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# Evaluating the Robustness of MDSS Forecast and Compliance with Recommendations


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## JOINT TRANSPORTATION RESEARCH PROGRAM

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**16. Abstract**
The Indiana Department of Transportation (INDOT) adopted the Maintenance Decision Support System (MDSS) for user-defined plowing segments in the winter of 2008–2009. Since then, many new data sources, including connected vehicle data, enhanced weather data, and fleet telematics have been integrated into INDOT winter operations activities. The objective of this study was to use these new data sources to conduct a systematic evaluation of the robustness of the MDSS forecasts. During the 2023–2024 winter season, 26 unique MDSS forecast data attributes were collected at 0-, 1-, 3-, 6-, 12-, and 23-hour intervals from the observed storm time for 6 roadway segments during 13 individual storms. In total, over 888,000 MDSS data points were archived for this evaluation. This study developed novel visualizations to compare MDSS forecasts to multiple other independent data sources, including connected vehicle data, National Oceanic and Atmospheric Administration (NOAA) weather data, road friction data and snowplow telematics.

Three Indiana storms, with varying characteristics and severity, were analyzed in detailed case studies. Those storms occurred on January 6th, 2024, January 13th, 2024, and February 16th, 2024. Incorporating these visualizations into winter weather after-action reports increased the robustness of post-storm performance analysis and allowed road weather stakeholders to better understand the capabilities of MDSS. The results of this analysis will provide a framework for future MDSS evaluations and implementations and training tools for winter operation stakeholders in Indiana and beyond.

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# EXECUTIVE SUMMARY

## Motivation

The Indiana Department of Transportation (INDOT) uses many data sources to plan and manage winter weather maintenance activities on their 29,000 miles of roadways. This management is typically done at a sub-district level and can have a high level of variability. To reduce uncertainty and variability, the Maintenance Decision Support System (MDSS) software ingests various weather models and generates a maintenance suggestion for a user-defined plowing segment. Each plowing segment, once added into the system, can be programmed with different treatment methods and connected to nearby Automatic Vehicle Location (AVL) truck data devices. This data feeds into the MDSS software and is considered when making maintenance recommendations. To get a better understanding of the robustness of the software, this study assembled both MDSS and external independent data sources characterizing roadway mobility and prevailing weather conditions to create after-action reports that help visualize the robustness of MDSS recommendations during a winter storm.

## Study

The Indiana Department of Transportation (INDOT) adopted MDSS for user-defined plowing segments in the winter of 2008–2009. Since then, many new data sources, including connected vehicle data, enhanced weather data, and fleet telematics have been integrated into INDOT winter operations activities. This study's objective was to use these new data sources to systematically evaluate the robustness of the MDSS forecasts. During the 2023–2024 winter season, 26 unique MDSS forecast data attributes were collected at 0-, 1-, 3-, 6-, 12-, and 23-hour intervals from the observed storm time for 6 roadway segments during 13 individual storms. In total, over 888,000 MDSS data points were archived for this evaluation. This study developed novel visualizations to compare MDSS forecasts to multiple other independent data sources, including connected vehicle data, National Oceanic and Atmospheric Administration (NOAA) weather data, road friction data, and snowplow telematics.

## Results

Three Indiana storms, with varying characteristics and severity levels, were analyzed in detailed case studies. The storms occurred on January 6th, 2024, January 13th, 2024, and February 16th, 2024. Incorporating these visualizations into winter weather after-action reports increased the robustness of post-storm performance analysis and allowed road weather stakeholders to better understand the capabilities of MDSS. The composite visualizations also enhanced the ability to facilitate constructive dialogue among stakeholders and between maintenance crews. The results of this analysis will provide a framework for future MDSS evaluations and implementations as well as training tools for winter operation professionals in Indiana and beyond.

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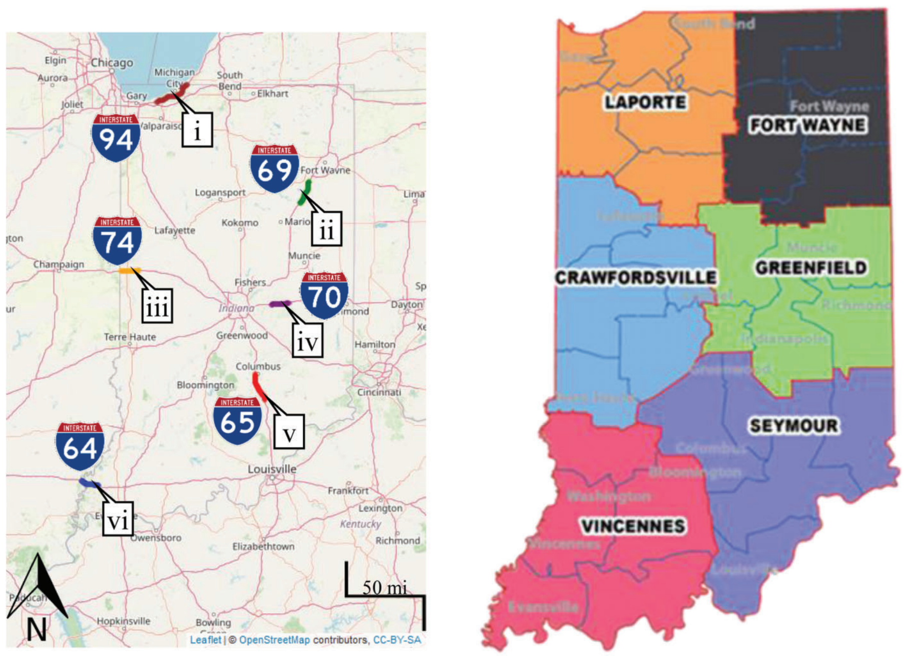
# 1. PROJECT OVERVIEW

## 1.1 MDSS Summary

Maintenance recommendations and other MDSS data are available through an interactive web portal. In this portal, agency employees can select individual, predefined routes across the state and access both past storms and future weather data forecasts. In this study, six MDSS plowing segments were selected to be analyzed. These segments are each in a different INDOT district and on a different interstate route. Including all six districts (Crawfordsville, Fort Wayne, Greenfield, LaPorte, Seymour, and Vincennes) ensured that this study was relevant for the entire state, and each of the six main primary interstates. These six plowing segments can be seen in Figure 1.1a, as callouts i through vi.

A total of 26 different MDSS data attributes were collected for each hour of winter storms. Data attributes are summarized in Table 1.1 with the type of data they represent (continuous or categorical). For this study, the focus was on maintenance alerts. Alerts are systematically generated beginning with the treatment prescriptions (e.g., "none," "plowing recommended," "chemical recommended," etc.). A chemical recommendation is also provided (e.g., "none," "Pre Wet NaCl"), with an associated application rate (e.g., "250 lb/mi"), when applicable. A typical maintenance




(a) Map of Interstate MDSS Plowing Segments

(b) INDOT District Map

**Figure 1.1** Selected routes where MDSS data was captured and analyzed.

TABLE 1.1
**MDSS Data Attributes**

| Attribute Name | Data Type | Attribute Name | Data Type |
|---|---|---|---|
| Slider Position | Continuous | Freezing Rain Percentage | Continuous |
| Forecast Timestamp | Continuous | Snow Percentage | Continuous |
| Weather Alerts | Categorical | Sleet Percentage | Continuous |
| Road Alerts | Categorical | Pavement Temperature | Continuous |
| Blowing Snow | Categorical | Ice Probability | Continuous |
| Maintenance Alerts | Categorical | Frost Probability | Continuous |
| Chemical | Categorical | Mobility Index | Continuous |
| Chemical Rate | Categorical | Measured Liquid Accumulation (-24h) | Continuous |
| Air Temperature | Continuous | Measured Ice Accumulation (-24h) | Continuous |
| Visibility | Continuous | Measured Snow Accumulation (-24h) | Continuous |
| Wind Speed | Categorical | Predicted Liquid Accumulation (+24h) | Continuous |
| Wind Direction | Categorical | Predicted Ice Accumulation (+24h) | Continuous |
| Rain Percentage | Continuous | Predicted Snow Accumulation (+24h) | Continuous |

alert combines these three attributes as recommendations (e.g., "chemicals recommended, PreWet NACL, 250 lb/mi").

### 1.2 Related Studies

Past research has been conducted on the MDSS software (Research Applications Laboratory, n.d.), mostly while the software was being initially developed (Mahoney et al., 2005; Petty & Mahoney, 2008; Seidl & Cypra, 2010; Ye et al., 2009). In general, this research found that the MDSS software was a useful tool, delivering accurate weather and road condition forecasts, and there were some opportunities to improve the maintenance recommendations. A study with MaineDOT (Maine Department of Transportation) (Cluett & Jenq, 2007) expressed the need for stakeholders to become more familiar with the software to better utilize its functionalities. Another study with Iowa DOT (Iowa Department of Transportation) (Pisano et al., 2005) determined that integrating third-party data sources into the software would increase its robustness. Similarly, a study with MnDOT (Minnesota Department of Transportation) (FHWA, n.d.) stated that integrating plow camera images with the MDSS data creates an enhanced overall situational awareness for both MnDOT and the traveling public.

In recent years, emerging and widespread availability of connected vehicle data 9–16 (Desai, Sakhare, et al., 2021; Desai, Saldivar-Carranza, et al., 2021; Hunter et al., 2021, 2024; Mathew et al., 2021; Sakhare et al., 2021, 2022, 2023), Intelligent Transportation Systems (ITS) camera images (Mathew et al., 2023), instrumented brine tankers (Mahlberg et al., 2024), fleetwide instrumentation of snowplow trucks with telematics devices (Desai et al., 2022; Mahlberg et al., 2021; Mathew et al., 2024), and dash cameras have opened many doorways into possible data visualizations and analysis. The current state of the art presents a unique opportunity to perform a novel evaluation of MDSS forecast recommendations with independent datasets characterizing roadway mobility and prevailing weather conditions. This study aims to evaluate the robustness of these forecasts to provide a framework for future MDSS evaluations and identify opportunities to fine-tune these forecasts for effective winter weather maintenance.

The following paper has been prepared, in part, during this project:

- Brinster, G. L., Desai, J., Overall, M. W., Gartner, C., Suryakant Sakhare, R., Mathew, J. K., Evans, N., & Bullock, D. (2024). Evaluating the robustness of MDSS maintenance forecasts using connected vehicle data. *Journal of Transportation Technologies, 14*(4), 549–569. https://doi.org/10.4236/jtts.2024.144030

## 2. 2023–2024 WINTER SEASON OVERVIEW

During the 2023–2024 winter season, 13 individual storms were identified as having either a significant enough impact on vehicle speeds or resulted in significant snowplow truck deployment. Indiana assesses mobility on 2,600 miles of interstate, with 5-minute probe data and calculates the number of miles operating below 45 mph. For the period of December 1, 2023, and March 1, 2024, Figure 2.1a shows a temporal visualization of miles of Indiana interstates operating under 45 mph, and Figure 2.1b shows the number of snowplows deployed. A district legend with colorized map for both Figure 2.1a and Figure 2.1b can be seen in Figure 1.1b. For the first 2 weeks of December, Figure 2.1a clearly shows Monday–Friday re-occurring congestion before the Holidays. The two biggest spikes in Figure 2.1a occurred on or around January 19, 2024, and February 16, 2024. Those storms had approximately 550 miles and 1,100 miles of interstate operating below 45 mph, respectively. Red shading is applied to the days where MDSS data was collected. Each storm spans a 72-hour period (day of greatest impact and 24 hours before and after). During the storm periods, MDSS data was collected in 1-hour intervals, at 0-, 1-, 3-, 6-, 12-, and 23-hour forecast steps, totaling more than 11,000 data points per storm.

Callout ix in Figure 2.1b highlights the storm with the greatest number of snowplows deployed across the state and callout xiii highlights the storm with overall greatest impact. This storm significantly impacted the entire state and serves as the study's focus.

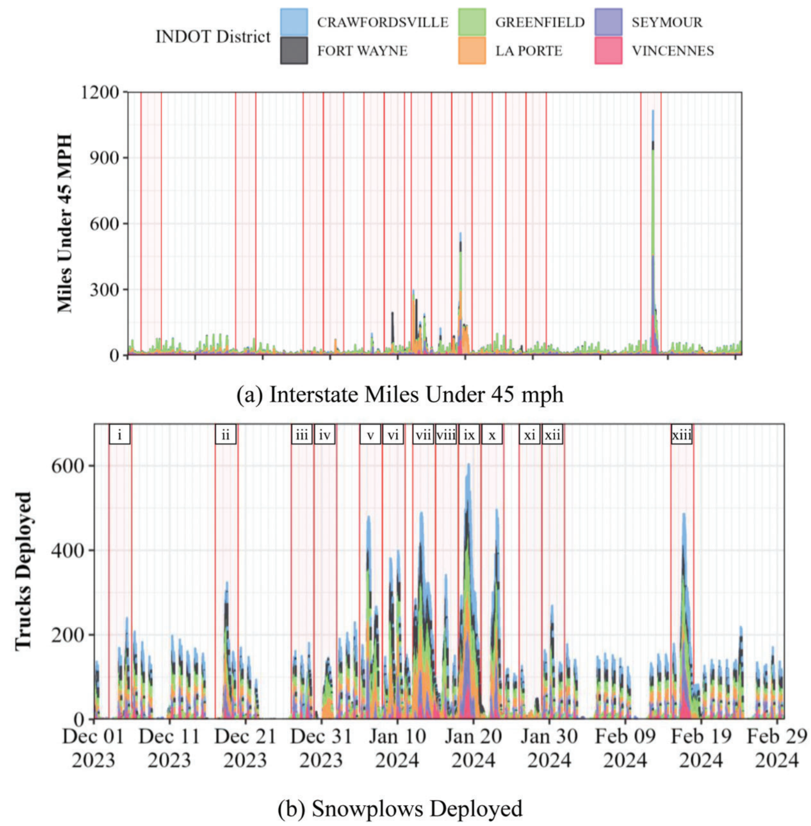



**Figure 2.1** Ticker plot for 2023–2024 winter season with callouts for winter storm dates.

## 3. DATA SOURCES

Once collected, the MDSS data must be compared to ground-truth data, allowing for a spatio-temporal alignment and analysis. Figure 3.1 shows graphical representations of four different data sources used in this study with the horizontal axis representing time of day and the vertical axis representing mile marker location along the interstate route.

### 3.1 Connected Vehicle Data

Figure 3.1a is a connected vehicle heatmap, showing the average speed for roughly 0.1-mile-long interstate segments, updated every 5 minutes. Connected vehicle data is essential in seeing the impact on vehicles traveling along the selected interstate. Past research in the connected vehicle space has estimated the penetration rate to be above 6% along Indiana interstates in 2022 (Sakhare et al., 2022) and has been applied to other winter and severe weather research (Desai et al., 2023; Mahlberg et al., 2021; Sakhare et al., 2023). Connected vehicle heatmaps have proved vital in measuring and visualizing freeway traffic conditions for many conditions including inclement weather events (Sakhare et al., 2024).

In this case, I-65 is the selected route, from MM 0 near Louisville, KY to MM 262 near Chicago, IL; see Figure 3.4a for 50-mile incremental callouts. Figure 3.1a, callout i indicates the main impact of the storm. This callout is constant through all four data sources in Figure 3.1, pointing to the same mile marker and time. The main impact occurs at 4 PM, the beginning of Friday's evening peak around MM 110, the center of Indianapolis. These factors compounded and resulted in a large impact, seen by the greatly reduced speeds.

### 3.2 Precipitation Rate

Looking at the storm progress through the state from Figure 3.4a to Figure 3.4g, the Doppler radar shows the storm impacting the northwest corner of the state first and then progressing southeasterly throughout the state. The progression can also be seen in Figure 3.1b, with the black (snow) precipitation impacting the northern end of the interstate more than 6 hours ahead of the bottom. This figure plots National Oceanic and Atmospheric Administration's (NOAA) High-Resolution Rapid-Refresh (HRRR) data. HRRR data provides hourly precipitation type, intensity, temperature, visibility and wind speed information gridded by 3 km by 3 km boundaries (Desai et al., 2023; Sakhare et al., 2023). The progression through the state can also be seen in Figure 3.1a, as vehicle speeds are decreased due to impaired driving conditions.

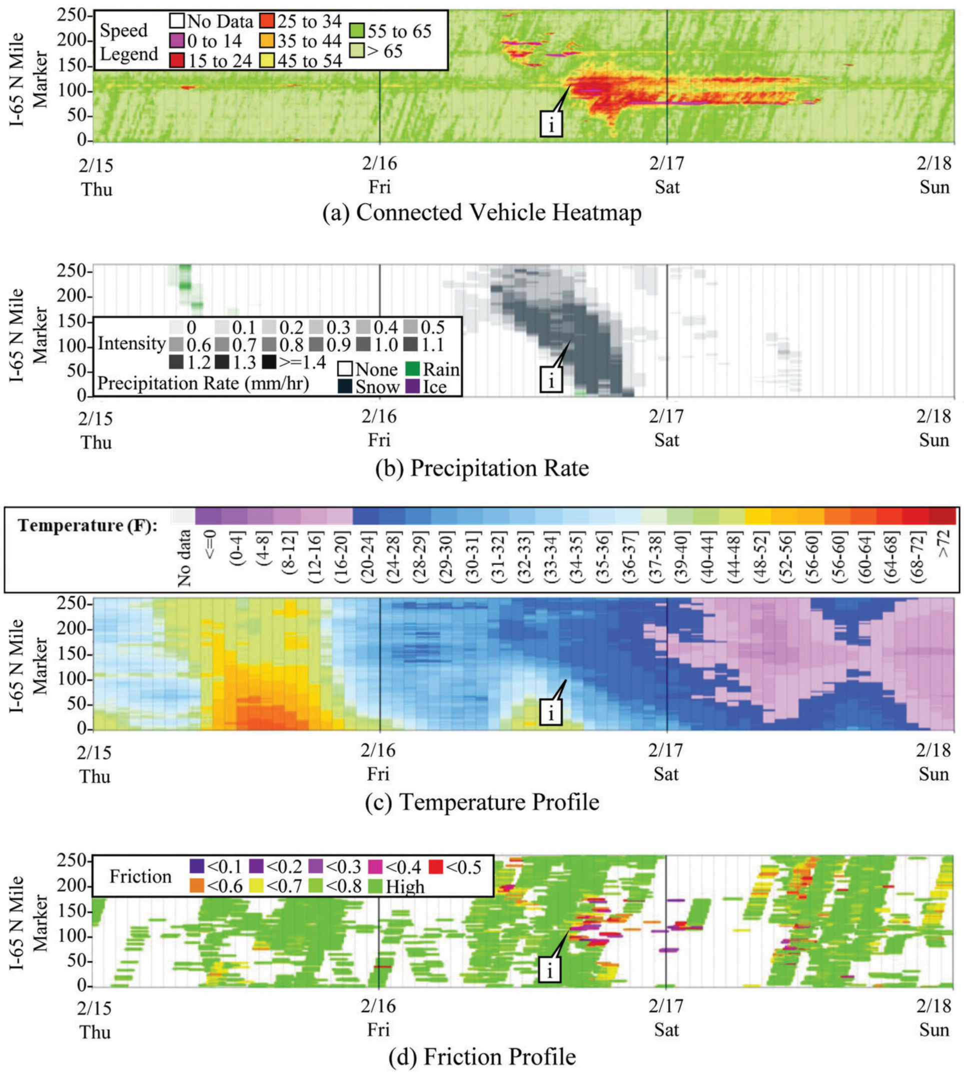



**Figure 3.1** Data sources plotted for February 16, 2024, winter storm.

### 3.3 Temperature Profile

One challenging aspect affecting maintenance for both INDOT and the MDSS software was the large decrease in temperature and uncertainty on when the temperature would fall below freezing. Figure 3.1c shows a temperature profile for I-65 during this winter storm, highlighting the nearly 30-degree drop in certain areas from Thursday to Friday. Temperatures dropped over 20 degrees by Saturday, totaling a near 50-degree drop in temperature over 48 hours.

### 3.4 Friction Profile

Figure 3.1d shows a friction profile for the same storm along I-65 by time and mile marker. Callout i indicates the beginning of the main storm impact and is characterized by a sharp reduction in friction values. This reduction in friction is critical to avoid, as it is ultimately what leads to many slide-offs and crashes. The friction values decreasing during this storm indicates that the reduction in vehicle speeds may not necessarily have been caused by the storm but was amplified because of it. This friction data has been effectively utilized by past studies for winter storm after-action assessments and monitoring roadway conditions (Li et al., 2020; Mahlberg et al., 2023). Previous studies have utilized snowplow telematics data in conjunction with connected vehicle data to evaluate winter operations performance measures and provide tactical adjustment opportunities based on observed traffic impacts of winter maintenance activity (Desai, Mahlberg, et al., 2021). This study utilized snowplow telematics data from devices onboard INDOT snowplows to provide contextual information on when and where snowplows were deployed during a winter storm to quantify the agency's response to a winter event.

### 3.5 Storm Impact Summary

Summarizing the data is important for obtaining an overall understanding of the storm's impact quickly.

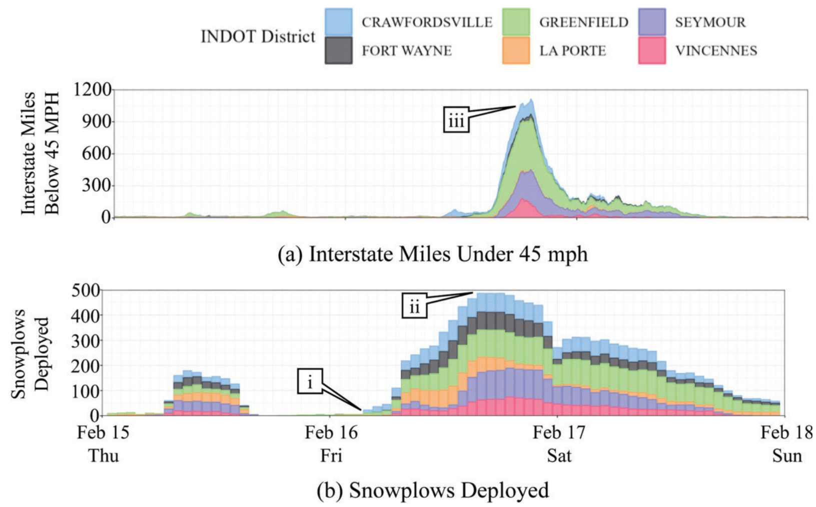



**Figure 3.2** February 16, 2024, storm impact to motorists and trucks deployed.

Figure 3.2 shows two plots summarizing the overall storm impact for motorists and snow removal agencies (INDOT). Figure 3.2a shows a "ticker" plot, commonly referred to as a "ticker tape" or "stock ticker" plot, for the total interstate miles under 45 mph in 5-minute intervals, summarizing the impact on motorists. This plot is colored by INDOT district, showing that the Greenfield district suffered the greatest impact to motorists during the peak of the storm, callout iii. Figure 3.2b summarizes the impact on INDOT, totaling the number of snowplows deployed per hour. This plot is colorized by the same INDOT districts and gives insight into when plowing, chemical application, and/or patrolling operations began, and how many trucks INDOT deployed. Callout i points to the initial deployment of trucks in both the Greenfield and Crawfordsville districts at 4:00 PM on Friday, February 16th. This deployment comes over 12 hours before the storm's main impact, showing that INDOT was proactive in patrolling and possibly applying chemicals well before the storm. Callout ii indicates the peak impact where nearly 500 trucks were deployed across the state. Seymour and Greenfield districts had the most snowplows deployed during this time, each with nearly 100 trucks.

Once captured, MDSS data can be plotted and compared, as seen in Figure 3.3. The data for this figure correlates to the I-465 MDSS plowing segment from MM 30 to MM 46. Figure 3.3a plots the MDSS predicted and actual snow accumulation values. The predicted snow is plotted in red, and the actual snow is plotted in blue. Snow accumulation is a critical part in the overall analysis as it serves as a proxy for estimating storm impact. For most of this storm, MDSS predicted more snow than was observed, indicating a conservative approach.

It is also possible to see the rate at which the snow accumulated. Figure 3.3b combines INDOT truck deployment, INDOT solid application rate and MDSS maintenance recommendations. The background of this graph is colorized by MDSS maintenance recommendations. These maintenance recommendations are at the 6-hour interval, resulting in the 6-hour "lag" in data on the leftmost side. The first gray box, callout i, on Thursday at 6 AM represents the forecasted recommendation for that time that was released Thursday at 12 AM. In the foreground of the maintenance recommendations is a bar chart representing the number of snowplows deployed across the MDSS plowing segment per hour. These bars are colorized by the solid application rate and scaled by the number of snowplows. This combined visual (Figure 3.3b) allows for a quick analysis of when the MDSS software suggested maintenance, when INDOT deployed their trucks and how aggressively they applied chemicals.

Figure 3.3c–d are segments of a similar connected vehicle heatmap to Figure 3.1a, but for the MDSS plowing segment on I-465. These figures have additional information overlaid on them that represent INDOT truck deployment. The blue lines indicate snowplow trajectory paths and solid black dots indicate the presence of automated brine tankers, equipment that pre-treat bridge decks and underpasses (callout iv) 24 hours before the main impact of the storm (Mahlberg et al., 2021, 2022, 2024). Figure 3.3e, f, and g correlate to cameras located along I-65 at callouts i, ii, and iii, respectively. These images are captured by roadside ITS cameras operated by INDOT. These images help to obtain visual confirmation of the actual conditions along the interstate at various locations and times.

### 3.5.1 Delta Speed 2 Visualization

Figure 3.4 shows various images of Doppler radar tiles, connected vehicle average speeds, plow truck locations, and chemical application trails overlayed on a map of Indiana at 3-hour intervals during the storm.

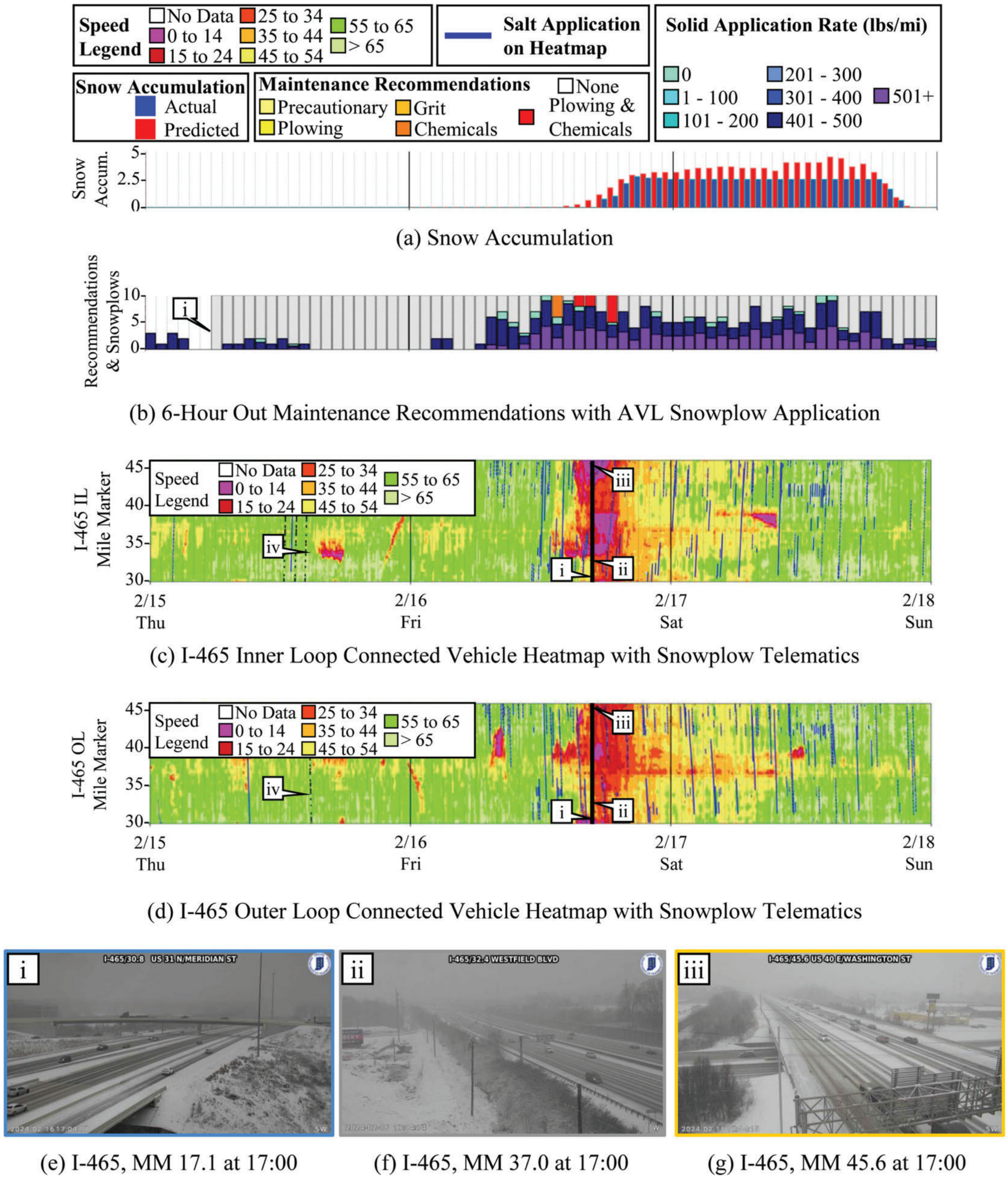



**Figure 3.3** Sample MDSS visualization for February 15th, 2024, storm.

This visualization of multiple data sources serves as a powerful tool to track the impact of winter storms before, during, and after the precipitation and serves as a unified real-time visual of winter weather maintenance operations and their impact on roadway mobility for stakeholders at the statewide as well as local level (Desai, Mahlberg, et al., 2021). Callouts i through vi in Figure 3.4a represent 50-mile intervals, from MM (mile marker) 250 at callout i to MM 0 at callout vi along I-65, giving a spatial reference.

During the time of this storm, the 2024 NBA All-Star Game and associated events were taking place in Indianapolis, motivating an additional MDSS route on I-465 near the events to be collected during this time. The MDSS plowing segment is located along I-465 between callouts i and ii in Figure 3.4b.

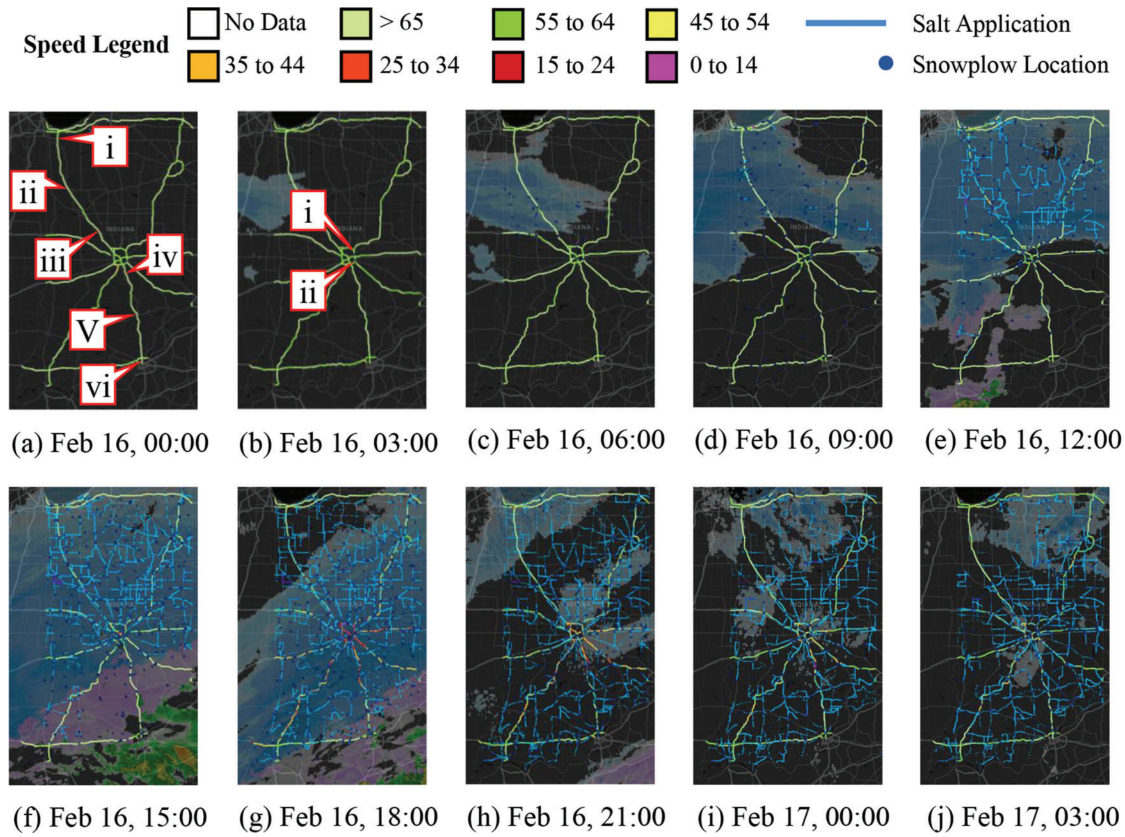



**Figure 3.4** February 16, 2024, winter storm Indiana interstate doppler, truck locations, heatmap and salt application.

## 4. ROUTE COMPARISON FOR THE FEBRUARY 16, 2024, WINTER STORM

### 4.1 I-65 Longitudinal Case Study

Having collected all of the data for each MDSS plowing segment (Figure 1.1a) during each winter storm (Figure 2.1b), it is possible to compare combined visuals on a route-by-route basis. Figure 4.1 visualizes all data for the I-65 MDSS plowing segment. Figure 4.1a and Figure 4.1b are similar to Figure 3.2a and Figure 3.2b, respectively, but the miles under 45 mph are classified by direction (I-65 N and I-65 S) rather than by district. Figure 4.1c is the snow accumulation for the I-65 MDSS plowing segment between MM 49.55 and MM 68.29. This segment of I-65 is highlighted by two black lines in Figure 4.1d through Figure 4.1g. Callouts point to the time when the precipitation began in both the actual accumulated snow plot (Figure 4.1c, callout ii) and precipitation plot (Figure 4.1e, callout iii). The snow would take some time to accumulate, making the slight lag between the precipitation (Figure 4.1e, callout iii) and accumulated snow (Figure 4.1c, callout ii), a powerful fact-check for both data sources. This is also around the same time that most snowplows are deployed across the state (Figure 4.1b). These figures are very powerful for agencies to analyze the overall response and determine if plows are deployed early, late or on-time and be able to adapt future protocol.

### 4.2 I-465 Beltway Case Study

Figure 4.2 contains the same plots as Figure 4.1, but for I-465. The I-465 MDSS plowing segment is between MM 30 and MM 46, highlighted by callout i pointing to two black lines in Figure 4.1d through Figure 4.1g. Due to the nature of I-465 being a relatively small-radius beltway, the storm impact was instant across the entire route. This is characterized by Figure 4.2d, e, f, and g having vertical changes, compared to the corresponding sub-figures in Figure 4.1. The importance of keeping I-465 safe and operational during the weekend of this storm was exponentially emphasized due to the NBA All-Star Game taking place. This coinciding event bringing above average vehicles can be seen in the snowplow deployment plot (Figure 4.2b) as the maintenance deployment began more than 6-hours prior to the storm. During the storm peak, the connected vehicle heatmap (Figure 4.2d) shows vehicle speeds under 45 mph for nearly the entire 53 miles of I-465. This correlates well to the total interstate miles under mph plot (Figure 4.2a) as the total sum of miles under 45 mph is slightly greater than 100 during the storm peak.

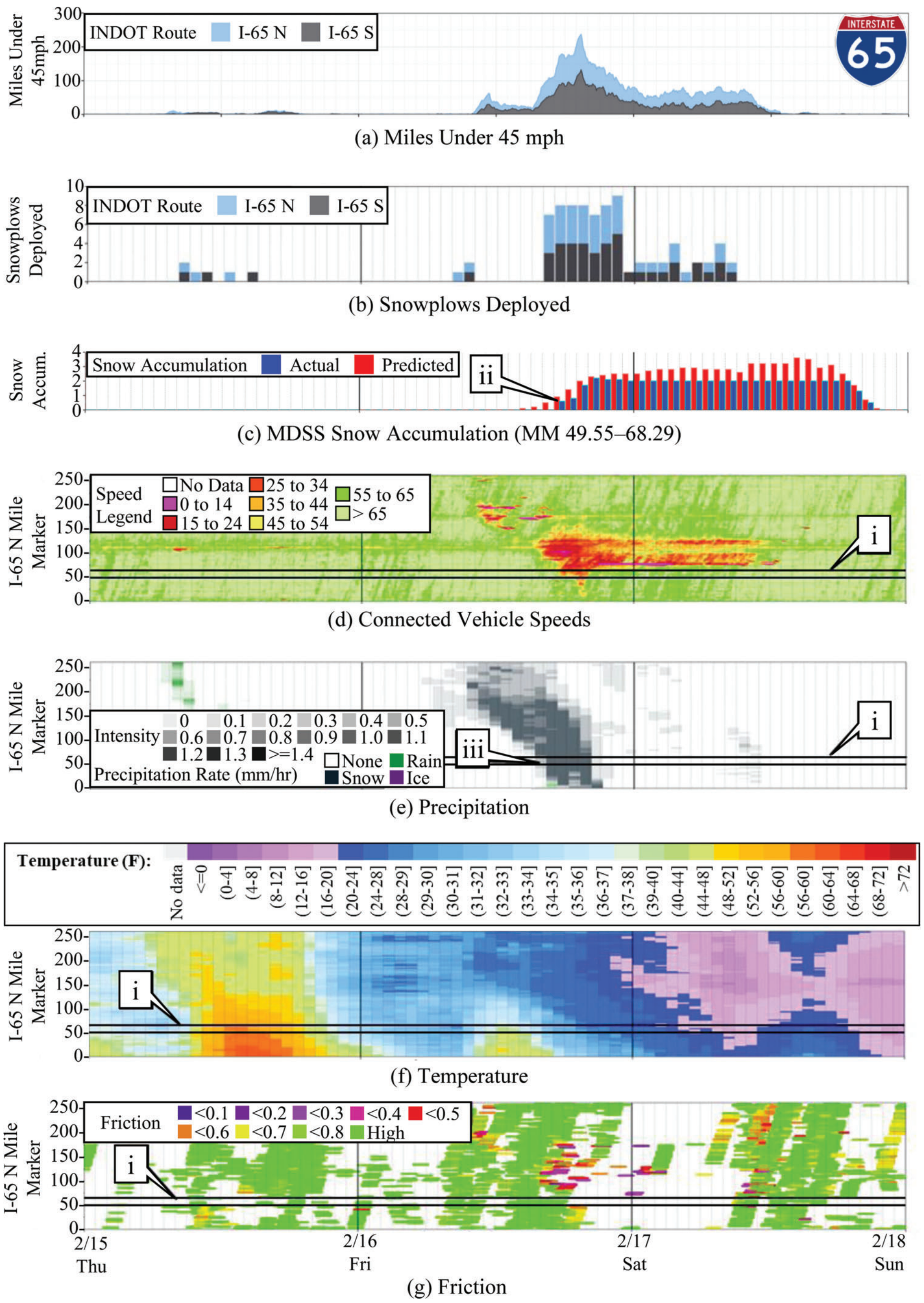



**Figure 4.1** Combination visual for I-65 during February 16, 2024, storm.

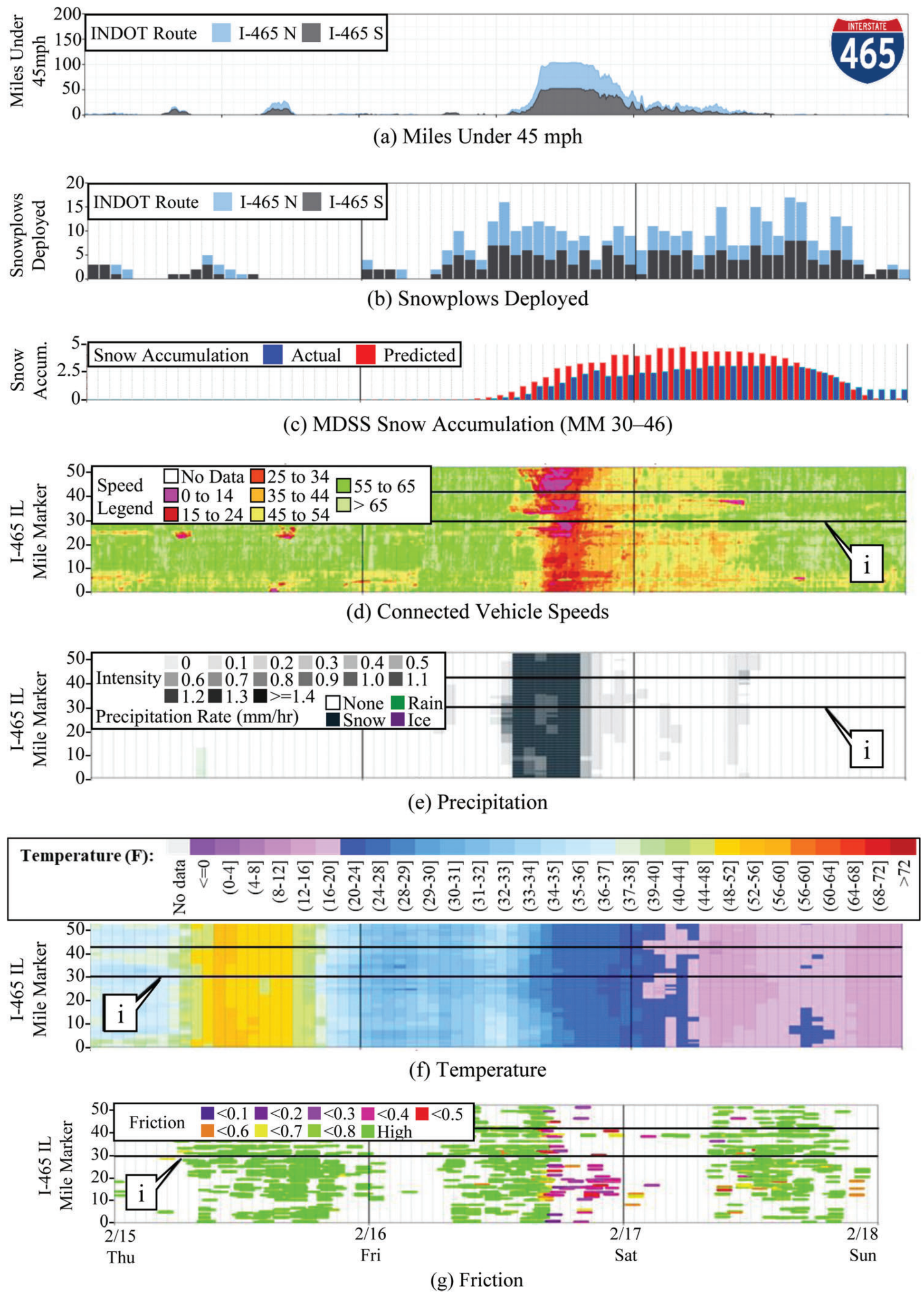



**Figure 4.2** Combined visual for I-465 during February 16, 2024, storm.

## 5. 2023–2024 WINTER SEASON CASE STUDIES

To fully understand the MDSS maintenance recommendations, three case studies were analyzed and broadly classified into either consistent, inconsistent or neutral.

### 5.1 February 16, 2024, I-465 Case Study

The first case study is located along the previous I-465 MDSS plowing segment (Figure 5.1). This segment is between MM 30 and MM 46 on the northeast corner of I-465 (Figure 5.1, callout i). This route was selected for the February 16, 2024, storm as it had the greatest number of snowplows deployed and vehicle speeds observed to be operating under 45 mph.

The data from this MDSS plowing segment, along with a connected vehicle heatmap produces a powerful visual aid (Figure 5.2) to track MDSS maintenance recommendations for the 24-hours leading up to and during the winter storm. Figure 5.2b through Figure 5.2g follow the same schema as Figure 3.3b and reduce in forecasting differential as they progress. In theory, the most accurate recommendations should come at the current hour differential, but agencies often plan multiple hours in advance to be able to mobilize operators. In this case, the maintenance recommendations are quite consistent throughout the progression, key for stakeholders to have advanced information on truck mobilization and material application. It is clear the trucks are mobilized far before the MDSS recommendations, but this is as expected. The software can make suggestions for the storm but is not suggesting any pre-treatment options. It is also ingesting AVL data, which indicates to the program that the route is already being maintained and does not suggest any further maintenance until the precipitation begins.

### 5.2 January 6, 2024, I-69 Case Study

The second case study is located along I-69 between MM 277.54 and MM 293.06 (Figure 5.3). This MDSS plowing segment is located just south of Fort Wayne, IN, near the southern I-69–I-469 interchange (Figure 5.3, callout i). This route was selected for the January 6, 2024, winter storm.

Looking at the combined MDSS recommendation figure (Figure 5.4), it is apparent that the MDSS maintenance recommendations are inconsistent throughout the progression from 23-hours out (Figure 5.4b) to the current hour (Figure 5.4g). The 23-hours out (Figure 5.4b) forecast shows a suggested chemical application for the morning of Saturday, January 6th, but the subsequent forecasts do not until 1-hour out (Figure 5.4f). This original recommendation aligns very closely with the predicted and actual snow accumulation, validating its legitimacy.

### 5.3 January 13, 2024, I-94 Case Study

The final case study is located along I-94 between MM 22.36 and MM 45.77 (Figure 5.5). This MDSS plowing segment is located near Michigan City, IN, near the southwestern Michigan border (Figure 5.5, callout i). This route was selected for the January 13, 2024, winter storm.

Figure 5.6 shows a very consistent and thorough maintenance recommendation trend. The 12-hour forecast (Figure 5.6c) is very similar to the subsequent forecasts for Saturday, January 13th. The 6-hour forecast (Figure 5.6d) is also like the subsequent forecasts for Friday, January 12th. At these forecast intervals, district stakeholders would have ample time to mobilize their operators and begin to plan for the storm, if they had not already done so. These consistent recommendations are very promising, as the proximity to Lake Michigan created a large lake effect and can often lead to abnormal storm patterns.

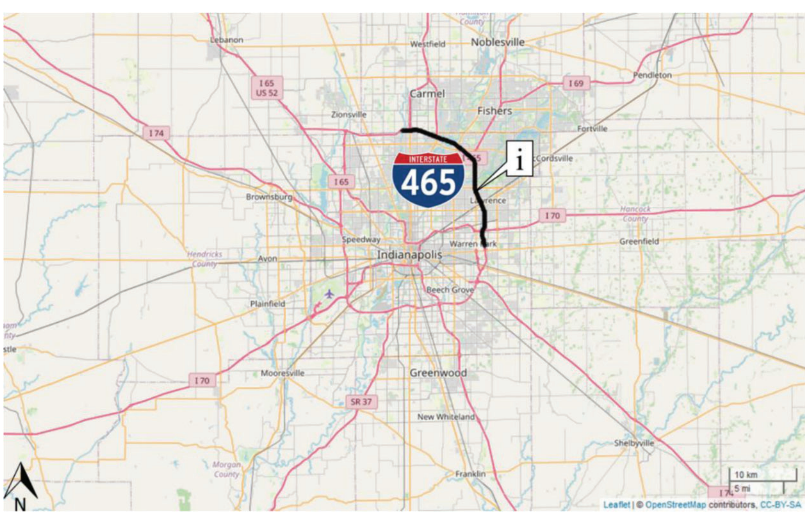



**Figure 5.1** Map of I-465 MDSS plowing segment.

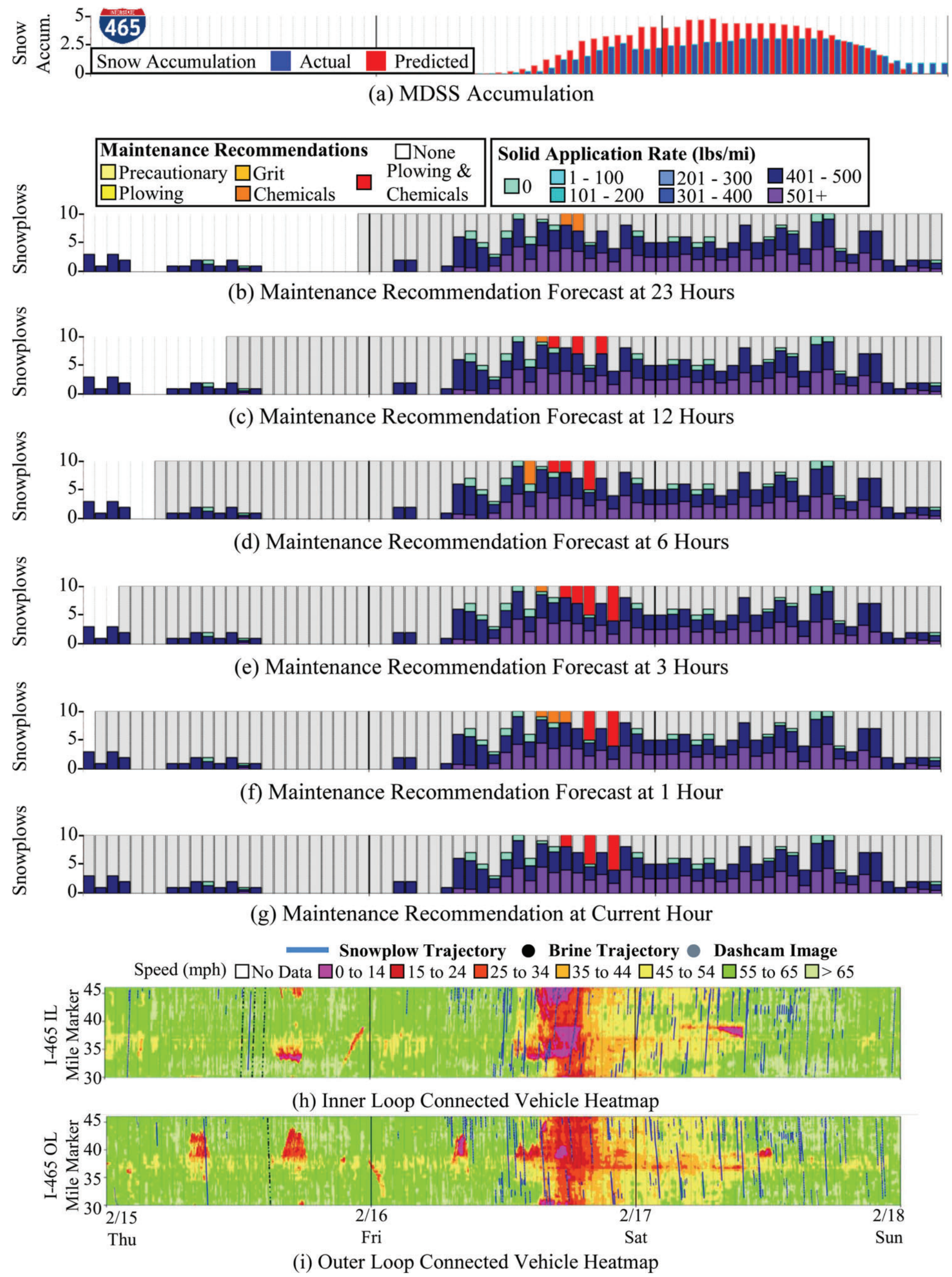



**Figure 5.2** February 16, 2024, winter storm, I-465 MM 30–46 MDSS maintenance recommendations.

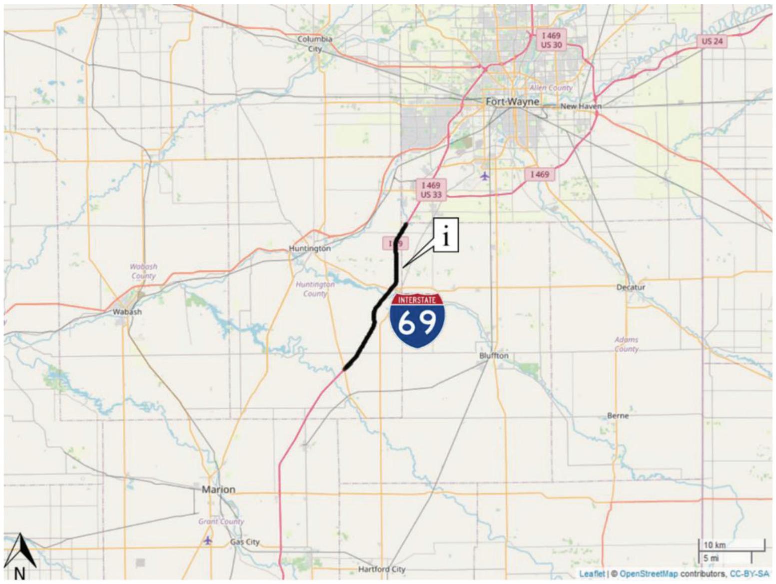



**Figure 5.3** Map of I-69 MDSS plowing segment.

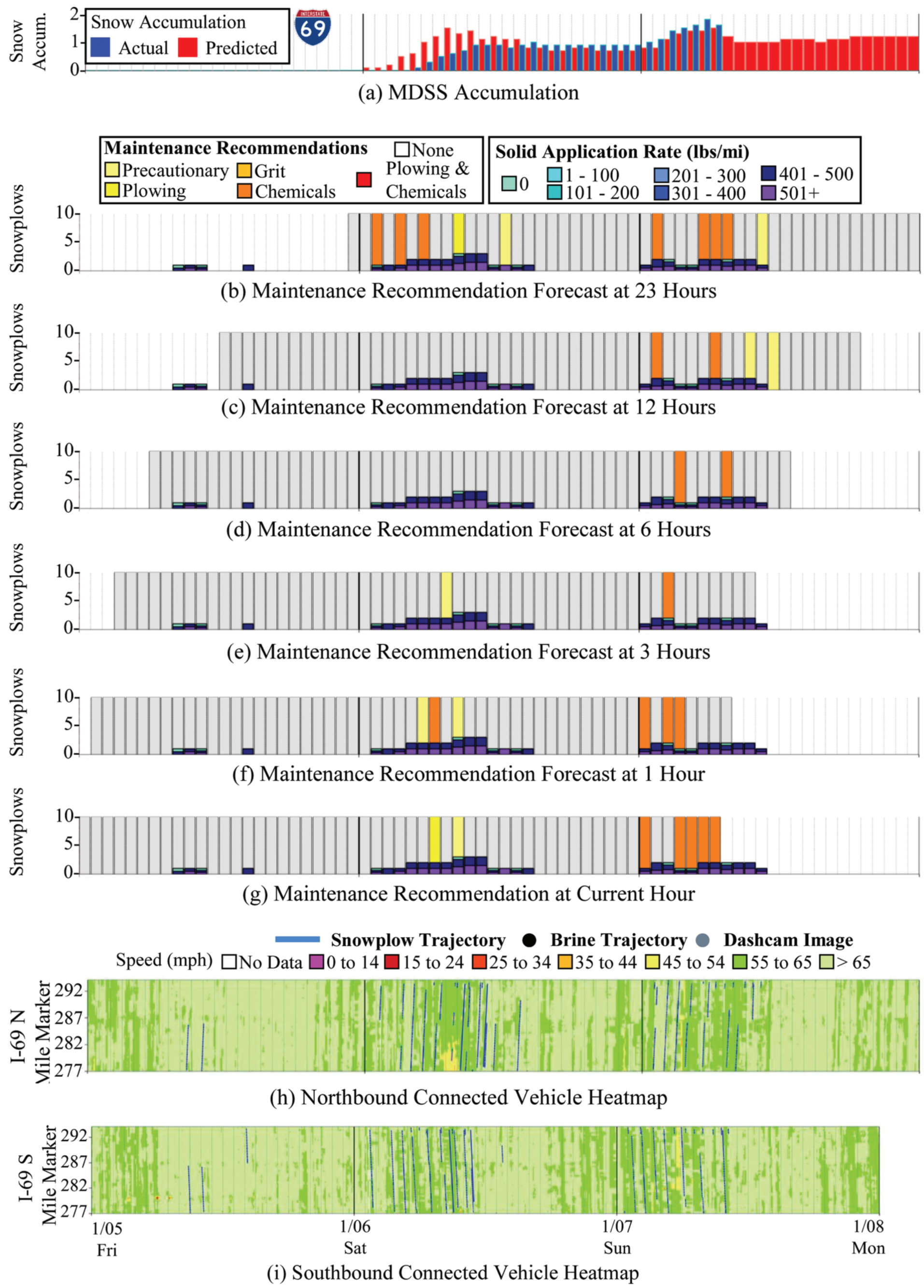



**Figure 5.4** January 6, 2024, winter storm, I-69 MM 277.54–293.06 MDSS maintenance recommendations.

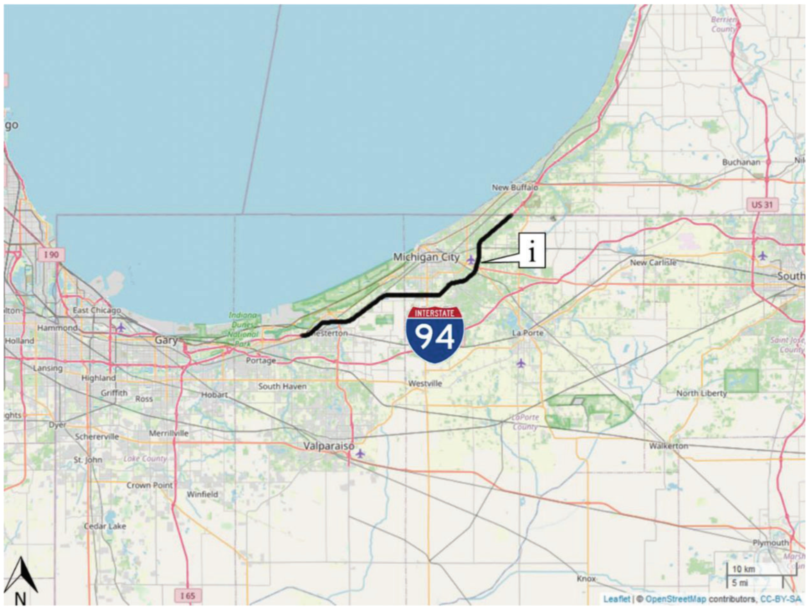



**Figure 5.5** Map of I-94 MDSS plowing segment.

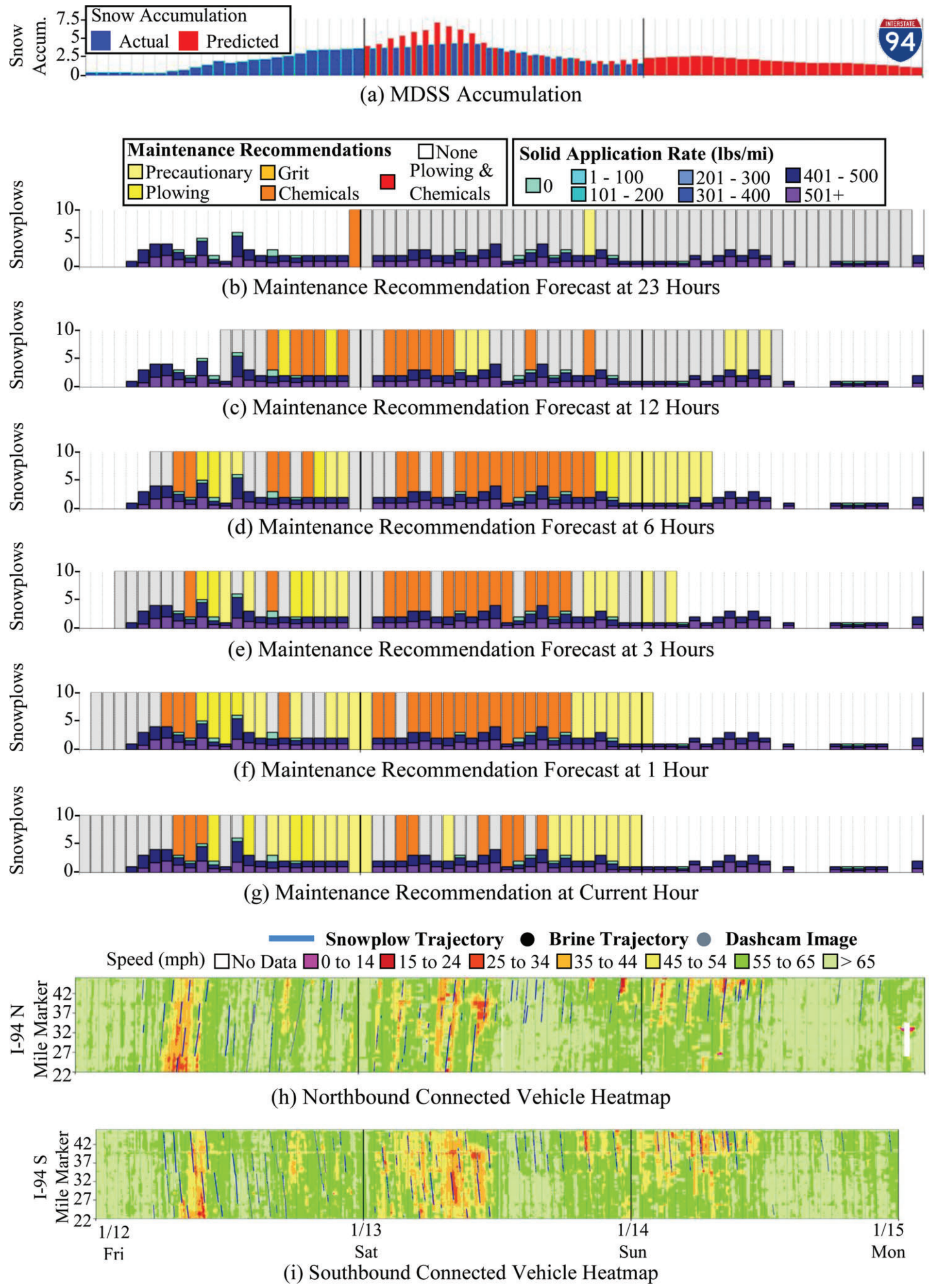



**Figure 5.6** January 13, 2024, winter storm, I-94 MM 22.36–45.77 MDSS maintenance recommendations.

## 6. FUTURE SCOPE AND SCALABILITY

This data and the associated visualizations can be adapted for performing after-action analysis on any type of storm, including ice, hail, snow and even rain. If agencies can actively utilize the software provided and feed input into the models, it will help to develop a more accurate maintenance recommendation forecast and ultimately a better winter weather maintenance program. The framework presented in this study could serve as a reference for evaluating and fine-tuning future MDSS forecasts, which will ultimately aid in data-driven decision making for effective winter weather maintenance operations and resource allocation. Future studies should document a broader set of inputs into the forecast model and analyze each provided input's impact on the eventual MDSS forecast and alignment with conditions observed on roadways.

Finally, MDSS uses truck position AVL data to provide agile adjustments to the forecast. It is important to understand if AVL shows a plow/salt truck in a segment, it assumes it is complying with the MDSS recommendation. However, very few trucks are currently equipped with plow up/down sensors or application rate feedback to the MDSS system. Integrating that AVL information into MDSS should be considered in the future.

## 7. CONCLUSIONS

This study integrated several independent datasets including connected vehicle speeds, connected vehicle friction, snowplow telematics, NOAA weather, and brine tanker telematics with MDSS recommendations. These datasets were collected for 6 interstate segments in the state of Indiana over the 2023–2024 winter season to evaluate the robustness of MDSS forecasts and present a framework for such future evaluations. Of the 13 total significant winter weather events with varying characteristics and severity, three were analyzed in detail. These three storms occurred on January 6th, 2024, January 13th, 2024, and February 16th, 2024. Incorporating a variety of visualizations into winter weather after-action reports increases the robustness of post-storm performance analysis and allows road weather stakeholders to better understand the capabilities of MDSS. Three case studies have been highlighted to represent cases where the weather changed so aggressively that it would be very difficult to predict (Figure 5.2), cases where the MDSS forecast did not deliver consistent messages as the forecasting threshold approached 0 (Figure 5.4) and cases where the MDSS forecast aligned well with observed INDOT truck deployment (Figure 5.6). The results of this analysis will provide a framework for future MDSS evaluations and training tools for winter operation professionals in Indiana.

## REFERENCES


Cluett, C., & Jenq, J. (2007). *A case study of the Maintenance Decision Support System (MDSS) in Maine* (Report No. FHWA-JPO-08-001). Battelle Seattle Research Center.

Desai, J. C., Sakhare, R., Rogers, S., Mathew, J. K., Habib, A., & Bullock, D. (2021). Using connected vehicle data to evaluate impact of secondary crashes on Indiana interstates. *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)* (pp. 4057–4063).

Desai, J. C., Saldivar-Carranza, E. D., Mathew, J. K., Li, H., Platte, T., & Bullock, D. M. (2021). Methodology for applying connected vehicle data to evaluate impact of interstate construction work zone diversions. *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)* (pp. 4035–4042).

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

Desai, J., Mathew, J. K., Li, H., & Bullock, D. M. (2022). Using connected truck trajectory data to compare speeds in states with and without differential truck speeds. *Journal of Transportation Technologies*, *12*(4), 681–695. https://doi.org/10.4236/jtts.2022.124039

Desai, J., Mathew, J. K., Li, H., Sakhare, R. S., Horton, D., & Bullock, D. M. (2023). Analysis of connected vehicle data to quantify national mobility impacts of winter storms for decision makers and media reports. *Future Transportation*, *3*(4), 1292–1309. https://doi.org/10.3390/futuretransp3040071

FHWA. (n.d.). *Weather Responsive Management Strategies (WRMS)–Minnesota DOT case study* (Report No. FHWA-HOP-19-080). FHWA Office of Operations. Retrieved June 26, 2024, from https://ops.fhwa.dot.gov/publications/fhwahop19080/index.htm

Hunter, M., Mathew, J. K., & Bullock, D. M. (2024). Estimation of connected vehicle penetration on US roads in Indiana, Ohio, and Pennsylvania. *Journal of Transportation Technologies*, *11*, 597–610. https://doi.org/10.4236/jtts.2021.114037

Hunter, M., Mathew, J. K., Cox, E., Blackwell, M., & Bullock, D. M. (2021). *Estimation of connected vehicle penetration rate on Indiana roadways* (JTRP Affiliated Reports Paper 37). Purdue University. https://doi.org/10.5703/1288284317343

Li, H., Saldivar-Carranza, E., Mathew, J. K., Kim, W., Desai, J., Wells, T., & Bullock, D. M. (2020). *Extraction of vehicle CAN bus data for roadway condition monitoring* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2020/20). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317212

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

Mahlberg, J. A., Mathew, J. K., Desai, J., & Bullock, D. M. (2024). Reducing distracted driving and improving consistency with brine truck automation. *Electronics*, *13*(2), 327. https://doi.org/10.3390/electronics13020327

Mahlberg, J., Matthew, J., Horton, D., McGavic, B., Wells, T., & Bullock, D. (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., Zhang, Y., Jha, S., Mathew, J. K., Li, H., Desai, J., Kim, W., McGuffey, J., Wells, T., 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 FHWA/IN/JTRP-2021/27). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317355

Mahoney, W. P., III., Bernstein, B., Wolff, J., Linden, S., Myers, W. L., Hallowell, R. G., Cowie, J., Stern, A. D., Koenig, G., Phetteplace, G., Schultz, P., Pisano, P. A., & Burkheimer, D. (2005). FHWA's maintenance decision support system project: Results and recommendations. *Transportation Research Record*, *1911*(1), 133–142. Retrieved June 26, 2024, from https://journals.sagepub.com/doi/abs/10.1177/0361198105191100113

Mathew, J. K., Desai, J., Cox, E. D., & Bullock, D. M. (2024). Application of connected truck data to evaluate spatiotemporal impact of rest area closures on ramp parking. *Journal of Transportation Technologies*, *14*(3), 289–307. https://doi.org/10.4236/jtts.2024.143018

Mathew, J. K., Desai, J., Li, H., & Bullock, D. M. (2021). Using anonymous connected vehicle data to evaluate impact of speed feedback displays, speed limit signs and

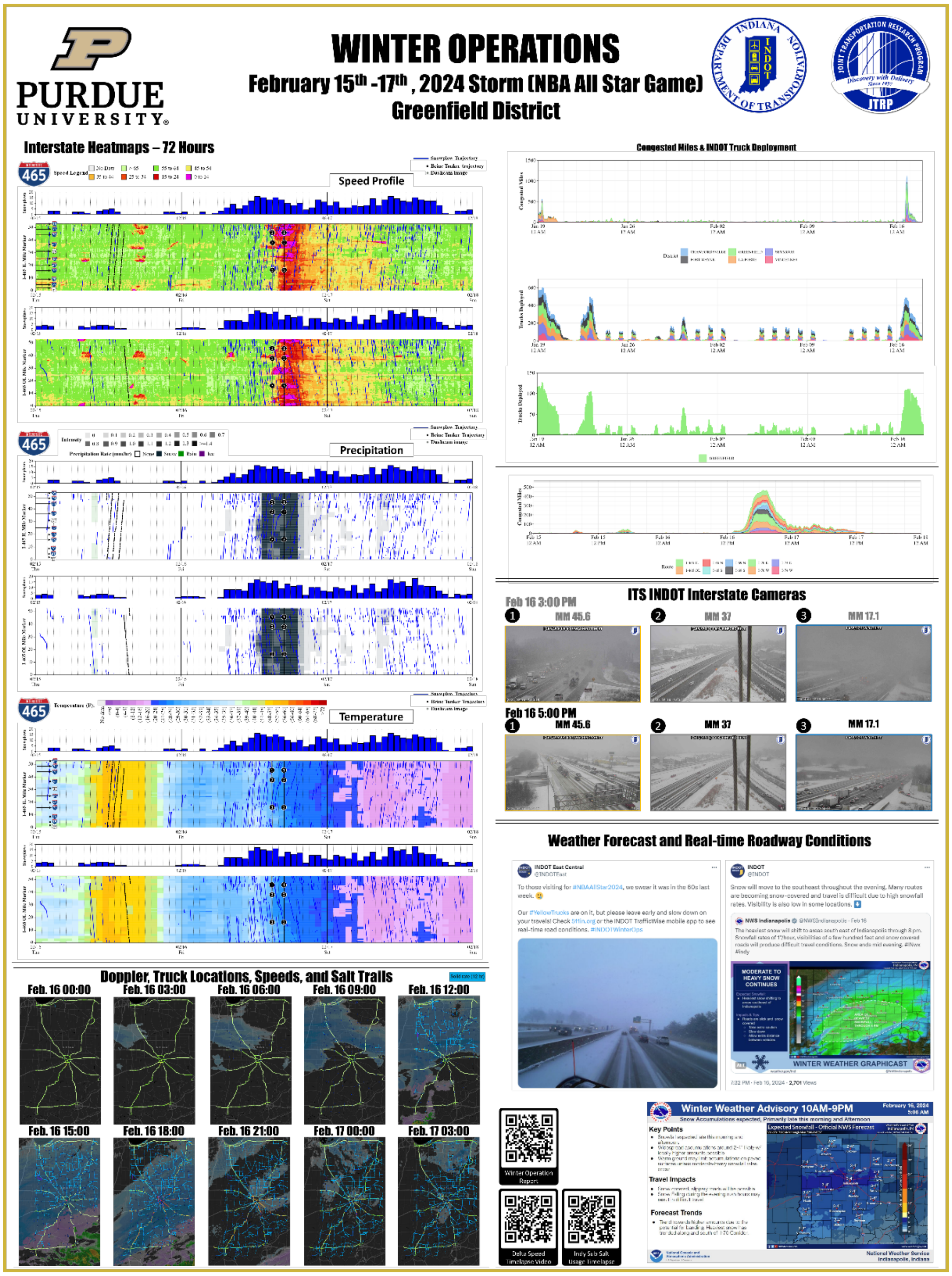
roadway features on interstate work zones speeds. *Journal of Transportation Technologies*, *11*(4), 545–560. https://doi.org/10.4236/jtts.2021.114034
Mathew, J. K., Malackowski, H. A., Gartner, C. M., Desai, J., Cox, E. D., Habib, A. F., & Bullock, D. M. (2023). Methodology for automatically setting camera view to mile marker for traffic incident management. *Journal of Transportation Technologies*, *13*(4). https://doi.org/10.4236/jtts.2023.134033
Petty, K. R., & Mahoney, W. P. (2008). The U.S. Federal Highway Administration winter road Maintenance Decision Support System (MDSS): Recent enhancements & refinements. In *Proceedings of the 14th SIRWEC Conference, Prague, Czech Republic*.
Pisano, P. A., Stern, A. D., & Mahoney, W. P., III. (2005). *The US Federal Highway Administration Winter Road Maintenance Decision Support System (MDSS) project: Overview and results*.
Research Applications Laboratory. (n.d.). *Maintenance decision support system* [Webpage]. Retrieved 26, 2024, from https://ral.ucar.edu/solutions/products/maintenance-decision-support-system-mdss
Sakhare, R. S., Desai, J. C., Mahlberg, J., Mathew, J. K., Kim, W., Li, H., McGregor, J. D., & Bullock, D. M. (2021). Evaluation of the impact of queue trucks with navigation alerts using connected vehicle data. *Journal of Transportation Technologies*, *11*(4), 561–576. https://doi.org/10.4236/jtts.2021.114035
Sakhare, R. S., Desai, J., Mathew, J., McGregor, J., Kachler, M., & Bullock, D. (2024). *Measuring and visualizing freeway traffic conditions: Using connected vehicle data* (Joint Transportation Research Program No. TPF-5(514)). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317751
Sakhare, R. S., Hunter, M., Mukai, J., Li, H., & Bullock, D. M. (2022). Truck and passenger car connected vehicle penetration on Indiana roadways. *Journal of Transportation Technologies*, *12*(4), 578–599. https://doi.org/10.4236/jtts.2022.124034
Sakhare, R. S., Zhang, Y., Li, H., & Bullock, D. M. (2023). Impact of rain intensity on interstate traffic speeds using connected vehicle data. *Vehicles*, *5*(1), 133–155. https://doi.org/10.3390/vehicles5010009
Seidl, W., & Cypra, T. (2010). Maintenance Decision Support System (MDSS). In J. Düh, H. Hufnagl, E. Juritsch, R. Pfliegl, H. K. Schimany, & H. Schönegger (Eds.), *Data and Mobility. Advances in Intelligent and Soft Computing*, *81*, 139–150.
Ye, Z., Strong, C. K., Shi, X., Conger, S. M., & Huft, D. L. (2009). Benefit–cost analysis of maintenance decision support system. *Transportation Research Record*, *2107*(1), 95–103. https://doi.org/10.3141/2107-10

# APPENDICES

**Appendix A. All-Star Game Storm Winter Weather Operations (February 15th–17th, 2024)**

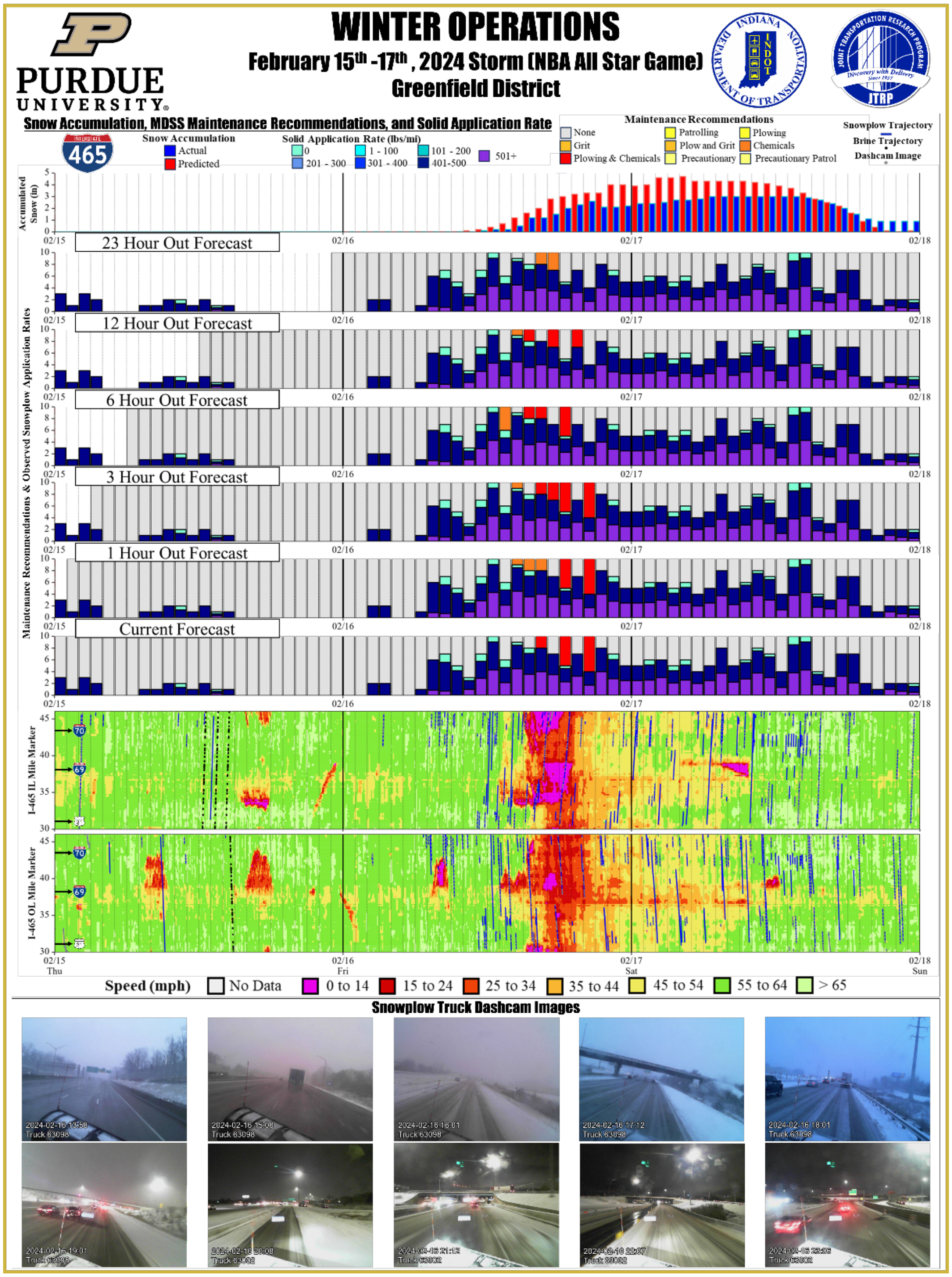
**Appendix B. All-Star Game Storm MDSS Recommendations (February 15th–17th, 2024)**

# APPENDIX A. ALL-STAR GAME STORM WINTER WEATHER OPERATIONS (FEBRUARY 15TH–17TH, 2024)




[February 15th–17th, 2024, NBA All-Star Game Storm Winter Weather Operations.pptx]

# APPENDIX B. ALL-STAR GAME STORM MDSS RECOMMENDATIONS (FEBRUARY 15TH–17TH, 2024)




[February 15th–17th, 2024, NBA All-Star Game Storm MDSS Recommendations.pptx]

## 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.

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