid City	472	Bison	477	MDC	
SD 79			176.00	199.10	23.10	NO	406		Rapid City	472	Bison	477	ESS	Ralph
SD 79			203.70	232.20	28.50	YES	318	SD-111-1	Rapid City	472	Bison	477	MDC	
US 12			80.50	101.68	21.18	YES	553	SD-119-1	Rapid City	472	Bison	477	MDC	
SD 71			10.00	35.50	25.50	NO	698		Rapid City	492	Hot Springs	494	MDC	
SD 79	N	Driving	26.80	43.00	16.20	YES	1,423	SD-36-1	Rapid City	492	Hot Springs	494	MDC	
SD 79	N	Passing	26.80	43.00	16.20	YES	378	SD-36-2	Rapid City	492	Hot Springs	494	MDC	
SD 79			37.00	44.67	7.67	NO	2,133		Rapid City	492	Hot Springs	494	MDC	
SD 79	N		43.00	61.68	18.68	NO	2,270		Rapid City	492	Hot Springs	494	ESS	Fairburn
SD 79	S		43.00	61.68	18.68	NO	2,295		Rapid City	492	Hot Springs	494	ESS	Fairburn
US 18			24.18	44.70	20.52	YES	1,952	SD-150-2	Rapid City	492	Hot Springs	494	MDC	
SD 407			0.00	1.79	1.79	YES	7,370	SD-35-2	Rapid City	492	Oelrichs	495	MDC	
US 18			44.70	61.80	17.10	NO	3,055		Rapid City	492	Oelrichs	495	MDC	
US 18			61.80	88.50	26.70	NO	821		Rapid City	492	Oelrichs	495	ESS	Oglala
US 18			88.50	103.56	15.06	YES	2,736	SD-35-1	Rapid City	492	Oelrichs	495	MDC	
US 18			103.56	120.99	17.43	YES	2,514	SD-149-1	Rapid City	492	Oelrichs	495	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 385	N		0.00	13.00	13.00	NO	695		Rapid City	492	Oelrichs	495	MDC	
US 385	S		0.00	13.00	13.00	NO	695		Rapid City	492	Oelrichs	495	MDC	
US 385			37.30	43.30	6.00	NO	1,551		Rapid City	492	Oelrichs	495	MDC	
SD 244			24.00	34.40	10.40	NO	1,642		Rapid City	491	Custer	496	MDC	
SD 36			36.00	45.20	9.20	YES	705	SD-24-2	Rapid City	491	Custer	496	MDC	
SD 40			32.00	47.90	15.90	NO	838		Rapid City	491	Custer	496	MDC	
SD 40			47.90	69.40	21.50	NO	530		Rapid City	491	Custer	496	MDC	
SD 87			47.20	57.90	10.70	NO	531		Rapid City	491	Custer	496	MDC	
SD 87			59.30	73.20	13.90	NO	595		Rapid City	491	Custer	496	MDC	
SD 87			73.20	79.30	6.10	NO	539		Rapid City	491	Custer	496	MDC	
SD 89			58.50	64.50	6.00	NO	826		Rapid City	491	Custer	496	ESS	Pringle
US 16			0.00	27.00	27.00	YES	1,451	SD-11-1	Rapid City	491	Custer	496	MDC	
US 16			27.00	40.50	13.50	YES	4,872	SD-04-1	Rapid City	491	Custer	496	MDC	
US 16			40.50	50.40	9.90	YES	5,278	SD-34-1	Rapid City	491	Custer	496	MDC	
US 16A			22.50	39.00	16.50	YES	1,491	SD-24-1	Rapid City	491	Custer	496	MDC	
US 16A			39.00	49.00	10.00	NO	402		Rapid City	491	Custer	496	MDC	
US 16A			49.00	55.60	6.60	NO	395		Rapid City	491	Custer	496	MDC	
US 16B	E		64.45	73.20	8.75	NO	7,532		Rapid City	491	Custer	496	MDC	
US 16B	W		64.45	73.20	8.75	NO	7,532		Rapid City	491	Custer	496	MDC	
US 385			48.00	55.36	7.36	YES	1,086	SD-06-2	Rapid City	491	Custer	496	MDC	

Hwy	Direction	Lane	Beginning MRM	End MRM	Total MRM	Segment in MDSS	AADT	MDSS Segment	Region	Maint Unit	Shop	Shop Code	Truck Equipment	ESS Location
US 385			55.36	66.93	11.57	YES	2,143	SD-06-1	Rapid City	491	Custer	496	MDC	
US 385			85.50	102.30	16.80	YES	1,801	SD-05-1	Rapid City	491	Custer	496	MDC	
SD 471			7.00	28.90	21.90	NO	150		Rapid City	492	Edgemont	497	NA	
SD 71			0.00	10.00	10.00	NO	123		Rapid City	492	Edgemont	497	NA	
SD 89			29.70	45.30	15.60	NO	1,025		Rapid City	492	Edgemont	497	MDC	
US 18			0.00	24.18	24.18	YES	1,588	SD-150-1	Rapid City	492	Edgemont	497	MDC	