JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
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Evaluating the Impact of Vehicle Digital Communication Alerts on Vehicles

**Rahul Suryakant Sakhare, Jairaj Desai, Jijo K. Mathew,
Woosung Kim, Justin Mahlberg, Howell Li, Darcy M. Bullock**

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AUTHORS

Rahul Suryakant Sakhare
Jairaj Desai
Justin Mahlberg
Graduate Research Assistants
Lyles School of Civil Engineering
Purdue University

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

Woosung Kim
Software Engineer
Lyles School of Civil Engineering
Purdue University

Howell Li
JTRP Senior Software Engineer
Lyles School of Civil Engineering
Purdue University
(765) 494-9601
howell-li@purdue.edu
Corresponding Author

Darcy M. Bullock, PhD, PE
Lyles Family Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University

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16. Abstract

Traditional methods for communicating the presence of maintenance activities and work zones have been done with a variety of fixed signs. The increase of in-vehicle connectivity on our roads—either directly integrated into the vehicle or via an application running on a mobile phone–provides an opportunity for additional communication to motorists about the presence of emergency vehicles, maintenance activities, or work zones. Although the exact form of the in-vehicle communication is evolving and will continue to do so, a critical first step is to leverage the extensive telematics currently deployed on the Indiana Department of Transportation Vehicles. The objective of this study was to conduct trial deployments on a variety of INDOT vehicles, and to begin a dialog with private sector partners about what information INDOT can share that will provide a safer roadway for all motorists, INDOT workers, and INDOT partners.

The final design of connected vehicles will likely change considerably over the next few years as market forces determine what type of information is directly integrated into the vehicle and what information is integrated via cell phones. This report identifies several examples where in-vehicle notification alerting drivers to the presence of service and contractor vehicles was acknowledged by drivers. Hard braking data is being used to determine if these alerts have a meaningful impact on safety. Early results indicate substantial reduction in hard braking events (from 29 to 3) between conditions when queue trucks are not used and when they are used. A larger data set is currently being collected with Hoosier Helpers to isolate the impact of the in-vehicle alerts.

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EXECUTIVE SUMMARY

Introduction

Traditional methods for communicating the presence of maintenance activities and work zones has been accomplished with a variety of fixed signs. Short-duration or mobile maintenance activities are often the most challenging situations for managing risks and communicating to the motorists. The increase of in-vehicle connectivity on our roads, either directly integrated into the vehicle or via an application running on a mobile phone, provides an opportunity to further communicate with motorists about the presence of emergency vehicles, maintenance activities or work zones. In-vehicle digital communication alerts have been identified as a way to improve communication with drivers of modern vehicles, and a critical first step in this communication is to leverage the extensive telematics currently deployed on the Indiana Department of Transportation vehicles. The objective of this study was to conduct trial deployments on a variety of INDOT vehicle; evaluate the impact of in-vehicle digital communication alerts and begin a dialog with private sector partners about what information INDOT can share that will create a safer roadway for all motorists, INDOT workers, and INDOT partners.

Findings

The design of connected vehicles will likely change considerably over the next few years as market forces determine what type of information is integrated directly into the vehicle and what information is integrated via cell phones. This report identifies several examples where in-vehicle notifications alerting drivers to the presence of service and contractor vehicles were acknowledged by the drivers. Hard braking data is being used to determine if these alerts have a meaningful impact on safety. Early results indicate a substantial reduction in hard braking events (from 29 to 3) between conditions when queue trucks are not used versus when they are used (Figure 9.1). A larger data set is currently being collected with Hoosier Helpers to isolate the impact of the in-vehicle alerts.

- Waze users are already actively using and acknowledging alerts triggered by public safety vehicles. The alert acknowledgments provide good evidence of the alert impact, but we will need to work collectively with the navigation and automotive OEMs to ensure that we are not introducing distractions that negatively impact safety.
- The significant reduction in hard braking events associated with queue trucks equipped with HAAS Alerts on I-65 was observed and compared to cases with no queue trucks or HAAS Alerts (Figure 9.1). Although it is not clear how much of this reduction is due to the visibility of the truck compared to the HAAS Alert, the reduction of hard braking (and hence crash risk) has been well received. Similar results have also been observed on Interstate I-69.

Implementation

Over the course of this study, the research team performed a pilot deployment of the HAAS Alert devices on various Indiana Department of Transportation (INDOT) vehicles across the state. In total, HAAS devices were installed on eight different vehicles from May 14 through August 31, 2020. Three of the eight vehicles operated in the Indianapolis area, two in Gary, one in Plymouth, one in West Lafayette and one on a research development vehicle that was active across the state. Data is currently being sent to local servers from HAAS servers using API connections for different vehicles across five different organizations that are operating queue trucks, Hoosier Helper, and/or Crew Cabs. Telematics records are ingested every 2 seconds with information on the location and timestamp for a moving vehicle, whereas alerts are triggered when the strobe lights are turned on. Over 4.3 million records and more than 18 thousand alerts were ingested for 34 different vehicles as of June 23, 2021. Qualitative results observed from multiple case studies are promising, but there is a need for a much larger sample size to draw a valid statistical conclusion.

As of June 28, 2021, telematics from 15 Hoosier Helpers have been integrated into the HAAS Alert system and approximately 20 Hoosier Helpers will serve as a control group (without HAAS integration). Over the next year, the hard-braking events associated with the Hoosier Helpers will be evaluated and a technical report summarizing the marginal impact will be provided in 2022.

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1. MOTIVATION

Traditional methods for communicating the presence of maintenance activities and work zones have been done with a variety of fixed signs. Several examples of these are shown in Figure 1.1. In the case of emergency response, signs are often incorporated onto the vehicle as shown in Figure 1.2. In fact, short-duration or mobile maintenance activities are often the most challenging situations for managing risks and communicating to the motorists (Figure 1.3). Figure 2.1 shows examples of Indiana Department of Transportation (INDOT) vehicles assisting at an incident.

The increase of in-vehicle connectivity on our roads, either directly integrated into the vehicle or via an application running on a mobile phone, provides an opportunity to provide additional communication to motorists of the presence of emergency vehicles, maintenance activities or work zones. Although the exact form of the in-vehicle communication is evolving and will continue to do so, a critical first step is to leverage the extensive telematics currently deployed on the Indiana Department of Transportation Vehicles. The objective of this study was to conduct trial deployments on a variety of INDOT vehicles to begin a dialog with private sector partners on what information INDOT can share that will provide a safer roadway for all motorists, INDOT workers, and INDOT partners.

Figure 1.1 Warning signs in temporary traffic control zones.

Figure 1.2 Example of a Hoosier Helper with an integrated sign (callout i) and markings on the back.

(a) Collision with INDOT crew cab

(b) INDOT maintenance vehicle hit on I-70 in 2020

Figure 1.3 Examples of INDOT vehicles after collision.

2. INTRODUCTION

Making roadways safer for all motorists, INDOT workers and INDOT partners is of prime focus for the agency. In-vehicle digital communication alerts have been identified as an opportunity to improve communication to drivers of modern vehicles. This study has made efforts into evaluating the impact of such in-vehicle digital communication alerts.

Figure 2.1 shows the ITS Camera image from mile marker (MM) 45.6 on Interstate I-465 at 5:06 PM on Thursday, August 13, 2020. Callout i points to the incident location that had blocked the leftmost lane for the ambulance. Callout ii shows the Hoosier Helper and INDOT worker responding to the incident location. It can be observed that the approaching traffic had to slow down immediately in response to the present Hoosier Helper and move over to the right lane. Critical scenarios like this increase risks for the occurrence of secondary crashes and expose both INDOT workers and motorists to the hazards of inattentive motorists. Furthermore, a study conducted in 2014 has shown that the congested crash rates at the back of the queue on all Indiana interstates were found to be 24 times greater than the uncongested crash rate (Mekker et al., 2020).

The presence of in-vehicle communication alerts can alert drivers and draw their attention as they approach slow-moving traffic due to various reasons such as crash incidents or ongoing work zone activity.

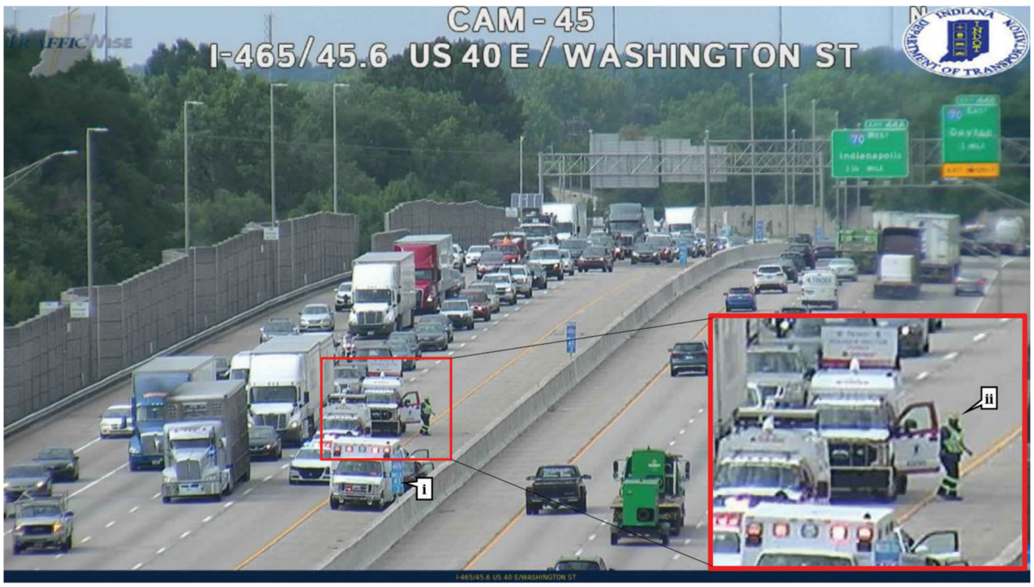


Figure 2.1 ITS Camera image on I-465 at MM 45.6 at 5:06 pm on Thursday, August 13, 2020.

3. IN-VEHICLE ALERTING CONCEPTS

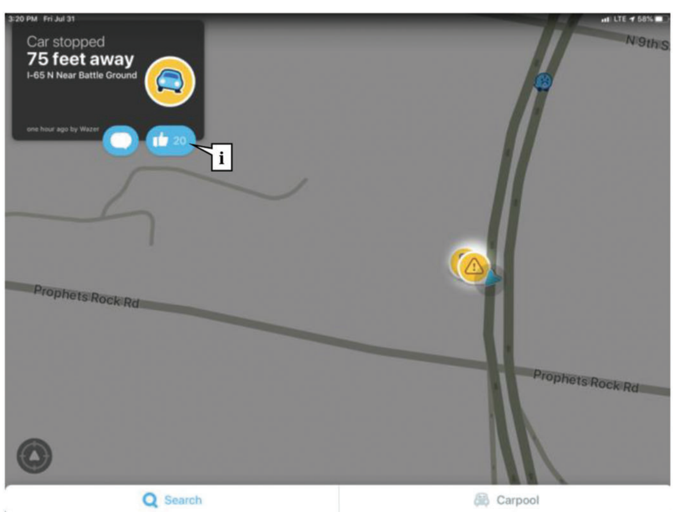
A vehicle installed with the onboard HAAS device has the capability of sending alerts to the HAAS server and then to the navigation applications such as Waze. The device is wired to the vehicle in such a way that the alerts are shown on Waze only when the vehicle turns on its strobe lights.

Figure 3.1a shows the crash scene mapping on I-65 in Tippecanoe County. Figure 3.1b shows the screen view on the Waze navigation application with an active alert during the crash scene mapping exercise conducted 2 days after the occurrence of the crash incident. Callout i shows that 20 motorists have acknowledged the alert that they had received in the form of "like" feature. The way alerts are shown to motorists is also a developing area. There is industry-wide dialog, much broader than this study, on the proper way to acknowledge or confirm incidents without creating an additional distraction.

The final form of connected vehicles will likely change considerably over the next few years as market forces determine what type of information is directly integrated into the vehicle and what information is integrated via cell phones. The following provide some framework for assessing this.

- Approximately 4.3% of vehicles on Indiana interstates in 2020 were fully connected to a connected vehicle provider (Hunter et al., 2021).
- Almost 100% of vehicles travel on our interstate have at least one cell phone in the vehicle.
- Although there is no published data, it is reasonable to assume somewhere around 20% of vehicles on Indiana roads are running some type of in-vehicle navigation

(a) Crash scene mapping on I-65 in Tippecanoe County



(b) Example of motorists acknowledging the alerts received on Waze navigation application

Figure 3.1 Crash scene mapping and Waze alert on I-65 in Tippecanoe County.

application, such as Waze, Apple, Google, Trimble, etc. (Trimble, 2020).

As an example, we now see that some vehicles provide posted speed limits directly on the dashboard (without the need for a mobile phone) and some apps such as Waze, Apple, and Google also display that information on their navigation screens. Figure 3.2 shows examples of vehicle dashboard screens with callout i pointing to the location of posted speed limits.

This example provides a vision of how the in-vehicle equipment is evolving but also suggests there is a significant void or opportunity for transportation agencies to partner with the connected vehicle sector to provide important information regarding maintenance activities and the presence of emergency vehicles on the roadway.

Figure 3.2 Vehicle dashboard screens showing posted speed limits (callout i).

4. PILOT DEPLOYMENT

Over the course of this study, the team performed pilot deployment of HAAS devices on various INDOT vehicles across the state. Figure 4.1 shows the deployment of the HAAS Alert device on a Hoosier Helper vehicle at the Indianapolis Traffic Management Center (TMC). Figure 4.1a shows the Hoosier Helper vehicle installed with the in-vehicle communication device from HAAS. Figure 4.1b shows the HAAS Alert device. Callout i points to the location where the device was installed on the vehicle.

In total, HAAS devices were installed on eight different INDOT vehicles. Figure 4.2 shows sample images from the installation of HAAS Alert devices on INDOT vehicles. Table 4.1 shows the summary of eight devices and installation details. The devices were deployed starting from May 14 through August 31, 2020. Three of the eight vehicles are operational in the Indianapolis area, two in Gary, one in Plymouth, one in West Lafayette and one on a research development vehicle active across the state.

(a) Hoosier Helper with installed HAAS Alert device at Indianapolis TMC

(b) HAAS Alert device

Figure 4.1 Example of deployment of HAAS Alert devices on INDOT vehicles.

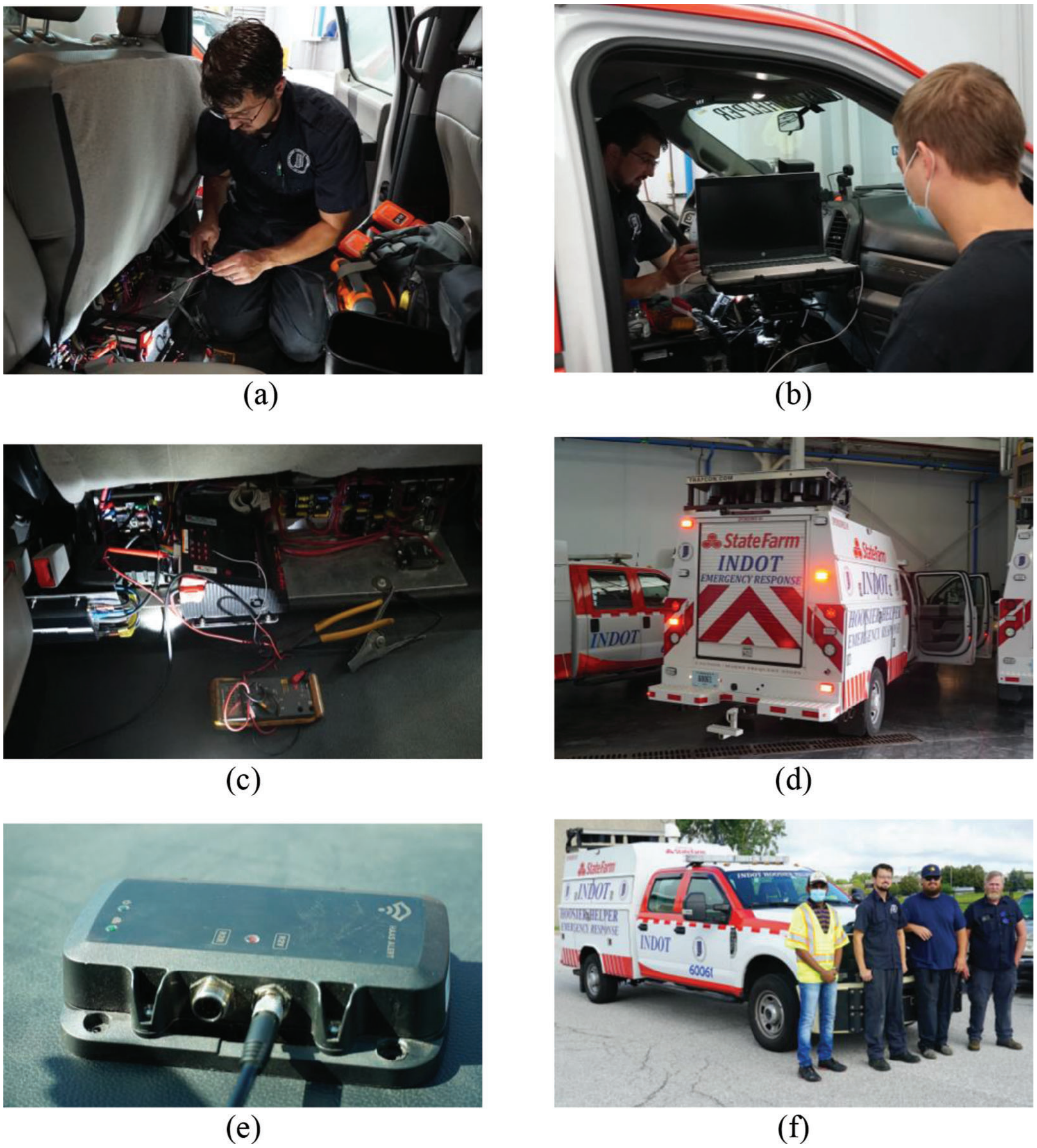


Figure 4.2 Images from coordination on installations of HAAS Alert devices.

TABLE 4.1
Summary of deployed HAAS Alert devices on INDOT vehicles

Sl. No.	HAAS Device ID	Vehicle	Deployment Location	Deployment Date
1	HA51AB945KW38XM	Hoosier Helper	Indianapolis	August 4, 2020
2	HA51AB945J6ALXR	Hoosier Helper	Gary	August 28, 2020
3	HA51AB945BUCHXL	Crew Cab	Indianapolis	August 5, 2020
4	HA51AB945JNKH9Y	Crew Cab	Gary	August 3, 2020
5	HA51AB945R72CNH	Crew Cab	Plymouth	July 21, 2020
6	HA51AB9454E7A63	Sweeper	Indianapolis	May 14, 2020
7	HA51AB945L7SDCU	Research and Development	Indiana	July 15, 2020
8	HA51AB945XLKEBY	Suburban	West Lafayette	August 31, 2020

5. DATA STRUCTURE AND INGESTION

Figure 5.1 shows the high-level network diagram of data transfers between the response vehicle on-site with the HAAS digital device and communication delivery to approaching motorists. Alerts from response vehicles such as queue trucks and Hoosier Helpers are fed into the cloud. These alerts are then pushed to navigation applications in real-time to alert motorists approaching these locations. The data transferred to the cloud can also be pulled into analytics dashboards and integrated with other traffic-related information such as queue progression and length. In addition, a feedback loop in terms of intelligent information can be provided to response vehicles such as queue trucks to assist in identifying deployment locations and strategies.

Data is currently being ingested to local servers from HAAS servers using API connections for 34 different vehicles across 5 different organizations. Table 5.1 shows the summary of data ingested as of June 23, 2021, at an organization level. Telematics records are ingested every 2 seconds with information of location and timestamp for a moving vehicle. Alerts are triggered when the strobe lights are turned on. Alerts are stored with information of start time when the strobe lights were turned on, end time when the strobe lights were turned off and location details.

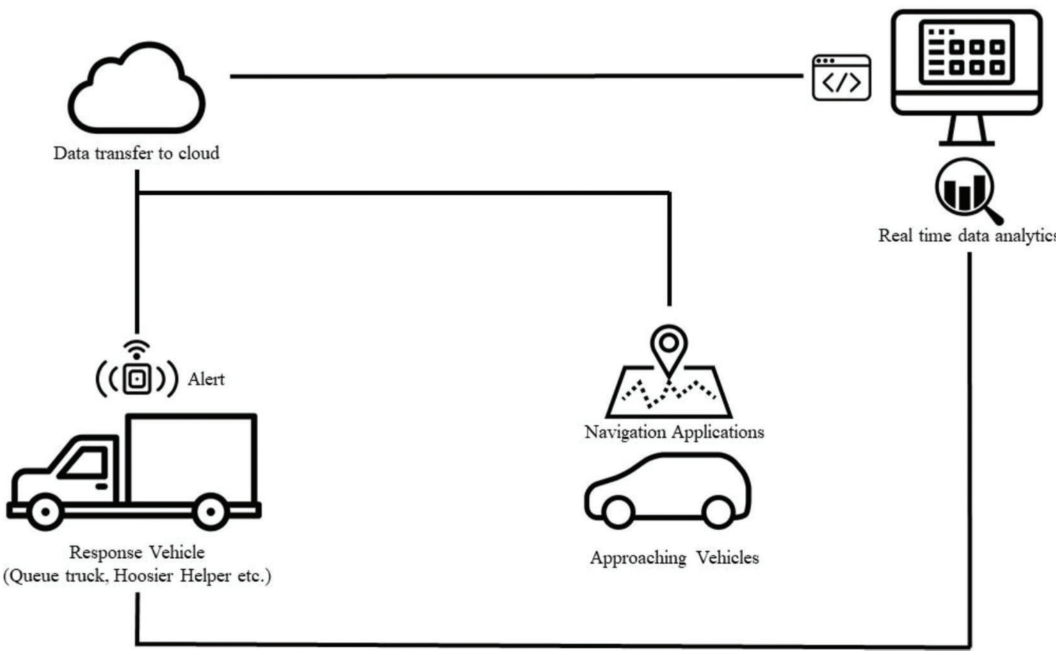


Figure 5.1 High-level network diagram of data transfers.

TABLE 5.1
Summary of data ingestion at an organization level

Sl. No.	Organization	Number of Vehicles with Onboard HAAS Alert Device	Total # Records	Total # Alerts
1	Indiana Department of Transportation (INDOT)	8	1,776,102	8,975
2	Lafayette Fire Department (LFD)	13	2,064,036	6,541
3	RoadSafe Traffic Systems (RST)	6	364,493	861
4	Traffic Control Specialists (TCS)	3	56,150	750
5	The Hoosier Company (THC)	4	92,734	1,282
	Total	*34*	*4,353,515*	*18,409*

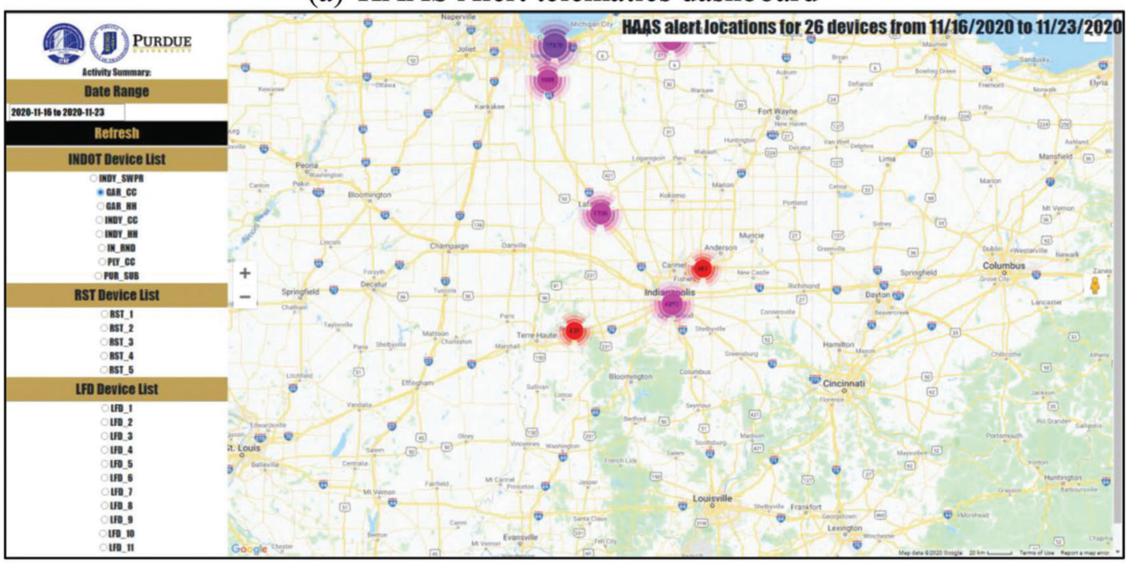
6. DASHBOARDS FOR ACTIVITY TRACKING

Table 6.1 shows the detailed number of telematics records and alerts gathered for each of the operational vehicles with HAAS devices by organization shown in Table 5.1. Dashboards were created for convenient visualization of this data. Figure 6.1 shows a snapshot of the telematics and map dashboard developed for activity tracking. Figure 6.1a shows the telematics dashboard that provides the information on the active hours with lights turned on, transporting hours or inactive hours for each vehicle by day. Figure 6.1b shows the map dashboard that highlights the location of the alerts from different vehicles.

TABLE 6.1
Summary of data ingestion by each HAAS ID

Sl. No.	Organization	HAAS ID	Type	Total No. of Records	Total No. of Alerts
1	INDOT	HA51AB9454E7A63	Emergency response	258,882	1,701
2		HA51AB945BUCHXL	Emergency response	95,127	913
3		HA51AB945J6ALXR	Emergency response	143,023	804
4		HA51AB945JNKH9Y	Emergency response	532,025	2,765
5		HA51AB945KW38XM	Emergency response	354,749	1,373
6		HA51AB945L7SDCU	Emergency response	54,600	72
7		HA51AB945R72CNH	Emergency response	219,349	1,308
8		HA51AB945XLKEBY	Emergency response	117,752	38
9	LFD	HA51AB013J8BNXV	Fire	1,254	12
10		HA51AB9456LS5XN	Fire	121,326	385
11		HA51AB945E49UHV	Fire	255,341	598
12		HA51AB945FP8SXN	Fire	151,979	911
13		HA51AB945JER2FX	Fire	133,598	210
14		HA51AB945JUXBEN	Fire	141,918	730
15		HA51AB945JVWA4H	Fire	162,989	630
16		HA51AB945PGYD6U	Fire	98,129	472
17		HA51AB945T4DE97	Fire	217,283	736
18		HA51AB945VSFC5M	Fire	252,388	926
19		HA51AB945W62AKR	Fire	337,518	126
20		HA51AB945X3PS85	Fire	40,508	291
21		HA51AB945X3PS85	Fire	149,443	514
22	RST	HA51AB0204JRBY7	Tow	13,941	53
23		HA51AB944SW7BRK	Emergency response	100,969	150
24		HA51AB9459PM8DH	Emergency response	86,386	249
25		HA51AB945HUV2XF	Emergency response	77,478	220
26		HA51AB9532JRSXG	Emergency response	31,763	95
27		HA51AB953E4HTJC	Emergency response	53,955	94
28	TCS	HA51AB014D4JH26	Emergency response	63	1
29		HA51AB0469C4AJY	Emergency response	26,764	179
30		HA51AB046DKUY54	Emergency response	29,319	570
31	THC	HA51AB0466RV3NH	Maintenance	9,597	211
32		HA51AB046C3BTRX	Maintenance	38,170	396
33		HA51AB046PRDGKN	Maintenance	11,310	168
34		HA51AB0476WPE3F	Maintenance	33,657	507

(a) HAAS Alert telematics dashboard



(b) HAAS Alert map dashboard

Figure 6.1 Telematics and map dashboards for activity tracking.

7. CONNECTED VEHICLE DATA CHARACTERIZING TRAFFIC STREAM

Trajectory data was made available by data providers that work directly with original equipment manufacturers (OEMs). The enhanced probe data from these connected passenger vehicles included an anonymized unique identifier with timestamp, geolocation, speed, heading and hard braking/acceleration as attributes. The provider of this data defines hard braking as any vehicle decelerations with a magnitude greater than 8.76 ft/s^2 (0.272 g). The reporting interval for the trajectory data is between 3–5 seconds (Saldivar-Carranza et al., 2021).

Figure 7.1 shows the time-space diagram of individual trajectories color-coded by speed bins also known as heatmaps for the section of I-65 from MM 165 to MM 185 on Thursday, May 27, 2021, for both directions of travel. The horizontal axis shows the time of the day whereas the vertical axis shows the mile marker. The hard-braking events are overlaid on top of the heatmap shown by red dots.

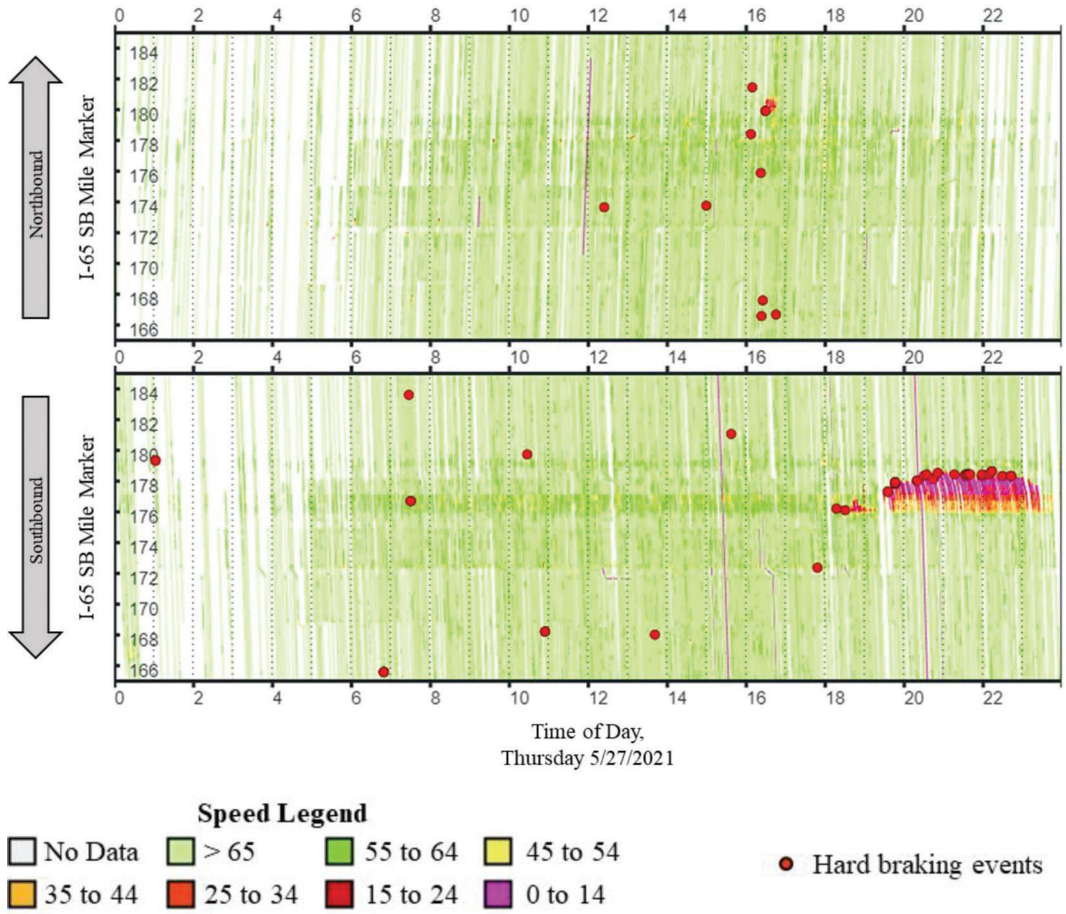


Figure 7.1 Heatmaps using trajectory data and overlaid with hard braking events (red dots).

8. INTEGRATION WITH HEATMAP TOOLS

Alerts received from the vehicles with HAAS devices are integrated with the existing heatmap tools. Figure 8.1 shows a snapshot of the heatmap tool which integrates the segment-based traffic data, trajectory-based traffic data, crash incidents, hard braking events, and HAAS Alerts in near real-time.

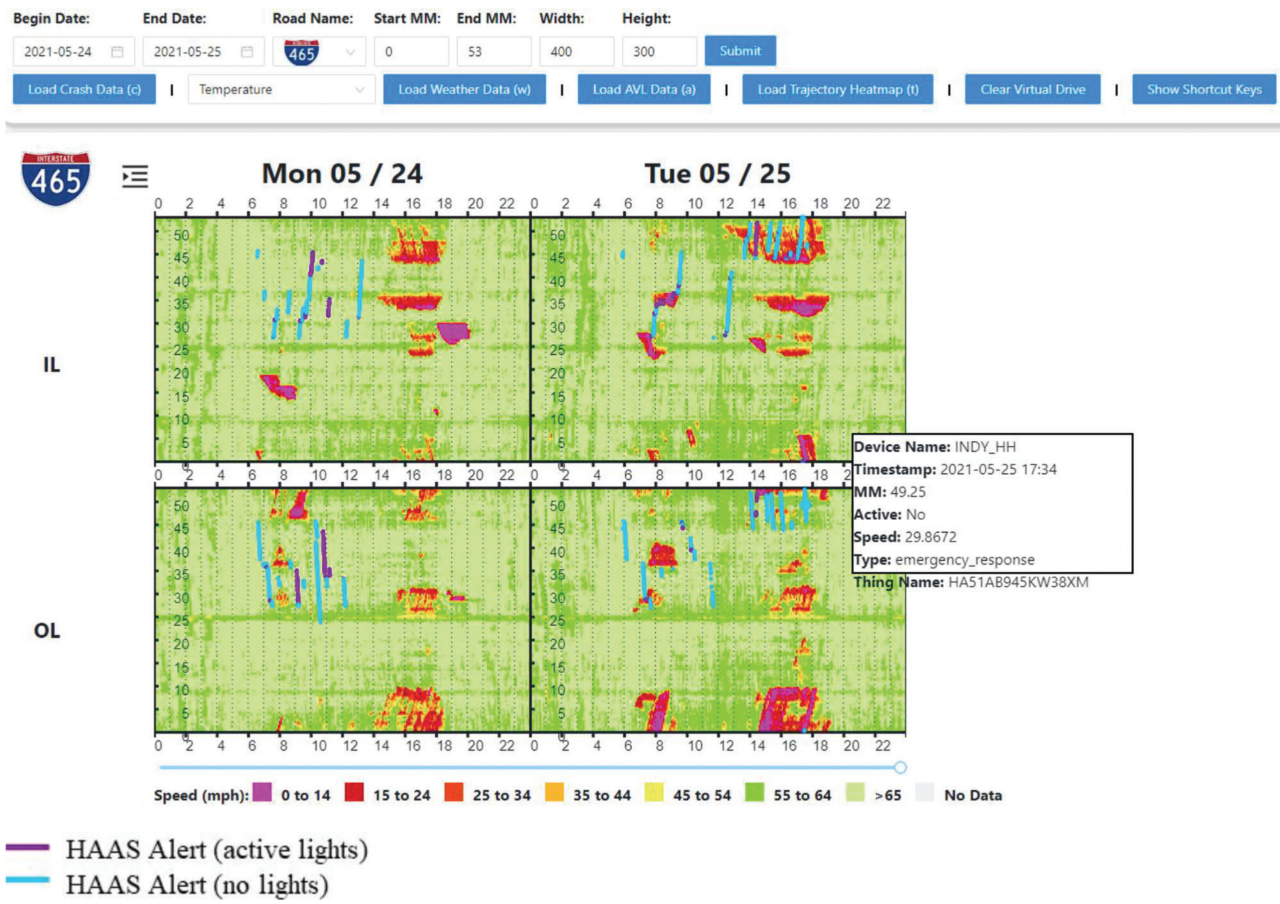


Figure 8.1 Integration of in-vehicle digital communication alerts with heatmap tools.

9. CASE STUDIES SHOWING IMPACT OF HAAS

9.1 Case Study on Interstate I-65

Figure 9.1a shows the heatmap for the stretch of I-65 from MM 165 to MM 185 in southbound direction on Thursday, May 27, 2021. A crash incident that occurred around 6 PM resulted in a queue for roughly 3 miles and lasting over 5 hours. Callout i points to the 29 hard braking events that occurred at the back of the queue caused by the incident. This incident was compared with similar traffic conditions on the previous day. Figure 9.1b shows I-65 from MM 135 to MM 155 in the same southbound direction of travel on Wednesday, May 26, 2021, during a similar time of the day. This congestion was due to the ongoing work zone activities around MM 144. In this case, a queue truck with an onboard HAAS Alert device was present as shown by the solid purple line. The queue truck was

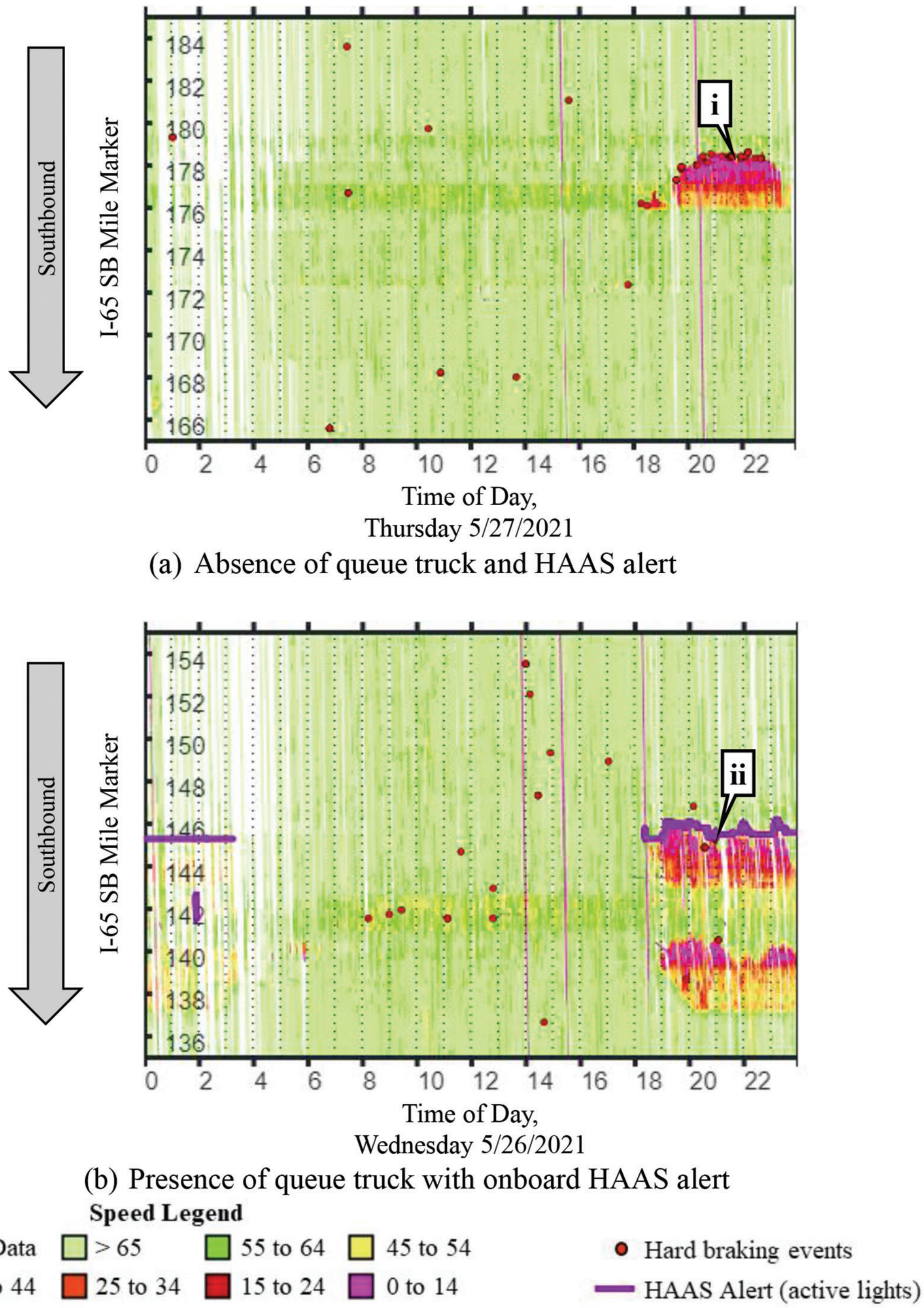
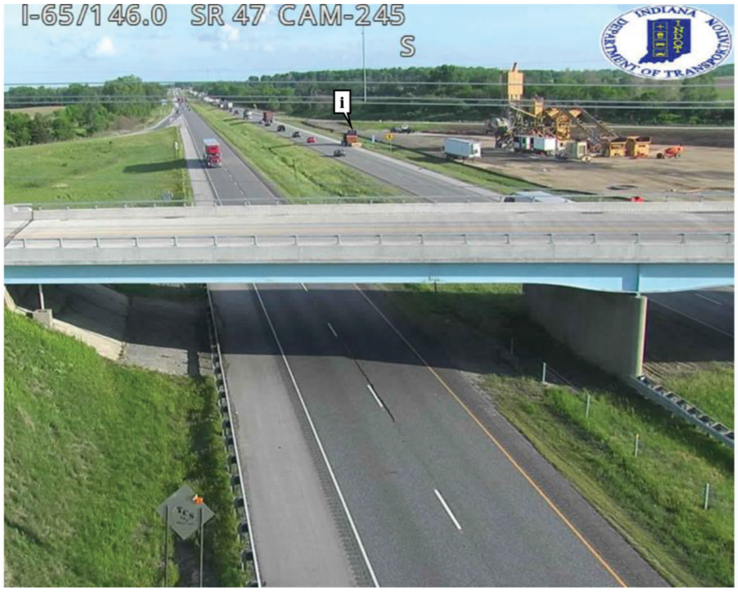


Figure 9.1 Comparison of hard braking events on I-65 southbound direction with and without the presence of queue truck with onboard HAAS Alert.



(a) ITS Camera image at MM 146 on I-65 at 7:27 PM on Wednesday, May 26, 2021

(b) Queue truck

Figure 9.2 Queue truck used to alert drivers.

alerting motorists visually as well through alerts sent through navigation applications used by drivers. Callout ii points to only three hard braking events that occurred during this congestion.

Figure 9.2a shows the ITS Camera image from MM 146 on I-65 at 7:27 PM on Wednesday, May 26, 2021. Callout i confirms the presence of the queue truck ahead of the work zone alerting the oncoming motorists. Figure 9.2b shows the example of a queue truck used to alert drivers.

The reduction in hard braking events was a combination of a queue truck visually alerting drivers and alerts sent on Waze. It is difficult to isolate the effect of each factor, however, this establishes a strong case for using on-vehicle digital communication to aide in reducing the number of hard braking events and improving the safety of motorists, INDOT workers, and INDOT partners.

9.2 Case Study on Interstate I-69

Figure 9.3 shows the heatmap for the work zone on I-69 in northbound direction for 9 days from Thursday, April 22 to Friday, April 30, 2021. Two queue trucks with onboard HAAS Alert devices were deployed in this work zone. Two queue trucks are often used in environments where there are rapidly developing queues and it is not feasible due to policy or road geometry to back up. The example in Figure 9.3 shows one such type of deployment with two queue trucks.

The heatmap is overlaid with the hard-braking events and crash incidents, as well as the HAAS activity. Callout i shows the active work zone for a

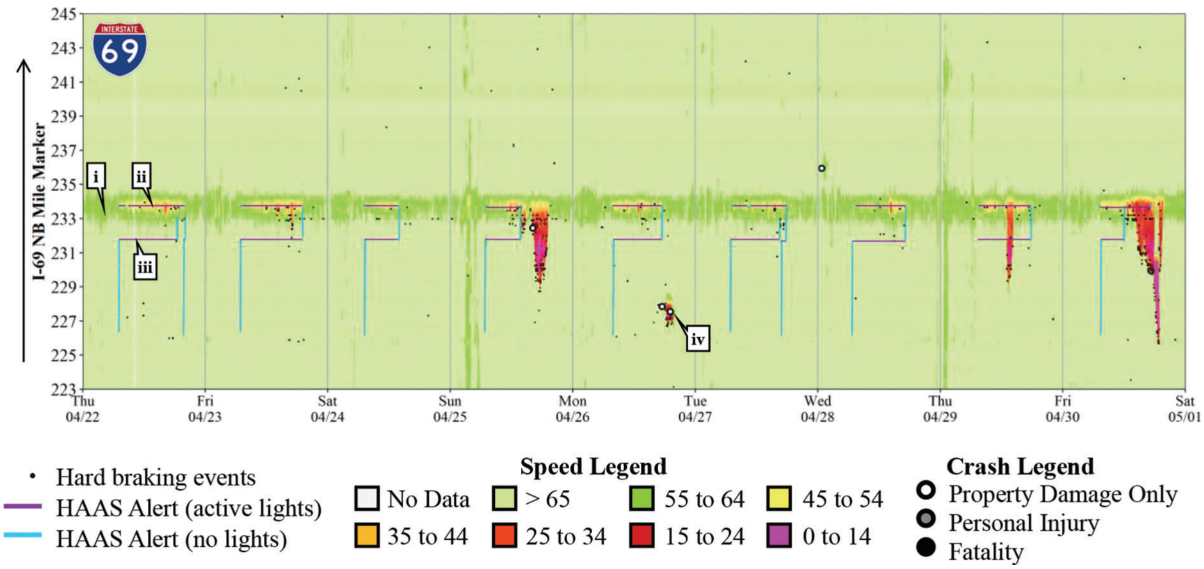


Figure 9.3 Work zone on I-69 with the presence of queue trucks with onboard HAAS devices.

2-mile section between approximately MM 233 to MM 235. Callout ii shows the location of the first queue truck present within the work zone. Callout iii shows the location of the second queue truck present ahead of the work zone. Both queue trucks were alerting the drivers visually, as well as through Waze. The purple line shows an active operation of the lights on the queue truck (alerts are sent) whereas the light blue line shows when the trucks were transporting to the location (no alerts are sent). Callout iv shows crash incidents that were not related to the work zone activity. Policies are still evolving on best practices for operating queue trucks and we expect graphics such as Figure 9.3 will be important tools for developing policies for best practices for operating two queue trucks.

Figure 9.4 shows a qualitative comparison between the number of hours when the queue trucks were alerting drivers with corresponding hard braking events and crash incidents. These are compared for 14 hours between 6 AM to 8 PM every day within the work zone and a 10-mile section ahead of the work zone. Callout i and ii shows days when queue trucks were active for less than 7 hours resulted in an increase of hard braking events and crash incidents, compared to other days with higher queue truck activity. Callout iii shows two crash incidents on Monday, 26 April. These incidents were independent of the work zone operations and occurred more than 5 miles ahead of the work zone location as shown by callout iv on Figure 9.3.

Table 9.1 shows the summary of queue truck activity along with the total number of hard braking events and crash incidents over 9 days for the work zone on I-69. On Sunday, April 25, the first and second queue truck were sending alerts only for 6.77 and 6.8 hours respectively between 6 AM to 8 PM. The lack of active queue trucks might have been plausible cause of the crash incident that occurred at the start of the work zone and 196 hard braking events. The two crash incidents on Monday were not related to the work zone operations as shown by callout iv on Figure 9.3. On Friday, April 30, the first queue truck within the work zone was alerting for 9.84 hours but the second queue truck ahead of the work zone was alerting for only 4.43 hours of the total of 14 hours. The lack of alerts might have been again the plausible cause of the increase in the number of hard braking events to 218 as the motorists were entering the work zone without the active alerts. This also makes a case in support for the presence of queue trucks ahead of the work zone compared to the presence of queue trucks within the work zone.

These qualitative results are promising but there is a need for a much larger sample size to draw a valid statistical conclusion.

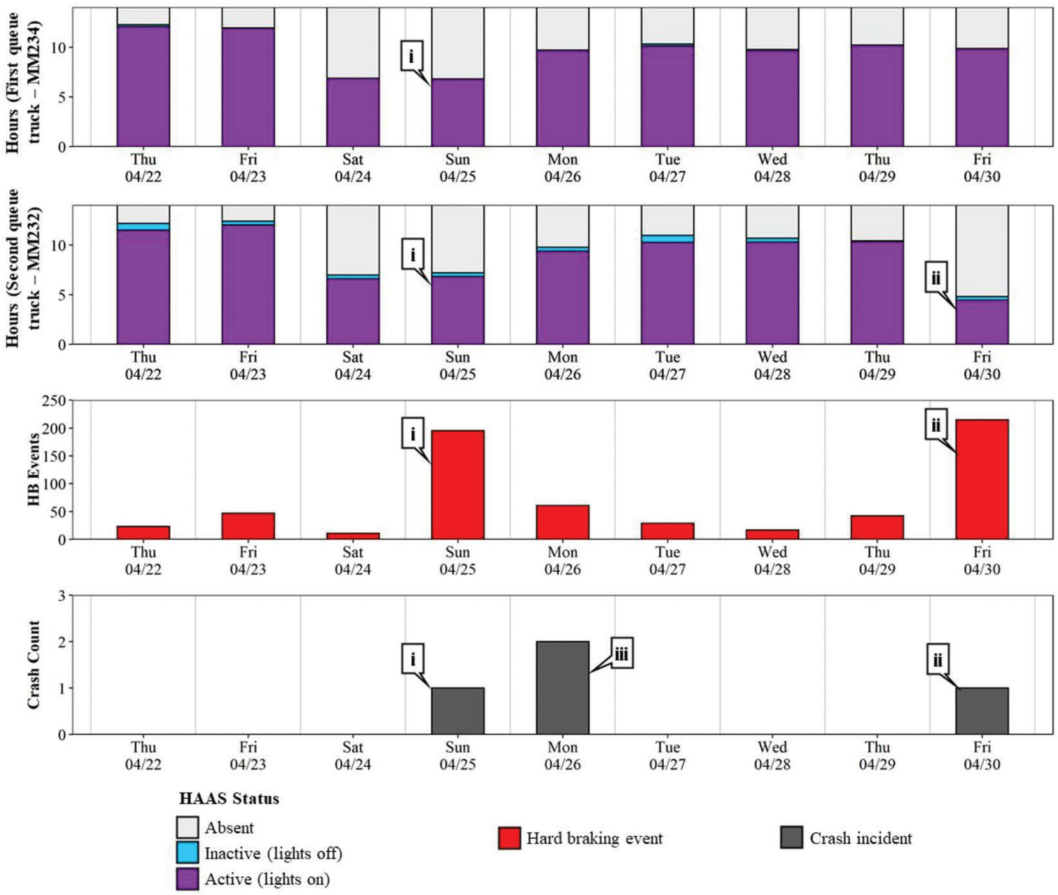


Figure 9.4 Impact of queue trucks on hard braking events and crash incidents.

TABLE 9.1
Summary statistics for the impact of queue trucks on hard braking events and crash incidents

	First Queue Truck Inside the Work Zone			Second Queue Truck Ahead of the Work Zone				
Date	No. of Hours Active (lights on)	No. of Hours Inactive (lights off)	No. of Hours Absent	No. of Hours Active (lights on)	No. of Hours Inactive (lights off)	No. of Hours Absent	Total Number of HB Events	Total Number of Crashes
4/22/2021 Thursday	12.08	0.2	1.72	11.48	0.7	1.82	24	–
4/23/2021 Friday	11.92	0.02	2.06	12.02	0.37	1.61	49	–
4/24/2021 Saturday	6.83	0.05	7.12	6.57	0.42	7.01	13	–
4/25/2021 Sunday	6.77	0.03	7.2	6.82	0.38	6.8	196	1
4/26/2021 Monday	9.67	0.02	4.31	9.38	0.38	4.24	65	2
4/27/2021 Tuesday	10.13	0.2	3.67	10.25	0.7	3.05	31	–
4/28/2021 Wednesday	9.67	0.1	4.23	10.28	0.38	3.34	20	–
4/29/2021 Thursday	10.18	0.05	3.77	10.32	0.08	3.6	48	–
4/30/2021 Friday	9.84	0.02	4.14	4.43	0.38	9.19	218	1

10. IMPLEMENTATION OF HOOSIER HELPER DATA THROUGH HAAS ALERTS

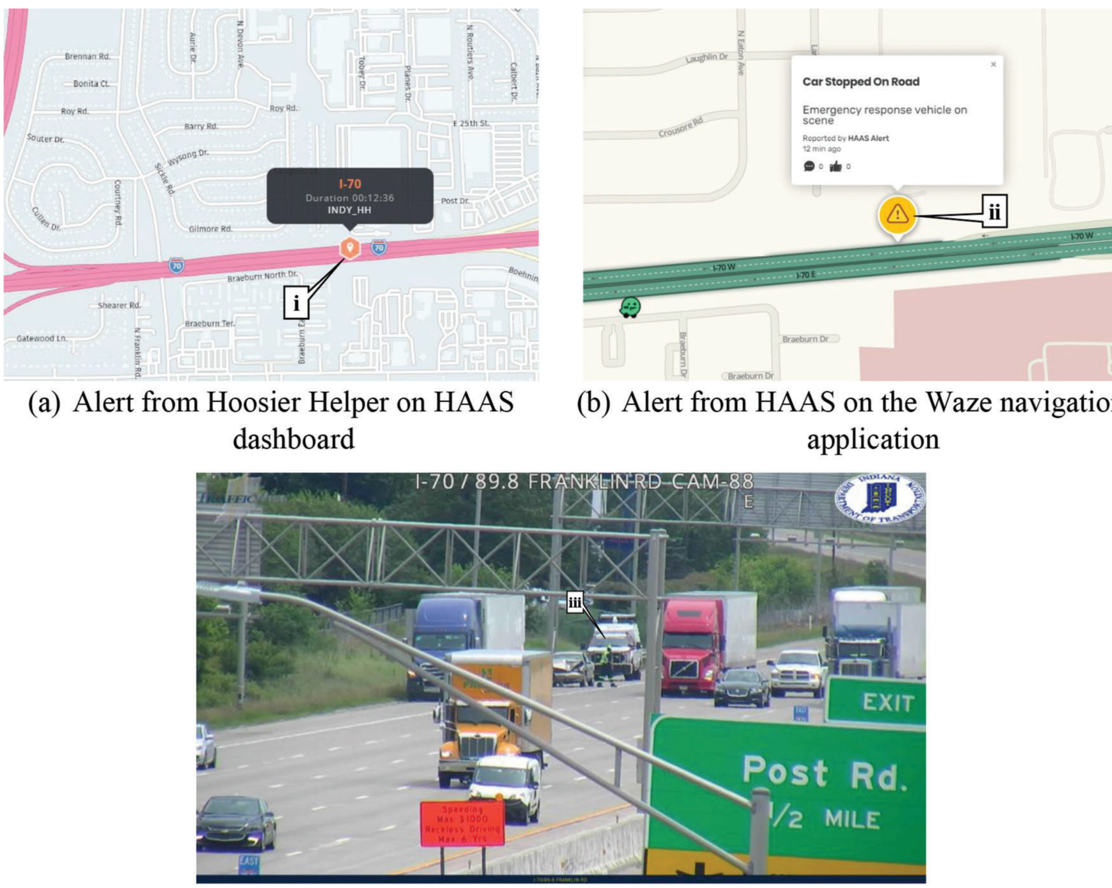
As shown in Figure 9.1 and Figure 9.3, early results of the HAAS Alerts show considerable promise, but there is a need to have much larger data to conduct a valid statistical analysis.

One opportunity to increase the sample size over a diverse set of conditions is to deploy the alerting on additional Hoosier Helper vehicles. The research team has coordinated with the INDOT TMC to use existing Hoosier Helper telematics to push alerts to HAAS servers every 30 seconds. Alerts are created when the speed is slower than 2 mph and the location of the Hoosier Helper is within proximity of 0.1 miles of the Indiana interstate.

Figure 10.1 shows an example of an alert created from Hoosier Helper on I-70 on Thursday, June 24, 2021. Figure 10.1a shows the alert on the HAAS dashboard from the Hoosier Helper. Callout i shows the location of the alert on the interstate. Figure 10.1b shows the alert the motorists would see on the Waze navigation application. Callout ii shows the location of the alert on the interstate. Figure 10.1c shows the ITS Camera image from MM 89.8 on I-70 at 12:57 PM on Thursday, June 24, 2021. Callout iii shows the INDOT worker and Hoosier Helper responding at the incident scene.

Figure 10.2 and Figure 10.3 also show similar examples of alerts pushed to the HAAS server and then to the Waze navigation application on Thursday, June 24, 2021, along I-465 and I-90 respectively.

As of June 28, 2021, telematics from 15 Hoosier Helpers have been integrated into the HAAS Alert system and approximately 20 Hoosier Helpers will serve as a control group (without HAAS integration).

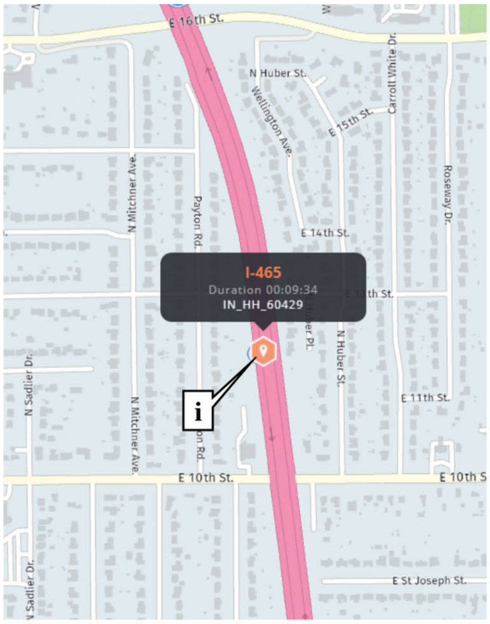


(a) Alert from Hoosier Helper on HAAS dashboard

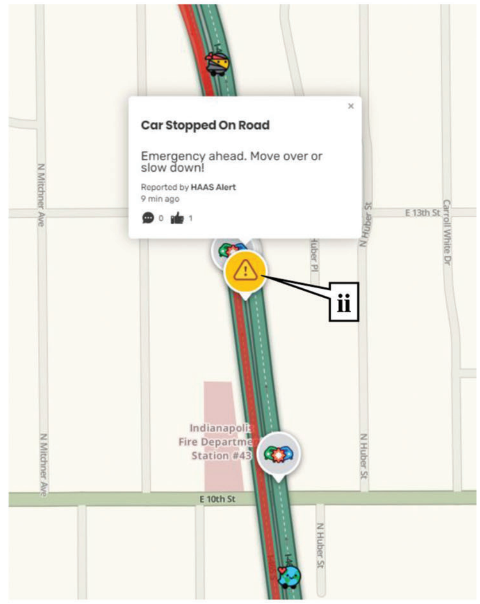
(b) Alert from HAAS on the Waze navigation application

(c) ITS Camera image from MM 89.8 on I-70 at 12:57, Thursday, June 24, 2021

Figure 10.1 Hoosier Helper alert on I-70 on Thursday, June 24, 2021.



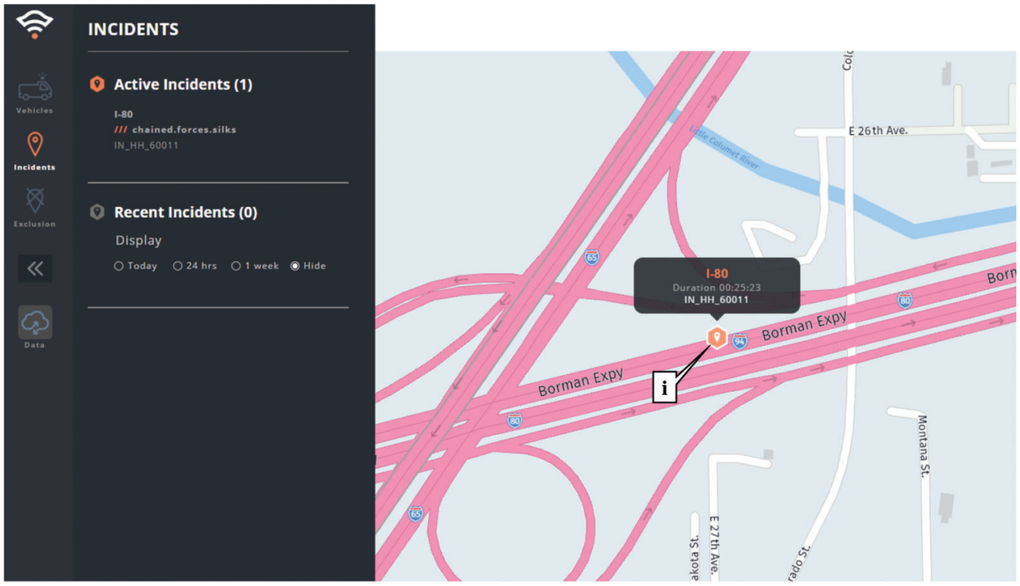
(a) Alert from Hoosier Helper on HAAS dashboard



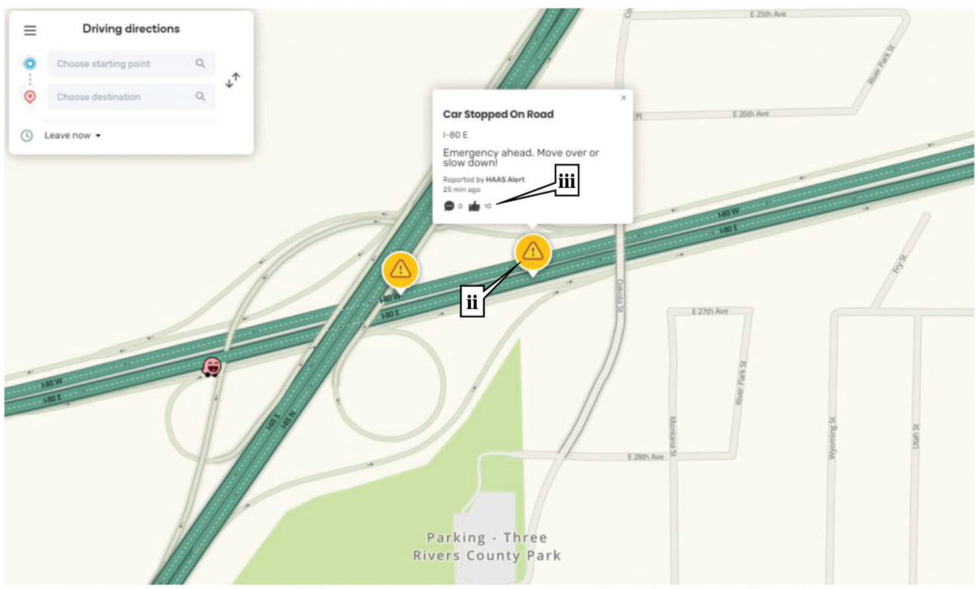
(b) Alert from HAAS on the Waze navigation application

(c) ITS Camera image from MM 44.4 on I-465 at 12:15, Thursday, June 24, 2021

Figure 10.2 Hoosier Helper alert on I-465 on Thursday, June 24, 2021.



(a) Hoosier Helper alert ingested to HAAS dashboard



(b) Alert to drivers on the Waze navigation application

Figure 10.3 Hoosier Helper alert on I-90 on Thursday, June 24, 2021.

11. SUMMARY OF EMERGING RESULTS AND RECOMMENDATIONS

The final form of connected vehicles will likely change considerably over the next few years as market forces determine what type of information is directly integrated into the vehicle and what information is integrated via cell phones.

- Figure 3.2 clearly indicates that in-vehicle notification will be complementing roadside signs moving forward.
- Figure 3.1 shows an example of how Waze alerts can be triggered by public safety vehicles in 2020 and Figure 10.1 shows similar integration with Hoosier Helper vehicles in June 2021.
- The companion Figure 10.2 and Figure 10.3 shows that Waze users are already actively using and acknowledging these alerts. The alert acknowledgments provide good evidence of the alert impact, but we will need to work collectively with the navigation and automotive OEMs to ensure that we are not introducing distractions that negatively impact safety.
- The reduction in hard braking events associated with queue trucks equipped with HAAS Alerts on I-65 is shown in Figure 9.1b compared to Figure 9.1a with no queue trucks or HAAS Alerts. Although it is not clear how much of this reduction is due to the visibility of the

truck compared to the Haas Alert, the reduction of hard braking (and hence crash risk) has been well received. Similar results have also been observed on I-69 (Figure 9.4).

- The 2021 integration of 15 Hoosier Helpers into the HAAS Alert system, with 20 vehicles remaining as a control group will provide an opportunity to estimate the marginal impact of the HAAS Alert.

Over the next year, the hard-braking events associated with the Hoosier Helpers will be evaluated and a technical memory summarizing the marginal impact will be provided in 2022.

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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.

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