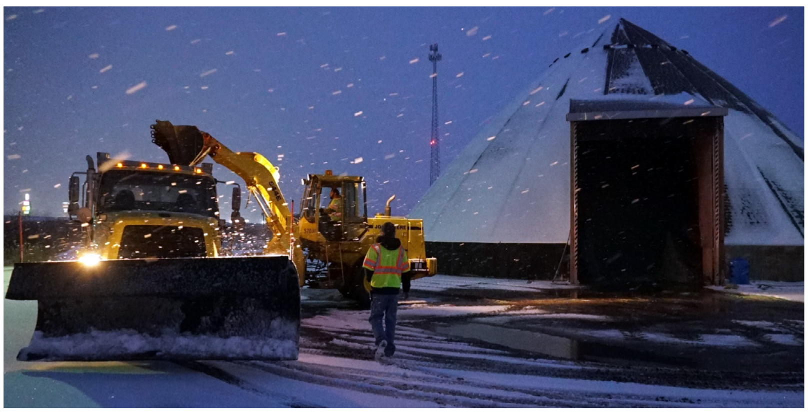
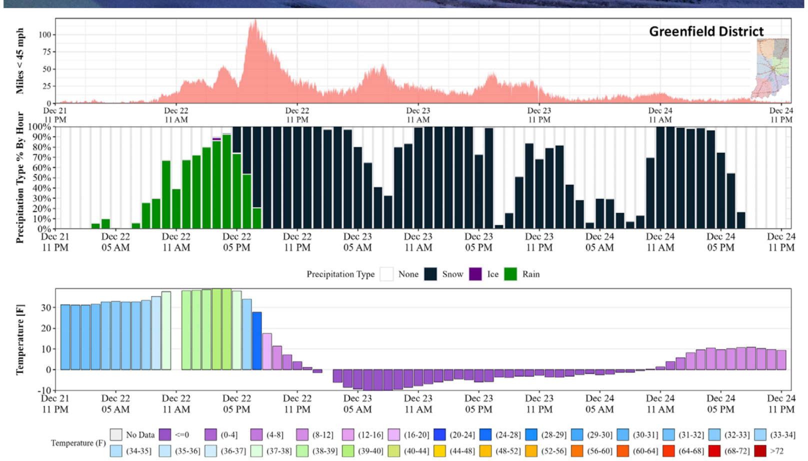
JOINT TRANSPORTATION
RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Crowdsourcing/Winter Operations Dashboard Upgrade





Justin A. Mahlberg, Jairaj Desai,
Haydn Malackowski, Howell Li, Jijo K. Mathew,
Rahul Suryakant Sakhare, Timothy Wells, Darcy M. Bullock

SPR-4603 • Report Number: FHWA/IN/JTRP-2023/21 • DOI: 10.5703/1288284317652

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JTRP-2023/21		

4. Title and Subtitle
Crowdsourcing/Winter Operations Dashboard Upgrade

5. Report Date
August 2023

6. Performing Organization Code

7. Author(s)
Justin A. Mahlberg, Jairaj Desai, Haydn Malackowski, Howell Li, Jijo K. Mathew, Rahul Suryakant Sakhare, Timothy Wells, Mike Nichols, and Darcy M. Bullock

8. Performing Organization Report No.
FHWA/IN/JTRP-2023/21

9. Performing Organization Name and Address
Joint Transportation Research Program
Hall for Discovery and Learning Research (DLR),
Suite 204 207 S. Martin Jischke Drive
West Lafayette, IN 47907

10. Work Unit No.

11. Contract or Grant No.
SPR-4603

12. Sponsoring Agency Name and Address
Indiana Department of Transportation (SPR)
State Office Building
100 North Senate Avenue
Indianapolis, IN 46204

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract
INDOT has recently completed the deployment of Parsons telematics-based dash-cameras, automatic vehicle locator (AVL) positions, and spreader rate monitoring across their winter operations fleet. The motivation of this study was to develop dashboards that integrate connected vehicle data into the real-time monitoring and after-action review of winter storms. Each month approximately 13 billion connected vehicle records are ingested for the state of Indiana and almost 99 billion weather data records are ingested nationwide in 15-minute intervals. This study developed techniques to utilize this connected vehicle data and weather data to monitor real-time mobility of interstates and post storm after-action assessments to identify improvement opportunities of winter operations activities. In multiple instances, these agile reviews have influenced operational changes in snow removal and maintenance around the state, leading to a marked improvement in observed mobility and safety.

17. Key Words
connected vehicle data, winter weather, winter operations, enhanced probe data, dashboards, weather impact

18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

RECOMMENDED CITATION

Mahlberg, J. A., Desai, J., Malackowski, H., Li, H., Mathew, J. K., Sakhare, R. S., Wells, T., & Bullock, D. M. (2023). *Crowdsourcing/winter operations dashboard upgrade* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2023/21). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317652

AUTHORS

Justin A. Mahlberg, PhD
JTRP Transportation Research Engineer
Lyles School of Civil Engineering
Purdue University

Jairaj Desai, PhD
JTRP Transportation Research Engineer
Lyles School of Civil Engineering
Purdue University

Haydn Malackowski
Graduate Teaching Assistant
Lyles School of Civil Engineering
Purdue University

Howell Li
JTRP Principal Research Analyst
Lyles School of Civil Engineering
Purdue University

Jijo K. Mathew, PhD
JTRP Transportation Research Engineer
Lyles School of Civil Engineering
Purdue University

Rahul Suryakant Sakhare
Graduate Research Assistant
Lyles School of Civil Engineering
Purdue University

Timothy Wells, PE
Research Section Manager
Indiana Department of Transportation

Darcy M. Bullock, PhD, PE
Lyles Family Professor of Civil Engineering
JTRP Director
Lyles School of Civil Engineering
Purdue University
(765) 494-2226
darcy@purdue.edu
Corresponding Author

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure. https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at http://docs.lib.purdue.edu/jtrp/.

NOTICE

EXECUTIVE SUMMARY

Motivation

INDOT has recently completed the deployment of Parsons telematics-based dash-cameras, automatic vehicle locator (AVL) positions, and spreader rate monitoring across their winter operations fleet. The motivation of this study was to develop dashboards that integrate connected vehicle data into a real-time monitoring and after-action review of winter storms.

Study

Each month approximately 13 billion connected vehicle records are ingested for the state of Indiana and almost 99 billion weather data records are ingested nationwide in 15-minute intervals. This study developed techniques to use connected vehicle data and weather data to monitor the real-time mobility of interstates and post storm after-action assessment to identify improvement opportunities for winter operations activities.

Results

Indiana has established a national reputation for winter operations and for utilizing various data sources in the decision-making process. In 2020, INDOT equipped their entire snowplow fleet with telematics to provide dash-camera images, locations, and spreader rate controls. Combining this extensive data source with connected vehicle and weather data provided a thorough analysis of winter storm operations and post-storm recovery. The findings from this project were used to guide INDOT winter operations staff. The following approaches have been adopted.

- Widespread use of the "heatmap" by both district and sub district INDOT staff for monitoring winter weather events.
- Widespread use of the "Deltaspeed" dashboard for real time monitoring of the position of winter operations vehicles during a storm along with high resolution doppler data and a real time road speed traffic layer.

The graphic summaries derived from connected snowplows, connected passenger cars, and weather data help facilitate constructive dialogue between a variety of field staff, agency decision makers, and public safety colleagues. These dashboards with objective road condition data provide a robust foundation for both field staff and operational decision makers during a winter storm and are rapidly being recognized and adopted by peer states.

Implementation

As indicated above, much of this research has already been integrated into agency business processes. One of the critical factors in this was a strong commitment by maintenance to calibrate salt spreaders and proactively maintain the telematics equipment in advance of each winter season. Although these activities will always be a challenge in a harsh winter operations environment, sustained maintenance of these critical items will be important for long term implementation and impact.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. PROJECT OVERVIEW

The Indiana Department of Transportation (INDOT) has equipped telematics and dash-cameras on their fleet of almost 1,100 snowplows to relay visual road condition information and facilitate data-driven decisions for winter weather maintenance (Mahlberg, Zhang, et al., 2021). The development of dashboards since the installation of telematics devices in 2020 has helped streamline operations and provide near real-time tools that decision makers use for redeployment and support during a winter storm event (Desai et al., 2021). These dashboards originally began with the incorporation of connected vehicle data and INDOT ITS cameras but were expanded to include National Weather Service data and friction data from vehicles on selected routes. These tools are used in near real-time for redeployment as well as a training tool through after-action reports to better prepare for the next winter storm event.

Several working sessions and webinars were held over the course of this project to facilitate dissemination of results. These training sessions were also integrated into 12 calibration workshops over the 2021–2022 and 2022–2023 winter seasons. In addition, the following is a list of papers prepared in part during this project to support implementation and outreach.

- Desai, J., Mahlberg, J., Kim, W., Sakhare, R., Li, H., McGuffey, J., & Bullock, D. M. (2021). Leveraging telematics for winter operations performance measures and tactical adjustment. *Journal of Transportation Technologies*, *11*(4), 611–627. https://doi.org/10.4236/jtts.2021.114038
- Mahlberg, J. A., Desai, J., Li, H., Sakhare, R. S., Wells, T., & Bullock, D. M. (2022). Calibration and confidence in snowplow fleet operations and fleet telematics. *Journal of Transportation Technologies*, *12*(4), 696–710. https://doi.org/10.4236/jtts.2022.124040
- Desai, J., Mathew, J., Li, H., Sakhare, R., Horton, D., & Bullock, D. M. (2022). *National mobility analysis for all interstate routes in the United States: August 2022*. Indiana Mobility Reports, 2022. https://doi.org/10.5703/1288284317585
- Desai, J., Mathew, H. Li, R. S. Sakhare, D. Horton, & D. M. Bullock. (2022). *National mobility analysis for all interstate routes in the United States: December 2022*. https://doi.org/10.5703/1288284317591

2. DATA ELEMENTS

Several connected vehicle data sources were used by this study towards developing tools for winter operations management. Traffic speeds were obtained from third party data suppliers in the form of passenger car and commercial truck trajectories as well as segment-based aggregated speeds. Real-time telematics information was recorded from INDOT's fleet of snowplows including geolocation, material application information as well as live dash-camera imagery at 1-minute frequency. Temperature and precipitation values from the National Oceanic and Atmospheric Administration were incorporated into traffic dashboards to provide a holistic view of prevailing roadway conditions (NOAA, n.d.).

Connected vehicle data at the trajectory and roadway segment level was ingested from the third-party data providers Wejo (starting July 1, 2019) and INRIX (dating to January 1, 2014). Connected vehicle driver events were provided by Wejo for selected periods in 2019, 2020, 2021 and continuously starting January 1, 2022. Snowplow telematics data including locations, material application rates, engine attributes and dashboard camera views were ingested from data provider Parsons (starting June 6, 2020). Weather data was made available from the National Oceanic and Atmospheric Administration (starting October 1, 2022). Friction data onboard production vehicles were ingested in collaboration with Nira Dynamics (starting October 1, 2021). Table 2.1 summarizes the data sources and approximate number of records.

TABLE 2.1
Data Ingestion Summary

Data Source	**Data Description**	**Number of Records**
Wejo	Passenger Car Trajectories	421.35 B
	Truck Trajectories	36.96 B
	Driver Events	6.72 B
INRIX	Segment-based Speeds	132.08 B
Parsons	Snowplow Telematics	327.55 M
National Oceanic and Atmospheric Administration	High Resolution Rapid Refresh	472.45 B
Nira Dynamics	Friction Data	224.88 M

3. INDIANA STATEWIDE WINTER OPERATIONS

3.1 Winter Storm After-Actions

A series of after-action interstate mobility reports were generated as part of this project for significant winter weather events over the past two winter seasons. The reports typically cover a 3-day period, conventionally aimed at including a day before and after the storm to show pre-storm preparations and post-storm traffic recovery in addition to mobility impacts during the storm for 10 interstate routes in Indiana. A summary of these reports by season is shown by Table 3.1. A library of after-action reports can be found here: https://doi.org/10.4231/ACMF-JY72.

An after-action report was created after each storm event to provide context in terms of mobility, statewide storm impact, and provide measure of precipitation type and amount over the winter storm. An overview illustrating the severity and duration for winter storm events for the 2022–2023 winter season can be observed in Figure 3.1. Figure 3.1a illustrates vehicle speeds operating below 45 mph on interstates and Figure 3.1b shows snowplow deployment counts during that same time period. Callout i shows the December 23rd, 2022, snow event which had the largest statewide impact and will be the storm of reference for the dashboard developments and use cases presented in the sections that follow.

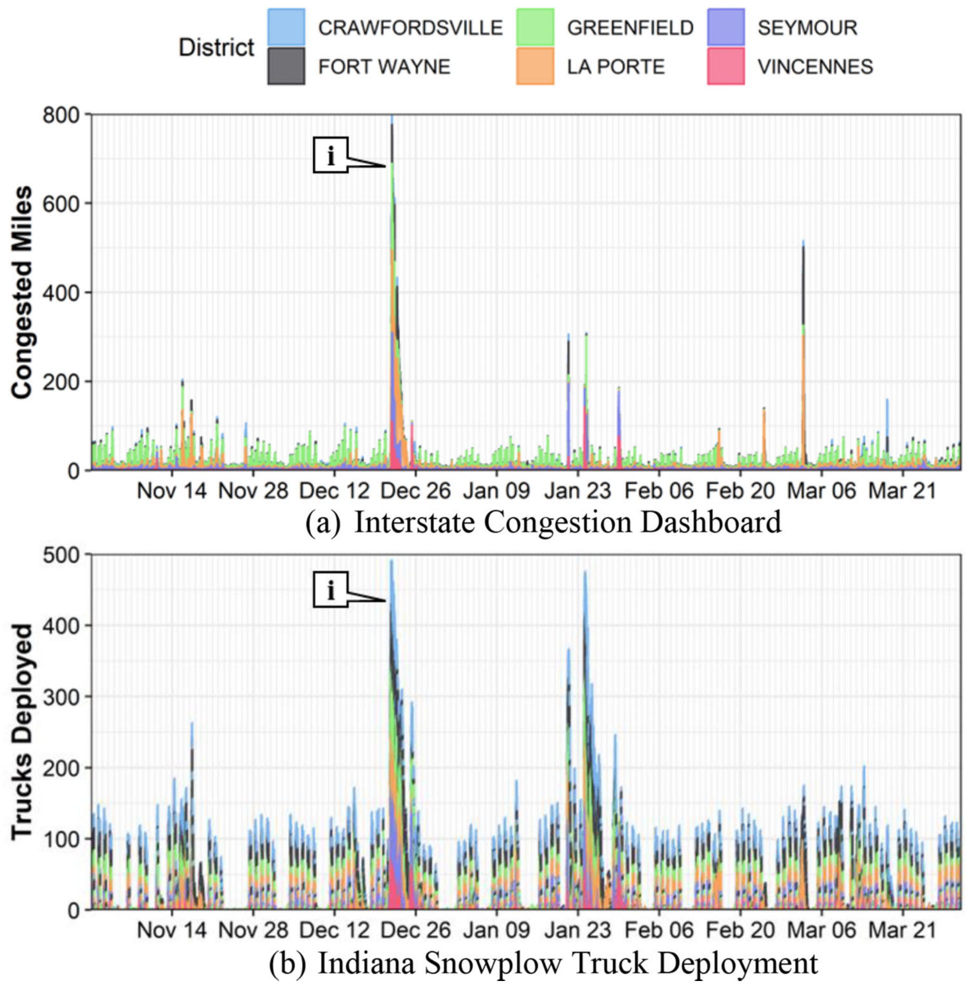
3.2 December 2022 Case Study

One of the dashboards developed in part during this project presents a unified look at weather, traffic speeds, state maintenance vehicle telematics all in one real-time visualization referred to as "Deltaspeed." Figure 3.2 shows four sample visualizations from this dashboard. Figure 3.2a shows a view of Indiana on December 22nd, 2022, at 12:00 PM before the storm hits. Figure 3.2b and 3.2c show 6-hour increments as the winter storm progresses through the state with Figure 3.2d showing conditions on December 23rd at 6:00 AM when the storm had mostly passed the state. During the winter storm, solid blue circles represent active snowplows on the roadway with sky blue trails indicating material application associated with their maintenance operations. The locations of state maintenance vehicles are depicted by red circles. Additionally real-time connected vehicle speeds on the interstate system are shown and colorized by speed with green operating at or above 55 mph and yellow to red operating below 55 mph. Accompanying time-lapse animations of this dashboard view as each winter storm progressed through the state are included as a link in the respective figure caption. INDOT has already developed solutions helping them inventory their salt stockpiles in near real-time and with the aid of snowplow telematics can now monitor real-time material application on snow routes (Mahlberg, Manish, et al., 2022; Manish et al., 2022).

Maintenance activities in the state of Indiana are managed by six districts (as well as sub district and unit level). For the purposes of summarizing operations, the district level grouping is used on most dashboards. The dashboards show the storm impact in terms of reduced vehicle speeds, precipitation by type, and temperatures (Figure 3.3). Figure 3.3a shows the Crawfordsville district (callout i) and the impact of all interstate regions in the district including parts of I-65, 70, and 74. area of the state. The peak impact of the storm can be seen between 5–8 PM on December 22nd, 2022. Just before 5 PM in the Crawfordsville district the precipitation switched from a rain/snow mix to 100% snow and temperatures fell below freezing (noted by callout ii). Figure 3.3b shows a similar graphic as Figure 3.3a but with a focus on the Greenfield district in the East Central of the state. Callout iii shows the Greenfield district location. Similar to Crawfordsville, precipitation changes to snow and temperature drops leading to a spike in vehicle speeds below 45 mph around 7 PM (callout iv, 2 hours later than Crawfordsville). This dashboard shows key decision makers how the storm progresses through the state and

TABLE 3.1
Summary of after-action reports

Winter Season	After-Action Reporting Days	Link
2021–2022	December 06–08, 2021	https://doi.org/10.4231/VQYN-1T24
	January 01–03, 2022	https://doi.org/10.4231/SDDJ-K923
	January 16–18, 2022	https://doi.org/10.4231/ZW7A-7291
	February 02–04, 2022	https://doi.org/10.4231/H4XP-RZ98
	February 16–18, 2022	https://doi.org/10.4231/FFVJ-FE82
	February 23–25, 2022	https://doi.org/10.4231/JQ8J-7807
2022–2023	December 22–24, 2022	https://doi.org/10.4231/XAXH-8N13
	January 21–23, 2023	https://doi.org/10.4231/CAD0-2985
	January 24–26, 2023	https://doi.org/10.4231/WZ91-PF09
	February 16–18, 2023	https://doi.org/10.4231/FFCN-HM31
	March 02–04, 2023	https://doi.org/10.4231/RJYS-VN71
	March 10–12, 2023	https://doi.org/10.4231/TC9N-0Z36
	March 13–15, 2023	https://doi.org/10.4231/RJQ8-YT10
	March 17–19, 2023	https://doi.org/10.4231/4NPC-1735



(a) Interstate Congestion Dashboard

(b) Indiana Snowplow Truck Deployment

Figure 3.1 Indiana statewide mobility and truck deployment for the 2022–2023 winter season categorized by INDOT district.

how quickly conditions change on snow routes allowing them the ability to prepare agile responses to ever changing conditions.

3.2.1 Indiana Interstate 70 Analysis

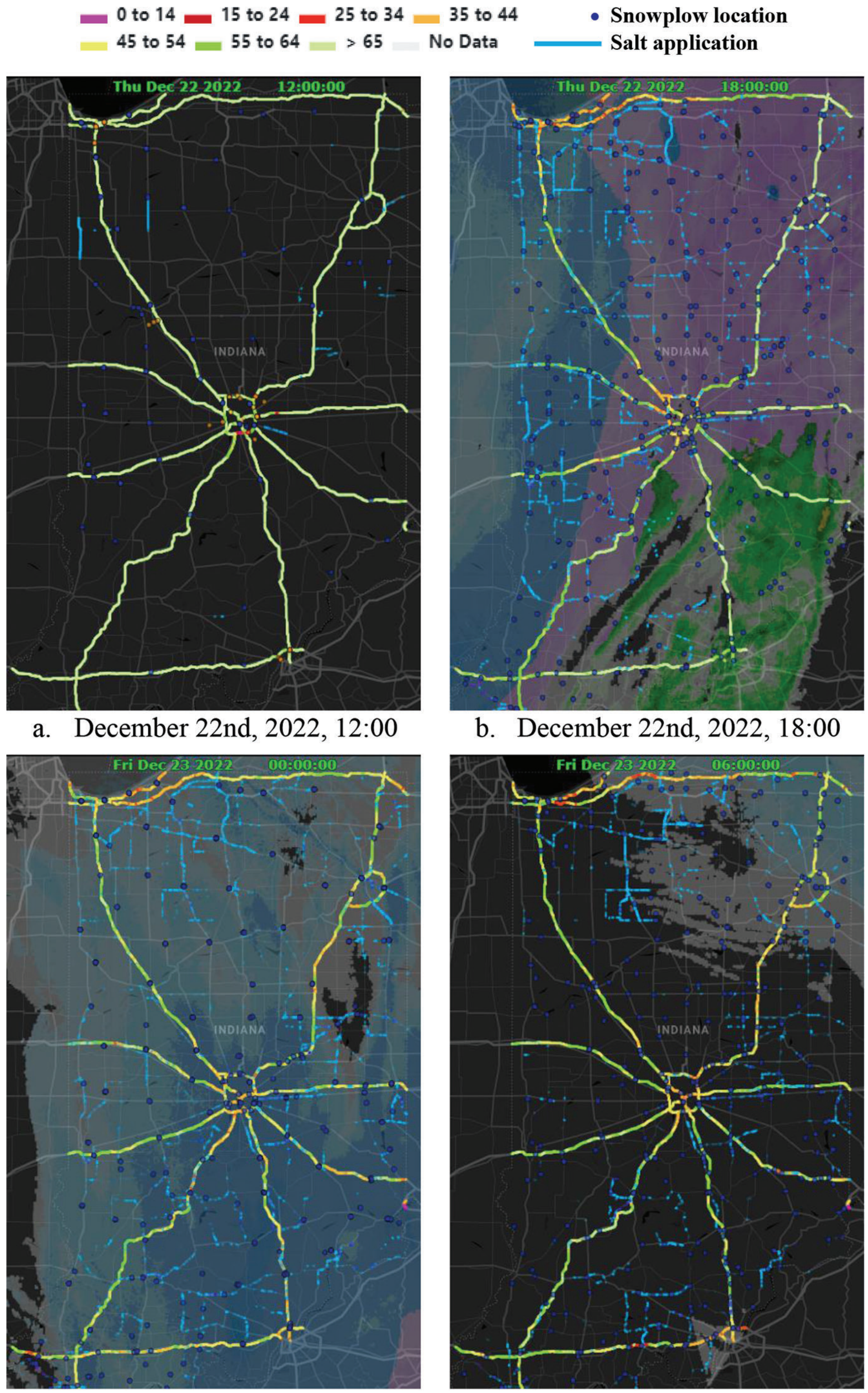
Using similar data, a dashboard that provides specific information on specific interstates also incorporates telematics to provide route level information. Figure 3.4 shows connected vehicle trajectories on I-70 across Indiana in both the eastbound and westbound directions. Mile marker 0 lies on the Indiana-Illinois border and mile marker 157 lies on the Indiana-Ohio border. The horizontal axis shows the time of day, and the vertical axis shows the corresponding mile marker on the interstate. Each vehicle trajectory is colorized by vehicle speeds with green at or above the speed limit and other colors showing reduced travel speeds. The blue lines represent a snowplow trajectory on the interstate. Looking at vehicle speeds it is apparent of the impact of the snowstorm beginning near Illinois (callout i) and having continued impact throughout the state until the Ohio border (callout ii). This graphic provides context on the storm impact and the corresponding measures taken to reduce the impact (snowplow deployment frequency).

Following a similar visual as Figure 3.4, Figure 3.5 instead shows temperatures as the storm front moves across the state. Callouts i and ii are at the same location and show temperatures falling below 32°F at the same time vehicle speeds slow on the interstate.

Figure 3.6 follows a similar format as Figure 3.4 and Figure 3.5 but shows the type of precipitation along with intensity and rates. At the same time that vehicle speeds reduce, and temperatures drop is when the precipitation transitions from rain to snow. Utilizing all of these visuals helps INDOT monitor the conditions on the roadway and the underlying weather that impacts road conditions.

3.2.2 Statewide Fleet Usage

As part of the project the agency wanted to monitor fleet usage and utilization. Figure 3.7 shows the miles traveled by each snowplow during the December 23rd, 2022, snowstorm for the fleet of nearly 500 trucks that were deployed. This visual shows what trucks drive the most miles during a storm event.

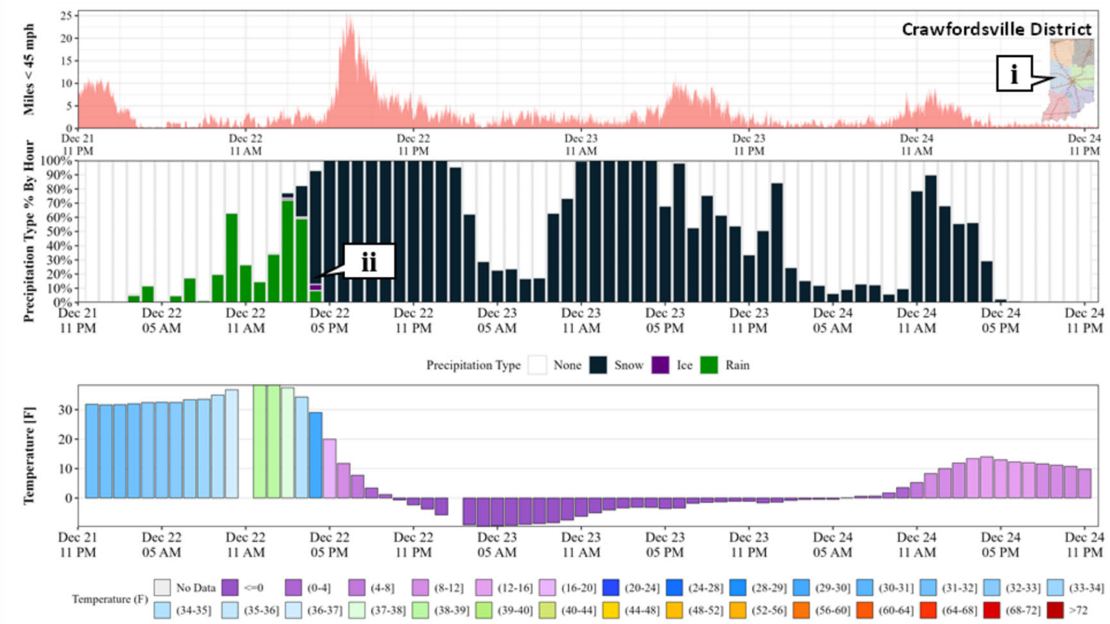


a. December 22nd, 2022, 12:00
b. December 22nd, 2022, 18:00
c. December 23rd, 2022, 00:00
d. December 23rd, 2022, 06:00

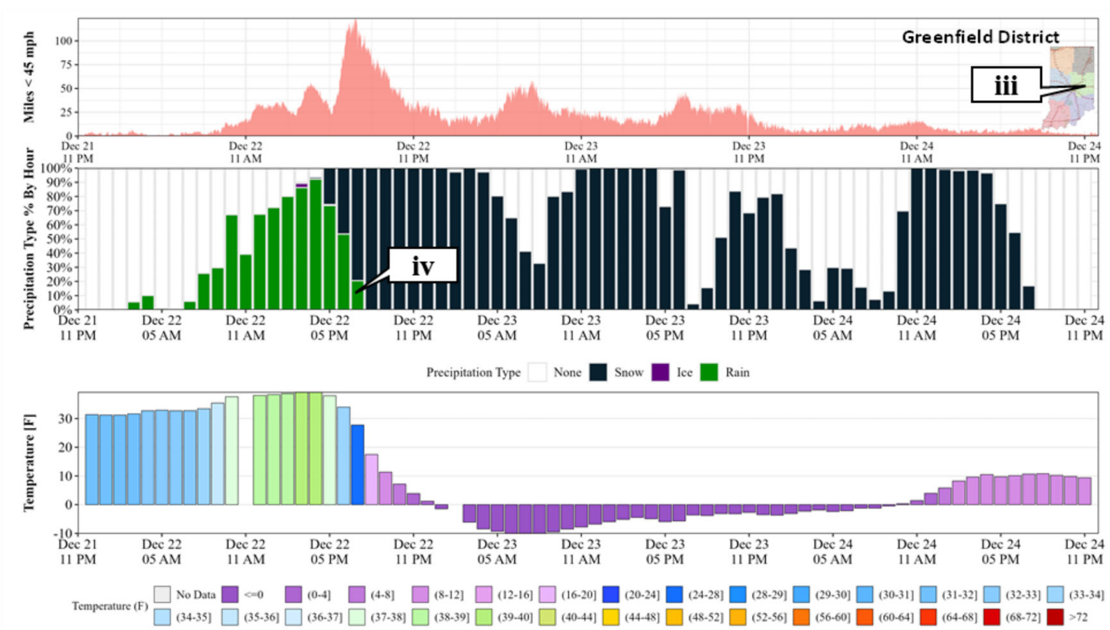
Figure 3.2 INDOT truck locations with salt application during the December 21st–24th, 2022, winter storm (Malackowski et al., 2023).

Only trucks traveling under speeds of 70 mph and reporting locations at a minimum of 5-minute frequency were included for this figure. This information can help facilitate balancing snow maintenance procedures and reconfiguring snow routes. Additionally, it can reduce workload and can provide guidance on fleet replacement.

Similar to Figure 3.7, Figure 3.8 shows the total salt applied by each snowplow. This graphic can help monitor how much salt was used and on what snow routes. This visual can also provide context for trucks in need of calibration as they may be over/under applying solid material. The distance traveled by each snowplow between consecutive waypoints and the



(a) Crawfordsville District



(b) Greenfield District

Figure 3.3 District analysis of vehicle congestion, precipitation, and temperatures for December 21st–24th, 2022.

recorded material application rate together were used to compute the solid material amounts applied by each snowplow. In an effort to filter outlier trucks that may have faulty calibrations, a maximum threshold of 600,000 lbs was used as the upper limit for solid material applied by snowplows across the storm's 4-day monitoring period. Discussions with relevant stakeholders and operators may provide an opportunity to modify this threshold accordingly. Additionally, some of the higher application rates are likely indicative of spreaders that need calibration. Conversely, due to the coarse reporting period for truck telematics data (1-minute in most cases), there may be instances of underreporting of solid material applied by trucks if the application period is shorter than the reporting frequency. As policies continue to encourage environmentally conscious winter operation maintenance, tracking salt usage and location becomes critical to agencies. Areas where a large portion of salt is used can provide insight for potential training opportunities from more experienced drivers on how to reduce the amount of salt used.

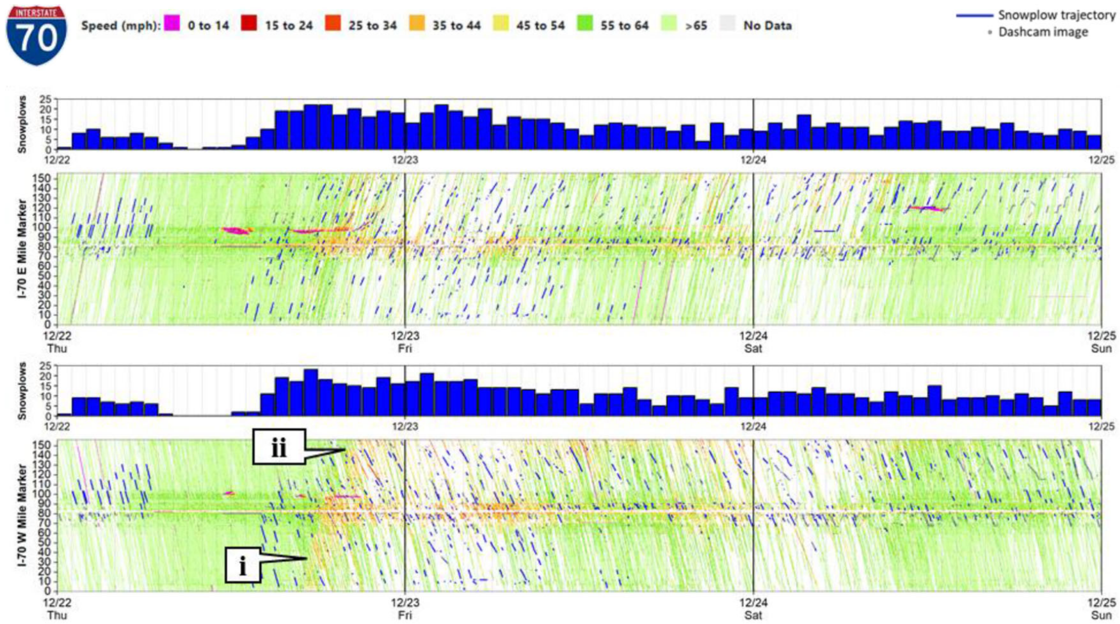


Figure 3.4 I-70 heatmap with vehicle speeds and snowplow trajectories.

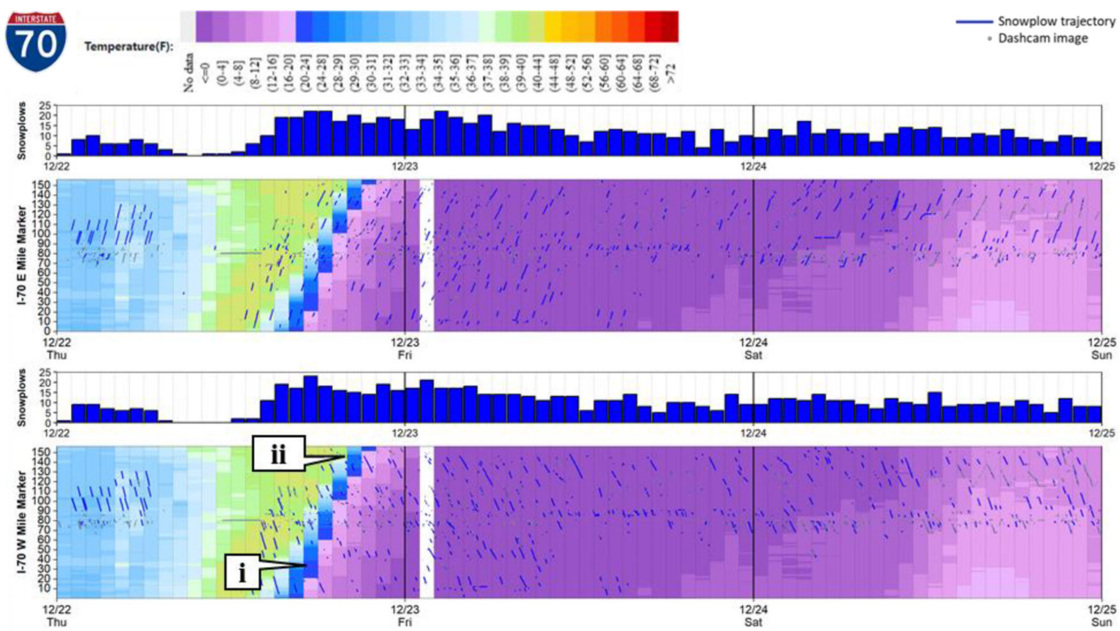


Figure 3.5 I-70 heatmap with temperatures and snowplow trajectories.

Additionally, the drivers that utilize little to no salt can provide insight as to how they were able to use mechanical means to keep the roadway clear without expensive material application.

Allocating each truck to their respective operating unit gives perspective on usage during a winter storm event at a high level. Figure 3.9 shows all INDOT maintenance units statewide. Locations where snowplows were frequently observed idling at zero speeds, presumably when loading solid/liquid material or during shift changes, were used to map each snowplow to an INDOT facility. Each unit is colored by miles travelled for all trucks operating out of a facility. Units with a large number of miles traveled can indicate monitoring activities or opportunities to restructure snow routes to reduce the length for operators. Balancing snow routes provides opportunities to improve operations statewide and have more frequent patrolling.

Figure 3.10 shows the salt applied by each unit for the same winter storm, which is of great interest to the state based on other initiatives in the salt inventory and

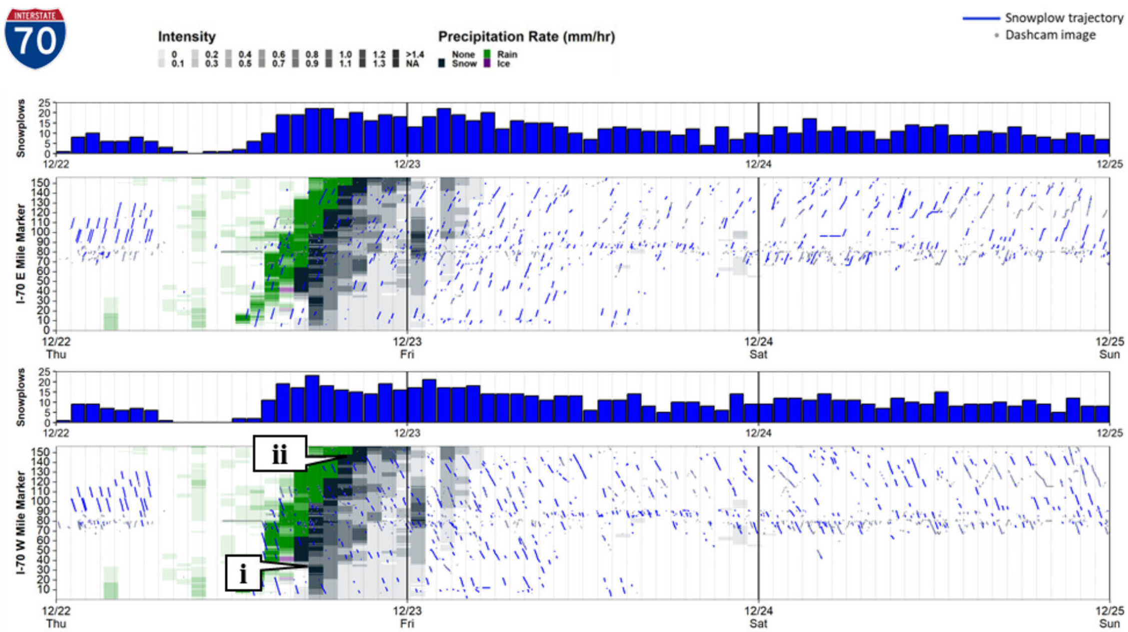


Figure 3.6 I-70 heatmap with precipitation and snowplow trajectories.

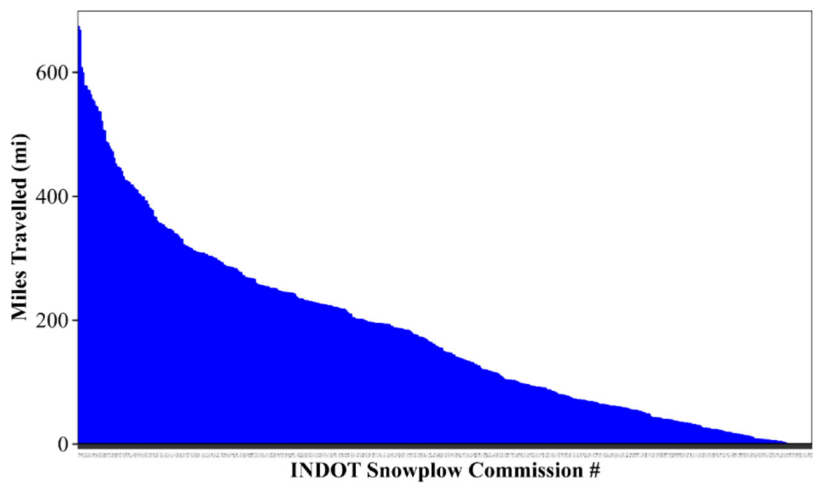


Figure 3.7 Miles traveled by snowplows from December 21st–24th, 2022.

tracking space (Mahlberg, Manish, et al., 2022; Mahlberg, Mathew, et al., 2022; Manish et al., 2022). Due to different winter maintenance procedures and weather impact, salt application varies at the district, subdistrict, and unit levels. These graphics provide context to quantify these variations and opportunities to reduce salt usage based on peer learning to identify best practices and successes among units. Additionally, the graphic can provide context to units who may need to address calibration of trucks and their fleet to prevent over/under application.

3.2.3 Opportunities for Enhanced Vehicle Data

Vehicle speeds, weather data, and AVL data provide context during a winter storm and help decision makers redeploy to mitigate impact. The combination of this data lacks actual road surface information which enhanced connected vehicle data can provide. Users and snowplows on the roadway during a storm can provide some of the best information for real-time roadway conditions (Desai et al., 2020; Mahlberg, Li, et al., 2022). Figure 3.11a shows friction values on Chicago highways for December 22nd, 2022, at 7:00 AM before the winter storm passes through the area (https://docs.lib.purdue.edu/imr/10/). Every road has a friction coefficient value above 0.6 with many of the roadways having values of 0.8 or higher, which represents dry pavements. When the storm passes through at 8:00 PM on December 22nd, there are fewer vehicles on the highways, and friction values all drop below 0.5 showing the degrading road conditions (Figure 3.11b). Relevant

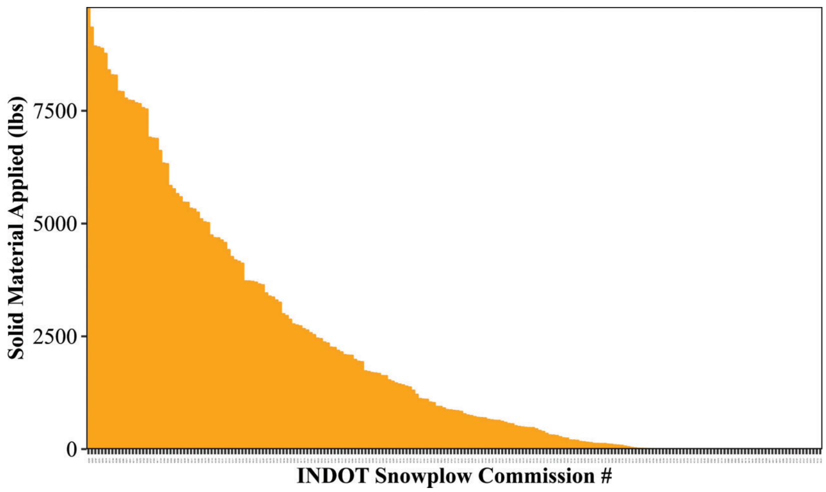


Figure 3.8 Solid material applied by snowplows from December 21st–24th, 2022.

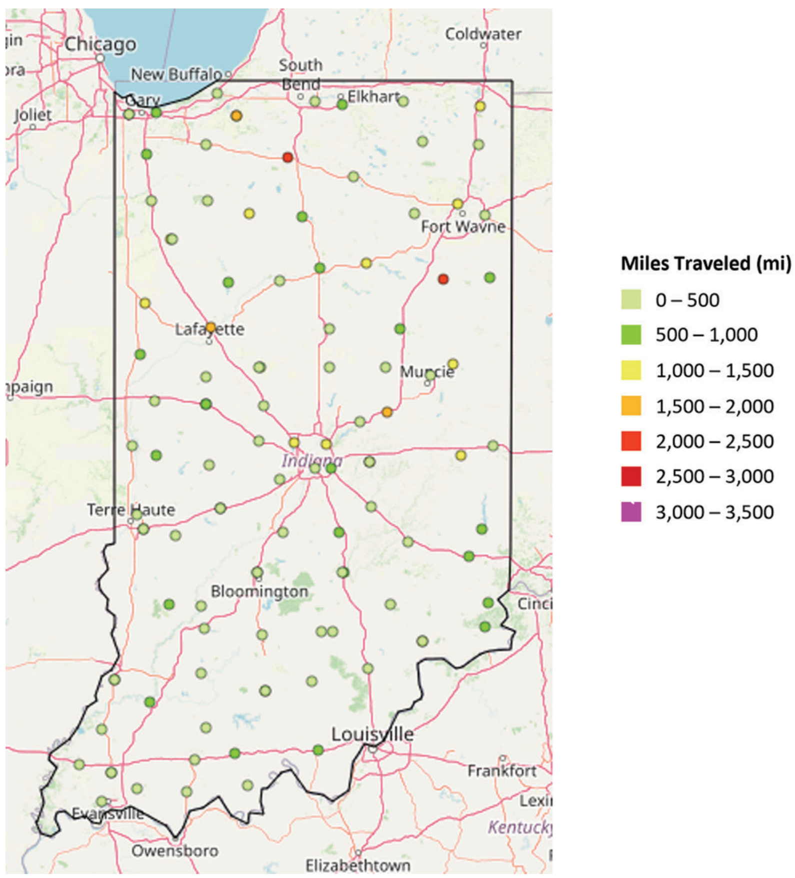


Figure 3.9 Total miles traveled by snowplows per INDOT unit from December 21st–24th, 2022.

local names for most interstate routes in the area and the corresponding instantaneous friction distribution along them are shown in a panel to the right for quick reference.

The value added from enhanced connected vehicle data lies in the ability to monitor actual roadway conditions during a storm event. As friction values degrade digital message signs can be used to warn drivers and snowplow deployment can be concentrated on these highways. Agile operational measures such as these would help mitigate the impact from the storm and improve mobility. The limited penetration on roadways during a storm event shows the degrading road conditions and the decrease in drivers using the roadways. As the penetration of connected vehicles continues to grow these gaps will continue to reduce but

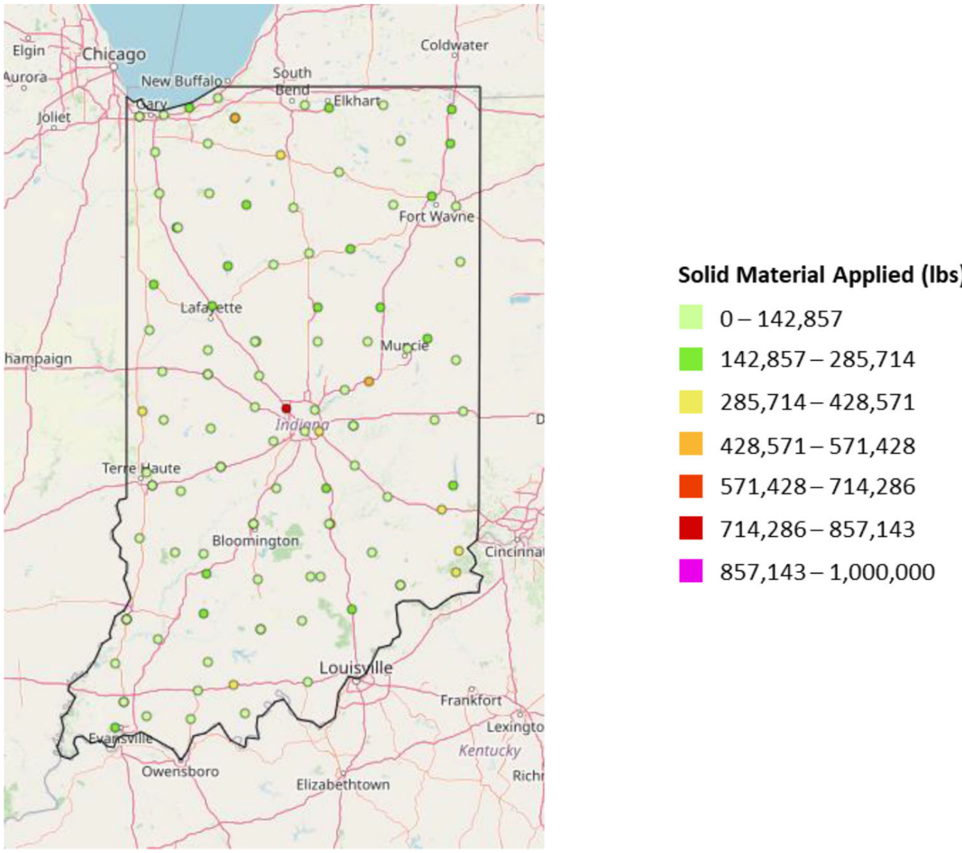


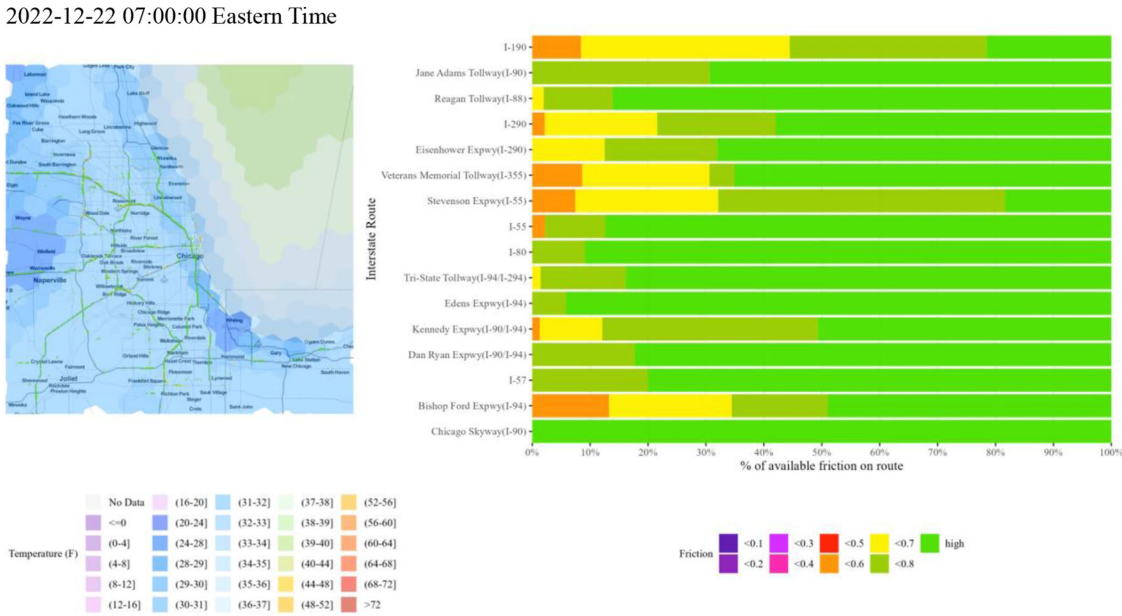
Figure 3.10 Total solid material applied by snowplows per INDOT unit from December 21st–24th, 2022.

when there is no data observed in various areas, this can be an indication of closed roads. Additionally, enhanced connected vehicle data provides an opportunity or indicators in the after-action report of when too much salt is applied. When there is a large amount of salt residue on the roadway, pavement markings are difficult to see for road users and connected/autonomous vehicles (Mahlberg, Sakhare, et al., 2021).

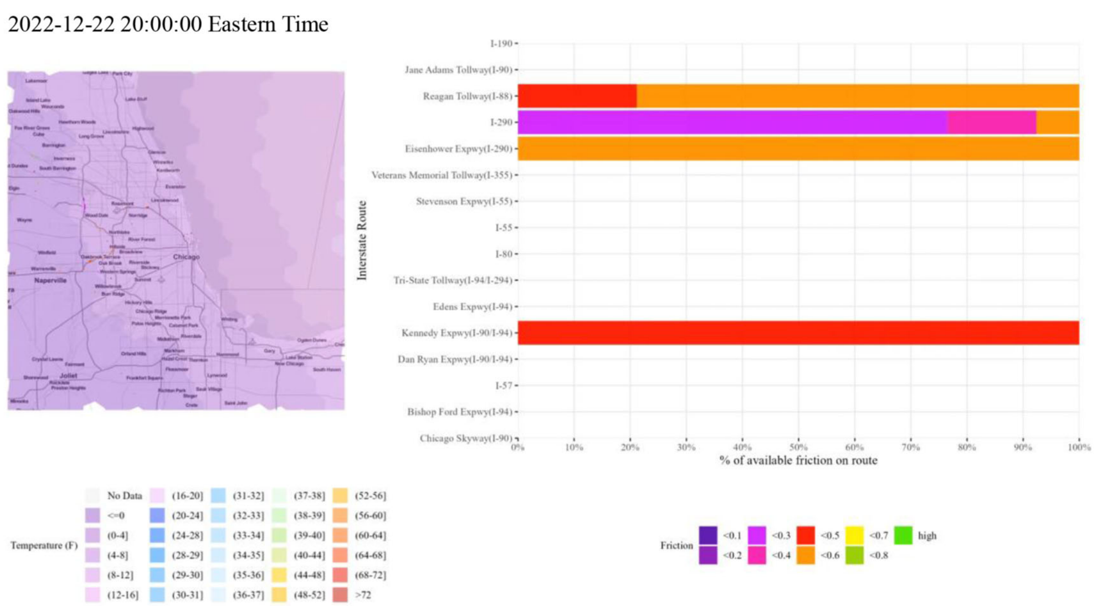
3.3 Fleet Utilization

As part of this study, the agency wants to leverage their fleet telematics to provide informed decisions for life-cycle analysis of their snowplow fleet. One of the ways to monitor that is by looking at the last time each unit was used. Figure 3.12 shows the snowplow commission number on the horizontal axis and the days since each unit was last used on the vertical axis for the Northern districts of Indiana. Figure 3.12a shows the time the snowplows were last seen in the LaPorte district, Figure 3.12b shows the Fort Wayne district, and Figure 3.12c shows the Crawfordsville district. This analysis shows all truck usage from May 1st, 2022, through April 30th, 2023, and makes evident the trucks that are used on a regular basis compared to the trucks that were maybe last observed only for their annual inspection. The horizontal black line on each graph is a 60-day window, while over 80% of trucks are used during this period there are still 19 trucks in LaPorte, 29 trucks in Fort Wayne, and 20 trucks in Crawfordsville that have not been used in the last 2 months.

A similar analysis is done for the Southern districts shown in Figure 3.13. Figure 3.13a shows Greenfield district, Figure 3.13b shows Vincennes district, and Figure 3.13c shows Seymour district. Similar to the Northern districts, over 80% of the trucks have been used in the last 2 months but there are 29 trucks in Greenfield, 32 trucks in Vincennes, and 19 trucks in Seymour that have not been used. Few of these trucks could be down for maintenance, and others could be used for only winter storm events. Some of these trucks may also have been retired and may need to be removed from the monitoring list and a small proportion might be candidates for retirement or overhaul.

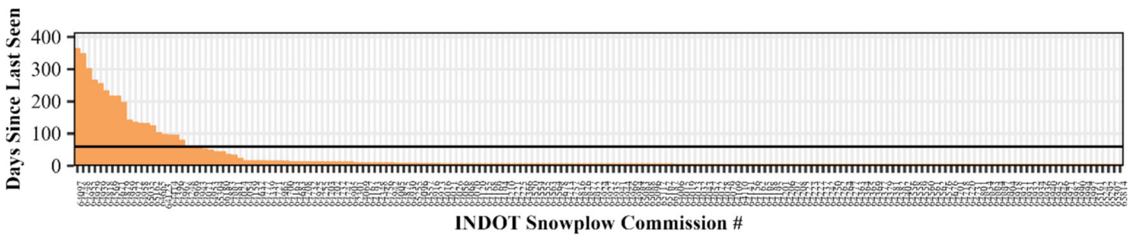


(a) Connected Vehicle Friction Values, December 22nd, 2022, at 07:00

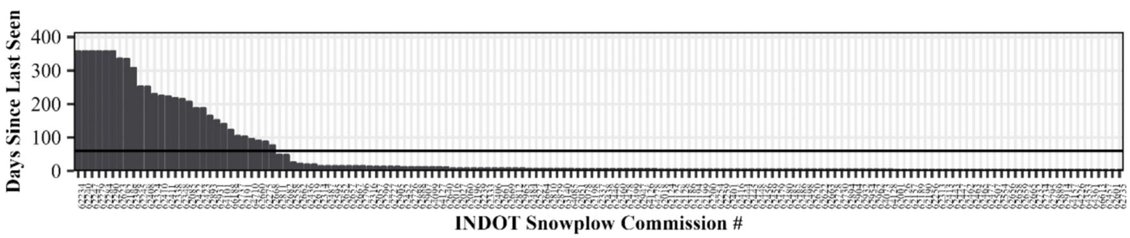


(b) Connected Vehicle Friction Values, December 22nd, 2022, at 20:00

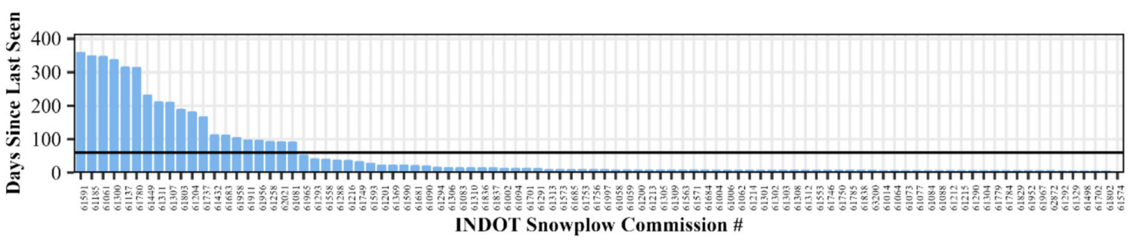
Figure 3.11 Connected vehicle friction data on Chicago interstates during the December 21st–24th, 2022, snowstorm.



(a) La Porte

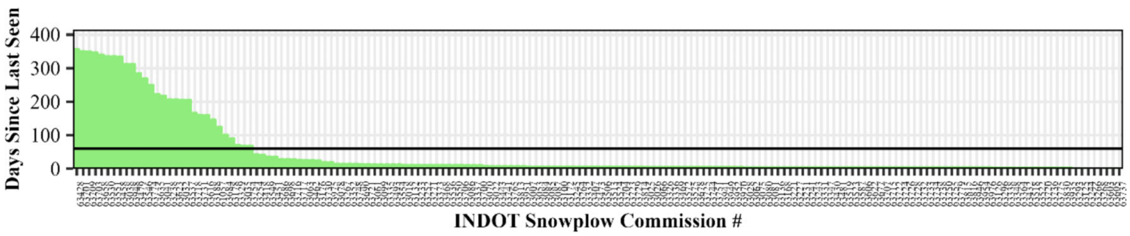


(b) Fort Wayne

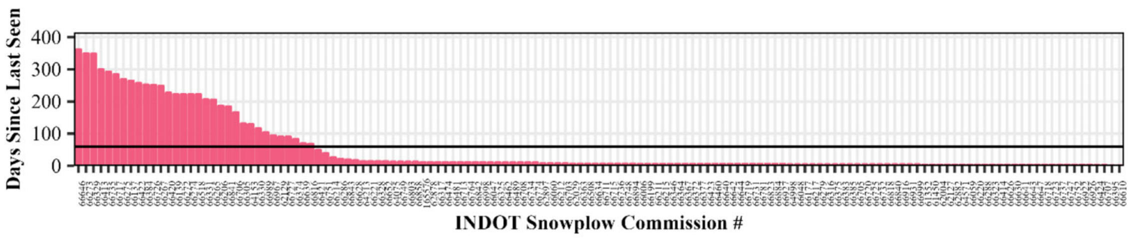


(c) Crawfordsville

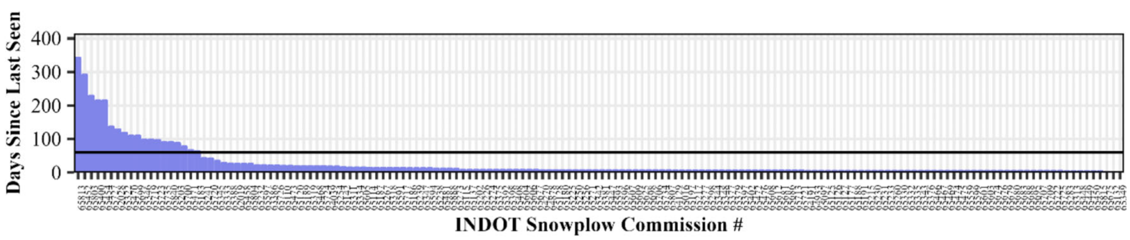
Figure 3.12 Northern Indiana fleet utilization.



(a) Greenfield



(b) Vincennes



(c) Seymour

Figure 3.13 Southern Indiana fleet utilization.

4. NATIONWIDE SCALABILITY

A recurring question among stakeholders is, how scalable are these techniques. Connected vehicle data, and weather data can be used nationwide and to provide great context in terms of winter operations. Figure 4.1 shows nationwide weather data and I-70 connected vehicle speeds. Below the nationwide map is a congestion profile or the connected vehicle speed for each section of interstate and the proportion for a 1-hour snapshot. Callout i on the map and in the congestion profile below, show I-70 in Kansas and the storm front that is moving across the nation. The impact of the storm on the interstate system is clearly visible, because directly east of the storm front in Missouri traffic speeds are at or above 55 mph. Another example can be seen at callout ii on the nationwide map and the congestion profile. At this time in Pennsylvania there is another weather front, possibly containing a mix of snow and ice, impacting traffic speeds.

Figure 4.2 shows a similar graphic as Figure 4.1 but 13 hours later. At this time the stormfront reaches and impacts Indiana (callout i). At 8:00 PM eastern, over half of I-70 is operating below the 55 mph which is evident from Figure 3.4. The ability imparted by connected vehicle data to look across state borders provides agencies with a unique opportunity to not only monitor impact and maintenance procedures in their region but also learn from other states on best practices for various storm types. This data also provides context for continuity across borders to ensure storm impact is mitigated at each border and mobility is not hindered by state lines.

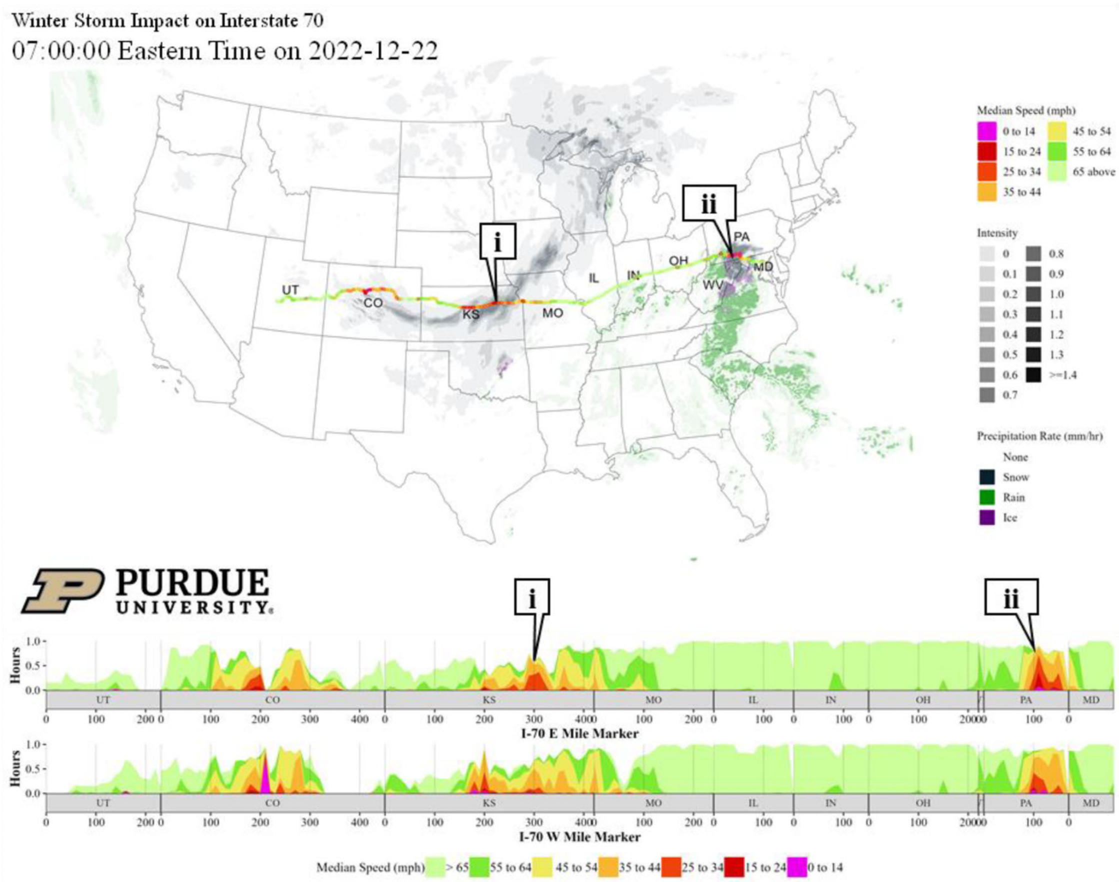


Figure 4.1 I-70 nationwide precipitation and vehicle speeds on December 22nd, 2022, at 07:00 Eastern.

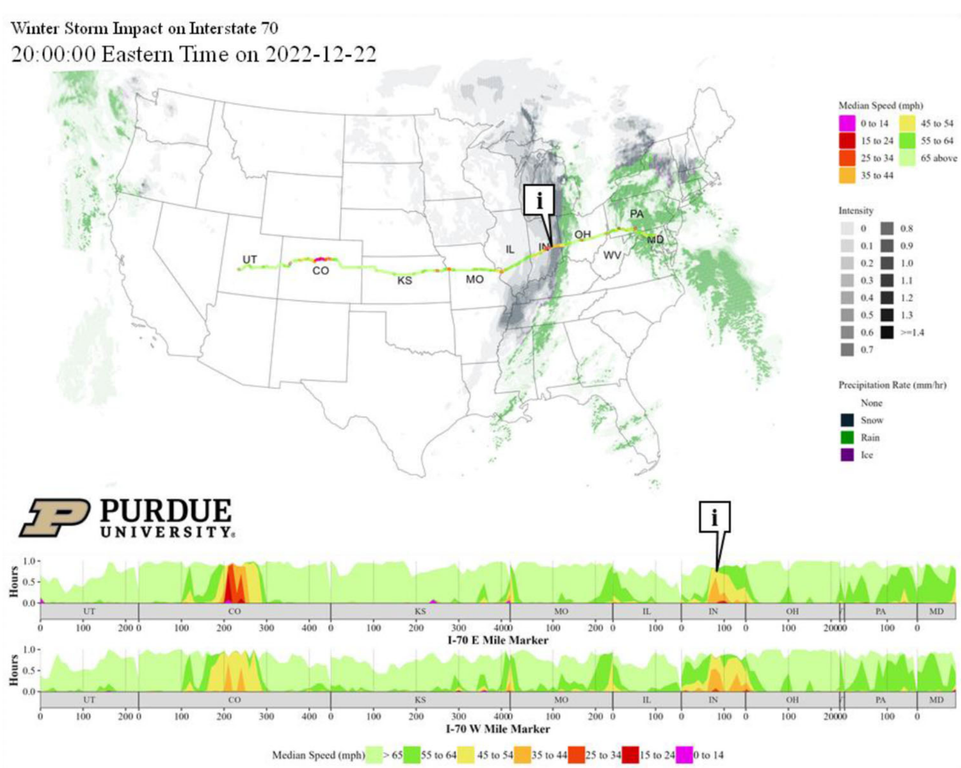


Figure 4.2 I-70 nationwide precipitation and vehicle speeds on December 22nd, 2022, at 20:00 Eastern.

5. CONCLUSIONS

The visualizations and analyses developed during this project have been instrumental for training and decision-making for roadway maintenance operations during winter weather events. The resulting tools and dashboards developed in part through this project provide near real-time as well as detailed after-action reviews of mobility and safety impacts on interstate roadways in Indiana.

The dashboards have been distributed to INDOT decision makers along with interactive training to provide context to dashboards and enable opportunities to suggest improvements. These dashboards continue to be improved and disseminated to public and private stakeholders across the state and expand across state borders as the scalable nature of these data analysis techniques continues to drive interest across the nation. A few of the dashboards that have been fully integrated and utilized by the agency include the following.

- The "heatmap" dashboard allows district and sub district INDOT staff for monitoring winter weather impact along routes they are responsible for managing maintenance activities on.
- The "Deltaspeed" dashboard for real time monitoring of the position of winter operations vehicle during a storm along with high resolution doppler data and a real time road speed traffic layer.

Incorporating additional data sources including weather and connected vehicle data have helped provide further context to conditions during a winter storm event. When this data is combined with snowplow dash-cameras and INDOT ITS cameras, a holistic picture for real-time conditions develops. Combining all these data sources led to a widespread acceptance of using these digestible visualizations such as heatmaps and Deltaspeed dashboards to proactively monitor winter operations and winter storm impact. Traditionally these evaluations would have relied on fixed infrastructure or evidence from radio communications with plow operators. In multiple instances, these agile reviews have influenced operational changes in snow removal and maintenance around the state, leading to a marked improvement in observed mobility and safety.

The scalability of these summaries has encouraged interest from peer states as well with several national webinars delivered by both Purdue and INDOT staff to share these best practices.

REFERENCES

Desai, J., Mahlberg, J., Kim, W., Sakhare, R. S., Li, H., McGuffey, J., & Bullock, D. M. (2021). Leveraging telematics for winter operations performance measures and tactical adjustment. *Journal of Transportation Technologies*, *11*(4), 611–627. https://doi.org/10.4236/jtts.2021.114038

Desai, J., Mathew, J. K., Kim, W., Liu, M., Li, H., Brooks, J. D., & Bullock, D. M. (2020). *Dashboards for real-time monitoring of winter operations activities and after-action assessment* (JTRP Affiliated Reports Paper 33). https://doi.org/10.5703/1288284317252

Mahlberg, J., Matthew, J. K., Horton, D., McGavic, B., Wells, T., & Bullock, D. M. (2022). *Intelligent sidewalk de-icing and pre-treatment with connected campus maintenance vehicles* (Center for Connected and Automated Transportation, Paper 13). https://doi.org/10.5703/1288284317572

Mahlberg, J. A., Li, H., Zachrisson, B., Leslie, D. K., & Bullock, D. M. (2022). Pavement quality evaluation using connected vehicle data. *Sensors*, *22*(23), 9109. https://doi.org/10.3390/s22239109

Mahlberg, J. A., Manish, R., Koshan, Y., Joseph, M., Liu, J., Wells, T., Mcguffey, J., Habib, A., & Bullock, D. M. (2022). Salt stockpile inventory management using LiDAR volumetric measurements. *Remote Sensing*, *14*(19), 4802. https://doi.org/10.3390/rs14194802

Mahlberg, J. A., Sakhare, R. S., Li, H., Mathew, J. K., Bullock, D. M., & Surnilla, G. C. (2021). Prioritizing roadway pavement marking maintenance using lane keep assist sensor data. *Sensors*, *21*(18), 6014. https://doi.org/10.3390/s21186014

Mahlberg, J., Zhang, Y., Sneha, J., Mathew, J. K., Li, H., Desai, J., Kim, W., Mcguffey, J., Krogmeier, J. V., & Bullock, D. M. (2021). *Development of an intelligent snowplow truck that integrates telematics technology, roadway sensors, and connected vehicle* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/27). West Lafayette, IN: Purdue. https://doi.org/10.5703/1288284317355

Malackowski, H. A., Mahlberg, J., Desai, J., Li, H., & Bullock, D. M. (2023, May 22). *Time lapse of weather, road speeds and INDOT trucks during a winter storm from December 22 to 25, 2022* [Datasets]. PURR. https://doi.org/10.4231/F2KN-BR43

Manish, R., Hasheminasab, S. M., Liu, J., Koshan, Y., Mahlberg, J. A., Lin, Y.-C., Ravi, R., Zhou, T., McGuffey, J., Wells, T., Bullock, D., & Habib, A. (2022). Image-aided LiDAR mapping platform and data processing strategy for stockpile volume estimation. *Remote Sensing*, *14*(1), 231. https://doi.org/10.3390/rs14010231

NOAA. (n.d.). *The high-resolution rapid refresh (HRRR)* [Webpage]. National Oceanic and Atmospheric Administration. Retrieved May 16, 2023, from https://rapidrefresh.noaa.gov/hrrr/

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

About This Report

An open access version of this publication is available online. See the URL in the citation below.

Mahlberg, J. A., Desai, J., Malackowski, H., Li, H., Mathew, J. K., Sakhare, R. S., Wells, T., & Bullock, D. M. (2023). *Crowdsourcing/winter operations dashboard upgrade* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2023/21). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317652