JOINT TRANSPORTATION
RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Continued Deployment of Indiana Work Zone Analytics

Myles W. Overall, Justin Mukai, Jairaj Desai, Rahul Suryakant Sakhare, Mischa Kachler, John McGregor, and Darcy M. Bullock

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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

Work zones along interstates often have increased congestion and crash rates when locations are close to or over capacity. Having agile monitoring methods to identifying emerging issues and challenges can provide data to transportation agency decision makers to refine maintenance of traffic plans and inform future designs.

This study developed techniques to fuse a multitude of data sources including connected vehicle speeds, connected vehicle hard-braking events, crash reports, digital alerts, commercial vehicle dash camera images, into a weekly interstate work zone report that gives stakeholders a holistic overview of their work zone operations and allowed for easy identification of opportunities for improvement. Approximately 249 weekly work zone reports were generated and distributed to approximately 100 stakeholders across the state on an approximately weekly basis. These reports provide an at-a-glance view of statewide, district, and route mobility, crash data, hard-braking, and most recently dash camera images to contextualize the heatmaps.

Outside of operational value within the state, these types of weekly reports have been developed for other states through a Transportation Pooled Fund Study on Work Zone Analytics with participation from the Federal Highway Administration and 8 other states, and helping shape USDOT's 23 CFR Part 630 Subpart J that was released on November 1, 2024.

The methodologies developed in this study serve as a framework for transportation agencies, practitioners, and other stakeholders looking to use emerging connected vehicle data, smart work zone data, among others, to monitor the performance of their work zones on a regular basis. The practice of estimating hard-braking events from raw connected vehicle data instead of relying on instantaneous hard-braking events with opaque vendor-defined braking thresholds now allows for greater freedom to tweak acceleration thresholds based on the roadway class being analyzed, and opens opportunities for dialogue among practitioners on determining ideal custom thresholds for freeways, arterials, or other facilities.

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work zones, hard-braking, connected vehicles, interstate mobility, safety, congestion	No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

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EXECUTIVE SUMMARY

Motivation

There is often increased congestion and crash rates in interstate construction zones, particularly in locations that are close to or over capacity. Developing agile monitoring methods to identify emerging challenges provides data to inform design decisions for future projects as well as flag projects that may benefit from modest changes in maintenance of traffic strategies.

Study

This project explored the viability of generating a Weekly Work Zone Report that looks at changes in crash rates, hard braking, and congestion on Indiana interstates. These techniques were focused on using large scale connected vehicle (CV) data for monitoring work zone operations on Indiana interstates.

This study developed techniques to fuse a multitude of data sources including CV speeds, CV hard-braking events, crash reports, digital alerts, and commercial vehicle dash camera images, into a weekly interstate work zone report that gives stakeholders a holistic overview of their work zone operations and allows for easy identification of opportunities for improvement.

Results

Approximately 249 Weekly Work Zone Reports were generated and distributed to approximately 100 stakeholders across the state on an approximately weekly basis. The value of these reports was:

1. Providing an at-a-glance view of statewide, district, and route mobility, crash data, hard braking, and, most recently, dash camera images to contextualize the heatmaps.
2. Building capacity across Indiana Department of Transportation (INDOT) and stakeholders to read heatmaps and hard-braking reports.
3. Developing an archive of mobility impacts that provides factual information on queue lengths, crash data, and hard braking that supplements institutional knowledge. This information is routinely used informally for agilely adjusting lane closure exceptions and is currently being assembled into a summary geographic information system (GIS) map to extend the reach of this institutional knowledge.
4. Other states have seen the value of these types of weekly reports, and a Transportation Pooled Fund Study on Work Zone Analytics with participation from the Federal Highway Administration and nine other states has been established.
5. This work has been used by the U.S. Department of Transportation to help shape 23 CFR Part 630 Subpart J that was released on November 1, 2024 (Highways, 2024).

Recommendations

The Weekly Work Zone Reports generated over the course of this project, and the associated data-processing and analysis methodologies, should serve as a framework for agencies, practitioners, and private sector stakeholders looking to use emerging CV data, smart work zone data, among others, to monitor the performance of their work zones on a regular basis. The practice of estimating hard-braking events from raw CV data instead of relying on instantaneous hard-braking events with opaque vendor-defined braking thresholds now allows for greater freedom to tweak acceleration thresholds based on the roadway class being analyzed and opens opportunities for dialogue among practitioners on determining ideal custom thresholds for freeways, arterials, or other facilities.

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1. PROJECT OVERVIEW

1.1 Introduction

Work zone safety and mobility is important for all stakeholders involved in transportation. With construction activities occurring year-round, it is vital for state and local agencies to be able to accurately monitor the performance of their work zones in near real-time so as to have the ability to flag safety and operational concerns as they arise and make agile adjustments where needed to improve mobility and safety for all users of the state's transportation infrastructure.

1.2 Scope and Objectives

The objective of this study was to utilize connected vehicle (CV) data, crash reports, and emerging data sources such as commercial vehicle dash camera imagery to generate weekly reports of work zone safety and mobility for Indiana interstates and help identify work zone maintenance of traffic (MOT) that have opportunities for improvement. Through the course of this study, detailed investigations into work zones were also conducted to provide feedback to designers on what worked well and where opportunities for improvement were identified.

1.3 Dissemination of Research Results

Throughout this project, there has been a sustained effort to produce weekly PowerPoint reports as well as communicate the techniques used to develop these weekly reports. Of particular note are the following reports:

- Sakhare, R. S., Desai, J., Mathew, J. K., McGregor, J., Kachler, M., & Bullock, D. M. (2024). *Measuring and visualizing freeway traffic conditions: Using connected vehicle data* (Joint Transportation Research Program No. TPF-5[514]). Purdue University. https://doi.org/10.5703/1288284317751
- Sakhare, R. S., Desai, J., Mathew, J. K., & Bullock, D. M. (2024). Assessing the interstate coverage of commercial trucks capable of providing roadway imagery via on-vehicle dash camera in the United States. *IEEE Access*, *12*, 173517–173529. https://doi.org/10.1109/ACCESS.2024.3503368

An extensive list of the key resources and foundational work in the work zone analytics space is available in Chapter 8.

Over the course of this project, the research team provided approximately 249 weekly work zone PowerPoint reports through SharePoint to the Indiana Department of Transportation (INDOT) and other stakeholders, including Indiana State Police (ISP), Federal Highway Administration (FHWA), and contractors. This report is structured in the following modules:

- Chapter 2: Discussion of previous work zone analytics and performance measurement technology.
- Chapter 3: A summary of the evolution of data elements incorporated in the Indiana Weekly Work Zone Report and a link to the SharePoint archive of those reports.
- Chapter 4: Details on the CV data used in the reports.
- Chapter 5: Summary of the concurrent dissemination performed during this project. This facilitated capacity building among the various stakeholders (INDOT and external partners) as well as integrating emerging best practices into agency decision making.
- Chapters 6, 7, and 8: Conclusions derived from this study, discussion of future research opportunities, and a summary of technical resources.

2. LITERATURE REVIEW

This section covers past efforts in the domain of measuring work zone safety and mobility performance and expands on how CV data are a viable source for conducting these measurements in near real-time.

2.1 Background on Work Zone Mobility Measurements

Researchers have used a variety of data sources and techniques to measure work zone mobility over the years. These data sources range from traditional fixed-spot speed sensors, Bluetooth probe tracking, cameras, and, more recently, probe vehicle data (Ansari et al., 2025; Ullman et al., 2011). Bluetooth probe data collected using both semipermanent and portable devices over a highway work zone on Interstate 65 (I-65) in Indiana were shown as an effective method to quantify travel time delay and diversion rates (Haseman et al., 2010). Portable Changeable Message Signs (PCMS) coupled with speed sensors were utilized to alert drivers of impending slowdowns downstream in Minnesota resulting in discernible changes in driver behavior (Hourdos et al., 2019). Video camera outputs combined with machine learning techniques have been utilized to analyze vehicle weaving on highway segments (W. Lin et al., 2024). More broadly, state departments of transportation (DOTs) around the country utilize an extensive network of intelligent transportation systems (ITS) cameras to monitor the mobility of their highway work zones. However, with more than 2,600 directional centerline miles of interstate roadway in Indiana alone, and that number exceeding 97,000 miles nationwide, measures involving fixed or portable infrastructure placement such as speed sensors, Bluetooth, or cameras do not scale at the networkwide level due to the associated labor and time-intensive costs of equipment installation, maintenance, and continuous operation. CV data can help address this limitation by providing a scalable solution which is temporally and spatially unconstrained for monitoring roadway mobility, provided the availability of enough data on the roadway being analyzed.

2.2 Background on Work Zone Safety Measurements

Crash reports have been the leading source of data for practitioners in measuring work zone safety, with some of the key performance measures being crash rate and crash severity, among others (Ullman et al., 2009; Yang et al., 2015). Past studies have modeled both work zone crash frequency and crash severity to identify causal factors of work zone crashes (Clark & Fontaine, 2015). Crash data, however, often suffer from human reporting errors in attributes including the location, time, and cause of the crash. These errors require extensive manual effort to process and clean crash report data to make it usable for longitudinal safety analysis. Additionally, crash histories take a significant time to develop, and stakeholders often have to wait months or years for a statistically significant number of crashes to flag a potential safety problem. Intrusion sensing technologies (Awolusi & Marks, 2019), fixed cameras (P.-S. Lin et al., 2023), and traffic control devices (Zhang & Gambatese, 2017) are some of the other solutions utilized by agencies to monitor and improve work zone safety. These solutions, while providing high-quality data, restrict monitoring efforts spatially and temporally based on sensing limitations. CV data, on the other hand, can provide this information across an entire work zone and in real-time by way of near-misses (hard-braking events), a significant rise in which may point to potential problems within a work zone in a matter of days or even hours provided enough availability of data.

2.3 Emergence and Applicability of CV Data

Over the past several years, CV data has emerged as a viable path forward for network-level monitoring of roadway mobility and safety without the traditional associated cost of sensor infrastructure installation and maintenance. Hard-braking events derived from CV data, an effective surrogate safety performance measure (Desai, Li, et al., 2021), provide an efficient tool for assessing crash risk while CV speed data provide an overview of roadway mobility. A precursor to this project had explored the viability of using CV data for winter operations monitoring as well as tactical work zone management and showed promising results (Desai et al., 2023). Since then, a number of other studies have also demonstrated the applicability of CV data to the work zone domain (Day et al., 2024; Sakhare, Desai, et al., 2022). An extensive list of these related resources can be found in Chapter 8.

The following section covers the Weekly Work Zone Report for Indiana interstates produced by this study, the various performance measures reported within, and the report's evolution over the past seven years in this landscape of changing CV data.

3. INDIANA INTERSTATE WEEKLY WORK ZONE REPORTS

3.1 Evolution of the Weekly Work Zone Report

Table 3.1 provides a high-level overview of the evolution of Indiana's Weekly Work Zone Report from 2018 to present day. The various performance measures and data sources driving them have been tabulated. Crash counts and mile-hours of congestion were the initial core components of each work zone report and have been for the entire reporting period. Mile-hours of congestion has been shown to be an effective measure at spatiotemporally quantifying the extent of congestion on a roadway (Mekker et al., 2019). As CV data sources and providers have evolved over the years, the report has adapted to include these emerging sources and the novel performance measures that can be derived from them including normalized and raw hard-braking events counts as well as change in hard-braking counts week by week. Most recently, commercial dash cameras have been integrated into these reports on an occasional basis.

3.2 Weekly Work Zone Reports by Season

Table 3.2 summarizes the 249 Weekly Work Zone Reports generated for each of the past 8 years. Hard-braking data were introduced into the reporting in the 2020 season and have continued to be included except for a 12-month period during a disruption in the CV data market for 2023–2024. The reporting

TABLE 3.1
Evolution of the Weekly Work Zone Report.

Performance Measure	Data Source	2018	2019	2020	2021	2022	2023	2024	2025
Mile-hours of Congestion	INRIX	✓	✓	✓	✓	✓	✓	✓	✓
Crash Counts	ARIES	✓	✓	✓	✓	✓	✓	✓	✓
Deltaspeed Occurrence	INRIX	✓	Dashboard Operational for Agency Use						
Queue Length Hours	INRIX	✓	✓	✓	✓				
Traffic Speed Heatmaps	INRIX		✓	✓	✓	✓	✓	✓	✓
Traffic Speed Heatmaps	Wejo			✓	✓	✓	✓		
Raw Hard-braking Event Counts	Wejo			✓	✓	✓	✓		
Weekly Change in Hard-braking	Wejo			✓	✓	✓	✓		
Normalized Hard-braking Event Counts	Wejo					✓	✓		
Driver Alerts	HAAS				✓				
Traffic Speed Heatmaps	StreetLight								✓
Raw Hard-braking Event Counts	StreetLight								✓
Normalized Hard-braking Event Counts	StreetLight								✓
Weekly Change in Hard-braking	StreetLight								✓

TABLE 3.2
Weekly Work Zone Reports by Season.

Construction Season	Monday of First Report	Monday of Final Report	Total Reports	Hard-Braking Data	Cumulative Heatmaps
2018	**July 9, 2018**	November 5, 2018	**18**		
2019	April 1, 2019	March 23, 2020	52		✓
2020	May 4, 2020	November 2, 2020	27	✓	✓
2021	May 3, 2021	October 25, 2021	26	✓	✓
2022	May 2, 2022	October 31, 2022	24	✓	✓
2023	May 8, 2023	December 11, 2023	34	✓	✓
2024	April 22, 2024	December 9, 2024	34		✓
2025	January 6, 2025	Ongoing	34	✓	✓

season generally runs from May to November each year which is the time when a majority of freeway construction takes place.

3.3 Key Components of the Weekly Work Zone Report

Figure 3.1 shows the general format of the Weekly Work Zone Report and is broken down into seven sections. The first section is the statewide summary (as shown in Figure 3.1 on Slides 3–10) which gives an overview of the state's interstate routes in terms of number of crashes per INDOT district and mile-hours of congestion per interstate route. The statewide section also includes a plot showing two top 50 hard-braking events by route and mile marker over the last two weeks, one showing the raw number of events and one showing the normalized events, to allow for a quick understanding of which locations may have seen increased or decreased hard-braking activity for the current week and in what direction these locations' safety performance may be trending.

Following the statewide summary section are six other sections, one for each INDOT district (CRW-Crawfordsville, FTW-Fort Wayne, GRN-Greenfield, LAP-La Porte, SEY-Seymour, VIN-Vincennes) to provide a more detailed analysis at the district level. Within each district's section, the following items are provided:

- A map showing the interstates in the district and the exits for each interstate
- Two plots showing the mile-hours of congestion for the district, one showing the mile-hours of congestion by different speed bins and the other showing them per interstate route
- Each interstate within the district is then further broken down to:
  - Mile-hours of congestion per direction
  - Two traffic speed heatmaps over the last two weeks,
  - Four hard-braking events per mile marker plots over the last two weeks
    - Two for raw events and two for normalized events
- The district section concludes with a summary slide comparing the last two weeks in terms of mile-hours below 45 mph, the worst day in terms of congestion, number of Property Damage Only (PDO) crashes, number of Personal Injury (PI) crashes, and number of back-of-queue crashes.

Figure 3.1 Sections of the Weekly Work Zone Report (Week of June 30, 2025).

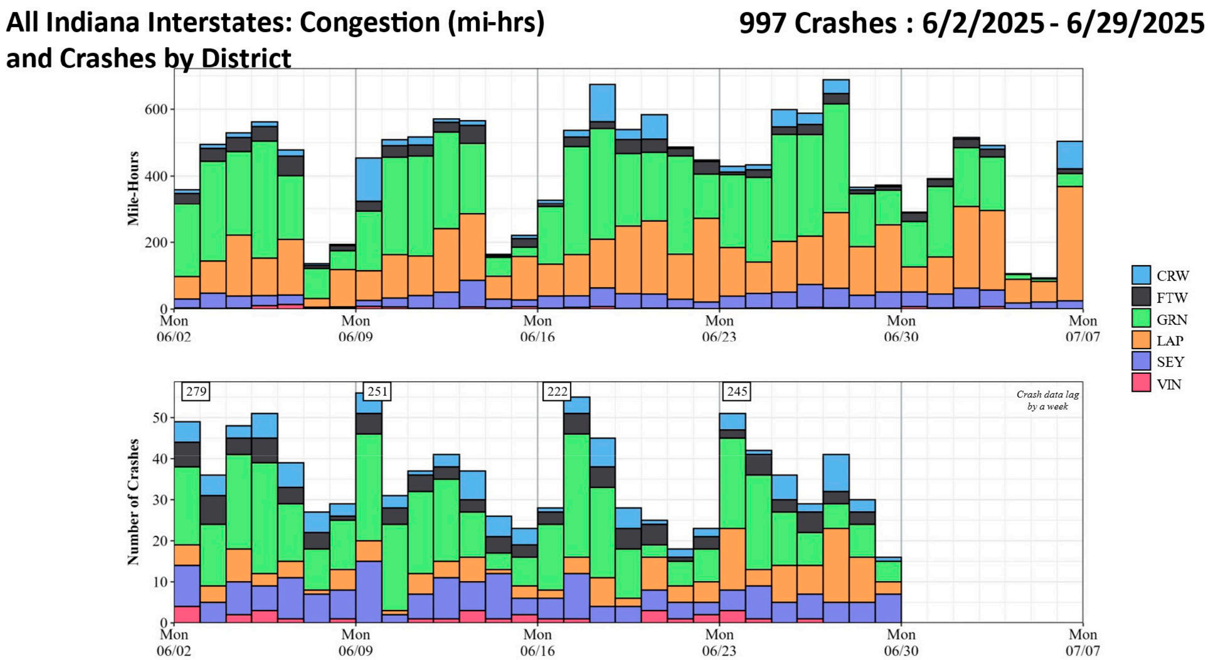


Figure 3.2 Statewide Congestion and Crash Counts.

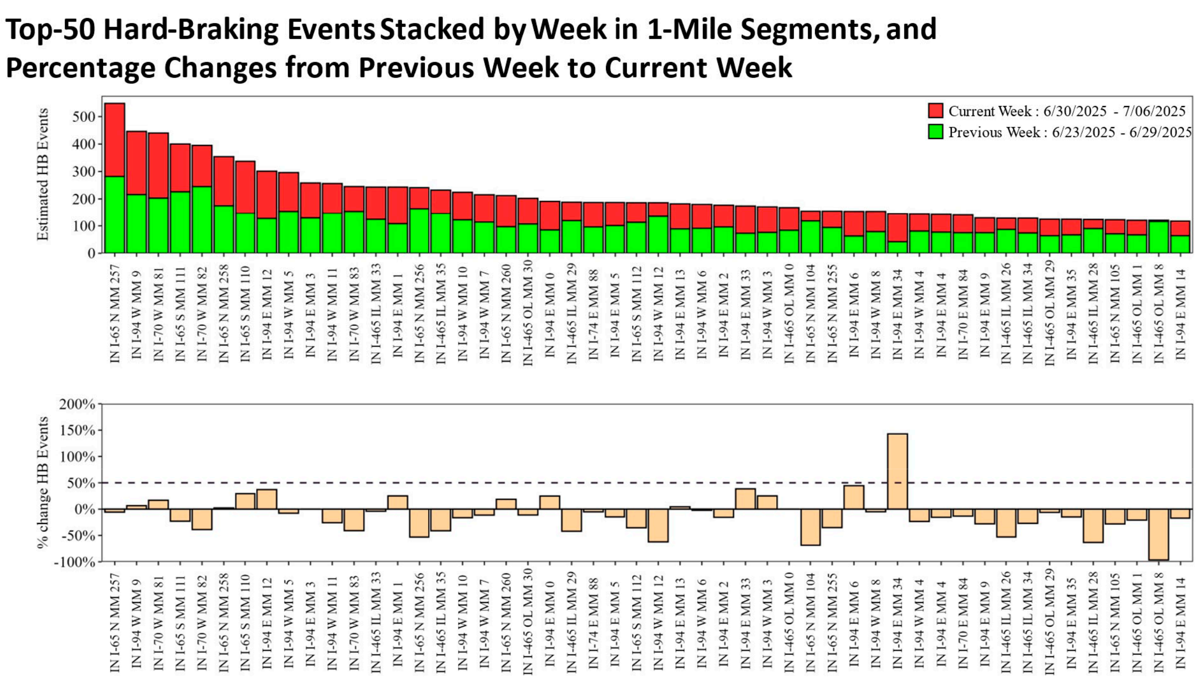


Figure 3.3 Change in Hard-Braking Events Week-Over-Week (Top 50 One-mi Sections).

Figure 3.2 highlights the mile-hours of congestion and the number of crashes for each of the six INDOT districts over the last five weeks in the statewide summary section of the Weekly Work Zone Report. While the top plot showing the mile hours of congestion is for the full five weeks, the bottom plot showing the number of crashes only shows four weeks due to crash data logs being updated one week behind to allow for more reports to be submitted.

Figure 3.3 highlights the top 50 hard-braking events plots in the statewide summary section of the Weekly Work Zone Report. The plots show two things:

- The top plot shows the top 50, 1-mi section of hard-braking event locations over the last two weeks, Pareto sorted with the location with the highest number of hard-braking events of the last two weeks on the far left and then descending to the right from there.

- The bottom plot shows the same over percent change in those 50 locations, up to 200% in the positive direction, showing an increase in hard-braking events at that location, or down to -100%, showing a decrease in hard-braking events.

An overview of the slides that make up a district section is shown in Figure 3.4 for the Fort Wayne (FTW) district (Slides 41–60). This section covers the two interstate routes passing through the FTW district, namely Interstate 69 (I-69) and Interstate 469 (I-469) shown by the interstate shields on Figure 3.4.

Figure 3.5 and Figure 3.6 show traffic speed heatmaps that are included in the Weekly Work Zone Report for each district and route combination showing the current and previous week, respectively, on consecutive slides. Previous studies have shown the effectiveness of these heatmaps to help quickly visualize as well as measure freeway mobility (Sakhare, Desai, Mathew, McGregor, et al., 2024). The horizontal axis represents the time of day over seven days of the week (Monday to Sunday), while the vertical axis represents a linear referenced mile marker location along the interstate route. The eastbound, northbound, or inner loop direction of travel is shown on the top heatmap with the opposing direction of travel shown by the bottom heatmap. These heatmaps provide an effective overview of the route's mobility performance, by way of CV speeds, and safety performance, by way of hard-braking events (current and previous week) and crash counts (previous week). Clusters of hard-braking events, if emerging, are easily identifiable from these heatmaps and help flag potential safety concerns to the relevant stakeholders. Dashed horizontal lines on the heatmaps show interstate exit locations for context. Oftentimes, CV trajectories are seen exiting the interstate at these locations if stuck behind an active incident or construction activity and then rejoining the interstate downstream beyond the incident's area of impact. To allow enough time for a majority of crash reports to be entered into the system, the current week heatmap does not include crash data.

Figure 3.7 shows hard-braking events for every 1-mi segment over the distance of the specific interstate and district. The plots are split per direction (northbound and southbound) as well as Figure 3.7a showing the previous week and Figure 3.7b showing the current week. Each color represents one of the seven days for the specific week and then are stacked on top of each other based on the specific 1-mile marker range of the hard-braking event.

While the Weekly Work Zone Report always covers the past two weeks, Figure 3.8 shows a cumulative heatmap PowerPoint that is also generated weekly to allow for a longitudinal comparison of a specific interstate. Similar to the Weekly Work Zone Report, the cumulative heatmaps PowerPoint is partitioned into six sections based on the INDOT districts with their respective interstates within those sections. Each week, the heatmaps for the current week are added to the report to allow for a comparison over the entire construction season. This format allows a user to easily toggle through multiple weeks of heatmaps at a time to see how the roadway conditions have evolved over time.

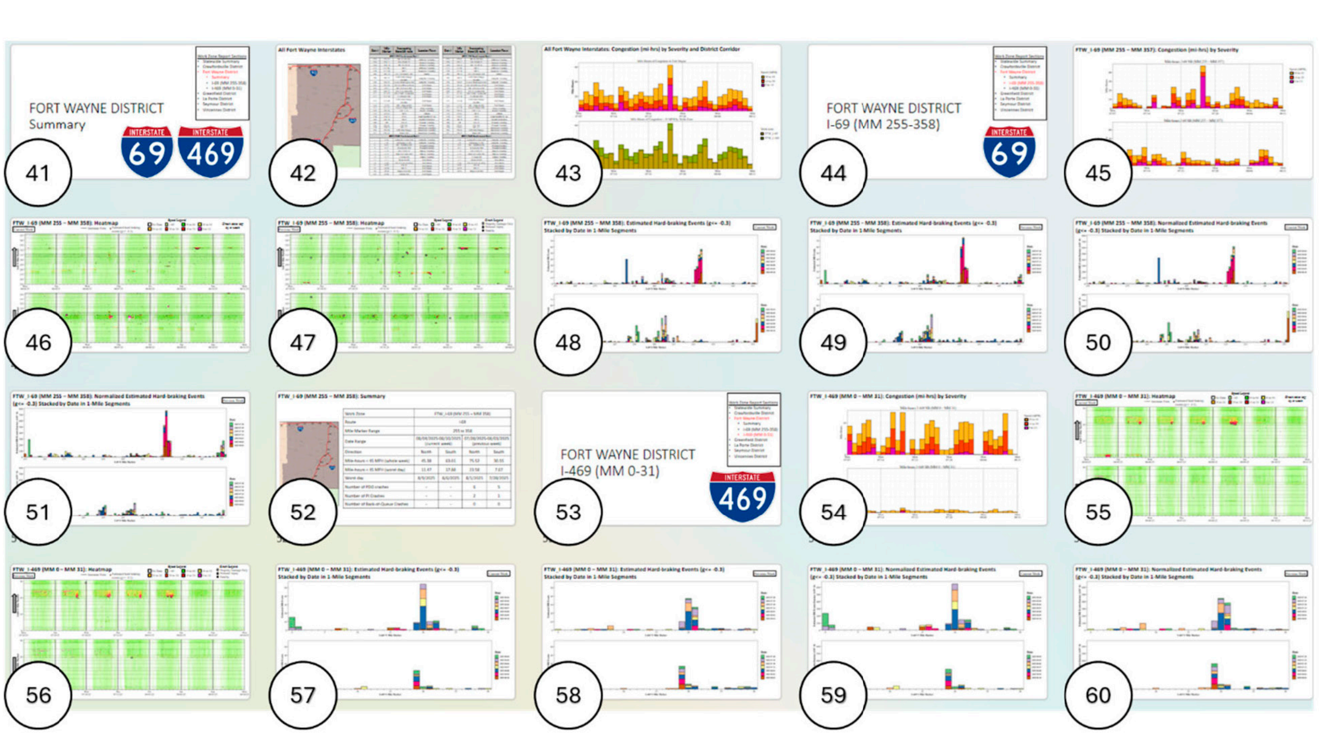


Figure 3.4 Fort Wayne District Summary Section of the Weekly Work Zone Report.

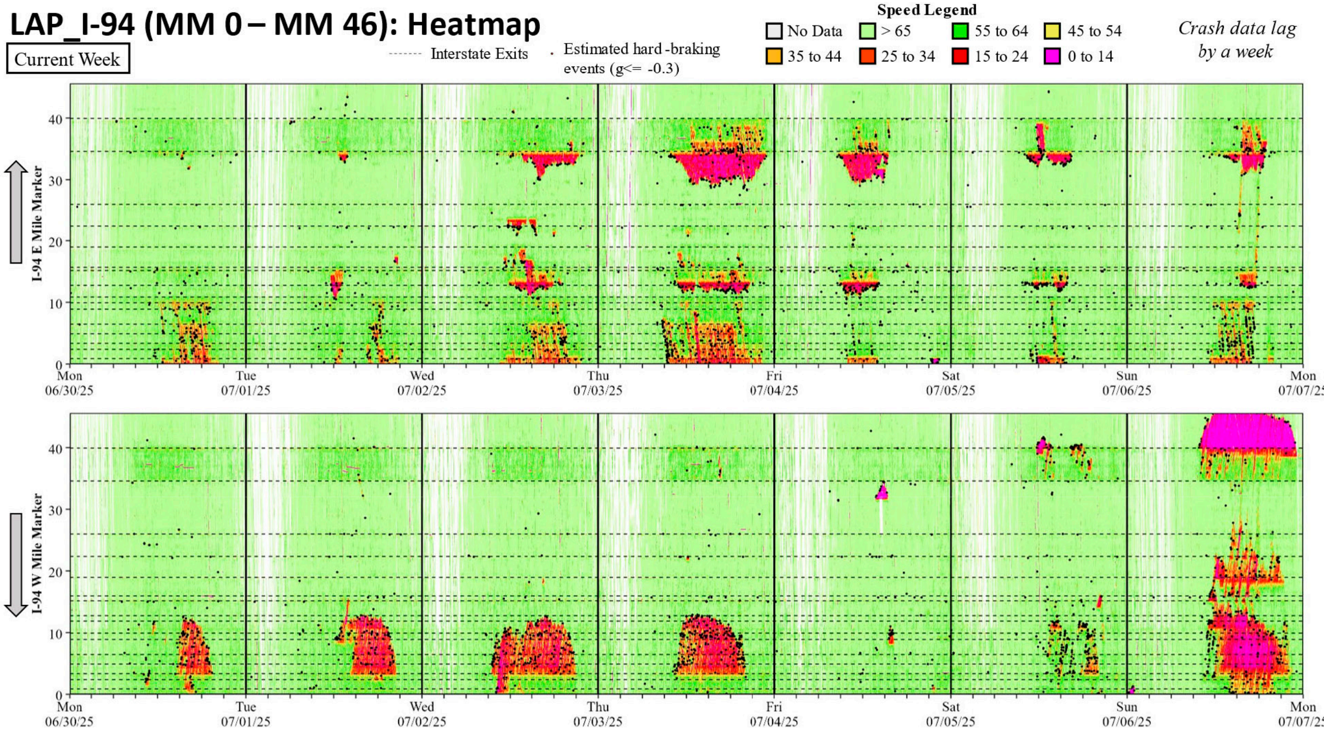


Figure 3.5 Current Week Heatmaps With Hard-Braking Data.

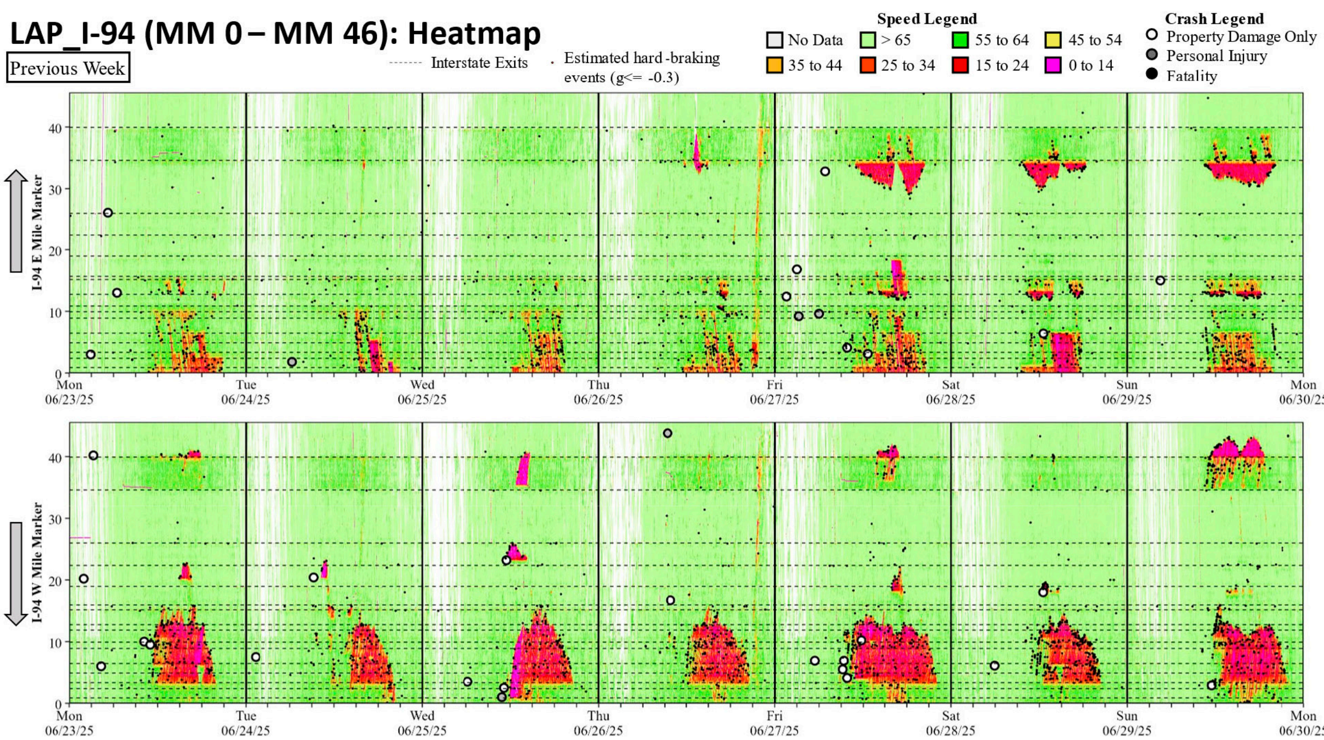
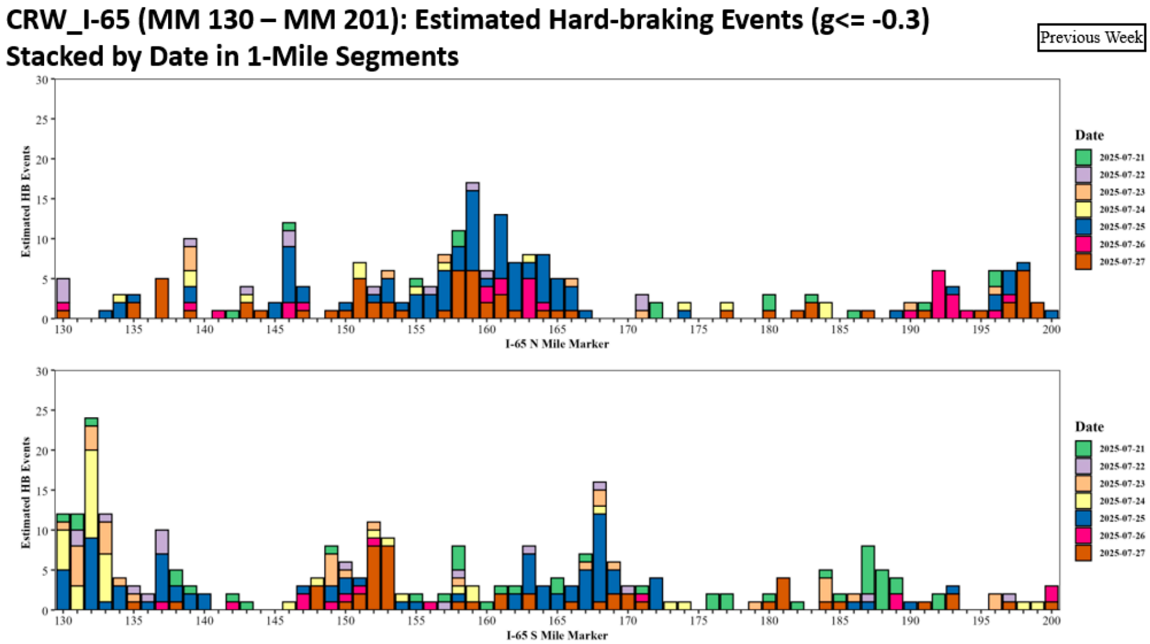
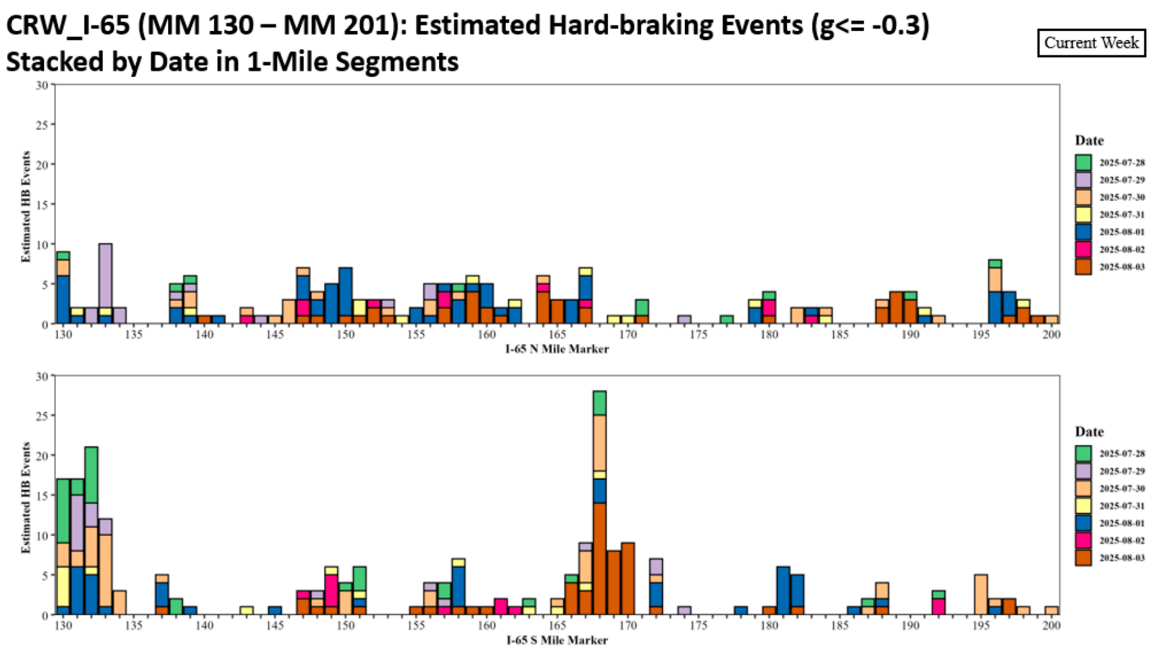


Figure 3.6 Previous Week Heatmaps With Hard-Braking and Crash Data.



(a) Previous Week



(b) Current Week

Figure 3.7 Week-Over-Week Changes in Hard-Braking Events by 0.1-mi.

The Weekly Work Zone Report distribution email is shown in Figure 3.9 and is sent out to more than 100 recipients on a weekly basis, ranging from INDOT staff at the statewide and district level as well as other stakeholders at ISP, FHWA, and Federal Motor Carrier Safety Administration (FMCSA). The email includes a link to the Weekly Work Zone Report as well as to the cumulative heatmaps. The email also includes three to five bullets point each week that highlight possible relevant items for further review from the reports like increases in congestion, large-scale incidents on the interstates, and increases in hard-braking events at a specific location. Finally, the report also includes plots from Figure 3.2 that highlight the mile-hours of congestion and the number of crashes for the previous five weeks.

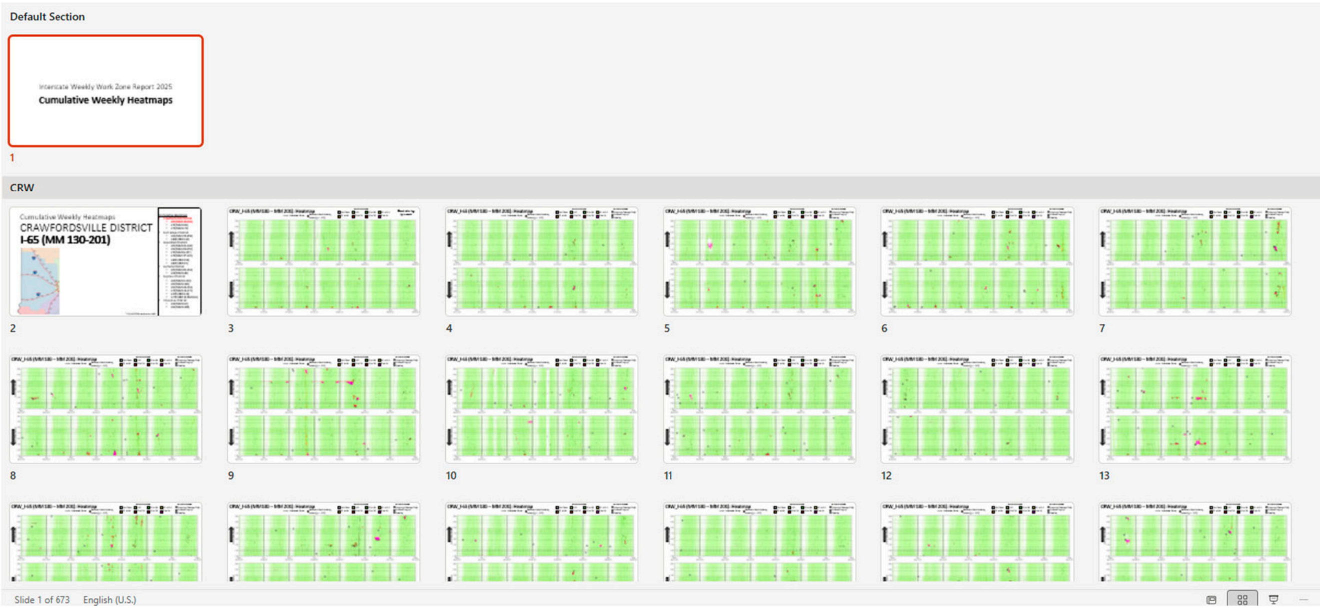
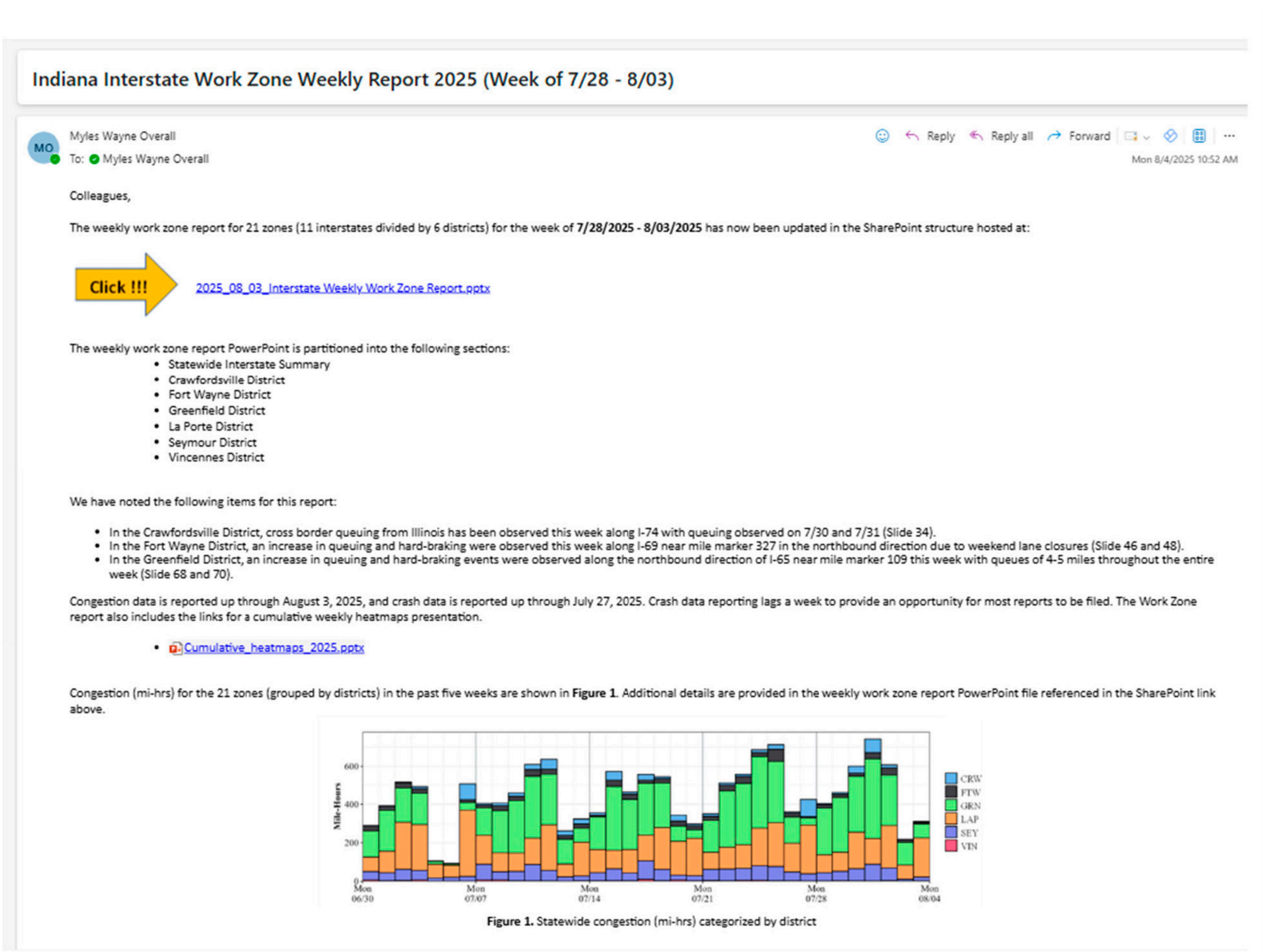


Figure 3.8 Cumulative Heatmaps for Longitudinal Comparisons.



Indiana Interstate Work Zone Weekly Report 2025 (Week of 7/28 - 8/03)

Myles Wayne Overall
To: Myles Wayne Overall
Mon 8/4/2025 10:52 AM

Colleagues,

The weekly work zone report for 21 zones (11 interstates divided by 6 districts) for the week of **7/28/2025 - 8/03/2025** has now been updated in the SharePoint structure hosted at:

Click !!! 2025_08_03_Interstate Weekly Work Zone Report.pptx

The weekly work zone report PowerPoint is partitioned into the following sections:

- Statewide Interstate Summary
- Crawfordsville District
- Fort Wayne District
- Greenfield District
- La Porte District
- Seymour District
- Vincennes District

We have noted the following items for this report:

- In the Crawfordsville District, cross border queuing from Illinois has been observed this week along I-74 with queuing observed on 7/30 and 7/31 (Slide 34).
- In the Fort Wayne District, an increase in queuing and hard-braking were observed this week along I-69 near mile marker 327 in the northbound direction due to weekend lane closures (Slide 46 and 48).
- In the Greenfield District, an increase in queuing and hard-braking events were observed along the northbound direction of I-65 near mile marker 109 this week with queues of 4-5 miles throughout the entire week (Slide 68 and 70).

Congestion data is reported up through August 3, 2025, and crash data is reported up through July 27, 2025. Crash data reporting lags a week to provide an opportunity for most reports to be filed. The Work Zone report also includes the links for a cumulative weekly heatmaps presentation.

- Cumulative_heatmaps_2025.pptx

Congestion (mi-hrs) for the 21 zones (grouped by districts) in the past five weeks are shown in **Figure 1**. Additional details are provided in the weekly work zone report PowerPoint file referenced in the SharePoint link above.

Figure 1. Statewide congestion (mi-hrs) categorized by district

Figure 3.9 Summary Email to Work Zone Report Distribution List.

4. DATA DESCRIPTION

The key data sources utilized in the creation of these weekly work zone reports as well as related investigations over the course of this project are covered in this section.

4.1 Connected Vehicle Data

CV data sourced from a third-party data provider were utilized for this study. The data account for a roughly 4–5% market penetration rate (Hunter et al., 2021; Sakhare, Hunter et al., 2022; Saldivar-Carranza et al., 2024) and include CV trajectory waypoints at nominally 3-s frequency. These waypoints are then linearly referenced to 0.1-mi sections of interstate roadways, a technique well-documented in past literature (Mathew et al., 2022), and aggregated at the 1-min level. This aggregation transforms the tens of billions of CV waypoints every month into manageable amounts of aggregated data for analysis and visualization. Each CV waypoint contains an associated geolocation, speed, heading, timestamp, and anonymized trajectory identifier attribute.

4.1.1 CV Speeds

Figure 4.1 shows a sample of 285,378 CV waypoints for just 1 min of data at 12:00 p.m. on August 26, 2025, for the state of Indiana and a roughly 10-mi border around the state for cross-border visibility. The data covers nearly all of the major interstate roadways, with expected clusters visible in the densely populated urban metropolitan areas, thus demonstrating widespread coverage.

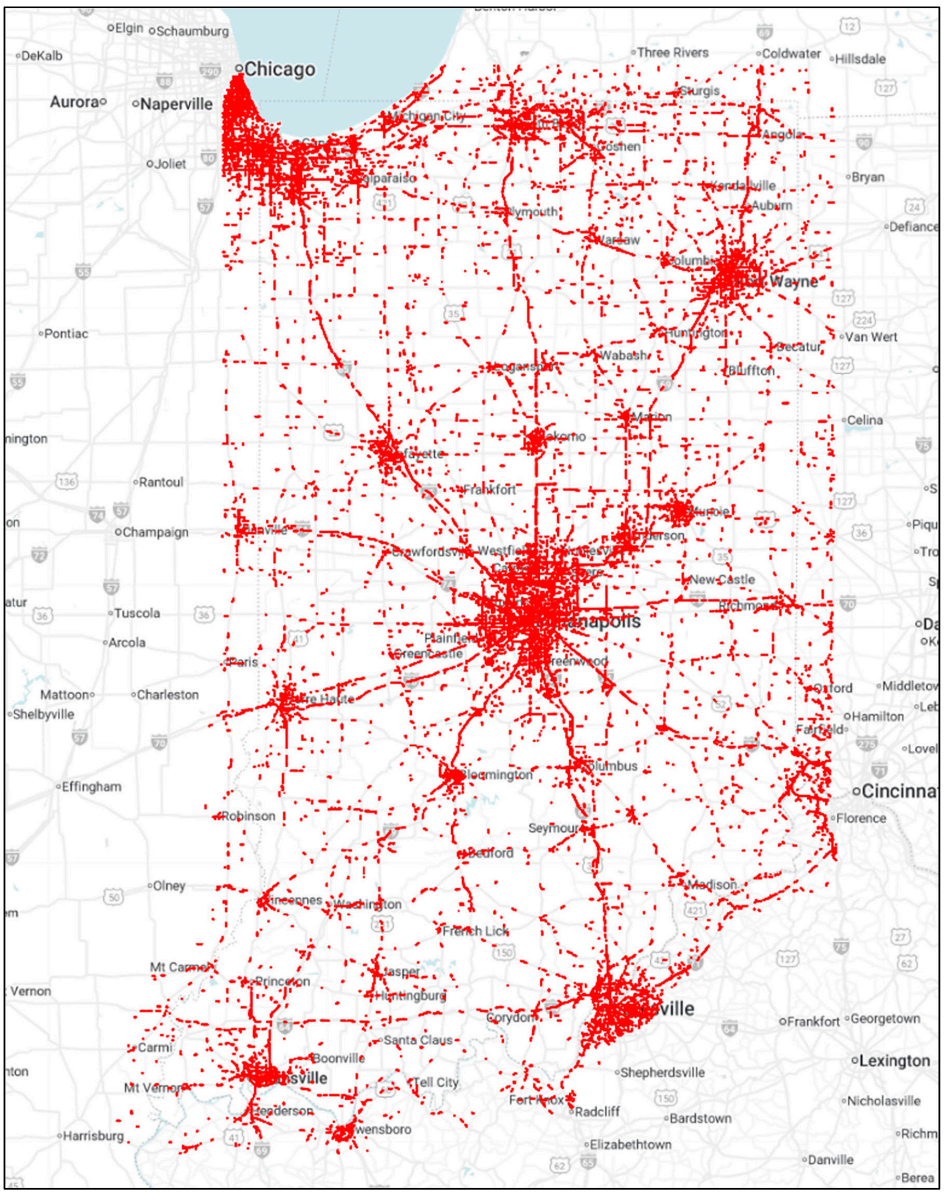


Figure 4.1 CV Waypoints for 12:00–12:01 p.m. (August 26, 2025).

4.1.2 CV Estimated Hard Braking

Using these CV trajectory waypoints, hard-braking and hard-acceleration events are calculated by computing the difference in speeds between consecutive CV waypoints of the same journey. For consistency, only those waypoints that are exactly 3 s apart are used for this computation. Any acceleration values above 0.1 *g* and below -0.1 *g* are ingested. This calculation allows for the ability to set custom thresholds below which hard-braking activity needs to be monitored on a particular corridor, which is especially helpful across different roadway classes where a hard-braking threshold of -0.25 *g* on freeways may not be directly transferable to a corridor of signalized intersections, for example.

4.2. Redacted Crash Reports

Weekly crash counts for all Indiana interstates were recorded during this project with historical data going back as far as 2019. A cumulative weekly crash count by year is shown in Figure 4.2 (current as of August 17, 2025). These were obtained by manually extracting crash data from the state's repository and cleaning and fixing inaccuracies by reading through crash narratives, news reports, and agency alerts about incidents to ensure accurate classification. Initially these plots started in January of each calendar year. More recently we have shifted the start of each plot to April 1 so that the crash counts during summer travel and construction are not impacted by varying winter events (Figure 4.3).

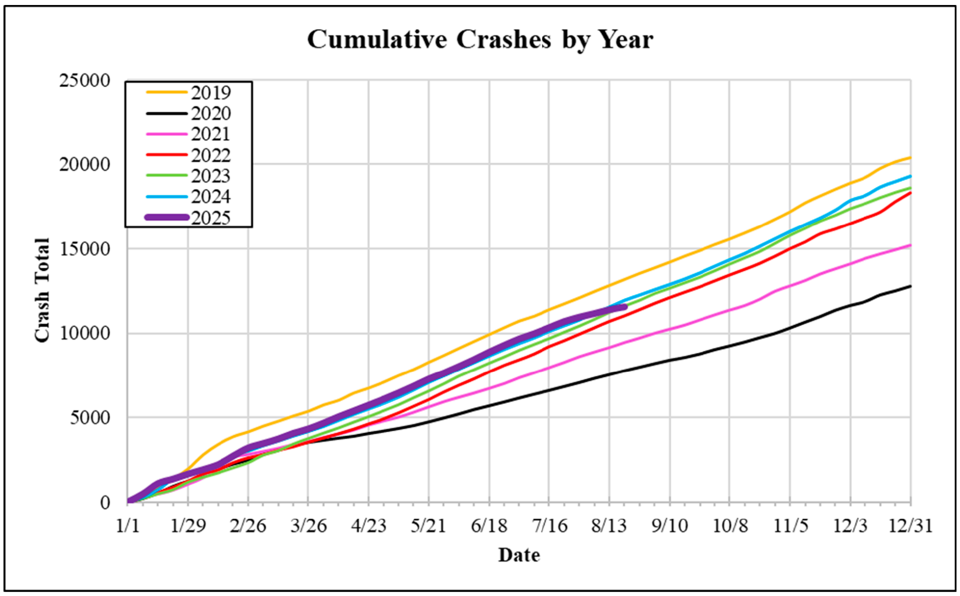


Figure 4.2 Cumulative Weekly Indiana Interstate Crash Counts by Year (2019–2025).

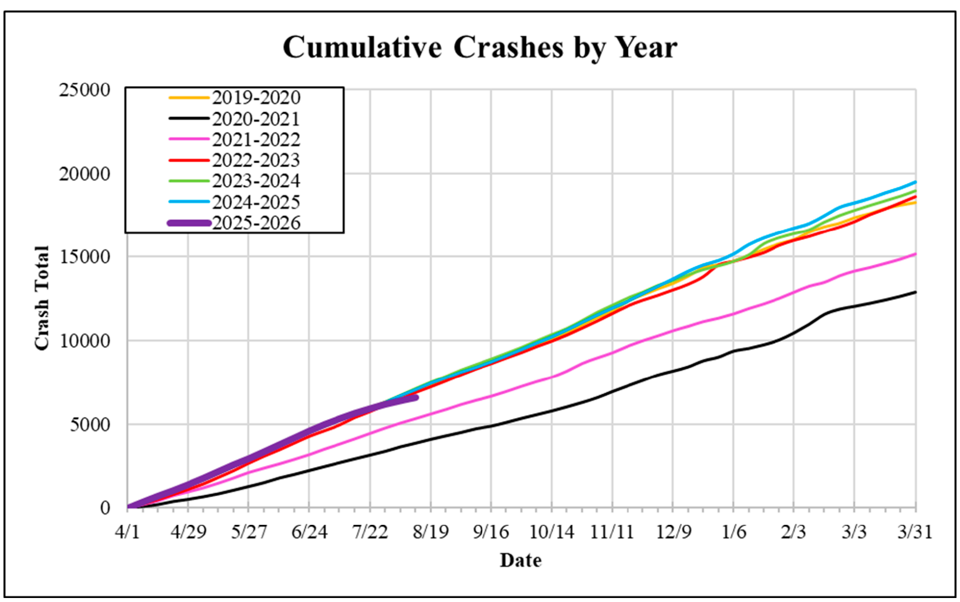


Figure 4.3 Cumulative Weekly Indiana Interstate Crash Counts by Year Beginning April 1 of Each Calendar Year (2019–2025).

5. DISSEMINATION OF RESEARCH RESULTS

The following sections briefly describe various methods by which the research results of this study, specifically findings from the Weekly Work Zone Reports, led to actionable insights and investigations.

5.1 Field Investigations (Drive Throughs and UAS Flights)

A number of field investigations of active construction work zones were conducted during this project using unmanned aerial systems (UAS) as well as drive through footage.

One such investigation of the I-65 Boone County work zone in 2022 is shown by the visualizations in Figure 5.1 and Figure 5.2. A short merge ramp from US 52 southbound onto I-65 southbound resulted in a significant rise in hard-braking activity from motorists looking to merge onto the mainline interstate but having to take action to yield to freeway traffic. A large cluster of hard-braking events is seen exactly AT the merge location The figure also includes a QR code linking to a UAS video showing one such incident of drivers having to hard-brake before merging.

A few miles upstream of this merge location, traffic was bifurcated into two separate lanes at mile marker (MM) 147 on I-65 southbound, as shown by the stitched image in Figure 5.2. A similar significant cluster of hard-braking events is seen at that bifurcation with drivers having to hard brake and realizing too late that they are approaching a bifurcation and lane shift.

These case studies and UAS flights conducted by the research team were instrumental in demonstrating the capabilities of UAS for conducting work zone monitoring and inspection. These practices have since been used by INDOT for aerial surveys of their work zones using in-house resources.

5.2 Work Zone Related Case Studies for Designer Feedback

A number of case studies were collected over the course of this project to provide feedback to designers regarding projects that performed well, as well as those with opportunities identified for improvements. Furthermore, dash camera imagery has been found to be effective in remotely monitoring work zones (Overall et al., 2026). The text that follows briefly summarizes two such case studies.

Figure 5.3 shows a dash camera image on I-69 southbound, specifically the entrance ramp at this location, that has a static work zone speed limit sign displaying 55 mph on right side of the entrance ramp while also having a work zone speed limit trailer that displays 50 mph with the “When Flashing” plaque below on the left side of the entrance ramp. By Indiana Code,

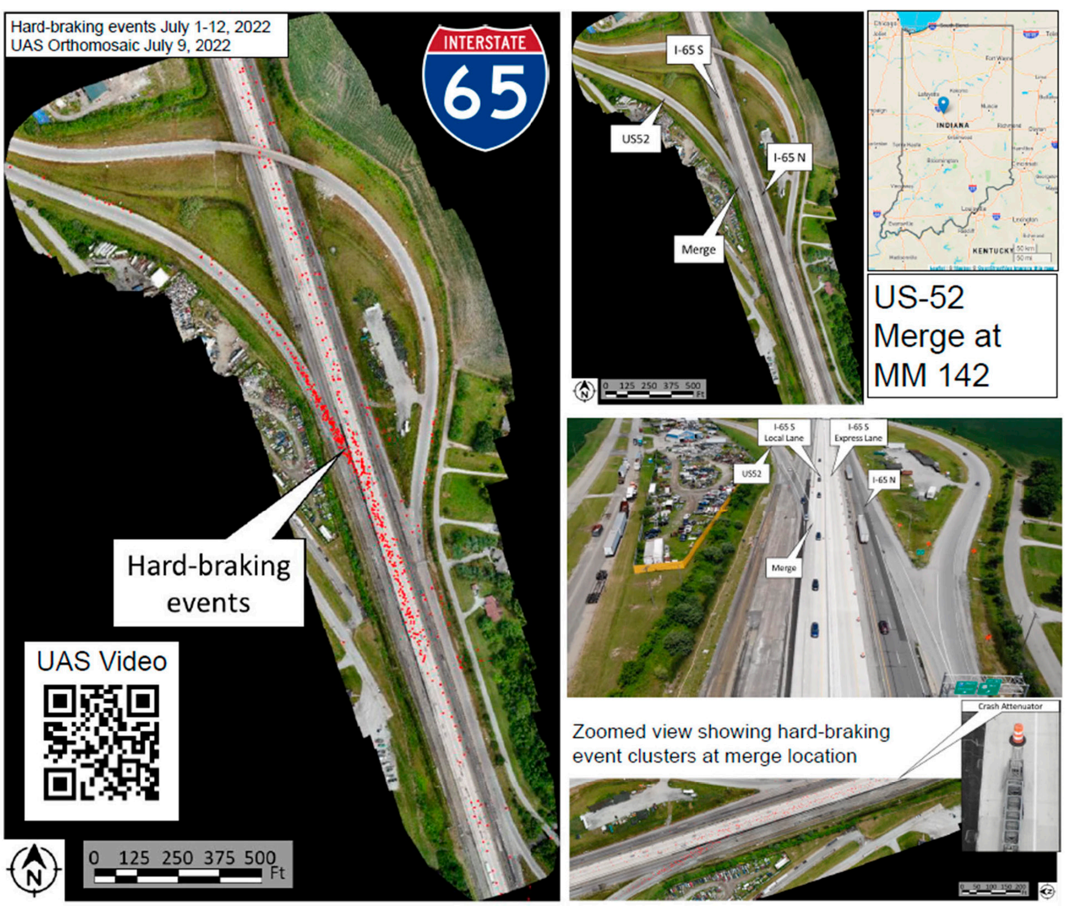


Figure 5.1 UAS and Hard-Braking Investigations of US 52 Merge at I-65.

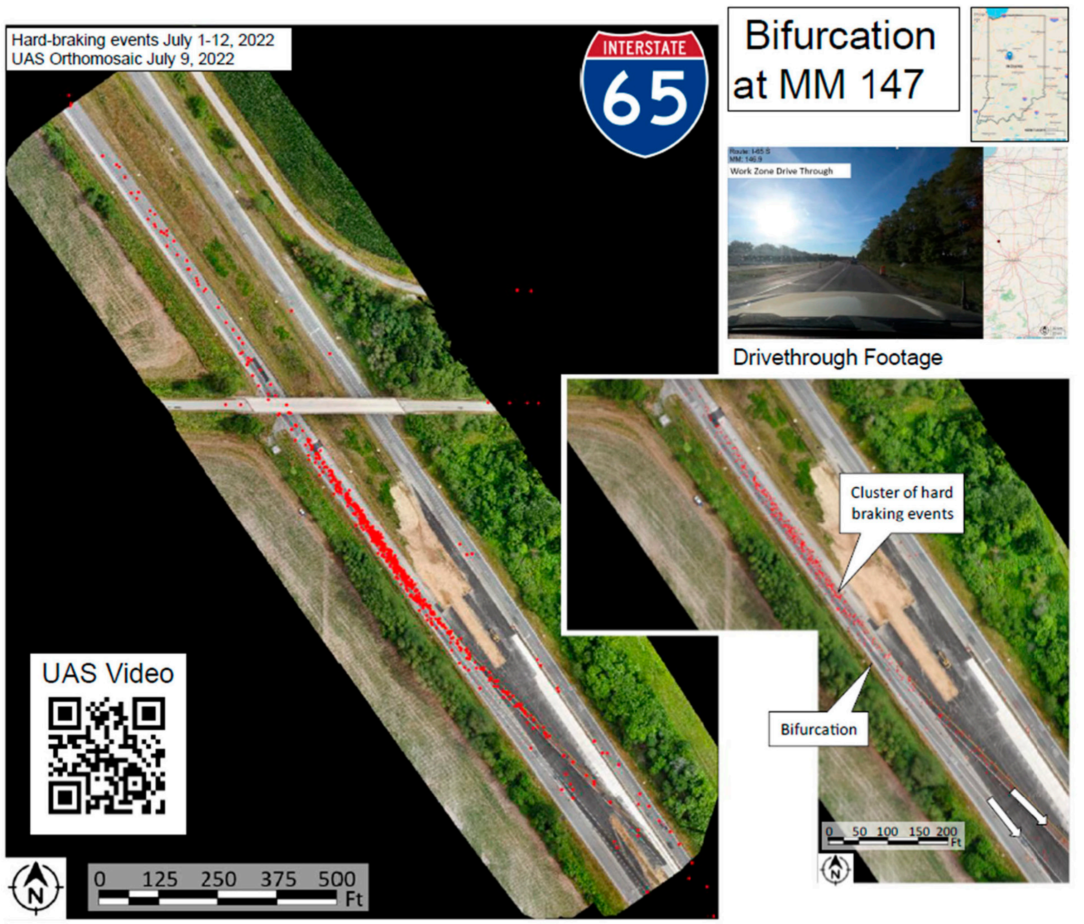


Figure 5.2 UAS and Hard-Brake Investigations of Bifurcation at I-65 SB MM 147.

Figure 5.3 Dash Camera Image Along Southbound I-69 Near MM 273 on August 12, 2024, Showing Different Speed Limit Signage at the Same Location.

the intermittent setup of “When Flashing” requires workers to present. However, if workers are present then that would also mean they are exposed with no positive protection, meaning a 45 mph speed limit should be used instead.

Figure 5.4 shows a dash camera image along northbound I-65 within a work zone that has a double lane shift in this direction. Several run-off and rollover crashes occurred immediately downstream of this location and had shown up several times on the Weekly Work Zone Report. By pulling dash camera images along this corridor throughout the project, the ability to change/update pavements, shoulder consistency, and signage was able to be completed to assist motorists in traversing this work zone section.

5.3 Indiana Interstate Weekly Heatmaps with Cross-Border Visibility

Over the course of this project, weekly heatmaps of 13 Indiana interstates with cross-border visibility of about 10 mi into neighboring states were prepared and disseminated to agency stakeholders. These heatmaps not only summarize CV speeds, but also have an overlay of estimated hard-braking events at two thresholds of 0.25 *g* and 0.3 *g*, along with summary counts of the same by 0.1-mi segment on the right side, as shown by Figure 5.5. As of this writing, 65 such weeks of heatmaps have been distributed. These heatmaps provide a quick summary visual of interstate safety and mobility for the past

Figure 5.4 Dash Camera Image Along Northbound I-65 Near MM 236 on July 12, 2025, Showing a Double Lane Shift Within a Work Zone.

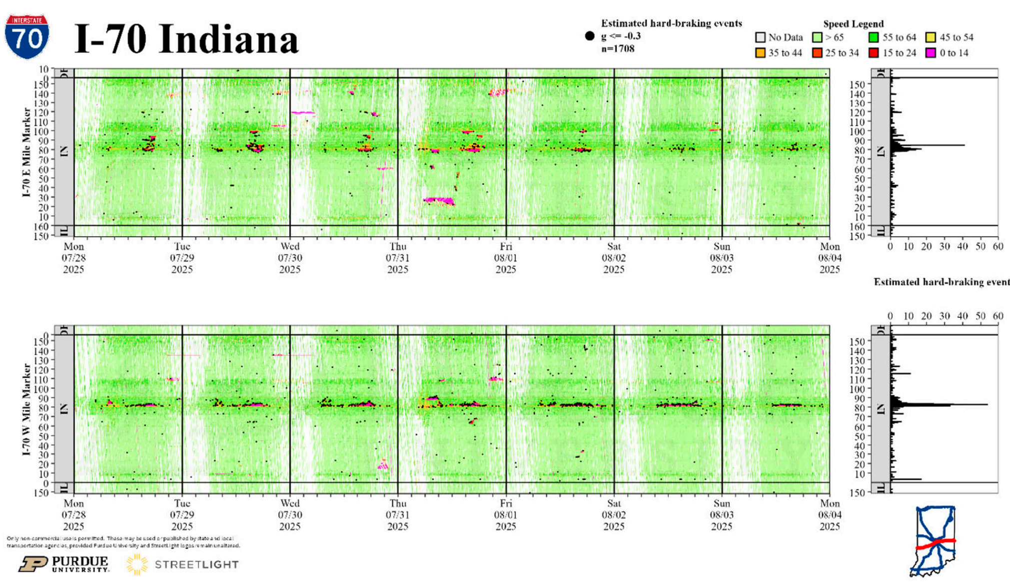


Figure 5.5 I-70 Traffic Speed Heatmap with Hard-Braking Events and Summary Counts by 0.1 mi (Week of July 28, 2025).

week and have been helpful in quickly flagging areas of interest that need further detailed investigation.

5.4 Trajectory Heatmap and Travel Times Dashboard

A number of dashboards have been developed either fully or in part during the course of this project and have helped the research team, as well as agency stakeholders, gain real-time insights into work zone mobility and safety performance. One such dashboard is the trajectory heatmap and travel times dashboard, a snapshot of which is shown by Figure 5.6 with a CV heatmap on the top and an aligned CV travel times plot on the bottom. This dashboard allows users to generate such visuals for any roadway with available CV data and is not just limited to interstates. This helps users gain insights into off-freeway travel trends and how freeway work zone construction impacts motorist travel times, detour tendencies, and overall network performance.

5.5 Bidirectional Trajectory Heatmap Dashboard

The bidirectional trajectory heatmap dashboard provides functionalities to visualize freeway mobility for both directions of travel in a single view for any interstate route. An example of this dashboard in use is shown by Figure 5.7 for Interstate 94 (I-94)

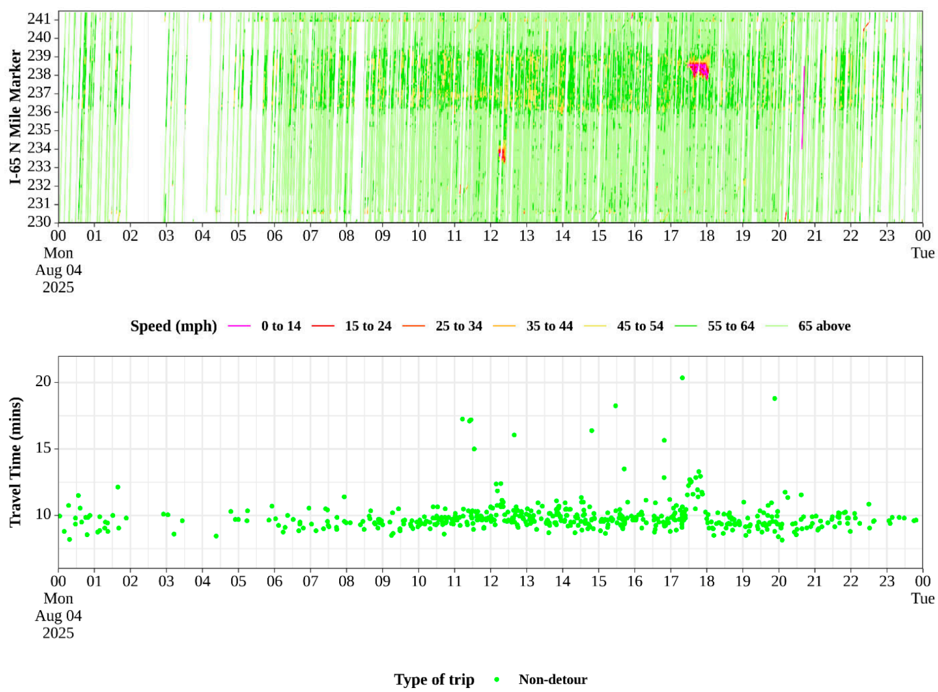


Figure 5.6 Sample Output of Traffic Speeds and Travel Times From the Dashboard for I-65 N MM 230-240 Work Zone (Monday, August 4, 2025).

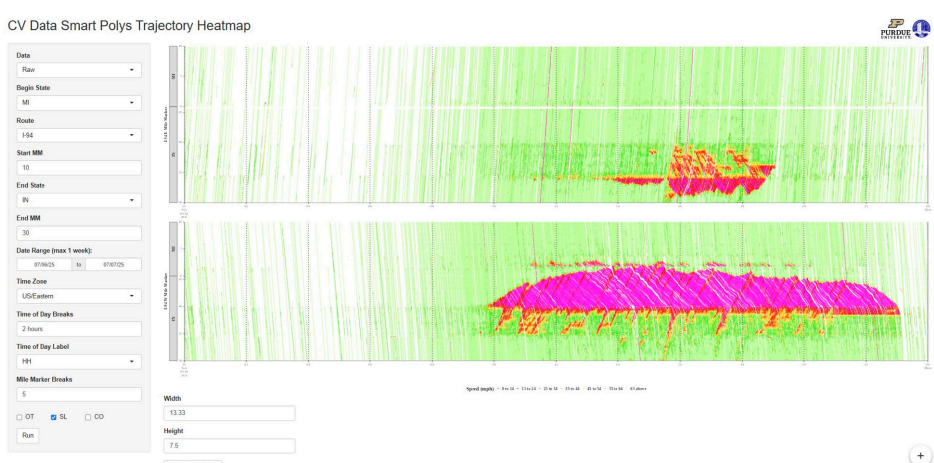


Figure 5.7 Sample I-94 Heatmap With Cross-Border Visibility Into Michigan.

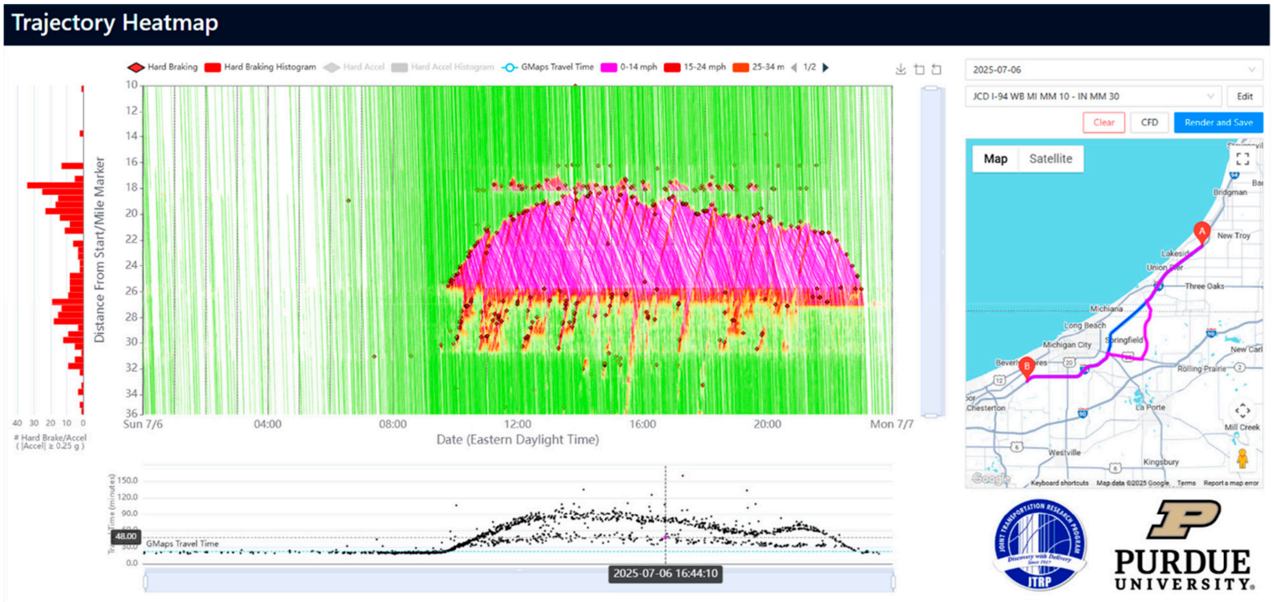


Figure 5.8 Trajectory Heatmap With Travel Times, Detours, and Hard Braking.

that provides 10-mi visibility into Michigan. Queues in the westbound direction of travel due to an active incident/work zone appear to extend beyond Indiana's border into Michigan. The extended 10-mi visibility into neighboring states is critical for state agencies to monitor how their operations are impacting surrounding states and vice versa, especially in case where construction work is being conducted near or at the border.

5.6 Trajectory Heatmap (Travel Times and Detours)

The most recent iteration of the trajectory heatmap dashboard with functionalities to visualize travel times as well as detour routes is shown by the visual in Figure 5.8 for the same stretch of roadway for I-94 westbound starting 10 mi into Michigan, shown by Figure 5.7. This dashboard includes an overlay of hard-braking data with customizable thresholds ranging from -0.1 *g* to -0.5 *g*. The current display shows hard-braking events at a threshold of -0.25 *g*. A map display on the right allows users to visualize the route adopted by each travel time point shown on the corresponding plot under the heatmap. The highlighted travel time, in this case of about 48 min, was significantly shorter than the travel time of about 77 min for the CVs stuck in the queue at the same time. The highlighted route in pink on the map shows the detour this CV adopted to bypass the zone of congestion by avoiding a 7-mi stretch of congested freeway. Such visualizations may aid state DOTs as well as district staff in visualizing the impact of construction activities and coordinating with local law enforcement for determining planned alternate routes for future lane closure activities based on observed real-world detour trends.

The aforementioned dashboards and investigation methods have now been formalized as part of this project, with agency staff directly accessing these tools to conduct their own analysis of work zone safety and mobility for proactive monitoring.

6. CONCLUSION

Through the course of this study, systematic procedures have been put in place over the past seven years or more for the agency to track work zone mobility and safety performance. In addition to the widespread institutionalization of the use of CV data for near real-time traffic condition monitoring, estimated hard-braking event data have also been incorporated into reporting procedures to provide proactive safety performance data. Methodologies were developed to compute hard-braking data directly from CV trajectory waypoints so as to not bias analysis and avoid over-reliance on automotive original equipment manufacturers (OEM)-defined thresholds of hard braking. This allows agencies the independence to set desired thresholds of hard braking based on the facility they are monitoring. As the CV data market continues to grow with multiple data providers, these estimation techniques will be important to ensure standardized ingestion, analysis, and comparisons across data providers and OEMs.

The methodologies and reporting procedures developed as part of this study provide practitioners with a framework to systematically monitor their work zones in near real-time and keep all stakeholders informed. Indiana's efforts in this space have now continued through a Transportation Pooled Fund Study with ten participating states. While the data used in this study are passenger vehicle based, follow-up research has demonstrated applicability and scalability to commercial truck data, as well (Sakhare et al., 2026).

The research team recommends adoption of these reporting procedures at the agency level for weekly agile monitoring of work zone construction activities across the state. With sufficient CV data availability, these procedures could very well be scaled to other roadway classes beyond interstates.

7. FUTURE RESEARCH

As the market penetration rates for CV data continue to grow and an increasing percentage of newer vehicles are instrumented, the representativeness of data utilized for near real-time roadway condition monitoring will further improve these reports. Connected truck data has shown promise in augmenting current CV data representativeness and provides good coverage during overnight hours when passenger vehicle volumes are low. Finally, as more states invest in digital smart work zone infrastructure, such as dynamic speed limit signs, smart arrow boards, among others, incorporating data from these into work zone performance monitoring will help stakeholders gain more holistic insight into the impacts of their individual work zone components and how they interact and influence work zone performance. Furthermore, the extended 10-mi visibility of CV data into neighboring states is critical for state agencies to monitor how their operations are impacting surrounding states and vice versa, especially in case where construction work is being conducted near or on the border.

8. RESOURCES

This section summarizes some of the key resources and foundational work available for work zone analytics described in previous sections. These have been developed over the past several years and summarized in one place here for quick reference.

8.1 Methodology for Monitoring Work Zone Traffic Operations

The following studies highlighted the use of traffic speed heatmaps and percentage change in hard-braking events for quickly identifying challenges on interstates and particularly within work zones, as well as identifying agile work zone management strategies (Desai, Rogers, et al., 2021; Sakhare, Desai, et al., 2022). Several case studies showed the rise in hard-braking events in particular zones and corresponding select crash incidents in the same zones.

The references to these studies are as follows:

- Sakhare, R. S., Desai, J., Li, H., Kachler, M. A., & Bullock, D. M. (2022). Methodology for monitoring work zones traffic operations using connected vehicle data. *Safety*, *8*(2), 41. https://doi.org/10.3390/safety8020041
- Desai, J., Rogers, S., Kim, W., Li, H., Horton, D., Poturalski, J., & Bullock, D. M. (2021). *Agile work zone management based on connected vehicle data* [Paper presentation]. 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), Indianapolis, IN, United States. https://doi.org/10.1109/ITSC48978.2021.9565039

8.2 Evaluating Impact of Work Zone Construction on Freeway Detours

A previous study utilized CV data to systematically evaluate the impact of diverting traffic from a construction zone on Interstate 70 (I-70) onto nearby arterial route US 40. Scalable techniques were presented to be able to perform such evaluations for any construction work zone (Desai, Saldivar-Carranza, et al., 2021). Additionally, a more scalable follow-up implementation was presented to document the impact of both planned and unplanned freeway closures on motorist route choice (Desai et al., 2022).

The references to these studies are as follows:

- Desai, J., Saldivar–Carranza, E., 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* [Paper presentation]. 2021 IEEE International Intelligent Transportation Systems Conference (ITSC), Indianapolis, IN, United States. https://doi.org/10.1109/ITSC48978.2021.9564873
- Desai, J., Scholer, B., Mathew, J. K., Li, H., & Bullock, D. M. (2022). Analysis of route choice during planned and unplanned road closures. *IEEE Open Journal of Intelligent Transportation Systems*, *3*, 489–502. https://doi.org/10.1109/OJITS.2022.3183928

8.3 Measuring and Visualizing Freeway Traffic Conditions

Over the years, spatiotemporal traffic speed heatmaps have been utilized extensively for monitoring traffic in near real-time or after-action studies on the impact of particular events, such as crashes, severe weather, and more. A monograph that details more than 50 case studies across the United States that demonstrate the techniques to measure queue lengths and duration directly from the heatmaps is prepared (Sakhare, Desai, Mathew, McGregor, et al., 2024; Sakhare, Desai, Mathew, & Bullock, 2024a).

The reference to this monograph and visualization can be found at:

- Sakhare, R. S., Desai, J., Mathew, J. K., McGregor, J., Kachler, M., & Bullock, D. M. (2024). *Measuring and visualizing freeway traffic conditions: Using connected vehicle data* (Joint Transportation Research Program No. TPF-5[514]). Purdue University. https://doi.org/10.5703/1288284317751
- Sakhare, R. S., Desai, J. C., Mathew, J. K., & Bullock, D. M. (2024). *Heatmap: spatiotemporal traffic speed graphics using connected vehicle data* [Dataset]. Purdue University Research Repository. https://doi.org/10.4231/7E38-FX40

8.4 Statewide Traffic Speed Profiles

Statewide traffic speed profiles summarize monthly mile-hours of congestion across the Indiana interstates. These are great visualizations for assessing longitudinal changes across large sections on statewide interstates (Sakhare et al., 2025a, 2025b; Sakhare, Li, et al., 2022).

These speed profiles can be assessed at following links:

- Sakhare, R. S., Desai, J., Horton, D., & Bullock, D. M. (2025b). *Indiana interstate speed profiles 2020–2024* (Indiana Mobility Reports). Purdue University. https://doi.org/10.5703/1288284317843
- Sakhare, R. S., Desai, J., Horton, D., & Bullock, D. M. (2025a). *Crawfordsville District interstate speed profiles: April 2020–March 2025* (Indiana Mobility Reports). Purdue University. https://doi.org/10.5703/1288284317852
- Sakhare, R. S., Li, H., Mathew, J. K., Desai, J., Horton, D., & Bullock, D. M. (2022). *Indiana interstate speed profiles 2018–2022* (Indiana Mobility Reports). Purdue University. https://doi.org/10.5703/1288284317589

8.5 Coverage of Commercial Trucks With Dash Camera Images

Commercial trucks with the capability of providing dash camera images are growing and present opportunities for virtually inspecting statewide work zones. Even though efforts in this space are still in their early stages, this study presented the frequency of such trucks travelling along interstates and its coverage across all interstates (Sakhare, Desai, Mathew, & Bullock, 2024b).

The initial study can be found at:

- Sakhare, R. S., Desai, J., Mathew, J. K., & Bullock, D. M. (2024). Assessing the interstate coverage of commercial trucks capable of providing roadway imagery via on-vehicle dash camera in the United States. *IEEE Access*, *12*, 173517–173529. https://doi.org/10.1109/ACCESS.2024.3503368

8.6 Connected Vehicle Data and Its Market Penetration Rates

CV data form the basis for several of the plots and analysis presented in the weekly work zone reports. One of the key factors in evaluating the data providers in this space is the market penetration rates for the CVs in a particular region. Previous studies have assessed the penetration rates of CVs and changes over time. For passenger cars, the penetration rates are roughly 4–5% whereas it is around 1% for commercial trucks on interstates (Hunter et al., 2021; Sakhare, Hunter, et al., 2022; Saldivar-Carranza et al., 2024).

The details for these studies and datasets can be found at:

- Saldivar-Carranza, E. D., Sakhare, R. S., Desai, J., Mathew, J. K., Sivakumar, A. J., Mukai, J., & Bullock, D. M. (2024). Impact of privacy filters and fleet changes on connected vehicle trajectory datasets for intersection and freeway use cases. *Smart Cities*, *7*(5), 2366–2391. https://doi.org/10.3390/smartcities7050093
- 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
- Hunter, M, Mathew, J. K., Li, H., & Bullock, D. M. (2021). Estimation of connected vehicle penetration on US roads in Indiana, Ohio, and Pennsylvania. *Journal of Transportation Technologies*, *11*(4), 597–610. https://doi.org/10.4236/jtts.2021.114037

8.7 Impact of Work Zone Safety Measures

CV data have been effectively utilized to quantitatively document the impacts of a number of work zone safety measures including: queue warning trucks (Sakhare, Desai, Mahlberg, et al., 2021), in-cab alerts (Desai, Saldivar-Carranza, et al., 2024), speed feedback displays (Mathew et al., 2021), and presence lighting (Sakhare, Desai, Mathew, et al., 2021), among others. References to relevant studies have been provided below:

- 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
- Desai, J., Saldivar-Carranza, E. D., Sakhare, R. S., Mathew, J. K., & Bullock, D. M. (2024). Impact of in-cab alerts on connected truck speed reductions in Indiana. *Vehicles*, *6*(4), 1857–1871. https://doi.org/10.3390/vehicles6040090
- 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
- Sakhare, R. S., Desai, J. C., Mathew, J. K., McGregor, J. D., & Bullock, D. M. (2021). Evaluation of the impact of presence lighting and digital speed limit trailers on interstate speeds in Indiana work zones. *Journal of Transportation Technologies*, *11*(2) 157–167. https://doi.org/10.4236/jtts.2021.112010

8.8 Surrogate Safety Measures for Work Zones

Instantaneous CV hard-braking events have been shown as an effective surrogate safety measure for crash incident counts in interstate work zones. This study conducted over the summer of 2019 for 23 construction work zones on Indiana interstates found approximately one crash per mile for every 147 hard-braking events in and around a construction site (Desai, Li, et al., 2021). This led to agencies adopting the recommendation of using hard-braking events to quickly identify emerging work zones of interest for further evaluation. The reference to this study is provided below:

- 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., 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., Sakhare, R. S., Mahlberg, J., Mathew, J. K., Li, H., & Bullock, D. M. (2023). *Implementation of enhanced probe data (CANBUS) for tactical workzone and winter operations management* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2023/18). Purdue University. https://doi.org/10.5703/1288284317643

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APPENDICES

Appendix A. List of Acronyms

Appendix B. Links to Weekly Work Zone Reports by Year

Appendix A. List of Acronyms

CFR	Code of Federal Regulations
CV	Connected Vehicle
DOT	Department of Transportation
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
HB	Hard-braking
INDOT	Indiana Department of Transportation
ISP	Indiana State Police
MM	Mile Marker
MOT	Maintenance of Traffic
OEM	Original Equipment Manufacturers
PCMS	Portable Changeable Message Sign
PDO	Property Damage Only
PI	Personal Injury
UAS	Unmanned Aerial System

Appendix B. Links to Weekly Work Zone Reports by Year

The table below includes links to the Weekly Work Zone Reports by Year from 2019 to 2025.

Table B.1 *Weekly Work Zone Reports by Year From 2019 to 2025.*

Year	Link
2019	2019 Reports
2020	2020 Reports
2021	2021 Reports
2022	2022 Reports
2023	2023 Reports
2024	2024 Reports
2025	2025 Reports

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 docs.lib.purdue.edu/jtrp/.

Further information about JTRP and its current research program is available at engineering.purdue.edu/JTRP.

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