

Evaluating the Benefits of Implementing Mobile Road Weather Information Sensors (Phase II)

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16. Abstract Several state departments of transportation have integrated mobile road weather information sensors (RWIS) and maintenance decision support systems (MDSS) to improve the performance of their winter maintenance operations. The main goal of this research project is to conduct a multi-year field study to evaluate the effectiveness of integrating mobile RWIS and MDSS into existing Illinois Department of Transportation (IDOT) winter maintenance operations. The project focused on eight research tasks. Tasks 1 through 3 comprised identifying IDOT study participants for the deployment of mobile RWIS units and MDSS; selecting, acquiring, installing, calibrating, and providing training on 12 mobile RWIS units acquired from three manufacturers; and conducting a multi-year field evaluation of mobile RWIS units and MDSS during three consecutive winter seasons to assess their operational performance and effectiveness. Salt usage data were collected and analyzed in task 4 through pairwise comparisons of snowplows with and without mobile RWIS units and MDSS to evaluate their effectiveness in reducing salt usage and improving roadway conditions. Surveys and follow-up interviews with winter maintenance personnel were conducted in Task 5 to gather and analyze feedback on the use, benefits, and operational challenges of mobile RWIS units and MDSS. Tasks 6 through 8 comprised evaluating the cost-effectiveness of the three mobile RWIS models and MDSS, identifying additional uses for mobile RWIS units, and developing recommendations for future deployment and use of mobile RWIS units and MDSS across Illinois.					
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EXECUTIVE SUMMARY

The main goal of this research project was to conduct a pilot study to evaluate the effectiveness of integrating mobile road weather information sensors (RWIS) and maintenance decision support systems (MDSS) into existing Illinois Department of Transportation (IDOT) winter maintenance operations. IDOT Districts 2, 5, and 6 were selected to participate in the study to provide a representative sample of winter maintenance and snow-removal operations in Illinois. The performance of mobile RWIS units was evaluated using 12 units acquired from three manufacturers (Lufft, Vaisala, and Teconer) to compare their effectiveness. The performance of MDSS was evaluated using nine MDSS routes in the 2022–2023 winter season and 15 additional routes in the 2023–24 and 2024–25 winter seasons. Installation of the 12 mobile RWIS units was completed by mounting the unit sensors on IDOT snowplows and supervisor vehicles, setting up the manufacturer phone/tablet app, and calibrating the unit. All mobile RWIS models could measure road surface friction, road surface temperature, and water film height as well as six road conditions (dry, wet, moist, slushy, snowy, and icy).

Four online training sessions were provided to winter maintenance operations personnel in each participating IDOT district: three sessions on the use of the installed mobile RWIS units and one session on the use of MDSS. Three online surveys and three follow-up interviews were conducted to gather and analyze feedback from IDOT personnel in the three participating districts on their experiences using mobile RWIS units and MDSS during the 2022–23, 2023–24, and 2024–25 winter seasons. The findings are summarized below:

- Use of mobile RWIS units resulted in moderate improvements in the level of service, the amount of salt/brine use, and working hours to prepare for winter events.
- The Lufft MARWIS model was reported to have the highest average accuracy of readings, followed by Teconer RCM511 and Vaisala MD30.
- The Lufft MARWIS model was reported to have the highest weighted average overall effectiveness, followed by Teconer RCM511 and Vaisala MD30.
- Lufft MARWIS was reported to have no damage during power washing, no iPad app issues, hardly any connection issues, and slightly below moderately frequent calibration issues.
- Teconer was reported to have no damage during power washing, hardly any phone app issues, slightly below moderately frequent connection issues, and slightly below moderately frequent calibration issues.
- Vaisala MD30 was reported to have hardly any damage during power washing, hardly any calibration issues, slightly above moderately frequent connection issues, and slightly below moderately frequent phone app issues.
- Use of MDSS resulted in moderate improvements in the level of service, fleet management, and working hours required to prepare for winter events.

- Top MDSS challenges encountered were inaccurate weather predictions, excessive treatment recommendations, and insufficient treatment recommendations.

The effectiveness of mobile RWIS units in reducing salt usage was evaluated using 36 pairwise comparisons of snowplows operating on routes with and without a mobile RWIS unit: 16 comparisons in the 2023–24 season and 20 comparisons in the 2024–25 season. Use of mobile RWIS units reduced the salt per travel distance rate, salt per salt distance rate, and salt distance to travel distance ratio by an average of 26%, 2%, and 18%, respectively. The effectiveness of MDSS in reducing salt usage was evaluated using 15 pairwise comparisons of snowplows operating on routes with and without MDSS during the 2023–24 winter season. Use of MDSS resulted in an average 3% reduction in salt per travel distance rate and a 1% increase in both the salt per salt distance rate and the salt distance to travel distance ratio.

The cost-effectiveness of each mobile RWIS unit model was evaluated using three financial performance metrics: net present value (NPV), payback period, and return on investment. The Teconer mobile RWIS unit provided the best overall cost-effectiveness with the highest NPV of \$36,114.23 and shortest payback period of 1.47 years, followed by Lufft MARWIS and Vaisala. A sensitivity analysis revealed the Teconer unit consistently delivered the highest NPV values for all annual salt usage rates that ranged from 56 to 280 tons per snowplow, while the NPV of Lufft MARWIS and Vaisala unit broke even at approximately 91 and 191 tons per snowplow per year, respectively. The cost-effectiveness of MDSS could not be confirmed for the analyzed 24 routes in this study during the 2023–24 winter season, because the estimated average annual MDSS savings of \$521.43 per route was substantially lower than its average annual cost of \$905.14 per route.

Four potential additional uses of mobile RWIS units were identified based on existing literature and the findings of this study. Additional uses include evaluating (a) performance of alternative winter maintenance materials, (b) performance of alternative winter maintenance equipment, (c) impact of tree canopy on pavement conditions, and (d) vehicle-to-infrastructure data integration. Five recommendations for the deployment and use of mobile RWIS and MDSS throughout Illinois were developed: (1) prioritize deployment of mobile RWIS units based on annual salt usage, (2) select mobile RWIS models based on cost-effectiveness and operational performance, (3) consider phased deployment of mobile RWIS units, (4) establish pre-season quality assurance protocol and training, and (5) consider use of MDSS for operational planning.

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CHAPTER 1: INTRODUCTION

PROBLEM STATEMENT

Several state departments of transportation (DOTs) have integrated mobile road weather information sensors (RWIS) and maintenance decision support systems (MDSS) to improve the performance of their winter maintenance operations. A recent Illinois Center for Transportation and Illinois Department of Transportation research project (R27-SP47) evaluated the effectiveness of commercially available mobile RWIS as well as gathered and analyzed the experiences of state DOTs in collecting real-time winter roadway conditions using mobile RWIS and MDSS (El-Rayes & Ignacio, 2022). The findings of this project confirmed the need for a pilot study that evaluates the implementation of mobile RWIS and MDSS to determine their effectiveness, implementation requirements, software/technology needs, operational challenges, and life cycle costs.

RESEARCH OBJECTIVES AND METHODOLOGY

The main goal of this research project is to conduct a pilot study to evaluate the effectiveness of integrating mobile RWIS and MDSS into existing IDOT winter maintenance operations. The research objectives of this project are as follows:

- 1) Identify potential districts, routes, and vehicles for use in the pilot study based on several criteria: areas with gaps in fixed RWIS coverage, roads with high average daily traffic such as interstate highways, locations with a history of blowing snow or icy roads (or both), locations with a high rate of winter weather–related crashes, and districts with a high level of interest from maintenance personnel.
- 2) Install mobile RWIS units on selected plows and supervisor vehicles identified in the previous task. Researchers in collaboration with the Technical Review Panel of this project will (a) select and acquire 12 mobile RWIS units developed by three manufacturers and used by other state DOTs, (b) mount and calibrate mobile RWIS units on participating vehicles, and (c) organize training sessions for winter maintenance operations personnel on the use of mobile RWIS units and MDSS.
- 3) Evaluate the effectiveness of currently used and the 12 newly purchased mobile RWIS units and MDSS during the first winter season (phase one). Researchers will provide recommendations for improving their performance in the second and third winter seasons of the project. This task is organized into the following subtasks:
 - 3.1) Collect all salt usage data of snowplows with and without mobile RWIS units and MDSS, including travel distance, salt distance, and total salt.
 - 3.2) Conduct interviews with IDOT winter maintenance personnel participating in the pilot study to gather and analyze their experiences installing, using, and maintaining mobile RWIS units and MDSS.
 - 3.3) Analyze all collected data from tasks 3.1 and 3.2 and provide recommendations for improving the performance of mobile RWIS and MDSS in all participating districts in the second and third winter seasons of the pilot study (Task 4 and 5).

- 4) Evaluate the effectiveness of deployed mobile RWIS and MDSS during the second winter season after implementing the recommendations from task 3.3 (phase two). The work in this task is similar to those described in tasks 3.1, 3.2, and 3.3.
- 5) Analyze the effectiveness of mobile RWIS units and MDSS during the third winter season after implementing the recommendations from the previous two winter seasons (phase three).
- 6) Analyze the effectiveness of all tested mobile RWIS units and MDSS in improving winter maintenance operations on Illinois roads in terms of their cost-effectiveness and life cycle cost, which consists of initial cost, operating cost, and realized savings from reduced salt usage.
- 7) Identify additional uses for mobile RWIS such as evaluating the effectiveness of different winter maintenance equipment and material such as plow blades, spreaders, pre-treatments, brine, and deicers.
- 8) Develop recommendations for future deployment of mobile RWIS units and MDSS throughout Illinois based on their analyzed performance as well as their implementation requirements, software/technology needs, operational challenges, and life cycle costs.

Figure 1 displays the project’s research methodology, which is divided into eight tasks that are described in more detail in the following chapters and appendix.

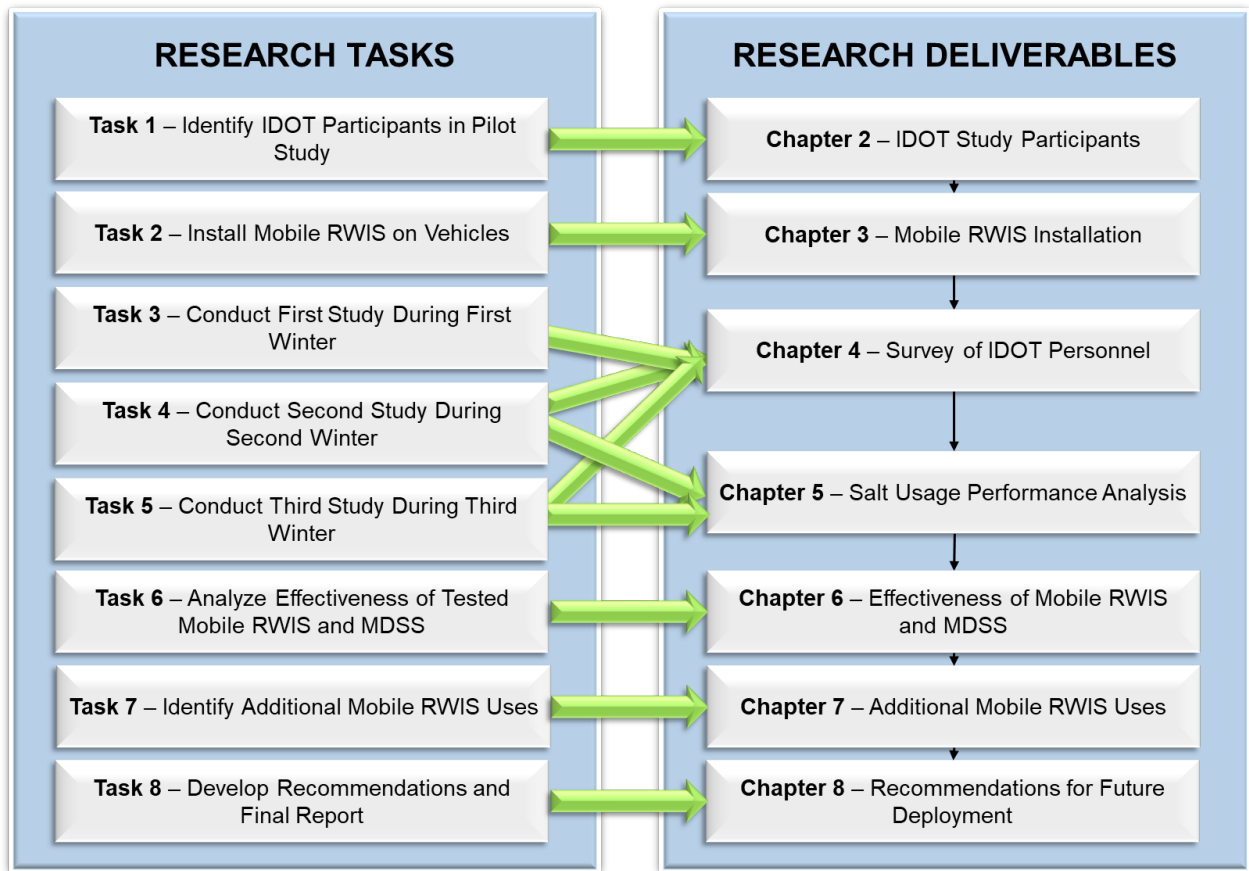


Figure 1. Diagram. Research tasks and deliverables.

CHAPTER 2: IDOT STUDY PARTICIPANTS

This chapter focuses on identifying IDOT districts, vehicles, and routes to study in this research project to maximize the potential benefits of using mobile RWIS units and MDSS.

PARTICIPATING IDOT DISTRICTS

The research team, in collaboration with the project’s Technical Review Panel (TRP), identified a list of IDOT districts for the deployment of mobile RWIS and MDSS based on interest from their personnel and their needs to improve winter maintenance operations. The identified districts were District 2 (Dixon), District 5 (Paris), and District 6 (Springfield), as presented in Figure 2. These districts were selected to provide a representative sample of winter maintenance and snow-removal operations in Illinois. For example, District 2 has 14,262.16 miles of IDOT roadways and has received an average annual snowfall of 34.6” over the past 20 years. Similarly, District 5 has 11,787.49 miles of IDOT roadways and has received an average annual snowfall of 18.4” over the past 20 years, while District 6 has 18,896.78 miles of IDOT roadways and has received an average annual snowfall of 18” over the past 20 years (IDOT, 2021; NWS, 2022). A list of users of mobile RWIS and MDSS were identified in each district. Users of mobile RWIS included snowplow drivers and operations supervisors, and users of MDSS included operations engineers, field engineers, and operations supervisors.

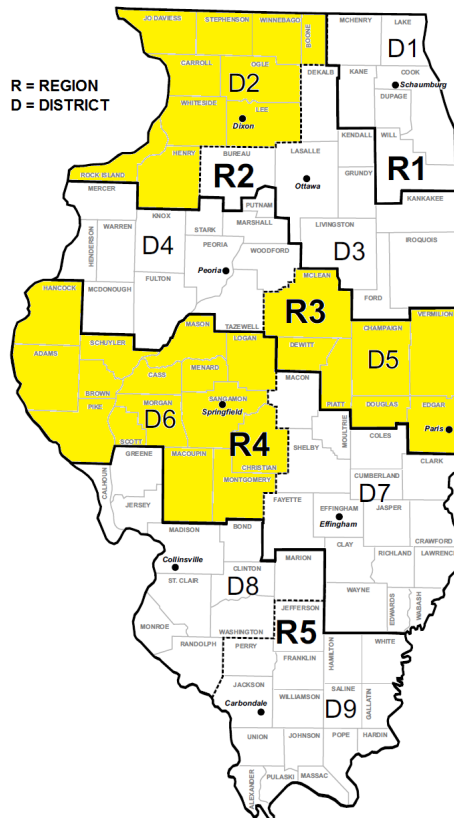


Figure 2. Map. Participating IDOT districts.

PARTICIPATING VEHICLES

Vehicles that were equipped with mobile RWIS units in this study were 75% snowplows and 25% supervisor vehicles based on a survey of state DOT recommendations (El-Rayes & Ignacio, 2022). This breakdown was due to three reasons:

1. Real-time information provided by mobile RWIS on snowplows can be acted upon directly by plow operators, whereas supervisors would need to contact a snowplow if they identified a roadway that required winter maintenance treatment.
2. Supervisors do not always actively monitor roadways during all storms.
3. The goal of mobile RWIS and MDSS is the effective clearing of roads and material management, which would benefit more from a higher snowplow deployment than supervisor vehicles (El-Rayes & Ignacio, 2022).

Accordingly, the four mobile RWIS units allocated to each participating district (D2, D5, and D6) were installed on three snowplows (75%) and one supervisor vehicle (25%) (Table 1).

The three mobile RWIS models tested in this study (Lufft MARWIS, Teconer RCM511-RTD411SA, and Vaisala MD30) were distributed among the participating districts so that each district used two types of models per winter season. This approach ensured each district had the opportunity to objectively compare mobile RWIS models based on their installation, calibration, training, and operation performance. The distribution of mobile RWIS models implemented during the 2022–23 winter season was extended into the 2023–24 season to allow additional use of the installed models due to the limited number of winter events experienced in the 2022–23 season (Table 1). To ensure all districts evaluated all three models, two units from one of the mobile RWIS models used in the 2022–23 and 2023–24 winter seasons in each district were replaced with two other units from the third unused model in the 2024–25 winter season. For example, two Vaisala units in District 2 were replaced with two Teconer units to allow both supervisors and snowplow operators to evaluate the performance of a new third model that was not used in the two previous winter seasons, as shown in Table 1. Districts 5 and 6 conducted equivalent exchanges, ensuring all three models were tested across the participating districts by the end of the study period. This rotation enabled the collection of more reliable and objective performance evaluations from more than one district for each tested mobile RWIS model.

Table 1. Distribution of Mobile RWIS Unit Models During the Three Winter Seasons

IDOT District	Type of Vehicle	Location	Mobile RWIS	First Winter 2022–23		Second Winter 2023–24		Third Winter 2024–25		
				Installation Date	Removal Date	Reinstallation Date	Removal Date	Mobile RWIS	Reinstallation Date	Removal Date
2	Supervisor	Milan	Vaisala	Feb 7, 2023	May 17, 2023	Oct 19, 2023	May 6, 2024	Teconer	Dec 15, 2024	April 17, 2025
	Snowplow 1	Milan	Vaisala	Feb 7, 2023	May 17, 2023	Oct 19, 2023	May 6, 2024	Teconer	Nov 20, 2024	April 17, 2025
	Snowplow 2	Amboy	Lufft	Feb 23, 2023	May 17, 2023	Oct 19, 2023	May 6, 2024	Lufft	Nov 20, 2024	April 17, 2025
	Snowplow 3	Amboy	Lufft	Feb 23, 2023	May 17, 2023	Oct 19, 2023	May 6, 2024	Lufft	Nov 20, 2024	April 17, 2025
5	Supervisor	Bloomington	Teconer	Feb 21, 2023	May 17, 2023	Oct 20, 2023	May 7, 2024	Lufft	Dec 4, 2024	May 8, 2025
	Snowplow 1	Bloomington	Teconer	Feb 21, 2023	May 17, 2023	Oct 20, 2023	May 7, 2024	Lufft	Dec 4, 2024	May 8, 2025
	Snowplow 2	Champaign	Vaisala	Feb 8, 2023	May 15, 2023	Oct 5, 2023	May 7, 2024	Vaisala	Dec 4, 2024	May 8, 2025
	Snowplow 3	Champaign	Vaisala	Feb 8, 2023	May 15, 2023	Nov 28, 2023	May 7, 2024	Vaisala	Dec 4, 2024	May 8, 2025
6	Supervisor	Lincoln	Lufft	Feb 24, 2023	May 15, 2023	Oct 20, 2023	May 7, 2024	Vaisala	Nov 13, 2024	May 8, 2025
	Snowplow 1	Lincoln	Lufft	Feb 24, 2023	May 15, 2023	Dec 11, 2023	May 7, 2024	Vaisala	Nov 13, 2024	May 8, 2025
	Snowplow 2	Springfield	Teconer	Feb 22, 2023	May 15, 2023	Oct 20, 2023	May 7, 2024	Teconer	Nov 13, 2024	May 8, 2025
	Snowplow 3	Springfield	Teconer	Feb 22, 2023	May 15, 2023	Dec 11, 2023	May 7, 2024	Teconer	Dec 15, 2024	May 8, 2025

PARTICIPATING ROUTES

A total of 12 mobile RWIS units and 24 MDSS routes were used in this study across D2, D5, and D6 to analyze and compare their performance. The 12 mobile RWIS units and their corresponding routes were distributed equally among the three IDOT districts. The 24 MDSS routes included nine routes established in the 2021–22 winter season and 15 additional routes identified by the TRP for use in the 2022–23, 2023–24, and 2024–25 winter seasons. The 24 MDSS routes were distributed equally among the three districts. The following sections summarize the distribution of the mobile RWIS units and MDSS routes per district.

District 2 Mobile RWIS Units

The four mobile RWIS units in District 2 included two Vaisala MD30 units and two Lufft MARWIS units. They were distributed among one supervisor vehicle and three snowplows in the 2022–23 and 2023–24 winter seasons to provide representative coverage of the district, as shown in their sample routes in Figure 3 and 4.

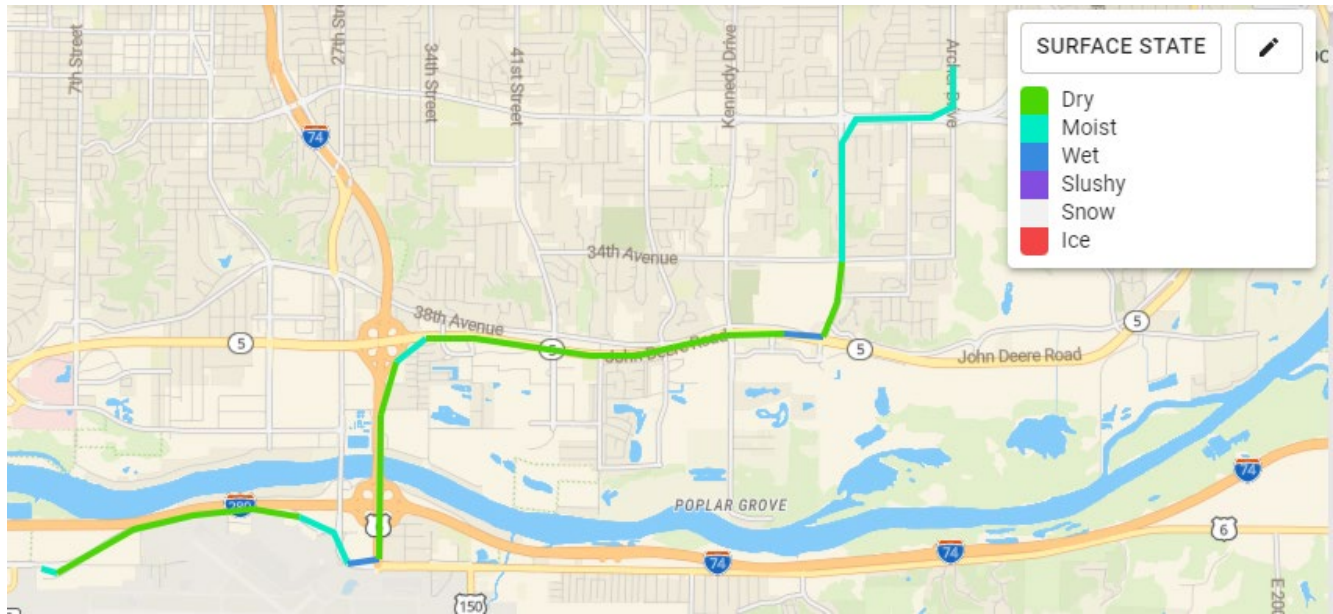


Figure 3. Screenshot. Sample route of a Vaisala mobile RWIS unit on a D2 supervisor vehicle.

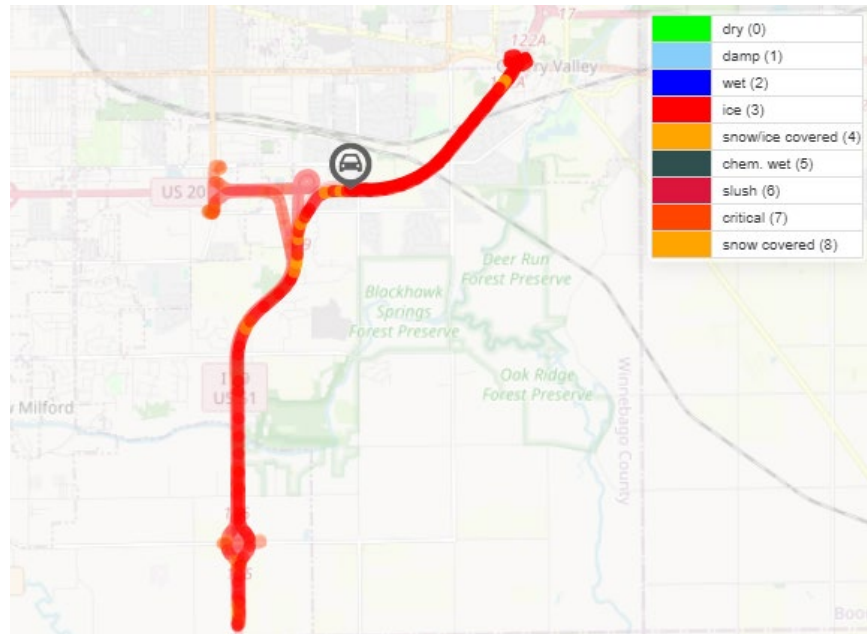


Figure 4. Screenshot. Sample route of a Lufft MARWIS unit on a D2 snowplow.

District 2 MDSS Routes

The MDSS routes in District 2 (D2.1, D2.2, D2.3, D2.4, D2.5, D2.6, and D2.7) were distributed among seven counties to provide a representative sample of the district routes, as shown in Figure 5 and Table 2.

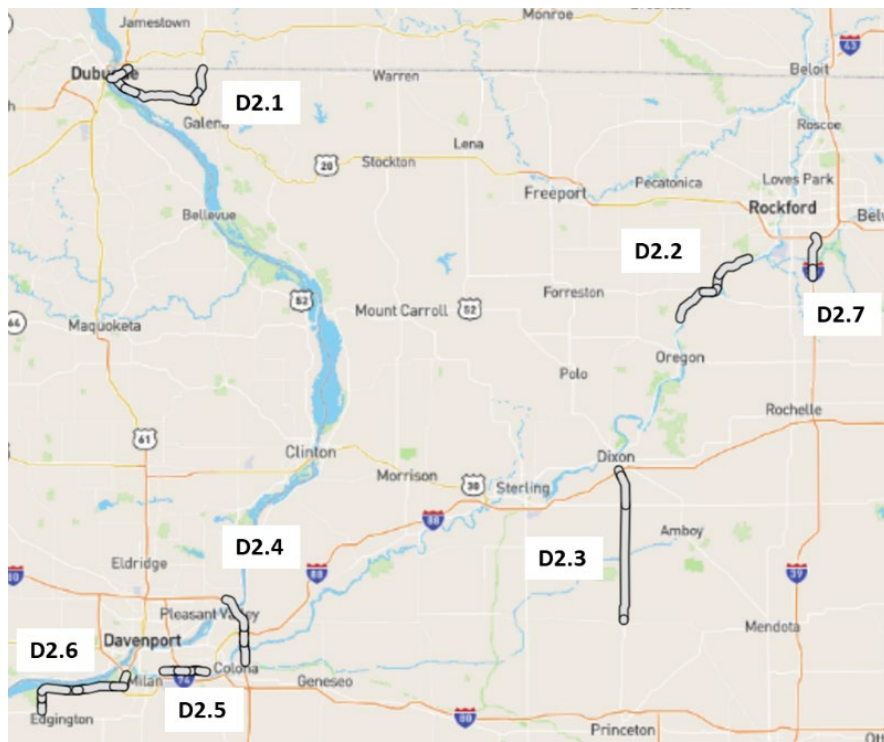


Figure 5. Screenshot. Participating MDSS routes in District 2.

Table 2. Participating MDSS Routes in District 2

Route #	Route Name	County	Route Description
D2.1	US 20 West Route	Jo Daviess	US 20 from US 20 & IL 84 N junct. to East Dubuque, IL 35 from US 20 to the Wisconsin state line, IL 84 from US 20 to the Wisconsin state line
D2.2	IL 2 North Route	Ogle	IL 2 from Banditti Rest Area (between Oregon and Byron, larger/north) to Meridian Road, IL 72 from Byron to German Church Road (Byron Bridge), Rest Areas
D2.3	IL 26 South Route	Lee and Bureau	IL 26 from Bloody Gulch Road on the south side of Dixon to Railroad St in Ohio, rest areas of Green River
D2.4	I-80 Route	Rock Island and Henry	I-80 Mississippi River Bridge (incl. bridge) to crossover @ MP 7.8, Ramps at I-80 and I-88, Outer Ramps @ Colona Exit 7 (EB off/WB on), Scenic Overlook, I-80 Scales
D2.5	IL 5 John Deere Rd	Rock Island and Henry	IL 5 (John Deere Rd) from Milan Beltway to John Deere Place
D2.6	IL 92 & Centennial Expy	Rock Island and Henry	IL 92/IL 192 to Centennial Expy & Centennial Expy to I-280
D2.7	I-39 US 20 to Ogle CL	Winnebago	I-39 US 20 to Ogle CL

District 5 Mobile RWIS Units

The four mobile RWIS units in District 5 include two Vaisala MD30 units and two Teconer units. They were distributed among one supervisor vehicle and three snowplows in the 2022–23 and 2023–24 winter seasons to provide representative coverage of the district, as shown in their sample routes in Figure 6 and 7.

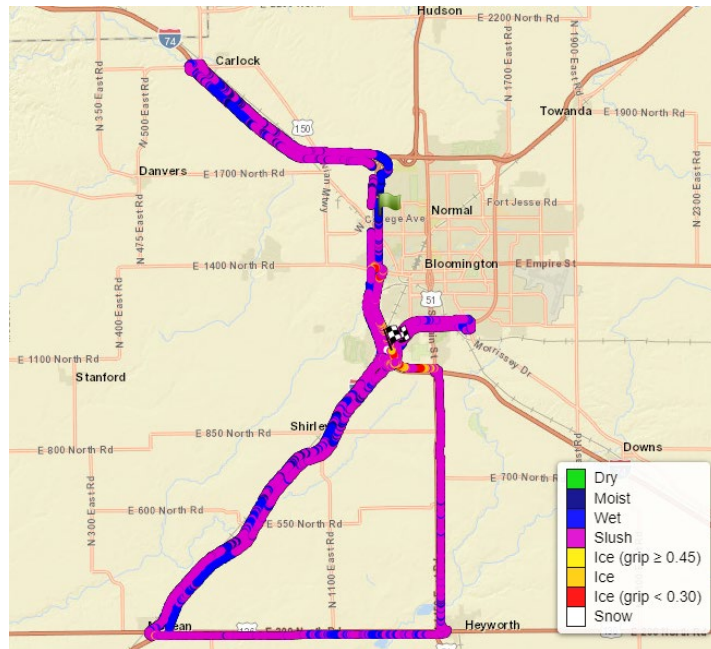


Figure 6. Screenshot. Sample route of a Teconer mobile RWIS unit on a D5 supervisor vehicle.

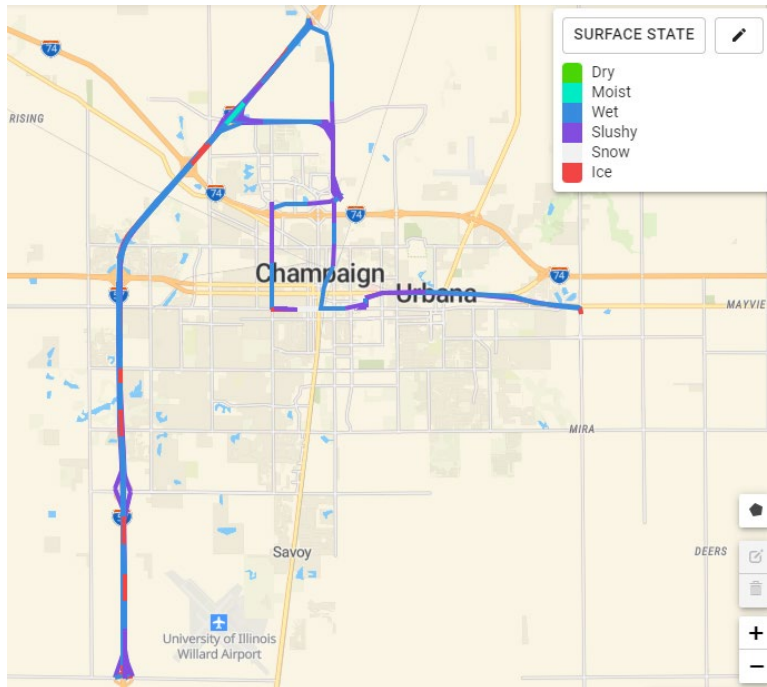


Figure 7. Screenshot. Sample route of a Vaisala mobile RWIS unit on a D5 snowplow.

District 5 MDSS Routes

The District 5 MDSS routes (D5.1, D5.2, D5.3, D5.4, D5.5, D5.6, D5.7, and D5.8) were distributed among two counties, as shown in Figure 8 and Table 3.

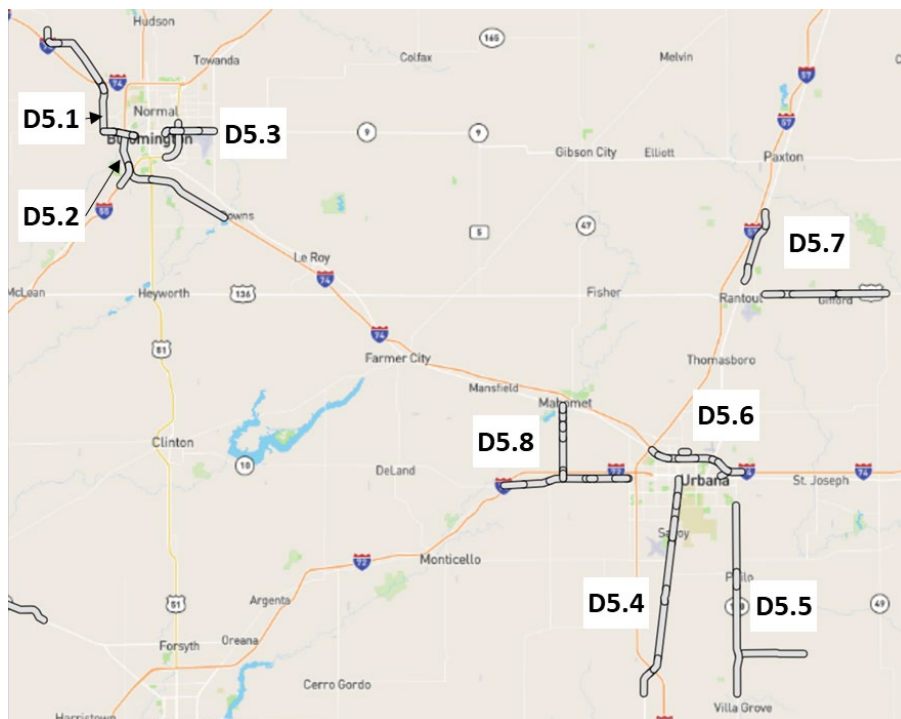


Figure 8. Screenshot. Participating MDSS routes in District 5.

Table 3. Participating MDSS Routes in District 5

Route #	Route Name	County	Route Description
D5.1	Rivian Motorway	McLean	White Oak Road, W to IL 9 & Mitsubishi Motorway, N to Carlock and Back. Help on Mitsubishi & I-74 Ramps
D5.2	I-74 East	McLean	Market St. intersection, south to Stringtown Road (155.5) north to IL 9, east to downs turnaround (141) and back to IL 9. Ramps at US 51
D5.3	Veterans Parkway	McLean	Start at US 150, north to Clearwater Ave., south then west to Bloomington High School tennis court at Towanda/Locust, east on IL 9 to Towanda Barnes Road, then back to US 150
D5.4	US 45	Champaign	US 45 from Springfield Ave. to South side I-57
D5.5	IL 130	Champaign	Douglas County Line to Windsor Road and CH 16-IL 130 to CH 12
D5.6	I-74 and Wilber Hts Rd	Champaign	I-74 from I-57 to E of Trumpet (MP 86.24) and Wilber Heights Road
D5.7	Leverette SR4	Champaign	Pennfield Rd to E edge of Rantoul & US 45 - Old State storage (N of Rantoul) to Ford Co. line
D5.8	Leverette SR 10	Champaign	IL 10 Staley Rd to I-72 overhead and IL 47 from IL 10 to US 150

District 6 Mobile RWIS Units

The four mobile RWIS units in District 6 include two Lufft MARWIS units and two Teconer units. They were distributed among one supervisor vehicle and three snowplows in the 2022–23 and 2023–24 winter seasons to provide representative coverage of the district, as shown in their sample routes in Figure 9 and 10.

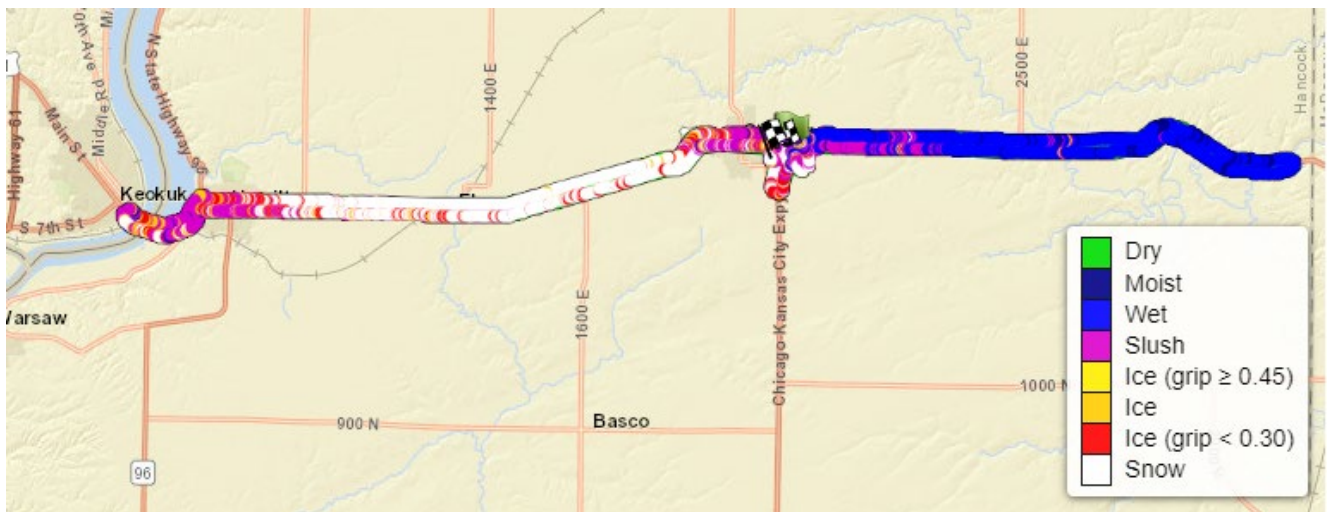


Figure 9. Screenshot. Sample route of a Teconer mobile RWIS unit on a D6 snowplow.

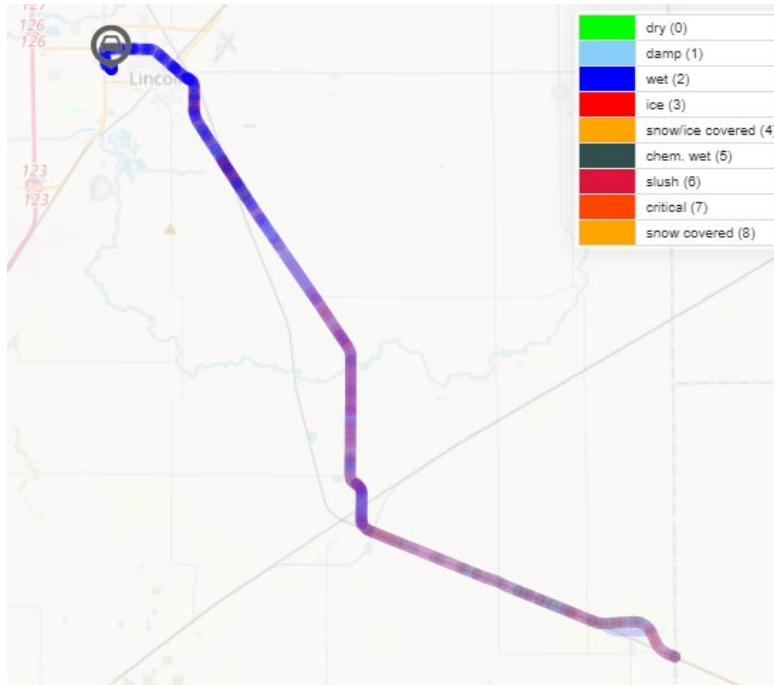


Figure 10. Screenshot. Sample route of a Lufft MARWIS mobile RWIS unit on a D6 snowplow.

District 6 MDSS Routes

The District 6 MDSS routes (D6.1, D6.2, D6.3, D6.4, D6.5, D6.6, D6.7, and D6.8) were distributed among six counties, as shown in Figure 11 and Table 4.



Figure 11. Screenshot. Participating MDSS routes in District 6.

Table 4. Participating MDSS Routes in District 6

Route #	Route Name	County	Route Description
D6.1	US 136/Keokuk Bridge	Hancock	US 136/Keokuk Bridge (Hamilton) to Carthage (Memorial Hospital)
D6.2	I-55 N from Exit 126 to McLean Co Line	Logan	Exit 126 to McLean Co Line
D6.3	I121 from Old 66 in Lincoln to Macon Co Line	Logan	I121 from Old 66 in Lincoln to Macon Co Line
D6.4	IL 103 Sugar Grove Church to US 24 / US 24 in Schyler Co	Schuyler	IL 103 Sugar Grove Church to US 24 / US 24 in Schyler Co
D6.5	Morgan/Sangamon Co Line to Macarthur E. turnaround	Sangamon	Morgan/Sangamon Co Line to Macarthur E. turnaround
D6.6	55 Sangamon OVHD to Toronto Rd, I-72 from 6th St to E. MacArthur turnaround	Sangamon	55 Sangamon OVHD to Toronto Rd, I-72 from 6th St to E. MacArthur turnaround
D6.7	IL 104 (E 1900th St) to Adams / Pike Co Line	Adams	IL 104 (E 1900th St) to Adams / Pike Co Line
D6.8	US 54 to Atlas/ IL 96 to Calhoun Co. Line	Pike	US54 from W. Junction IL 106 to Atlas. IL 96 S. to Calhoun Co. Line

CHAPTER 3: MOBILE RWIS INSTALLATION

This chapter focuses on the installation of 12 mobile RWIS units on nine snowplows and three supervisor vehicles in IDOT Districts 2, 5, and 6. Installation of the units was accomplished in four subtasks. First, select and acquire 12 mobile RWIS units provided by three manufacturers to compare their performance and effectiveness. Second, install the 12 mobile RWIS units on participating vehicles. Third, analyze the capabilities and accuracy of the three mobile RWIS models in collecting various road and weather data. Fourth, provide training to winter maintenance operations personnel on the use of mobile RWIS units and MDSS. The following sections discuss the four subtasks in detail.

SELECTION AND ACQUISITION OF MOBILE RWIS UNITS

This subtask focused on identifying and acquiring 12 mobile RWIS units from three manufacturers that were used and recommended by other state DOTs. The three most-used mobile RWIS units by state DOTs and not currently used by IDOT are Lufft MARWIS, Vaisala MD30, and Teconer (El-Rayes & Ignacio, 2022). Of the three mobile RWIS manufacturers not currently used by IDOT, Lufft MARWIS was reported to be the most used by 10 DOTs (El-Rayes & Ignacio, 2022). Four Lufft MARWIS, four Vaisala MD30, and four Teconer units were acquired to compare their performance and effectiveness. They were deployed in the identified IDOT districts, vehicles, and routes described in Chapter 2. This deployment was designed to provide two types of mobile RWIS models per district per winter season to ensure each district may objectively compare mobile RWIS models based on their installation, training, and operation.

INSTALLATION OF MOBILE RWIS UNITS

This subtask focused on installing the acquired 12 mobile RWIS units on their assigned vehicles in each district. Survey findings revealed that state DOTs recommended installing mobile RWIS units on snowplows either directly behind the plow on the front bumper or in the wheelhouse between the vehicle cab and truck bed (El-Rayes & Ignacio, 2022). The following subsections describe the installation of the Vaisala MD30, Teconer, and Lufft MARWIS units.

Vaisala MD30 Units

The four Vaisala MD30 units were installed on three snowplows and one supervisor vehicle (Table 1). The Vaisala MD30 unit consists of a sensor, Bluetooth module enclosure, and RoadAI phone app. Installation was performed in three steps: (1) mounting the unit sensor and Bluetooth module enclosure, (2) setting up the unit RoadAI phone application, and (3) calibrating the unit.

Mounting of Vaisala MD30 Sensors and Bluetooth Module Enclosures

Vaisala recommends mounting the MD30 sensor on the front or the side of the snowplow and supervisor vehicle. As shown in Figure 12, Vaisala reports the front of the vehicle (location a) to provide the most accurate readings for the overall set of road and weather parameters. Accordingly, the four MD30 sensors were mounted on the front of three snowplows and one supervisor vehicle. The MD30 sensor was mounted on the front bumper of the snowplows and directed at the wheel path using a manufacturer-provided bracket (Figure 13). The MD30 sensor was mounted on the

supervisor vehicle's front bumper using a towing hook provided by the manufacturer and was directed at the wheel path (Figure 14). Vaisala recommends the mounting height of its MD30 sensors to range from 20 and 110 cm above ground level. The three MD30 sensors were installed on snowplows at a mounting height between 105 and 110 cm, while the MD30 sensor was installed on the supervisor vehicle at a mounting height of 47 cm above ground level.

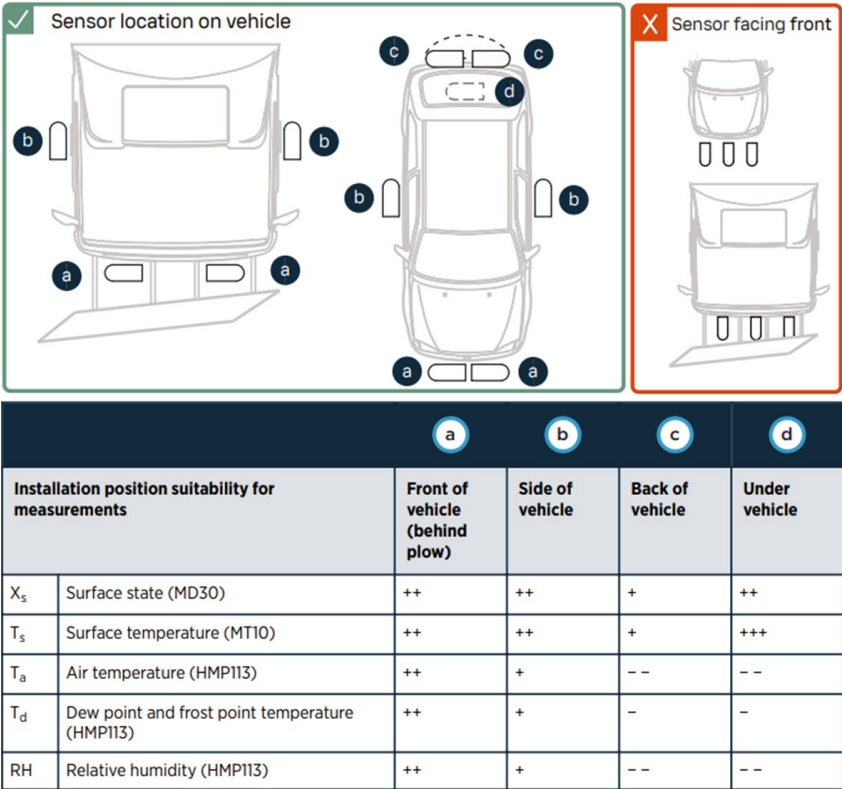


Figure 12. Screenshot. Vaisala MD30 recommended mounting position (Vaisala, 2025).



Figure 13. Photo. Mounting position of a Vaisala MD30 sensor on a snowplow.



Figure 14. Photo. Mounting position of a Vaisala MD30 sensor on a supervisor vehicle.

Upon mounting the MD30 unit sensors, a suitable location was selected inside the vehicle cabin for mounting the MD30 Bluetooth module enclosure, as shown in Figure 15. This MD30 Bluetooth module enclosure was then connected to the MD30 sensor using an extension cable and the vehicle power source using a power cable (Figure 15).

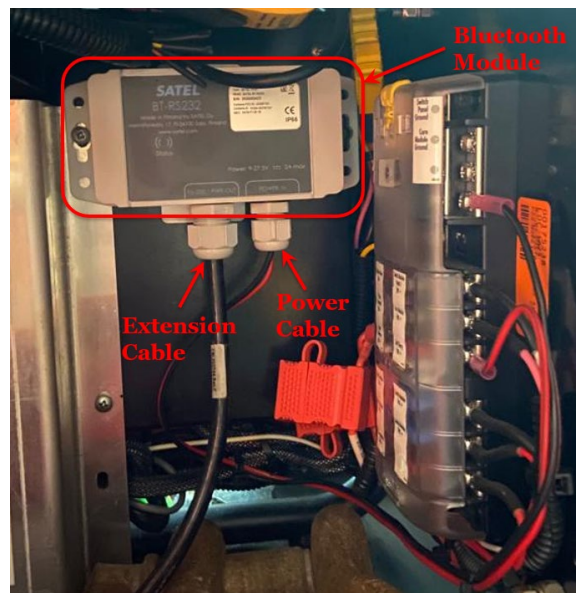


Figure 15. Photo. Bluetooth module wiring.

Setting up the RoadAI Phone Application

This step focused on setting up the RoadAI phone app to transfer collected road and weather data by the sensor via Bluetooth to the RoadAI phone application for in-vehicle display. The phone application consists of two interfaces: (1) a sensor view that shows the entire set of road and weather

data recorded by the MD30 sensor, and (2) a camera view that shows the road ahead of the snowplow that can be used to refer to a data point. To evaluate the accuracy of the data collected by the sensor, a field test was conducted by pouring water on the ground to verify that the reported road surface conditions change from dry to wet.

Calibration of Vaisala MD30 Units

This step focused on calibrating the MD30 sensor to ensure the accuracy of its measurements after installation. Calibration was performed by placing a manufacturer reference plate on the ground in the direct line of sight of the sensor under natural light and selecting the plate reference calibration option from the phone application (Figure 16).

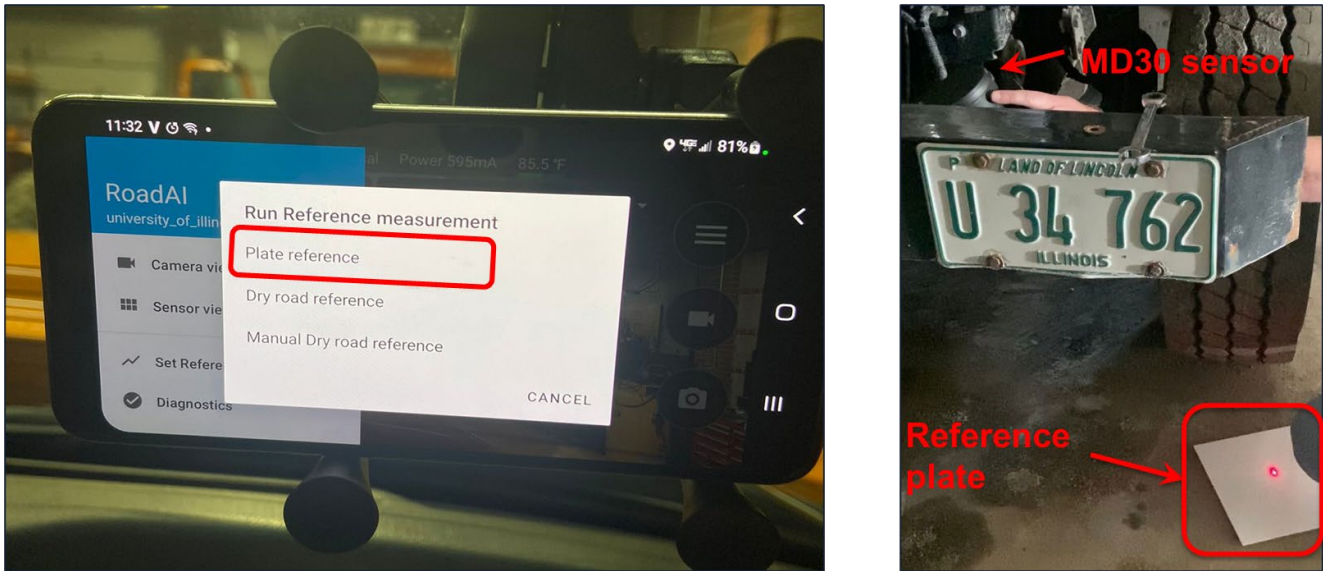


Figure 16. Photo. Calibration of Vaisala MD30 sensor.

Teconer Systems

The four Teconer systems were installed on three snowplows and one supervisor vehicle (Table 1). The Teconer system consists of two sensors (RTD411SA and RCM511) and an RCM phone app. The RTD411SA sensor measures the pavement surface temperature, relative humidity, and dew point temperature. The RCM511 sensor detects the pavement surface state (dry, moist, wet, slushy, snowy, icy) and measures water and ice layer thickness, which are used to calculate the friction coefficient. Installation of the three Teconer components was performed in three steps: (1) mounting the unit sensors, (2) setting up the unit RCM phone app, and (3) calibrating the unit.

Mounting of Teconer Systems

The Teconer system was mounted on the snowplows' front bumpers facing the wheel path using a magnetic fixture provided by the manufacturer (Figure 17). The Teconer system was mounted on the rear of the supervisor vehicle facing away from the vehicle exhaust using a ball-joint tow hitch and sensor arm provided by the manufacturer (Figure 18). The mounting height recommended for installing the Teconer system is between 22 and 36 in. from ground level with a maximum mounting

height of 48 in. The three Teconer systems were installed on snowplows at an average mounting height of 38.5 in., while the Teconer system was installed on the supervisor vehicle at a mounting height of 22 in. above ground level. The Teconer sensors on snowplows were connected directly to the vehicle key power supply using cable extensions. The Teconer sensors on the supervisor vehicle were connected to the trailer power supply on the tow hitch using their own cables without the need for extension.



Figure 17. Photo. Mounting position of Teconer sensors on a snowplow.



Figure 18. Photo. Mounting position of Teconer sensors on a supervisor vehicle.

Setting Up of RCM Phone App

This step focused on setting up the RCM phone app to transfer collected road and weather data by the sensors via Bluetooth to the RCM phone app for in-vehicle real time display. To evaluate the accuracy of the data collected by the sensor, a field test was conducted by pouring water on the ground to verify ice and water layer thickness measurements (Figure 19).

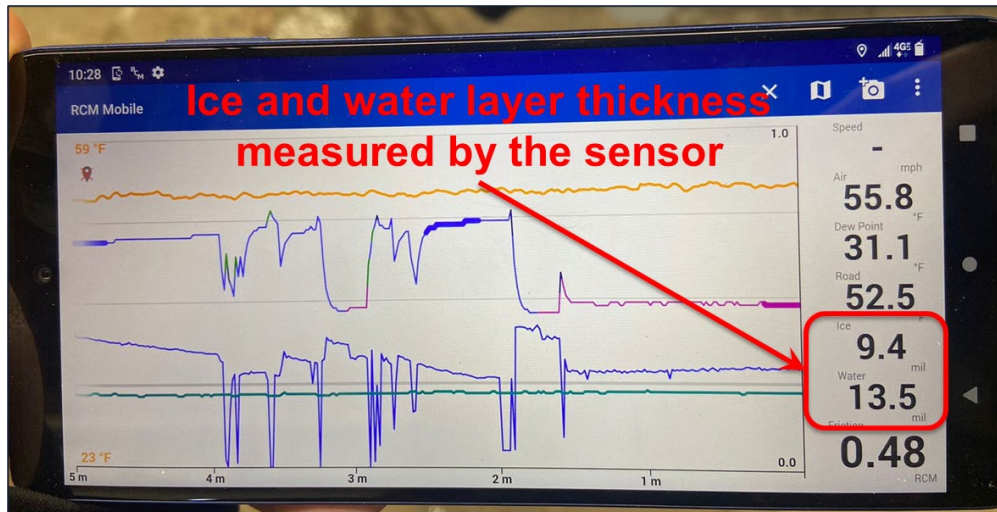


Figure 19. Photo. Verifying RCM phone app readings.

Calibration of Teconer Systems

This step focused on calibrating the RCM511 sensor to ensure the accuracy of its measurements after installation. Calibration was initiated from the phone application and performed by placing a manufacturer gray calibrator on the ground in the sensor's direct line of sight under natural light (Figure 20). The RTD411SA sensor should be calibrated by the manufacturer only if removed from its mounting position and mounted again at a height exceeding 48 in.



Figure 20. Photo. Calibration of Teconer system using gray calibrator.

Lufft MARWIS Units

The four Lufft MARWIS units were installed on three snowplows and one supervisor vehicle (Table 1). The Lufft MARWIS unit consists of a sensor, protective housing, and MARWIS iPad app. Installation of the units was performed in three steps: (1) mounting the unit sensor and protective housing, (2) setting up the unit MARWIS iPad app, and (3) calibrating the unit.

Mounting of Lufft MARWIS Units

The Lufft MARWIS unit was mounted on the front bumper of the snowplows, facing the wheel path (Figure 21). The Lufft MARWIS unit was mounted at the rear of the supervisor vehicle using a manufacturer-provided sensor arm attached to the tow hitch (Figure 22). Lufft MARWIS recommends the sensor mounting height to be within 6 ft from ground level. The three MARWIS units were installed on snowplows at an average mounting height of 40 in. The MARWIS units installed on snowplows were connected directly to the vehicle key power supply using manufacturer-supplied cables. The Lufft MARWIS unit was connected to the supervisor vehicle's trailer power supply at the tow hitch using the manufacturer-provided cables.



Figure 21. Photo. Mounting position of Lufft MARWIS unit on a snowplow.



Figure 22. Photo. Mounting position of Lufft MARWIS unit on a supervisor vehicle.

Setting Up MARWIS iPad App

This step focused on setting up the MARWIS iPad app to transfer road and weather data collected by the sensor via Bluetooth to the MARWIS iPad app for in-vehicle display. To evaluate the accuracy of data collected by the sensor, a field test was conducted by pouring water on the ground to verify that the reported road surface conditions changed from dry to wet.

Calibration of Lufft MARWIS Units

This step focused on calibrating the MARWIS sensor to ensure the accuracy of its measurements after installation. Calibration can be performed using the MARWIS app by setting up its configuration to specify the road surface type (asphalt or concrete), as shown in Figure 23.

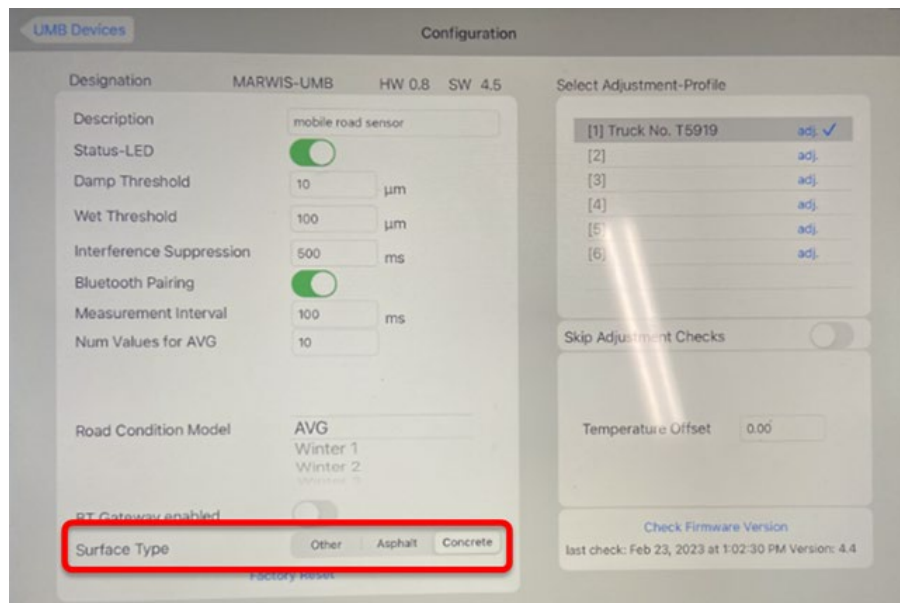


Figure 23. Photo. Configuration of road surface type in Lufft MARWIS.

CAPABILITIES AND ACCURACY OF MOBILE RWIS MODELS

This section compares the capabilities of the three mobile RWIS models used in collecting (a) road and surface conditions, including road surface condition, road surface temperature, water film height, ice percentage, friction, snow layer thickness, and ice layer thickness; (b) weather data, including ambient air temperature, dew point temperature, and relative humidity; and (c) location data, including latitude, longitude, altitude, speed, direction, travel distance, and map link to the manufacturer server. These capabilities vary depending on the type of mobile RWIS model, as shown in Table 5. For example, all mobile RWIS models can measure the friction, road surface temperature, and water film height as well as six road conditions (dry, wet, moist, slushy, snowy, and icy). Lufft MARWIS is the only model that can measure a seventh road condition: chemically wet. Similarly, Vaisala MD30 is the only model capable of measuring a road's snow layer thickness. The road's ice condition, on the other hand, can be measured by Vaisala MD30 and Teconer RCM511-RTD411SA using the ice layer thickness and by Lufft MARWIS using the ice percentage, as shown in Table 5.

Table 5. Capabilities of Mobile RWIS Models in Collecting Road and Weather Data

Mobile RWIS Model	Lufft MARWIS	Teconer RCM511-RTD411SA	Vaisala MD30
Road and Surface Conditions			
Road Condition	All seven conditions		
Dry		✓	✓
Wet		✓	✓
Moist		✓	✓
Slush		✓	✓
Snow		✓	✓
Ice		✓	✓
Chemically Wet			
Road Surface Temperature	✓	✓	✓
Friction	✓	✓	✓
Ice Percentage	✓		
Water Film Height	✓	✓	✓
Snow Layer Thickness			✓
Ice Layer Thickness		✓	✓
Weather Data			
Ambient Air Temperature	✓	✓	✓
Dew Point Temperature	✓	✓	✓
Relative Humidity	✓	✓	✓
Location Data			
Date and Time	✓	✓	✓
Roadway Images	✓	✓	✓
Latitude	✓	✓	✓
Longitude	✓	✓	✓
Altitude	✓	✓	
Speed	✓	✓	
Direction	✓	✓	
Travel Distance		✓	
Map Link			✓

The accuracy of the collected road and weather data by the three mobile RWIS models was also analyzed by comparing the collected mobile RWIS weather data to those reported by nearby fixed RWIS sites within approximately 10 miles. This comparison analysis was conducted by identifying the collected mobile RWIS air temperature, road temperature, dew point temperature, and relative humidity at the closest distance of an existing fixed RWIS site, as shown for the Teconer unit example in Figure 24. The comparisons between the collected weather data parameters are summarized in Tables 6, 7, and 8, respectively.

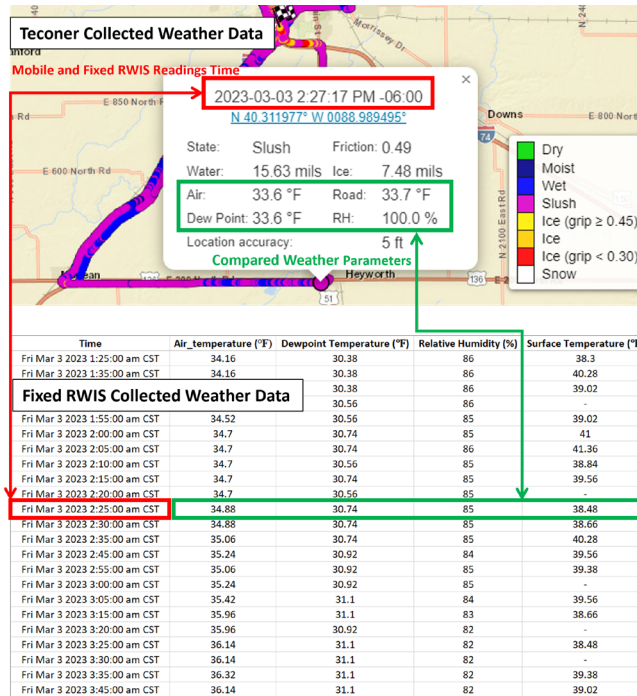


Figure 24. Screenshot. Comparison of collected weather data by Teconer unit and fixed RWIS site.

Table 6. Average Differences between Lufft MARWIS and Fixed RWIS Weather Data

Road Surface Temperature (°F)				
Data Point	Distance (miles)	Lufft MARWIS	Fixed RWIS	Difference (°F)
1	10.80	38.67	35.60	3.07
2	17.50*	40.86	39.20	1.66
Average Absolute Difference (°F)				2.36
Range of Absolute Difference (°F)				1.41
Air Temperature (°F)				
Data Point	Distance (miles)	Lufft MARWIS	Fixed RWIS	Difference (°F)
1	10.80	34.95	34.70	0.25
2	17.50*	38.51	34.88	3.63
Average Absolute Difference (°F)				1.94
Range of Absolute Difference (°F)				3.38
Dew Point Temperature (°F)				
Data Point	Distance (miles)	Lufft MARWIS	Fixed RWIS	Difference (°F)
1	10.80	38.73	33.98	4.75
2	17.50*	32.52	33.80	-1.28
Average Absolute Difference (°F)				3.02
Range of Absolute Difference (°F)				3.47
Relative Humidity (%)				
Data Point	Distance (miles)	Lufft MARWIS	Fixed RWIS	Difference (%)
1	17.50*	74.15	95.00	-20.85

*Due to the limited availability of close fixed RWIS sites to the Lufft MARWIS routes, an additional data point at 17.5 miles was included.

Table 7. Average Differences between Teconer RCM511-RTD411SA and Fixed RWIS Weather Data

Road Surface Temperature (°F)				
Data Point	Distance (miles)	Teconer RCM511-RTD411SA	Fixed RWIS	Difference (°F)
1	0.00	30.30	28.58	1.72
2	0.00	29.90	30.20	-0.30
3	0.00	19.30	21.38	-2.08
4	0.00	41.00	43.52	-2.52
5	0.32	33.70	33.98	-0.28
6	2.46	23.30	19.76	3.54
7	2.46	40.90	37.94	2.96
8	2.46	34.90	31.64	3.26
Average Absolute Difference (°F)				2.08
Range of Absolute Difference (°F)				3.26
Air Temperature (°F)				
Data Point	Distance (miles)	Teconer RCM511-RTD411SA	Fixed RWIS	Difference (°F)
1	0.00	30.90	29.30	1.60
2	0.00	30.90	28.76	2.14
3	0.00	14.90	17.42	-2.52
4	0.00	38.70	39.56	-0.86
5	0.32	33.60	33.44	0.16
6	2.46	24.30	17.06	7.24
7	2.46	40.50	35.60	4.90
8	2.46	37.60	31.10	6.50
Average Absolute Difference (°F)				3.24
Range of Absolute Difference (°F)				7.08
Dew Point Temperature (°F)				
Data Point	Distance (miles)	Teconer RCM511-RTD411SA	Fixed RWIS	Difference (°F)
1	0.00	25.20	26.78	-1.58
2	0.00	24.30	26.42	-2.12
3	0.00	5.90	10.58	-4.68
4	0.00	36.30	39.38	-3.08
5	0.32	33.60	32.54	1.06
6	2.46	24.10	8.96	15.14
7	2.46	38.30	33.80	4.50
8	2.46	32.90	24.62	8.28
Average Absolute Difference (°F)				5.05
Range of Absolute Difference (°F)				14.08
Relative Humidity (%)				
Data Point	Distance (miles)	Teconer RCM511-RTD411SA	Fixed RWIS	Difference (%)
1	0.00	79.00	91.00	-12.00
2	0.00	76.00	90.00	-14.00
3	0.00	66.90	74.00	-7.10
4	0.00	91.20	99.00	-7.80
5	0.32	100.0	97.00	3.00
6	2.46	99.30	70.00	29.30
7	2.46	91.90	93.00	-1.10
8	2.46	83.00	76.00	7.00
Average Absolute Difference (%)				10.16
Range of Absolute Difference (%)				28.20

Table 8. Average Differences between Vaisala MD30 and Fixed RWIS Weather Data

Road Surface Temperature (°F)				
Data Point	Distance (miles)	Vaisala MD30	Fixed RWIS	Difference (°F)
1	0	73.31	62.96	10.35
2	0	35.01	35.60	-0.59
3	1.92	65.07	63.32	1.75
4	10.91	31.12	30.20	0.92
5	10.91	25.90	30.00	-4.10
6	10.91	21.54	27.00	-5.46
7	10.91	27.84	30.40	-2.56
Average Absolute Difference (°F)				3.67
Range of Absolute Difference (°F)				9.76
Air Temperature (°F)				
Data Point	Distance (miles)	Vaisala MD30	Fixed RWIS	Difference (°F)
1	0	58.75	49.28	9.47
2	0	35.58	35.24	0.34
3	1.92	52.11	48.92	3.19
4	10.91	33.48	28.60	4.88
5	10.91	27.50	30.90	-3.40
6	10.91	18.50	14.00	4.50
7	10.91	28.98	29.10	-0.12
Average Absolute Difference (°F)				3.70
Range of Absolute Difference (°F)				9.35
Dew Point Temperature (°F)				
Data Point	Distance (miles)	Vaisala MD30	Fixed RWIS	Difference (°F)
1	0	36.19	37.04	-0.85
2	0	34.91	33.08	1.83
3	1.92	36.78	34.70	2.08
4	10.91	30.41	26.20	4.21
5	10.91	25.23	28.00	-2.77
6	10.91	10.59	9.00	1.59
7	10.91	27.60	26.60	1.00
Average Absolute Difference (°F)				2.05
Range of Absolute Difference (°F)				3.36
Relative Humidity (%)				
Data Point	Distance (miles)	Vaisala MD30	Fixed RWIS	Difference (%)
1	0	42.79	63.00	-20.21
2	0	97.38	92.00	5.38
3	1.92	55.74	58.00	-2.26
4	10.91	88.35	91.00	-2.65
5	10.91	91.04	89.00	2.04
6	10.91	70.73	77.00	-6.27
7	10.91	94.50	89.00	5.50
Average Absolute Difference (%)				6.33
Range of Absolute Difference (%)				18.17

The comparison analysis shows that the accuracy of the mobile RWIS models depends on the model, type of data, and distance between the mobile and fixed RWIS sites. For example, the average absolute difference between the collected road surface temperature by mobile and fixed RWIS was 2.36°F, 2.08°F, and 3.67°F for Lufft MARWIS, Teconer RCM511-RTD411SA, and Vaisala MD30, respectively, (Tables 6, 7, and 8). The range of absolute difference between the collected road surface temperature was 1.41°F, 3.26°F, and 9.76°F for Lufft MARWIS, Teconer RCM511-RTD411SA, and Vaisala MD30, respectively (Tables 6, 7, and 8). Similarly, the difference between the collected air temperature measurements varied based on the distance between the mobile and fixed RWIS locations (Tables 6, 7, and 8). Table 9 presents a summary of the difference between the collected mobile RWIS and fixed RWIS data. The least average absolute difference between the collected road surface temperature, air temperature, dew point temperature, and relative humidity were provided by Teconer RCM511-RTD411SA, Lufft MARWIS, Vaisala MD30, and Vaisala MD30, respectively.

Table 9. Average Absolute Difference between Mobile RWIS Models and Closest Fixed RWIS Sites

Road and Weather Data	Lufft MARWIS	Teconer RCM511-RTD411SA	Vaisala MD30
Road Surface Temperature (°F)	2.36	2.08	3.67
Air Temperature (°F)	1.94	3.24	3.70
Dew Point Temperature (°F)	3.02	5.05	2.05
Relative Humidity (%)	20.85	10.16	6.33

TRAINING OF IDOT WINTER MAINTENANCE OPERATIONS PERSONNEL

This task focused on providing training on the use of the installed mobile RWIS units and MDSS to winter maintenance operations personnel in each participating IDOT district.

Mobile RWIS Training

The research team coordinated with the mobile RWIS manufacturers/distributors to ensure that all identified IDOT personnel have sufficient training, manuals, and tools to effectively utilize the installed mobile RWIS units. Three online training sessions were organized on March 16 and 17, 2023, (see Table 10) that were attended by the research team, IDOT district representatives, and operations supervisors.

Table 10. Mobile RWIS Training Sessions Dates

Mobile RWIS Manufacturer	Training Session Date
Lufft MARWIS	March 16, 2023, at 12 p.m.
Teconer	March 16, 2023, at 2 p.m.
Vaisala	March 17, 2023, at 12 p.m.

The Lufft MARWIS training session was held on March 16, 2023, for 1 hour 15 minutes. This session provided training on the (1) Lufft MARWIS embedded sensors and measurement parameters, (2) unit setup and calibration, and (3) use of MARWIS iPad app and View Mondo interface to access the recorded road and weather data. The Teconer training session was held on March 16, 2023, for 56 minutes. This session provided training on the use of the Teconer online server for accessing road and weather data collected by sensors during each winter event. The Vaisala training session was held on

March 17, 2023, for 58 minutes. This session provided training on (a) MD30 sensor components and measurement parameters, (b) MD30 unit installation steps, (c) RoadAI phone app setup and usage, and (d) RoadAI online map user interface to access the MD30 data collected and check the devices' technical details.

MDSS Training

The DTN ClearPath Weather overview session was held on November 20, 2023, for 1 hour 40 minutes. This session provided training on the use of weather forecasting tools within MDSS and its provided maintenance recommendations to snowplow operators including guidance on maintenance type, material, application rate, and application start and end time, as shown in Figure 25 and 26. MDSS maintenance type provides recommendations on plow up/down (Figure 26). MDSS maintenance material specifies the type of treatment material such as prewet salt and salt brine (Figure 26). MDSS recommendations for application rate and time provide guidance on the quantity of treatment material in pounds per lane mile as well as the start and end time of treatment (Figure 26). These recommendations are identified by MDSS based on current and forecasted road and weather conditions as well as types of treatment material used in each district, as shown in the example of calcium treatment material in Table 11.

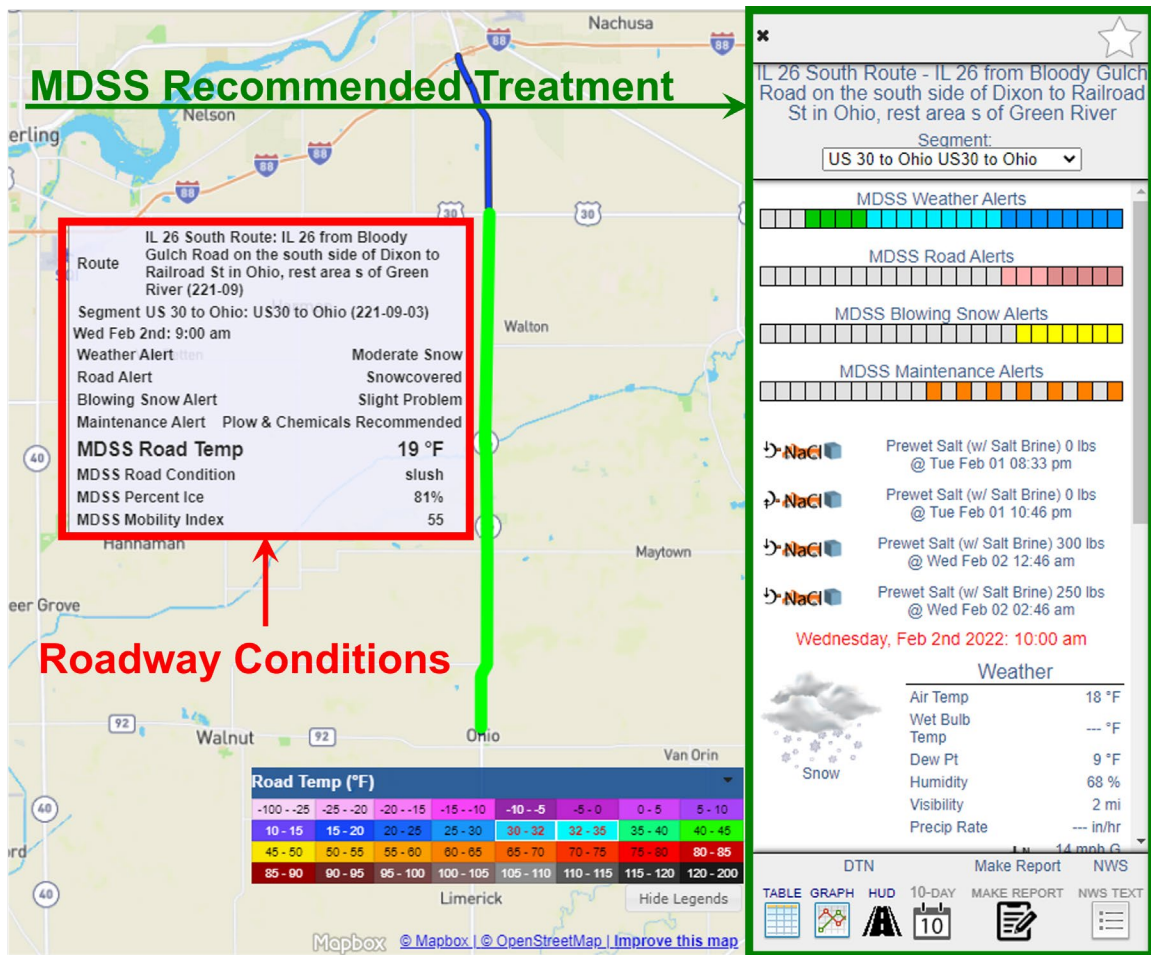


Figure 25. Screenshot. MDSS treatment recommendations.

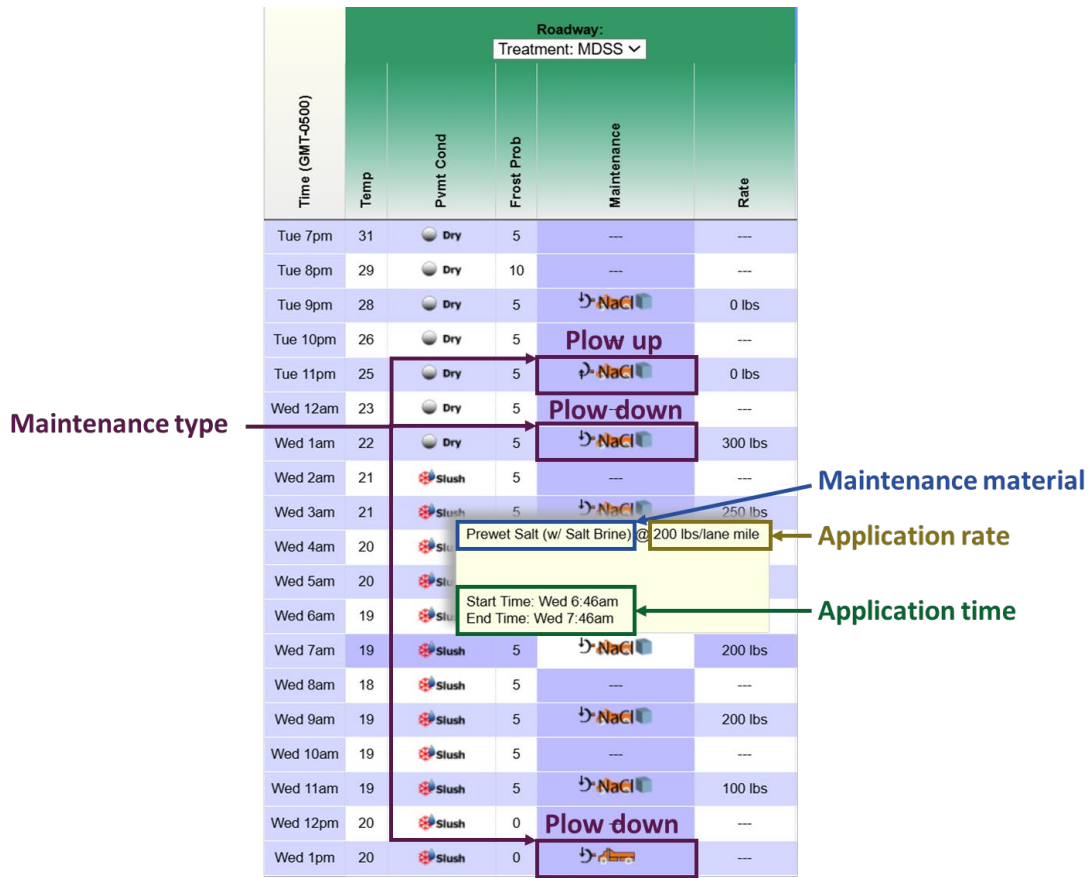


Figure 26. Screenshot. Example of MDSS treatment type, material, application rate, and time.

Table 11. Example of Calcium Treatment Material in District 2

Maintenance Material Name	Material 1 Prewet Rock Salt	Material 2 Prewet Rock Salt/CaCl ₂ flake 3:1	Material 3 Prewet Rock Salt/CaCl ₂ flake 1:1
Type	Prewet	Prewet	Prewet
Percent of Chemical	1	1	1
Percent of Grit	0	0	0
Prewet Chem.	Salt Brine	Salt Brine	Salt Brine
Rate of Prewet Application (gal/ton)	7-8 gal/ton	7-8 gal/ton	7-8 gal/ton
Max. Temp (°F)	35 and falling	20	10
Min. Temp (°F)	28	10	5
Minimum Application Rate (lb/ln-mi Dry/Prewet or gal/ln-mi Brine)	75	75	75
Average Application Rate (lb/ln-mi Dry/Prewet or gal/ln-mi Brine)	150	250	350
Maximum Application Rate (lb/ln-mi Dry/Prewet or gal/ln-mi Brine)	500	500	500

CHAPTER 4: SURVEY OF IDOT PERSONNEL

This chapter presents the findings of an online survey and follow-up interviews conducted to gather and analyze feedback from IDOT personnel in the three participating districts on their experiences using mobile RWIS units and MDSS during the 2022–23, 2023–24, and 2024–25 winter seasons. The following two sections highlight key procedures and results of the conducted surveys as well as follow-up interviews with IDOT operations supervisors.

SURVEY

The survey was designed following the best practices provided by the American Association for Public Opinion Research (AAPOR, 2023). The survey was developed in collaboration with the project’s Technical Review Panel (TRP) and was designed to take less than 15 minutes to complete. It was developed using an online surveying platform (Google Forms) to facilitate distribution and collection of survey data. A link to the online survey was emailed to each participating IDOT district. The appendix presents the full list of survey questions emailed to the three participating IDOT districts. The survey questions were grouped into six sections: (1) background of survey respondents, (2) use and effectiveness of mobile RWIS, (3) problems and challenges of mobile RWIS, (4) use and effectiveness of MDSS, (5) problems and challenges of MDSS, and (6) recommendations. The following sections summarize the findings of the six categories of the survey questions.

Survey Respondents

A total of 10, 17, and 12 complete survey responses were received from the three participating districts during the 2022–23, 2023–24, and 2024–25 winter seasons, respectively (Table 12). The reported job titles of the 39 survey respondents were field engineers, operations supervisors, and highway maintainers (Figure 27).

Table 12. Number of IDOT District Responses

Season	IDOT District	Number of Responses
2022–23	2	–
	5	8
	6	2
	Total	10
2023–24	2	8
	5	5
	6	4
	Total	17
2024–25	2	3
	5	3
	6	6
	Total	12
Total		39

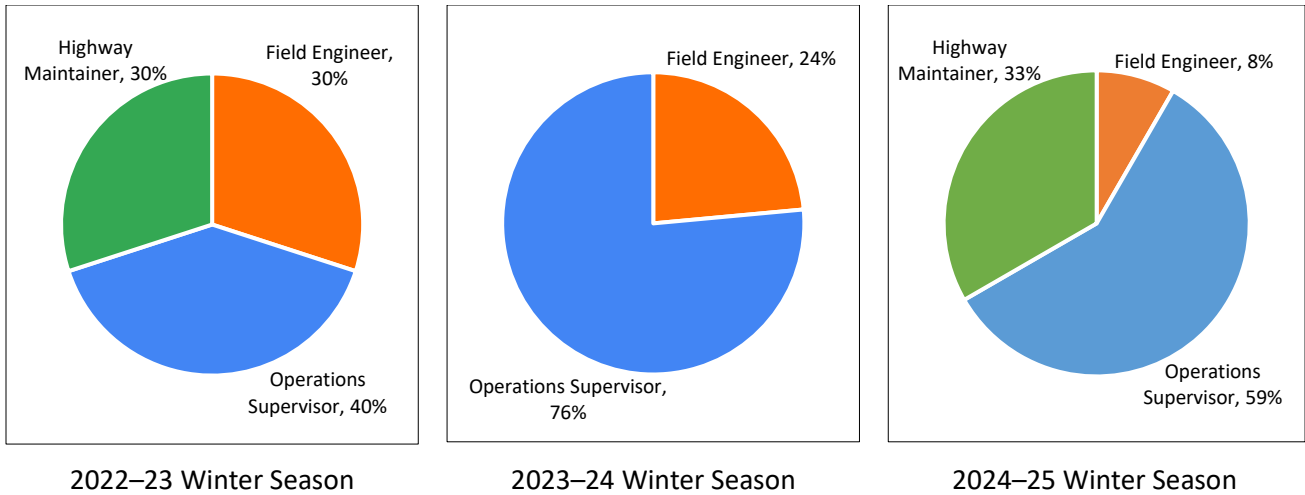


Figure 27. Chart. Job titles of IDOT district respondents.

Use and Effectiveness of Mobile RWIS

Respondents were asked to (1) identify the mobile RWIS model used in their district winter maintenance operations from a list of three mobile RWIS models (Lufft MARWIS, Teconer RCM511-RTD411SA, and Vaisala MD30) and (2) report their frequency of use from a list of four options: never, 1 to 2 times, 3 to 5 times, and more than 5 times. The percentages of respondents that reported using Lufft MARWIS during the 2022–23, 2023–24, and 2024–25 winter seasons were 0%, 11.8%, and 42%, respectively (Figure 28). The reported 0% use of the Lufft MARWIS units during the 2022–23 winter season was caused by a delay in their acquisition and installation during the first winter season of the study. Similarly, the percentage of respondents that reported using Teconer RCM511-RTD411SA during the 2022–23, 2023–24, and 2024–25 winter seasons were 20%, 5.9%, and 33%, respectively. The percentage of respondents that reported using Vaisala MD30 during the 2022–23, 2023–24, and 2024–25 winter seasons were 30%, 17.6%, and 33%, respectively (Figure 28).

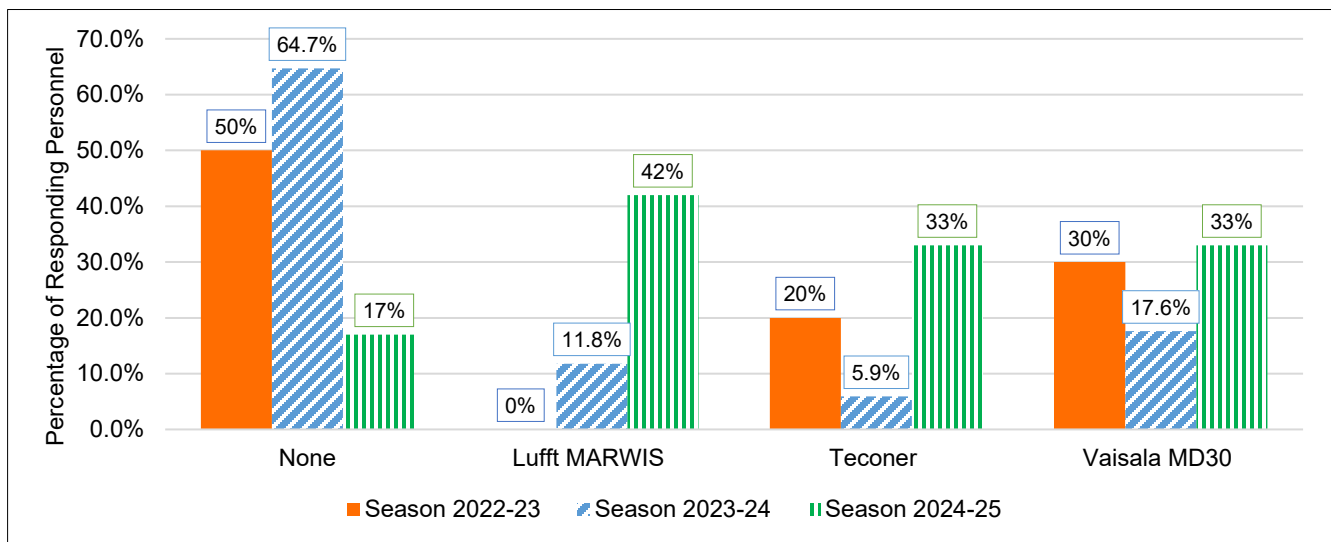


Figure 28. Graph. Percentage of IDOT personnel using mobile RWIS units.

The survey findings on the frequency of using mobile RWIS units indicate that the percentages of respondents who never used a mobile RWIS unit during the 2022–23, 2023–24, and 2024–25 winter seasons were 50%, 64.7%, and 17%, respectively (Figure 29). On the other hand, the percentages of respondents who used MDSS more than five times steadily increased over the three seasons: 0%, 17.6%, and 33% during the 2022–23, 2023–24, and 2024–25 winter seasons, respectively. The percentage of respondents who used it 1 to 2 times and 3 to 5 times are shown in Figure 29. Note that respondents who reported never using a mobile RWIS unit were not asked to provide answers to the remaining questions on the effectiveness and challenges of using mobile RWIS units.

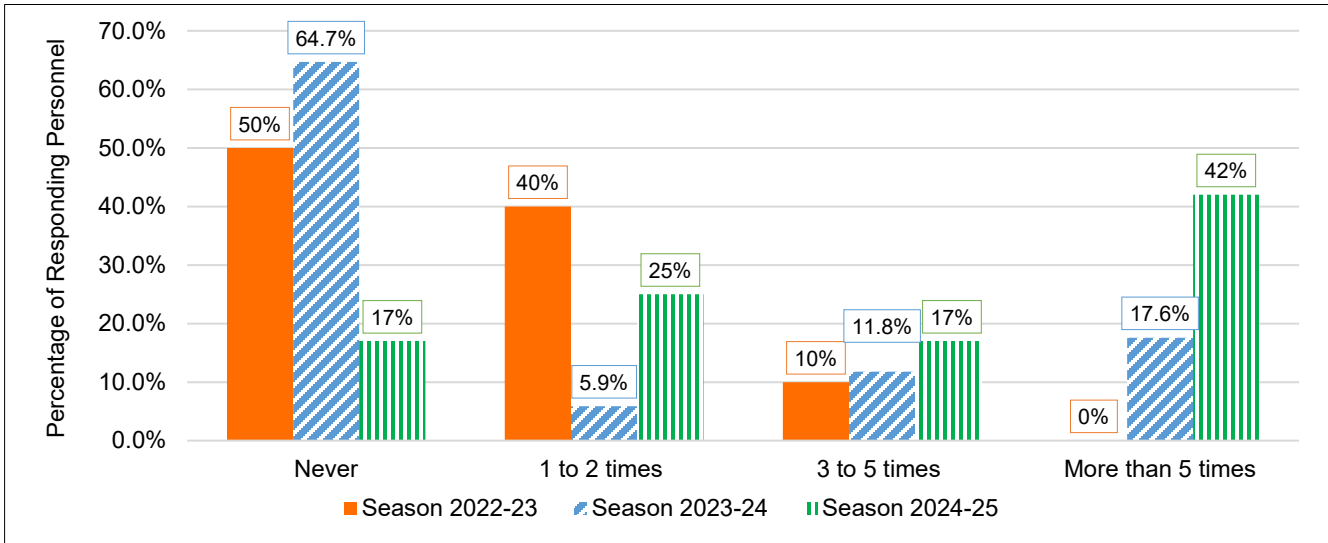


Figure 29. Graph. Frequency of using mobile RWIS units by responding IDOT personnel.

Respondents were asked to evaluate the effectiveness of mobile RWIS units in reducing the amount of salt/brine used in deicing and anti-icing operations, improving the level of service, shortening snow-removal duration, and decreasing working hours to prepare for winter events. Respondents were asked to rate the effectiveness of mobile RWIS units as “not effective,” “moderately effective,” “very effective,” or “not applicable.” To identify the average impact of mobile RWIS units, each reported benefit was represented numerically using a scale from 0 to 2, where 0 represents “not effective” and 2 represents “very effective.” A weighted average effectiveness of each mobile RWIS benefit was calculated. The top three reported mobile RWIS benefits by responding IDOT personnel during the 2023–24 and 2024–25 winter seasons are improving the level of service, reducing the amount of salt/brine use, and decreased working hours to prepare for winter events, as shown in Table 13 and Figure 30. Note that the reported benefits of mobile RWIS during the 2022–23 season were not included in this analysis because they were not statistically significant due to the limited survey responses on their use during that season.

Table 13. Effectiveness of Mobile RWIS Units

Mobile RWIS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable	Weighted Average
Winter Season	Three-point scale				
	0	1	2	–	0 to 2
Reduced salt/brine use					
2023–24	1	3	0	2	0.75
2024–25	1	5	1	3	1
Improved level of service					
2023–24	0	3	1	2	1.25
2024–25	2	4	2	2	1
Shorter snow removal duration					
2023–24	2	2	0	2	0.5
2024–25	5	2	1	2	0.5
Decreased working hours to prepare for winter events					
2023–24	0	4	0	2	1
2024–25	4	4	0	2	0.5

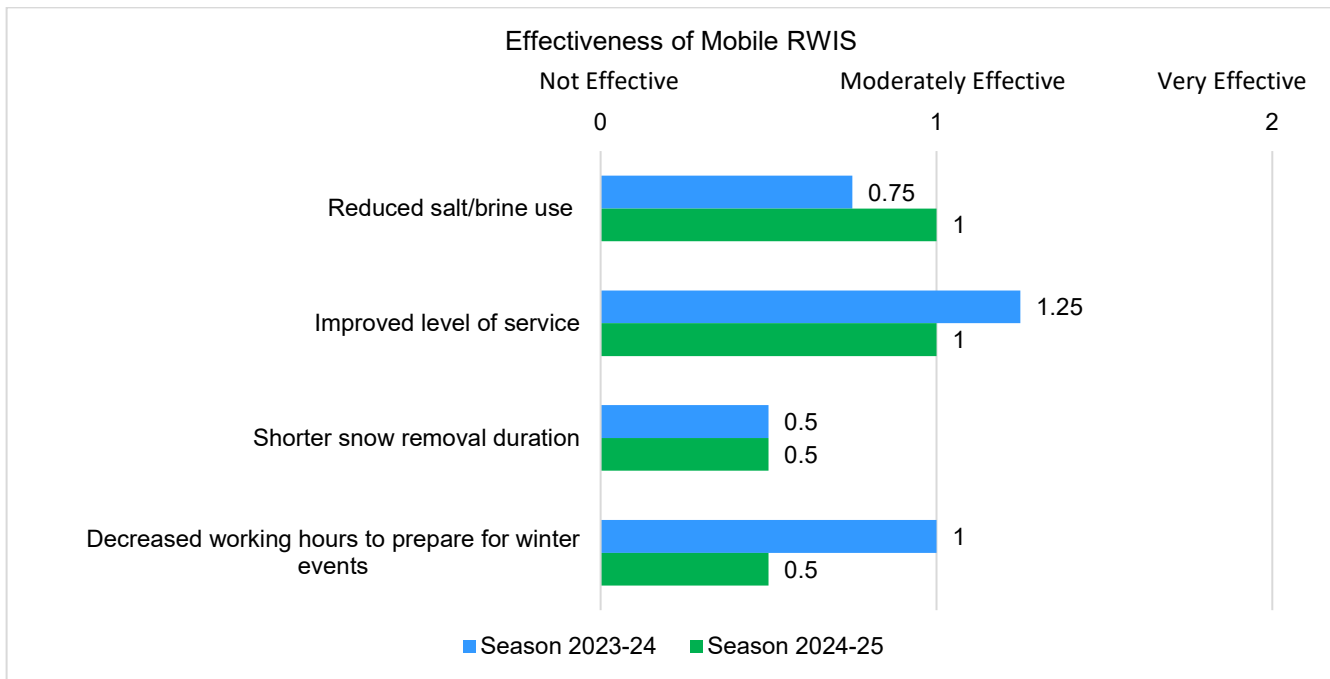


Figure 30. Graph. Effectiveness of mobile RWIS units.

During the 2024–25 season, respondents were asked to answer an additional question to compare the ease of use and practicality of using mobile RWIS models during the study period by rating each model as “most practical,” “moderately practical,” “least practical,” or “did not use this model.” To assess the average performance of each mobile RWIS model, each response was represented numerically using a scale from 1 to 3, where 1 represents “least practical,” 2 represents “moderately

practical,” and 3 represents “most practical.” A weighted average performance was calculated for each mobile RWIS model (Table 14). The responses for this question showed that the Lufft MARWIS model was reported to have the highest weighted average of 2.2, which is slightly higher than “moderately practical” in terms of its ease of use, followed by Vaisala MD30 and Teconer RCM511.

Table 14. Ease of Use and Practicality of Mobile RWIS Models

Ease of Use and Practicality	Least Practical	Moderately Practical	Most Practical	Did Not Use This Model	Weighted Average
Three-point scale	1	2	3	–	1 to 3
Lufft MARWIS	1	2	2	5	2.20
Teconer RCM511	2	3	0	5	1.60
Vaisala MD30	1	3	0	6	1.75

Respondents were also asked to evaluate the accuracy of readings for each mobile RWIS model using a similar approach to the one used in the previous question focusing on their practicality (Table 15). The Lufft MARWIS model was reported by IDOT personnel to have the highest weighted average of 2.4, which is between “moderately accurate” and “most accurate,” followed by Teconer RCM511 and Vaisala MD30.

Table 15. Accuracy of Readings of Mobile RWIS Models

Accuracy of Readings	Least Accurate	Moderately Accurate	Most Accurate	Did Not Use This Model	Weighted Average
Three-point scale	1	2	3	–	1 to 3
Lufft MARWIS	1	1	3	5	2.40
Teconer RCM511	1	4	0	5	1.80
Vaisala MD30	3	1	0	6	1.25

Additionally, respondents were asked to assess the overall effectiveness of each mobile RWIS model (Table 16). The Lufft MARWIS model was reported by IDOT personnel to have the highest weighted average of 2, which represents “moderately effective,” followed by Teconer RCM511 and Vaisala MD30.

Table 16. Overall Effectiveness of Mobile RWIS Models

Overall Effectiveness	Least Effective	Moderately Effective	Most Effective	Did Not Use This Model	Weighted Average
Three-point scale	1	2	3	–	1 to 3
Lufft MARWIS	1	3	1	5	2.00
Teconer RCM511	2	3	0	5	1.60
Vaisala MD30	3	1	0	6	1.25

Operational Challenges of Mobile RWIS

IDOT district personnel were asked to compare the three tested mobile RWIS models based on the frequency of challenges encountered while using each model using a three-point scale: none, moderately frequent, and very frequent. A weighted average was calculated for the frequency of

encountered challenges using a similar approach to the one described in the “Use and Effectiveness of Mobile RWIS” section, as shown in Table 17 and Figure 31. The evaluated operational challenges in this question were (1) calibration issues, (2) connection issues, (3) phone app/iPad issues, and (4) damaged unit during power washing.

For calibration issues, the Lufft MARWIS model had the highest weighed average frequency of 0.75, which is slightly below “moderately frequent,” followed by Teconer RCM511 and Vaisala MD30. Regarding connection issues, the Vaisala MD30 model had the highest weighed average frequency of 1.25, which is slightly above “moderately frequent,” followed by Teconer RCM 511 and Lufft MARWIS. Note that during the 2024–25 winter season reinstallation, two of the four Teconer units experienced connection issues and were returned to the manufacturer for repair. For phone app/iPad issues, the Vaisala MD30 model had the highest weighed average frequency of 0.75, which is slightly below “moderately frequent,” followed by Teconer RCM 511, while Lufft MARWIS reported no issues. For a damaged unit during power washing, the Vaisala MD30 model was reported to have a weighted average frequency of 0.25, while Lufft MARWIS and Teconer RCM511 had no reported occurrences.

Table 17. Frequency Mobile RWIS Units Encountered Challenges

Mobile RWIS Challenges	None	Moderately Frequent	Very Frequent	Not Applicable	Weighted Average
Three-point scale	0	1	2	–	0 to 2
Calibration issues					
Lufft MARWIS	2	1	1	6	0.75
Teconer RCM511	3	1	1	5	0.60
Vaisala MD30	2	1	0	7	0.33
Connection issues					
Lufft MARWIS	3	1	0	6	0.25
Teconer RCM511	3	0	2	5	0.80
Vaisala MD30	1	1	2	6	1.25
Phone app/iPad issues					
Lufft MARWIS	3	0	0	7	0.00
Teconer RCM511	4	1	0	5	0.20
Vaisala MD30	2	1	1	6	0.75
Damaged unit during power washing					
Lufft MARWIS	4	0	0	6	0.00
Teconer RCM511	5	0	0	5	0.00
Vaisala MD30	3	1	0	6	0.25

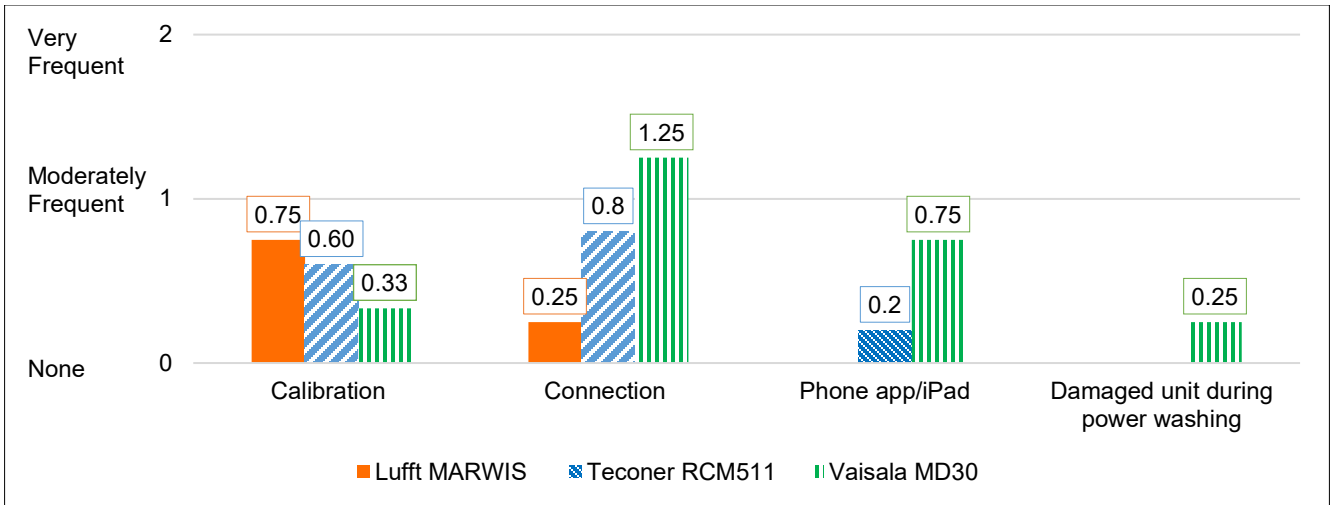


Figure 31. Graph. Average frequency that mobile RWIS units encountered challenges.

Use and Effectiveness of MDSS

Survey respondents were asked to provide feedback on the use of MDSS in their districts during the 2022–23, 2023–24, and 2024–25 winter seasons. IDOT personnel were asked to identify whether they used a mobile device or a desktop as an MDSS display and to report the frequency of using MDSS from a list of four options: never, 1 to 2 times, 3 to 5 times, and more than 5 times. The percentage of respondents that reported using MDSS on mobile devices during the 2022–23, 2023–24, and 2024–25 winter seasons were 30%, 24%, 33%, respectively (Figure 32). The percentage of respondents that reported using MDSS on desktops during the 2022–23, 2023–24, and 2024–25 winter seasons were 30%, 41%, and 25%, respectively (Figure 32).

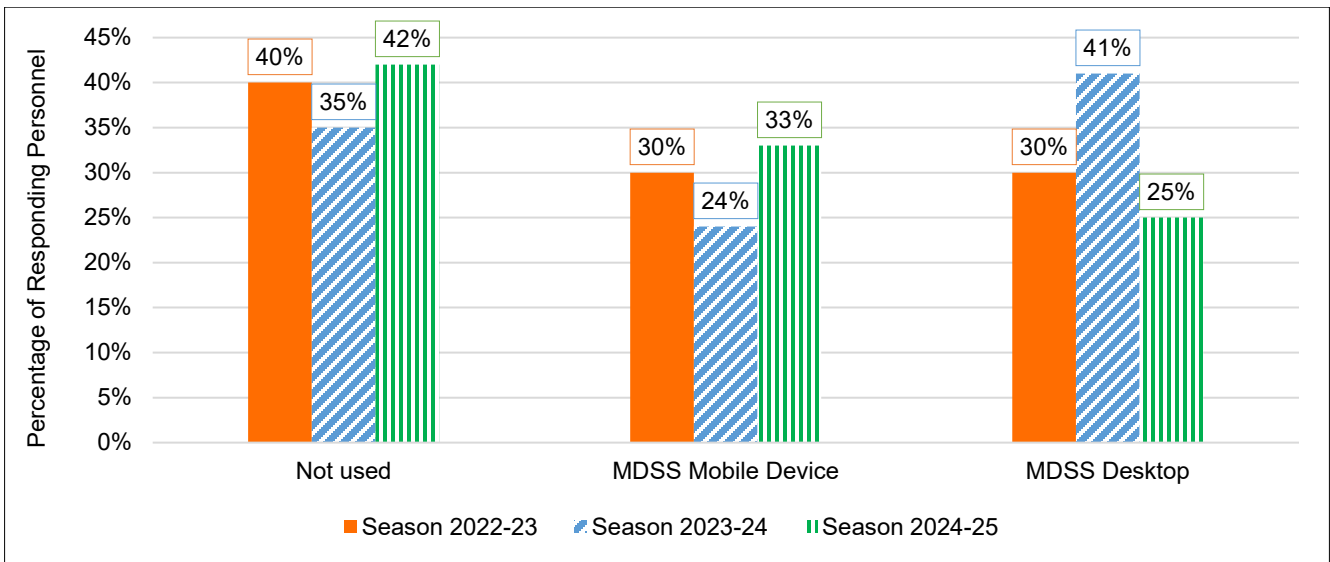


Figure 32. Graph. Percentage of IDOT personnel who used MDSS.

The survey findings on the frequency of MDSS use indicate that the percentage of respondents who never used MDSS during the 2022–23, 2023–24, and 2024–25 winter seasons were 40%, 35%, and 42%, respectively (Figure 33). On the other hand, the percentage of respondents who used MDSS more than 5 times during the 2022–23, 2023–24, and 2024–25 winter seasons were 20%, 41%, and 25%, respectively. The percentage of respondents who used it 1 to 2 times and 3 to 5 times are also shown in Figure 33.

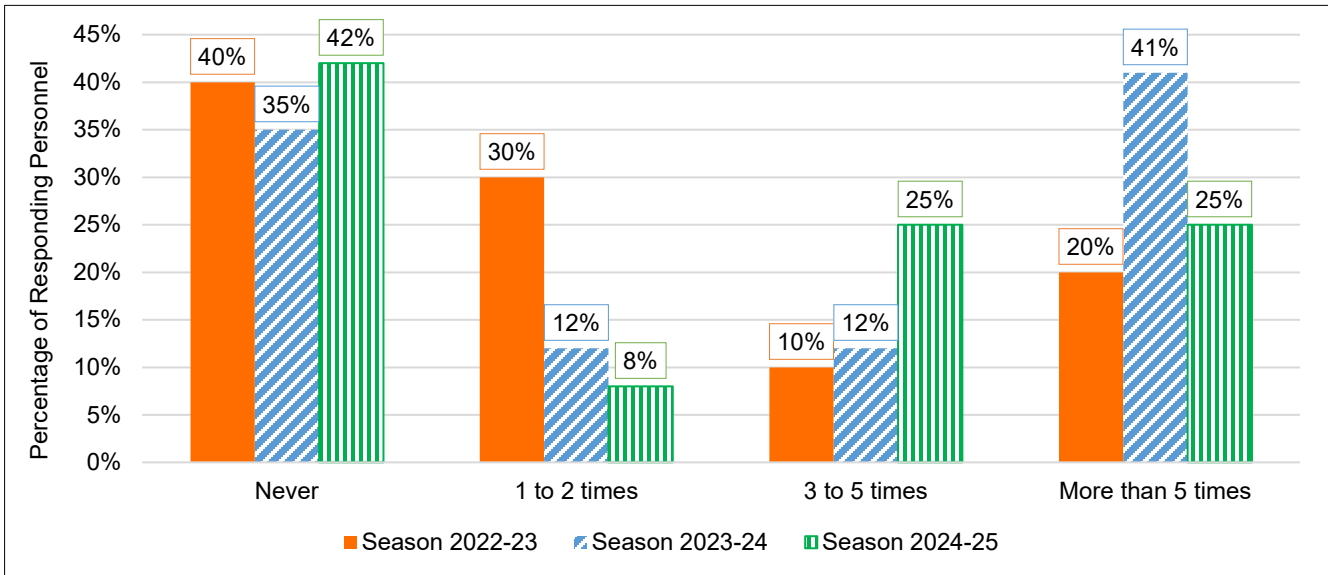


Figure 33. Graph. Frequency of MDSS use by responding IDOT personnel.

Respondents were asked to evaluate the effectiveness of MDSS in reducing the amount of salt/brine used in deicing and anti-icing operations, improving level of service, shortening snow-removal duration, decreasing working hours to prepare for winter, and enhancing fleet management during winter events. Respondents were asked to rate the effectiveness of MDSS as “not effective,” “moderately effective,” “very effective,” or “not applicable.” To identify the average impact of MDSS, each reported benefit was represented numerically using a scale from 0 to 2, where 0 represents “not effective” and 2 represents “very effective.” A weighted average effectiveness of each MDSS benefit was calculated (Table 18). The top three MDSS benefits that were reported to have the highest weighted average effectiveness by responding IDOT personnel across all three seasons are improving level of service, enhancing fleet management during winter events, and decreased working hours required to prepare for winter events, as shown in Table 18 and Figure 34.

Table 18. Weighted Average Effectiveness of MDSS

MDSS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable	Weighted Average
Winter Season	Three-point scale				0 to 2
	0	1	2	–	
Reduction in salt/brine					
2022–23	2	2	0	2	0.5
2023–24	1	5	1	4	0.5
2024–25	1	4	0	2	0.8
Improved level of service					
2022–23	1	3	0	2	0.75
2023–24	1	4	3	3	0.75
2024–25	1	5	1	0	1
Shorter snow removal duration					
2022–23	2	2	0	2	0.5
2023–24	1	6	1	3	0.5
2024–25	3	4	0	0	0.57
Decreased working hours to prepare for winter events					
2022–23	1	2	0	3	0.67
2023–24	1	5	2	3	0.67
2024–25	2	4	1	0	0.86
Better fleet management during winter events					
2022–23	1	2	0	3	0.67
2023–24	0	6	2	3	0.67
2024–25	1	4	1	1	1

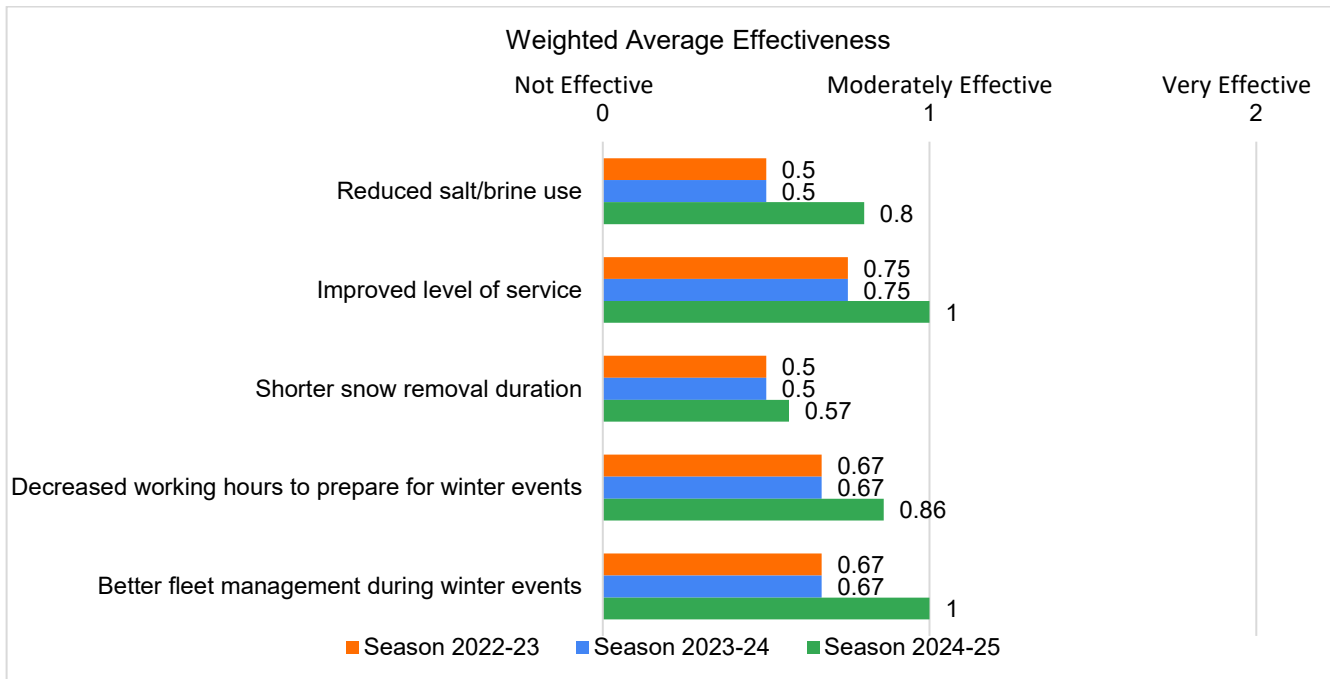


Figure 34. Graph. Effectiveness of MDSS.

Operational Challenges of MDSS

IDOT district personnel were asked to report the frequency of challenges encountered while using MDSS using a three-point scale: none, moderate, and very. The list of challenges included in the survey are inaccurate weather prediction, mobile app/desktop issues, excessive treatment recommendations, insufficient treatment recommendations, and/or other problems. A weighted average was calculated for the frequency of encountered challenges using a similar approach to the one described in the “Use and Effectiveness of MDSS” section. The top three MDSS challenges that were reported to have the highest weighted average frequency by respondents are inaccurate weather predictions, excessive treatment recommendations, and insufficient treatment recommendations (Figure 35).

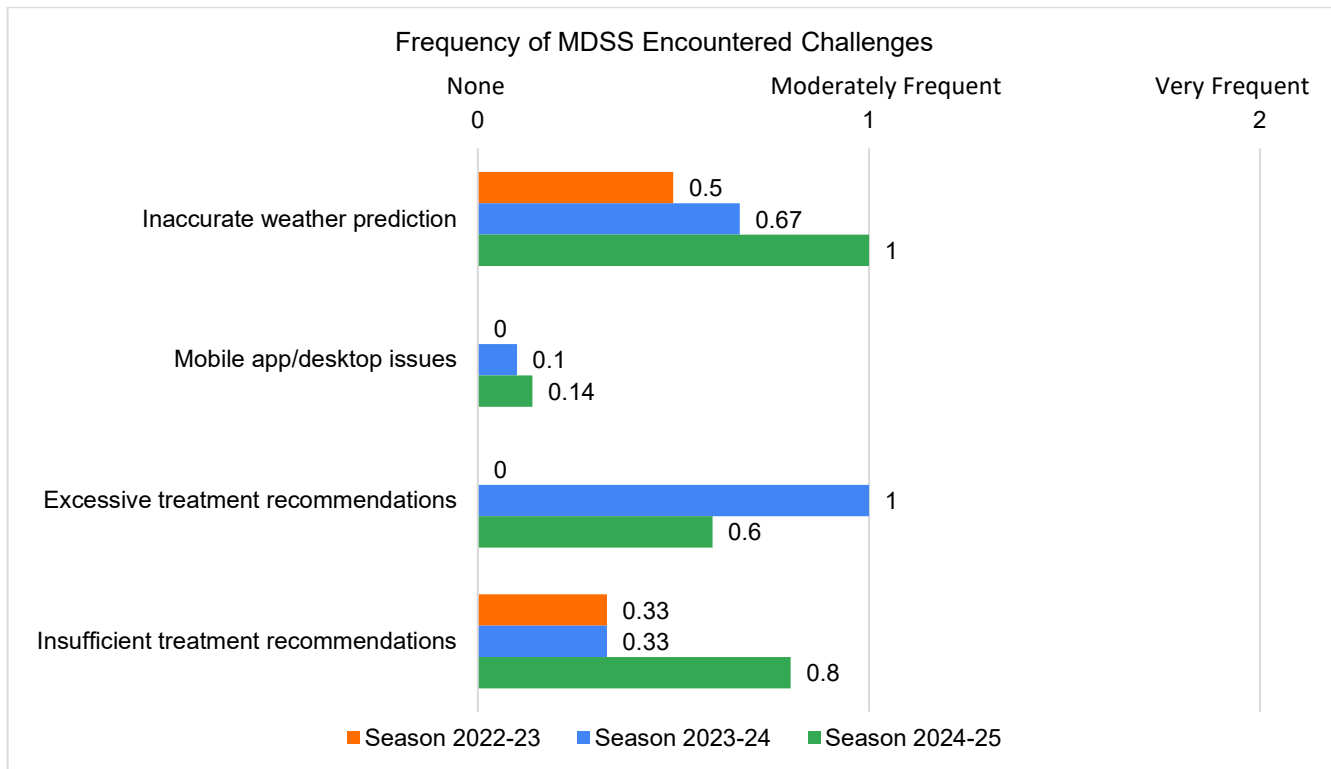


Figure 35. Graph. Frequency of MDSS encountered challenges.

Training Needs for Mobile RWIS and MDSS

Survey respondents were asked to report their need for more training on the use of mobile RWIS units and MDSS during the 2022–23 and 2023–24 winter seasons. During the 2022–23 season, 50% of responding IDOT personnel were interested in receiving training for the use of MDSS and mobile RWIS units, 30% were somewhat interested, and 20% were uninterested (Figure 36). In the 2023–24 season, 47% of responding IDOT personnel were interested in receiving training on the use of mobile RWIS units, 35% were somewhat interested, and 18% were uninterested, while for the use of MDSS, 53% were interested, 41% were somewhat interested, and 6% were uninterested (Figure 36).

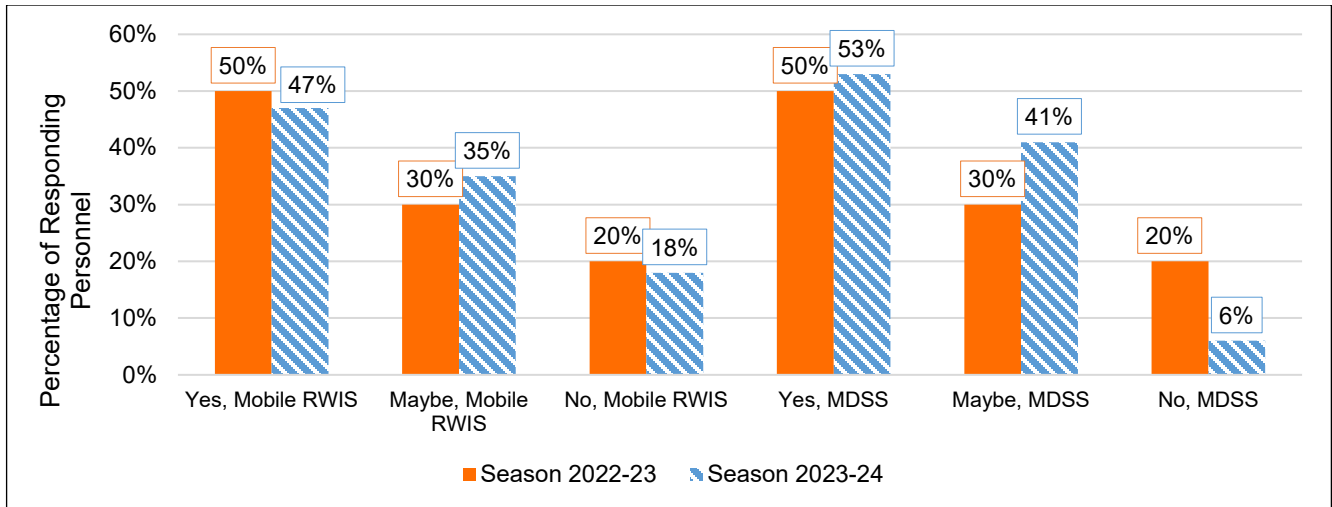


Figure 36. Graph. IDOT personnel interest in mobile RWIS and MDSS training.

FOLLOW-UP INTERVIEWS

In addition to the online survey, three interviews were conducted with operations supervisors from Districts 2 and 5 to collect feedback on their experience using mobile RWIS units and MDSS during the study period. The goal of these interviews was to complement the survey findings and provide more detailed assessment of the operational performance of the used mobile RWIS models and the MDSS system. The interviews were conducted using video conferencing software (Zoom Meetings) with each lasting approximately 30 to 45 minutes. Each interview consisted of 12 questions organized and grouped into two sections that focused on the use and effectiveness of mobile RWIS and MDSS (Table 19).

Table 19. Interview Questions for IDOT Operations Supervisors

1. Mobile RWIS
1.1. Are snowplow operators allowed to adjust salt applications rate based on mobile RWIS readings?
1.2. Did mobile RWIS affect your winter maintenance operations including salt usage, plowing frequency? If yes, how?
1.3. Do mobile RWIS friction readings affect your maintenance recommendations or you mainly rely on pavement temperature?
1.4. Have you noticed performance improvements in material usage or roadway grip between operators who used mobile RWIS and those who did not? What type of improvements?
1.5. Which mobile RWIS model provided overall better performance?
1.6. What is your assessment of mobile RWIS effectiveness in reducing salt amount and/or improving roadway grip?
a. Would you continue using it in future winters?
b. Would you recommend district wide deployment?
2. MDSS
2.1. How accurate are MDSS weather forecasts and recommendations compared to the actual road and weather conditions observed?
2.2. Did you follow MDSS recommendations for salt application rate?
a. If no, why?
b. If yes, did you apply the recommendations to nearby routes?
2.3. Does limited staffing affect your ability to utilize MDSS recommendations?
2.4. Do you recommend having an MDSS display in vehicle, or will it be a distraction for the operators?
2.5. What is your assessment of MDSS effectiveness in reducing salt amount and/or improving roadway grip?
a. Would you continue using it in future winters?
b. Would you recommend district wide deployment?
2.6. If you had to choose between mobile RWIS and MDSS, which do you prefer?

Mobile RWIS Use and Effectiveness

This section highlights the main findings of the conducted follow-up interviews with operations supervisors on the use and effectiveness of mobile RWIS in terms of salt rate adjustments, use of mobile RWIS readings, operational benefits, performance comparison, and preference between mobile RWIS and MDSS.

Salt Rate Adjustments

Supervisors were asked to report if snowplow operators are allowed to adjust the salt application rate based on mobile RWIS readings, and Table 20 summarizes their responses. All supervisors reported that operators are not authorized to make independent adjustments and any changes to application rates are implemented only after supervisor review and approval. One supervisor mentioned that this required approval process ensures consistency in application practices across all roads. Another supervisor noted that snowplow operators are hired seasonally and they often need additional training.

Table 20. Salt Application Rate Adjustments by Operators

Supervisor	Salt Rate Adjustment by Operators
Supervisor 1	Follow supervisor instructions; operators need more training
Supervisor 2	Must inform supervisor; stay consistent across all roads
Supervisor 3	Must call supervisor in advance

Mobile RWIS Readings

Supervisors were asked to report on the use of mobile RWIS readings in determining winter maintenance decisions, and Table 21 summarizes their responses. All supervisors reported that they primarily rely on pavement temperature in determining winter maintenance decisions. Two supervisors noted that ice thickness is critical for detecting slick road conditions, with one supervisor also using friction readings to check for slippery conditions. The third supervisor reported that he monitors the air temperature drop rate to anticipate corresponding changes in the pavement temperature and to determine the start time of treatment.

Table 21. Mobile RWIS Readings Use by Supervisors

Supervisor	Mobile RWIS Readings
Supervisor 1	Pavement temperature comes first, followed by ice indicators and friction readings to check for slippery conditions
Supervisor 2	Pavement temperature and ice film
Supervisor 3	Pavement temperature with monitoring of air temperature drop rate

Operational Benefits of Mobile RWIS

Supervisors were also asked to report on the operational benefits of deploying mobile RWIS units during winter maintenance operations, and Table 22 summarizes their responses. They reported several benefits, including reduced salt usage, enhanced treatment decision-making, workforce savings, and improved monitoring of critical locations such as bridges. In addition, all supervisors supported the continued use of mobile RWIS in future winters and district-wide deployment provided the units are used properly. One supervisor indicated that additional information about ice thickness, road condition, and friction would be helpful.

Table 22. Mobile RWIS Benefits Reported by Operations Supervisors

Supervisor	Reported Mobile RWIS Benefits	Use in Future Winters	District-Wide Deployment
Supervisor 1	Reduction in salt usage; facilitated treatment decisions	Yes	Yes
Supervisor 2	Manpower savings due to live readings	Yes	Yes
Supervisor 3	Improved level of service during icy events; enhanced bridge monitoring	Yes	Yes, if used properly

Comparison of Mobile RWIS Models

Supervisors were asked to compare the performance of mobile RWIS models used by their maintenance yards during the study period. One supervisor who used Vaisala MD30 and Teconer

RCM511 indicated both models performed comparably. This supervisor reported that connectivity issues and inaccurate readings were observed in both models, although the Vaisala unit was perceived to have better quality. The supervisor also raised concerns regarding the mounting location of the Teconer unit near the vehicle’s exhaust. Another supervisor who used both Teconer RCM511 and Lufft MARWIS reported a preference for the MARWIS unit due to its more user-friendly interface and reliable connectivity compared to the Teconer unit.

MDSS Use and Effectiveness

This section highlights the main findings of the follow-up interviews with operations supervisors on the use and effectiveness of MDSS in terms of accuracy of forecasts, use of recommendations, use of in-vehicle MDSS displays, and overall benefits.

Accuracy of Weather Forecasts

Supervisors were asked to report on the accuracy of MDSS weather forecasts compared to their field observations of road and weather conditions, and Table 23 summarizes their responses. Responses varied among supervisors, with two reporting that MDSS provided more accurate forecasts than other sources and reliable forecasts for two to three days. One supervisor reported that MDSS provided less accurate forecasts of hourly conditions, and another supervisor reported that they relied on alternative weather forecasting sources.

Use of Treatment Recommendations

Supervisors were also asked to report on the use of MDSS treatment recommendations, and Table 23 summarizes their responses. One supervisor stated that the recommendations were used as a baseline and adjusted based on field observations. The other two supervisors reported that the recommendations were not followed, primarily due to staffing constraints, with one maintenance yard operating at approximately 50% of its required staffing level.

Table 23. Reported Accuracy of MDSS Forecasts and Use of Treatment Recommendations

Supervisor	Reported Accuracy of MDSS Forecasts	Use of Treatment Recommendations
Supervisor 1	Relied on alternative sources	Not used
Supervisor 2	More accurate than other sources	Used as a baseline and adjusted based on conditions
Supervisor 3	Reliable for 2–3 days forecast; less accurate of hourly conditions	Not used

In-Vehicle MDSS Displays

Supervisors were asked to evaluate the need for in-vehicle MDSS displays in snowplow vehicles. All three supervisors reported that the utility of these displays depends on operator training, staffing levels, and interface simplicity. One supervisor expressed concern that in-cab displays could distract operators, particularly those with limited familiarity with technical devices. Another noted that tablet devices, such as iPads, were more practical and easier for operators to use than smartphones when using mobile RWIS units.

MDSS Benefits

Supervisors were asked to assess the effectiveness of MDSS in reducing salt usage and improving roadway snow coverage conditions and to indicate whether they would continue using the system in future winter seasons. Table 24 summarizes their responses. One supervisor noted that access to weather-related information through MDSS was beneficial for managing storms of varying scales and for anticipating when a storm might impact their area by monitoring conditions in nearby locations. Another supervisor reported that MDSS helped determine the timing of treatments, reducing salt loss on dry pavement, and highlighted the usefulness of weather forecasting for operational planning. One supervisor noted that the system facilitated quicker treatment decisions and helped recognize deteriorating road conditions early. All three supervisors reported they would continue using MDSS in future winters if available. Although they acknowledged that limited staffing hindered full utilization of MDSS recommendations during the study period, they reported the benefits of MDSS in providing weather forecasting for operational planning.

Table 24. MDSS Benefits Reported by Operations Supervisors

Supervisor	Reported Effectiveness	Use in Future Winters
Supervisor 1	Weather-related information provides value to operational decision-making	Yes
Supervisor 2	Helped with timing of treatments; prevented salt loss on dry pavement; forecasting was helpful	Yes
Supervisor 3	Facilitated quicker decision-making; helped recognize deteriorating road conditions early	Yes

Preference between Mobile RWIS and MDSS

Supervisors were also asked to share their preference between mobile RWIS and MDSS, and Table 25 summarizes their responses. One supervisor stated that mobile RWIS is more suitable for supervisors' real-time monitoring and MDSS is more useful for supporting snowplow operators. Another supervisor noted that mobile RWIS is more cost-effective but recommended using MDSS for interstate routes. The third supervisor reported that a combination of both systems provides benefits during winter storms, including accurate short-term weather forecasts and localized real-time readings of road temperature, air temperature, and ice thickness. This supervisor also noted that MDSS treatment recommendations are often not implemented due to limited staffing, and MDSS was primarily used for weather forecasts that can be obtained from alternative sources.

Table 25. Supervisors Reported Preference between Mobile RWIS and MDSS

Supervisor	Mobile RWIS	MDSS
Supervisor 1	Recommended for supervisor's real time monitoring	Recommended for snowplow operators
Supervisor 2	More cost-effective	Recommended for interstate routes
Supervisor 3	Provides helpful real-time localized road and weather parameters	Alternatives sources may be used for forecast since MDSS recommendations often not implemented due to limited staffing

CHAPTER 5: SALT USAGE ANALYSIS

This chapter focuses on evaluating the effectiveness of mobile RWIS units and MDSS in reducing salt usage during the 2023–24 and 2024–25 winter seasons. This task was performed in three steps: (1) collecting and comparing salt usage data of snowplows with and without mobile RWIS and MDSS during five analyzed storms in the 2023–24 winter season and seven analyzed storms in the 2024–25 winter season, (2) evaluating the overall effectiveness of all analyzed mobile RWIS units in reducing salt usage, and (3) analyzing the overall performance of MDSS in decreasing salt usage. The following sections describe the three analysis steps.

COLLECTION AND COMPARISON OF SALT USAGE DATA

This step focused on collecting and comparing salt usage data of snowplows with mobile RWIS and MDSS to those of snowplows with neither during the 2023–24 and 2024–25 winter seasons. Data were collected using Precise, a fleet management tool used by IDOT. The Precise system collects and stores detailed historical snowplow data including vehicle location, traveled routes, travel distance, salt distance, and salt usage. The Precise system collected all relevant data on salt usage by snowplows with and without mobile RWIS units as well as snowplows with and without MDSS to compare salt usage during all recorded snowstorms in the 2023–24 and 2024–25 winter seasons. For example, the Precise system was also used during seven snowstorms during the 2024–25 winter season to collect all relevant salt usage data for four snowplows with mobile RWIS, nine non-mobile RWIS snowplows, 12 MDSS snowplows, and two non-MDSS snowplows to compare their salt usage.

For each storm, salt usage data were collected and compared for multiple pairs of snowplows with and without mobile RWIS or MDSS that are operating on nearby routes with similar types and lane numbers. For example, salt usage data were collected and compared for one snowplow equipped with a Lufft MARWIS mobile RWIS unit (T57688) and another nearby snowplow with no mobile RWIS unit (T59509) with both operating on a two-lane route during the storm from February 12 to 13, 2025, as shown in Figure 37 and Table 26. The collection and comparison of salt usage data for this example was performed using six main steps, as shown in Figure 37.

Step 1: Identify a pair of snowplows with and without mobile RWIS unit/MDSS operating on nearby routes with a similar type of road and lane numbers, as shown in the example of a Lufft MARWIS unit in Table 26 and Figure 37.

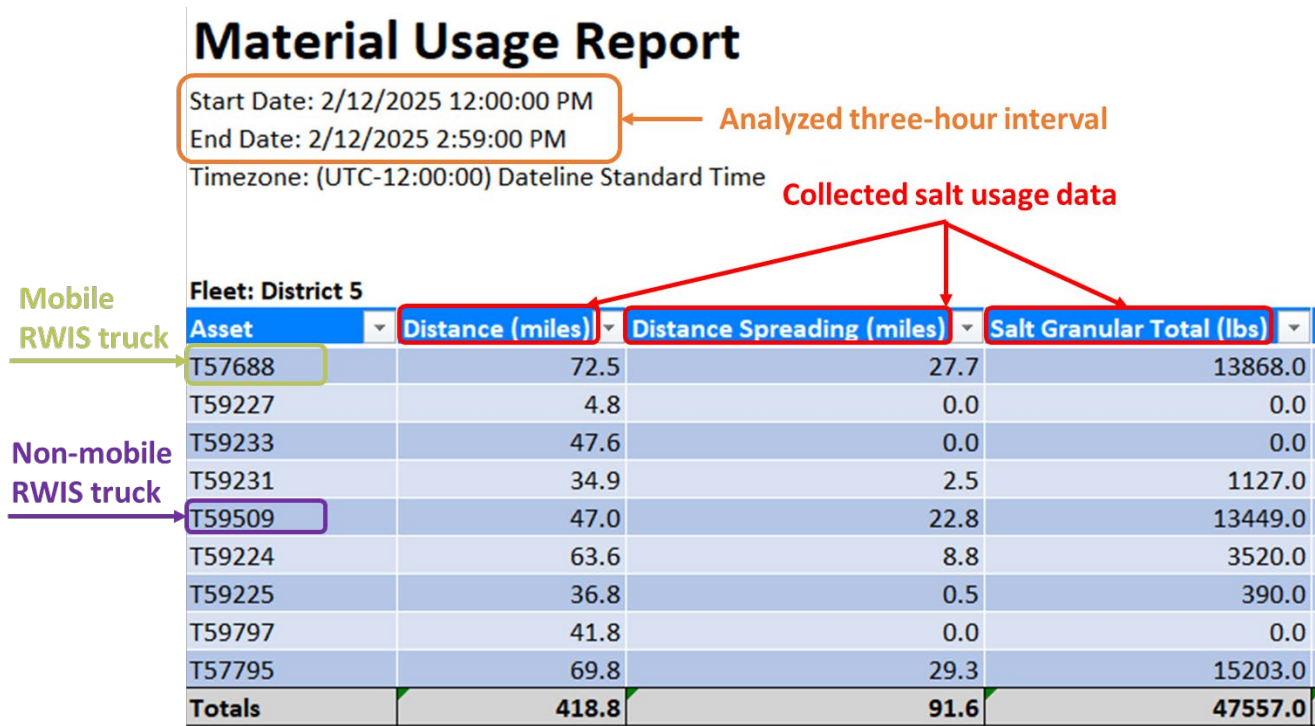


Figure 38. Screenshot. Collection of salt usage data from Precise for analyzed snowplows.

Step 3: Use the data collected in Step 2 to analyze the salt usage performance of both analyzed snowplows during each three-hour interval using three performance metrics: salt per travel distance rate, salt per salt distance rate, and salt distance to travel distance ratio.

- Salt per travel distance rate** is the ratio between the total amount of salt in pounds and travel distance in miles, and it represents the rate of applying salt per traveled mile. This metric can be used to represent the effectiveness of mobile RWIS units/MDSS in targeting road segments requiring salt application based on their real-time conditions collected by mobile RWIS units and/or recommendations provided by MDSS. For example, the salt per travel distance for the analyzed snowplows with and without mobile RWIS unit in Figure 37 from 12:00 p.m. to 3:00 p.m. on February 12, 2025, were 191.28 lb/mile and 286.15 lb/mile, respectively. In this example, the reduction in the salt per travel distance rate of the snowplow with mobile RWIS could be attributed to snowplow operators making more informed decisions on targeting salt application areas based on real-time road and weather data provided by the mobile RWIS unit.
- Salt per salt distance rate** is the ratio between the total amount of salt and salt distance, and it represents the rate of applying salt per mile of spreading salt. This metric can be used to evaluate the impact of mobile RWIS units/MDSS in adjusting salt application rates in response to real-time road conditions measured by the mobile RWIS unit. For example, the salt per salt distance for the analyzed snowplows with and without mobile RWIS unit in Figure 37 from 12:00 p.m. to 3:00 p.m. on February 12, 2025, were 500.65 lb/mile and 589.87 lb/mile, respectively. In this example, the relative reduction in the salt per salt distance rate of the

snowplow with mobile RWIS could be attributed to snowplow operators adjusting salt application rates based on real-time road and weather data provided by the mobile RWIS unit.

- **Salt distance to travel distance** is the ratio between the salt application distance of the snowplow and its travel distance. A lower ratio indicates salt is applied selectively only in needed areas rather than being dispersed continuously throughout the entire route segment. For example, the salt distance to travel distance ratio for the analyzed snowplows with and without a mobile RWIS unit in Figure 37 from 12:00 p.m. to 3:00 p.m. on February 12, 2025, were 38% and 49%, respectively.

Step 4: Identify outlier data points in the collected and calculated data that might have been caused by errors during the collection and storage of real-time salt usage. Three types of data outliers were identified: (1) salt distance cannot exceed travel distance, (2) total salt cannot be zero if the salt distance is a positive integer, and (3) salt per salt distance rate cannot exceed the maximum operational rate of 650 lb per salt mile. All outlier data points that did not comply with the first two criteria were excluded from the analysis. Other outlier data points that did not comply with the third criteria were adjusted to cap their salt per salt distance at the maximum operational rate of 650 lb/mile. For example, from 12:00 a.m. to 3:00 a.m. on February 13, 2025, the salt per salt distance rate exceeded this threshold of 650 lb/mile, so it was capped at 650 lb/mile, and the total salt and salt per travel distance were adjusted accordingly, as shown in Step 4 in Figure 37.

Step 5: Calculate the weighted average of the salt per travel distance rate and salt per salt distance rate over all the intervals ($i = 1$ to l) of the analyzed storm using Figure 39 and 40, respectively. Compute the salt distance to travel distance ratio during the entire analyzed storm using Figure 41.

$$\begin{aligned} & \text{Weighted average salt per travel distance rate} \\ &= \frac{\sum_{i=1}^l \text{travel distance}_i \times \text{salt per travel distance rate}_i}{\sum_{i=1}^l \text{travel distance}_i} \end{aligned}$$

Figure 39. Equation. Weighted average salt per travel distance rate calculation.

$$\text{Weighted average salt per salt distance rate} = \frac{\sum_{i=1}^l \text{Salt distance}_i \times \text{salt per salt distance rate}_i}{\sum_{i=1}^l \text{Salt distance}_i}$$

Figure 40. Equation. Weighted average salt per salt distance rate calculation.

$$\text{Average salt distance to travel distance ratio} = \frac{\text{Total salt distance}}{\text{Total travel distance}}$$

Figure 41. Equation. Average salt distance to travel distance ratio calculation.

The use of weighted averages provides a more accurate and representative assessment of the salt usage performance of both snowplows. Given the variability in salt and travel distances across the

three-hour intervals, using a weighted average ensures that intervals with greater distances have a larger impact on the overall average, while intervals with smaller distances contribute proportionally less. This approach accounts for the inconsistent salt usage in each three-hour interval, resulting in a more precise evaluation of overall performance.

Step 6: Calculate the percentage difference in salt per salt distance rate, salt per travel distance rate, and salt distance to travel distance ratio averages resulting from the use of a mobile RWIS unit or MDSS. A positive difference indicates reduced salt usage by snowplows with mobile RWIS units and/or MDSS that could be attributed to snowplow operators making more informed decisions on salt application time, location, and rate due to additional real-time roadway conditions provided by mobile RWIS units and/or salt recommendation rates provided by MDSS. For example, a 6% difference in salt per salt distance rate between the MARWIS snowplow and the non-mobile RWIS snowplow means that the mobile RWIS snowplow used 6% less salt compared to the non-mobile RWIS snowplow during the analyzed storm from February 12 to 13, 2025, as shown in Figure 37.

Note that the salt usage data collection and comparison in Figure 37 represents only one pairwise comparison example between a snowplow with a Lufft MARWIS and another with no mobile RWIS unit during a single storm from February 12 to 13, 2025. A similar analysis was conducted for 19 additional pairwise comparisons during the 2024–25 season and another 16 comparisons during the 2023–24 season between snowplows with other mobile RWIS models (Lufft MARWIS, Teconer RCM511-RTDA411SA, and Vaisala MD30) and nearby snowplows with no mobile RWIS units, as shown in Table 27 and 28.

MOBILE RWIS PERFORMANCE

A total of 36 pairwise comparisons were conducted to compare the salt usage of snowplows equipped with various mobile RWIS models and nearby snowplows without mobile RWIS units to evaluate the effectiveness of mobile RWIS units in reducing salt usage. These 36 pairwise comparisons included 16 comparisons during five storms in the 2023–24 season and 20 comparisons during seven storms in the 2024–25 season, as shown in Table 27 and 28.

During the 2023–24 winter season, the 16 pairwise comparisons indicated that the use of mobile RWIS units resulted in a 32% reduction in salt per travel distance rate, 8% reduction in salt per salt distance rate, and 12% reduction in salt distance to travel distance ratio compared to nearby snowplows without a mobile RWIS unit (Table 27). Similarly, the 20 pairwise comparisons conducted during the 2024–25 winter season indicated that the use of mobile RWIS units during the 2024–25 winter season resulted in an average reduction of 27% in salt per travel distance rate, 1% reduction in salt per salt distance rate, and 26% reduction in salt distance to travel distance ratio compared to nearby snowplows without a mobile RWIS unit (Table 28). Overall, across all 36 pairwise comparisons, the use of mobile RWIS units during the study period resulted in an average of 26% reduction in salt per travel distance rate, 2% reduction in salt per salt distance rate, and 18% reduction in salt distance to travel distance ratio compared to nearby snowplows without a mobile RWIS unit (Table 28). These reductions could be attributed to the real-time road and weather data provided by mobile RWIS units which enabled snowplow operators to make more informed decisions on salt application time,

location, and rate. These observed reductions in salt usage are consistent with the survey findings on the effectiveness of mobile RWIS, in which respondents identified reduced salt and brine use as the second top benefit of mobile RWIS units.

The results also revealed variability in performance across the three mobile RWIS models during the 2023–24 and 2024–25 seasons, as shown in Table 27 and 28. For example, the average reductions in salt per travel distance rate provided by snowplows with Lufft MARWIS, Teconer, and Vaisala during the 2023–24 season were 26%, 45%, and 18%, respectively (Table 27). During the 2024–25 season, the average reductions in salt per travel distance rate provided by snowplows with Lufft MARWIS, Teconer, and Vaisala were 17%, 50%, and 18%, respectively (Table 24). When aggregated across all analyzed storms in the 2023–24 and 2024–25 seasons, the reductions in salt per travel distance rate were 20%, 47%, and 17% for Lufft MARWIS, Teconer, and Vaisala, respectively (Table 27 and 28).

Table 27. Salt Usage Performance of Mobile RWIS Units During 2023–24 Winter Season

District	Storm Duration	Truck Number		Travel Distance (miles)		Salt Distance (miles)		Salt per Travel Distance Rate			Salt per Salt Distance Rate			Salt Distance/Travel Distance		
		Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Reduction	Non-Mobile RWIS	Mobile RWIS	Reduction	Non-Mobile RWIS	Mobile RWIS	Reduction
2	12-13 Jan	T59200	T59194 (Lufft)	819.6	530.3	439.5	268.6	195.4	75.9	61%	368.4	249.7	32%	54%	51%	6%
	5-7 Jan	T59200		191.7	375.8	119.6	231.9	222.3	209.7	6%	356.4	339.8	5%	62%	62%	1%
	21-23 Jan	T59200		584.8	596.7	403.5	329.2	293.0	236.4	19%	424.7	428.5	-1%	69%	55%	20%
Lufft MARWIS Average								234.4	173.1	26%	390.5	345.8	11%	62%	56%	9%
5	12-13 Jan	T59231	T57688 (Teconer)	589.9	609.7	228.8	141.5	98.9	53.5	46%	298.0	319.1	-7%	39%	23%	40%
	18-20 Jan	T59231		493	450.1	84.4	116.9	50.8	43.6	14%	442.4	304.1	31%	17%	26%	-52%
6	12-13 Jan	T59800	T59802 (Teconer)	506.6	1323.4	179.6	209.7	125.9	33.5	73%	391.1	211.3	46%	35%	16%	55%
	12-13 Jan	T57695	T57699 (Teconer)	488	220	113.3	14.9	84.6	17.2	80%	378.0	453.0	-20%	23%	7%	71%
	18-20 Jan	T57695		441.1	369.5	53.3	37.3	59.3	38.3	35%	492.9	504.1	-2%	12%	10%	16%
	5-7 Jan	T57695		361.2	129.1	123.7	48.3	112.9	46.8	59%	329.6	329.5	0%	34%	37%	-9%
21-23 Jan	T57695	682.2		507.4	320.8	161.6	165.5	165.4	0%	351.9	519.6	-48%	47%	32%	32%	
Teconer Average								103.4	56.7	45%	361.0	343.0	5%	30%	22%	27%
2	12-13 Jan	T59825	T59191 (Vaisala)	580.1	67.1	238	42.7	103.8	12.4	88%	378.1	308.9	18%	41%	64%	-55%
	18-20 Jan	T59827		358.7	486.2	209.6	238	244.6	149.3	39%	468.0	329.1	30%	58%	49%	16%
5	12-13 Jan	T59227	T59233 (Vaisala)	407.6	397.7	80.6	68.8	64.8	49.4	24%	461.7	478.6	-4%	20%	17%	13%
	8-9 Jan	T59225		239.7	272.6	90.9	60.5	150.7	102.8	32%	420.1	505.5	-20%	38%	22%	41%
	12-13 Jan	T59225	T59224 (Vaisala)	367.5	376.9	57.1	57.1	55.1	60.2	-9%	479.1	541.2	-13%	16%	15%	2%
	8-9 Jan	T57795	310.4	217.2	75.8	73.2	94.5	123.7	-31%	433.0	413.4	5%	24%	34%	-38%	
Vaisala Average								114.9	93.9	18%	430.4	400.1	7%	33%	34%	-2%
Average for 2023–24 Winter Season								135.1	91.7	32%	389.6	358.8	8%	37%	32%	12%

Table 28. Salt Usage Performance of Mobile RWIS Units during 2024–25 Winter Season

District	Storm Duration	Truck Number		Travel Distance (miles)		Salt Distance (miles)		Salt per Travel Distance Rate			Salt per Salt Distance Rate			Salt Distance/Travel Distance		
		Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Reduction	Non-Mobile RWIS	Mobile RWIS	Reduction	Non-Mobile RWIS	Mobile RWIS	Reduction
2	10-12 Jan	T59200	T59194 (Lufft)	167.4	103.7	53.7	57.4	112.1	92.4	18%	412.6	475.3	-15%	27%	19%	28%
	11-13 Feb	T59200		807.8	807.2	280.8	237.1	182.6	116.7	36%	405.2	400.5	1%	45%	29%	35%
	14-17 Feb	T59200		740.3	646.3	116.6	4.4	160.4	113.8	29%	369.1	305.5	17%	43%	37%	14%
5	12-15 Dec	T59509	T59688 (Lufft)	635	534.9	212.9	233.5	138.1	178.0	-29%	412.0	407.9	1%	34%	44%	-30%
	4-6 Jan	T59509		872.7	783.5	87.4	101.2	43.0	57.9	-34%	429.6	447.9	-4%	10%	13%	-29%
	10-12 Jan*	T59509		781.3	970.8	226.8	182.9	118.7	84.6	29%	408.8	449.2	-10%	29%	19%	35%
	12-13 Feb	T59509		551.4	643.9	196.2	175.8	160.7	116.0	28%	451.7	424.8	6%	36%	27%	23%
	14-17 Feb	T59509		620.3	672.8	124.7	154.1	73.7	78.5	-6%	366.8	342.8	7%	20%	23%	-14%
Lufft MARWIS Average								147.43	122.71	17%	416.78	420.6	-1%	26%	26%	0%
6	1-3 Dec	T57695	T57699 (Teconer)	97	136.6	23.3	18	73.9	44.3	40%	307.5	336.4	-9%	24%	13%	45%
	4-6 Jan	T57695		436	277.4	152.7	64.1	81.7	39.5	52%	460.8	462.9	0%	35%	23%	34%
	10-12 Jan	T57695		511.4	631.8	148.7	113.1	118.0	70.6	40%	405.7	394.3	3%	29%	18%	38%
	11-13 Feb	T57695		354.7	257.1	102.3	34.1	100.9	47.4	53%	349.9	357.0	-2%	29%	13%	54%
	14-17 Feb	T57695		288.5	391.4	148.6	100.6	187.7	88.1	53%	364.3	342.9	6%	52%	26%	50%
	17-19 Feb	T57695		466.8	541.5	61.5	13	58.2	9.2	84%	442.0	382.6	13%	13%	2%	82%
Teconer Average								102.22	50.66	50%	400.22	384.9	4%	30%	16%	47%
5	1-3 Dec	T57795	T59224 (Vaisala)	82.5	57.2	60.4	25.3	162.2	169.8	-5%	375.1	309.5	17%	32%	55%	-73%
	12-15 Dec	T57795		368.9	297.7	131.1	107.5	200.0	265.4	-33%	284.3	385.9	-36%	35%	29%	15%
	4-6 Jan	T57795		292.2	173.2	38.2	5.5	188.6	33.2	82%	317.6	86.7	73%	16%	1%	96%
	10-12 Jan	T57795		848.1	739.4	230.4	143.8	234.5	133.9	43%	320.3	302.7	5%	73%	44%	40%
	11-13 Feb	T57795		431.3	598.7	194.4	174.5	133.2	170.8	-28%	374.9	473.0	-26%	36%	36%	-2%
	14-17 Feb	T57795		476.4	541.2	207.1	201.6	26.8	4.1	84%	438.5	529.3	-21%	13%	3%	76%
Vaisala Average								130.66	107.60	18%	389.39	396.9	-2%	40%	28%	29%
Average for 2024–25 Winter Season								124.9	99.5	20%	386.0	397.2	-3%	32%	24%	24%
Overall Average for 2023–24 and 2024–25 Winter Seasons								129.2	96.3	26%	387.8	378.2	2%	34%	28%	18%

*For detailed calculations steps, see Figure 37.

MDSS PERFORMANCE

A total of 24 pairwise comparisons were conducted to compare the salt usage of snowplows with MDSS and nearby snowplows without MDSS to evaluate the effectiveness of MDSS in reducing salt usage using a procedure similar to the one described in the “Collection and Comparison of Salt Usage Data” section. These 24 pairwise comparisons included 15 comparisons during five storms in the 2023–24 season and 9 comparisons during seven storms in the 2024–25 season, as shown in Table 29 and 30, respectively.

During the 2023–24 winter season, the findings of the 15 pairwise comparisons indicated that the use of MDSS resulted in an average 3% reduction in salt per travel distance rate and a 1% increase in both the salt per salt distance rate and the salt distance to travel distance ratio compared to nearby snowplows without MDSS, as shown in Table 29. During the 2024–25 winter season, the findings of the nine pairwise comparisons indicated that the use of MDSS during that season did not result in reductions in salt usage (Table 30). MDSS trucks exhibited higher salt application rates compared to nearby non-MDSS trucks across all metrics: the salt per travel distance rate, salt per salt distance rate, and salt distance to travel distance ratio are higher by an average of 14%, 10%, and 6%, respectively (Table 30).

Note that the 2024–25 season results might not represent the impact of using MDSS on reducing salt usage because the three interviewed IDOT maintenance yard supervisors reported in the “Follow-Up Interviews” section in Chapter 4 that MDSS recommendations in the 2024–25 winter season were frequently not implemented due to limited snowplow operator staffing. Accordingly, the evaluation of MDSS effectiveness in reducing salt usage and the cost-effectiveness analysis presented in Chapter 6 are based only on the 2023–24 winter season performance.

Table 29. Salt Usage Performance of MDSS During 2023–24 Winter Season

District	Storm Duration	Truck Number		Travel Distance (miles)		Salt Distance (miles)		Salt per Travel Distance Rate			Salt per Salt Distance Rate			Salt Distance/Travel Distance		
		Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Reduction	Non MDSS Truck	MDSS Truck	Difference	Non MDSS Truck	MDSS Truck	Reduction
5	5-7 Jan	T57795	T59225	393.1	224.8	145	83.8	121.9	161.0	-32%	330.4	431.8	-31%	36.9%	37.3%	-1%
	8-10 Jan			346.8	253.5	75.7	90.7	94.6	150.7	-59%	433.6	421.1	3%	21.8%	35.8%	-64%
	12-13 Jan			399.8	501.1	39.8	57	41.2	54.6	-33%	413.6	480.0	-16%	10.0%	11.4%	-14%
	18-20 Jan			439.5	445.3	74	31.9	72.5	39.0	46%	430.8	545.1	-27%	16.8%	7.2%	57%
	21-23 Jan			538.3	546.6	232.3	220.5	156.5	168.4	-8%	362.7	417.4	-15%	43.2%	40.3%	7%
6	5-7 Jan	T59212	T59209	162.4	263.9	63.7	171.1	80.8	223.7	-177%	206.1	345.0	-67%	39.2%	64.8%	-65%
	8-10 Jan			650.5	289.4	102.8	55.7	49.3	74.7	-52%	311.8	388.3	-25%	15.8%	19.2%	-22%
	12-13 Jan		T59804	748	1155	120.2	119.7	48.6	53.0	-9%	302.2	490.1	-62%	16.1%	10.4%	36%
	18-20 Jan			544.1	381.2	34.5	43.9	21.2	55.2	-160%	334.8	478.9	-43%	6.3%	11.5%	-82%
	21-23 Jan			717.7	439.8	408	354.4	171.7	202.8	-18%	302.1	251.6	17%	56.8%	80.6%	-42%
6	5-7 Jan	T57697	T57695	147.2	383	109.1	130.3	292.7	113.3	61%	394.9	333.2	16%	74.1%	34.0%	54%
	8-10 Jan			352.8	272.1	4.5	1.7	7.0	4.1	42%	549.6	650.0	-18%	1.3%	0.6%	51%
	12-13 Jan			407.7	1155	70.6	140.8	75.1	49.2	34%	433.6	403.8	7%	17.3%	12.2%	30%
	18-20 Jan			473.9	441.1	110.3	53.3	99.2	59.6	40%	426.1	492.9	-16%	23.3%	12.1%	48%
	21-23 Jan			606.3	682.2	250.3	320.8	209.1	165.5	21%	506.4	351.9	31%	41.3%	47.0%	-14%
Average for 2023–24 Winter Season								98.1	94.7	3%	369.2	373.9	-1%	28.0%	28.3%	-1%

Table 30. Salt Usage Performance of MDSS During 2024–25 Winter Season

District	Storm Duration	Truck Number		Travel Distance (miles)		Salt Distance (miles)		Salt per Travel Distance Rate			Salt per Salt Distance Rate			Salt Distance/Travel Distance		
		Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Non MDSS Truck	MDSS Truck	Difference	Non MDSS Truck	MDSS Truck	Difference	Non MDSS Truck	MDSS Truck	Difference
5	1-3 Dec	T57795	T59227	89.4	215.4	60.4	52.7	216.38	100.58	54%	320.26	411.12	-28%	68%	24%	64%
	12-15 Dec			368.9	277.5	131.1	84.7	102.75	127.28	-24%	374.87	475.15	-27%	36%	31%	14%
	4-6 Jan		T59225	686	759.3	42.2	34.7	28.21	28.27	0%	458.51	618.65	-35%	6%	5%	26%
	10-12 Jan			848.1	870	230.4	253.8	112.08	134.04	-20%	412.57	459.47	-11%	27%	29%	-7%
	11-13 Feb			437.2	478.2	194.4	114.1	180.17	112.95	37%	405.20	473.39	-17%	44%	24%	46%
	14-17 Feb			476.4	291.5	207.1	150.2	160.44	219.25	-37%	369.07	425.51	-15%	43%	52%	-19%
6	1-3 Dec	T59212	T59804	116.1	28.7	13.6	10.7	38.08	74.91	-97%	325.07	200.93	38%	12%	37%	-218%
	11-13 Feb			474.7	390.7	134.9	173.7	58.87	140.33	-138%	263.66	315.64	-20%	28%	44%	-56%
	14-17 Feb			294.3	238.6	119	183.9	130.88	228.29	-74%	323.68	296.19	8%	40%	77%	-91%
Average for 2024–25 Winter Season								104.91	119.56	-14%	367.67	405.63	-10%	34%	36%	-6%

CHAPTER 6: COST-EFFECTIVENESS OF MOBILE RWIS AND MDSS

This chapter focuses on assessing the cost-effectiveness of all tested mobile RWIS units and MDSS in improving winter maintenance operations on Illinois roads during the 2023–24 and 2024–25 winter seasons. The assessment evaluates their life cycle costs, including initial and operating costs, as well as realized savings resulting from reduced salt usage. The following two sections summarize the cost-effectiveness results for both mobile RWIS units and MDSS.

MOBILE RWIS

This section evaluates the cost-effectiveness of mobile RWIS units during the 2023–24 and 2024–25 winter seasons. The evaluation was conducted in three steps: (1) quantifying annual cost savings generated by the reduction in salt usage by snowplows equipped with mobile RWIS units, (2) calculating the initial and operational costs of the three tested mobile RWIS unit models, and (3) analyzing their cost-effectiveness using three financial performance metrics (net present value, payback period, and return on investment).

Mobile RWIS Salt Savings

The performance of mobile RWIS models in reducing salt usage was assessed based on the findings presented in the “Mobile RWIS Performance” section. It reported that the deployment of mobile RWIS units resulted in reductions in salt per travel distance that ranged from 17% to 47% based on a mobile RWIS model, as shown in Tables 31, 32, and 33. Annual salt savings (SS_i) of each of the three mobile RWIS unit models i can be estimated as the product of multiplying (1) average percentage reduction in the salt per travel distance rate (R_i) of each mobile RWIS unit model i , (2) average amount of salt (S) in tons used by a snowplow at the state or district levels, and (3) unit cost rate of salt (C), as shown in Figure 42.

$$SS_i = R_i \times S \times C$$

Figure 42. Equation. Annual salt savings calculation.

Where

- R_i is the average percentage reduction in the salt per travel distance rate of each mobile RWIS unit model i .
- S is the average amount of salt used by a snowplow at the state or district levels (tons).
- C is the unit cost rate of salt (\$/ton).

The three parameters in Figure 42 were estimated based on the following assumptions. First, the average percentage reduction in the salt per travel distance rate (R_i) of each mobile RWIS unit model i was estimated based on its performance during all the analyzed storms of the 2023–24 and 2024–25 winter seasons (Table 31, 32, and 33).

Table 31. Lufft MARWIS Salt Usage Performance During 2023–24 and 2024–25 Winter Seasons

Winter Season	District	Storm Duration	Truck Number		Travel Distance (miles)		Total Salt (lb)		Salt per Travel Distance Rate		
			Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Reduction (R)
2023–24	2	12-13 Jan	T59200	T59194 (Lufft)	819.6	530.3	161920	67079	195.4	75.9	61%
		5-7 Jan	T59200		191.7	375.8	42623	75153	222.3	209.7	6%
		21-23 Jan	T59200		584.8	596.7	171365	141056	293.0	236.4	19%
2024–25	5	12-15 Dec	T59509	T59688 (Lufft)	212.9	233.5	87709	95237	138.1	178.1	-29%
		4-6 Jan	T59509		87.4	101.2	37549	45326	43.0	57.8	-34%
		10-12 Jan	T59509		635	534.9	92710	82162	118.7	84.6	29%
		11-13 Feb	T59509		872.7	783.5	88622	74687	160.7	116.0	28%
		14-17 Feb	T59509		781.3	970.8	45743	52824	73.7	78.5	-6%
	2	10-12 Jan	T59200	T59194 (Lufft)	167.4	103.7	16603	16706	162.2	169.8	-5%
		11-13 Feb	T59200		807.8	807.2	104118	120465	200.0	265.4	-33%
		14-17 Feb	T59200		740.3	646.3	51930	2860	188.6	33.2	82%
	Lufft MARWIS Average									170.9	136.0

Table 32. Teconer Salt Usage Performance During 2023–24 and 2024–25 Winter Seasons

Winter Season	District	Storm Duration	Truck Number		Travel Distance (miles)		Total Salt (lb)		Salt per Travel Distance Rate		
			Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Reduction (R)
2023–24	6	12-13 Jan	T59800	T59802 (Teconer)	506.6	1323.4	37339	35550	125.9	33.5	73%
		12-13 Jan	T57695	T57699 (Teconer)	488	220	70247	44319	84.6	17.2	80%
		18-20 Jan	T57695		441.1	369.5	26271	18804	59.3	38.3	35%
		5-7 Jan	T57695		361.2	129.1	40776	15915	112.9	46.8	59%
		21-23 Jan	T57695		682.2	507.4	112902	83974	165.5	165.4	0%
	5	12-13 Jan	T59231	T57688 (Teconer)	589.9	609.7	42824	6750	98.9	53.5	46%
18-20 Jan		T59231	493	450.1	68174	45146	50.8	43.6	14%		
2024–25	6	1-3 Dec	T57695	T57699 (Teconer)	97	136.6	7164	6055	73.9	44.3	40%
		4-6 Jan	T57695		436	277.4	70364	29674	81.7	39.5	52%
		10-12 Jan	T57695		511.4	631.8	60334	44596	118.0	70.6	40%
		11-13 Feb	T57695		354.7	257.1	35793	12174	100.9	47.4	53%
		14-17 Feb	T57695		288.5	391.4	54140	34497	187.7	88.1	53%
		17-19 Feb	T57695		466.8	541.5	27184	4974	58.2	9.2	84%
Teconer Average									102.9	54.4	47%

Table 33. Vaisala Salt Usage Performance During 2023–24 and 2024–25 Winter Seasons

Winter Season	District	Storm Duration	Truck Number		Travel Distance (miles)		Total Salt (lb)		Salt per Travel Distance Rate		
			Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Non-Mobile RWIS	Mobile RWIS	Reduction (R)
2023–24	2	12-13 Jan	T59825	T59191	580.1	67.1	89986	13191	103.8	12.4	88%
		18-20 Jan	T59827	(Vaisala)	358.7	486.2	98096	78315	244.6	149.3	39%
	5	12-13 Jan	T59227	T59233	407.6	397.7	37211	32929	64.8	49.4	24%
		8-9 Jan	T59225	(Vaisala)	239.7	272.6	38190	30580	150.7	102.8	32%
		12-13 Jan	T59225	T59224	367.5	376.9	27385	30903	55.1	60.2	-9%
		8-9 Jan	T57795	(Vaisala)	310.4	217.2	32820	30264	94.5	123.7	-31%
2024–25	5	1-3 Dec	T57795	T59224 (Vaisala)	82.5	57.2	19344	7658	234.5	133.9	43%
		12-15 Dec	T57795		368.9	297.7	49145	50851	133.2	170.8	-28%
		4-6 Jan	T57795		292.2	173.2	16750	2911	26.8	4.2	84%
		10-12 Jan	T57795		848.1	739.4	95055	68343	112.1	92.4	18%
		11-13 Feb	T57795		431.3	598.7	78771	69880	182.6	116.7	36%
		14-17 Feb	T57795		476.4	541.2	76434	61595	160.4	113.8	29%
Vaisala Average									123.1	101.7	17%

A weighted average amount of salt (S) used by a snowplow in the three participating districts was estimated using their reported salt usage data during the 2023–24 and 2024–25 winter seasons (Table 34). For each district, an average salt usage per snowplow was calculated based on its reported total salt usage and number of snowplows in the two winter seasons. For example, in District 2, a total of 171 snowplows applied 43,893 tons of salt in the 2023–24 season and 46,351 tons in the 2024–25 season, which corresponds to an average application rate of approximately 256.7 and 271.1 tons per snowplow, respectively, resulting in a two-season average of 263.9 tons (Table 34). These two-season average salt usage per snowplow were then used to calculate a weighted average salt usage of 194.3 tons per snowplow in the three districts using a salt usage weight (Table 34). This salt usage weight for each district was calculated as the ratio between its two-season average and the sum of all averages in the three districts (Table 34). This weighting approach accounts for the higher impact of districts with larger salt usage per snowplow.

Table 34. District Salt Usage in 2023–24 and 2024–25 Winter Seasons

District	Number of Snowplows*	Salt Usage (Tons)*		Salt Usage per Snowplow			Salt Usage Weight
		2023–24	2024–25	2023–24	2024–25	Two-Season Average	
2	171	43,893	46,351	256.7	271.1	263.9	0.55
5	164	21,223	18,130	129.4	110.5	120.0	0.25
6	208	22,915	17,926	110.2	86.2	98.2	0.20
Weighted Average Salt Usage per Snowplow (Tons)						194.3	

*Data obtained from Illinois Department of Transportation FY26 (2025-2026) Winter Weather Fact Sheet (IDOT, 2026a).

The salt unit cost rate (C) was calculated in two steps: (a) calculating a two-season average salt unit cost rate for each district based on their reported cost data during the 2023–24 and 2024–25 winter seasons, and (b) estimating a weighted average salt unit cost rate in the three participating districts of

\$89.45 per ton using a weighted average approach similar to the one described in the previous section (Table 35).

Table 35. District Salt Unit Cost Rate in 2023–24 and 2024–25 Winter Seasons

District	Salt Unit Cost (\$/Ton)		
	2023–24*	2024–25*	Two-Season Average
2	\$92.54	\$83.29	\$87.92
5	\$96.08	\$86.22	\$91.15
6	\$93.56	\$89.46	\$91.51
Weighted Average Salt Unit Cost (\$/Ton)			\$89.45

*Data obtained from Illinois Department of Transportation (FY18-FY26) Statewide County-Level Salt Cost History Dataset (IDOT, 2026b)

Based on these assumptions, the average annual salt savings of the three tested mobile RWIS models were calculated (Table 36). The results of this analysis show that Teconer provides the highest annual savings of \$8,169.00, followed by Lufft at \$3,476.17, and Vaisala at \$2,954.74 based on the three aforementioned assumptions (Table 36).

Table 36. Annual Salt Savings for Mobile RWIS Models Based on 2023–24 Winter Season Salt Usage

Mobile RWIS Model	Reduction in Salt per Travel Distance Rate (R)	Salt Usage per Snowplow (S)	Salt Unit Cost Rate (C)	Annual Savings (\$S)
Lufft	20%	194.3	89.45	\$3,476.17
Teconer	47%	194.3	89.45	\$8,169.00
Vaisala	17%	194.3	89.45	\$2,954.74

Mobile RWIS Costs

A total of 12 mobile RWIS units were purchased from three manufacturers at an initial cost of approximately \$102,242, as shown in Table 37. Based on the assumption that the unit’s expected service life was seven years, their operational costs were calculated and combined with the annualized purchase costs to estimate the total annual cost for each mobile RWIS unit model. Operational costs include annual cellular service charges calculated based on their monthly rates of \$41.71 for iPads and \$48.86 for smartphones. In addition, Vaisala units require an annual subscription fee of \$1,091.20 per unit. When both purchase and operational costs are added, the total annualized cost per unit is \$1,507.98 for Lufft, \$2,176.03 for Teconer, and \$2,770.41 for Vaisala, as shown in Table 38.

Table 37. Mobile RWIS Units Initial Cost

Mobile RWIS Model	Unit Cost	Quantity	Total Cost
Lufft	\$7,052.19	4	\$27,128.76
Teconer	\$11,128.00	4	\$44,512.00
Vaisala	\$7,650.25	4	\$30,601.00
Total		12	\$102,241.76

Table 38. Mobile RWIS Units Annual Cost

Mobile RWIS Unit Model	Annualized Purchase Cost (7 years)	Annual Cellular Service Charges	Annual Subscription Cost	Total Annual Cost
Lufft	\$1,007.46	\$500.52	–	\$1,507.98
Teconer	\$1,589.71	\$586.32	–	\$2,176.03
Vaisala	\$1,092.89	\$586.32	\$1091.20	\$2,770.41

Mobile RWIS Cost-Effectiveness Evaluation

The cost-effectiveness of each mobile RWIS unit model was evaluated using three financial performance metrics (net present value, payback period, and return on investment).

Net Present Value

The net present value (NPV) accounts for the time value of money by discounting future benefits and costs over the assumed service life of the mobile RWIS units. NPV is calculated as the sum of the discounted difference between annual salt savings and annual operational costs over the analysis period (Figure 43). A positive NPV indicates the benefits of the mobile RWIS investment exceed its costs, whereas a negative NPV indicates the costs outweigh the benefits.

$$NPV = \sum_{t=1}^n \frac{S_t - C_t}{(1 + r)^t} - C_0$$

Figure 43. Equation. Net present value calculation.

Where

- S_t is the annual salt savings in year t .
- C_t is the operational cost in year t .
- C_0 is the initial investment cost.
- r is the discount rate.
- n is the mobile RWIS unit lifespan.

Payback Period

The payback period represents the time required for the initial investment cost to be recovered through net annual savings calculated using the equation in Figure 44.

$$PB = \frac{C_0}{S_a - C_a}$$

Figure 44. Equation. Payback period calculation.

Where

- C_0 is the initial investment cost.
- S_a is the annual salt savings.
- C_a is the annual operational cost.

Return on Investment

The return on investment (ROI) was used to assess the overall profitability of mobile RWIS units over their estimated lifespan. ROI was calculated as the ratio of the net benefits defined as total savings minus total operational costs and the initial investment cost to the initial investment cost (Figure 45).

$$ROI = \frac{\sum_{t=1}^n (S_t - C_t) - C_0}{C_0}$$

Figure 45. Equation. Return on investment calculations.

Where

- S_t represents the salt savings in year t .
- C_t represents the operational cost in year t .
- C_0 is the initial investment cost.
- n is the assumed service life of the mobile RWIS unit.

Using the financial metrics described above and the salt savings calculated in Table 36, the economic performance of the three mobile RWIS models were calculated and compared based on a lifespan of 7 years and a discount rate of 3%, as shown in Table 39. The Teconer mobile RWIS unit provided the best overall cost-effectiveness performance with the highest NPV of \$36,114.23, shortest payback period of 1.47 years, and the highest ROI of 377%. The Lufft MARWIS unit provided the second-best cost-effectiveness performance with a NPV of \$11,486.95, payback period of 2.37 years, and ROI of 195%. The Vaisala unit exhibited the lowest cost-effectiveness performance with a NPV of \$307.22, a payback period of 5.99 years, and ROI of 17%.

Table 39. Mobile RWIS Units Models Cost-Effectiveness Based on Statewide Salt Usage

Mobile RWIS Unit Model	Initial Cost	Annual Operational Cost	Annual Salt Savings (SS)	NPV	Payback Period	ROI
Lufft	\$7,052.19	\$500.52	\$3,476.17	\$11,486.95	2.37	195%
Teconer	\$11,128.0	\$586.32	\$8,169.00	\$36,114.23	1.47	377%
Vaisala	\$7,650.25	\$1,677.52	\$2,954.74	\$307.22	5.99	17%

Mobile RWIS Sensitivity Analysis

A sensitivity analysis was conducted for each mobile RWIS unit model to analyze the sensitivity of its cost-effectiveness to variations in annual salt usage that may vary based on the severity of winter

season and the specific district in Illinois. Variations in salt usage per snowplow in this analysis were represented by 10 ton increments while maintaining the average percentage reduction in the salt per travel distance rate (*R*) of each RWIS unit model calculated based on its performance during all the analyzed storms of the 2023–24 and 2024–25 winter seasons. This approach quantifies how changes in salt usage per snowplow affect annual salt savings, NPV, payback period, and ROI. In addition, this analysis identifies threshold salt-usage levels at which the investment becomes economically viable, highlighting the conditions under which each mobile RWIS unit model unit generates a positive return and recovers its initial cost.

Lufft MARWIS

The sensitivity analysis findings show that low annual salt usage levels of 50 to 90 tons per snowplow makes the Lufft MARWIS unit not cost-effective due to its negative NPV (Table 40). The Lufft MARWIS unit becomes cost-effective at an annual rate of 91 tons per snowplow, where NPV and ROI become positive and continue to increase steadily at higher usage with NPV exceeding \$21,038.16 and ROI surpassing 348% at 280 tons (Table 40).

Table 40. Lufft MARWIS Sensitivity Analysis

Annual Salt Usage per Snowplow (tons)	Reduction in Salt per Travel Distance Rate (<i>R</i>)	Annual Salt Savings (\$S)	Net Annual Savings	NPV	Payback Period	ROI
50	20%	\$894.50	\$393.98	-\$4,597.58	17.90	-61%
60	20%	\$1,073.40	\$572.88	-\$3,482.99	12.31	-43%
70	20%	\$1,252.30	\$751.78	-\$2,368.39	9.38	-25%
80	20%	\$1,431.20	\$930.68	-\$1,253.79	7.58	-8%
90	20%	\$1,610.10	\$1,109.58	-\$139.19	6.36	10%
100	20%	\$1,789.00	\$1,288.48	\$975.40	5.47	28%
110	20%	\$1,967.90	\$1,467.38	\$2,090.00	4.81	46%
120	20%	\$2,146.80	\$1,646.28	\$3,204.60	4.28	63%
130	20%	\$2,325.70	\$1,825.18	\$4,319.20	3.86	81%
140	20%	\$2,504.60	\$2,004.08	\$5,433.80	3.52	99%
150	20%	\$2,683.50	\$2,182.98	\$6,548.39	3.23	117%
160	20%	\$2,862.40	\$2,361.88	\$7,662.99	2.99	134%
170	20%	\$3,041.30	\$2,540.78	\$8,777.59	2.78	152%
180	20%	\$3,220.20	\$2,719.68	\$9,892.19	2.59	170%
190	20%	\$3,399.10	\$2,898.58	\$11,006.78	2.43	188%
200	20%	\$3,578.00	\$3,077.48	\$12,121.38	2.29	205%
210	20%	\$3,756.90	\$3,256.38	\$13,235.98	2.17	223%
220	20%	\$3,935.80	\$3,435.28	\$14,350.58	2.05	241%
230	20%	\$4,114.70	\$3,614.18	\$15,465.17	1.95	259%
240	20%	\$4,293.60	\$3,793.08	\$16,579.77	1.86	277%
250	20%	\$4,472.50	\$3,971.98	\$17,694.37	1.78	294%
260	20%	\$4,651.40	\$4,150.88	\$18,808.97	1.70	312%
270	20%	\$4,830.30	\$4,329.78	\$19,923.56	1.63	330%
280	20%	\$5,009.20	\$4,508.68	\$21,038.16	1.56	348%

Teconer

The sensitivity analysis results of the Teconer unit show high cost-effectiveness even at low to moderate annual salt usage rates (Table 41). Cost-effectiveness breaks even around an annual rate of 56 tons per snowplow, where NPV becomes positive. Cost-effectiveness improves rapidly as annual salt usage increases, with NPV approaching \$58,500 and ROI reaching 604% at 280 tons (Table 41).

Table 41. Teconer Sensitivity Analysis

Annual Salt Usage per Snowplow (tons)	Reduction in Salt per Travel Distance Rate (R)	Annual Salt Savings (\$S)	Net Annual Savings	NPV	Payback Period	ROI
50	47%	\$2,102.08	\$1,515.76	-\$1,684.42	7.34	-5%
60	47%	\$2,522.49	\$1,936.17	\$934.89	5.75	22%
70	47%	\$2,942.91	\$2,356.59	\$3,554.19	4.72	48%
80	47%	\$3,363.32	\$2,777.00	\$6,173.50	4.01	75%
90	47%	\$3,783.74	\$3,197.42	\$8,792.80	3.48	101%
100	47%	\$4,204.15	\$3,617.83	\$11,412.10	3.08	128%
110	47%	\$4,624.57	\$4,038.25	\$14,031.41	2.76	154%
120	47%	\$5,044.98	\$4,458.66	\$16,650.71	2.50	180%
130	47%	\$5,465.40	\$4,879.08	\$19,270.02	2.28	207%
140	47%	\$5,885.81	\$5,299.49	\$21,889.32	2.10	233%
150	47%	\$6,306.23	\$5,719.91	\$24,508.63	1.95	260%
160	47%	\$6,726.64	\$6,140.32	\$27,127.93	1.81	286%
170	47%	\$7,147.06	\$6,560.74	\$29,747.24	1.70	313%
180	47%	\$7,567.47	\$6,981.15	\$32,366.54	1.59	339%
190	47%	\$7,987.89	\$7,401.57	\$34,985.84	1.50	366%
200	47%	\$8,408.30	\$7,821.98	\$37,605.15	1.42	392%
210	47%	\$8,828.72	\$8,242.40	\$40,224.45	1.35	418%
220	47%	\$9,249.13	\$8,662.81	\$42,843.76	1.28	445%
230	47%	\$9,669.55	\$9,083.23	\$45,463.06	1.23	471%
240	47%	\$10,089.96	\$9,503.64	\$48,082.37	1.17	498%
250	47%	\$10,510.38	\$9,924.06	\$50,701.67	1.12	524%
260	47%	\$10,930.79	\$10,344.47	\$53,320.98	1.08	551%
270	47%	\$11,351.21	\$10,764.89	\$55,940.28	1.03	577%
280	47%	\$11,771.62	\$11,185.30	\$58,559.58	0.99	604%

Vaisala

The sensitivity analysis of the Vaisala unit shows its limited cost-effectiveness, with negative NPV at annual salt usage rates of 50 to 190 tons per snowplow (Table 42). Cost-effectiveness breaks even around 191 tons, where NPV and ROI become positive and continue to increase steadily at higher annual salt usage rates with NPV surpassing \$8,400 and ROI exceeding 135% at 200 tons.

Table 42. Vaisala Sensitivity Analysis

Annual Salt Usage per Snowplow (tons)	Reduction in Salt per Travel Distance Rate (R)	Annual Salt Savings (\$S)	Net Annual Savings	NPV	Payback Period	ROI
50	17%	\$760.33	-\$917.20	-\$13,364.63	–	-184%
60	17%	\$912.39	-\$765.13	-\$12,417.23	–	-170%
70	17%	\$1,064.46	-\$613.07	-\$11,469.82	–	-156%
80	17%	\$1,216.52	-\$461.00	-\$10,522.41	–	-142%
90	17%	\$1,368.59	-\$308.94	-\$9,575.00	–	-128%
100	17%	\$1,520.65	-\$156.87	-\$8,627.59	–	-114%
110	17%	\$1,672.72	-\$4.80	-\$7,680.19	–	-100%
120	17%	\$1,824.78	\$147.26	-\$6,732.78	51.95	-87%
130	17%	\$1,976.85	\$299.33	-\$5,785.37	25.56	-73%
140	17%	\$2,128.91	\$451.39	-\$4,837.96	16.95	-59%
150	17%	\$2,280.98	\$603.46	-\$3,890.55	12.68	-45%
160	17%	\$2,433.04	\$755.52	-\$2,943.15	10.13	-31%
170	17%	\$2,585.11	\$907.59	-\$1,995.74	8.43	-17%
180	17%	\$2,737.17	\$1,059.65	-\$1,048.33	7.22	-3%
190	17%	\$2,889.24	\$1,211.72	-\$100.92	6.31	11%
200	17%	\$3,041.30	\$1,363.78	\$846.49	5.61	25%
210	17%	\$3,193.37	\$1,515.85	\$1,793.89	5.05	39%
220	17%	\$3,345.43	\$1,667.91	\$2,741.30	4.59	53%
230	17%	\$3,497.50	\$1,819.98	\$3,688.71	4.20	67%
240	17%	\$3,649.56	\$1,972.04	\$4,636.12	3.88	80%
250	17%	\$3,801.63	\$2,124.11	\$5,583.53	3.60	94%
260	17%	\$3,953.69	\$2,276.17	\$6,530.93	3.36	108%
270	17%	\$4,105.76	\$2,428.24	\$7,478.34	3.15	122%
280	17%	\$4,257.82	\$2,580.30	\$8,425.75	2.96	136%

The findings of this sensitivity analysis were also used to compare the performance of the tested mobile RWIS models in terms of three cost-effectiveness metrics (NPV, payback period, and ROI). The sensitivity analysis of the NPV metric shows that Teconer consistently delivers the highest NPV values for all analyzed annual salt usage rates (Figure 46). The Lufft MARWIS begins with a negative NPV at annual salt usage rate of 50 tons per snowplow and steadily increases, breaking even at approximately 91 tons per snowplow. The NPV of Vaisala continues to be negative until it breaks even at approximately 191 tons mainly due to its annual subscription cost (Figure 46).

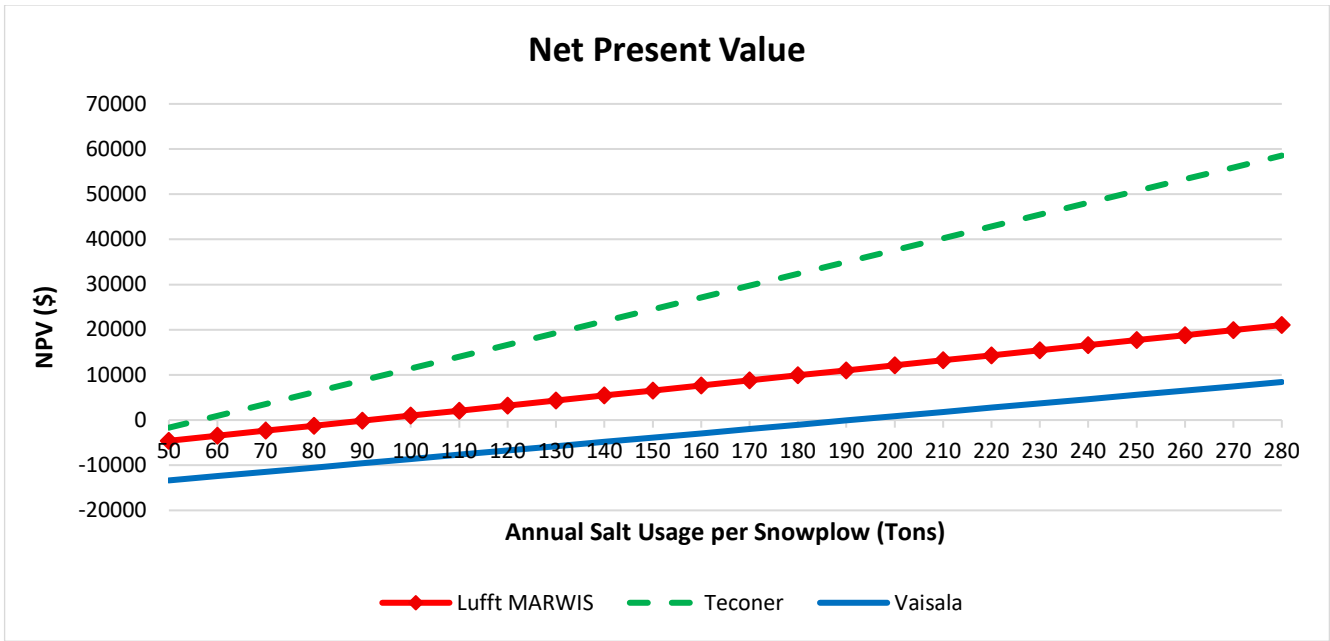


Figure 46. Graph. Mobile RWIS units net present value comparison.

The sensitivity analysis of the payback period metric shows that Teconer provides the shortest payback period (7.34 to 0.99 years) for annual salt usage rates spanning 50 to 280 tons per snowplow, as shown in Figure 47. Similarly, the payback period of Lufft MARWIS ranged from 17.90 to 1.56 years for annual salt usage rates spanning 50 to 280 tons per snowplow, while Vaisala shows the least favorable profile, starting with 51.29 years at 120 tons before falling to 2.96 years at 280 tons, as shown in Figure 47.

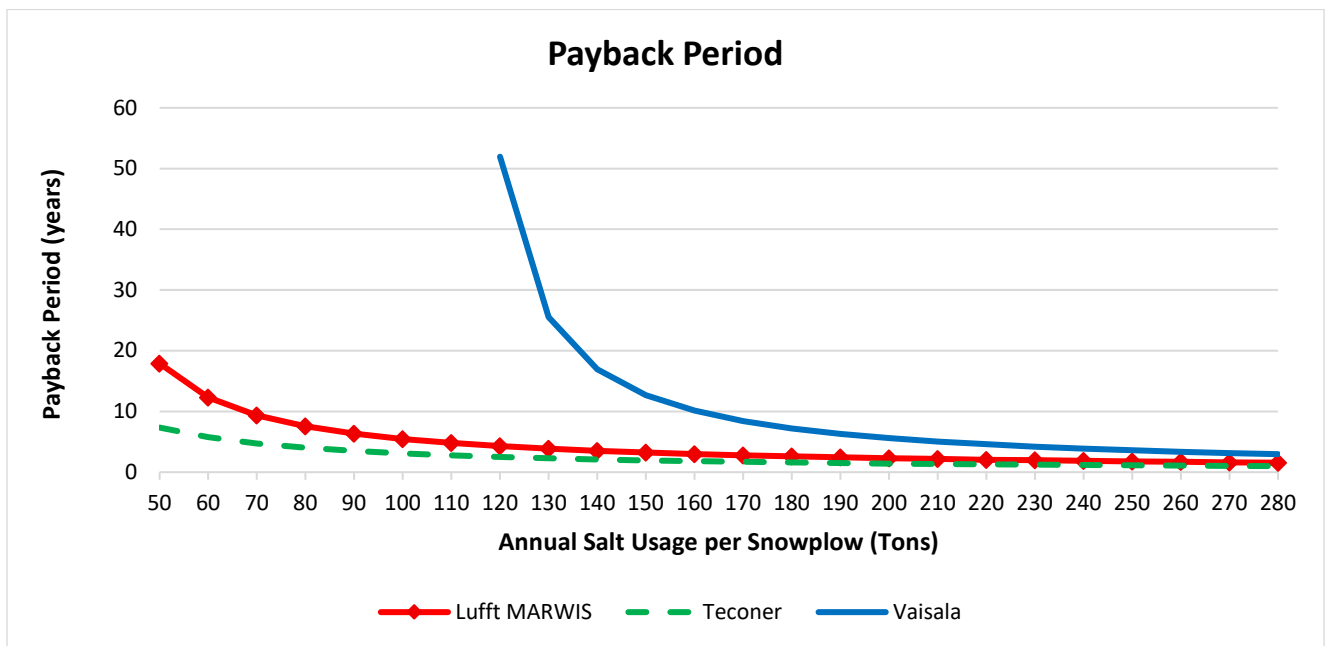


Figure 47. Graph. Mobile RWIS units payback period comparison.

The sensitivity analysis of the return on investment metric shows that Teconer provides the highest ROI, rising from -5% to 604% for annual salt usage rates ranging from 50 to 280 tons per snowplow (Figure 48). The Lufft MARWIS begins with a negative ROI of -61% at 50 tons per snowplow and steadily rises, reaching 348% at 280 tons per snowplow. The Vaisala units' ROI starts at -184% and only becomes positive at approximately 182 tons per snowplow, ultimately achieving a 136% ROI at 280 tons per snowplow.

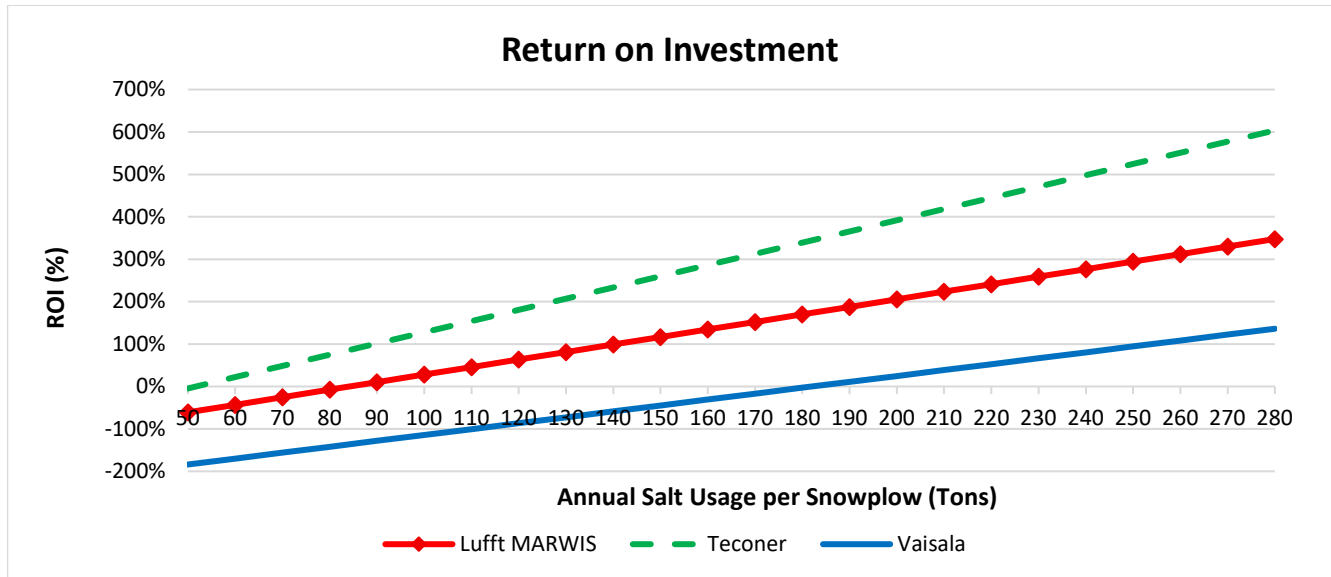


Figure 48. Graph. Mobile RWIS units return on investment comparison.

MDSS

This section evaluates the cost-effectiveness of MDSS based only on performance during the 2023–24 winter season. As stated in the “MDSS Performance” section, MDSS performance during the 2024–25 winter season was not considered in this analysis because the three interviewed IDOT maintenance yard supervisors reported that MDSS recommendations were frequently not implemented during that season due to limited snowplow operator staffing. This analysis considered only the 2023–24 winter season salt performance, and the evaluation was conducted in three steps: (1) quantifying annual cost savings generated by the reduction in salt usage by snowplows equipped with MDSS, (2) calculating the initial and annual subscription costs of MDSS, and (3) analyzing cost-effectiveness.

MDSS Salt Savings

The performance of MDSS in reducing salt usage was assessed based on findings presented in Chapter 5: Deployment of MDSS resulted in an average reduction in salt per travel distance of 3% during all analyzed storms in the 2023–24 winter season (see Table 29). The annual salt savings from MDSS can be estimated using the equation provided in Figure 42, applying the same assumptions discussed in the “Mobile RWIS Salt Savings” section. The results show that MDSS provides an average annual savings of \$521.43.

MDSS Costs

MDSS subscription costs were paid for 24 routes in the three participating districts (Table 43). Note that the subscription cost for these 24 routes in year 1 was higher than subsequent years due to their one-time initialization cost. The total MDSS subscription cost for the 24 routes during the three years of study was \$65,169.97, which corresponds to an average cost of \$905.14 per MDSS route.

Table 43. MDSS Cost

Subscription Year	Total Cost	Cost per Route
Year 1	\$30,109.97	\$1,254.58
Year 2	\$17,655.00	\$735.63
Year 3	\$17,405.00	\$725.21
Total/Average	\$65,169.97	\$905.14

MDSS Cost-Effectiveness Evaluation

The cost-effectiveness of an average MDSS route in this study can be evaluated by comparing its annual subscription cost to its annual salt usage savings. The aforementioned estimated average annual MDSS savings of \$521.43 per route due to salt usage reduction is substantially lower than its average annual cost of \$905.14 per route. Accordingly, the findings of this analysis, which was limited only to the 2023–24 winter season, do not confirm the cost-effectiveness of the analyzed 24 MDSS routes in this study. Nevertheless, MDSS was reported to provide other operational benefits including improved access to weather-related information, more effective timing of treatment applications, quicker operational decision-making, and earlier recognition of deteriorating roadway conditions by the surveyed IDOT personnel.

CHAPTER 7: ADDITIONAL USES FOR MOBILE RWIS UNITS

This chapter focuses on exploring potential additional uses of mobile RWIS units beyond their primary role of monitoring real-time pavement conditions during winter events. The following four potential additional uses of mobile RWIS units were identified based on existing literature and the performance analysis of mobile RWIS units conducted in this study.

WINTER MAINTENANCE MATERIALS EVALUATION

ODOT (2017a) employed a Lufft MARWIS-equipped vehicle to evaluate the field performance of various liquid deicers under operational winter conditions. The study assessed the effects of eight deicer formulations on pavement temperature and road surface friction, capturing the dynamic interactions between applied deicers, snow, and ice under varying environmental and traffic conditions (ODOT, 2017a). The Lufft MARWIS unit measurements revealed spatial variations in deicer efficacy related to traffic patterns and pavement microclimates, demonstrating that field conditions could significantly influence product performance. These findings provided high-resolution empirical evidence that informed ODOT's winter maintenance recommendations, including the selection of appropriate liquid deicers for specific temperature ranges and application strategies to maximize road safety and efficiency (ODOT, 2017a). Similarly, IDOT can utilize its acquired mobile RWIS units to evaluate the performance and effectiveness of alternative types and quantities of winter maintenance materials on Illinois roads.

WINTER MAINTENANCE EQUIPMENT EVALUATION

Mobile RWIS units may also assess the performance of alternative winter maintenance equipment, including plow blades and spreaders. The effectiveness of alternative plow blades and spreaders in improving winter maintenance operations and roadway conditions can be quantified and compared by collecting and analyzing mobile RWIS measurements such as friction and road surface temperature after plowing operations. These mobile RWIS measurements can be used to provide an objective comparison of the performance of alternative plow blades and spreaders and, therefore, can be used by IDOT to identify and deploy best-performing equipment to maximize the efficiency and effectiveness of their roadway winter maintenance operations.

ASSESSMENT OF TREE CANOPY EFFECTS ON PAVEMENT CONDITIONS

Mobile RWIS can assess localized environmental factors that influence pavement conditions and snow-removal operations such as tree canopy effects. ODOT (2020) reported using several vehicles equipped with mobile RWIS to investigate the effects of tree canopy on pavement condition, safety, and maintenance. Tree canopies over rural highways caused concern for ODOT maintenance personnel, noting that excessive shading on the roadway during winter allowed snow and ice to remain on the pavement longer, which has the potential to increase potholes, create inconsistent road conditions for drivers, and cause cars to hydroplane due to moisture dripping onto ice-covered surfaces. Additionally, canopy coverage or shaded roadway sections have been reported to require increased maintenance by ODOT personnel (ODOT, 2017b). Similarly, IDOT can utilize acquired

mobile RWIS units to evaluate the impact of local environmental factors such as tree canopy on Illinois roadway winter maintenance operations.

VEHICLE-TO-INFRASTRUCTURE INTEGRATION

Mobile RWIS can be integrated with vehicle-to-infrastructure (V2I) systems to transmit real-time pavement condition data such as temperature, friction, and moisture to vehicles and traffic management centers. This capability enables dynamic winter maintenance decision-making, including adaptive deicer application and plowing operations, while providing drivers with timely warnings of hazardous roadway conditions. V2I integration also supports the evaluation of materials, equipment, and operational strategies by enabling real-time data sharing within connected vehicle environments. Furthermore, it contributes to broader intelligent transportation systems by facilitating data fusion with fixed RWIS stations, traffic sensors, and weather forecasting systems, enhancing predictive maintenance capabilities and improving roadway safety and operational efficiency (FHWA, 2016).

CHAPTER 8: RECOMMENDATIONS

This chapter provides recommendations for the deployment and use of mobile RWIS and MDSS throughout Illinois based on the main findings of this study and its analysis of (1) conducted survey and follow-up interviews, (2) salt usage performance, (3) cost-effectiveness, (4) implementation requirements, and (5) operational challenges. The following sections summarize the findings of the five analyses and provide recommendations for the deployment of mobile RWIS and MDSS in Illinois.

SURVEY AND FOLLOW-UP INTERVIEWS

This section highlights key findings from the online survey and follow-up interviews with IDOT operations supervisors related to future deployment of mobile RWIS and MDSS. Survey respondents reported that use of mobile RWIS units resulted in moderate improvements in the level of service, the amount of salt/brine use, and working hours to prepare for winter events. Similarly, respondents reported that the use of MDSS resulted in moderate improvements in the level of service, fleet management during winter events, and working hours to prepare for winter events. With respect to the performance of mobile RWIS models, respondents ranked Lufft MARWIS as the highest-performing unit in terms of ease of use and practicality, accuracy of readings, and overall effectiveness. Respondents also reported that Teconer outperformed Vaisala in terms of accuracy of readings and overall effectiveness, while Vaisala was rated higher than Teconer in terms of its ease of use and practicality. There was consistently high level of interest among respondents in receiving additional training on the use of both mobile RWIS and MDSS across the study seasons.

The follow-up interviews with operations supervisors provided additional operational insights that complemented the survey findings. All supervisors supported the continued use of mobile RWIS in future winters and district-wide deployment, provided the units are used effectively. Regarding mobile RWIS data, supervisors reported that pavement temperature is the primary parameter used to support winter maintenance decision-making, while ice thickness and friction measurements are used as supplementary indicators for identifying potentially slippery roadway conditions. Supervisors indicated they would continue using MDSS for operational planning in future winters if available. They noted, however, that limited staffing constrained their ability to fully implement MDSS recommendations.

SALT USAGE PERFORMANCE

This section highlights the main findings of the conducted salt usage performance of mobile RWIS units and MDSS during the 2023–24 and 2024–25 winter seasons. Use of mobile RWIS units during the two seasons resulted in an average 26% reduction in salt per travel distance rate compared to nearby snowplows without a mobile RWIS unit operating on similar types of roads. Among the evaluated models, Teconer achieved the highest reduction (47%), followed by Lufft MARWIS (20%), and Vaisala (17%). Use of MDSS resulted in an average 3% reduction in salt per travel distance rate in the 2023–24 season, while in the 2024–25 season, use of MDSS did not result in reductions in salt usage when recommendations were frequently not implemented due to staffing limitations. These findings revealed that the use of mobile RWIS provided more reductions in salt usage during winter

maintenance operations compared to MDSS, and that the MDSS recommendations were not fully implemented by participating districts due to limited staffing.

COST-EFFECTIVENESS

The cost-effectiveness analysis further supports the operational benefits of mobile RWIS deployment. Among the evaluated models, Teconer provided the best economic performance, achieving the highest net present value, shortest payback period, and highest return on investment. Lufft MARWIS also showed favorable economic performance, particularly for routes with moderate to high annual salt usage. In contrast, the Vaisala model demonstrated limited economic benefits under typical salt usage conditions, largely due to its annual subscription fees. The sensitivity analysis results also indicated that the economic performance of mobile RWIS units is strongly influenced by route-level salt usage. Routes with higher annual salt demand generate greater economic returns from mobile RWIS deployment. The findings of the MDSS cost-effectiveness analysis during the 2023–24 winter season did not provide cost savings for the 24 MDSS routes in this study. Accordingly, these findings highlight the cost-effectiveness of mobile RWIS models, especially for routes with higher levels of annual salt usage.

IMPLEMENTATION REQUIREMENTS

Deployment of mobile RWIS units and MDSS in participating districts required preseason installation, calibration verification, and connectivity checks to ensure their effective use in snow-removal operations. Additional implementation requirements include robust Bluetooth connectivity between sensors and in-cab applications (e.g., RoadAI, RCM, MARWIS), stable cellular connectivity to manufacturer servers, and practical in-vehicle display units and user interfaces to improve the efficiency and effectiveness of winter maintenance operations. Additionally, consistent vehicle power supply and subscription management, where applicable, are critical to maintaining uninterrupted system operation and providing real-time access to collected data, enabling supervisors to monitor roadway conditions remotely from their offices. There is a need for training on the use of mobile RWIS readings and MDSS recommendations for winter maintenance supervisors and operators.

OPERATIONAL CHALLENGES

This section highlights the operational challenges of mobile RWIS units and MDSS reported by survey respondents and interviewed operations supervisors. The operational performance and challenges of mobile RWIS units varied based on the model type. For example, Lufft MARWIS was reported to have no damage during power washing, no iPad app issues, hardly any connection issues, and slightly below moderately frequent calibration issues. Teconer was reported to have no damage during power washing, hardly any phone app issues, slightly below moderately frequent connection issues, and slightly below moderately frequent calibration issues. Vaisala MD30 was reported to have hardly any damage during power washing, hardly any calibration issues, slightly above moderately frequent connection issues, and slightly below moderately frequent phone app issues. For MDSS, survey respondents reported that their top encountered challenges were inaccurate weather predictions, excessive treatment recommendations, and insufficient treatment recommendations. The follow-up

interviews with operations supervisors also indicated that MDSS forecasts are reliable for 2–3 days forecasts and provide less accurate forecasts of hourly conditions, which is consistent with the survey findings.

RECOMMENDATIONS FOR FUTURE DEPLOYMENT

The following recommendations for the deployment and use of mobile RWIS and MDSS throughout Illinois were developed based on analysis of the conducted surveys, salt usage performance, cost-effectiveness, implementation requirements, and operational challenges.

1. **Prioritize Deployment of Mobile RWIS Units Based on Annual Salt Usage:** Cost-effectiveness and operational benefits of mobile RWIS units varied based on the annual salt usage per snowplow. Benefits include reductions in salt usage, improved monitoring of roadway conditions, and enhanced decision-making during winter maintenance operations. Future deployment of mobile RWIS units across Illinois should prioritize IDOT districts and routes with the highest annual salt usage per snowplow to maximize the cost-effectiveness and returns of this investment.
2. **Select Mobile RWIS Models Based on Cost-Effectiveness and Operational Performance:** The Teconer model achieved the highest economic return followed by Lufft MARWIS and Vaisala. Survey respondents reported that Lufft MARWIS provided the highest operational performance in terms of ease of use, reading accuracy, least operational challenges, and overall effectiveness, followed by Teconer and Vaisala. IDOT districts may prefer to deploy Teconer, if cost-effectiveness is more important than operational performance, and Lufft MARWIS in cases where operational performance is deemed more important.
3. **Consider Phased Deployment:** IDOT may consider phased deployment of mobile RWIS units and gradually expand their use based on performance. Future deployment of mobile RWIS units in IDOT districts can be implemented in three sequential phases: (a) deploying mobile RWIS units on a limited set of 5%–10% of the district fleet; (b) analyzing the cost-effectiveness and operational performance of this initial deployment using similar procedures to those described in Chapters 4, 5, and 6; and (c) gradually expanding the deployment of mobile RWIS to additional segments of the fleet only if the initial deployment was proven to improve the cost-effectiveness and operational performance of winter maintenance operations.
4. **Establish Pre-Season Quality Assurance Protocols and Training:** To ensure reliable system performance, IDOT may consider establishing a standardized pre-season quality assurance protocol for mobile RWIS units. This protocol should include verification of sensor mounting, power supply, connectivity, and calibration in accordance with manufacturer guidelines. IDOT districts should also provide effective pre-season training for operators and supervisors to ensure proper use of the technology, accurate interpretation of sensor data, and effective integration of real-time roadway condition information into winter maintenance operations.
5. **Consider Use of MDSS for Operational Planning:** Although the cost-effectiveness of MDSS could not be confirmed during this study due to limited staffing to fully implement its recommendations, MDSS was reported by interviewed IDOT supervisors to provide other

operational benefits: improved access to weather-related information, more effective timing of treatment applications, quicker operational decision-making, and earlier recognition of deteriorating roadway conditions. IDOT may consider future deployment of MDSS in districts that need these operational benefits and do not have limited staffing to ensure that its recommended treatment actions can be implemented effectively to maximize the cost-effectiveness of using MDSS.

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APPENDIX: SURVEY OF IDOT PERSONNEL

SURVEY QUESTIONS FOR 2022–23 AND 2023–24 WINTER SEASONS

This survey is designed to collect feedback from IDOT personnel on their experiences utilizing mobile RWIS units and MDSS.

1) Basic Information

- What is your name? (optional) _____

- Which district do you represent?
 - District 2
 - District 5
 - District 6

- What is your current job title? _____

- Did you use MDSS during winter maintenance?
 - Yes, desktop computer
 - Yes, mobile device
 - No

2) Use and Effectiveness of Mobile RWIS

- Which mobile RWIS unit did you utilize? (Select all that apply)
 - Lufft MARWIS
 - Teconer RCM511
 - Vaisala MD30

- Which vehicle type did you operate while using mobile RWIS?
 - Supervisor vehicle
 - Snowplow
 - Not applicable

- How many times did you use mobile RWIS?
 - Never
 - 1 to 2 times
 - 3 to 5 times
 - More than 5 times

- Please report the effectiveness of mobile RWIS in providing the following benefits using a scale from not effective to very effective

Mobile RWIS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable
Reduced salt/brine use				
Improved level of service				
Shorter snow removal duration				
Decreased working hours to prepare for winter events				
Other				

- Did mobile RWIS units provide overall improvements in your winter maintenance?
 - Yes
 - Somewhat
 - No
 - Not applicable
- Compare the overall effectiveness of all mobile RWIS models utilized by your District in improving winter maintenance operations.

Mobile RWIS Model	Most Effective	Moderately Effective	Least Effective
Lufft MARWIS			
Teconer RCM511			
Vaisala MD30			

3) Problems and Challenges of Mobile RWIS

- Please report the frequency of encountering the following problems/challenges during your use of mobile RWIS units using a scale from none to very frequent

Mobile RWIS Challenges	None	Moderately Frequent	Very Frequent	Not Applicable
Calibration issues				
Inaccurate readings				
Connectivity issues				
Mobile app issues				
Damaged units when power washing truck				
Damaged wiring				
Other				

4) Use and Effectiveness of MDSS

- How often did you utilize MDSS during winter maintenance?
 - Never
 - 1 to 2 times
 - 3 to 5 times
 - More than 5 times
- When did you typically utilize MDSS? (Select all that apply)
 - Prior to winter maintenance operations
 - During winter maintenance operations
 - After winter maintenance operations

- Please report the effectiveness of MDSS in providing the following benefits using a scale from not effective to very effective

MDSS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable
Reduced salt/brine use				
Improved level of service				
Shorter snow removal duration				
Decreased working hours to prepare for winter events				
Better fleet management during winter events				
Forecasting winter storms				
Other				

- Did MDSS provide overall improvements in your winter maintenance?
 - Yes
 - Somewhat
 - No
 - Not applicable

5) Problems and Challenges of MDSS

- Please report the frequency of encountering the following problems/challenges during your use of MDSS system using a scale from none to very frequent

MDSS Challenges	None	Moderately Frequent	Very Frequent	Not Applicable
Inaccurate weather prediction				
Mobile app/desktop issues				
Excessive treatment recommendations				
Insufficient treatment recommendations				
Communication to snowplow operators				
Other				

6) Recommendations

- Do you need more training for the use of Mobile RWIS units?
 - Yes
 - No
 - Maybe

- Do you need more training for the use of MDSS?
 - Yes
 - No
 - Maybe

- Please provide any additional recommendations to improve the benefits of utilizing the MDSS and Mobile RWIS units _____

SURVEY QUESTIONS FOR 2024-25 WINTER SEASON

This survey is designed to collect feedback from IDOT personnel on their experiences utilizing mobile RWIS units and MDSS.

1) Basic Information

- What is your name? (optional) _____
- What is your truck number? (optional) _____
- Which district do you represent?
 - District 2
 - District 5
 - District 6
- What is your current job title? _____
- Did you use MDSS during winter maintenance?
 - Yes, desktop computer
 - Yes, mobile device
 - No

2) Use and Effectiveness of Mobile RWIS

- Which mobile RWIS unit did you utilize? (Select all that apply)
 - Lufft MARWIS
 - Teconer RCM511
 - Vaisala MD30
- Which vehicle type did you operate while using mobile RWIS?
 - Supervisor vehicle
 - Snowplow
 - Not applicable
- How many times did you use mobile RWIS?
 - Never
 - 1 to 2 times
 - 3 to 5 times
 - More than 5 times
- Please report the effectiveness of mobile RWIS in providing the following benefits using a scale from not effective to very effective

Mobile RWIS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable
Reduced salt/brine use				
Improved level of service				
Shorter snow removal duration				
Decreased working hours to prepare for winter events				
Other				

- Did mobile RWIS units provide overall improvements in your winter maintenance?
 - Yes
 - Somewhat
 - No
 - Not applicable
- Compare the **ease of use and practicality** of all mobile RWIS models utilized by your District during winter maintenance operations.

Mobile RWIS Model	Most Practical	Moderately Practical	Least Practical	Did Not Use This Model
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Compare the **accuracy of readings** of all mobile RWIS models utilized by your District during winter maintenance operations.

Mobile RWIS Model	Most Accurate	Moderately Accurate	Least Accurate	Did Not Use This Model
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Compare the **overall effectiveness** of all mobile RWIS models utilized by your District in improving winter maintenance operations.

Mobile RWIS Model	Most Effective	Moderately Effective	Least Effective	Did Not Use This Model
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

3) Problems and Challenges of Mobile RWIS

- Please report the **level of calibration issues** encountered during your use of each mobile RWIS model using a scale from none to very frequent.

Mobile RWIS Model	None	Moderately Frequent	Very Frequent	Not Applicable
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Please report the **level of connection issues** encountered during your use of each mobile RWIS model using a scale from none to very frequent.

Mobile RWIS Model	None	Moderately Frequent	Very Frequent	Not Applicable
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Please report the **level of phone app/iPad issues** encountered during your use of each mobile RWIS model using a scale from none to very frequent.

Mobile RWIS Model	None	Moderately Frequent	Very Frequent	Not Applicable
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Please report the frequency of the mobile RWIS model being **damaged during power washing of the truck** using a scale from none to very frequent.

Mobile RWIS Model	None	Moderately Frequent	Very Frequent	Not Applicable
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Please report the frequency of the mobile RWIS model being **non-operational** during your use of using a scale from none to very frequent.

Mobile RWIS Model	None	Moderately Frequent	Very Frequent	Not Applicable
Lufft MARWIS				
Teconer RCM511				
Vaisala MD30				

- Please report the frequency of encountering the following problems/challenges during your use of mobile RWIS units using a scale from none to very frequent

Mobile RWIS Challenges	None	Moderately Frequent	Very Frequent	Not Applicable
Calibration issues				
Connectivity issues				
Mobile app issues				
Damaged units when power washing truck				
Other				

4) Use and Effectiveness of MDSS

- How often did you utilize MDSS during winter maintenance?
 - Never
 - 1 to 2 times
 - 3 to 5 times
 - More than 5 times

- When did you typically utilize MDSS? (Select all that apply)
 - Prior to winter maintenance operations
 - During winter maintenance operations
 - After winter maintenance operations

- Do you adjust salt application rates based on MDSS recommendations?
 - Yes
 - No

- If no, please explain why your salt application rate do not follow MDSS recommendations _____

- Please report the effectiveness of MDSS in providing the following benefits using a scale from not effective to very effective

MDSS Benefits	Not Effective	Moderately Effective	Very Effective	Not Applicable
Reduced salt/brine use				
Improved level of service				
Shorter snow removal duration				
Decreased working hours to prepare for winter events				
Better fleet management during winter events				
Forecasting winter storms				
Other				

- Did MDSS provide overall improvements in your winter maintenance?
 - Yes
 - Somewhat
 - No
 - Not applicable

5) Problems and Challenges of MDSS

- Please report the frequency of encountering the following problems/challenges during your use of MDSS system using a scale from none to very frequent

MDSS Challenges	None	Moderately Frequent	Very Frequent	Not Applicable
Inaccurate weather prediction				
Mobile app/desktop issues				
Excessive treatment recommendations				
Insufficient treatment recommendations				
Communication to snowplow operators				
Other				



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