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Quantifying the Impact of In-Cab Alerts on Truck Speed Reductions in Ohio

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Abstract

In-cab alerts warn commercial vehicle drivers of upcoming roadway incidents, slowdowns and work zone construction activities. This paper reports on a study evaluating the driver response to in-cab alerts in Ohio. Driver response was evaluated by measuring the statistical trends of vehicle speeds after the in-cab alerts were received. Vehicle speeds pre and post in-cab alert were collected over a 47 day period in the fall of 2023 for trucks traveling on interstate roadways in Ohio. Results show that approximately 22% of drivers receiving Dangerous Slowdown alerts had reduced their speeds by at least 5 mph 30 seconds after receiving such an alert. Segmenting this analysis by speed found that of vehicles traveling at or above 70 mph at the time of alerting, 26% reduced speeds by at least 5 mph. These speed reductions suggest drivers taking actional measures after receiving alerts. Future studies will involve further analysis on the impact of the types of alerts shown, roadway characteristics and overall traffic conditions on truck speeds passing through work zones.

Keywords

In-Cab Alerts, Connected Truck Data, Driver Alerts, Dangerous Slowdowns

1. Background

Enhancing commercial truck safety continues to be an important goal for both federal and state agencies in the United States. According to the Federal Highway Administration (FHWA), in 2022, large commercial trucks (single unit and combination trucks) traveled more than 320 billion vehicle miles (VMT), which is a little more than 10% of all VMT [1] and according to the Federal Motor Carrier Safety Administration (FMCSA), nearly 13% of all roadway fatalities that occurred in 2021 involved a commercial truck [2]. Additional statistics show that in 2021, there were nearly 494,000 crashes involving large commercial trucks out of which 5149 (roughly 1%) were fatal and around 22% resulted in an injury [3]. The FMCSA also highlights speeding of any kind and distraction/inattention as the two prominent factors contributing to about 7% and 5%, respectively, of all large truck fatalities in 2021 [2]. Careless driving and following improperly also accounted for a total of 6.5%. Speeding or driving too fast was also found to be one of the most common causes of truck rollover accidents [4] [5]. Further investigations have also led to human-related factors as the most prominent causes of truck accidents [6] [7] [8] and hence, mitigation strategies on improving situational awareness could play a huge role in enhancing truck safety.

Several mitigation measures have been adopted to improve truck safety in the areas of roadway infrastructure (such as surface treatments and addition of ramps/lanes), communication infrastructure (rumble strips, static/dynamic warning signs and messages) and compliance with safety rules (regular inspection and hours of service regulation for drivers). With the proliferation of connected vehicle (CV) technology, one area that could benefit from additional enhancement is communication and incident warnings. Providing advance notifications and in-cab warnings to trucks ahead of incidents such as work zones, slowdowns, congestion, high rollover and high wind zones, and other safety hazards could significantly improve the situational awareness of the drivers.

In 2023, Ohio Department of Transportation (DOT) implemented a contract with a commercial alerts provider to deliver in-cab safety alerts and advisories to commercial trucks on Ohio highways. Alerts for dangerous slowdowns, congestion ahead, rollover zones, high wind zones as well as a variety of other configurable alerts are directly sent over cellular network to the driver's smartphone running a dedicated app or the electronic logging device (ELD) in the truck, thus alleviating the need for any extra in-cab retrofits. In addition to broadcasting the alerts, the provider also collects information on how the drivers react to these alerts. Although several mitigation measures have been implemented in the past and numerous before/after studies have been conducted to assess the overall effectiveness of these mitigation strategies, understanding their impact on driver behavior has always been difficult. With this additional information on driver reaction, it is now possible to quantify the potential impact of these in-cab alerts on the resulting driver behavior. This study provides an overall assessment of two alert types—dangerous slowdowns and congestion—on truck speeds and the resulting driver behavior after receiving these alerts.

2. Literature Review

A variety of safety treatments and strategies have been adopted by state DOTs to reduce the number and severity of commercial motor vehicles crashes [9]. Roadway infrastructure improvements include high-friction treatments, cross-slope breaks, escape ramps, climbing and passing lanes, and exclusive truck roadways.

Communication infrastructure improvements include static/dynamic warning signs and signals, pavement markings and incident warnings including queue detection at work zones and low visibility and/or high wind warnings. Studies have shown that these communication improvements have a significant impact on enhancing commercial truck safety [10]-[16]. However, deploying warning systems and dynamic message signs throughout the highway network is both expensive and challenging.

Recent advancements in CV technology now provide an opportunity to detect incidents and deliver digital alerts and advisories to navigation apps and in-cab entertainment systems or logging devices. Studies have found that a relatively low market penetration of CVs, around 3% - 6%, is sufficient for the accurate and reliable estimation of queue length [17]. The results also showed that CV data allowed for faster detection of bottlenecks and queue formation. Several studies have also shown the applicability of CV data for queue detections and incident management [18] [19] [20]. A CV data-driven analysis from May-July 2021 in Indiana found that a combination of queue warning trucks and digital alerts to Waze reduced hard-braking events by 80% ahead of impending queues at work zones [21]. The Pennsylvania Turnpike equipped more than 150 maintenance and service patrol vehicles with the ability to broadcast emergency alerts and found that roadside crashes reduced from thirty in 2018 to zero in 2020 [22]. FHWA's Next Generation Traffic Incident Management (TIM) under Every Day Counts (EDC-6) initiative also highlights the importance of digital alerts and responder-to-vehicle (R2V) alerts for active responders in the vicinity and for back-of-queue warning [23] as a new potential implementation option for improving TIM strategies [24].

Few studies have assessed the impact of in-cab alerts and messages on improving truck safety. A simulator study conducted as a part of the Wyoming DOT CV Pilot Program on sending advanced weather event and work zone notifications to commercial trucks found that the CV notifications have promising safety benefits in improving driver behavior and response times [25] [26]. The study also highlighted that the display of multiple work zone warnings may have introduced little to moderate distraction for some participants. Another driving simulator study aligned with this Pilot Program found that CV notifications enhance situational awareness of truck drivers and drivers adapt their driving behavior based on these notifications [27].

The Kentucky Transportation Center (KTC) partnered with the Kentucky Transportation Cabinet (KYTC) and a private vendor to demonstrate a proof of concept for the delivery of timely in-cab alerts to warn CMV drivers of approaching roadway hazards [28]. A survey conducted by the team showed that alerts on work zones and traffic congestion were the most preferred alerts among CMV drivers. Other alerts of particular interest included real-time incidents and CMV parking. Virginia DOT and the Virginia Transportation Research Council (VTRC) is currently having a research project in progress to evaluate this technology and to understand how drivers react to these alerts [29].

3. Study Scope and Objectives

The objective of this study is to understand the impact of two alerts—dangerous slowdowns and congestion—on Ohio highways (**Figure 1**). This study evaluated the driver response to in-cab alerts by measuring the statistical trends of vehicle speeds after the in-cab alerts were received.

Study Location

Figure 1 shows an overview of the study location—nominally the interstate system in Ohio comprising of 8 primary and 14 auxiliary routes spanning a total of nearly 3,400 directional centerline miles of roadway. Five major primary interstate routes in the state—I-70, I-71, I-75, I-77 and I-90 have been denoted by their shields for additional context.

4. In-Cab Alerts Data

Data from commercial vehicles receiving in-cab alerts was obtained from a third party in-cab alerts provider. Waypoint information for each commercial vehicle receiving an alert was available at nominally 1-second frequency with speed,

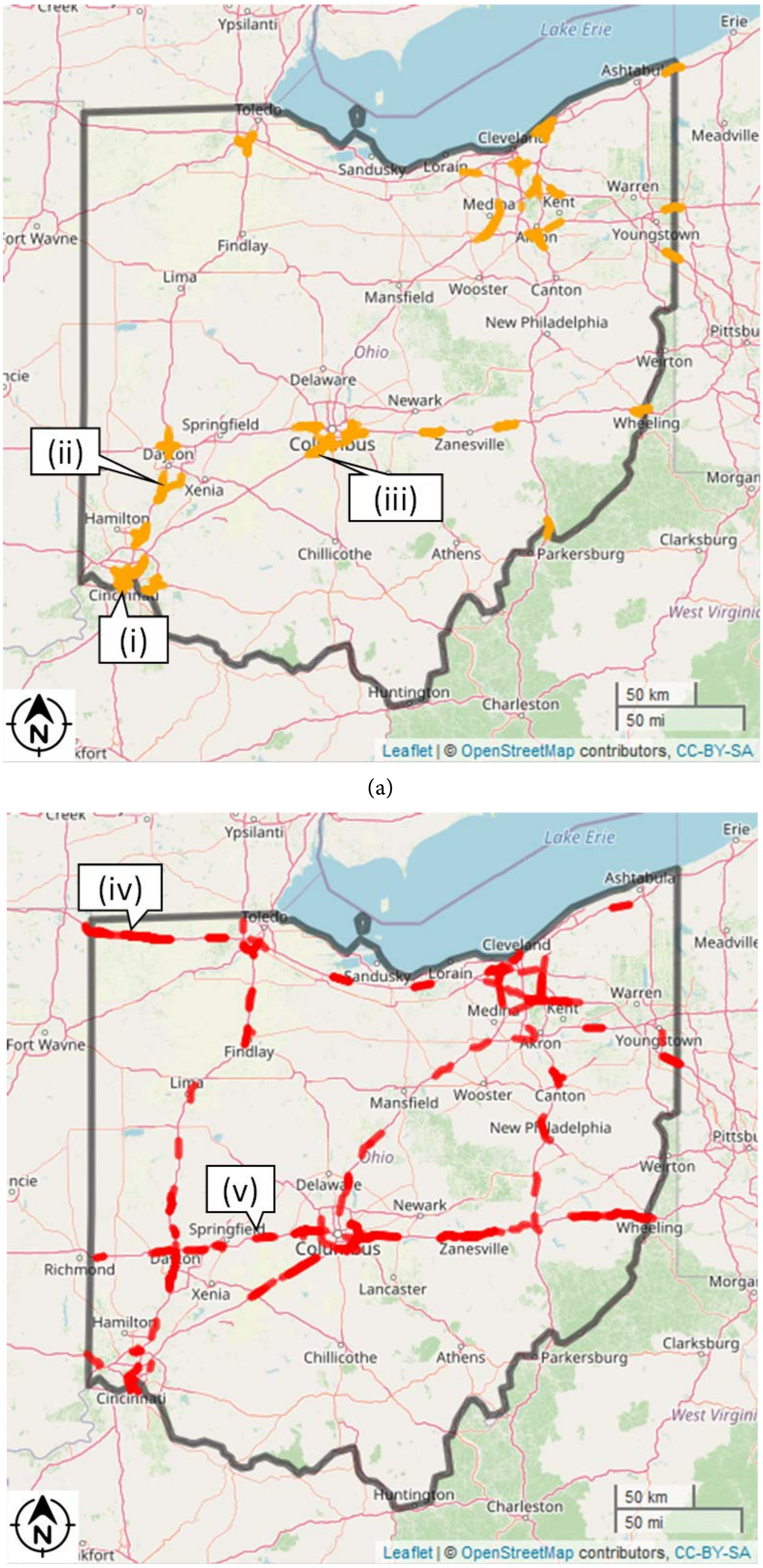
Figure 1. Study location.

bearing, geolocation, and acceleration attributes along with the timestamp at which it received an alert. Generally, data was observed to have been recorded from 60 seconds preceding an alert to nearly 5 minutes after receiving an alert providing a good cross-section of commercial vehicle driver reaction before and after an alert was received. Each such instance of a commercial vehicle receiving an alert is referred to as a "visit" henceforth.

The dataset contained 3089 unique visits spanning from September 28 through November 13, 2023, with 2449 visits corresponding to Congestion alerts and the remaining 640 corresponding to Dangerous Slowdown alerts. These visits together accounted for a total of nearly 850,000 commercial vehicle waypoints over the six-week study period. These alerts are delivered to commercial vehicles through their electronic logging devices (ELD's) or a companion mobile app, without the need for any additional equipment in the cab, and are driven by a third-party connected vehicle data provider that identifies congestion and dangerous slowdown incidents on U.S. roadways in near real-time. Congestion is an alert that represents an abnormal queuing of traffic that is different than historical patterns. Dangerous/Sudden Slow Down is an alert when the real-time speeds from a road segment and the up-stream segment have a greater than 35 mph difference. This segment based approach for identifying sudden changes in speed was first proposed by Li *et al.* in 2019 [30]. Locations where rapidly forming congestion creates an unexpected slowdown raise the risk of a back of queue collision. Recent research with high resolution trajectories and other alerting techniques have demonstrated that hard-braking events in these areas can be reduced by up to 80% [21].

4.1. Alert Locations

Figure 2 shows a spatial representation of every commercial vehicle waypoint recorded during the study period on Ohio's Interstate system. In-cab alerts data were categorized into individual visits as stated earlier – with each visit representing a commercial vehicle receiving an in-cab alert at a particular location. The set of waypoints representing each visit have been visualized in **Figure 2**. **Figure 2(a)** clearly shows that congestion alerts were heavily concentrated in the urban centers of the state including Cincinnati, Cleveland, Columbus, Dayton and Toledo, being indicative of recurring congestion incidents resulting from commuter traffic during the morning and evening travel peaks. Dangerous Slowdown alert locations in **Figure 2(b)** on the other hand were observed to be more spatially spread out with quite a few occurrences in the rural interstate sections of Ohio, being indicative of non-recurring instances of slowdowns on interstate roadways. The top three locations in terms of visit count for Congestion alerts were I-75 near Cincinnati (callout i), I-75 near Dayton (callout ii) and I-71 near Columbus (callout iii), all urban sections of interstate. Conversely, the top locations for Dangerous Slowdown alerts were both directions of travel of the western end of the I-80 turnpike from I-280 (callout iv) to the Indiana-Ohio



(a)

(b)

Figure 2. Recorded geolocations of in-cab alerts. (a) Congestion alerts; (b) Dangerous slowdown alerts.

border and westbound I-70 from Columbus to the Indiana-Ohio border (callout v), relatively rural sections of interstate roadway.

4.2. Reporting Frequency

At the individual visit level, 84% of all waypoints were observed to be under a 2-second reporting frequency (callout i), with 95% of waypoints being at or under 2-seconds (callout ii) and 99% of all waypoints being at or under a 6-second reporting frequency (callout iii) as demonstrated by the cumulative distribution plot of reporting frequencies in Figure 3.

4.3. Using Speed as a Surrogate for Evaluating Driver Reaction to Alerts

This high frequency recording fidelity provides an opportunity to perform a detailed analysis of driver reactions on receiving an in-cab alert as well as the computation of instantaneous acceleration to identify instances of hard-braking or hard-acceleration. Prior studies have shown strong correlation between instantaneous connected vehicle hard-braking events and crash incidents on interstate construction work zones as well as upstream of signalized intersections, thus demonstrating potential for use of commercial vehicle hard-braking events flagged by OEM-determined braking thresholds as a surrogate safety indicator [31] [32]. However, access to 1 - 2 second frequency trajectory data such as that

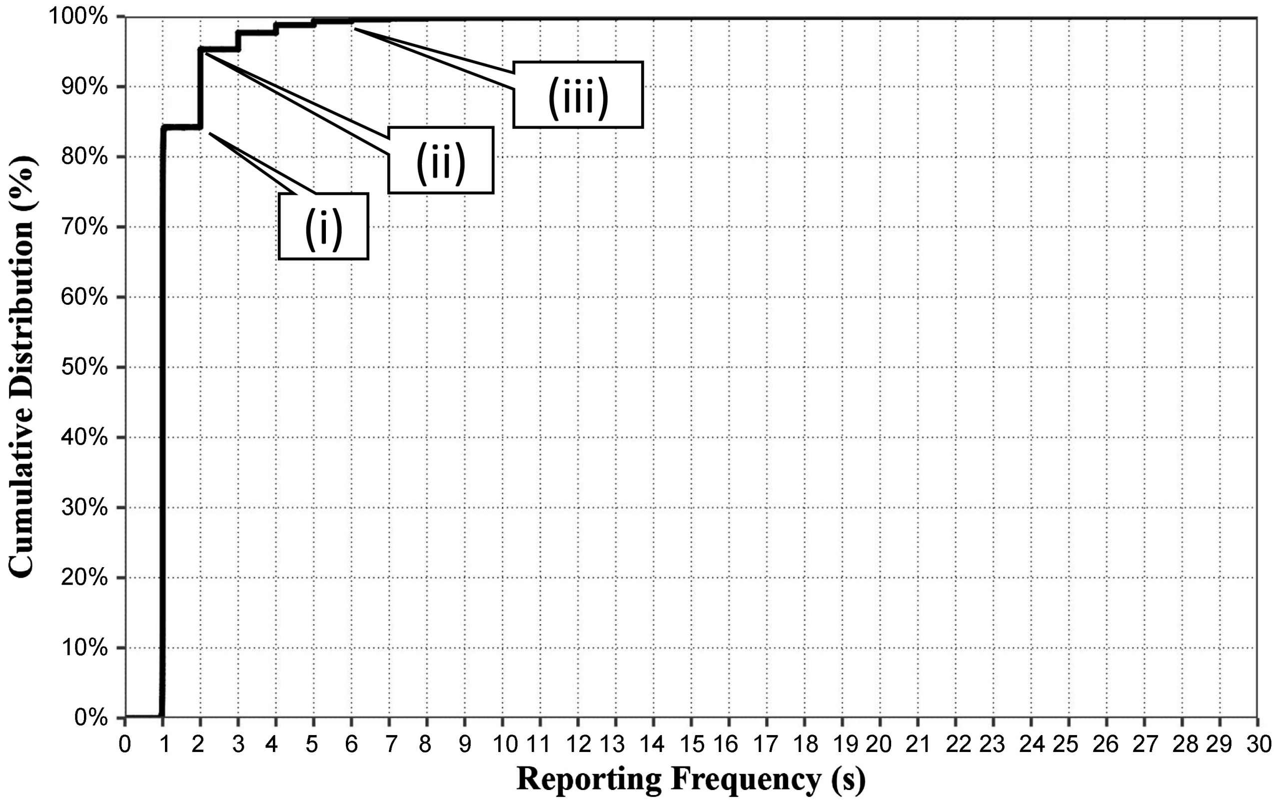


Figure 3. Reporting frequency of connected truck waypoint data that received in-cab alerts.

utilized by this study will allow stakeholders to set their own deceleration event thresholds for flagging safety concerns.

5. Methodology

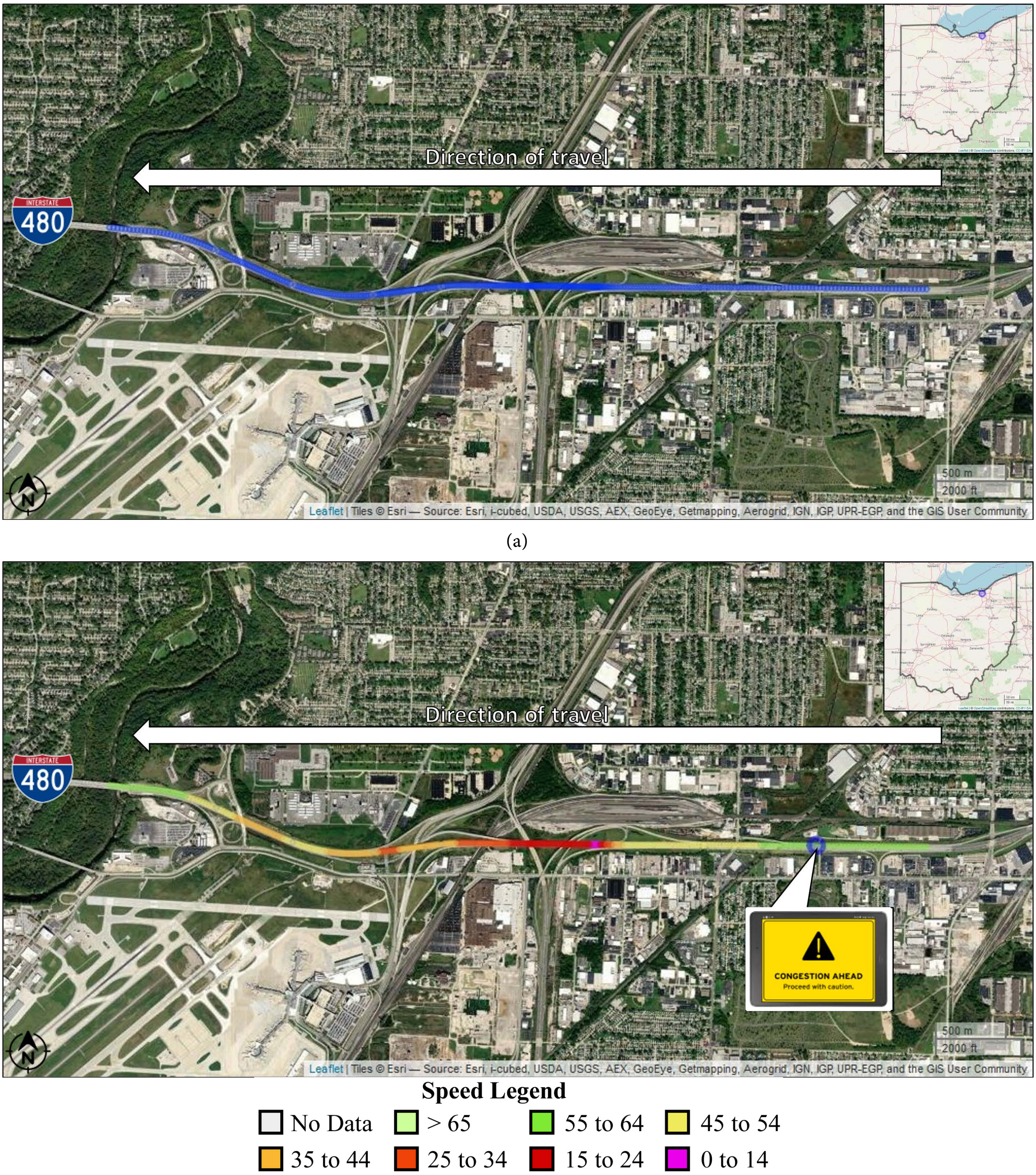
In order to ensure the analysis of each visit always had a reference speed record for the time at which an alert was received, each visit was assigned a "speed_at_alert" value based on the timestamp at which the alert was received. However, out of a total 3089 visits, only 2949 visits had speeds recorded exactly at the time of alerting possibly due to gaps in data reporting. For the sections that follow in the interest of consistency, the study has focused only on these 2949 visits (approximately 95% of total available visits) and their associated 806,000 waypoints. 80% of these visits corresponded to a Congestion alert while the remaining 20% were associated with Dangerous Slowdown alerts.

For each truck waypoint recorded in a visit, a change in speed (referred to as delta speed from here on) was computed from the "speed_at_alert" and a time gap was computed to temporally reference each waypoint with respect to the time at which the truck received an alert. This methodology is well illustrated by the visualizations of a sample visit's timeline in **Figure 4**. For a visit receiving the Congestion alert on I-480 in the westbound direction near Cleveland area, **Figure 4(a)** shows a map of the waypoints recorded for this visit as well as the direction of travel. Similarly, **Figure 4(b)** shows a color-coded version of this map where each waypoint is colorized by the recorded speed, as well as a blue hollow circle indicating the location at which the truck received the Congestion alert.

A speed profile plot of this sample visit is depicted by the longitudinal scatter chart in **Figure 5**. The horizontal axis represents time from alert starting 30 seconds prior (T-30) and ending at 5 minutes after (T+300) the receipt of alert. The vertical axis represents the recorded speed (in miles per hour) of the commercial vehicle at each recorded waypoint during this time period. Callout i refers to the assumed time of alerting – as reported by the data provider (T = 0 seconds), callout ii represents the start of the braking window at 58 seconds and callout iii represents the end of the 17-second braking window at 75 seconds. This overall visual helps demonstrate driver reaction to receiving an alert – first the vehicle was operating at free flow speeds, then after receiving the alert the driver slowly reduced the speeds before safely entering the congested part of the roadway from about T+75 to T+270 and finally recovered to free flow speeds at about five minutes after the alert when the truck would have most likely passed the zone of congestion.

6. Results

As demonstrated by the speed profile in **Figure 5**, similar profiles for each truck visit were generated, and by pivoting the analysis off the timestamp at which each such alert was received, observations can be made on speed reductions with reference to time of alert receipt. A control band of −5 mph to +5 mph of speed



(a)

(b)

Figure 4. Sample visit timeline. (a) Recorded geolocations for Westbound Truck; (b) Geolocations colorized by speed of westbound truck trajectory with location of "congestion ahead" alert.

changes was established to account for minor brake pedal taps and outliers in recorded data as well as to discern significant speed reductions, an indicator for driver reaction to alert. **Figure 6(a)** and **Figure 6(b)** show a second-by-second

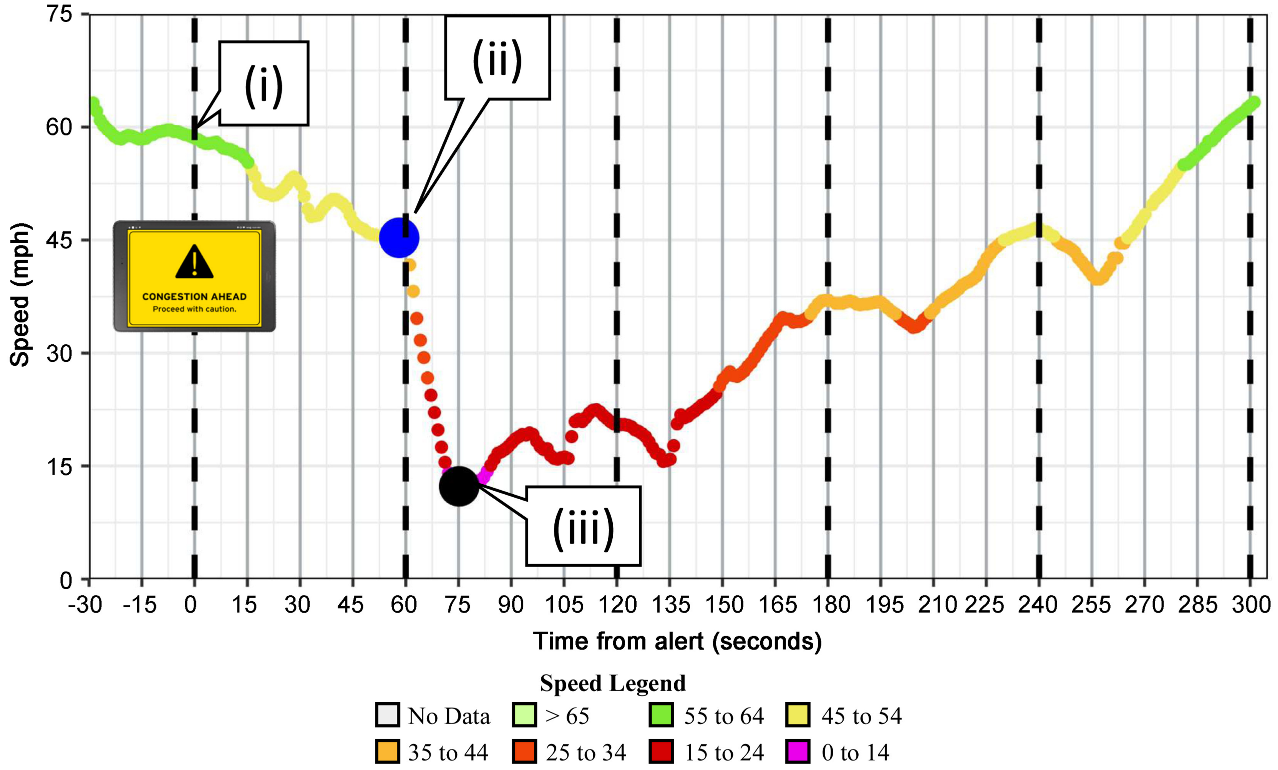


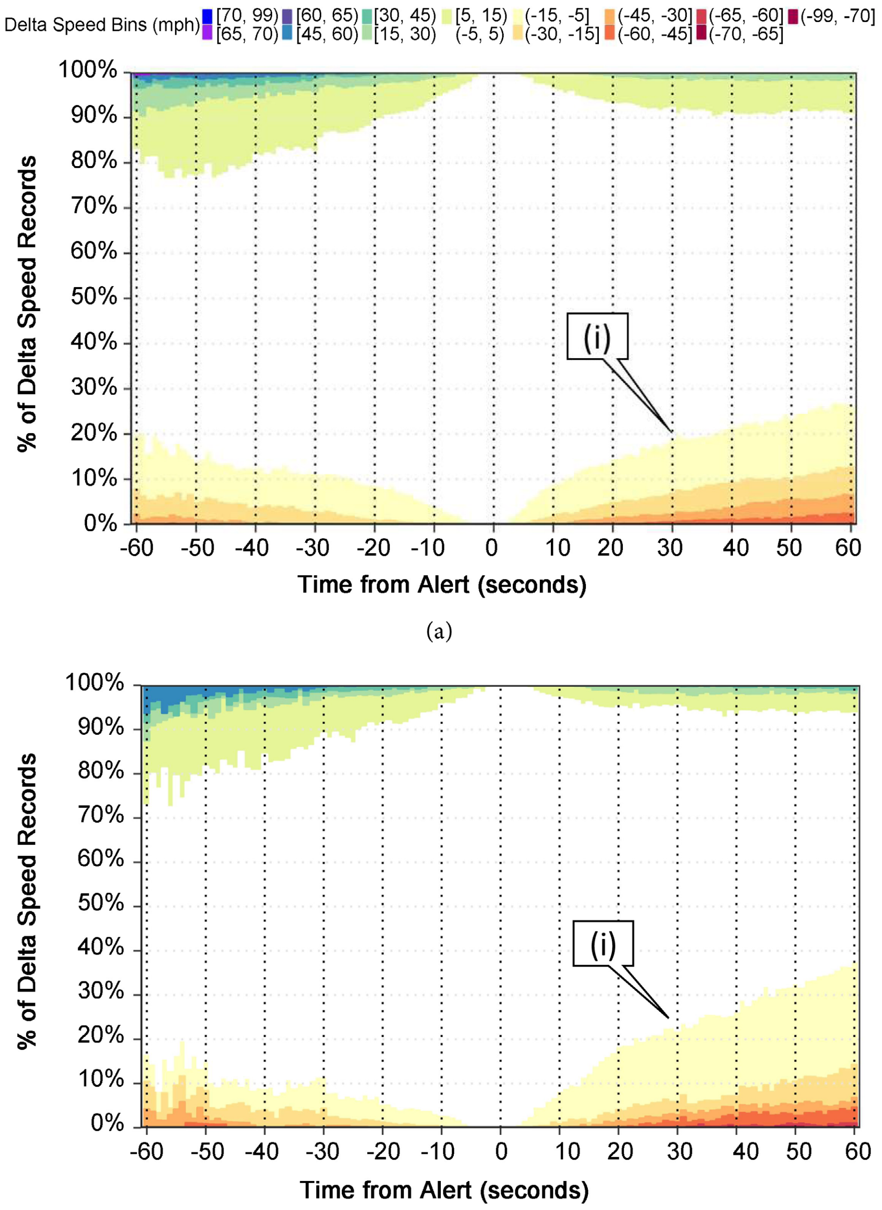
Figure 5. Speed profile of sample visit.

summary visualization of observed cumulative speed reductions for each alert type up to 60 seconds after an alert was received. A central white band corresponds to the control delta speed threshold of −5 mph to +5 mph.

Over 19% of visits receiving Congestion alerts and nearly 22% of visits receiving Dangerous Slowdown alerts had reduced speeds by 5 mph or more 30 seconds after alert. General trends also show that in case of both alert types, the proportion of speed reductions of at least 5 mph are far more after the alert than the proportion of speed increases illustrating the significant traffic calming potential of this technology.

An overall summary of cumulative speed reductions observed among the 2949 visits half a minute after receiving an alert is shown in **Table 1**. With a very low speed reduction threshold of 0.01 mph, dangerous slowdown alerts show 62.7% of visits reducing their speeds while congestion alerts show 56% of visits complying. As speed reduction thresholds increase to 5 mph, near 20% compliance is observed for both alert types.

Further segmented analyses were performed by categorizing visits by the speed at which the commercial vehicle was traveling at the time it received an in-cab alert. A cumulative frequency distribution plot of change in speed half a minute after receiving an alert for visits segmented by their speed at the time of alert (from ≥45 mph to ≥70 mph) are shown in **Figure 7**. Callout i points to nearly 26% of visits having reduced their speeds by at least 5 mph 30 seconds after alert that were traveling at or above 70 mph at time of alert. This indicates



(a)

(b)

Figure 6. Observed speed reductions by type of alert. (a) Congestion alerts (2350 unique visits); (b) Dangerous slowdown alerts (599 unique visits).

the significant potential of this emerging technology in bringing down speeds in advance of slowdowns and congestion incidents potentially saving lives by reducing the risk of secondary or back-of-queue crashes. Such performance measures are especially vital to monitor the effectiveness of this technology when used for sending advance warnings of construction work zones hoping to slow down free flow traffic to within work zone speed limits.

7. Conclusions

This research uses in-cab alerts data to study the impact of Congestion and

Table 1. Cumulative speed reductions 30 seconds after alert.

Cumulative Speed Reduction of at least x mph 30 seconds after alert	% of visits showing corresponding cumulative speed reductions 30 seconds after alert	
	Congestion Alerts	Dangerous Slowdown Alerts
0.01	56.0	62.7
0.50	48.0	53.3
1.00	40.8	47.3
2.00	32.9	37.7
3.00	27.3	31.8
4.00	22.7	27.0
5.00	19.1	21.9

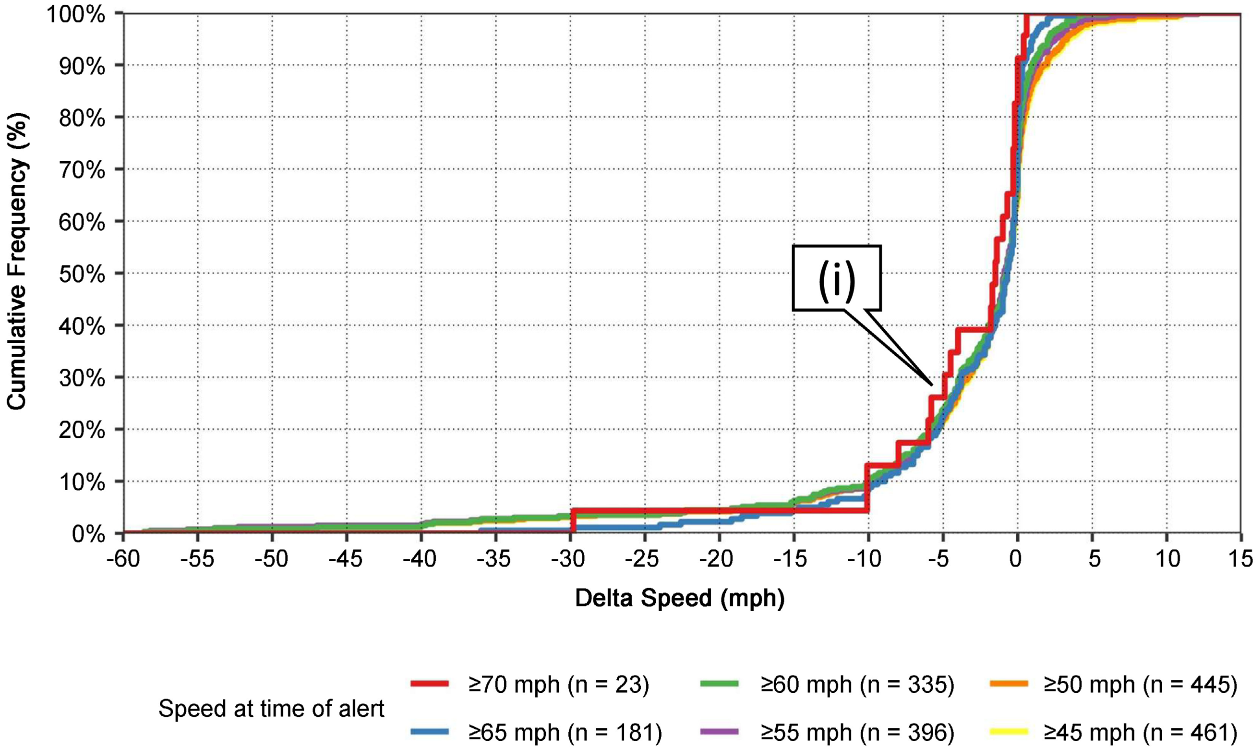


Figure 7. Cumulative speed reductions 30 seconds after alert compared to speed at time of alert for Dangerous Slowdown alerts.

Dangerous Slowdown alerts on driver reaction over a six-week period on the interstate system in Ohio. The change in truck speed after a driver received the alert, was used as a surrogate for characterizing driver response to alerts.

Nearly 3000 instances of trucks receiving alerts and over 800,000 truck waypoints and speeds were analyzed as part of this study (**Figure 2**). A methodology was first presented to prepare a consistent dataset that could be pivoted off of the time at which a truck received an alert to analyze impacts on driver behavior before and after an alert.

Results showed nearly 1 in 5 truck visits had reduced their speeds by at least 5 mph 30 seconds after receiving a Congestion or Dangerous Slowdown alert. Further analysis on speed reductions with respect to speed at time of alerting showed that nearly one in four truck visits traveling at or above 70 mph at time of alerting had reduced their speeds by at least 5 mph 30 seconds after the Dangerous Slowdown alert (**Figure 7**). Finally, at very low speed reduction thresholds, the study found that more than half of the trucks receiving either type of alert had lowered their speeds 30 seconds after alert. These encouraging results point to the potential significance of this emerging in-cab alerts technology at improving highway safety by promoting safe driving behavior and increasing driver awareness while providing a first-of-its-kind look at quantifying driver reaction by speeds recorded directly onboard vehicles receiving these alerts.

Overall, Dangerous Slowdown alerts seemed to show higher percentage of trucks reducing their speeds compared to Congestion alerts (**Table 1**), thus indicating a potential impact of the type of alert shown on driver reaction. Future studies in this space will incorporate a multitude of datasets including different roadway characteristics, overall traffic speeds, types of alerts, prevailing weather conditions, time of day among others to conduct in-depth investigations into the various factors that may influence driver reactions to in-cab alerts. However, the results presented by this first study will be an important first step in demonstrating the significant potential of this technology to agencies as well as commercial vehicle stakeholders.

Due to limitations on real-time traffic data availability for this study period, the in-cab alerts data was the only source of measuring driver reaction for this study. Future studies will use real-time traffic data to validate congestion and slowdown incidents, and also provide additional context on the spatial and temporal extent of incidents to accurately determine driver reaction from the moment of alerting to when the truck first reaches the incident location. This will help agencies determine ideal advance warning distances and times for effecting the desired driver reaction.

While the focus of this pilot study was exclusively on driver reaction to receiving in-cab alerts, future studies by this team will use widely available data from passenger cars as well as commercial vehicles to demonstrate the trickle down impacts that a portion of commercial vehicles receiving in-cab alerts could have on calming overall traffic speeds on roadways. Additionally, spatial and temporal analysis of advance warning distance and time for sending these alerts will help provide important feedback to state departments of transportation as well as private sector stakeholders looking to accelerate the widespread implementation of this technology to improve highway safety and promote safe driving behavior by increasing driver awareness.

In addition to the two alert types focused on in this study—Congestion and Dangerous Slowdown, alerts providers have the ability to transmit multiple types of messages including warnings on service vehicles, active work zones, road closures, public service advisories, steep grades, brake check areas, high rollover zones, low bridges, rest areas, inclement weather as well as speed advisories. Targeted alerts in regions of planned short-term or long-term construction have the potential to warn commercial vehicles well in advance of their approaching the work site thus helping reduce the risk of hard-braking and thus contributing to safe driving practices. The authors hope that this study and its results will present the impetus and motivation for agencies around the nation to implement and accelerate in-cab alerting deployments towards achieving the overarching goal of improving safety for all road users.

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Conflicts of Interest

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

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