

Evaluating the Robustness of MDSS Maintenance Forecasts Using Connected Vehicle Data

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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 increases the robustness of post-storm performance analysis and allows 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 as well as training tools for winter operation stakeholders in Indiana and beyond.

Keywords

Weather Forecasting, Winter Weather, Connected Vehicle Data,

After-Action Report

1. Introduction

The Indiana Department of Transportation (INDOT) uses many data sources to plan and manage winter weather maintenance activities on 29,000 miles of roads. 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 available automatic vehicle location (AVL) truck data in the region. 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 aimed at gathering 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.

1.1. Literature Review

Past research has been conducted on the MDSS software [1], mostly while the software was being initially developed [2]-[5]. 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) [6] 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) [7] determined that integrating third-party data sources into the software would increase its robustness. Similarly, a study with MnDOT (Minnesota Department of Transportation) [8] 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], Intelligent Transportation Systems (ITS) camera images [17], instrumented brine tankers [18], fleetwide instrumentation of snowplow trucks with telematics devices [19]-[21], 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 perform such an evaluation of the robustness of these forecasts to provide a framework for future MDSS evaluations and identifying opportunities to fine-tune these forecasts for effective winter weather

maintenance.

1.2. MDSS Overview

Maintenance recommendations and other MDSS data are available through an interactive web portal. In this portal, agency employees can select individual, pre-defined routes across the state and access both past storms and future weather data forecasts. In this study, 6 MDSS ploCONTIwing 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, La Porte, Seymour and Vincennes) ensured that this study was relevant for the entire state, and each of the 6 main primary interstates. These six plowing segments can be seen in **Figure 1(a)**, as callouts i through vi.

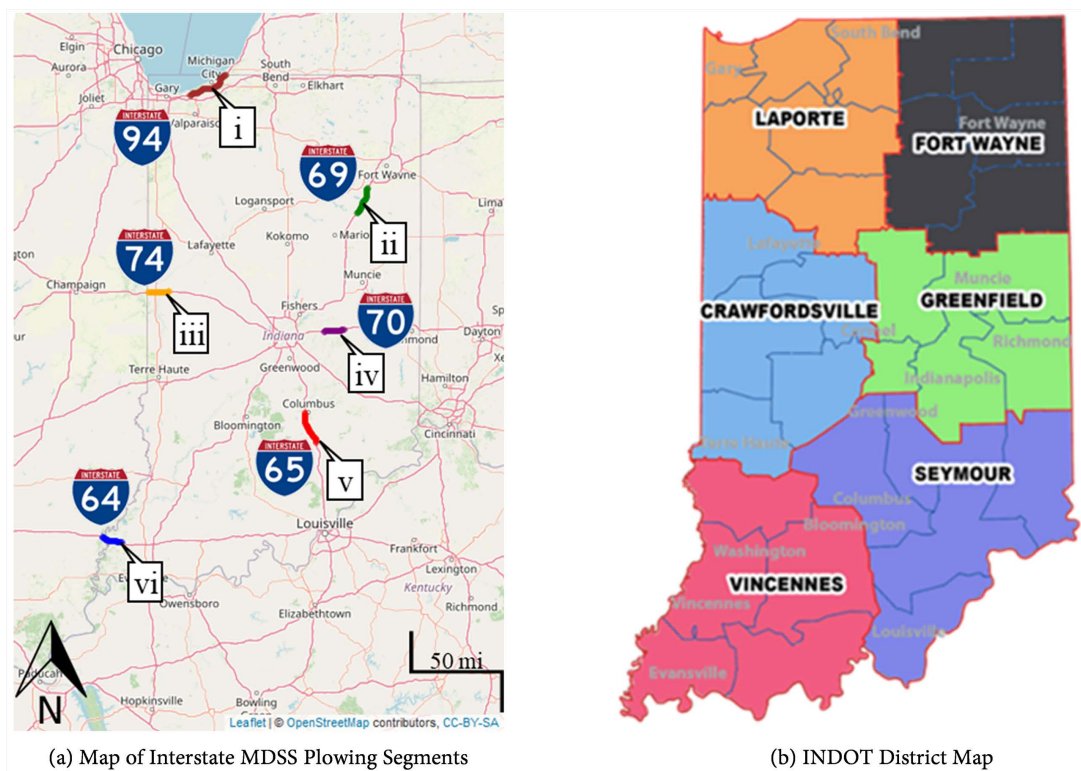


Figure 1. Selected routes where MDSS data was captured and analyzed.

A total of 26 different MDSS data attributes were collected for each hour of winter storms. Data attributes are summarized in **Table 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,” “PreWet NaCl”), with an associated application rate (e.g. “250 lb/mi”), when applicable. A typical maintenance alert combines these three attributes as recommendations (e.g., “Chemicals Recommended, PreWet NaCl, 250 lb/mi”).

Table 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

1.3. Motivation

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 2600 miles of interstate, with 5-minute probe data and calculates the number of miles operating below 45mph. For the period of December 1, 2023, and March 1, 2024, **Figure 2(a)** shows a temporal visualization of miles of Indiana interstates operating under 45 MPH, and **Figure 2(b)** shows the number of snowplows deployed. A district legend with the colorized map for both **Figure 2(a)** and **Figure 2(b)** can be seen in **Figure 1(b)**. For the first two weeks of December, **Figure 2(a)** clearly shows Monday-Friday re-occurring congestion before the Holidays. The two biggest spikes in **Figure 2(a)** occurred on or around January 19, 2024 and February 16, 2024. Those storms had approximately 550 miles and 1100 miles of interstate operating below 45mph, 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(b)** highlights the storm with the greatest number of snowplows deployed across the state, and callout xiii highlights the storm with the greatest overall impact. This storm significantly impacted the entire state and serves as the study's focus. **Figure 3** shows various images of Doppler radar tiles, connected vehicle average speeds, plow truck locations, and chemical application trails overlaid on a map of Indiana at 3-hour intervals during the 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 [22]. Callouts i through vi in **Figure 3(a)** 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.

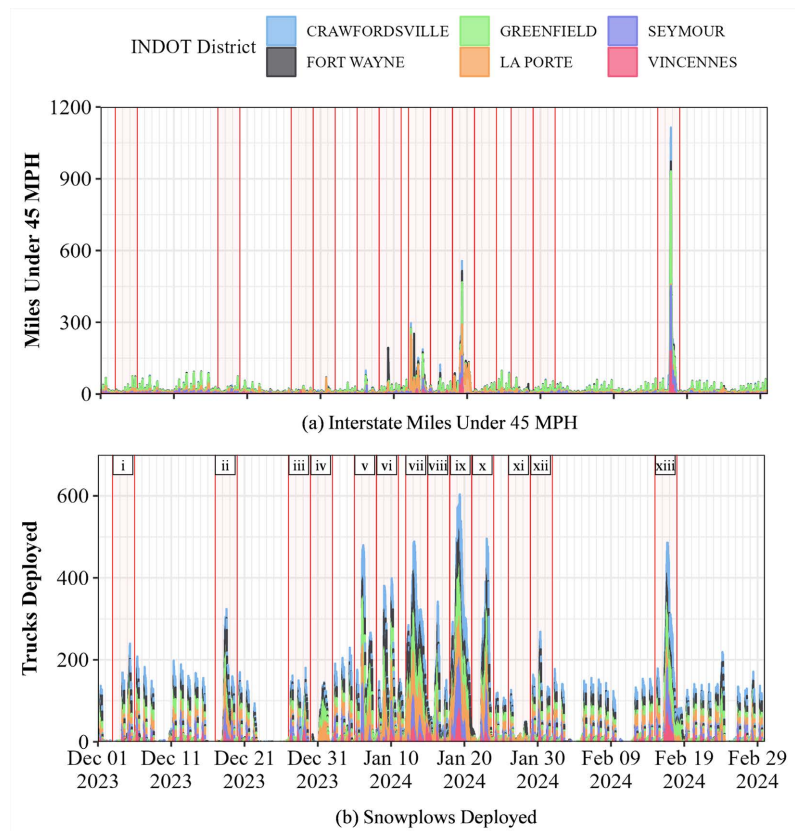


Figure 2. Ticker plot for 2023-2024 winter season with callouts for winter storm dates.

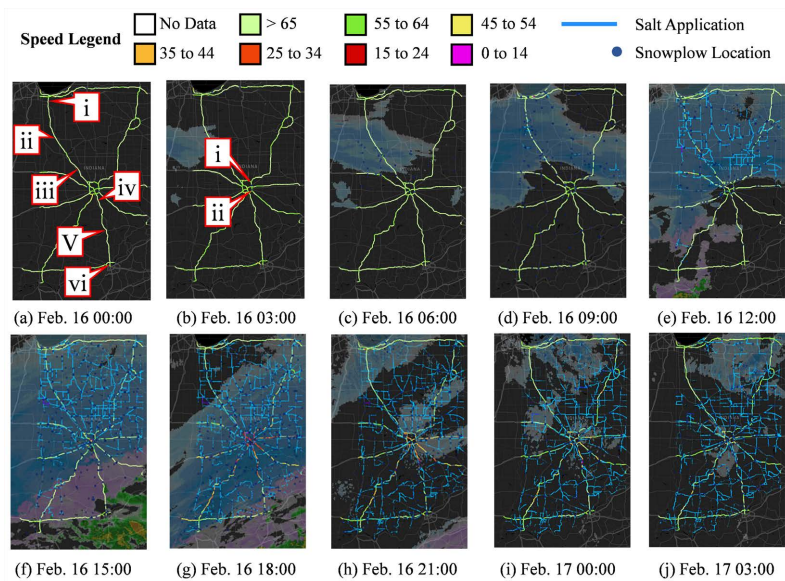


Figure 3. February 16, 2024, winter storm Indiana interstate doppler, truck locations, heatmap and salt application.

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(b)**.

2. Data Sources

Once collected, the MDSS data must be compared to ground-truth data, allowing for a spatio-temporal alignment and analysis. **Figure 4** shows graphical representations of 4 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.

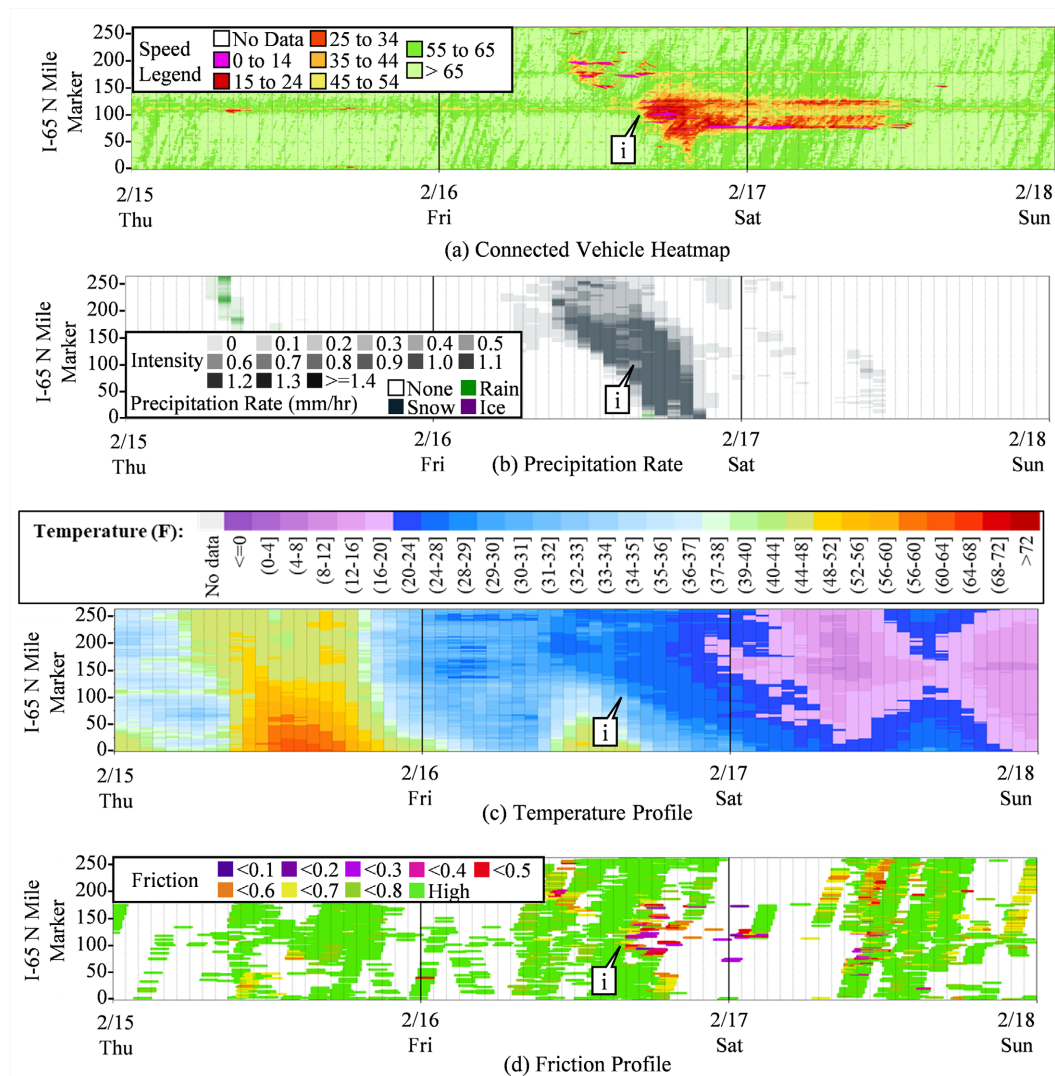


Figure 4. Data sources plotted for February 16, 2024 winter storm.

2.1. Connected Vehicle Data

Figure 4(a) 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 been applied to other winter and severe weather research [14] [21]. Connected vehicle heatmaps have proved vital in measuring and visualizing freeway traffic conditions for many conditions including inclement weather events [23].

In this case, I-65 is the selected route, from MM 0 near Louisville, KY to MM 262 near Chicago, IL; see **Figure 3(a)** for 50-mile incremental callouts. **Figure 4(a)**, callout i indicates the main impact of the storm. This callout is constant through all four data sources in **Figure 4**, 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.

Limitations

Connected vehicle data allows for a unique perspective on near real-time traffic patterns, but does come with some limitations. These limitations include latency, penetration rate and the quantity of data needed for analysis. Latency for the segment-based data used in this study is approximately 1 - 5 minutes; other trajectory-based data has observed latency between 30 to 60 seconds [24]. The connected vehicle penetration rate has been estimated to be above 6% along Indiana interstates in 2022 [9], an increase from 4.3% in 2020 [12]. This penetration rate, although less than 10%, is still representative of actual traffic conditions and can be leveraged for a variety of use cases [24]. Analysis of connected vehicle data can be difficult due to the large volume of data. Prior studies found that over 500 billion data records were available, covering all 50 US states, and amassed tens of TBs (terabytes) of data. This amount of data is not only difficult to manage and analyze, but also expensive to store in a readily available database [25] [26].

2.2. Precipitation Rate

Looking at the storm progress through the state from **Figure 3(a)** to **Figure 3(g)**, 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 4(b)**, 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 [14] [24]. The progression through the state can also be seen in **Figure 4(a)**, as vehicle speeds are decreased due to impaired driving conditions.

2.3. 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 4(c)** 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 more than 20 degrees by Saturday, totaling a near 50-degree drop in temperature over the course of 48 hours.

2.4. Friction Profile

Figure 4(d) 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 [27] [28]. 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 [22]. 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.

2.5. Storm Impact Summary

Summarizing the data is important for obtaining an overall understanding of the storm's impact quickly. **Figure 5** shows two plots summarizing the overall storm impact for motorists and snow removal agencies (INDOT). **Figure 5(a)** 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 5(b)** summarizes the impact on INDOT, totaling the number of snowplows deployed per hour. This plot is colored 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.

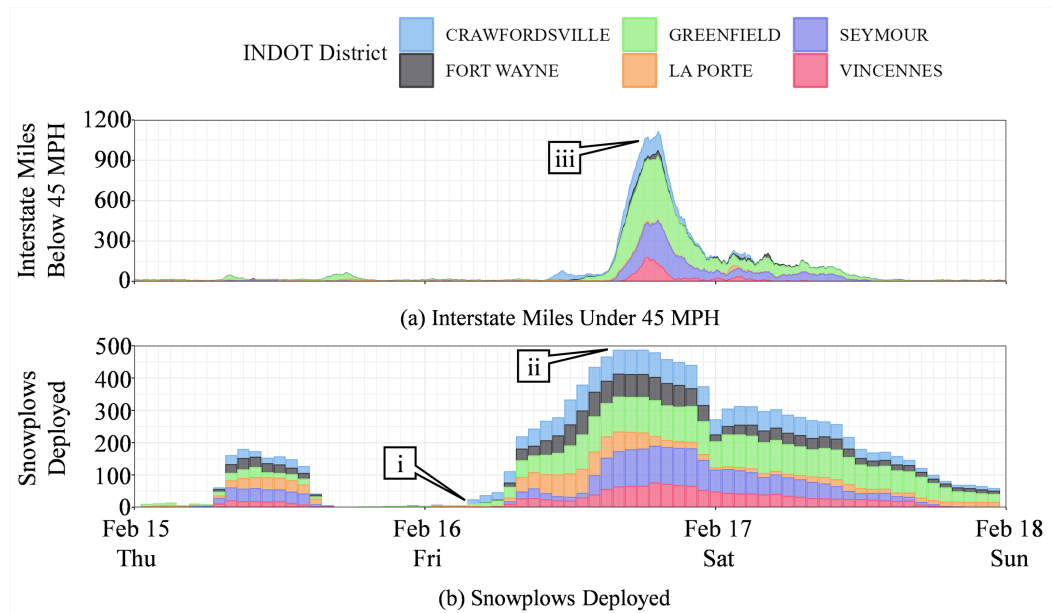


Figure 5. February 16, 2024 storm impact to motorists and trucks deployed.

Once captured, MDSS data can be plotted and compared, as seen in **Figure 6**. The data for this figure correlates to the I-465 MDSS plowing segment from MM 30 to MM 46. **Figure 6(a)** 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 6(b)** 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 6(b)**) allows for a quick analysis of when the MDSS software suggested maintenance, when INDOT deployed their trucks and how aggressively they applied chemicals.

Figure 6(c) and **Figure 6(d)** are segments of a similar connected vehicle heatmap to **Figure 4(a)**, but for the MDSS plowing segment on I-465. These sub figures have additional information that represents 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 [18] [21]

[29]. **Figure 6(e)**, **Figure 6(f)** and **Figure 6(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.

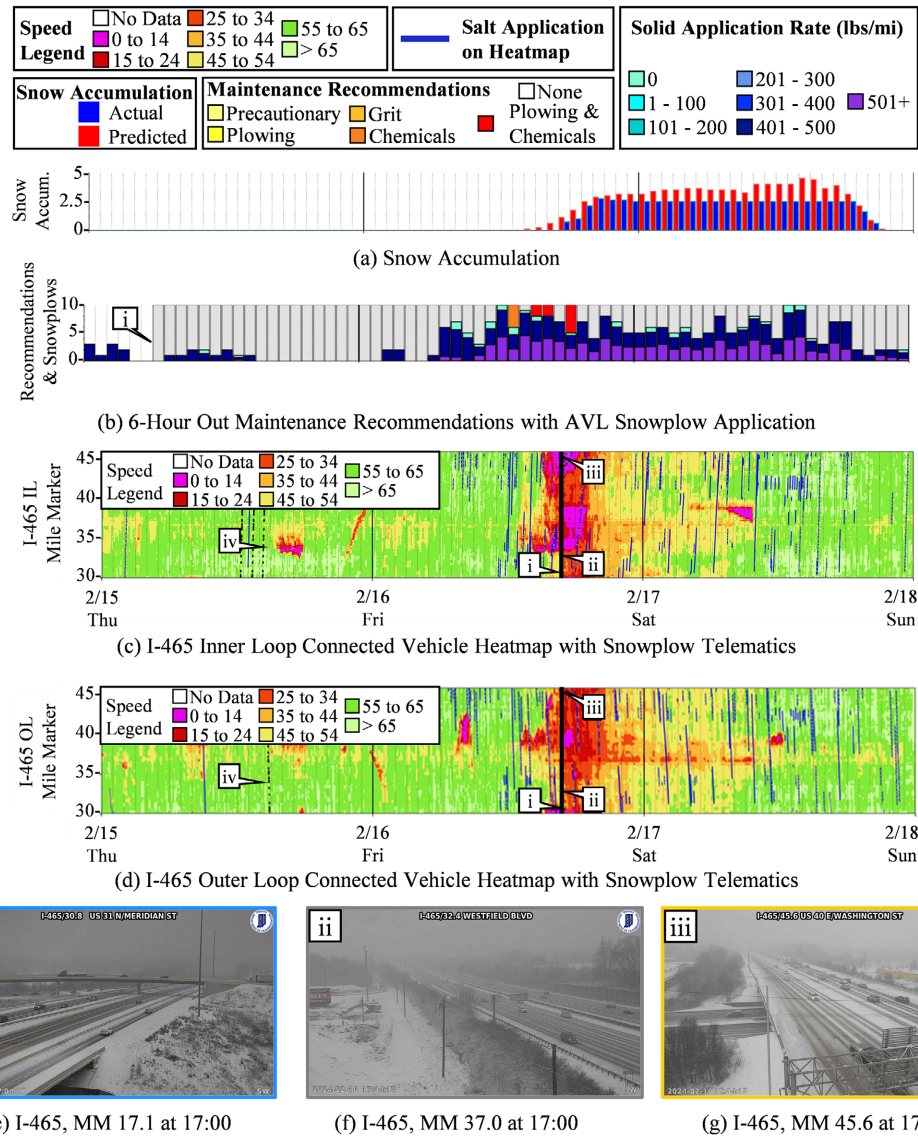


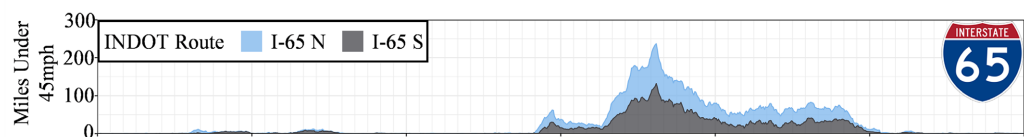
Figure 6. Sample MDSS visualization for February 15th, 2024 storm.

3. Route Comparison for February 16, 2024 Winter Storm

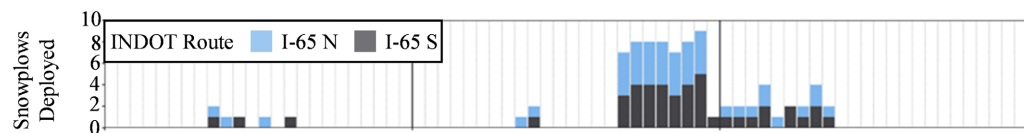
3.1. I-65 Longitudinal Case Study

Having collected all of the data for each MDSS plowing segment (**Figure 1(a)**) during each winter storm (**Figure 2(b)**), it is possible to compare combined visuals on a route-by-route basis. **Figure 7** visualizes all data for the I-65 MDSS plowing segment. **Figure 7(a)** and **Figure 7(b)** are similar to **Figure 5(a)** and **Figure 5(b)**, respectively, but the miles under 45 MPH are classified by direction (I-65 N

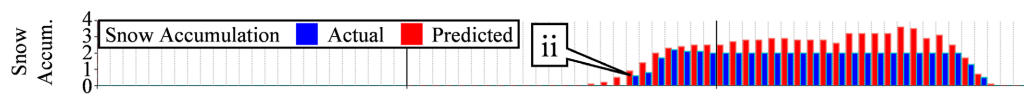
and I-65 S) rather than by district. **Figure 7(c)** is the snow accumulation for the I-65 MDSS plowing segment between MM 49.55 and MM 68.29. This segment of I-65 is highlighted by two black lines in **Figure 7(d)** through **Figure 7(g)** Callouts point to the time when the precipitation began in both the actual accumulated snow plot (**Figure 7(c)**, Callout ii) and precipitation plot (**Figure 7(e)**, Callout iii). The snow would take some time to accumulate, making the slight lag between the precipitation (**Figure 7(e)**, Callout iii) and accumulated snow (**Figure 7(c)**, Callout ii), a powerful fact-check for both data sources. This is also around the same time that the majority of snowplows are deployed across the state (**Figure 7(b)**). 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.



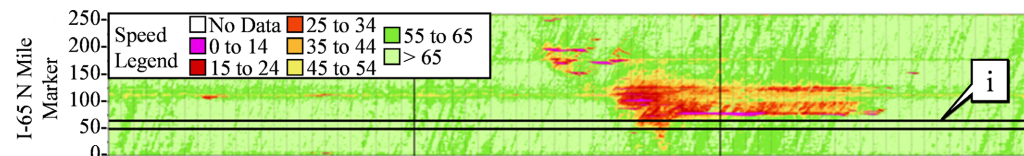
(a) Miles Under 45 MPH



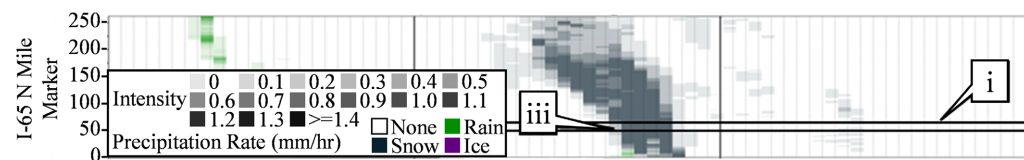
(b) Snowplows Deployed



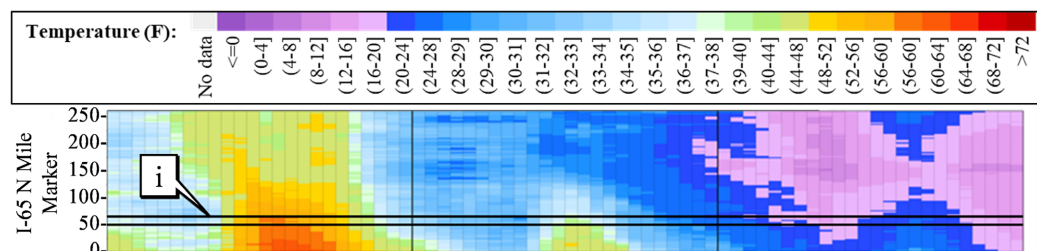
(c) MDSS Snow Accumulation (MM 49.55 – 68.29)



(d) Connected Vehicle Speeds



(e) Precipitation



(f) Temperature

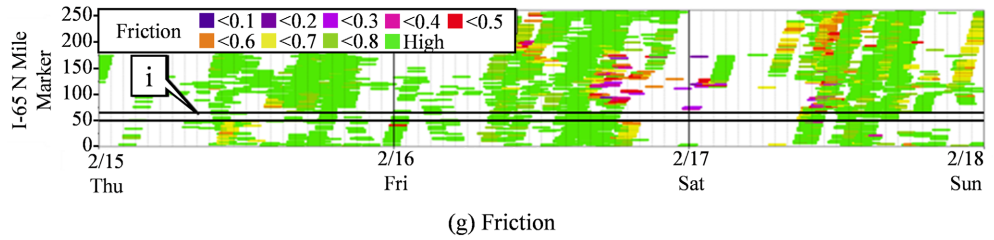
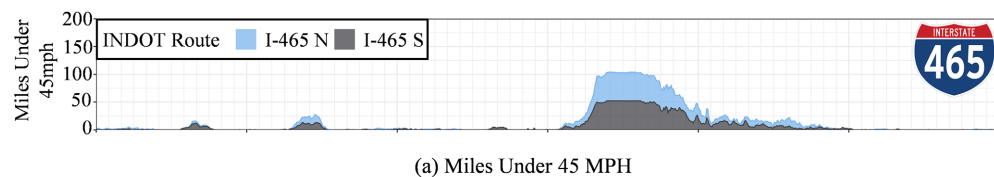


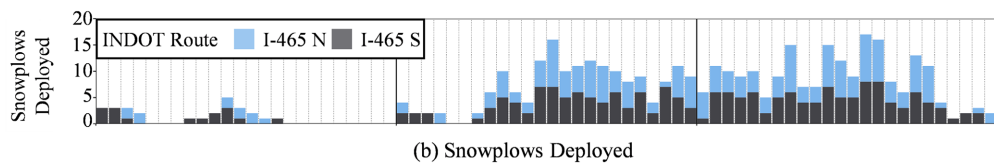
Figure 7. Combination visual for I-65 during February 16, 2024 storm.

3.2. I-465 Beltway Case Study

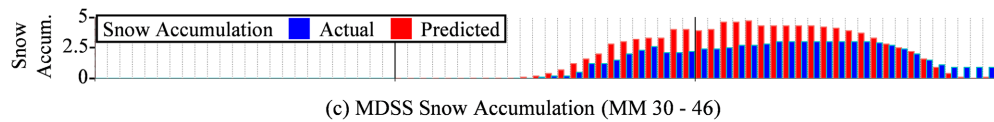
Figure 8 contains the same plots as Figure 7, but for I-465. The I-465 MDSS plowing segment is between MM 30 and MM 46, highlighted by callout i pointing to two black lines in Figure 7(d) through Figure 7(g). Due to the nature of I-465 being a relatively small-radius beltway, the storm impact was fairly instant across the entire route. This is characterized by Figure 8(d), Figure 8(e), Figure 8(f) and Figure 8(g) having vertical changes, compared to the corresponding sub-figures in Figure 7. 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 8(b)) as the maintenance deployment began more than 6-hour prior to the storm. During the storm peak, the connected vehicle heatmap (Figure 8(d)) 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 8(a)) as the total sum of miles under 45 MPH is slightly greater than 100 during the storm peak.



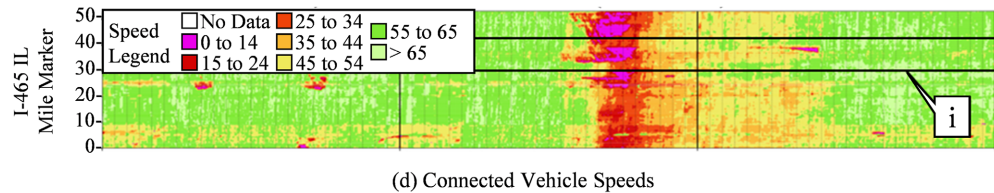
(a) Miles Under 45 MPH



(b) Snowplows Deployed



(c) MDSS Snow Accumulation (MM 30 - 46)



(d) Connected Vehicle Speeds

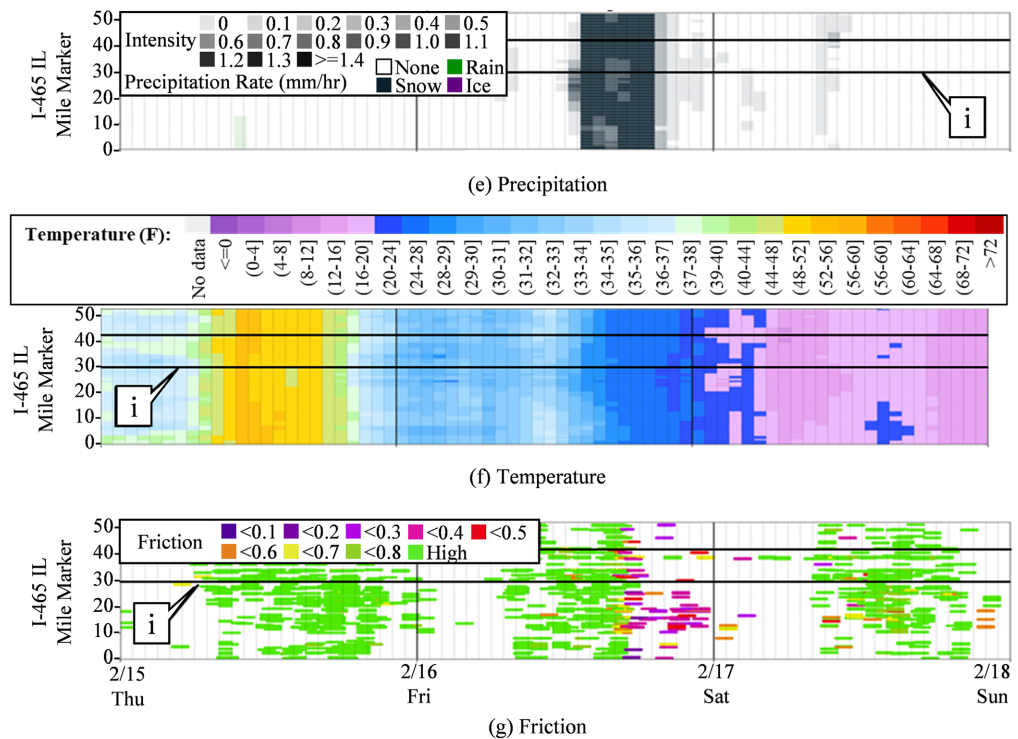


Figure 8. Combined visual for I-465 during February 16, 2024 storm.

4. 2023-2024 Winter Season Case Studies

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

4.1. February 16, 2024, I-465 Case Study

The first case study is located along the previous I-465 MDSS plowing segment (**Figure 9**). This segment is between MM 30 and MM 46 on the northeast corner of I-465 (**Figure 9**, 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 produce a powerful visual aid (**Figure 10**) to track MDSS maintenance recommendations for the 24-hour leading up to and during the winter storm. **Figure 10(b)** through **Figure 10(g)** follow the same schema as **Figure 6(b)**, 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.

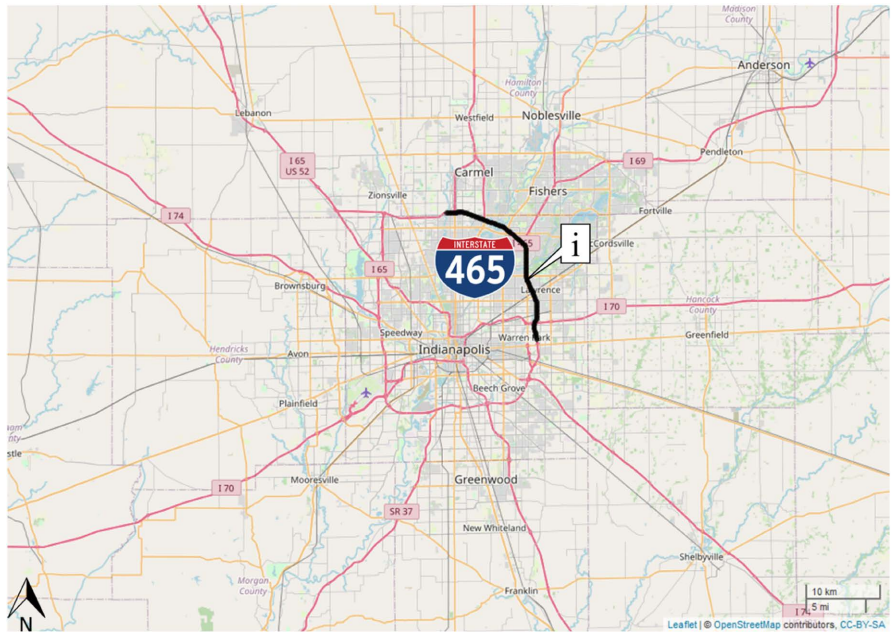
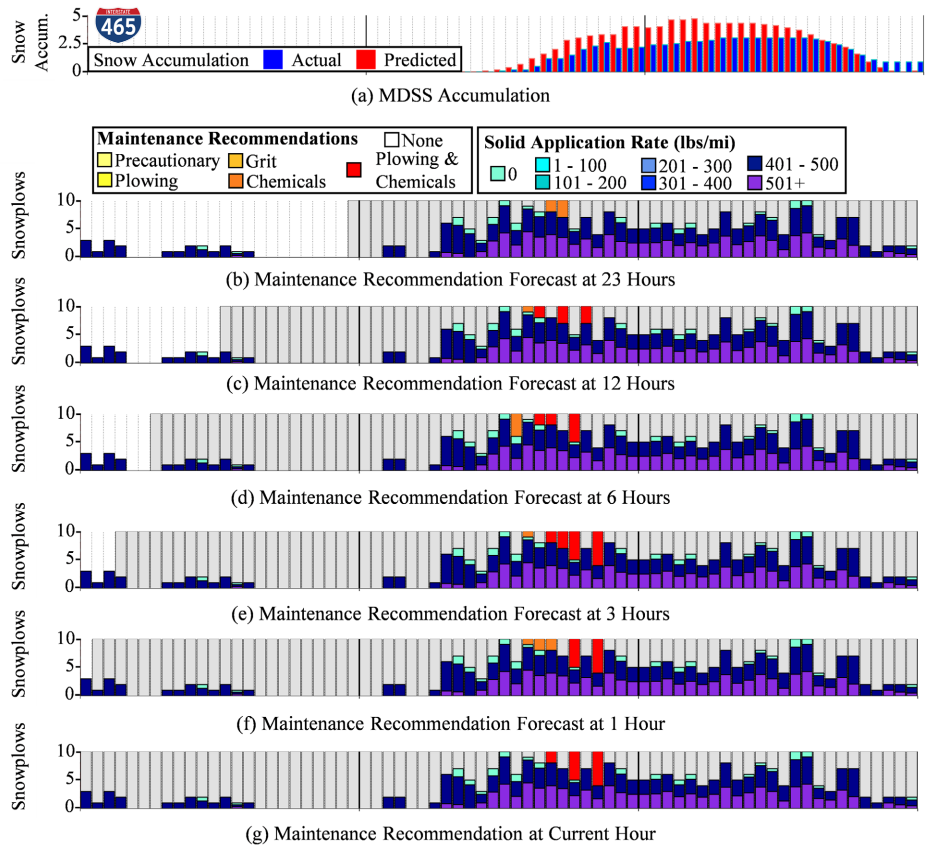


Figure 9. Map of I-465 MDSS plowing segment.



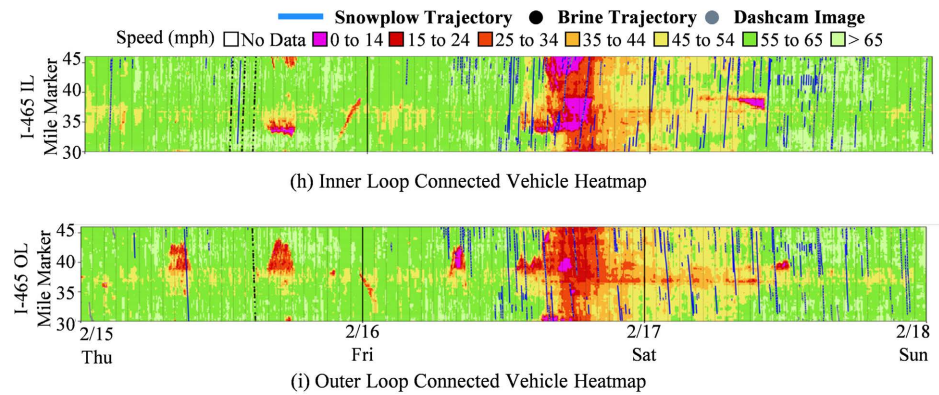


Figure 10. February 16, 2024 Winter storm, I-465 MM 30 - 46 MDSS maintenance recommendations.

4.2. 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 11**). This MDSS plowing segment is located just south of Fort Wayne, IN, near the southern I-69 - I-469 interchange (**Figure 11**, Callout i). This route was selected for the January 6, 2024 winter storm.

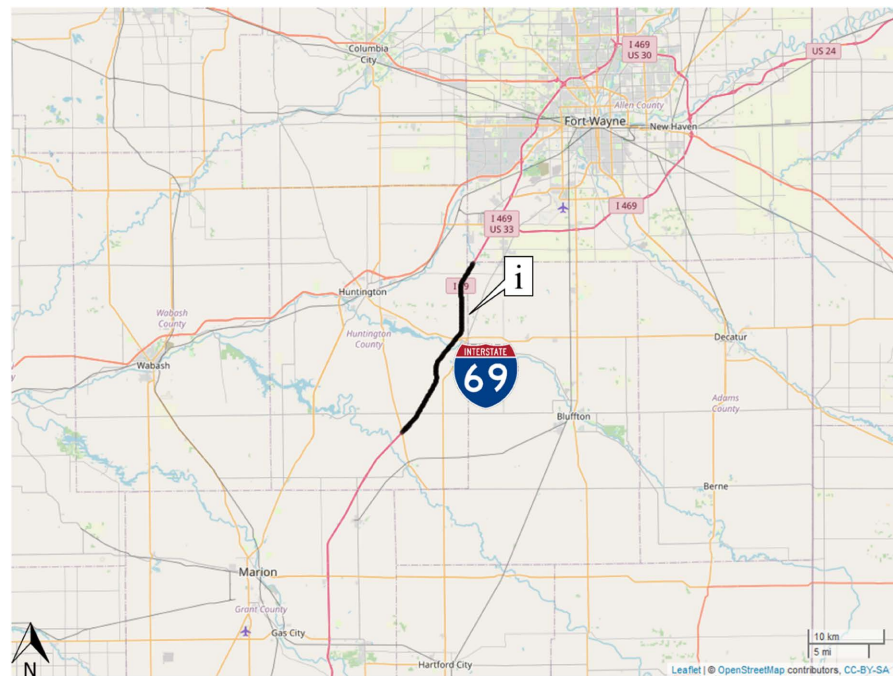


Figure 11. Map of I-69 MDSS plowing segment.

Looking at the combined MDSS recommendation figure (**Figure 12**), it is apparent that the MDSS maintenance recommendations are inconsistent throughout the progression from 23-hour out (**Figure 12(b)**) to the current hour (**Figure 12(g)**). The 23-hour out (**Figure 12(b)**) forecast shows a suggested chemical application for the morning of Saturday, January 6th, but the subsequent forecasts

do not until 1-hour out (Figure 12(f)). This original recommendation aligns very closely with the predicted and actual snow accumulation, validating its legitimacy.

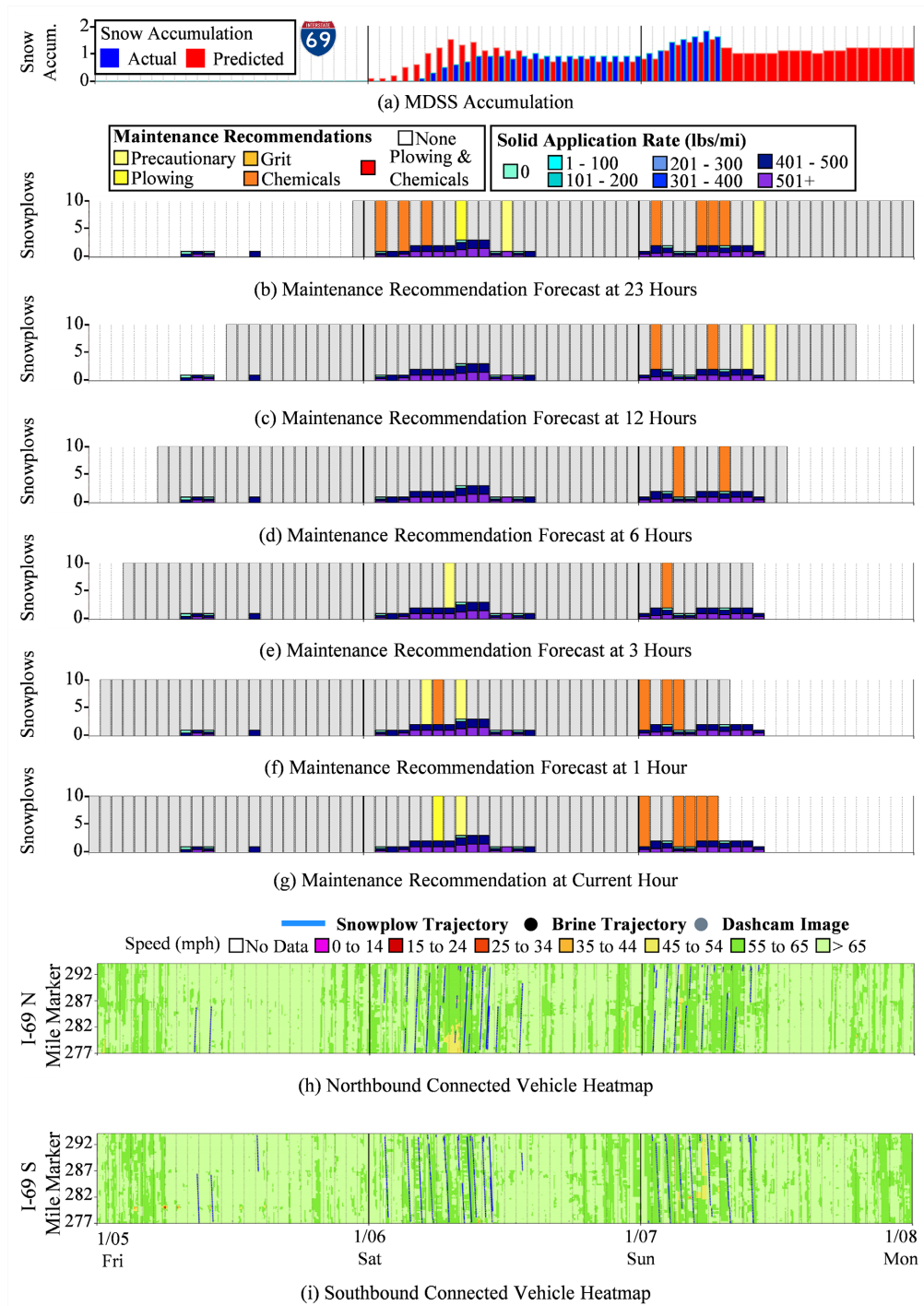


Figure 12. January 6, 2024 Winter storm, I-69 MM 277.54 - 293.06 MDSS maintenance recommendations.

4.3. 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 13). This MDSS plowing segment is located near Michigan City, IN, near the southwestern Michigan border (Figure 13, Callout i). This route was selected for the January 13, 2024 winter storm.

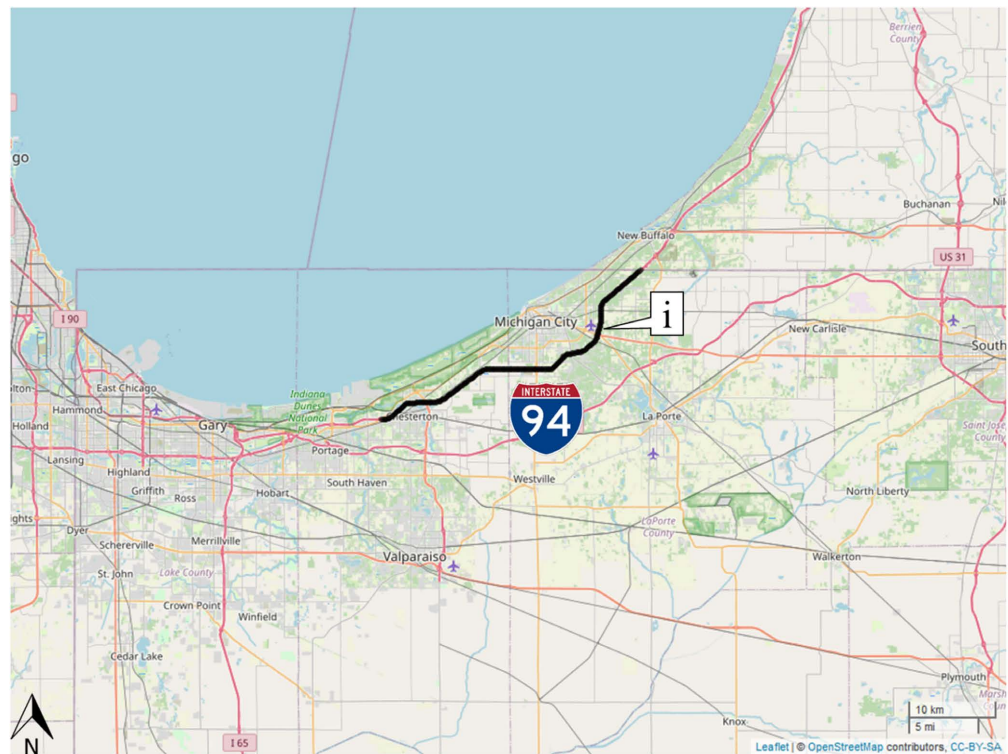
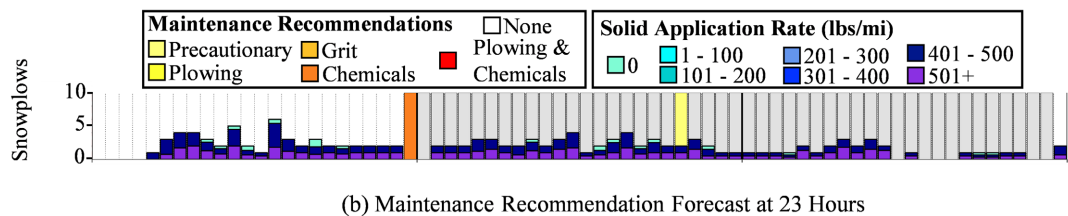
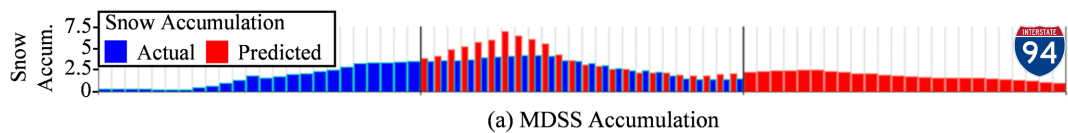


Figure 13. Map of I-94 MDSS plowing segment.

Figure 14 shows a very consistent and thorough maintenance recommendation trend. The 12-hour forecast (Figure 14(c)) is very similar to the subsequent forecasts for Saturday, January 13th. The 6-hour forecast (Figure 14(d)) is also similar to 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.



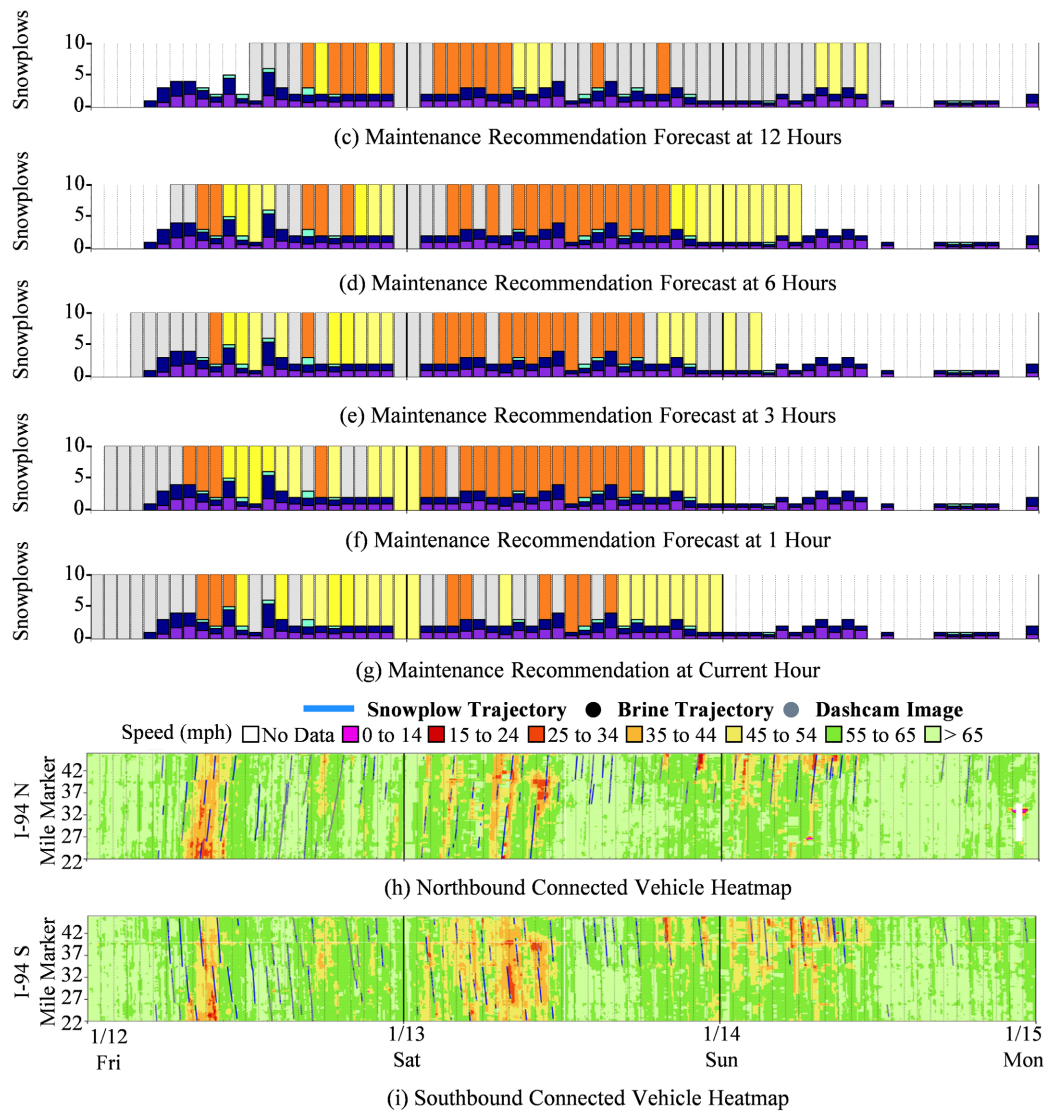


Figure 14. January 13, 2024 Winter Storm, I-94 MM 22.36 - 45.77 MDSS Maintenance Recommendations.

5. 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 2023-24 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 10), cases where the MDSS forecast did not deliver consistent messages as the forecasting threshold approached 0 (Figure 12) and cases where the MDSS forecast aligned well with observed INDOT truck deployment (Figure 14). The results of this analysis will provide a framework for future MDSS evaluations and training tools for winter operation professionals in Indiana.

6. Future Scope

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.

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Conflicts of Interest

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

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