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Intelligent Sidewalk De-icing and Pre-treatment with Connected Campus Maintenance Vehicles

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CENTER FOR CONNECTED AND AUTOMATED TRANSPORTATION

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16. Abstract

Salt brine is routinely used by transportation agencies to pre-treat critical infrastructure such as bridges, ramps, and underpasses in advance of winter storms. Traditional manual techniques of the operator turning on and off the brine controls while driving at highway speeds introduces driver distraction and consistency problems. Purdue University and industry partners collaborated with agencies to develop an automated brine application system for deicing and pretreatment during winter operations. The system leverages existing precision Real-Time Kinematic (RTK) technology used for spraying chemicals in the agriculture industry to control brine application. This automated brine system enhances safety, reduces driver workload, ensures efficient application of brine, and reduces environmental impact. The team prototyped the system on an electric utility vehicle (for campus roads and urban sidewalks) and subsequently scaled deployment to two 5,500-gallon brine tankers for treating interstates and major arterials with brine. This deployment on the 5,500-gallon tanker used on I-465 in Indianapolis eliminated the need for the truck driver to turn on and off a switch 600 times during pre-treatment for a single storm. Extrapolating to an entire season, this eliminated several thousand driver distraction events and improved the consistency of brine application to bridges.

17. Key Words Real-Time Kinematic (RTK) technology, brine, automation, automated material spreading.		**18. Distribution Statement** No restrictions.	
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1. INTRODUCTION

Winter maintenance is an important transportation issue at a national level, as it severely impacts transportation efficiency, and safety. Salt brine is routinely used by transportation agencies to pre-treat critical infrastructure such as bridges, ramps, and underpasses in advance of winter storms. Brine is a salt water mixture, which can be applied before a winter precipitation event. Brine has found to be more effective in pre-treatment measures and has reduced winter operation cost and salt usage (*1*, *2*). Traditional manual techniques of the operator turning on and off the brine controls while driving at highway speeds introduces driver distraction and consistency problems.

The objective of this project was to identify and develop an automated system for turning on and off the brine controls on a vehicle without operator intervention using GPS positioning. The benefit of this is reduced driver distraction and improved consistency of brine application.

Examples of the importance of automating material application can be seen in Figure 1 below. Figure 1a illustrates a Purdue campus tunnel penetration where brine application must be turned off when the sidewalk is being pre-treated to prevent salt intrusion into the tunnel. Figure 1b shows the obstacles and pedestrians that a driver must avoid while driving vehicles that apply brine and demonstrates the importance of reducing driver distractions while applying brine. Figure 1c illustrates the importance of pre-treatment on interstate highways to maintain passenger car and freight mobility during a winter storm.

a) Tunnel Access on Purdue University Campus

b) Obstacles and Students on Campus

c) Traffic Congestion during a Winter Storm

Figure 1. Motivation for development of automatic material application

In addition to reducing driver distraction while applying brine, there is also a challenge in training drivers so they have a clear understanding of where brine must be turned on and off during either a sidewalk route (Figure 1a,b) or on the highway network (Figure 1c).

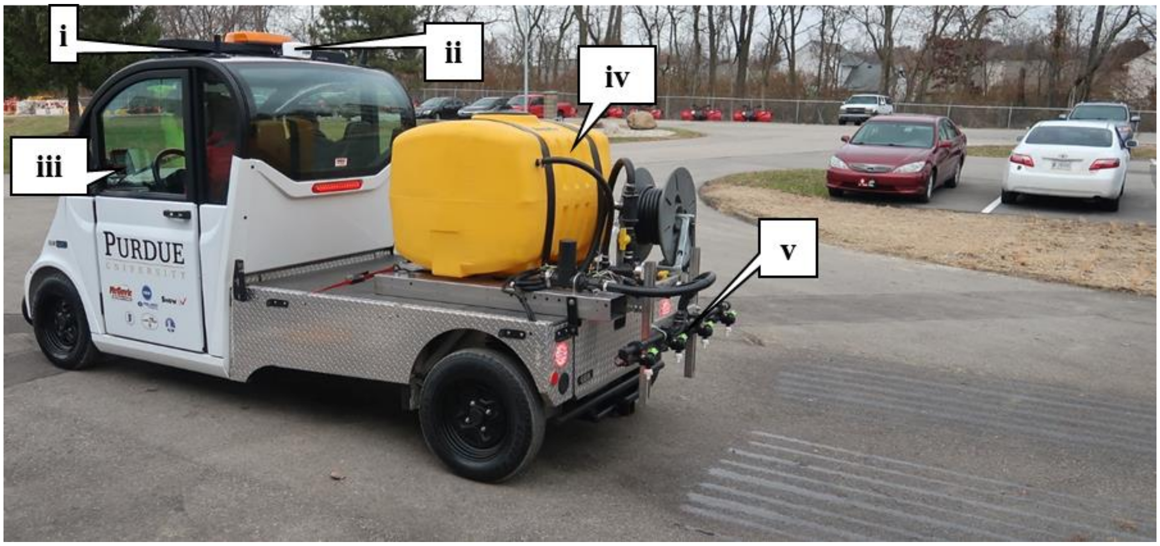
The agriculture industry has faced similar challenges in applying chemicals to fields and has developed GPS based controls for turning on and off sprayers. The team, along with sponsors and industry partners, developed an automated brine application system for deicing and pretreatment during winter operations. The system leverages existing precision Real-Time Kinematic (RTK) technology used for spraying chemicals in the agriculture industry to control brine application. This system reduces driver workload and ensures consistent application of brine. The team prototyped the system on an electric utility vehicle for campus roads and urban sidewalks (Figure 2). The use of this prototype provided many insights which were then scaled up on a 5,500-gallon brine tanker capable of treating interstates and major arterials.

Therefore, the research product not only increased the body of knowledge regarding winter maintenance, but also showed how the process of ice control could be facilitated cost-effectively through new technologies. A companion cost sharing study, funded by Indiana Department of Transportation has published a report titled "Development of an Intelligent Snowplow Truck that Integrates Telematics Technology, Roadway Sensors, and Connected Vehicle" (*3*) and the use cases were published in a journal paper titled "Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment" (*4*).

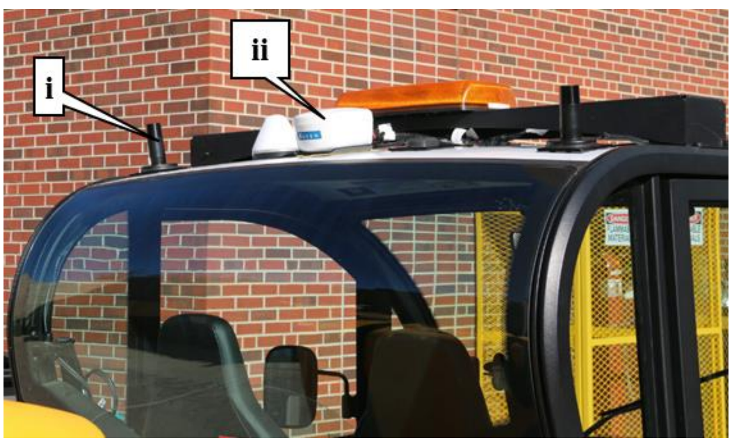
2. DEVELOPMENT APPROACH

The development of an automated brine application system for de-icing and pretreatment during winter operations was successfully implemented and tested during the project. The system used existing precision Real-Time Kinematic (RTK) technology used for spraying chemicals in the agriculture industry to control brine application (Figure 2) (*5*).

This innovation allows agencies to remotely send a prescription map with application zones and their rates to the in-cab operator. The system will automatically turn on/off the application at the prescribed rate when the vehicle enters/exits the application zones (Figure 3). In addition to material savings by preventing double application on previously applied areas, the system enables multiple vehicles to work on the same brine route. This improves efficiency and using the real-time job sync prevents application that other operators may have already captured. Upon job completion, the system generates a report highlighting the application areas and their rates, which agencies can use for after-action analysis to better manage material usage and assess winter maintenance operations.
Figure 2a shows the prototyped system on an electric utility vehicle for campus roads and urban sidewalks. Callout *i* is the cellular receiver for RTK correction, callout *ii* is the GPS receiver, callout *iii* is the user interface, callout *iv* is the 100-gallon brine tank and callout *v* is the spray bar. Figure 2b shows a focused image of the RTK antenna (callout *i*) and the GPS antenna (callout *ii*). Figure 2c shows a focused image of the user interface (callout *iii*) and the slingshot modem (callout *vi*). The slingshot modem is the interface that enables the remote sending and receiving of prescription maps, the real-time job sync, as well as post application reports.



a) Components of the Prototype Vehicle



b) Focused Photo of RTK and GPS Antenna

c) Focused Photo of User Interface and Slingshot Module

Figure 2. Equipment adaptation on prototype vehicle.

An example of a prescription map can be observed in Figure 3 below. The prescription map has user-defined zones with specified application rates. The shown prescription map has 4 unique application rates of 30, 40, 50, and 60 gallons per acre. After development of a prescription map, the file is loaded into the brine sprayer controller which can be seen in Figure 4 and then applied to the pavement surface (Figure 5).

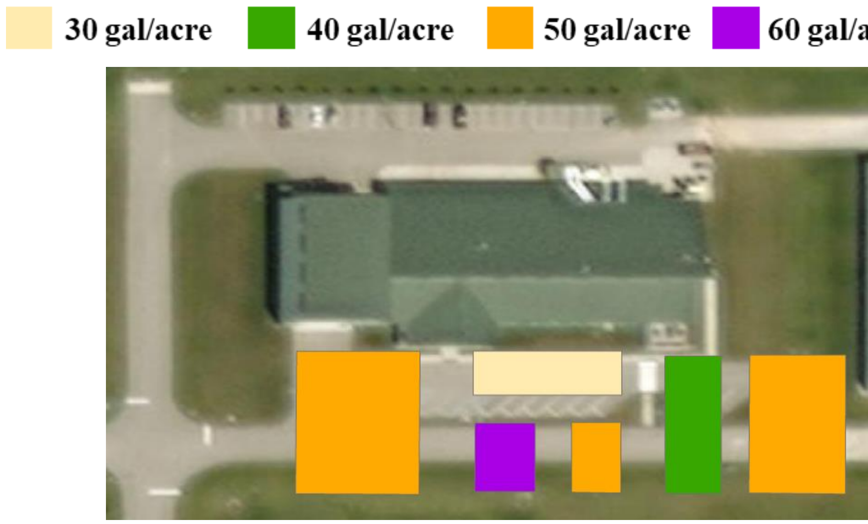
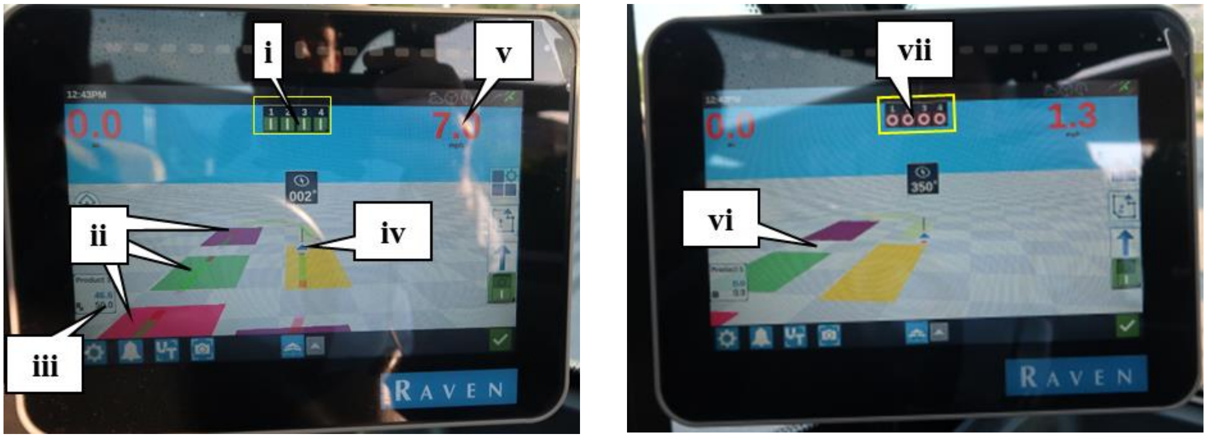


Figure 3. Prescription map at Purdue University Agronomy Center for Research and Education in West Lafayette, Indiana.

The loaded prescription map from Figure 3 can be seen loaded in the user interface in Figure 4 below. Figure 4a callout *i* shows the operator nozzle activation status, callout *ii* shows the pre-defined spray zones, callout *iii* shows the target application rate and the actual application rate, callout *iv* is the current position of the vehicle and callout *v* is the current speed of the vehicle. Each of these aspects are important as this is logic the operating system uses when determining nozzle status. The user first defines the application zone as a shapefile and loads the file as a job into the system. Once the job is loaded, the operating system monitors the current position of the vehicle, speed and the defined spray zones. Once the vehicle enters the spray zones, the nozzles open allowing application of material at the desired rate while adjusting for the vehicle's speed. Figure 4a shows when the vehicle is in the application zone and applying material, Figure 4b shows when the vehicle is out of the spray zone and not applying material. This can be observed by callout *vi* where there are no application zones and callout *vii* where the nozzles are closed.



a) User Interface with Nozzles Active
b) User Interface with No Nozzles Active

Figure 4. Example of the user interface.

Automatic application ensures consistent and reliable application as seen in Figure 5. The material application begins and ends consistently between each pass, with slight variation due to different vehicle speeds. The brine application observed in Figure 5 comes directly from the prescription map in Figure 3.

Figure 5. Precision application in spray zones.

Another advantage to automating material application is the opportunity to prevent double or over application. When the system has applied material to a location it will not reapply in the same location unless the operator specifically wants to. An example of this can be found in Figure 6 below. The original pass can be observed as callout *i*, the second overlapping pass is callout *ii* and the location where the application overlaps is callout *iii*. At callout *iii* the nozzles deactivated as they were about to overlap with the previous pass.

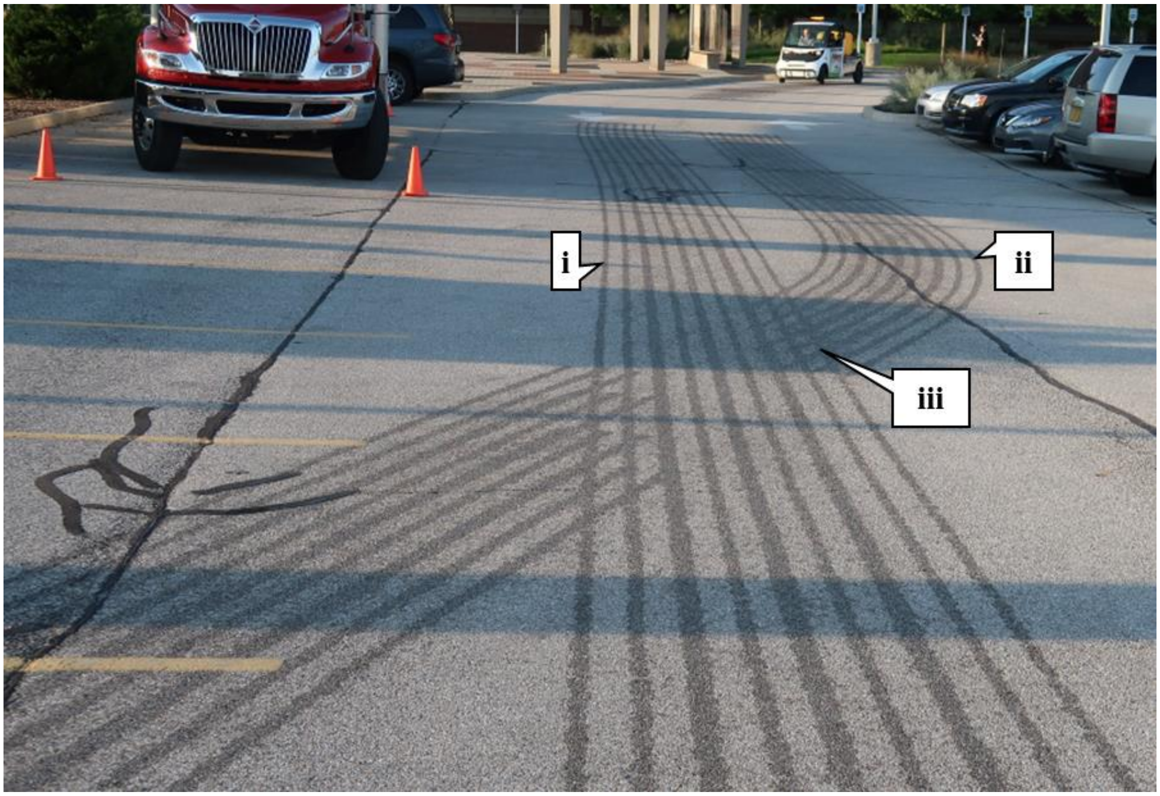


Figure 6. Precision technology reduces over application.

The development of this technology was then utilized over the 2020-2021 winter season on Purdue University sidewalks. The vehicle was used on approximately 2.5 miles of the campus sidewalks and was deployed whenever the grounds and maintenance crew applied brine to the rest of campus. Throughout the season, there were six times brine was applied: 12/15/2020, 01/22/2021, 01/25/2021, 01/28/2021, 02/10/2021, and 02/12/2021. This testing period validated the use and functionality of the technology. Figure 7 shows the vehicle being utilized during a winter precipitation event.

Figure 7. Precision brine prototype vehicle applying material at Purdue University.

3. OUTREACH AND ENGAGEMENT

An important element of this project was engaging with winter operations professional responsible for maintaining both urban campus environments (Figure 1a, b) and Interstate highways (Figure 1c). Both of these groups were actively engaged in implementing this technology on their respective winter operations vehicles. The prototype was utilized on Purdue Campus for testing purposes and was brought around the state of Indiana to aid in training and education purposes. Table 1 shows a summary of various outreach activities performed during the project period. Almost 40 events were held and the vehicle was demonstrated at many of the locations. Local operators had the opportunity to drive the vehicle through application zones and observe the vehicle both internally and externally.

Table 1. Outreach Activities

Date	Event
01/29/20	Vincennes Calibration Demonstration
02/04/20	La Porte Calibration Demonstration
02/12/20	Sigma Xi Poster Presentation
02/20/20	Greenfield Calibration Demonstration
02/26/20	Winter Operation Webinar
02/27/20	JTRP Executive Meeting
03/05/20	Work Truck Show
03/10/20	Purdue Road School Presentations
04/07/20	CCAT Webinar
07/07/20	Automated Brine Collaboration – Initial Meeting
08/24/20	Automated Brine Collaboration – Progress Update
09/14/20	Crawfordsville Calibration Demonstration
09/21/20	Coordination with Purdue Facilities – Partner on Sidewalk Brine Routes
09/23/20	Coordination with Purdue Facilities – Sidewalk Driving Tour
10/02/20	McGavic Outdoor Power Open House
10/07/20	Boone County Calibration Workshop
10/08/20	INDOT Winamac Unit Calibration Workshop
10/19/20	City of Lafayette Safety Briefing
10/20/20	Hamilton County Safety Briefing
10/26/20	Fulton County Calibration Workshop
10/30/20	Hendrick County Snowplow Roadeo
06/27/21	LTAP Brine and Calibration Workshop
07/14/21	City of Valparaiso and Porter County Calibration Workshop
09/29/21	ASPIRE NSF Research Center
10/06/21	Seymour Calibration Demonstration
10/07/21	Purdue Executive Associate Dean
10/08/21	Fort Wayne Calibration Demonstration
10/13/21	Greenfield Calibration Demonstration
10/15/21	La Porte Calibration Demonstration
10/20/21	Vincennes Calibration Demonstration
10/22/21	Greenfield Brine Training
10/27/21	Crawfordsville Calibration Demonstration
10/29/21	May Mobility Team
11/12/21	Volkswagen and City of Indianapolis Planning Meeting
11/22/21	INDOT Open House
01/11/22	TRB Technical Session

Representative photos from the outreach events can be seen in Figure 8 below. Figure 8a is from the October 8th, 2020 winter maintenance calibration workshop in Winamac, Indiana. This workshop involved INDOT employees and local agencies, including the Pulaski County Highway Department. Due to COVID restrictions, there were 3 workshops with over 70 total participants for the day. At each workshop, there were three training stations including snow plow calibration, brine making and demonstration of the automated precision brining equipment and winter operation telematic dashboards. Figure 8b is from the July 14th, 2021 winter maintenance calibration workshop at the City of Valparaiso Maintenance Facility. The workshop focused on the precision brine equipment and snowplow calibration. The city was particularly interested in the brine equipment for use on city sidewalks and for use by the city parks department for winter maintenance. Figure 8c is from the January 11th, 2022 Transportation Research Board (TRB) technical session where the technology was presented in a lectern session to interested agencies and industry partners. The prototype proved to be a valuable training and educational piece as it allowed the operators to understand the technology and allowed them to provide suggestions on development for future implementation.

a) October 08th, 2020 INDOT Winamac Unit Calibration Workshop

b) July 14th, 2021 City of Valparaiso Calibration Workshop

c) January 11th. 2022 TRB Technical Session

Figure 8. Outreach activities with agencies.

4. OUTPUTS, OUTCOMES, AND IMPACTS

The campus sidewalk prototype provided valuable insight of the technology which enabled the team to scale the deployment to a 5,500-gallon brine tanker used to treat several hundred miles of Indiana Interstates. Figure 9a shows the brine tanker. Figure 9b callout *i* shows the left spray channel, callout *ii* shows the right spray channel and callout *iii* shows the center spray channel. The side channels allow application on multiple lanes and coverage of merge/diverge lanes and exit ramps.

a) Scaling to 5,500-gallon Brine Tanker

b) Equipment Adaptation on 5,500-gallon Brine Tanker

Figure 9. Scaling the prototype to INDOT fleet vehicle.

Further details on this interstate deployment can be found in the Joint Transportation Research Program (JTRP) Technical Report titled "Development of an Intelligent Snowplow Truck that Integrates Telematics Technology, Roadway Sensors, and Connected Vehicle" (*3*). Overall, the study found that on Interstate 465, the interstate surrounding Indianapolis, Indiana, there were over 100 application zones that the operator would need to activate and deactivate material application on each pass around the 50 mile ring road. Since all lanes must be treated in both directions, the drivers travel well over 300 miles pre-treating the lanes in advance of a winter storm and must turn on and off the brine application over 600 times for just one storm. Depending on the traffic and driver workload, it is possible that some application zones can be missed, thus leading to uneven application rates between runs and drivers. The technology ensures consistent application regardless of drivers, traffic, and other conditions.

Implementation of the technology in both the prototype vehicle and the brine tanker has led to many engagement opportunities with winter operation professionals that have been critical partners in refining the technology (Figure 7, Table 1). In addition, several virtual training videos were developed that are summarized in Table 2.

Table 2. Developed demonstration and training material.

Title	Link
Intelligent Snow Plow: Importance of Brine Application	https://doi.org/10.4231/MECJ-AN70
Intelligent Snow Plow: Automated Precision Brine Application	https://doi.org/10.4231/X34H-9Z21
Precision Brine Application for Pre-Treatment and De-icing of Urban Campus Roads and Sidewalks	https://youtu.be/5s0rhkzk6MI
Intelligent Snow Plow: Automated Precision Brine Application on Interstate 465	https://doi.org/10.4231/1MFV-RD45
INDOT Smart Brine Tanker	https://youtu.be/MxjvrbYSbzc

4.1 Outputs – Publications

- Mahlberg, J., Y. Zhang, J. Sneha, J. K. Mathew, H. Li, J. Desai, W. Kim, J. Mcguffey, J. V Krogmeier, and D. M. Bullock. Development of an Intelligent Snowplow Truck That Integrates Telematics Technology , Roadway Sensors , and Connected Vehicle, Joint Transportation Research Program, West Lafayetee, IN, 2021. https://doi.org/10.5703/1288284317355.

- Desai, J., J. Mahlberg, W. Kim, R. Sakhare, H. Li, J. McGuffey, and D. M. Bullock. Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment. *Journal of Transportation Technologies,* Vol. 11, No. 04, 2021, pp. 611–627. https://doi.org/10.4236/jtts.2021.114038.

4.2 Outcomes

- Increased understanding and awareness of transportation issues
- Increases in the body of knowledge
- Improved processes, technologies, techniques and skills in addressing transportation issues
- Enlargement of the pool of trained transportation professionals
- Adoption of new technologies, techniques or practices

4.3 Impacts

- Funding for this project has made possible the adoption of new technology for the winter maintenance industry. Through the project it was found that that brining operations on I-465, the interstate around Indianapolis, had over 600 locations where brine was required. By automating the brining process, this technology removes distractions from the driving task. That way, the driver can focus on traffic and driving the vehicle safely, and know that the correct amount of brine is applied at appropriate locations.
- This technology currently is used for liquid material but then could be expanded to solid materials making winter operation maintenance safer for all road users.

4.4 Technology Transfer

- As shown in Table 2 training material has been developed to demonstrate the technology use and functionality.
- Documents for set-up and operating were also provided to agency users for continued usage.

4.5 Challenges and Lessons Learned

- The adaptation of a agricultural controller for use on interstates presented several problems including:
  - Unable to apply material at speeds greater than 30 mph
  - Loss of satellite signal at overpasses
  - Limitations of file sizes
- Solutions have been identified for each problem through software patches with the controller provider.

5. SYNOPSIS OF PERFORMANCE INDICATORS

5.1 Part I

The research from this research project was disseminated to over 500 people from industry, government, and academia. The research was presented at several conferences, including the

- 2020 Work Truck Show,
- 2020 Purdue Road School Presentation,
- 2020 CCAT Webinar,
- 2021 INDOT Open House Webinar and the
- 2022 Transportation Research Board Annual Meeting in Washington, DC.

During the study period: (a) the PI and graduate research assistance incorporated material from this research in 2 undergraduate graduate transportation-related course (CE 299 and CE 361); (b) 1 graduate students participated in this research project and were funded by this grant during the study period.

5.2 Part II

Research Performance Indicators:

- 1 JTRP technical report and
- 1 peer-reviewed journal article was produced from this project: Desai, J., J. Mahlberg, W. Kim, R. Sakhare, H. Li, J. McGuffey, and D. M. Bullock. Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment. *Journal of Transportation Technologies*, Vol. 11, No. 04, 2021, pp. 611–627. https://doi.org/10.4236/jtts.2021.114038.
- One (1) other research projects was funded by sources other than UTC and matching fund sources.

At the time of writing, there are no new technologies, procedures/policies, and standards/design practices that were produced by this research project.

Leadership Development Performance Indicators: This research project generated

- 10 academic engagements, and
- 30 industry engagements.

Education and Workforce Development Performance Indicators:

- The methods, data and/or results from this study are being incorporated in the INDOT Management Information System, where much of their technical content is stored.
- Several truck drivers were trained to operate the two tractor trailor brine tank deployments.

Technology Transfer Performance Indicators: Regarding this CCAT research project, there were many media stories referencing the research or other related activities by INDOT through Twitter and other social media platforms. Collaboration Performance Indicators: There was collaboration with other agencies as 1 agency provided matching funds.

6. CONCLUSIONS AND FUTURE WORK

Purdue University and industry partners collaborated with agencies to develop an automated brine application system for deicing and pretreatment during winter operations. The system leverages existing precision Real-Time Kinematic (RTK) technology used for spraying chemicals in the agriculture industry to control brine application. This automated brine system enhances safety, reduces driver workload, ensures efficient application of brine, and reduces environmental impact. The team prototyped the system on an electric utility vehicle (for campus roads and urban sidewalks) and subsequently scaled deployment to two 5,500-gallon brine tankers for treating interstates and major arterials with brine. This deployment on the 5500-gallon tanker used on I-465 in Indianapolis eliminated the need for the truck driver to turn on and off a switch 600 times during the pre-treatment of a single storm. Extrapolating to an entire season, this eliminated several thousand driver distraction events and improved the consistency of brine application to bridges.

This innovative research product was demonstrated in almost 40 events/field demonstrations with Indiana agencies and presentations at various conferences, including the TRB annual conference and the Indiana Department of Transportation Open House (Table 1). These demonstrations and presentations helped to increase the understanding and awareness of the efficiency of a smart deicing system for sidewalks (and prospectively, roads and runways in future applications).

Winter maintenance is an important transportation issue at a national level as it severely impacts mobility, transportation efficiency, and safety. Therefore, the research product not only increased the body of knowledge regarding winter maintenance, but also showed how the process of ice control could be facilitated cost-effectively through new technologies. The involvement of students in all aspects of this project helps increase the pool of transportation professionals trained to address problems of winter maintenance. The adoption of this new technology benefits residents and businesses located at areas subject to freeze conditions during the winter season.

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4. Desai, J., J. Mahlberg, W. Kim, R. Sakhare, H. Li, J. McGuffey, and D. M. Bullock. Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment. *Journal of Transportation Technologies*, Vol. 11, No. 04, 2021, pp. 611–627. https://doi.org/10.4236/jtts.2021.114038.

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APPENDIX: JOURNAL PAPERS PUBLISHED FROM THIS WORK

CCAT Project Title: Intelligent Sidewalk De-icing and Pre-treatment with Connected Campus Maintenance Vehicles

Paper 1

Desai, J., J. Mahlberg, W. Kim, R. Sakhare, H. Li, J. McGuffey, and D. M. Bullock. Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment. *Journal of Transportation Technologies*, Vol. 11, No. 04, 2021, pp. 611–627. DOI: 10.4236/jtts.2021.114038.

Abstract:

The Indiana Department of Transportation (INDOT) maintains 29,000 lane miles of roadway and operates a fleet of nearly 1,100 snowplows and spends upwards of $60 million annually on winter maintenance operations. Since winter weather varies considerably, allocation of snow removal and deicing resources are highly decentralized to facilitate agile response. Historically, real-time two-way radio communication with drivers has been the primary monitoring system, but with 6 districts, 29 subdistricts, and over one hundred units it does not scale well for systematic data collection. Emerging technology such as real-time truck telematics, hi-resolution NOAA data, dash camera imagery, and crowdsourced traffic speeds can now be fused into dashboards. These real-time dashboards can be used for systematic monitoring and allocation of resources during critical weather events. This paper reports on dashboards used during the 2020-2021 winter season derived from that data. Nearly 13 million location records and 11 million dash camera images were collected from telematics onboard 1,105 trucks. Peak impact of nearly 1,570 congested miles and 610 trucks deployed was observed for a winter storm on February 15th, 2021 chosen for further analysis. In addition to tactical adjustments of resources during storms, this system-wide collection of resources allows agencies to monitor multiple seasons and make long-term strategic asset allocation decisions. Also, from a public information perspective, these resources were found to be useful to agencies that interface with the media (and social media) during large storms to provide real-time visual updates on conditions throughout the state from pre-treatment, through cleanup.