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Calibration and Confidence in Snowplow Fleet Operations and Fleet Telematics

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Abstract

The Indiana Department of Transportation (INDOT) spends approximately $30 to $60 million a year on deicing salt and operates a fleet of 1,000 winter operations trucks distributed among 140 locations. The entire fleet is now instrumented with location telematics, and all new trucks have integrated dash cameras, salt spreader application rate and plow up/plow down integrated into the telematics link. When winter storms occur, they have varying regional impacts and INDOT monitors several data sources including National Weather Service (NWS) live doppler, National Severe Storms Laboratory's (NSSL) Multi-Radar Multi-Sensor (MRMS) products, road weather monitoring stations, and connected vehicles (CV) that provide roadway segment operating speeds. This paper discusses how telematics has been integrated to provide a comprehensive view of conditions, truck asset locations, and material distribution maps. The telematics identified widely varying salt spreader rates for the same calibration settings and equipment in preliminary analysis. A calibration box is developed to allow offload calibration to occur within 10 minutes without weighing or transporting the fleet vehicle. The method is deployed across six districts at INDOT for over 1000 snowplows. A sampling of eight trucks in the fleet found the proposed calibration method reduced salt application on average of 45%. This paper describes a series of telematics dashboards for managing winter operations and details the methods developed for 140 geographically distributed truck units to conduct simple, fast, and effective calibration.

Keywords

Telematics, Winter Operations, Snowplows, Weather, Calibration

1. Introduction

The Federal Highway Administration's (FHWA) Road Weather Management Program estimates that agencies in the United States spend upwards of $2 billion annually on their winter maintenance operations [1]. The Indiana Department of Transportation (INDOT) spends approximately $30 to $60 million a year on deicing salt and operates a fleet of 1000 winter operations trucks distributed across 140 units in the state. This fleet is managed and operated by approximately 2000 staff and covers approximately 29,000 lane miles of roadways [2].

Recent advances in the availability of traffic data, weather models, and telematics technology coupled with an increase in widespread affordability and accessibility have enabled agencies, including INDOT, to instrument their fleet of maintenance vehicles and utilize statewide tracking dashboards to better monitor and assess the effectiveness of roadway maintenance operations in near real-time [3] [4] [5]. The statewide integration of a Maintenance Decision Support System (MDSS) into its planning operations in the winter of 2008-2009 helped INDOT save nearly $12 million by reducing salt usage by 40.9 percent [6]. Additionally, INDOT operates 33 Road Weather Information Systems (RWIS) that help it better anticipate an impending winter storm event, pre-treat roadways well in advance of the first precipitation event and thus help save on material costs [7]. INDOT also has been utilizing LiDAR-based mobile/portable infrastructure to accurately monitor salt usage during the winter storm season to better estimate current and future material demand [8].

With increased reliance on accurate data for decision-making, it is of utmost importance for agencies to maintain strong institutional practices of sensor calibration as on-board sensors operating in harsh winter weather conditions may be prone to failure and require regular recalibration. This ensures accurate and repeatable measurements and subsequently improves confidence in an agency's day-to-day operations.

The remainder of this paper is structured as follows: Section 2 provides motivation behind this research; the implementation and use of telematics on snowplows are introduced in Section 3; Section 4 covers opportunities to scale fleet operations and calibration by telematics; calibration procedure, practices, and fleetwide implementation are discussed in Section 5 and Section 6, respectively; and finally, a summary of the study conclusions and recommendations for future research are provided in Section 7.

2. Motivation

Over 70% of the population in the US lives in an area that experiences winter weather. To ensure motorist safety and uninterrupted roadway mobility, many agencies use de-icing salt to mitigate impact of winter weather on road travel and accelerate recovery [9] [10]. Winter storm conditions often rapidly deteriorate as a storm progress thus making it difficult for agencies to maintain level of service if accurate data is not provided at the beginning of a storm. **Figure 1(a)** shows night snow-covered roadways, **Figure 1(b)** shows daytime blowing

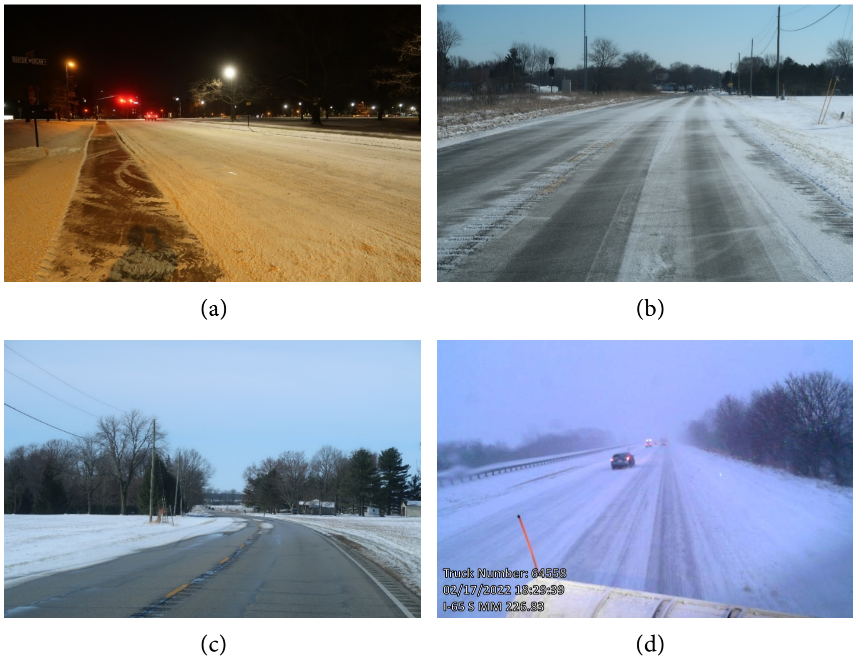


Figure 1. Motivation for snowplow operations and continuous condition monitoring. (a) Snow-covered night conditions; (b) blowing snow conditions; (c) wet-pavement conditions; (d) snow-covered interstate.

conditions, **Figure 1(c)** shows daytime wet-pavement, and **Figure 1(d)** shows a dash camera image from a snowplow during a winter storm event in Indiana. These photos illustrate just a few examples of different conditions motorists and agencies manage during a winter storm.

Salt application amounts depend on many variables including duration of storm, precipitation rate and intensity, ambient and pavement temperature, among other factors. **Figure 2** below shows nationwide salt usage and cost per ton of salt expended by states for the 2018-2019 winter season, with Indiana alone accounting for almost 309,000 tons of salt. With annual salt expenditures in the $30 to $60 million range, it is important for agencies to have systematic and scalable techniques for monitoring salt usage. Furthermore, as agencies seek to incorporate sustainable practices, accurately tracking salt usage, particularly in sensitive water sheds, becomes very important.

INDOT annual salt expenditures for the past 5 seasons are shown in **Table 1** [12]. Improved efficiencies in the application process can dramatically impact expenditure in an agency's road salt budget.

Agencies can ensure efficient material application through a properly calibrated fleet. **Figure 3** below shows an example of salt residue observed on the roadway after a winter storm event. Although exact cause of this excess salt is not clear, this often occurs when the hydraulic driven salt spreader on the truck is not properly calibrated. In addition to being costly, creating unnecessary environmental impact, it also can make viewing the lane lines difficult for both human drivers and advanced driver assistance systems (ADAS) that rely on detecting lane markings [13].

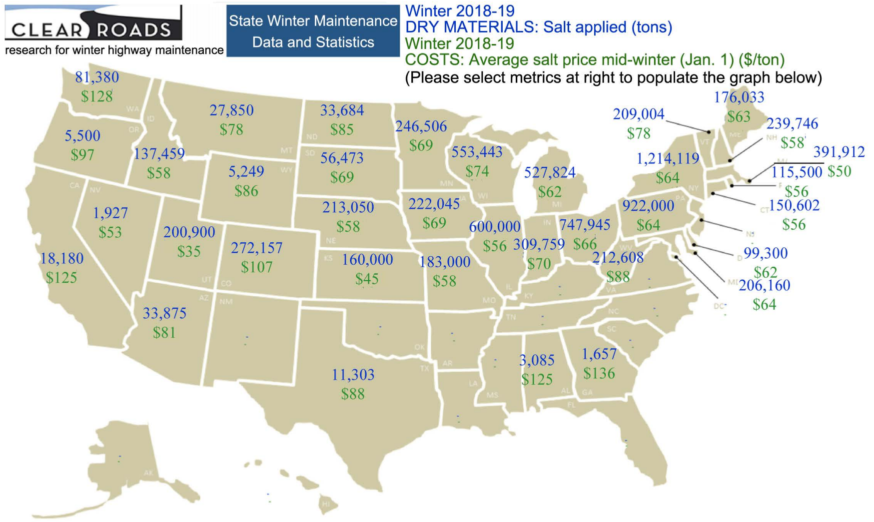


Figure 2. Salt usage and cost statewide across the US in 2018-2019. Image source: annual survey of state winter maintenance data. Clear roads. https://clearroads.org/winter-maintenance-survey [11].

Figure 3. Salt residue from over-applied salt.

Table 1. Annual INDOT fiscal year road salt cost.

Year	Total Salt Costs
2017-2018	$30,590,000
2018-2019	$41,719,000
2019-2020	$56,367,000
2020-2021	$46,352,000
2021-2022	$43,015,000

The Ohio Department of Transportation found the accuracy for bed scale sensors embedded on its snowplows varied from 2.2% to 8.4% for calibrated and uncalibrated sensors respectively [14]. It is imperative for a snowplow to disperse the optimal amount of material at a given speed to prevent resource waste as well as over-application resulting in hazardous travel conditions for motorists. Studies have observed that a mere 5-mile increase in snowplow speed over the prescribed value could results in a 66% loss in material [15].

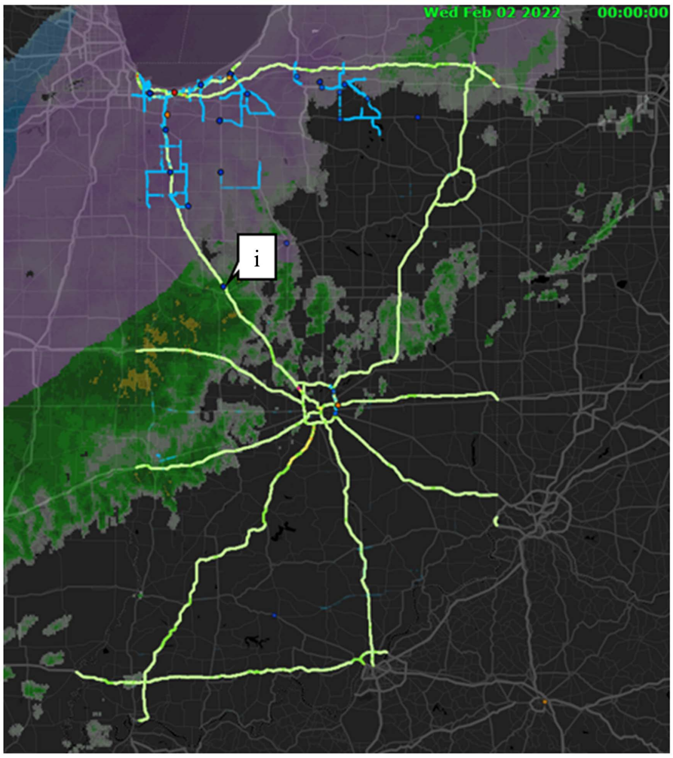
3. Dashboards for Monitoring Fleet Deployment and Mobility Impacts

The use of telematics on snowplows provides valuable insight for systemwide deployment and monitoring. Merging real-time truck telematics, dash camera imagery, crowdsourced traffic speeds, and high-resolution National Weather Service (NWS) data provides decision makers with the ability to make data-driven resource allocation decisions during a winter storm event. **Figure 4** below shows an integrated web interface of these data sources utilized by INDOT with doppler reflectivity, interstate traffic speeds, snowplow locations (solid blue circles), and salt application rates as light blue lines [3]. **Figure 4(a)** shows the beginning of a winter storm event on February 2nd, 2022, at 12:00 am. Callout i refers to a snowplow operating on I-65 and at that moment in time there were 82 trucks deployed statewide. **Figure 4(b)** shows conditions as of 6:00 pm on February 3rd, 2022, and at this moment there is a clearly discernible statewide impact of winter weather in response to which 530 trucks were deployed. This dashboard integrates multiple data sources to provide a holistic view of the winter storm impact in real-time, which can enable decision makers to allocate resources in an efficient manner.

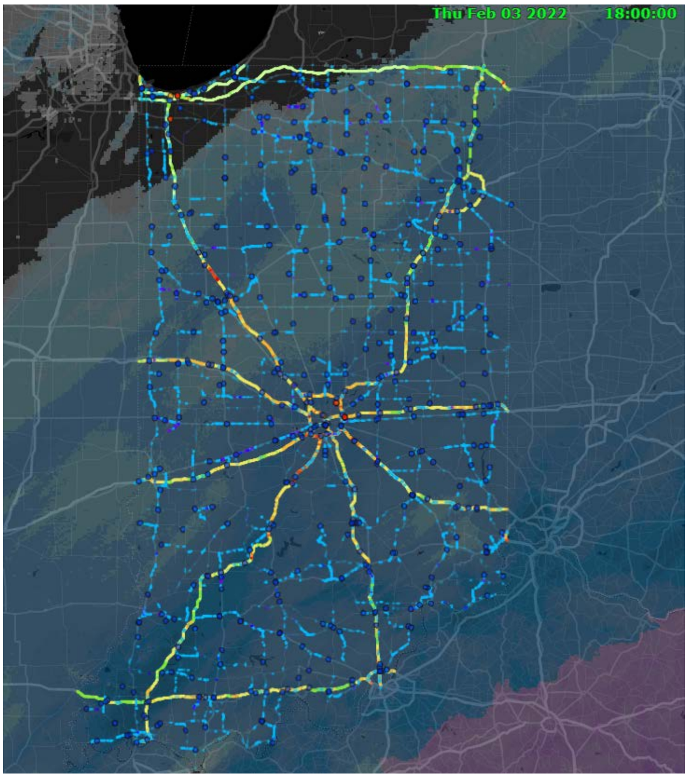
After a winter storm event, district and agency-level after-action reports can be created to determine systemwide impact and strategize future deployment. **Figure 5(a)** below shows the number of miles of interstate operating below 45 miles per hour and **Figure 5(b)** shows the number of trucks deployed each hour. The four visible peaks each represent a winter storm event from January 31st, 2022, to February 28th, 2022 (callout i - iv), callout i had the most impact statewide with over 1000 miles of interstate impacted and 851 unique trucks deployed. Callout iii shows a winter storm event that had the greatest impact on the La Porte district.

For an agency to be able to mitigate winter storm impacts, it is important to have a properly calibrated and functioning fleet of snowplows. A well calibrated snowplow (**Figure 6**) should have consistent flow of material while applying (callout i) and should be able to distribute material to cover the entire travel lane (callout ii) and consider ice hazards on bridges (callout iii).

Due to the varying conditions of a snow storm the application amount may vary dynamically over the course of a storm. **Table 2** is a salt application and action table that recommends an application rate based on pavement temperature and weather conditions provided by the New Hampshire Best Management Practices [16]. It should be noted that once pavement temperature drops below 15 degrees Fahrenheit, salt application is not recommended as its effectiveness drastically decreases.



(a)



(b)

Figure 4. Snowplow fleet deployment for February 02-04, 2022, winter storm. (a) 12:00 AM, Wed Feb 02, 2022-82 Trucks Deployed Statewide; (b) 6:00 PM, Thu Feb 03, 2022-530 Trucks Deployed Statewide.

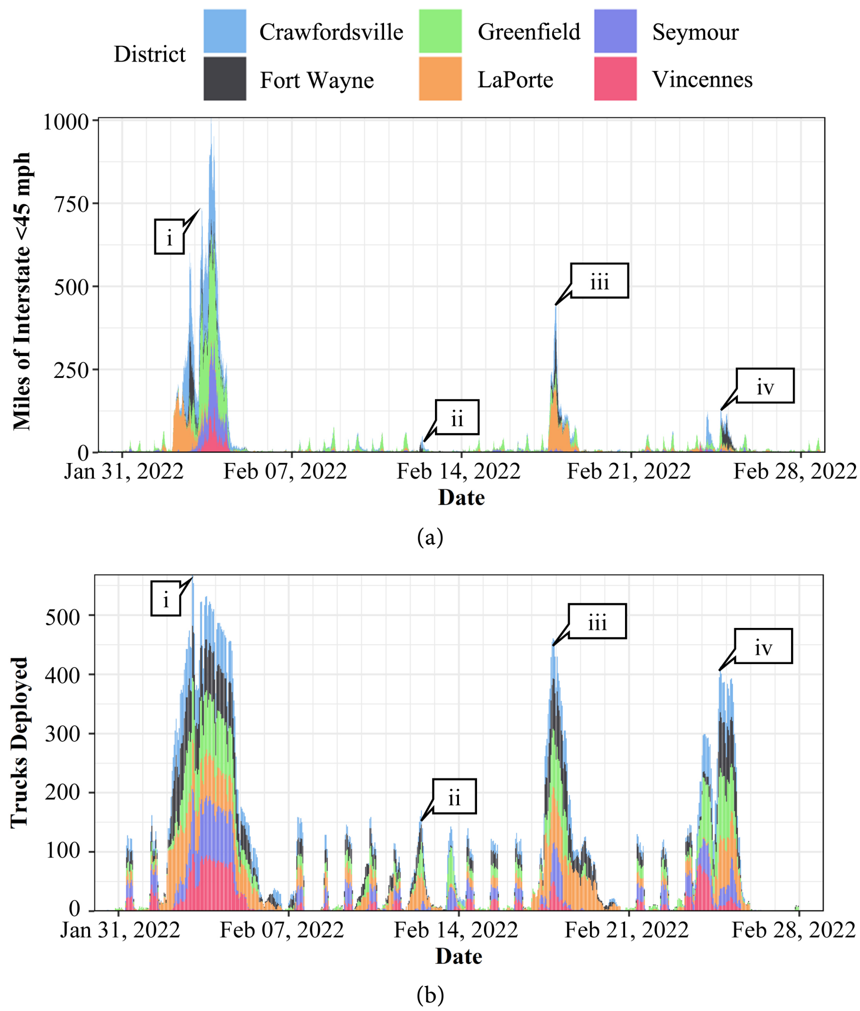


Figure 5. Winter storm deployment and interstate mobility impact for Jan 31st-Feb 28th, 2022. (a) Miles of Indiana Interstates operating below 45 mph, colored by INDOT District; (b) INDOT snowplow deployment by hour.

Figure 6. Application of appropriate treatment rates.

Table 2. Recommended application rates for deicing.

Pavement Temp. (˚F) and Trend (↑ ↓)	Weather Condition		Maintenance Actions			Application Rate Dry Salt (lbs/per lane mile)
	Snow	Freezing Rain	Plow	Apply Materials Intersection Only	Apply Materials All Routes	
>30 ↑	✓		✓	✓		150
		✓			✓	200
30 ↓	✓		✓		✓	200
		✓			✓	225
25 - 30 ↑	✓		✓		✓	225
		✓			✓	225 - 275
25 - 30 ↓	✓		✓		✓	75
		✓			✓	275 - 300
20 - 25 ↑	✓	✓	✓		✓	275 - 300
20 - 25 ↓	✓		✓		✓	300 - 325
		✓			✓	325 - 400
15 - 20 ↑	✓		✓		✓	325
		✓			✓	325 - 400
15 - 20 ↓	✓	✓	✓		✓	350
0 to 15 ↑ ↓	✓		✓			Not recommended
<0	✓		✓			Not recommended

Source: pass the salt: efficient snow & ice management 2018. https://www.uvm.edu/seagrant/sites/default/files/uploads/Santoso_GreenSnowProHandouts_sm.pdf [16].

4. Early Implementation Opportunities Identified by Telematics

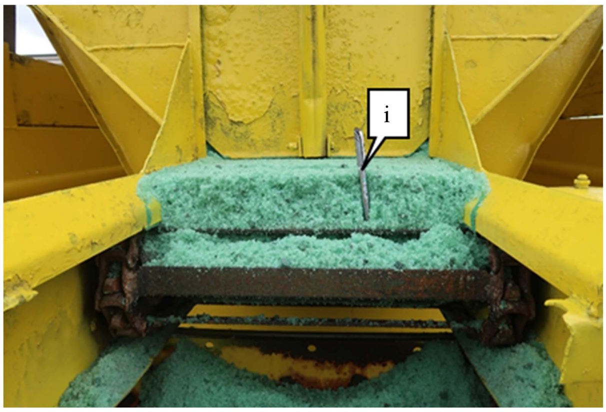
Current means of snowplow sensor calibration require scales to weigh the truck before and after calibration or determine offloaded salt amounts through other means. This process can take upwards of 1 - 2 hours and can be expensive to scale for a fleet of 1000 trucks. The new method proposed in the next section eliminates the need for weighing the truck altogether and reduces the time needed to calibrate to 10 minutes.

5. Calibration Protocol

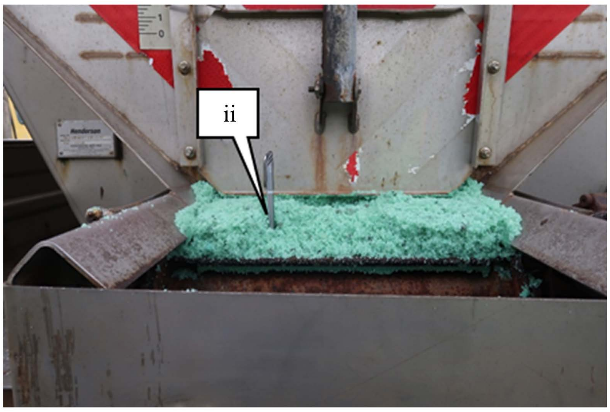
5.1. Legacy Methods

INDOT fleet of over 1000 snowplows with varying types of spreader controllers, and material spreading mechanisms. Even the same type of controller and spreader may have slight variations in calibration techniques and spread rates. Figure 7(a) below shows a V-box salt spreader with a conveyor belt. Callout i refers to three inches of salt that is offloaded from this truck. Figure 7(b) shows another V-box with a conveyor belt and callout ii shows two inches offloaded. These trucks have identical spreader controllers and have the same calibration inputs, but at a designated rate of 250 lbs per mile the yellow truck (Figure 7(a)) will apply more material than the silver truck (Figure 7(b)). This difference reveals the need for calibration and standard practices, including gate height.

The standard calibration methods provided by controller manufacturers have three steps that include calibrating the spinner/auger (if equipped), the offload amount, and the speed of the vehicle. These three components provide a system calibration that ensures driving at various speeds on the roadway that the system offputs the correct amount of material. The most time-consuming part of calibration is the offload amount as it requires running the system until almost a ton of material is offloaded and then determining the amount of material offloaded. One method can be seen in Figure 8(a), which is measuring the truck before offloading, offloading the truck, and reweighing the truck afterwards. This method



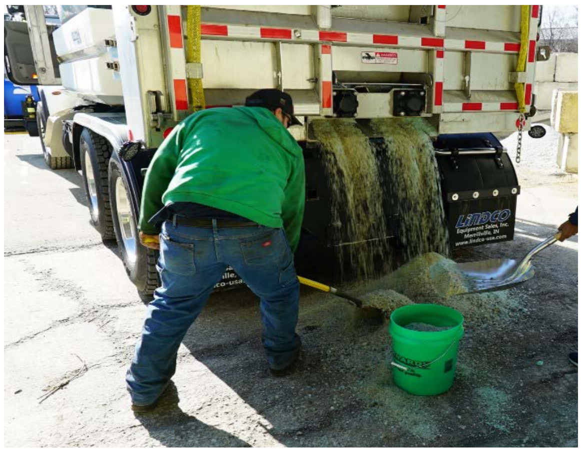
(a)



(b)

Figure 7. Motivation for standard calibration practices. (a) Salt Offload from INDOT Spreader with Gate Opened 3"; (b) Salt Offload from INDOT Spreader with Gate Opened 2".

(a)



(b)

Figure 8. Legacy methods for calibrating offload amounts. (a) Weigh Truck for Offload Amount; (b) Shovel Buckets for Offload Amount.

is time and labor intensive as many facilities do not have scales on-site and requires driving to the nearest weigh station before and after offloading. Another way is to have local law enforcement assist with their scales on-site. Aside from weighing the truck an alternative method is shoveling the salt into a container and counting or weighing each container to get the total offload amount (**Figure 8(b)**). These methods are both very time consuming and labor intensive.

5.2. Proposed Calibration Method

A novel volumetric-based calibration procedure was developed to reduce calibration time, increase scalability, and reduce cost for agencies. **Figure 9** shows the prototype (*i.e.* "calibration box"), a bottomless box constructed out of aluminum sign backing that holds a known volume and assumed weight accounting for the moisture content of the salt. The offload calibration determines the weight of the truck before and after offload and inputs the offloaded amount into the controller. The calibration box eliminates the need for weighing the truck, allowing agencies to calibrate a truck in less than 10 minutes.

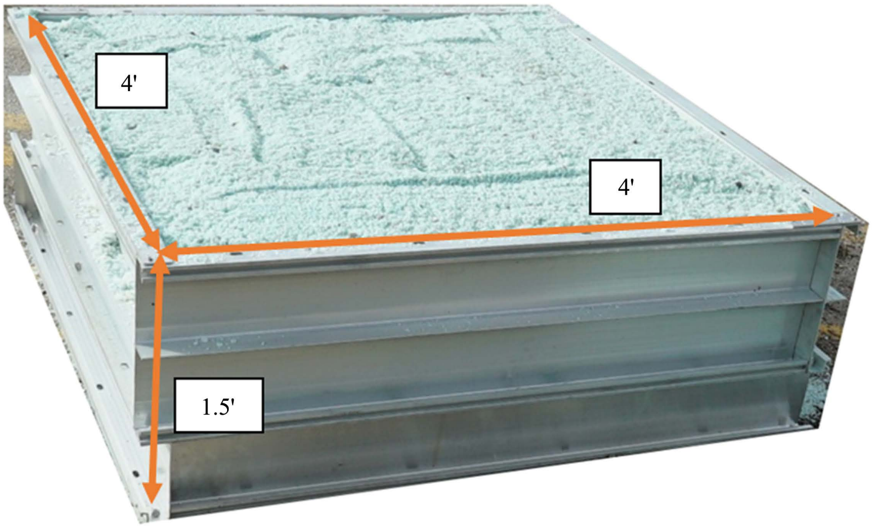


Figure 9. Calibration box for new calibration procedure.

Use of the calibration box can be seen in Figure 10 below. The procedure begins with Figure 10(a) where the salt is offloading into the box. Once the box is full the offloading stops, and the operator must level the salt to ensure it is full (Figure 10(b)). The operator can then input the offload amount into the controller and remove the calibration box (Figure 10(c)). Once the offload calibration is complete the operator can complete the final step of the calibration process which is the speed calibration (Figure 10(d)). A complete training guide that was developed for implementation can be found in Table A1 in the Appendix.

6. Implementation and Discussion

To aid in the new calibration procedure, training sessions conducted over six workshops were held in each district of INDOT. Table 3 below shows the date of the calibration workshop in each district and the number of trucks from each district. The calibration workshops had over 200 INDOT employees in attendance. Handouts, videos, and other training materials were developed to aid in calibration which was then applied to INDOT's fleet of over 1000 snowplows. The training material provided is listed in Table A1.

The calibration workshops calibrated the complete system of the snowplow with a focus on calibrating the offload amount using the calibration box. While conducting these training sessions, the initial calibration inputs were noted and after the offload calibration the same calibration value was recorded. Table 4 shows a summary of 8 trucks and their initial calibration value, the post calibration value, and the percent change of offload material. These values were taken directly from the manufacturer controller and for 7 out of the 8 trucks the percent change in offload amount reduced by over 45%. This reduction amounts to a significant reduction in costs and material usage for the agency when scaled statewide.

(a) (b) (c) (d)

Figure 10. Proposed calibration procedure utilizing the calibration box. (a) Place box under chute and offload into the box; (b) level the box and enter the offload amount in the controller; (c) remove box and return the salt to the inventory; (d) perform the speed calibration.

Table 3. Calibration workshop trainings.

Date	District	Number of Trucks
10/06/2021	Seymour	172
10/08/2021	Fort Wayne	166
10/13/2021	Greenfield	193
10/15/2021	La Porte	223
10/20/2021	Vincennes	166
10/27/2021	Crawfordsville	170

Table 4. INDOT spreader controller calibration values.

Truck Number	Before Calibration	After Calibration	% Change in Salt Application
61,208	15.0	7.1	−52.6%
64,377	14.3	7.2	−49.7%
63,536	15.0	7.1	−52.6%
64,124	12.7	6.8	−46.5%
66,641	15.0	7.3	−51.3%
62,457	15.0	7.0	−53.3%
61,004	8.6	7.1	−17.4%
64,056	13.9	7.4	−43.2%

7. Conclusions and Future Scope

This study showed the use of fleet telematics to monitor winter weather maintenance activities and discussed the importance of both telematics and well-calibrated systems to effectively allocate assets and resources. A calibration box was prototyped which allowed offload calibration to occur within 10 minutes without weighing or transporting the fleet vehicle. The method was deployed across six districts at INDOT for over 1000 snowplows. A sampling of eight trucks in the fleet found the proposed calibration method reduced salt application on average of 45%.

Calibrating the trucks enabled the accurate monitoring of application rates and increased confidence in the data for decision making. These results and implementation suggest the proposed calibration method is effective and can be utilized by agencies to calibrate their equipment. Longer-term continued calibration material and training will ensure knowledge transfer and enable agencies to effectively reduce winter mobility impacts while being environmentally responsible with material application. Additionally, further research on identifying telematics use cases and implementation should be considered for developing fleet utilization metrics, resource allocation and redeployment during a winter storm event.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix

Table A1. Calibration training resources.

Title	Link
Calibration Workshop Training Time-lapse	https://doi.org/10.4231/XBET-8A88
How to Calibrate the Volumetric Box	https://doi.org/10.4231/RNV9-8F21
Muncie Advantage + Controller Calibration	https://doi.org/10.4231/9S3K-9J39
Muncie Omni Controller Calibration	https://doi.org/10.4231/CRCY-FF55
Certified Power Freedom 2 Controller Calibration	https://doi.org/10.4231/7015-1X74
FORCE America 5100ex Controller	https://doi.org/10.4231/NEY0-9F04
10/06/2021 Seymour Calibration Workshop	https://youtu.be/1pZQSHcoMhc