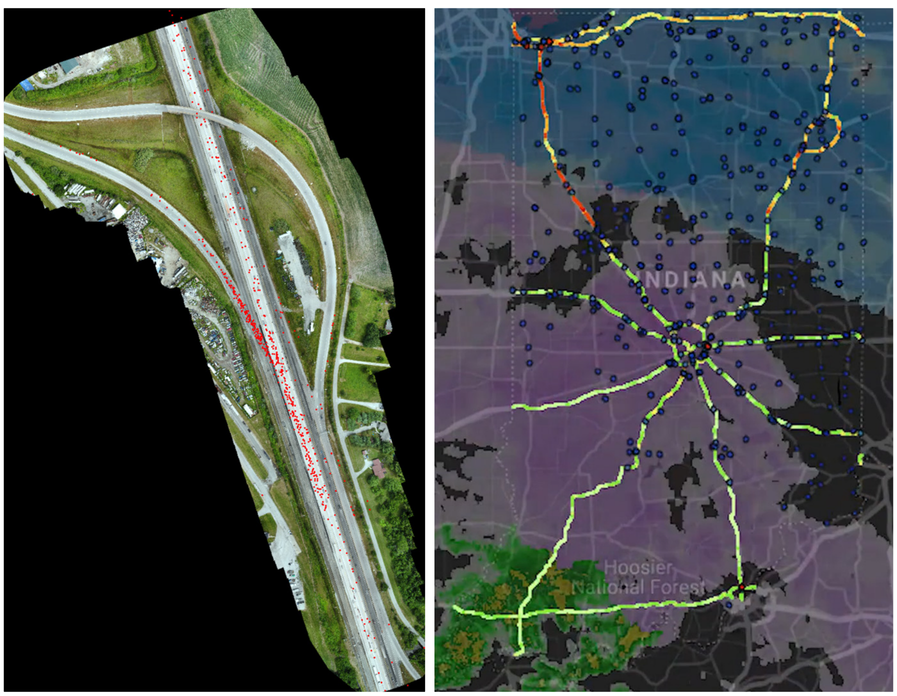
JOINT TRANSPORTATION
RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Implementation of Enhanced Probe Data (CANBUS) for Tactical Workzone and Winter Operations Management



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

For over a decade, segment-based probe data has been extensively used by transportation stakeholders for monitoring mobility on Indiana roadways. However, enhanced probe data from connected vehicles includes a richer dataset that can provide more detailed real-time and after-action reviews. This enhanced data includes detailed vehicle trajectories, at 3s resolution, and "event data." This event data is near real-time and includes hard-braking events, hard-acceleration events, weather-related data, including wiper activations and some seat belt usage data. This project developed a set of methodologies and resulting visualizations that enables the use of emerging connected vehicle data in operational decision-making on work zone management and winter operations activities. Each month approximately 13 billion connected vehicle records are ingested for Indiana. During peak periods, approximately 625,000 records per minute are ingested. Without substantial processing, this large data set is "data-rich, information-poor." This study developed techniques to rapidly assign relevant data to interstate segments so that visual graphics could be efficiently generated. This provided the ability for both real-time monitoring as well as after action assessment to identify opportunities to improve both work zone operations and winter operation activities. The summaries derived from these datasets have helped promote effective actionable dialog among agencies, contractors, and public safety colleagues towards the overarching goal of improving interstate safety and mobility.

17. Key Words
enhanced probe data, connected vehicle data, winter weather, construction, work zone, winter operations, interstate mobility

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EXECUTIVE SUMMARY

Motivation

For over a decade, segment-based probe data has been extensively used by transportation stakeholders for monitoring mobility on Indiana roadways. However, enhanced probe data from connected vehicles includes a richer dataset that can provide more detailed real-time and after-action reviews. This enhanced data includes detailed vehicle trajectories, at 3s resolution, and "event data." This event data is near real-time and includes hard-braking events, hard-acceleration events, and weather-related data, including wiper activations and some seat belt usage data. This project developed a set of methodologies and resulting visualizations that enables the use of emerging connected vehicle data in operational decision-making on work zone management and winter operation activities.

Study

Each month approximately 13 billion connected vehicle records are ingested in Indiana. During peak periods, approximately 625,000 records per minute are ingested. Without substantial processing, this large data set is "data-rich, information-poor." This study developed techniques to rapidly assign relevant data to interstate segments so that visual graphics could be efficiently generated. This provided the ability for both real-time monitoring as well as after-action assessment to identify opportunities to improve work zone operations and winter operation activities.

Results

Indiana has established a national reputation for articulating the synergies in using connected vehicle data for both winter operations monitoring and work zone safety. Although these use cases are quite different and involve a completely different set of stakeholders, the underlying analysis of connected vehicle data is very similar. The findings for this project were used to guide both the Indiana Task Force on Workzone Safety that was established in August 2019 and the INDOT winter operations staff. Approaches that have been adopted are the following.

- Widespread acceptance of the use of hard-braking as a surrogate safety measure. These techniques are not only being used within INDOT, but also being widely adopted at a national level. The benefit of this approach is that emerging issues can be identified in a few weeks with hard-braking data instead of waiting months/years for a statistically significant number of crashes to occur.
- Widespread use of the "heat map" for monitoring construction zones, significant crashes, and winter weather events.

The graphic summaries derived from these two data sets and tools have facilitated constructive dialog between a variety of agencies, contractors, and public safety colleagues that are leading to improved operations of interstates in Indiana and the rapid adoption of these approaches by peer states.

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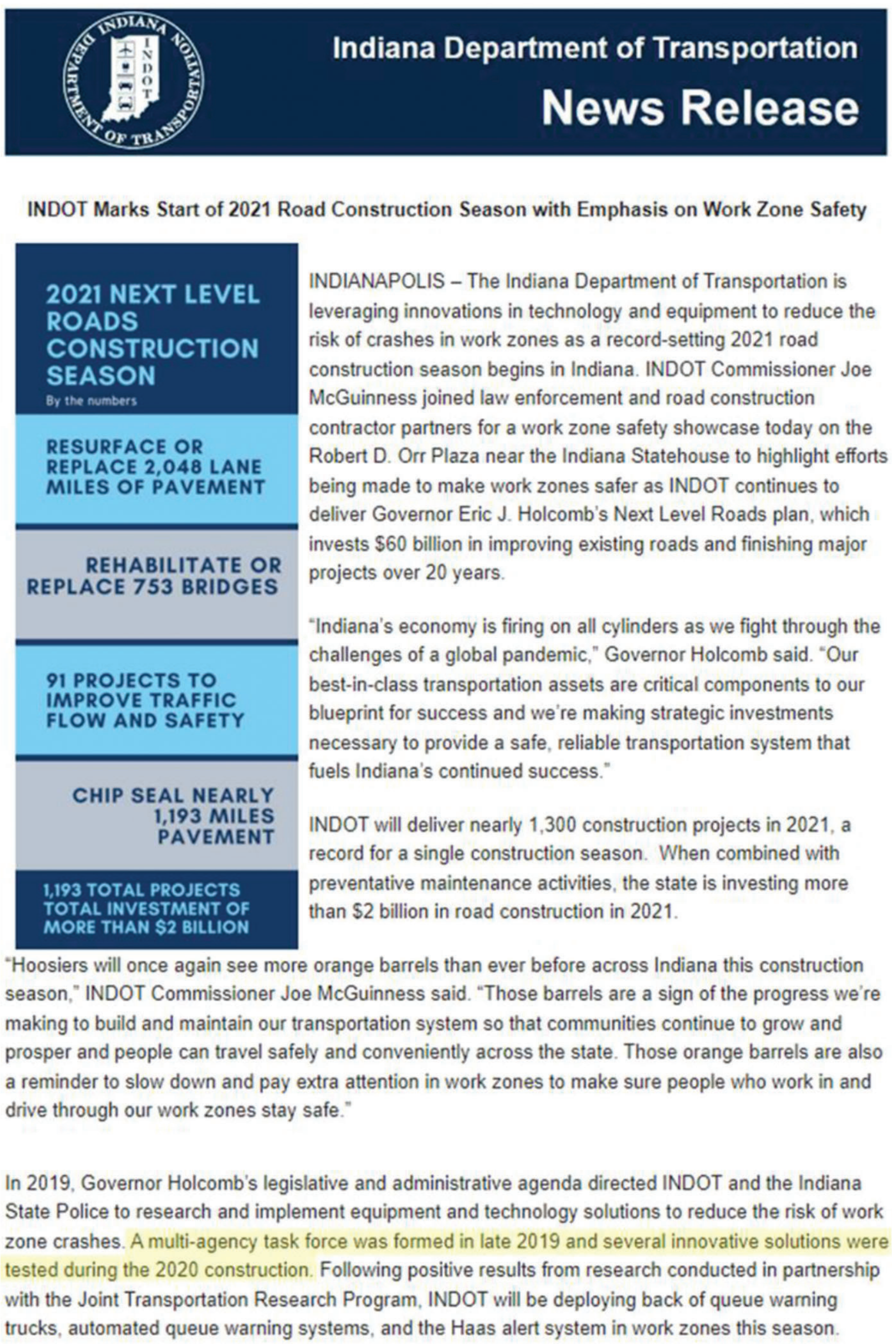
1. PROJECT OVERVIEW

Two of the foremost use cases identified by this project for leveraging the benefits of enhanced probe data can broadly be categorized into tactical work zone management and winter weather operations. In fact, tactical work zone management is so important to the state, Governor Holcomb established the Indiana Task Force on Workzone Safety in 2019 (INDOT, 2021) (Figure 1.1).

Winter operations have similar importance and stochastic variation from weather forecasts can lead to challenging roadway conditions, an example of which is shown by an aerial view in Figure 1.2 of roadway conditions on I-65 Northbound MM ~201–215 on February 18, 2022, in Indiana. Connected vehicle data is the only scalable technique for monitoring rapid deviations in weather activities that significantly impact roadway operations.

Several working sessions and webinars were held over the course of this project to facilitate dissemination of results. In addition, the following is a list of papers that were prepared in part during this project.


Indiana Department of Transportation

News Release

INDOT Marks Start of 2021 Road Construction Season with Emphasis on Work Zone Safety

2021 NEXT LEVEL ROADS CONSTRUCTION SEASON
By the numbers

RESURFACE OR REPLACE 2,048 LANE MILES OF PAVEMENT

REHABILITATE OR REPLACE 753 BRIDGES

91 PROJECTS TO IMPROVE TRAFFIC FLOW AND SAFETY

CHIP SEAL NEARLY 1,193 MILES PAVEMENT

1,193 TOTAL PROJECTS TOTAL INVESTMENT OF MORE THAN $2 BILLION

INDIANAPOLIS – The Indiana Department of Transportation is leveraging innovations in technology and equipment to reduce the risk of crashes in work zones as a record-setting 2021 road construction season begins in Indiana. INDOT Commissioner Joe McGuinness joined law enforcement and road construction contractor partners for a work zone safety showcase today on the Robert D. Orr Plaza near the Indiana Statehouse to highlight efforts being made to make work zones safer as INDOT continues to deliver Governor Eric J. Holcomb's Next Level Roads plan, which invests $60 billion in improving existing roads and finishing major projects over 20 years.

"Indiana's economy is firing on all cylinders as we fight through the challenges of a global pandemic," Governor Holcomb said. "Our best-in-class transportation assets are critical components to our blueprint for success and we're making strategic investments necessary to provide a safe, reliable transportation system that fuels Indiana's continued success."

INDOT will deliver nearly 1,300 construction projects in 2021, a record for a single construction season. When combined with preventative maintenance activities, the state is investing more than $2 billion in road construction in 2021.

"Hoosiers will once again see more orange barrels than ever before across Indiana this construction season," INDOT Commissioner Joe McGuinness said. "Those barrels are a sign of the progress we're making to build and maintain our transportation system so that communities continue to grow and prosper and people can travel safely and conveniently across the state. Those orange barrels are also a reminder to slow down and pay extra attention in work zones to make sure people who work in and drive through our work zones stay safe."

In 2019, Governor Holcomb's legislative and administrative agenda directed INDOT and the Indiana State Police to research and implement equipment and technology solutions to reduce the risk of work zone crashes. A multi-agency task force was formed in late 2019 and several innovative solutions were tested during the 2020 construction. Following positive results from research conducted in partnership with the Joint Transportation Research Program, INDOT will be deploying back of queue warning trucks, automated queue warning systems, and the Haas alert system in work zones this season.

Figure 1.1 INDOT news release highlighting the Indiana task force on work zone safety.

Figure 1.2 Roadway conditions on I-65 Northbound MM ~201–215 on February 18, 2022 (Fifield, 2022).

- Desai, J., Li, H., Mathew, J. K., Cheng, Y.-T., Habib, A., & Bullock, D. M. (2021). Correlating hard-braking activity with crash occurrences on interstate construction projects in Indiana. *Journal of Big Data Analytics in Transportation*, *3*(1), 27–41. https://doi.org/10.1007/s42421-020-00024-x
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- Desai, J., Mathew, J. K., Li, H., Sakhare, R. S., Horton, D., & Bullock, D. M. (2022). *National mobility analysis for all interstate routes in the United States: December 2022*. West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317591

2. DATA ELEMENTS

2.1 Data Ingestion Summary

A multitude of enhanced probe data sources were leveraged by this study towards the dual use cases of work zone and winter operations management and have been briefly summarized in Table 2.1. 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. 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.

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 (starting 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). Digital alert data onboard INDOT's Queue Warning Trucks and other maintenance vehicles in the state's fleet were ingested in collaboration with HAAS Alert (starting May 4, 2020).

2.2 Scale of Data

TABLE 2.1
Data Ingestion Summary

Data Source	Data Description	Number of Records
Wejo	Passenger Car Trajectories	368.06 B
	Truck Trajectories	35.97 B
	Driver Events	5.94 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
HAAS	Maintenance Vehicle Telematics	24.77 M

3. TACTICAL WORKZONE MANAGEMENT

3.1 Work Zone Safety Task Force

A multi-agency task force was established in late 2019 directing INDOT and the Indiana State Police towards researching solutions to reducing work zone crashes in collaboration with the Joint Transportation Research Program. Various stakeholder engagements in the form of these work zone safety task force meetings were part of this project. A summary of the meeting dates, format and the hosting facility is presented in Table 3.1.

A curated selection of pictures from the meetings listed in Table 3.1 is included in Figure 3.1. Figure 1.1a was captured during a Work Zone Safety Showcase at the Indiana Statehouse involving the demonstration of queue warning trucks implemented widely during the 2021 construction season.

3.2 Hard-Braking Events in Work Zones

A recent study (Desai, Li, et al., 2021) looking at interstate work zones around the state of Indiana found a strong correlation between hard-braking events and crash incidents in interstate construction work zones. This provides researchers and practitioners with the data-driven support needed to begin using hard-braking event data as a surrogate for identifying potential safety hazards in a much shorter timeframe than it would take if using crash history. The study identified that for every crash per mile on an interstate work zone, 147 hard-braking events were observed per mile as shown by the scatter plot of crashes per mile versus hard-braking events per mile in Figure 3.2.

3.3 Key Real-Time Dashboards

A suite of heatmap dashboards, both at the segment level and trajectory level were developed in part over the course of this project. These dashboards provide real-time access to connected vehicle data on roadways in Indiana and multiple other states.

Figure 3.3 shows a real-time view of the heatmap dashboard depicting connected vehicle speeds aggregated at the 0.1-mile roadway segment level on Interstate roadways in Indiana, specifically the 53-mile long I-465 beltway around Indianapolis for February 22–24, 2023. The horizontal axis represents the time of day while the vertical axis represents the mile marker location along the route. Speeds are colored from purple to green ranging from 0–14 mph to above 65 mph.

Figure 3.4 shows a zoomed view of the previous heatmap focusing on a non-recurring instance of congestion caused by a traffic incident around MM

TABLE 3.1
Work Zone Safety Task Force Meetings

Date	Meeting Format	Facility
October 21st, 2019	In-Person	INDOT Central Office
November 14th, 2019	In-Person	INDOT Central Office
December 6th, 2019	In-Person	INDOT Central Office
January 30th, 2020	In-Person	Indianapolis Traffic Management Center
March 2nd, 2020	In-Person	INDOT Central Office
February 4th, 2021	Virtual	Online
April 19th, 2021	In-Person	Work Zone Plaza Event Indianapolis
June 22nd, 2021	In-Person	Boone County Fairgrounds
August 16th, 2021	In-Person	INDOT Central Office
February 25th, 2022	In-Person	Indianapolis Traffic Management Center
August 11th, 2022	In-Person	Indianapolis Traffic Management Center

(a) April 19, 2021

(b) June 22, 2021

(c) February 25, 2022

(d) August 11, 2022

Figure 3.1 Engagement with stakeholders through work zone safety solutions task force meetings.

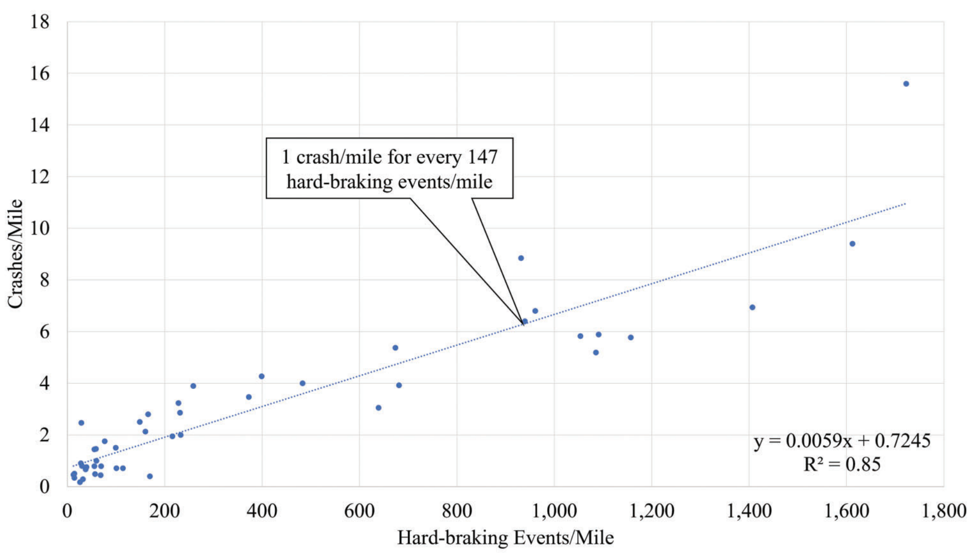


Figure 3.2 Scatter plot showing crashes and hard-braking events per mile across 23 interstate work zones in Indiana for July 1–August 31, 2019, with a linear trendline.

20-25 on I-465 IL on February 23, 2023. Hard-braking events recorded on connected vehicles are shown by solid red circles and visibly outline the back of the resulting queue.

A companion dashboard to the aforementioned aggregated heatmap was generated, namely the trajectory heatmap shown in Figure 3.5, which visualizes every single connected vehicle trajectory traversing a

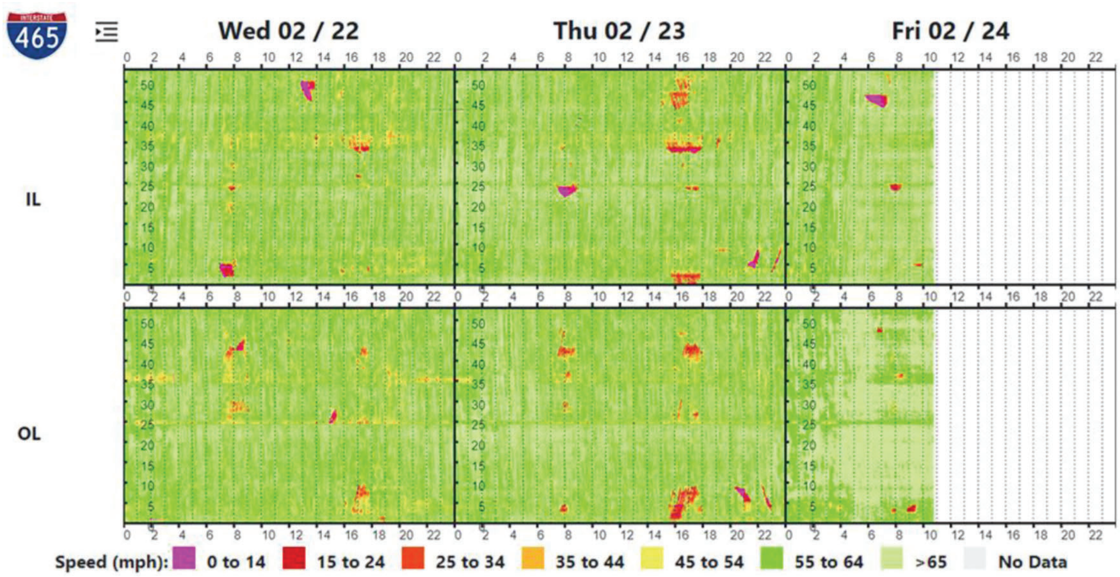


Figure 3.3 Real-time aggregated heatmap view of I-465 MM 0-53 around Indianapolis as of 10:46 AM, February 24, 2023.

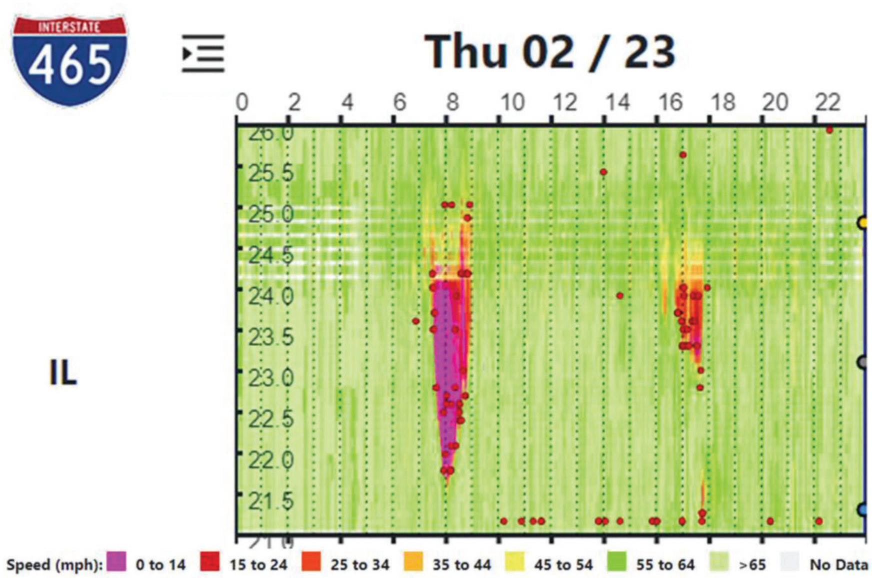


Figure 3.4 Heatmap view of traffic incident on I-465 IL MM 22–25 February 23, 2023, depicting hard-braking events at the back of the queue (solid red circles).

chosen route with speeds colored on the same scale. A supplementary module at the bottom of the heatmap depicts travel times experienced by connected vehicles on this route. The module helps characterize the impacts of the traffic incident on travel times, which have increased from about 10 minutes just before 8 AM to as high as 40 minutes at the peak of congestion. Each black dot represents the travel time experienced by a unique connected vehicle on the route.

This trajectory level visualization additionally helps highlight how vehicles encountering instances of recurring or non-recurring congestion often choose to adopt alternate routes in a bid to limit travel time impacts. Figure 3.6 shows such an example of a trajectory heatmap of I-70 MM 24-67 on April 10, 2022, of vehicles navigating sequential construction work zones with travel times more than double to as high as 90 minutes compared to a free flow travel time of approximately 40 minutes. The accompanying clip in the figure caption shows an animation of the individual route plotted for every single connected vehicle depicted on the heatmap and highlights the diversity of alternate route choice.

3.4 Queue Warning Trucks (QWT)

Another domain where enhanced probe data such as hard-braking events have proved invaluable is in helping INDOT evaluate the effectiveness of its queue

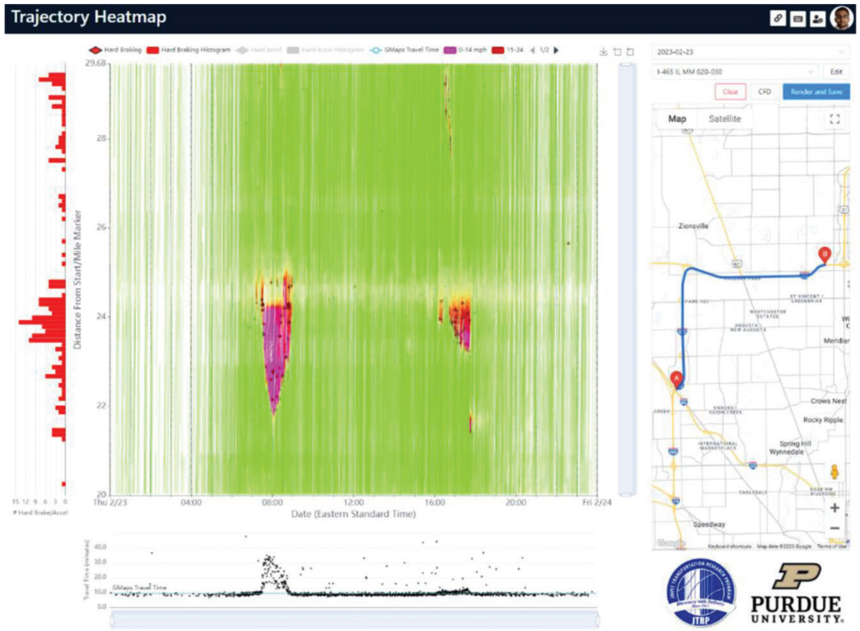


Figure 3.5 Trajectory heatmap view of I-465 IL MM 20–30 February 23, 2022, showing connected vehicle travel times navigating the traffic incident increasing from about 10 minutes just before 8 AM.

Figure 3.6 Trajectory heatmap view of sequential work zones on I-70 EB MM 24-67 resulting in connected vehicle travel times as high as 90 minutes on April 10, 2022, (animated trajectories at Purdue Traffic Lab, 2022a).

warning truck program. A recently concluded study (Sakhare et al., 2021; Sakhare, Mahlberg, et al., 2022), presented as part of the Transportation Research Board Annual Meeting 2022 (Figure 3.7), showed nearly 80% reduction in hard-braking events at the back of queue in the presence of queue warning trucks compared to queues not utilizing a QWT. This research was presented as part of the Transportation Research Board Annual Meeting 2022 (Figure 3.7).

3.5 Weekly Interstate Work Zone and Hard-Braking Reports

Safety and mobility changes across INDOT's six districts were analyzed over the four summers of 2019 through 2022. Findings from these analyses were reported in a publication outlining methodologies for monitoring work zone operations using CV data (Sakhare, Desai, et al., 2022). A month-by-month summary of a total of 77 weekly work zone reports generated over this project's period is included for reference in Table 3.2.

3.5.1 Summary of Weekly Work Zone Reports

A median crossover case study on I-70 EB, published in a study as a part of this project (Sakhare, Desai, et al., 2022), observed monthly hard-braking events rise by about 33% during the period of the crossover operation in this work zone. Heatmaps and corres-

Figure 3.7 Dissemination of QWT research at TRB Annual Meeting 2022.

TABLE 3.2
Summary of Weekly Work Zone Reports Developed for Three Seasons

Construction Season	Month	Number of Reports
2020	May	3
	June	5
	July	4
	August	5
	September	4
	October	4
	November	2
2021	May	4
	June	4
	July	4
	August	5
	September	4
	October	4
	November	1
2022	May	4
	June	3
	July	5
	August	3
	September	3
	October	5
	November	1

ponding camera images (C1, C2, C3) for three significant crash incidents occurring on September 4, October 3, and October 24, 2021, are represented in Figure 3.8. Significant queuing as long as 15 miles was observed during these incidents with scene clearance times ranging from about 7 to 13 hours. Case studies such as these show the unique opportunity that real-time availability of connected vehicle m and event data provides for operational data-driven decision making for stakeholders.

3.6 Unmanned Aerial System (UAS) Mapping of Interstate Work Zones at Locations With High Numbers of Hard-Braking Events

Unmanned Aerial Systems, commonly referred to as UAS, provide a safe and efficient manner of mapping construction work zones without any impedance to traffic while still capturing accurate and usable imagery. To demonstrate the applications of this technique to mapping work zones, a number of mapping missions capturing a set of work zones on Interstates 65, 69, 70, and 465 were conducted over the summer and winter of 2022 to identify potential hot spots of hard-braking activity with current field imagery for context to aid stakeholders in managing potential safety hazards. A summary of mapping activity conducted over work zones along with dates and locations is presented in Table 3.3. These mapping methods have already been used by multiple public safety agencies around the state in collaboration with the Indiana Criminal Justice Institute and Purdue University to quickly map crash scenes and aid recovery efforts to reduce the risk of secondary crashes at the back of queues (Desai, Mathew, Zhang, et al., 2022).

Visualizations were developed overlaying connected vehicle event data (such as hard-braking) on top of current orthomosaic imagery from each of these work zones to identify potential safety hazards. Examples from the I-65 work zone in Boone County near Lebanon are depicted in the Figures 3.9 and 3.10 showing clusters of hard-braking events prior to the southbound interstate bifurcating as well as US-52 southbound traffic merging into the southbound interstate.

Oblique images captured at the aforementioned two locations on I-65 in Boone County, IN as well as links to short clips demonstrating challenges faced by vehicles navigating the work zone are depicted in Figure 3.11.

Selected composite imagery on I-70 and I-65 from the aforementioned mapping activities have been shown in Figures 3.12 and 3.13 for context.

After-action reviews of the I-65 MM 141.8 US-52 merge location in Boone County showed a steep reduction in hard-braking events after a change in road geometry was put in place late in the fall of 2022. Before, during and after plots of a normalized count of hard-braking events at this location are included for reference in Figure 3.14.

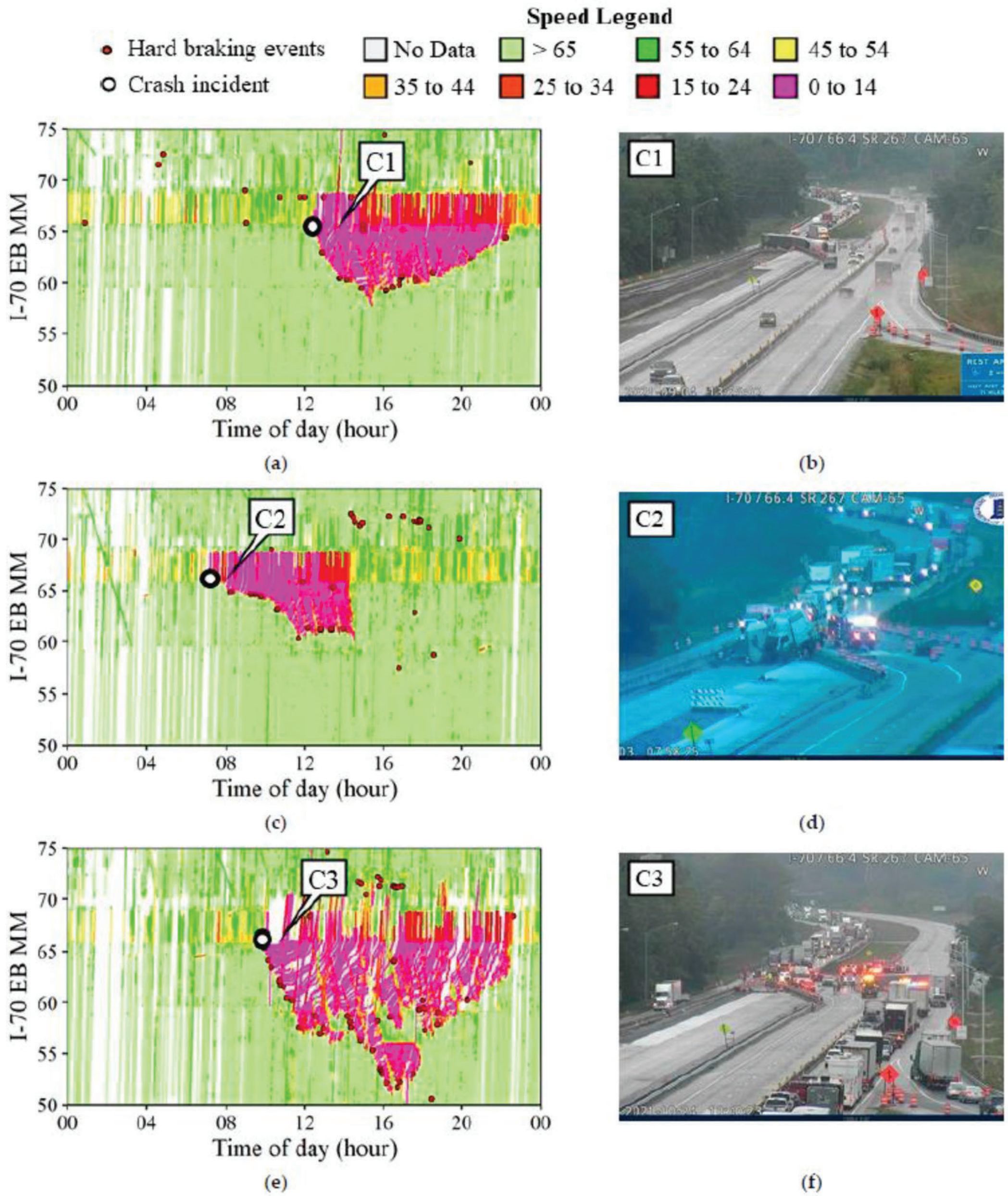
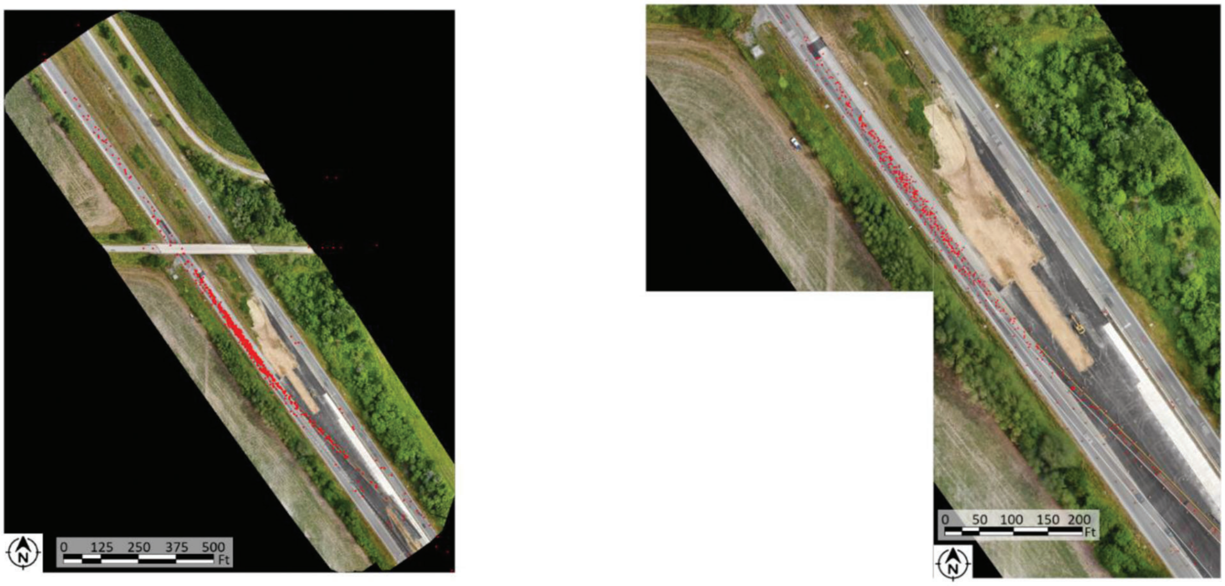


Figure 3.8 Traffic speed heatmaps and camera images on I-70 EB showing three separate crash incidents at the same median crossover.

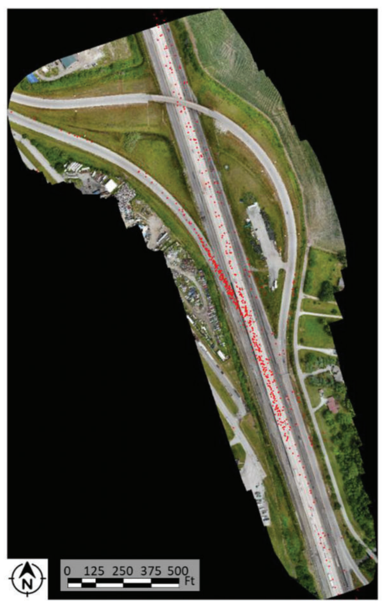
TABLE 3.3
Summary of UAS Mapping of Interstate Work Zones

Date	Interstate Route	Approximate Location
July 9th, 2022	I-65	Lebanon (Boone County)
July 29th, 2022	I-70	Greenfield District
August 2nd, 2022	I-65	Lebanon (Boone County)
August 5th, 2022	I-65	ATL (Tippecanoe County)
August 27th, 2022	I-465/I-69	Clear Path Project
October 5th, 2022	I-65	Lebanon (Boone County)
December 11th, 2022	I-65	Lebanon (Boone County)

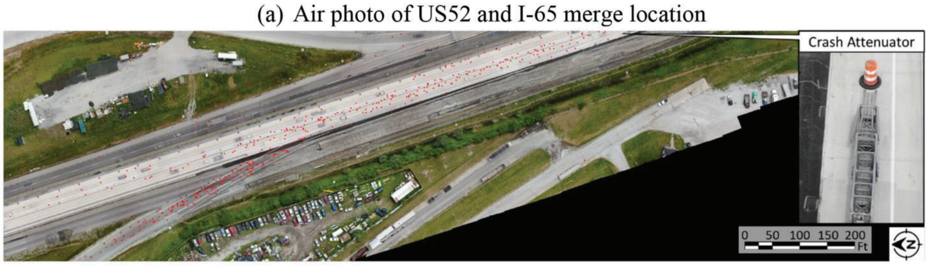


(a) Air photo of I-65 bifurcation location (b) Zoomed view of bifurcation

Figure 3.9 I-65 SB MM 147 bifurcation (as of July 9, 2022) with hard-braking events overlaid (red dots) for July 1–12, 2022 (Purdue Traffic Lab, 2022c).



(a) Air photo of US52 and I-65 merge location



(b) Zoomed view of merge location

Figure 3.10 I-65 SB MM 141.8 US-52 merge (as of July 9, 2022) with hard-braking events overlaid (red dots) for July 1–12, 2022 (Purdue Traffic Lab, 2022b).

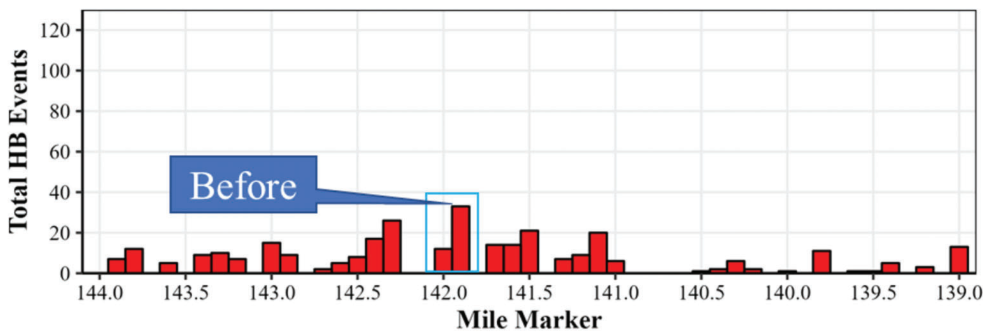
(a) I-65 SB MM 247 Bifurcation, brake lights show drivers encountering the split (Purdue Traffic Lab, 2022c)

(b) I-65 SB MM 141.8 US-52 short merge ramp (Purdue Traffic Lab, 2022b)

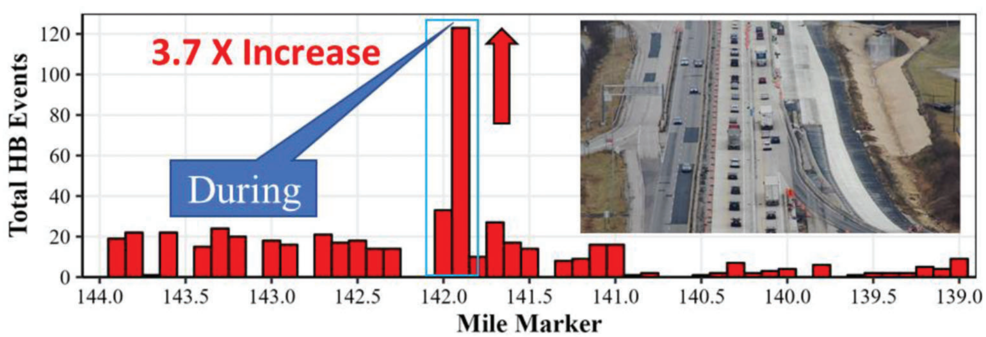
Figure 3.11 Oblique images of areas of interest on I-65 Boone County work zone (as of July 9, 2022).

Figure 3.12 I-70 EB east crossover (as seen on July 29, 2022).

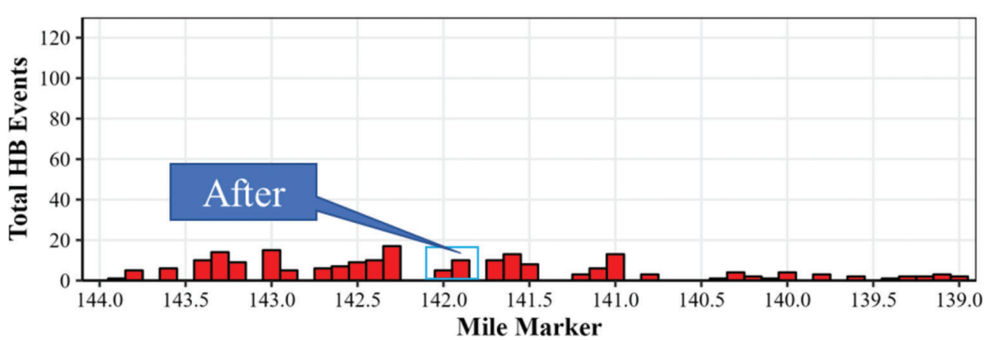
Figure 3.13 I-65 SB Boone County bifurcation at MM 147 (as seen on August 2, 2022).



(a) Before construction (5/20–6/20)



(b) During construction–short merge ramp (6/20–12/20)



(c) After road geometry change (12/21–1/20)

Figure 3.14 After-action review of normalized count of hard-braking events in the region of I-65 SB and US-52 merge (May 20, 2022–January 20, 2023).

4. WINTER OPERATIONS MANAGEMENT

4.1 Mobility Review (2019–2022)

A multi-year mobility review of the Indiana Interstate system is depicted in Figure 4.1. Mile-hours of congestion totaled over all interstate routes are represented on the vertical axis with weekly aggregation levels shown on the horizontal axis from January 2019–January 2022. A significant spike in mile-hours of congestion is visible in January and February 2021 corresponding with two severe winter weather events impacting the state.

4.2 Selected Interstate Heatmaps

A collection of interstate heatmaps for Interstate 94 in northwestern Indiana demonstrating the severe impacts of winter weather on interstate mobility over the past three winters are included in Figures 4.2 and 4.3.

Figure 4.2 shows a heatmap visualization for I-94 over the winter storm period from February 14–16, 2021, where at multiple instances the entire interstate was operating in congested conditions (median speed below 45 mph).

Similarly, Figure 4.3 shows an I-94 heatmap for the winter storm period of February 16–18, 2022, where inclement weather impacted interstate mobility from about 2 PM on February 17 to the early morning hours of February 18, 2022.

Figure 4.4 represents an I-94 heatmap for the period of December 22–24, 2022, coinciding with one of the more significant winter storms that impacted nearly

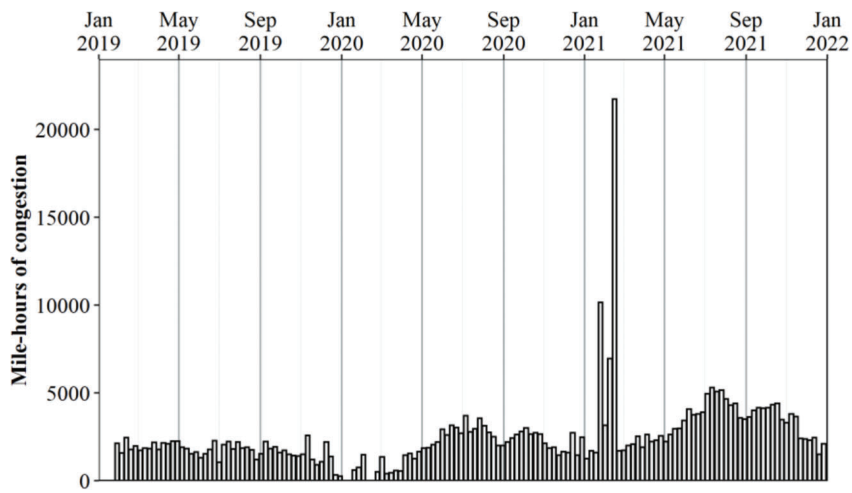


Figure 4.1 Review of interstate mobility 2019–2022.

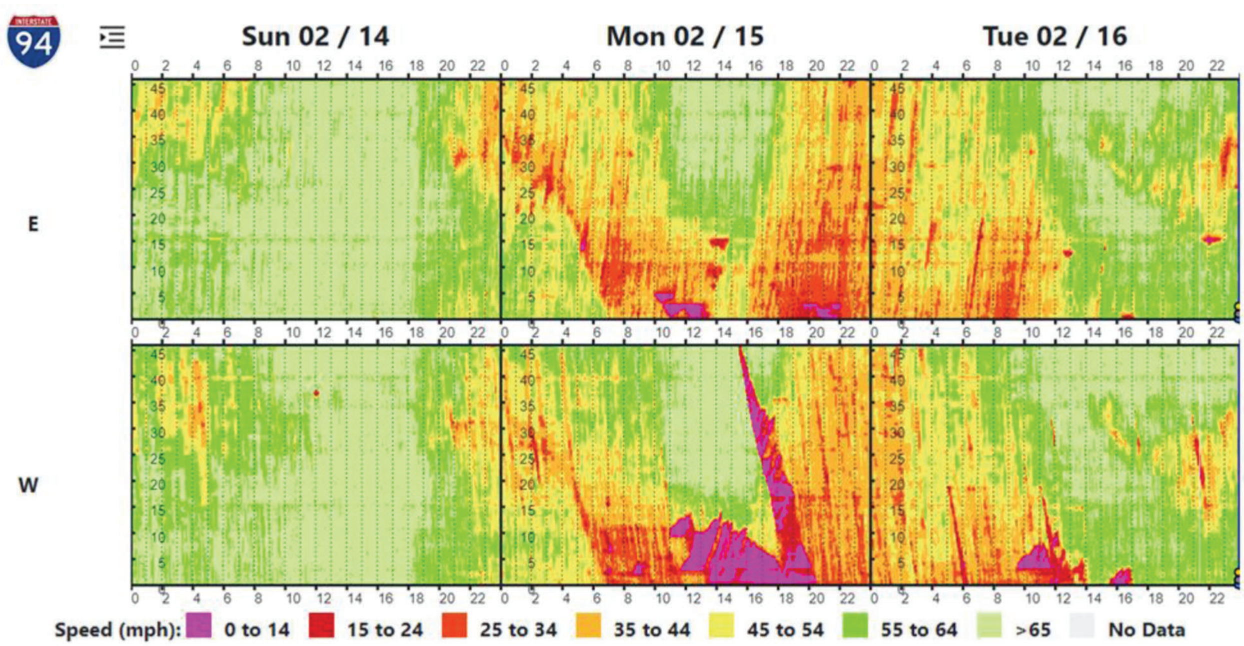


Figure 4.2 Interstate 94 heatmap (February 14–16, 2021, winter storm).

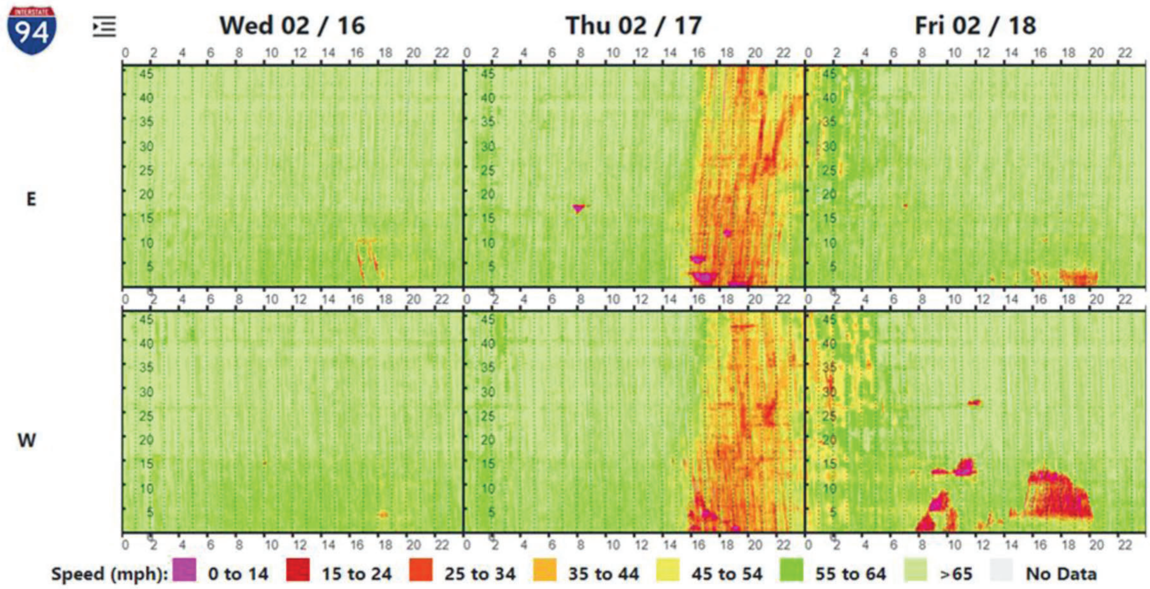


Figure 4.3 Interstate 94 heatmap (February 16–18, 2022, winter storm).

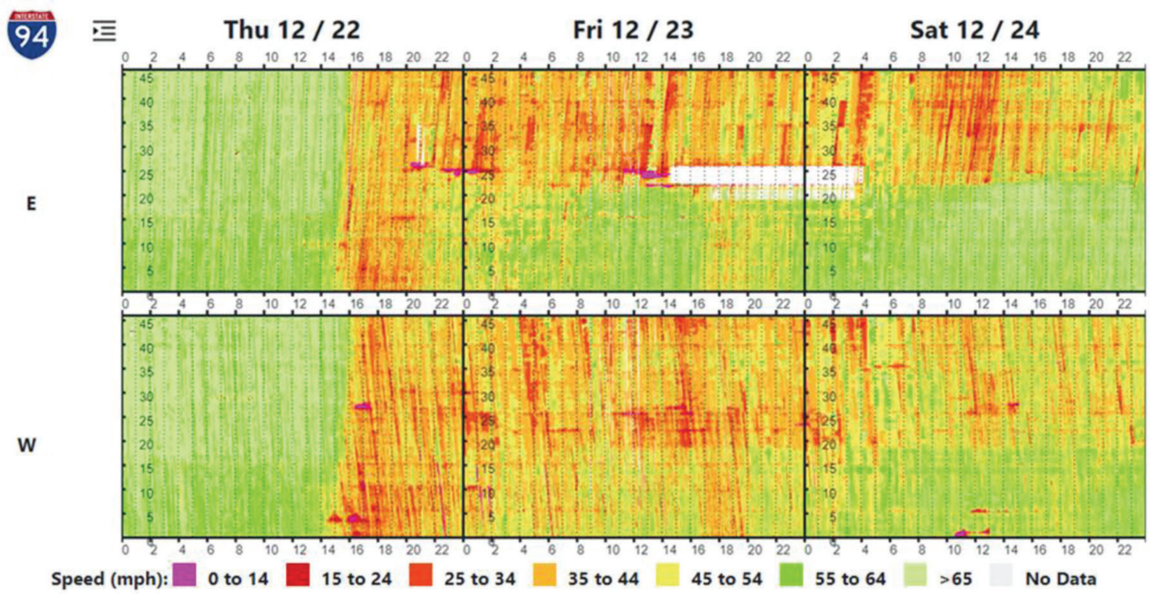
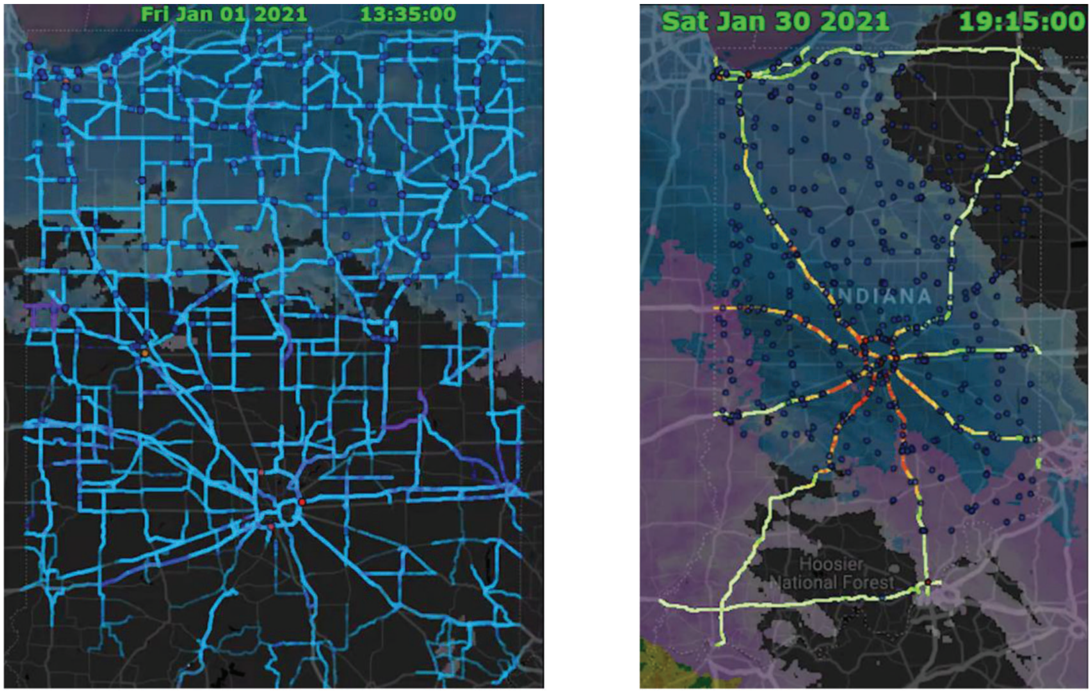


Figure 4.4 Interstate 94 heatmap (December 22–24, 2022, winter storm).

two-thirds of the US population. The empty white region on December 23 stretching into the early hours of December 24 shows a roadway closure where no connected vehicles traversed the 3–5 mile stretch of the interstate.

4.3 Winter Operations Dashboard

One of the dashboards developed in part by this project presents a unified look at weather, traffic, state maintenance vehicle telematics all in one real-time visualization. Figure 4.5 shows two sample visualizations from this dashboard. Figure 4.5a shows a view of central and northern Indiana for the January 1, 2021, winter storm with blue circles representing active snowplows on the roadway with sky blue trails indicating material application associated with their maintenance operations. The location of state maintenance vehicle are depicted by red circles. Figure 4.5b depicts a similar visualization at the state level including snowplow locations as well as real-time connected vehicle speeds on the interstate system. Accompanying time-lapse animations of this dashboard view as each winter storm progressed through the state are included as links in the respective subfigure captions. The Indiana Department of Transportation has already developed solutions helping them inventory their salt stockpiles in near real-time (Mahlberg, Manish, et al., 2022; Manish et al., 2022) and with the aid of snowplow



(a) January 1, 2021, Winter Storm (Purdue Traffic Lab, 2021a)

(b) January 30, 2021, Winter Storm (Purdue Traffic Lab, 2021b)

Figure 4.5 Sample visualizations from winter operations dashboard.

TABLE 4.1
Summary of After-Action Reports Developed for Winter Storms for Three Seasons

Winter Season	Report Days	Season's Total Reports
2020–2021	January 1–3, 2021 January 14–16, 2021 January 24–26, 2021 January 29–31, 2021 February 3–5, 2021 February 6–8, 2021 February 9–11, 2021 February 14–16, 2021 March 13–15, 2021	9
2021–2022	December 6–8, 2021 January 1–3, 2022 January 16–18, 2022 February 2–4, 2022 February 16–18, 2022 February 23–25, 2022	6
2022–2023	December 22–24, 2022 January 21–23, 2023 January 24–26, 2023 February 16–18, 2023	4

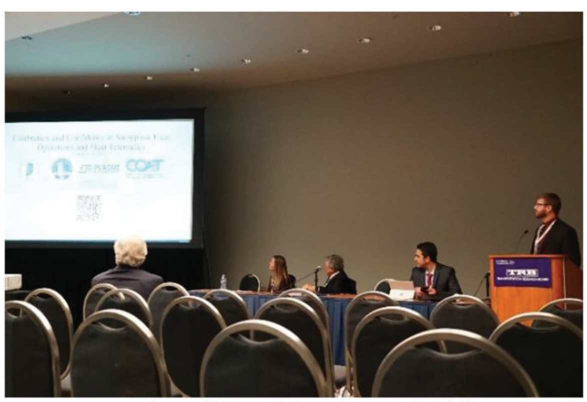
telematics can now track and visualize real-time material application on snow routes.

4.4 Summary of After-Action Data

A series of after-action mobility reports were generated as part of this project for significant winter weather events over the past three winter seasons. The reports 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. A summary count of these reports by season is shown by Table 4.1.

(a) Discussions following lectern presentation of TRBAM-22-02228 (Desai, Mahlberg et al., 2021)

(b) Discussions following lectern presentation of TRBAM-22-02228 with INDOT colleague Jeremy McGuffey



(c) Lectern presentation of TRBAM-23-01921 (Mahlberg, Desai, et al., 2022)

Figure 4.6 Dissemination of results.

4.5 Dissemination of Research Results

Two of the research articles focusing on winter operations and published as a part of this project (Desai, Mahlberg, et al., 2021; Mahlberg, Desai, et al., 2022) were presented in lectern sessions at the Transportation Research Board's 101st and 102nd Annual Meeting respectively in Washington, DC. Images from these presentations and the discussions that followed with attendees are included for reference in Figure 4.6.

5. NATIONWIDE SCALABILITY

The analysis techniques and visualizations described in the preceding sections were subsequently adopted to scalably analyze every interstate route in the United States (522 unique routes in 49 states and the District of Columbia) for the months of August (Desai et al., 2022a) and December 2022 (Desai et al., 2022b). As earlier stated, the August analysis provides insights into work zone mobility around the nation while the December analysis presents the mobility impact of winter storms on the interstate system. Additionally, the national analysis presents trip data at the 0.1-mile level for each interstate enabling the tracking of how electric, hybrid and internal combustion engine vehicle adoption and long-range travel progresses over time (Desai, Mathew, et al., 2021). Monthly aggregated graphics in the form of speed profiles and congestion tickers provide an overall view of mobility at the national, state and route level. Example heatmaps from I-15 in Arizona and I-70 in Ohio in Figure 5.1 and Figure 5.2 show how mobility impacts due to construction activities and winter storms respectively can be easily visualized.

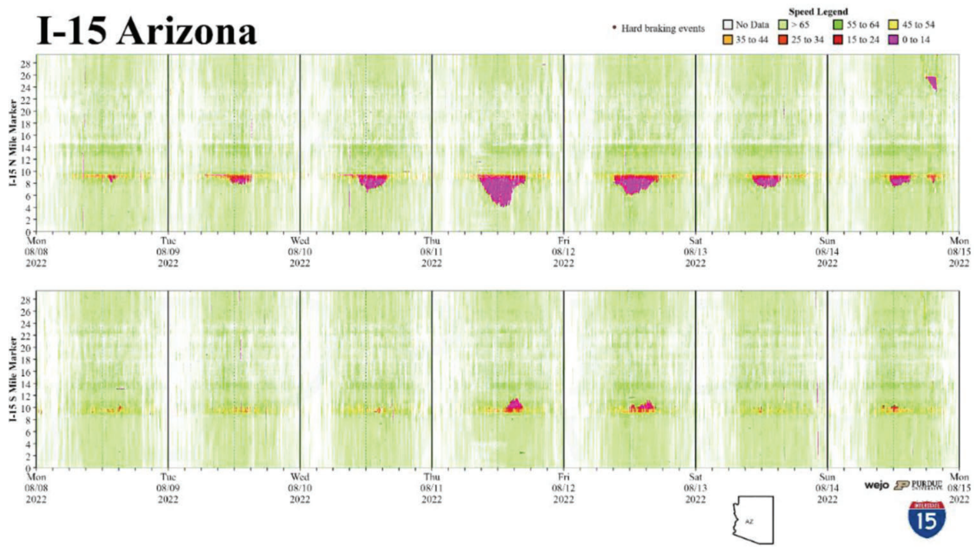


Figure 5.1 I-15 Arizona heatmap August 8–15, 2022, shows mobility impacts of a bridge replacement project over the Virgin River from MM 8-10.

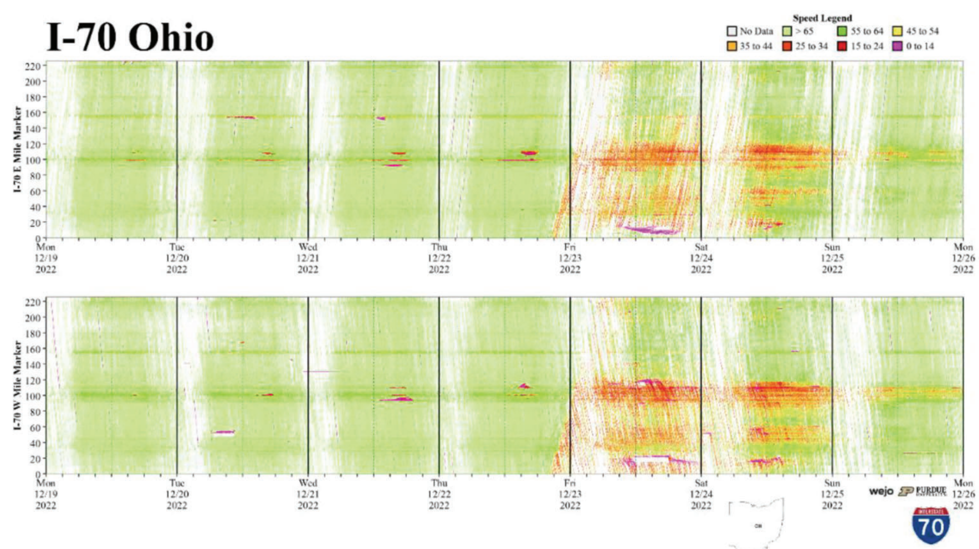


Figure 5.2 I-70 Ohio heatmap December 19–26, 2022, shows mobility impacts of a severe winter storm event on December 23–24, 2022.

6. CONCLUSIONS

The methodologies, analysis techniques, and resulting visualizations developed over the course of this project have served a dual purpose in helping aid both summer construction and winter maintenance operations by providing near real-time as well as detailed after-action reviews of mobility and safety impacts on interstate roadways in Indiana.

A series of dashboards developed over the course of this project are now in operation and being widely used by public and private stakeholders across the state as well as at the federal level aided in part by the demonstrated scalability of these techniques, such as the following:

- aggregated heatmap (with aggregated truck trajectories, aggregated passenger vehicle trajectories and segment-based data);
- trajectory heatmap; and
- winter operations dashboard.

Correlating driver events such as hard-braking with crash incidents on interstate construction projects have helped inspire a widespread acceptance of using hard-braking events as a surrogate safety measure in near real-time, reducing stakeholders' dependence on crash data which often takes weeks, months and even years of collection to provide actionable insights. Easily digestible visualizations such as heatmaps and speed profiles have helped INDOT proactively monitor work zone congestion and identify areas of concern during construction. In multiple instances, these agile reviews have influenced MOT changes in construction zones around the state leading to a marked improvement in observed mobility and safety. The weekly work zone safety and mobility reports have now been institutionalized over the course of the past three construction seasons with input from a wide range of stakeholders and provide invaluable operations monitoring as well as feedback to designers for similar future construction projects. Probe data has also been effectively leveraged towards evaluating multiple work zone safety solutions, such as queue warning trucks, speed feedback displays and presence lighting among others.

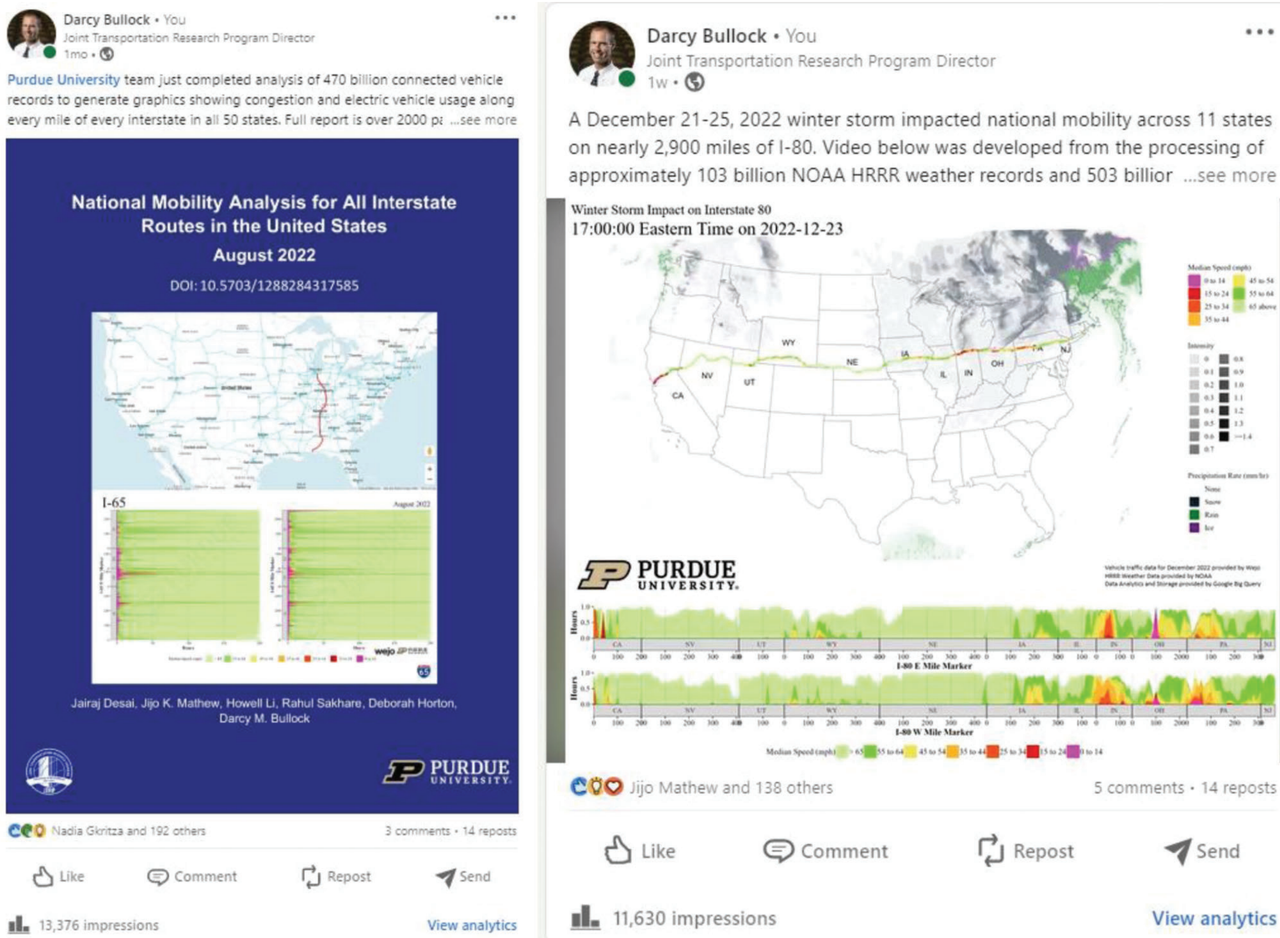
The incorporation and amalgamation of snowplow and maintenance vehicle telematics data along with connected vehicle trajectories has provided a unique visualization for winter maintenance operations in evaluating the effectiveness of a state fleet's response to inclement weather events. This evaluation traditionally would have solely relied on fixed infrastructure in the form of ITS cameras or anecdotal evidence in the form of radio communications with plow operators. The data can now reinforce real-time feedback from traffic conditions observed by connected vehicles.

The summaries derived from these datasets have helped promote effective actionable dialog among agencies, contractors, and public safety colleagues towards the overarching goal of improving interstate safety and mobility. The inherent scalability of these summaries has encouraged interest from peer states as well and may lead to potential collaborations among state departments of transportation towards managing cross-border construction as well as winter weather maintenance operations.

The following list of technical papers have been published in part of this project and a summarized access count is shown in Table 6.1. Additional outreach carried out on LinkedIn for the national mobility reports reached a combined audience of nearly 25,000 users and elicited 332 reactions in total from a diverse spectrum of industry stakeholders. The corresponding outreach posts are included in Figure 6.1 for reference.

TABLE 6.1
Research Outreach

Publication Title	Views/Downloads	Citations	Publication Date
Correlating Hard-Braking Activity with Crash Occurrences on Interstate Construction Projects in Indiana	4,489	24	November 16, 2020
Methodology for Monitoring Work Zones Traffic Operations Using Connected Vehicle Data	2,497	5	June 1, 2022
Evaluation of the Impact of Queue Trucks with Navigation Alerts Using Connected Vehicle Data	2,349	10	September 6, 2021
Leveraging Telematics for Winter Operations Performance Measures and Tactical Adjustment	947	10	September 10, 2021
Calibration and Confidence in Snowplow Fleet Operations and Fleet Telematics	339	–	September 15, 2022
National Mobility Analysis for All Interstate Routes in the United States: August 2022	188	1	January 5, 2023
National Mobility Analysis for All Interstate Routes in the United States: December 2022	67	–	February 13, 2023



(a) January 5, 2023, Outreach (b) February 16, 2023, Outreach

Figure 6.1 LinkedIn outreach of national mobility reports.

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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.

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