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Evaluation of A Truck In-Cab Alert System

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The results suggest that in-cab alerts from an evaluated system reach 6–12% of commercial vehicles across Virginia's interstate corridors, with congestion alerts typically notifying 2–7 trucks per event while dangerous slowdown (DSD) alerts notify 1–2 trucks. Analysis of vehicle trajectories shows that over 91% of trucks maintain their initial speed in the first 10 seconds after receiving an alert, with speed reductions becoming more pronounced over time. Speed response varies significantly based on initial conditions, with trucks traveling at lower initial speeds (50–55 mph) more frequently reducing their speed compared to those at higher speeds. While this behavior suggests a greater likelihood of speed reduction in denser traffic conditions, it is unclear whether this is directly due to the alert itself or influenced by prevailing traffic speeds.

Large carriers report successful integration of in-cab alerts with other safety technologies, though the system's greatest potential may lie in reaching smaller carriers without advanced driver assistance systems. With eleven state agencies now using the system and showing positive results despite modest penetration rates, VDOT should continue providing these alerts while exploring partnerships with other states to reduce costs. Economic analysis indicates the program costs would be justified by preventing just one injury crash every 17 months.

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FINAL REPORT

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ABSTRACT

Transportation agencies have long communicated directly with truck drivers regarding weigh station compliance and parking availability, sometimes making use of applications provided by private third-party partners. One of these applications has expanded capabilities that allow agencies to transmit safety alerts directly to drivers through the in-cab electronic logging device systems. In December 2022, VDOT partnered with one of these providers to issue emergency weather-related restrictions and congestion alerts directly to drivers via push notifications directly on the in-cab electronic logging devices (ELDs) or smartphone devices running the in-cab alert app. This project studied the characteristics of the in-cab alerts in terms of coverage and scope, estimated market penetration, and observable effects on driver behavior from GPS traces.

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FINAL REPORT

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INTRODUCTION

In December 2022, VDOT began paying for the ability to push congestion, dangerous slowdown (DSD), and custom weather/incident alerts to trucks via the in-cab alert system Drivewyze, an intelligent transportation systems application used by truck drivers to interface with weigh station bypassing systems. The Drivewyze application uses cellular networks to transmit congestion alerts, height and route restrictions, and work zone reminders to drivers through an app on drivers' smartphones or via in-cab electronic logging devices (ELDs). Congestion, DSD, and custom alerts are only displayed if VDOT continues to pay the provider for the service. These alerts are provided to system subscribers alongside other free alerts such as steep grades and low bridges, as well as alerts available through the $5 per driver per month Safety+ service such as speed enforcement areas and severe weather. Given that there are approximately 3,000 tractor trailer crashes on Virginia roadway network each year, leveraging such in-cab alerts could play a critical role in enhancing truck safety statewide.

Under the current contract, VDOT pays $228,453 for 12 months of service, with annual renewals. Drivewyze provides other alerts such as bridge height warnings and rollover alerts regardless of VDOT's contract, as these rely on third party data. The system coverage area includes all of Virginia, and several weigh stations currently use the technology. Figure 1 shows a map of the Drivewyze weigh station bypass locations within and surrounding Virginia.

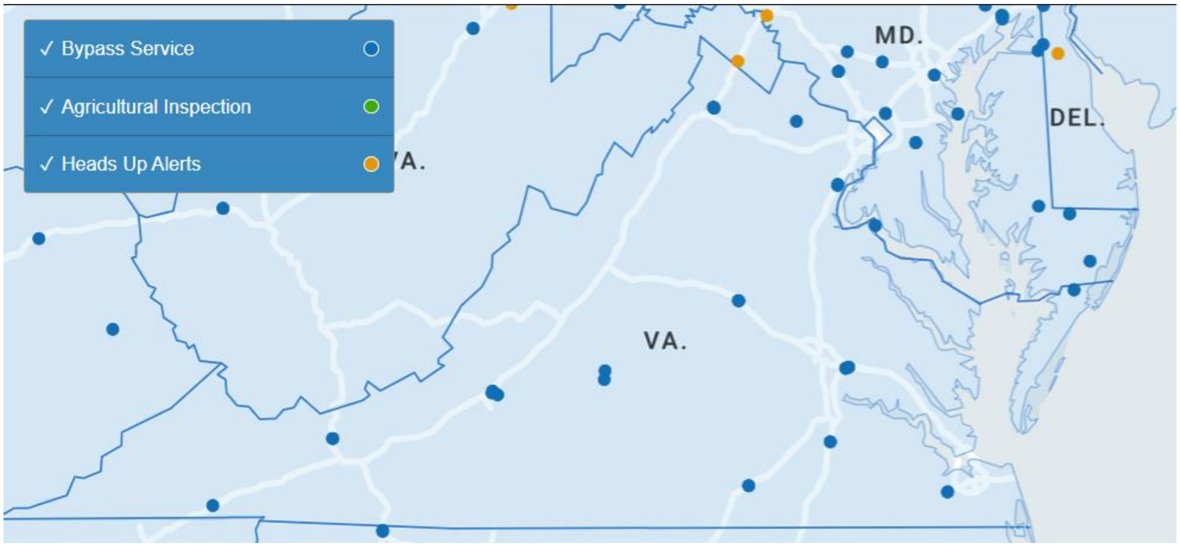

Figure 1. Drivewyze Weigh Station Coverage Area. From https://drivewyze.com/coverage-map/

In order for VDOT to assess the value of in-cab alerts, their basic characteristics, scope of operation and driver responses to messages must be understood. Although VDOT has access to raw and aggregated data on the number of messages and vehicle position data at one-second frequency from GPS immediately after alerts are issued, there has been no attempt to estimate the coverage area, message penetration rate, and driver reaction to messages. A better understanding of these attributes will allow VDOT to assess the value of alerts and better understand driver responses.

PURPOSE AND SCOPE

The purpose of this study was to provide VDOT with the information necessary to evaluate whether continued investment in the in-cab alert system is warranted. Specifically, the study aimed to:

1. To determine the general characteristics of an in-cab alert system, e.g. notification delay, message design, effective range, ability to target specific trucks or roads, messages per day, variation in message volume by region or time of day, etc.
2. To determine the percentage of the truck fleet that can and do receive alerts from VDOT.
3. To measure the extent to which drivers may be responding to message alerts, either by speed changes, self-rerouting, or other measures.

The scope of the study is focused on in-cab alerts issued by Drivewyze under contract with VDOT. These alerts consist of congestion alerts, DSD alerts, and customized weather alerts. Throughout this report, “in-cab alerts” refer to these types of alerts rather than alerts issued regardless of VDOT involvement or systems that issue alerts based on the vehicle’s own sensors such as collision warning or lane keeping.

METHODS

To accomplish the study objectives, the following tasks were performed.

1. Literature review.
2. Stakeholder interviews.
3. Carrier interviews.
4. Alert data analysis.
5. Economic breakeven analysis.

Literature Review

A review of the literature was conducted to summarize research on the topics of commercial vehicle in-cab alert systems, characteristics of the evaluated system, analyses of its field deployments, effects of alerts on driver behavior, market penetration estimates, and cost-benefit analyses of system deployments. Reviewed sources included relevant scientific literature, trade publications, and government reports. The search was conducted on Google Scholar and the Transport Research International Documentation (TRID) database, using forward and backward citation of relevant articles.

Stakeholder Interviews

This task conducted interviews with staff at other state DOTs and turnpikes known to have contracted with Drivewyze to provide congestion warnings generated automatically from INRIX probe speed data. According to Drivewyze, 11 transportation agencies paid for congestion and DSD alerts as of November 2024. The states and the dates on which they began operations are listed in Table 1.

Table 1. Transportation Agencies Issuing Congestion and DSD Alerts with Drivewyze.

Agency	Date Initiated
North Carolina Department of Transportation	May 2021
Ohio Department of Transportation	December 2021
New Jersey Department of Transportation	January 2022
Pennsylvania Turnpike Commission	September 2022
Georgia Department of Transportation	October 2022
Virginia Department of Transportation	December 2022
Delaware Department of Transportation	September 2023
Texas Department of Transportation	June 2024
Arkansas Department of Transportation	May 2024
Indiana Department of Transportation	April 2024
Florida Turnpike	November 2024

To avoid potential bias, states were contacted directly to determine relevant contacts for interviews rather than relying on Drivewyze’s recommended contacts. Interviews were conducted in January 2025 towards the end of the project schedule to capture agency perspectives after maximum experience with the system. Interviews were conducted by video conference and by phone.

The purpose of these interviews was to gain an understanding of agencies' experience with in-cab alerts and their general impressions. Agencies were also asked whether they had conducted or funded any analysis of the system's effectiveness either in terms of speed reductions, crash reductions, or any other metric. Both published and unpublished studies were sought.

Of the agencies using Drivewyze, interviews were conducted with Georgia DOT, North Carolina DOT, New Jersey DOT, the Pennsylvania Turnpike Commission, Delaware DOT, and Texas DOT. These agencies were selected based on similarities to VDOT in terms of geographic location and size, as well as responsiveness to interview requests. The Eastern Transportation Coalition (ETC) was also interviewed, as member agencies purchase Drivewyze alerts through a contract negotiated by ETC. All agencies interviewed were ETC members with the exception of Texas DOT.

Carrier Interviews

This purpose of this task was to understand the use of in-cab alerts from the commercial vehicle operator perspective. Interviews were conducted with representatives from two larger carriers. Carriers were asked about their perceptions of in-cab alerts, perceived value of congestion alerts, and for any internal research, either formal or informal, that carriers use to assess the benefits and risks of the system. Carriers were identified through contacts at the Virginia Tech Transportation Institute.

Alert Data Analysis

Data Collection and Preparation

This study employed three primary data sources: (1) trajectory data, which provides second-by-second vehicle tracking after receiving an alert by the in-cab system, (2) incident data by the service provider, and (3) Continuous Count Station (CCS) classification data from VDOT. All datasets are critical for understanding system penetration, driver behavior, and spatial-temporal distribution of the alerts.

Trajectory Data

The trajectory data, provided in JSON format, includes detailed information about truck movements, and is triggered by alerts. Each trajectory starts at the moment an alert is received by the in-cab ELD and records vehicle speed, location, and direction approximately every second for up to 5 minutes. However, there can be missing timestamps in the data. Some key fields within the trajectory data include:

- safety_visit_id: Unique identifier for the vehicle trip
- visit_utc_unix_ts: Timestamp indicating when the alert was issued
- alert_shown: Type of alert displayed (e.g., dangerous slowdown, congestion)
- location_name: Name of the location, user-definable by VDOT, where the alert was issued (e.g., D1: I-81 EB TN Border to Wytheville)
- deceleration_in_mph: Maximum deceleration observed during the trip, which is imprecise and should be recomputed as recommended by the service provider
- points: GeoJSON feature, which contains the following
    - geometry: Point coordinates (latitude and longitude)
    - properties.speed: Vehicle speed
    - properties.timestamp: Timestamp for each point

The service provider provided two separate batches of trajectory data, covering different time periods: the first batch (1/16/2023 to 5/31/2023) and the second batch (1/4/2024 to 5/27/2024). During the interval between these periods, the service provider updated their data system, resulting in some format changes between the two datasets. Notably, the first batch included a unique identifier labeled "safety_visit_id", whereas the column was absent from the second batch. Despite the core data fields remain largely similar across both batches, inconsistencies in field names exist between those two batches of data. Each month of trajectory data amounts to approximately 1.5 GB, making efficient data handling and storage critical for analysis.

The data preparation process begins with converting the JSON-formatted data into a structured tabular format for easier tracking and analysis. To ensure consistency and facilitate trip identification, a unique trip identifier is assigned to records in the second batch. Since the dataset provides only a rough deceleration measure, a more precise calculation was performed by analyzing speed variations over time. Additionally, the GeoJSON feature was processed and spatially joined with Continuous Count Station (CCS) traffic information to assess the penetration rate of alert-system-equipped trucks.

Incident Data

The incident data contains records of congestion and DSD incidents, along with information on when and where alerts were issued to drivers. Like the trajectory data, the incident data was delivered in two separate batches, covering different time periods. The first batch covers incidents from 6/1/2023 to 1/31/2024, and the second batch from 1/4/2024 to 5/26/2024.

The key fields within the incident data include:

- incident_id: Unique identifier for each recorded incident
- incident_type: Specifies whether the incident is congestion or a dangerous slowdown
- start_time/end_time: The timestamp indicating when the incident started/ended
- duration_minutes: The total duration of the incident in minutes
- alerts_locations: The location where alerts were displayed
- alert_count: The total number of times an alert was issued for the incident

It is important to note that the time periods covered by the incident data do not fully align with those of the trajectory data, with only partial overlap. Due to the misalignment, not all analyses can be conducted for all time periods.

Continuous Count Station (CCS) Data

The Continuous Count Station (CCS) data, obtained from VDOT database, provides traffic volume by vehicle classification at fixed roadway locations. These data serve as a baseline for estimating the penetration rate of alert-system-equipped trucks in this study. The dataset records traffic counts in 15-minute intervals, including classification by vehicle type and traffic volume based on the Federal Highway Administration (FHWA) vehicle classification system (Federal Highway Administration 2014). While CCS data can be reported at the lane level, this study only uses per-direction traffic volume, aggregating all lanes in the same travel direction.

Evaluation of Alert Dissemination

This task evaluated the effectiveness of the in-cab alert system by analyzing the temporal and spatial characteristics of alert dissemination. The analysis included trends in monthly alert counts and the durations of congestion and DSD events. Additionally, the number of vehicles receiving alerts was examined to assess system performance and coverage. These analyses were conducted at both the statewide and interstate levels to identify corridor-specific variations in event duration and alert reach.

This task also verified the delivery of alerts. The research team installed the provider's mobile application and conducted multiple test drives through geofenced alert areas in Virginia. Because congestion and DSD alerts are dynamic and can occur along different parts of the roadway, it is cost-prohibitive to conduct drive tests solely to encounter a sufficient number of these alerts for analysis. In contrast, low bridge alerts are fixed in location and have static geofencing polygons, allowing for repeated tests to confirm consistent alert delivery. As a result, tests focused particularly on low bridge alerts, documenting the location and timing of alert delivery through screenshots and field notes. Special attention was paid to the relationship between alert timing and driving maneuvers to identify potential safety concerns related to alert delivery timing.

Estimate the Market Penetration Rate

The market penetration rate of the in-cab alert system was estimated by comparing the number of trucks that received alerts to the total number of trucks passing through the same location. This estimation process begins with selecting Continuous Count Stations (CCS) as reference points for truck volume data. Alerts issued within a specified radius of 15 miles (7.5 miles upstream and 7.5 miles downstream of the CCS location) were identified to ensure that alerts correspond to trucks that would likely pass by the CCS. This distance was determined in consultation with the Technical Review Panel (TRP), considering typical interstate travel speeds and the 15-minute aggregation interval of CCS volume data.

For each 15-minute interval, the study identified the alerts received within that time frame and counts the number of unique trucks that received alerts. This count was then compared to the CCS-recorded truck volume for the same interval to estimate the market penetration rate. Given that the in-cab system is more commonly installed on trucks operated by freight companies, the study focused on FHWA Class 8 and above as the target truck volume. By aligning alert data with observed truck volumes at CCS locations, the study provided an assessment of the proportion of freight trucks equipped with the in-cab system and evaluates its coverage across different roadway segments.

Evaluation of Truck Speed Adjustments Following Alerts

Truck speed adjustments following alerts are evaluated by analyzing vehicle trajectory data after an alert is received. The trajectory data used in this analysis covered the period from January 16, 2023, to May 31, 2023, as discussed in the Data Collection and Preparation section. The dataset consists of second-by-second updates, capturing truck speed and location at a 1-second interval following the alert. Since the dataset only included trajectory data after an alert is received, the analysis focuses on speed adjustments relative to the truck's initial speed at the time of the alert. To ensure meaningful analysis, only trucks with an initial speed exceeding 50 mph are included, filtering out those already traveling at lower speeds due to congestion. Trucks are categorized into five speed groups based on their initial speed: 50–55 mph, 55–60 mph, 60–65 mph, 65–70 mph, and greater than 70 mph. The study classified speed changes into four categories: no speed drop (<3 mph), minor speed drop (3–5 mph), moderate speed drop (5–10 mph), and significant speed drop (>10 mph). The proportion of trucks in each category is analyzed to assess how quickly and substantially trucks respond to alerts.

It is important to note that this analysis did not establish a direct causal relationship between the alert and the observed speed changes. Trucks may adjust their speed in response to prevailing traffic conditions rather than the alert itself. Since there is no control or benchmark dataset to isolate the effect of an alert, the results should be interpreted as descriptive rather than causal. Given alerts are issued for DSD or congestion situation, it was expected that trucks will eventually reduce their speed as they approach these affected areas. The longer the time after receiving an alert, the more likely trucks were influenced by downstream traffic conditions. However, these findings still provide valuable insights into truck behavior, particularly in the moments immediately following an alert.

Custom Weather Alerts Case Study

This task examined VDOT's use of custom in-cab alerts for emergency weather conditions. The research team reviewed email records of alert requests and analyzed alert data from January 2025 as a representative month to understand geographic coverage, alert volumes, and vehicle reach. The case study included examining coordinate data for geofenced locations, counting alerts and unique vehicles reached at each location, and documenting the types of emergency conditions that triggered alerts.

Economic Breakeven Analysis

This task attempted to determine the required reduction in crashes to justify the financial investment in in-cab alert systems. In a traditional cost-benefit analysis of a safety feature, the number of crashes that would be affected by the safety feature are measured, and their economic costs estimated and summed. Then, a crash modification factor that estimates the proportion of crashes that would be prevented with the safety features is estimated and applied to the targeted crashes. The difference between the total crash costs before and after applying the safety feature is the expected economic benefit.

The relationship between congestion warnings and crash avoidance is not well understood in the literature. Kidando et al. (2024) estimated crash modification factors for congestion alerts by comparing crash rates of rear-end truck crashes in congestion before and after the introduction of an in-cab alert system in Ohio. They estimated a 23% reduction in fatal crashes, despite only 8% of trucks receiving congestion alerts, suggesting that much of the reduction was due instead to other factors such as increased use of Advanced Driver-Assistance Systems (ADAS) crash avoidance features. An end-of-queue warning system in Texas consisting of radar speed sensors, portable changeable message signs, and transverse rumble strips yielded a 44% reduction in crashes (Ullman, Iragavarapu, and Brydia 2016). It was unclear how much of the reduction was due to the use of portable message signs or the rumble strips. A Federal Motor Carrier Safety Administration study was unable to find a statistically significant crash rate reduction of forward collision warning systems on commercial vehicles (Hickman et al. 2013).

In the absence of reliable crash modification factors for congestion warnings, the analysis instead focused on the number of crashes that must be prevented in order to offset system costs. This is referred to as a breakeven analysis.

As system costs were known, the analysis focused on estimating the costs of crashes likely to be reduced by in-cab congestion warnings for large trucks. Crash costs were obtained from U.S. Department of Transportation (2024) guidance. These values were based on analysis from Blincoe et. al (2023) Page 46, Table 2-9, "Incidence Summary, 2019" and adjusted to 2023 dollar values. Values were further adjusted from per person (for fatal and injury) and per vehicle (for PDO) to per crash. This was accomplished by assuming 1.09 fatalities per fatal crash, 1.43 injuries per injury crash, and 1.77 vehicles per PDO crash. Values include not only quality-adjusted life years, but also congestion and environmental costs. The economic costs are shown in Table 2.

Table 2. Economic Value by Crash Severity (United States Department of Transportation 2024)

Severity	Monetized Value per Crash (2023 $)
Fatal	$14,806,000
Injury	$329,500
Property Damage Only (PDO)	$9,500

RESULTS AND DISCUSSION

Literature Review

The literature review is divided into three main sections: in-cab commercial vehicle safety alert products, general characteristics of the evaluated in-cab alert system, and field evaluations of the in-cab alerts including driver surveys, market penetration estimates, effect on driver behavior, and cost-benefit analyses.

In-Cab Commercial Vehicle Safety Alert Systems

Safety alerts such as crash, disabled vehicle, and congestion warnings have been available on smartphone navigation apps since 2009, with Waze providing crowdsourced alerts and along with its later purchase by Google and partial integration of its crowdsourced alerts into Google Maps. A 2018 survey of truck drivers found that 26% used either Google Maps or Waze as their primary navigation application (Flintsch et al. 2019). The study may have undercounted Google/Waze users, as drivers who used both Google/Waze and a truck-specific GPS system like Garmin were recorded as using only the truck-specific system.

There are several products designed to monitor driver safety and provide alerts to the driver when dangerous behavior is detected as well as driver-specific reports for fleet managers. Alerts are generally based on data onboard sensors such as video and radar and do not integrate third-party speed data. The main products are Azuga, Lytx, Mobileye, NetraDyne, Samsara, Teletrac Navman, and PrePass. Kidando et al. (2024) provide a summary of the technologies. A pilot study of Prepass alerts was conducted by the Kentucky Transportation Cabinet (Howell, Walton, and Koo 2021).

Performance Characteristics of Evaluated System

In the evaluated in-cab alert system, alerts are issued to drivers via a smartphone application or directly through the truck's electronic logging device (ELD). ELDs record drivers' service hours electronically to ensure compliance with federal hours of service regulations. In part due to their ability to communicate over cellular networks, ELDs may run additional applications that allow drivers to bypass weigh stations and facilitate fleet management. These applications have expanded to allow transmission of safety alerts based on external real-time data.

Drivers are provided a range of alerts based on the drivers' subscription plan. Drivers under the free plan receive most safety-related alerts, while those with Safety+ paid subscriptions can additionally receive alerts on speed enforcement zones, high-theft areas, and severe weather. A list of all alerts is available on Drivewyze's website (Drivewyze, n.d.), as well as in Table 3.

Table 3. Alert Types (Drivewyze, n.d.)

Name	Description	Free or Paid
Sudden Slowdown	Drivers receive real-time alerts using speed data on areas where sudden slowdowns occur.	Free
Unexpected Slowdown	Drivers receive real-time information on areas experiencing more than usual traffic.	Free
Steep Grade	Drivers are alerted of upcoming roads with 5% grade declines or higher.	Free
Work Zone	Drivers are alerted when approaching a work zone or lane closure.	Free
Service Vehicle	Alerts of service vehicles that have stopped and are working on roads ahead of them.	Free
Brake Check	Site-specific alerts when approaching areas where drivers should check their brakes.	Free
Public Service and Agency Virtual Sign	Public safety messages from government agencies participating in the Smart Roadways program.	Free
Low Bridge	Alerts drivers 1–2 blocks before low bridges, with location-specific clearance.	Free
Rollover	Drivers are notified when approaching areas with significant rollover history.	Free
Runaway Ramp	Drivers are notified when approaching a location where a truck escape ramp is available.	Free
Rest Area	Drivers are provided parking space availability at rest areas and other parking centers.	Free
Real-Time Cargo Theft Alerts	Drivers alerted when entering high risk areas for theft, as identified by CargoNet®.	Paid (Safety+)
Speed Alerts	Drivers are alerted when entering areas with historically high rates of speed enforcement.	Paid (Safety+)
Severe Weather Alerts	Drivers are alerted when approaching potentially dangerous weather or poor road conditions.	Paid (Safety+)
Custom Alerts	Custom messages designed by fleet managers.	Paid (Safety+)

This study focused on congestion and DSD alerts, referred to in the literature as "Unexpected Slowdown" and "Sudden Slowdown," respectively. In its default state, congestion alerts are issued when the current travel time exceeds historical travel time by 3 minutes or more. These alerts are issued 3 miles prior to the congestion. DSD alerts are triggered when a speed differential 35 mph or greater is detected between two 100-meter segment as measured by INRIX. DSD alerts are issued 2 miles prior to the speed change (Federal Highway

Administration 2023; Kidando et al. 2024). Alerts are generated automatically from crowdsourced speed data purchased from INRIX.

Evaluations

Driver Surveys

A survey of 24 trucking companies was conducted by Kidando et al. (2024). Among companies surveyed, 12.5% reported using Drivewyze exclusively for safety alerts, while 16.7% reported using Drivewyze alongside other safety alert products. Only 16.7% indicated not using any safety alert products. In a similar survey of 584 drivers (many of whom were employed by state DOTs, but some percentage employed by private companies), 32% of drivers found "sudden slowdown" alerts to be "very effective" compared to 7% "not effective" and 36% "not applicable" or "no response" (Kidando et al. 2024). Drivers reported similar reactions to "traffic congestion" alerts, with 30% "very effective" compared to 6% "not effective" and 39% "not applicable" or "no response." There is evidence that the survey results may be biased towards fleets with safety alerts installed, as 28% of drivers reporting using Drivewyze compared to only 8% penetration rate when comparing issued alerts to observed truck volumes (Kidando et al. 2024).

Market Penetration

Kidando et al. (2024) studied 1,230 unique incidents where alerts were issued in Ohio between January 2022 and January 2024. The average observed penetration rate was 8.0% (95^{th} CI = 8.0%, 9.0%) with a median of 5%.

Driver Behavior

Drivewyze (2020) conducted a pilot study of congestion and DSD alerts for the Georgia Department of Transportation (GDOT) in 2020. The analysis covered 10 sites over 45 days, resulting in over 500,000 alerts issued. The study analyzed braking events as derived from acceleration rates based on GPS position data. Acceleration rates between $-2\ m/s^2$ and $-7\ m/s^2$ were classified as hard braking events, with events below $-7\ m/s^2$ were removed as GPS anomalies. The control group consisted of trucks with location tracking but that were not members of the Drivewyze Safety Program. The study is therefore not a randomized control study, as fleets enrolled in the Drivewyze Safety Program may have different requirements for drivers and different technologies for tracking and enforcing safety, a fact acknowledged by the authors.[1] Trucks receiving alerts exhibited 4% to 19% fewer hard braking events compared to the control group at 7 of the 10 sites evaluated.

[1] "Alerts were shown only to drivers subscribed to Drivewyze safety service. Presumably, those fleets are more conscious of the importance of a safety program, and those drivers may be exposed to more safety training outside of the project. The population of drivers monitored but not shown an alert also belong to fleets that have expressed an interest in Drivewyze services, so there may be differences between those drivers and the typical driver on the road." (Drivewyze 2020)

Desai et al. (2024) studied the effect of in-cab congestion and DSD alerts on driver speed in Ohio over 47 days in 2023. The authors collected waypoints associated with 2,449 unique congestion alerts and 640 DSD alerts. Approximately 19.1% of drivers receiving congestion alerts and 21.9% of drivers receiving DSD alerts reduced their speeds by 5 mph within 30 seconds after receiving the alert. Only 56% of vehicles demonstrated any speed reductions after 30 seconds after receiving a congestion alert, compared to 62.7% for DSD alerts. Speed reductions were generally greater for DSD alerts than for congestion alerts.

Desai et al. (2024) conducted a similar study of the effective of in-cab congestion and DSD alerts on speed reductions in Indiana. Approximately 20,000 alerts were collected along 44 corridors between April and June 2024. After filtering for reporting gaps and redundant alerts issued to the same truck at the same event, 13,525 congestion alerts and 1,060 DSD alerts were analyzed. Results showed that 15% of trucks lowered their speeds by at least 5 mph within 30 seconds of receiving a congestion alert, compared to 21% of those receiving DSD alerts. Surprisingly, the authors found that 8.1% of congestion alerts and 8.3% of DSD alerts were issued to vehicles traveling a 45 mph or less, suggesting that a portion of alerts are issued to vehicles that have already encountered congestion.

Kidando et al. (2024) analyzed driver speed reductions based on 6,808 sample trajectories collected between September 28, 2023 and February 14, 2024 in Ohio. In their study, 81% of drivers responded by applying the brakes within 50 seconds of receiving an alert, with 35% responding within 10 seconds.

Cost-Benefit Analyses

A report for the Ohio Department of Transportation estimated the benefit-cost ratio for congestion and DSD alerts as 22.56 (Kidando et al. 2024). This was derived by calculating the number of crashes for each severity level that might be affected by the alerts, adjusting by crash modifications factors and multiplied by United States Department of Transportation (2024) crash costs. The benefit-cost ratio was highly dependent on the crash modification factors. These were obtained by dividing after-period (2022–2023) crash rates by before-period (2018–2019) crash rates. These yielded fairly high crash rate reductions, e.g., a 23% reduction in fatal crashes. This is counterintuitive given that only 8% of trucks appear to have been issued alerts. As designed, the benefit-cost analysis assigns all credit for crash reductions to the alerts despite its low market penetration, while ignoring other contributing factors such as forward collision warning systems (Federal Motor Carrier Safety Administration 2009). Due to these confounding factors, the benefit-cost ratio of 22.56 is probably an overestimation.

Stakeholder Interviews

Interviews were conducted with representatives of five transportation agencies that have implemented congestion and DSD in-cab alerts: Georgia DOT, North Carolina DOT, New Jersey DOT, the Pennsylvania Turnpike Commission, Delaware DOT, and Texas DOT. The Eastern Transportation Coalition (ETC) was also interviewed as they are the vendor through which all agencies except for Texas DOT purchased the service.

Based on interviews, agencies are generally supportive of in-cab alerts while noting areas for improvement. Annual costs range from just over $200,000 per year to over $500,000 per year, depending on whether custom alerts are supported. Agencies were sensitive to the system costs, given relatively low penetration rates. North Carolina calculated that the cost per alert issued varied between $1 and $5 depending on the number of alerts issued in a given month.

Several agencies reported technical challenges that have since been addressed. New Jersey DOT and North Carolina DOT initially attempted to validate the transmission and accuracy of alerts by using the provider's smartphone application and driving near congested areas. Agencies noted that these alerts were not being received, which was due to a default setting on the app that was corrected in mid-December 2024.

Texas DOT observed high rates of speed compliance. In their first 3 months of deployment, 40% of drivers reduced their speeds by 5 mph within 2 miles of receiving an alert. After expanding to all Interstates in Texas, a study conducted after 6 months found that 30% of drivers reduced their speeds by 5 mph within 0.5 miles of receiving the alert, and 60% after 2 miles. The reductions after 2 miles may be due in part to trucks encountering the congestion they were warned about, as DSD alerts are issued 2 miles upstream of the slowdown. Congestion alerts, however, are approximately 10 times more prevalent than DSD alerts, so any bias may be small.

The Pennsylvania Turnpike noted some false negatives in alert generation after spot checking with their own vehicles. Like many other agencies, they would like to increase market penetration without marketing the service and are exploring relationships with commercial vehicle safety consortiums and the insurance industry.

New Jersey DOT has used issued custom in-cab alerts instructing drivers to avoid using left lanes. Alerts cannot be issued at the lane-level but are issued to all trucks passing requested locations, and function as virtual dynamic message signs. North Carolina DOT has also used custom alerts to notify drivers of road closures, and are piloting a program to issue Highway Emergency Linked Platform (HELP) alerts directly to ELDs (Wells 2024).

A key concern among agencies is market penetration and cost-effectiveness. According to Texas DOT, a provider claimed coverage of up to 60% of ELDs, although it was unclear if this meant the percentage of units on the road or percentage of models on the market, as there are over 1,000 models of ELDs. When comparing alerts issued to truck volumes at a given location, agencies reported market penetrations of between 8% and 10%.

Agencies are exploring methods to improve market penetration. The ETC is considering a data portal whereby any developer may access data on congestion and DSD alert locations in real-time and issue alerts via their ELD apps. This would allow other ELD app developers to transmit congestion and DSD alerts, potentially increasing penetration rates. Despite these challenges, most agencies plan to continue using the system while seeking opportunities for expanded coverage and reduced costs.

Carrier Interviews

Interviews with staff of two major commercial vehicle carriers provided insights into how large fleets utilize in-cab alerts and other safety technologies. One carrier operates approximately 10,500 trucks with about 70% receiving safety alerts, while the other manages around 14,000 drivers covering travelling nearly 1 billion miles annually. One company issued in-cab alerts through their ELDs, while the other used company-issued tablets designed to restrict in-motion usage.

The carriers reported positive experiences with in-cab alerts, particularly for low bridge alerts, traffic congestion warnings, and work zone notifications. One company noted that the data quality from the in-cab alert provider exceeds that of third-party mapping platforms they use for truck routing. They have independently validated behavioral changes in their drivers' responses to alerts and observed fewer near-misses, though they noted it's too early to make definitive claims about safety improvements.

Both carriers emphasized that in-cab alerts are just one component of their comprehensive safety systems. They utilize advanced driver assistance systems (ADAS) including lane departure warnings, following distance monitors, and collision mitigation systems. One carrier reported a 68% reduction in rear-end crashes and 94% reduction in crash severity after implementing collision mitigation technology. The companies also mentioned exploring emerging technologies, such as infrared systems for road temperature detection and camera systems that can detect adverse weather conditions and alert drivers accordingly.

Notably, one company belongs to an informal consortium of other large carriers, of whom the majority use in-cab alerts and receive congestion and DSD alerts while simultaneously using ADAS features such as collision warning systems. According to the respondent, these carriers collectively represent about 6% of all commercial vehicle-miles-traveled (VMT) nationally. Given that 8–10% of trucks are observed to receive in-cab alerts from the evaluated system, and that a majority of the 6% of truck VMT represented by the consortium not only receive these same alerts but also use collision warning systems, this suggests that a large portion of the vehicles receiving alerts may also have ADAS features installed. While these percentages are anecdotal, it provides some evidence that alerts might be somewhat redundant if provided primarily to vehicles with ADAS. Increasing the market penetration of in-cab alert systems could provide access to carriers with fewer or no ADAS features installed, thereby providing greater crash reduction potential.

Alert Data Analysis

Alert Delivery Verification

The in-cab alert system supports various types of alerts, including weather warnings, road closures, and infrastructure-related hazards such as low bridges. The alerts are geofenced, ensuring that drivers receive notifications only when they approach relevant locations.
The system interface allows drivers to access active services, such as safety notifications, while bypassing other features if needed. As seen in Figure 2, the app's dashboard displays available

services, including active safety notifications. When an alert is triggered, the system presents a message on the driver's screen, offering critical details like height restrictions and recommended detour routes. The alerts can be dynamic, adjusting based on the direction of travel.

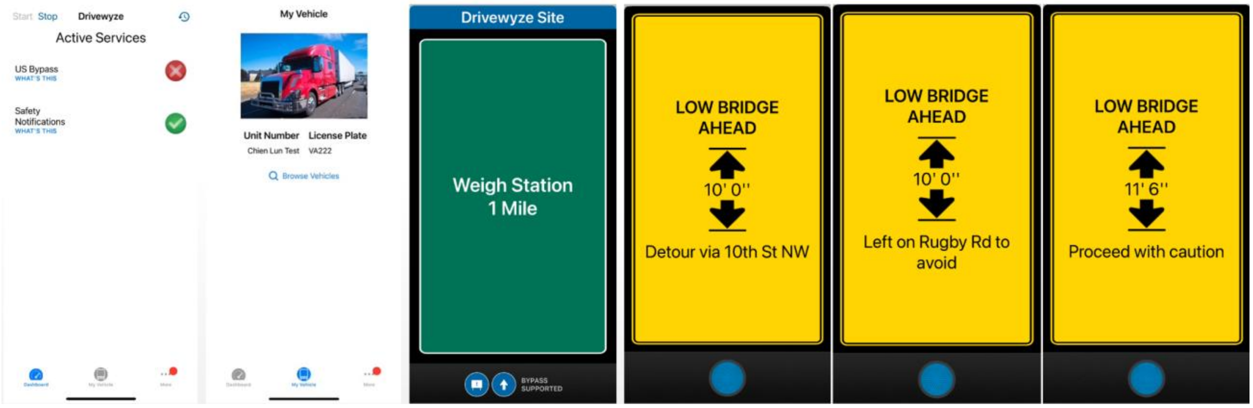

Figure 2. In-Cab Alert System App Interface and Alerts

Figure 3 illustrates different alerts for the same low bridge hazard in Charlottesville, where the system provided alternate detours via 10th Street NW or Rugby Road, depending on the vehicle's direction.

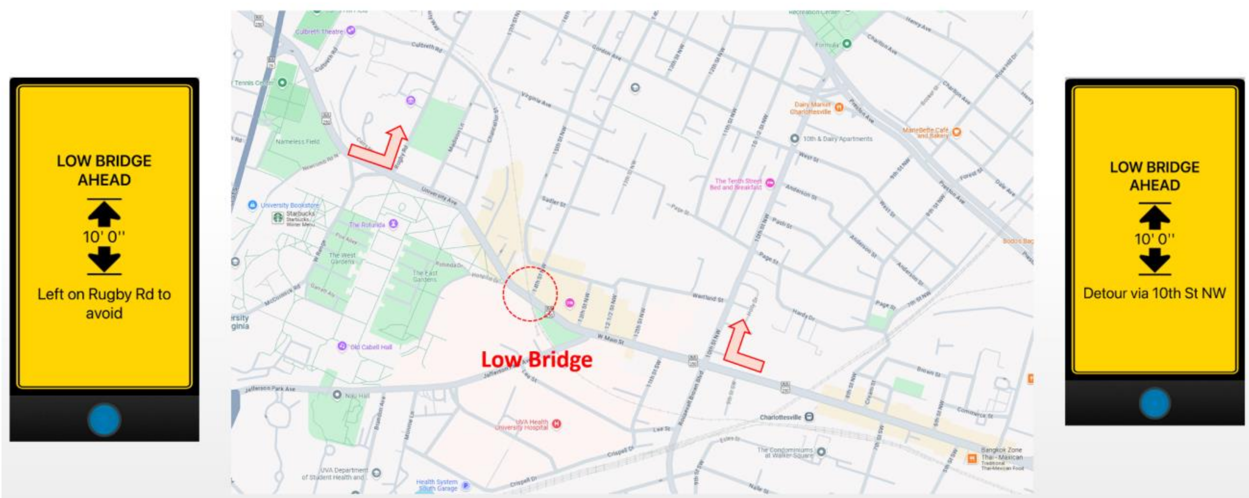

Figure 3. Low Bridge Warning Alerts and Suggested Detour Routes

To evaluate the alert delivery of the in-cab system, the research team installed the provider's app and conducted field tests at several locations within Virginia. By driving through the geofenced area, the team was able to verify the consistency of the alert delivery. As shown in Figure 4, sequential screenshots confirm that notifications were consistently delivered at the same location across multiple runs. The research team conducted 30 test runs across two different low bridge locations, covering all approach directions. Results confirmed that alerts were delivered 100% of the time at the designated locations.

Figure 4. Alert Delivery for Low Bridge Warning at Downtown Charlottesville, Virginia

Another low-bridge alert location was identified in Crozet, Virginia, where the bridge site is adjacent to a four-way stop-controlled intersection. As shown in Figure 5, a key issue observed at this site is that vehicles traveling westbound on VA-240 and making a left turn at the intersection receive the low-bridge alert in the middle of the turn. This timing could potentially be distracting for drivers, as they are actively maneuvering through the intersection when the notification appears.

Recognizing the safety concerns associated with this timing, the research team reached out to the alert system operator. They acknowledged the issue and expressed a willingness to modify the geofencing polygon to adjust the alert's activation point, aiming to mitigate potential driver distraction. However, this case raises a broader concern: there may be other locations with similar issues where alerts are triggered at less-than-ideal moments, but these instances remain unidentified. A more systematic review of geofencing placements could help refine alert delivery, ensuring they provide timely and effective warnings without introducing unintended hazards.

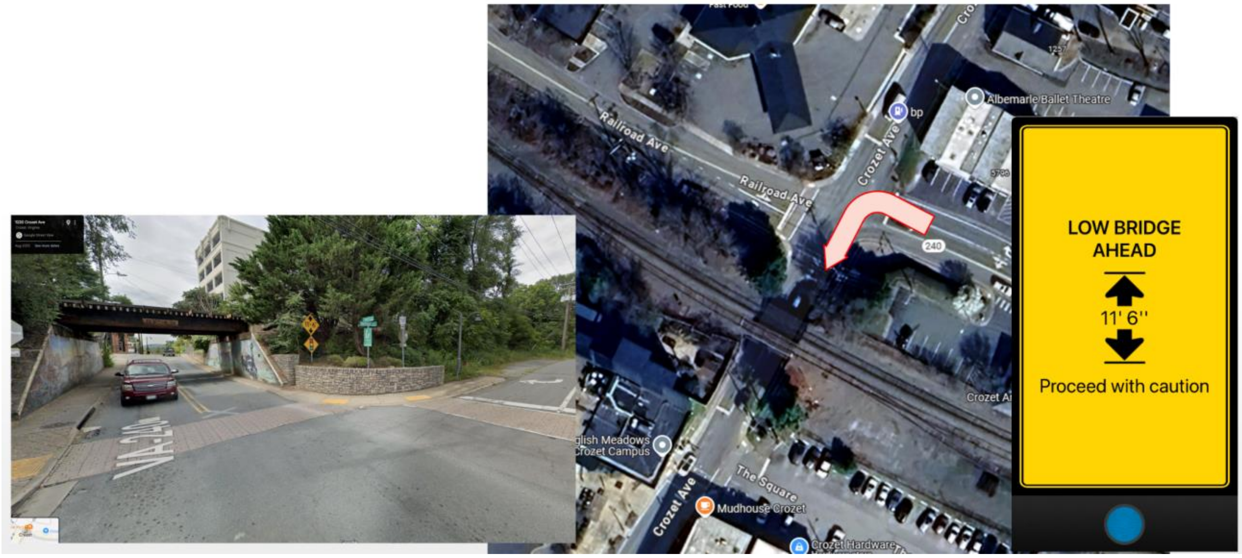

Figure 5. Low-Bridge Alert at a Four-Way Stop Intersection in Crozet, Virginia

Evaluation of Alert Dissemination

Alert Counts in Virginia

Table 4 presents the monthly count of congestion and DSD events and alerts from June 2023 to May 2024. Over this period, the total number of events recorded was 20,437, consisting of 14,102 congestion events and 6,325 DSD events. A total of 107,996 congestion alerts were issued for 14,102 congestion events, averaging approximately 7.66 alerts per congestion event. Meanwhile, 12,365 DSD alerts were issued for 6,325 DSD events, resulting in an average of 1.96 alerts per event.

The highest number of monthly alerts occurred in May 2024, with 15,912 congestion alerts and 711 DSD alerts, while the lowest was in September 2023, with 4,701 congestion alerts and 918 DSD alerts. From January to May 2024, the overall trend showed an increase in congestion events, although February experienced a slight decrease, which is expected given its shorter duration. Despite this fluctuation, the ratio of alerts per congestion event remained relatively stable. In contrast, the number of DSD events declined beginning in December 2023, suggesting either a reduction in sudden slowdowns or adjustments in alerting criteria that resulted in fewer detected events.

Table 4. The Count of Congestion and Dangerous Slowdown (DSD) Alerts by Month

Month	Count of Congestion Events	Count of Congestion Alerts	Count of DSD Events	Count of DSD Alerts	Total Event Counts
2023 - June	965	8,404	1,327	3,021	2,292
2023 - July	1,025	9,028	459	804	1,484
2023 - August	988	8,256	551	897	1,539
2023 - September	708	4,701	589	918	1,297
2023 - October	1,024	7,488	702	1,097	1,726
2023 - November	683	6,804	452	759	1,135
2023 - December	713	6,262	272	488	985
2024 - January	1,133	12,039	304	1,130	1,437
2024 - February	1,036	6,782	340	668	1,376
2024 - March	1,689	12,011	467	959	2,156
2024 - April	1,879	13,309	475	913	2,354
2024 - May	2,259	15,912	387	711	2,646
Total	14,102	107,996	6,325	12,365	20,427

Event Duration and Alert Distribution

Figure 6 illustrates the distribution of event durations for congestion and DSD events over time. The x-axis represents the month and event type (congestion or DSD), while the y-axis represents event duration in minutes. The whiskers on each box indicate the 15th and 85th percentile values, displaying the range of durations for each event type across different months.

The average duration of congestion events is 49.91 minutes, with a median duration of 26 minutes. Many congestion events persist beyond 200 minutes, and some outliers exceed 1,000 minutes, reflecting sustained disruptions in traffic flow. Conversely, DSD events exhibit significantly shorter durations, with an average duration of 9.88 minutes and a median of 6 minutes, emphasizing their transient nature compared to congestion events.

Several congestion events lasting over 1,000 minutes were identified, primarily occurring on I-95 Southbound near the North Carolina state border and all on the same day. These extended-duration congestion events raise questions about their underlying causes. A review of the Virginia incident database (VaTraffic) did not reveal corresponding reported incidents, suggesting that these events were not attributed to major crashes or construction within Virginia. However, an analysis of archived probe speed data using RITIS indicates a significant speed drop during these extended events, confirming that the congestion was not a data anomaly but a real traffic condition. This suggests that these congestion periods may have been caused by disruptions in North Carolina that spilled over into Virginia’s road network.

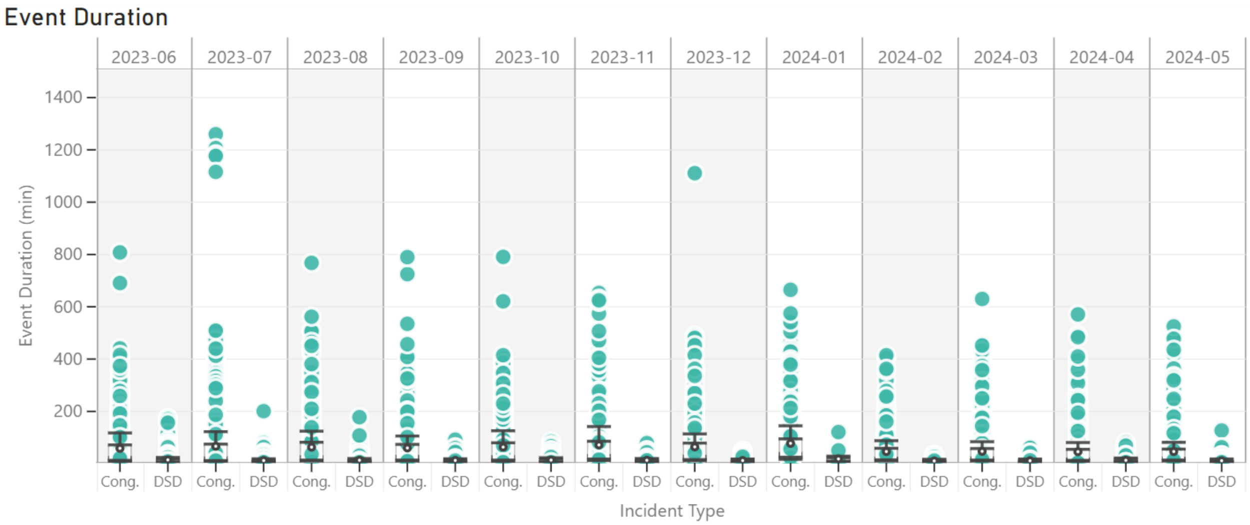

Figure 6. The event duration box-and-whisker plot by month and event type, where the boxes represent the 25th and 75th percentile values. (Cong. stands for congestion; DSD stands for dangerous slowdown)

Number of Vehicles Receiving Alerts per Event

Figure 7 illustrates the number of vehicles that received an alert per congestion and DSD event, providing insight into how many alert-system-equipped trucks were directly impacted by these events. The x-axis represents the month and incident type, distinguishing between congestion and DSD events. The y-axis represents the number of vehicles alerted per event. Similar to Figure 6, the whiskers on each box indicate the 15th and 85th percentile values, with individual data points represent the number of vehicles alerted per event.

Congestion events tend to impact a significantly larger number of vehicles per event compared to DSD events, likely due to their longer durations. Many congestion events resulted in 50 or more trucks receiving alerts, with some outliers exceeding 200 trucks per event. Conversely, DSD events impact fewer vehicles per event, with most alerts falling below 20 vehicles. This pattern aligns with the longer duration of congestion events observed in Figure 6, as more trucks pass through the affected roadway during a prolonged congestion period, increasing the total number of vehicles that receive an alert. For congestion events, the average number of vehicles receiving is 7.33, while the median is 4. In contrast, DSD events have an average alert count of 1.87, with a median of 1.

One may observe from the above discussion that:

1. Longer congestion events tend to alert more vehicles, as more trucks enter the affected roadway segment over time.
2. DSD alerts are typically issued only once per event, given their short duration.

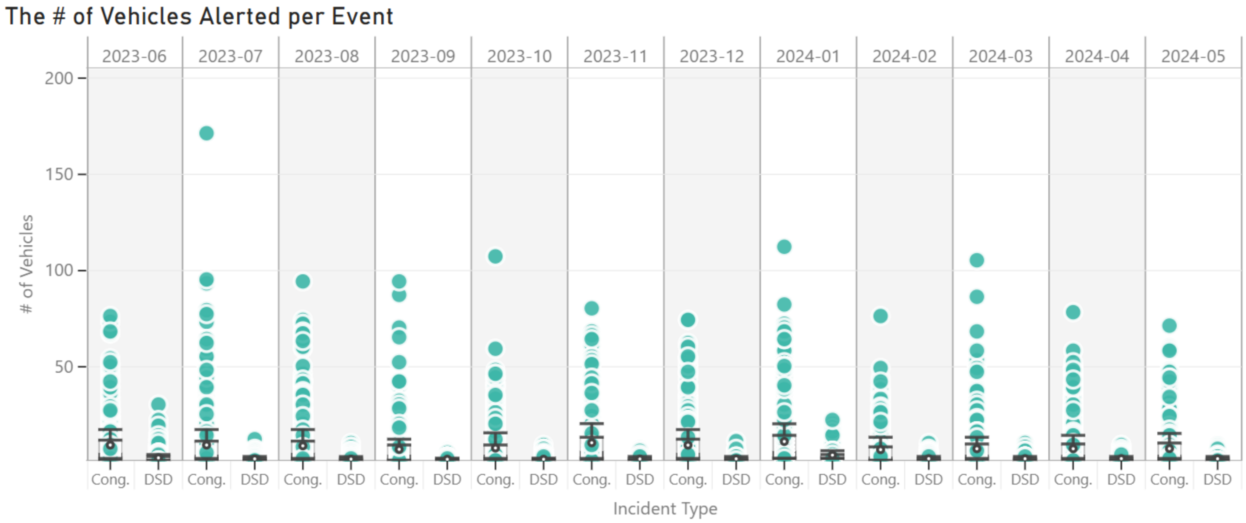

Figure 7. The number of vehicles alerted per event box-and-whisker plot by month and event type, where the boxes represent the 25th and 75th percentile values. (Cong. stands for congestion; DSD stands for dangerous slowdown)

Interstate-Level Analysis of Event Duration and Alerted Vehicles

Table 5 provides a breakdown of congestion and DSD event durations, as well as the number of vehicles that received alerts per event, for Virginia Interstates.

The average congestion event duration varies widely by interstate, with I-95 (57.44 minutes), I-81 (52.84 minutes), and I-495 (53.22 minutes) having the longest average durations. The median congestion duration for these interstates also remains relatively high, ranging from 23 to 31 minutes. Conversely, shorter congestion durations are observed on I-581 (34.62 minutes), I-66 (33 minutes), and I-77 (37.72 minutes), where congestion events tend to resolve more quickly. For DSD events, the average durations are significantly shorter than congestion events, with most interstates reporting averages between 6 and 16 minutes. I-395 (15.39 minutes), I-581 (14.91 minutes), and I-64 (12.04 minutes) exhibit longer DSD event durations. The median DSD duration for these interstates ranges from 8 to 11 minutes, whereas that on most other interstates ranges from 4 to 6 minutes. This observation signifies the transient nature of DSD events.

The number of trucks receiving alerts per event also varies by interstate. I-81 (10.24 trucks), I-95 (9.32 trucks), and I-495 (7.65 trucks) report the highest number of alerted vehicles per congestion event, consistent with their higher average congestion event durations; the median values for these interstates are 7, 6, and 4, respectively. For DSD events, the number of alerted vehicles per event remains lower across all interstates, with I-95 (2.33 trucks), I-81 (2.09 trucks), and I-77 (2.06 trucks) leading in the truck alert counts per DSD event. The median values remain 1 or 2 trucks per DSD event for all interstates, emphasizing that most DSD alerts are generally received by only a small number of trucks.

The interstate-level analysis of event duration and the number of alerted vehicles exhibits a similar trend to the overall findings observed across Virginia, that is: (1) longer congestion events tend to alert more vehicles than shorter DSD events, and (2) DSD alerts are typically issued to only 1 or 2 trucks.

Table 5. Interstate-Level Analysis of Event Duration and Number of Vehicles Receiving Alerts for Congestion and DSD Events

Interstate	Congestion Event Duration (minutes)		DSD Event Duration (minutes)		Number Alerted Vehicles per Congestion Event		Number Alerted Vehicles per DSD Event	
	Average	Median	Average	Median	Average	Median	Average	Median
I-64	38.6	22	12.04	8	3.19	2	1.46	1
I-66	33	21	9.62	6	2.47	2	1.56	1
I-77	37.72	22	9.28	6	7.34	5	2.06	1
I-81	52.84	28	8.54	6	10.24	7	2.09	2
I-85	43.5	31	10.69	8	4.6	4	1.87	1
I-95	57.44	29	10.05	6	9.32	6	2.33	2
I-195	-	-	-	-	-	-	-	-
I-264	42.86	25	-	-	1.24	1	-	-
I-295	37.9	25	8.45	6	3.52	2	1.54	1
I-395	-	-	15.39	11	-	-	1.22	1
I-464	-	-	-	-	-	-	-	-
I-495	53.22	23	6.83	4	7.65	4	1.83	1
I-581	34.62	18	14.91	10	2.02	1	1.67	1
I-664	38.3	30	7.74	5	2.77	2	1.42	1

* “-” indicates sample size less than 1 for that interstate.

Spatial Analysis of Alert Locations

Figure 8 illustrates the spatial distribution of congestion alert events across Virginia in February 2024, distinguishing between alerts issued on weekdays (red) and weekends (blue). One can observe that a higher density of congestion alerts observed along major interstate corridors, particularly I-95, I-81, and I-64. The Richmond area, the Northern Virginia regions, and the Hampton Roads area show significant clustering of weekday congestion alerts, reflecting heavy traffic volume during business days. Weekend congestion alerts, represented by blue dots, appear more sporadic. The presence of weekend congestion may be attributed to leisure travel, for example, the congestion on I-95 near Fredericksburg. The spatial patterns suggest that congestion events throughout the week may be driven by different demand factors on weekdays versus weekends.

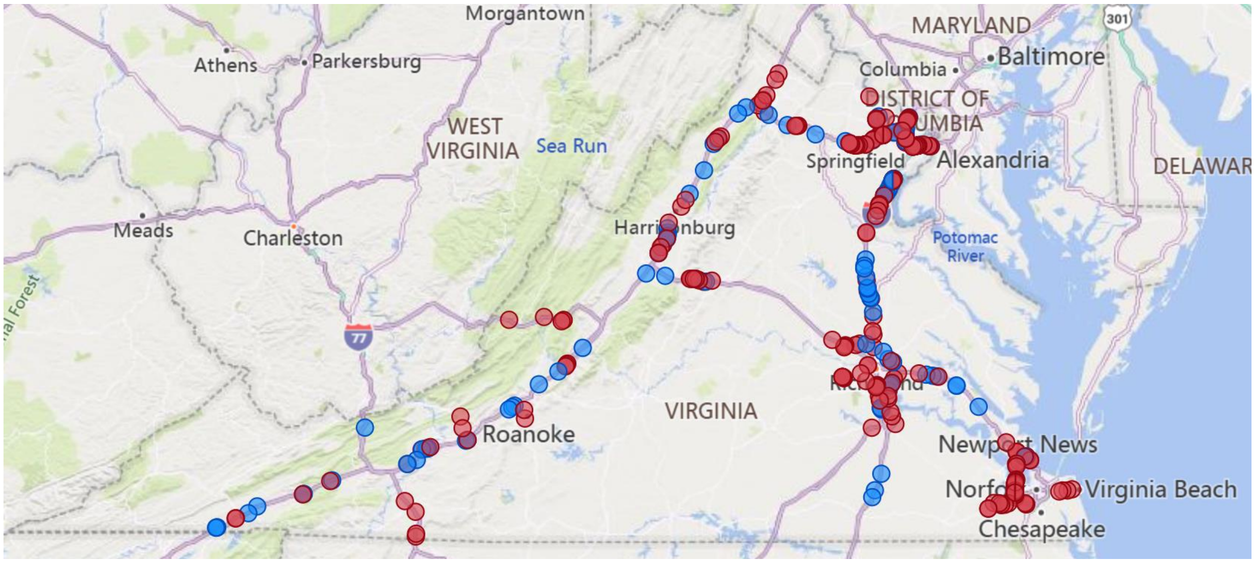

Figure 8. Spatial Distribution of Congestion Alert Events by Weekdays (red dots) and Weekends (blue dots) in February 2024.

Figure 9 illustrates the spatial distribution of DSD alerts across Virginia in February 2024, with red dots representing weekday events and blue dots indicating weekend events. Compared to congestion alerts, DSD alerts are more evenly distributed along Virginia's interstate corridors. This observation suggests that, unlike congestion events, sudden slowdowns occur across segments rather than being concentrated in specific bottleneck locations. However, notable concentrations of DSD alerts are observed near the Hampton Roads Bridge-Tunnel (I-64 and I-664) area, where truck speeds may be influenced by tunnel-related factors, and along I-81, where speed reductions may be affected by grade impacts on truck speeds.

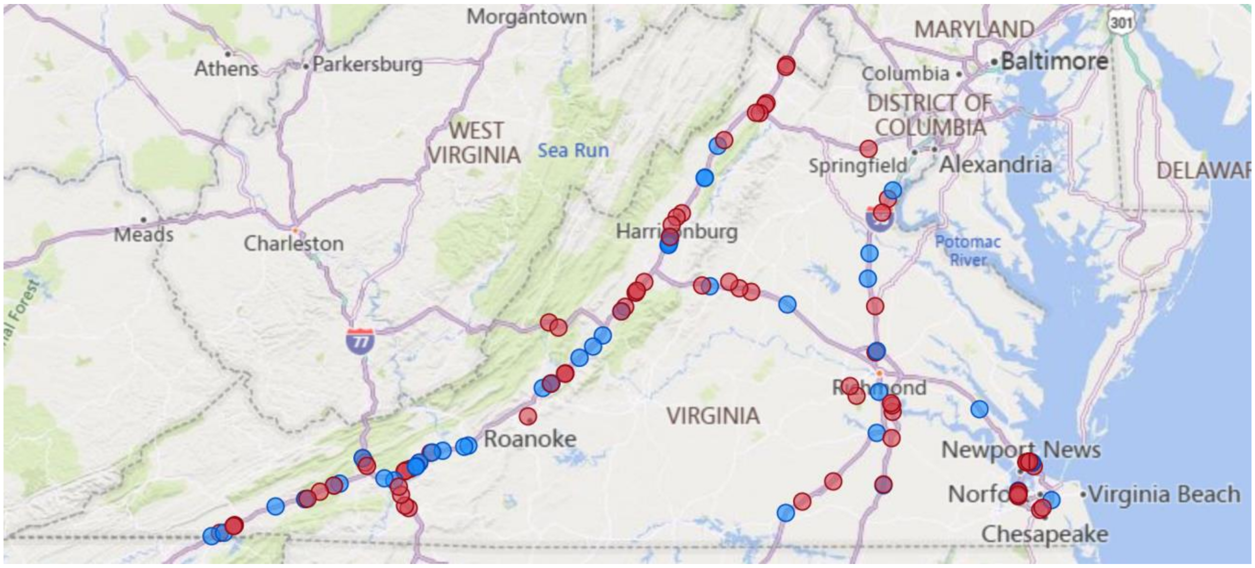

Figure 9. Spatial Distribution of DSD Alert Events by Weekdays (red dots) and Weekends (blue dots) in February 2024.

Estimate the Market Penetration Rate

Figure 10 and Figure 11 present the estimated market penetration rates of in-cab alerts for congestion and DSD events, respectively, along interstates I-64, I-81, and I-95. To ensure sufficient data availability and minimize variability in the estimates, three CCS locations were strategically selected along each interstate, positioned near known alert hotspots. Selecting CCS sites with frequent alerts helps improve the reliability of market penetration estimates by reducing random fluctuations in the data. In contrast, selecting CCS sites with infrequent alerts could introduce higher randomness in the penetration rate calculations, as sporadic alerts may disproportionately affect the results and obscure meaningful trends. Due to trajectory data availability issues, as outlined in the Data Collection and Preparation section, market penetration rate estimation is limited to two periods: January 2023 to May 2023 and January 2024 to May 2024.

Figure 10 illustrates the market penetration rate of congestion alerts along the three interstates. The x-axis represents the study months, while the y-axis indicates the percentage of trucks receiving congestion alerts relative to the total truck volume at the CCS locations. The market penetration rate along I-64 consistently ranges between 10% and 12% throughout both study periods. I-95 shows similar penetration rates, ranging between 8% and 13%. In contrast, I-81 exhibits the lower market penetration rate, remaining stable between 6% and 9%. These results indicate that congestion alerts reach a higher proportion of trucks on I-64 and I-95 as compared to I-81. Additionally, the month-to-month fluctuations in market penetration are relatively small, suggesting that the alert reach remains consistent over time.

Figure 11 illustrates the market penetration rate trends for DSD alerts. The penetration rates for DSD alerts are consistently lower than those for congestion alerts. I-64 again demonstrates higher penetration rate, peaking at approximately 7% in March 2024 and maintaining a range of 5–7% throughout the study period. I-95 exhibits penetration rates between 4–8%, while I-81 fluctuates between 2–5%. A key factor contributing to the lower market penetration of DSD alerts is the transient nature of DSD events. As shown in Table 5, the median duration of DSD events is typically less than 15 minutes, which is shorter than the 15-minute aggregation interval used for CCS volume calculations. This misalignment between event duration and volume aggregation can lead to an underestimation of the actual market penetration rate for DSD alerts, as some DSD events may not fully overlap with the CCS measurement intervals.

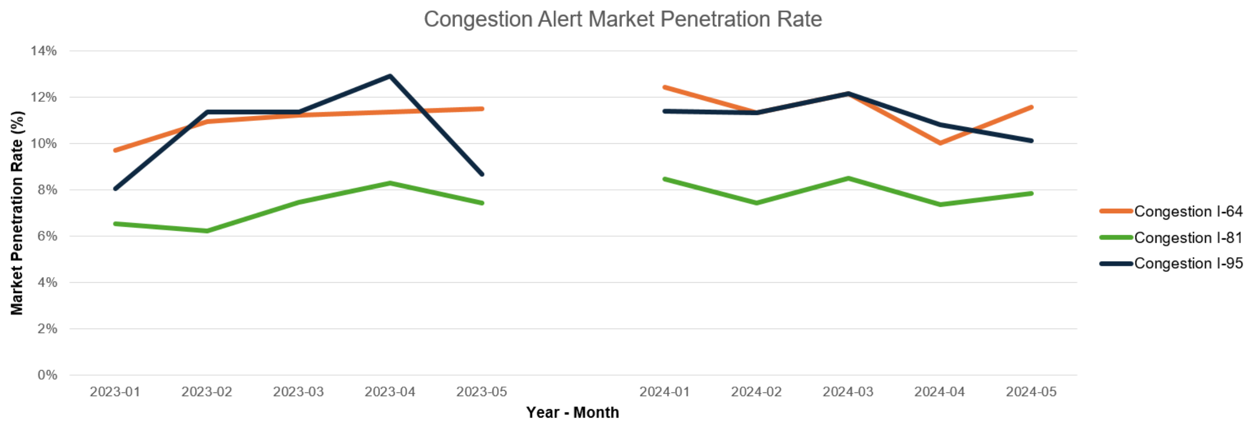

Figure 10. Congestion Alert Market Penetration Rate on I-64, I-81, and I-95.

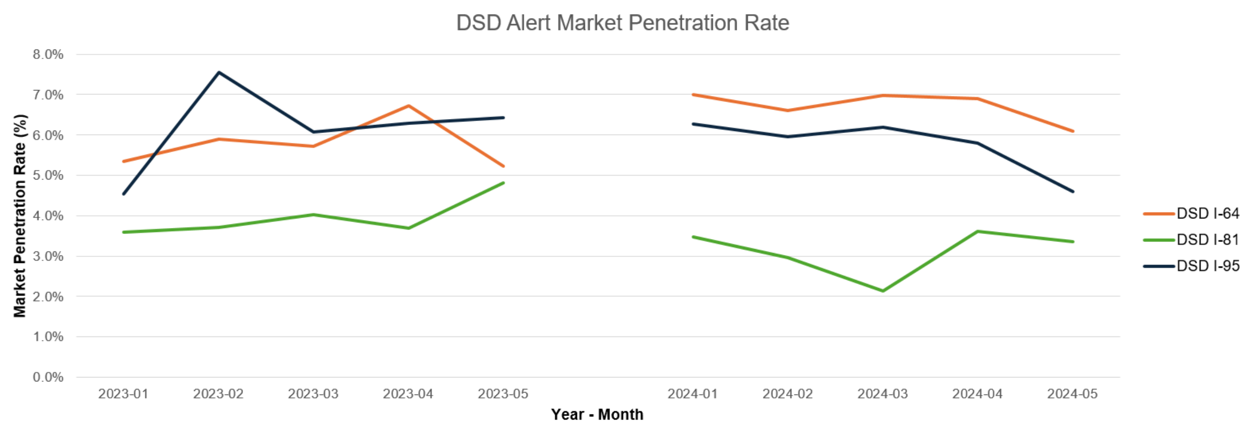

Figure 11. DSD Alert Market Penetration Rate on I-64, I-81, and I-95.

Evaluation of Truck Speed Adjustments Following Alerts

Figure 12 illustrates the speed adjustments of trucks after receiving an alert, showing the distribution of speed changes over time. The dark blue dots represent data points from DSD alerts, while the light blue dots correspond to congestion alerts. The analysis considers only trucks that were initially traveling above 50 mph to remove cases where vehicles were already moving at lower speeds due to congestion or other factors unrelated to the alert. This ensures that observed speed changes more accurately reflect driver responses to the alerts rather than pre-existing conditions. The x-axis represents time in seconds after receiving an alert, while the y-axis shows the change in speed relative to the initial speed. The box-and-whisker plots represent the median, interquartile range, and the 15th and 85th percentile values, while individual data points provide a broader view of the distribution. The majority of trucks maintain a speed change within ±5 mph immediately after receiving an alert. However, as time progresses, the spread of speed changes widens, with an increasing number of trucks exhibiting significant slowdowns. This trend suggests that some trucks maintain their initial speeds but are later, notably after 60 seconds, forced to decelerate upon reaching a congestion queue.

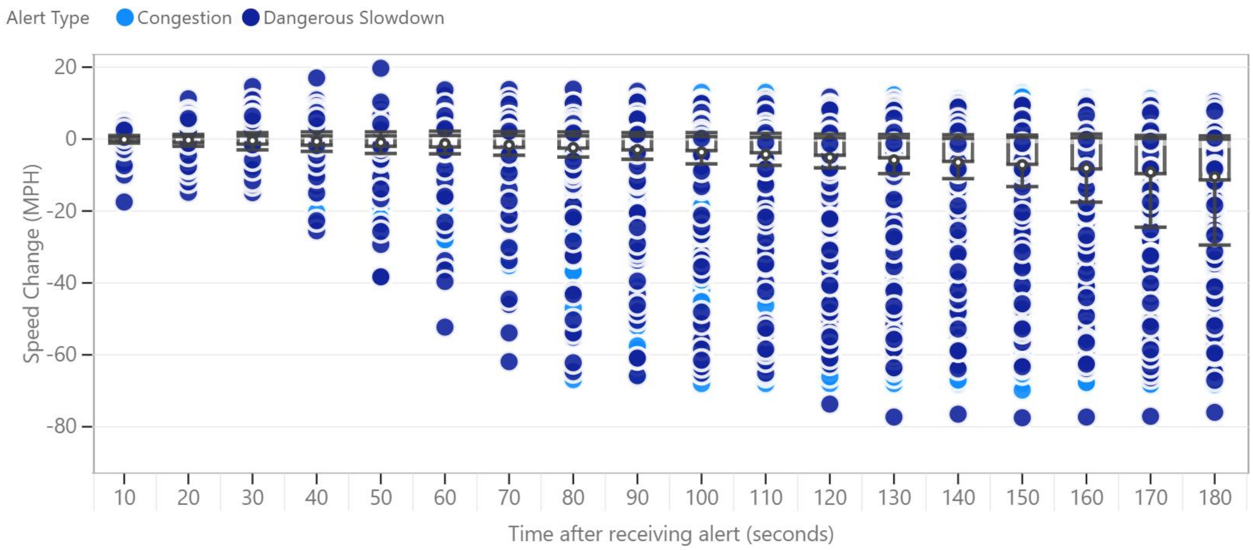

Figure 12. Distribution of Truck Speed Changes Over Time After Receiving Alerts, where the boxes represent the 25th and 75th percentile values.

Table 6 presents the distribution of truck speed reductions at different time intervals (10, 30, and 60 seconds) after receiving an alert, categorized by initial speed groups. The majority of trucks in all speed groups experience a speed drop of less than 3 mph, with values ranging from 91.1% to 95.9%. This suggests that, within such a short timeframe, most drivers do not react immediately with substantial braking or speed adjustments. Trucks initially traveling between 65–70 mph and 60–65 mph are the least likely to slow down, with 95.9% and 95.4% of vehicles, respectively, experiencing a speed drop of less than 3 mph after 10 seconds. In contrast, trucks in the 50–55 mph group show a slightly lower percentage (91.1%), indicating a marginally higher tendency for these vehicles to reduce their speed immediately. This could suggest that lower-speed trucks are already operating in denser traffic conditions or closer to congestion, either prompting a quicker response to alerts, or adjust their speed in response to prevailing traffic speeds. For trucks initially traveling at speeds exceeding 70 mph, the response pattern differs from the other speed groups. In the first 10 seconds after receiving an alert, 92.9% of these trucks exhibit a speed reduction of less than 3 mph, which is slightly lower than the other groups. The slight increase in responsiveness among the highest-speed trucks could be attributed to drivers' recognition of the risk associated with maintaining excessive speeds in the presence of a potential slowdown or congestion ahead. Despite this, the difference remains relatively small, indicating the vast majority of trucks in this category still maintain their speed.

By 30 seconds after receiving an alert, a more noticeable divergence in speed adjustments is observed among different speed groups. For trucks initially traveling at speeds exceeding 70 mph, 76.1% still maintain a speed reduction of less than 3 mph, a significant decrease from the 92.9% observed at T = 10 seconds. This suggests that while most trucks in this category do not immediately react to the alert, a larger proportion begin to slow down as time progresses. Compared to lower speed groups, the >70 mph category shows the most pronounced shift toward greater speed reductions, with 9.7% slowing down by 3–5 mph, 10.6% slowing by 5–10 mph, and 3.6% slowing by more than 10 mph. For trucks in speed groups other than the >70 mph category, the percentage of trucks maintaining their speed (speed drop < 3 mph) gradually decreases as the initial speed decreases. For instance, while 87.5% of trucks in the 65–70 mph group and 87.0% in the 60–65 mph group maintain their speed within 3 mph, this percentage drops to 83.5% for 55–60 mph trucks and 83.2% for 50–55 mph trucks. Simultaneously, the proportion of trucks making more significant speed reductions (>10 mph) increases as the initial speed decreases. In the 65–70 mph and 60–65 mph groups, 1.6% and 2.1% of trucks, respectively, reduce their speed by more than 10 mph. However, this percentage rises to 3.2% for 55–60 mph trucks and further to 4.1% for 50–55 mph trucks. This aligns with expectations, as trucks traveling at lower speeds are more likely to be operating in denser traffic conditions where they may need to slow down more aggressively to accommodate congestion or react to upcoming slowdowns. The trend remains largely the same at T = 60 seconds.

Table 6. Speed Drop of Trucks Following Alerts at Different Time Intervals

Initial Speed (mph)	Speed Drop after *T* seconds (mph)											
	T = 10				*T* = 30				*T* = 60			
	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10
> 70 (*n* = 2,817)	92.9%	4.3%	2.4%	0.4%	76.1%	9.7%	10.6%	3.6%	64.5%	11.5%	13.8%	10.2%
65~70 (*n* = 13,624)	95.9%	2.6%	1.3%	0.2%	87.5%	6.4%	4.5%	1.6%	80.1%	7.3%	7.4%	5.2%
60~65 (*n* = 13,431)	95.4%	2.9%	1.3%	0.4%	87.0%	6.1%	4.8%	2.1%	80.7%	6.6%	7.0%	5.7%
55~60 (*n* = 5,721)	92.2%	4.8%	2.2%	0.9%	83.5%	6.7%	6.5%	3.2%	77.0%	7.2%	7.9%	7.9%
50~55 (*n* = 3,172)	91.1%	4.6%	2.7%	1.5%	83.2%	6.6%	6.2%	4.1%	76.7%	6.6%	6.4%	10.3%

Table 7 and Table 8 present how truck speeds change in the 10, 30, and 60 seconds following an alert on Interstate 95 in the NOVA and Richmond Districts, respectively. Like the previous findings, the vast majority of trucks across all initial speed groups show a small speed reduction—less than 3 mph—within the first 10 seconds (*T* = 10). However, closer inspection reveals noticeable district-level and speed-group-level differences as time progresses.

In Table 7 (NOVA), trucks traveling above 70 mph at the time of the alert exhibit the lowest share maintaining their speed to within 3 mph (83.0%), compared to between 89% and 93% for lower speed groups. This hints that drivers traveling at higher speeds in NOVA are a bit more inclined to start slowing down immediately—perhaps due to heightened risk perception—though the majority still reduce speed by less than 3 mph. By contrast, in Table 8 (Richmond), all speed groups—including those over 70 mph—show 94–96% of trucks keeping their speed drop under 3 mph at *T* = 10. Even the >70 mph group exhibits 95.0% in this lowest reduction category, suggesting that trucks in Richmond are somewhat less likely to begin braking or adjusting speed in the first 10 seconds. One possible explanation is that traffic or roadway conditions on I-95 in Richmond, at least for this dataset, may not prompt the same immediate reaction to alerts as seen in NOVA.

After 30 seconds, more pronounced differences emerge, especially among higher-speed trucks. In NOVA (Table 7), the >70 mph group's share of trucks reducing speed by <3 mph drops sharply from 83.0% at *T* = 10 to only 46.8% at *T* = 30. Simultaneously, a sizeable fraction moves into the 3–5 mph (19.1%) and 5–10 mph (23.4%) reduction ranges, with 10.6% reducing speed by more than 10 mph. In Richmond (Table 8), while high-speed trucks also begin to decelerate by *T* = 30, the proportion maintaining a speed drop <3 mph (80.6%) remains much higher than in NOVA. The lower percentages in the larger speed-drop categories (only 1.9% >10 mph for >70 mph trucks) suggest that trucks in Richmond are still more likely to hold near-constant speeds, at least in the first half-minute after receiving an alert. Meanwhile, for moderate-speed ranges (60–65 mph, 55–60 mph), a clear majority—over 87%—continues to exhibit less than a 3-mph change, mirroring the trend of relatively modest speed adjustments at this stage.

Overall, these district-level comparisons suggest that while the general pattern of "limited immediate reaction followed by gradually larger speed reductions" holds in both regions, NOVA shows a quicker and more substantial shift toward larger speed drops—particularly for high-speed trucks. This behavior may be attributed to the much denser traffic in NOVA, prompting drivers to respond more quickly to alerts or anticipated slowdowns. Meanwhile, in Richmond, the majority of trucks remain in the "speed drop <3 mph" category for a longer period, reflecting that local conditions may allow drivers to maintain their speed somewhat longer before making more significant adjustments.

Table 7. Speed Drop of Trucks Following Alerts at Different Time Intervals for Interstate I-95 in NOVA District

Initial Speed (mph)	Speed Drop after *T* seconds (mph)											
	T = 10				*T* = 30				*T* = 60			
	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10
> 70 (*n* = 47)	83.0%	8.5%	4.3%	4.3%	46.8%	19.1%	23.4%	10.6%	29.8%	10.6%	31.9%	27.7%
65~70 (*n* = 437)	89.2%	5.5%	4.3%	0.9%	66.8%	13.3%	14.2%	5.7%	52.9%	15.8%	16.7%	14.6%
60~65 (*n* = 735)	93.6%	3.0%	2.6%	0.8%	77.1%	7.5%	10.1%	5.3%	65.6%	10.3%	11.8%	12.2%
55~60 (*n* = 459)	90.4%	4.8%	2.4%	2.4%	80.6%	6.1%	6.3%	7.0%	70.8%	8.7%	8.1%	12.4%
50~55 (*n* = 305)	93.1%	1.3%	3.0%	2.6%	85.0%	3.9%	5.9%	5.2%	83.3%	3.9%	2.6%	10.2%

Table 8. Speed Drop of Trucks Following Alerts at Different Time Intervals for Interstate I-95 in Richmond District

Initial Speed (mph)	Speed Drop after *T* seconds (mph)											
	T = 10				*T* = 30				*T* = 60			
	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10	< 3	3 ~ 5	5 ~ 10	> 10
> 70 (*n* = 160)	95.0%	3.1%	1.9%	0%	80.6%	6.3%	11.3%	1.9%	70.6%	15%	8.1%	6.3%
65~70 (*n* = 1,573)	96.6%	2.2%	1.1%	0.1%	88.8%	6.4%	3.8%	1.0%	81.5%	8.5%	7.1%	2.9%
60~65 (*n* = 1,976)	96.0%	2.6%	1.3%	0.1%	87.9%	6.3%	4.5%	1.4%	81.0%	7.8%	6.8%	4.4%
55~60 (*n* = 790)	94.8%	2.9%	1.6%	0.6%	88.9%	4.7%	4.1%	2.4%	82.4%	5.8%	6.2%	5.6%
50~55 (*n* = 289)	95.2%	1.7%	2.1%	1.0%	88.2%	3.1%	4.5%	4.2%	80.3%	7.6%	5.2%	6.9%

Case Study: VDOT's Use of an In-Cab Alert System for Emergency Weather Notifications

VDOT actively monitors roadway and weather conditions to identify potential hazards that may significantly impact truck travel, including winter storms, flooding, and other severe weather events. When hazardous conditions are identified, VDOT sends email requests to the alert system operator, specifying details such as location coordinates, roadway directions, and the approximate geofencing area. These requests may include messages such as "VA Winter Storm Friday – Expect Icy Conditions" for a specified timeframe or "Rt 58 at Forest Road 90, Road closed in both directions due to washout - barriers are in place, 36.650072, -81.705617 to 36.645111, -81.736228," with flexibility for the alert system operator to adjust language to align with their platform's format.

Once the request is received, the alert system operator configures a geofence around the designated location, ensuring that trucks equipped with the in-cab alert platform receive notifications when entering the affected area. These alerts provide truck drivers with critical, real-time information to help them prepare for hazardous conditions. The system retains alert data for 90 days before it is automatically removed. While VDOT staff maintain records of these alert requests through email, a centralized log exclusively dedicated to emergency alerts is not currently in place. In 2024 and 2025, VDOT has issued alerts for hurricane-related closures, major construction projects, and other emergency events that impact roadway access in addition to weather related alerts.

Example of Monthly Alert Activity: January 2025

In January 2025, VDOT issued several emergency alerts, including winter weather notifications on January 3 and January 9, and a special alert for the "495Next Big Beam Weekend" on January 23, which was submitted by the NoVA district. A staff member from the alert system operator provided a summary table outlining the total number of alerts issued and the number of unique vehicles reached at various geofenced locations. Table 9 shows the locations, coordinates, and the volume of custom weather alerts delivered to drivers.

Table 9. Custom Weather Alert Locations, Coordinates, and Counts

Site ID	Road	Location	Bearing	Approx. Fence Location	#Alerts	#Vehicles
18663	I-64	Richmond	EB	37.49772687873108, -77.03706343424797	1207	901
18664	I-64	Charlottesville	WB	38.02117502003614, -78.41836832440173	774	656
18665	I-81	Winchester	SB	39.22815507858032, -78.13678486275954	2587	2204
18666	I-64	Norfolk	NB	36.80281189617214, -76.19811004339111	324	258
18667	I-64	Williamsburg	NB	37.252384169318645, -76.64198177420738	1069	746
18668	I-64/I-77	Beckley WV	SB	37.84009175913585, -81.22688967276163	1761	1599
18669	I-64	Lewisburg WV	EB	37.82178145053194, -80.44133360123128	372	335
18670	I-26	Johnson City TN	NB	36.3040219239346, -82.33536877279617	731	624
18671	US 25E	Middlesboro KY	SB	36.65690448599177, -83.7009879710357	268	226
18672	I-85	Henderson	EB	36.32342647651675, -78.45642952138567	1029	867
24113	I-81	Bristol	NB	36.65829483642459, -77.55698208994467	1538	1370
18673	I-95	Emporia	NB	36.65895520933564, -77.55727477710417	1791	1308
24114	I-95	MD Border	SB	38.784951811068886, -77.17871914603423	2663	1971
24115	I-95	South of Richmond	SB	37.37382786338402, -77.4059443300304	2130	1592
24116	I-95	South of Petersburg	SB	37.21047455125037, -77.37161013617178	893	708
24117	I-95	North of Petersburg	NB	37.2661596132283, -77.39632339087768	1998	1498
24118	I-95	North of Richmond	NB	37.682580478081206, -77.4517273350617	3226	2230

Emergency alerts extended beyond Virginia’s borders to include major trucking corridors in nearby states such as Maryland, West Virginia, Tennessee, and Kentucky. This broad geographic reach ensures that truck drivers approaching Virginia can receive critical alerts before entering affected areas. Because the system retains data for only 90 days, maintaining a record of these alerts requires proactive downloads for any long-term analysis or correlation with crash and traffic data.

Challenges and Considerations

Efficient record-keeping is essential to maintaining an effective emergency alert program. While VDOT staff currently rely on email archives to track alert requests, a centralized logging system could enhance accessibility and organization. The in-cab system has been found to reach approximately 6–12% of trucks on Virginia's interstates, a penetration rate that may remain consistent during major weather events. Additionally, due to the 90-day retention policy, agencies seeking to analyze the effectiveness of emergency alerts must retrieve data in a timely manner.

Unlike DSD or congestion alerts, emergency alerts—especially those related to weather—do not directly trigger vehicle trajectory tracking. As a result, their impact is more challenging to quantify through immediate speed changes. Instead, these alerts may influence drivers' decisions regarding route selection or departure timing, variables that are inherently more difficult to measure with available data.

Summary

Strong coordination between VDOT's Corridor Management team and the alert system operator is essential for ensuring timely notifications during weather-related and other emergency events. By identifying hazardous areas quickly and issuing precise requests, VDOT can help drivers navigate safely through challenging conditions. Given that alert data is only available for 90 days, reviewing its effectiveness must be done soon after events occur. Establishing a more structured approach to logging and archiving alerts would enhance VDOT's ability to assess long-term trends and refine alert strategies.

Economic Breakeven Analysis

VDOT purchases the ability to post congestion and DSD alerts from the in-cab alert provider via the Eastern Transportation Coalition, who in turn holds the contract with the provider. The cost to VDOT is 2023 was $228,453. These costs are generally in-line with those from other states as reported in the stakeholder interviews conducted as part of this study and from Ohio's published payments (Kidando et al. 2024).

In one year between June 2023 and May 2024, alerts were issued to 128,423 trucks at unique events. This figure removes redundant alerts pushed to the same truck and the same event. The effective cost to VDOT is $1.78 per truck notified per event. The values are shown in Table 10.

Table 10. Alert Counts and Costs

Metric	Value
VDOT's 2023 cost	$228,453
Alerts issued in one year (June 2023–May 2024)	128,423
VDOT cost per alert per truck	$1.78

The economic costs of crash events were obtained from the US Department of Transportation (2024). Dividing these values by the annual cost of the contract yields the number of crashes that must be prevented by any single severity to produce a benefit-cost ratio greater than 1. As one example, a fatal crash has an economic cost of over $14 million dollars. At an annual cost to VDOT of $228,453, one fatal crash must be prevented every 64 years to justify program costs. Time-value of money is ignored as contract costs are not based on an initial investment but are paid annually and expected to increase with inflation. Similarly, adjustments for inflation were not considered as the cost of the contract and the economic costs of crashes are both assumed to increase at the same rate. If contract costs increase at a rate faster than crash costs, then more crashes would need to be prevented. Conversely, if crash costs increase at a rate faster than contract costs, then fewer crashes would need to be prevented.

Estimates of required crash reductions to breakeven on costs to VDOT are shown in Table 11. It should be noted that only one crash severity level must be met to achieve a benefit-cost ratio of 1 or greater. For example, if one fatal crash is avoided in the first 64 years, then the benefit-cost ratio would exceed one even if there were no change in injury and PDO crash rates.

Table 11. Crashes Avoided to Justify Costs of Providing In-Cab Alerts

Crash Severity	Costs (2023 USD)	Events Prevented to Attain a Benefit-Cost Ratio of 1.0	Time Between Events Prevented to Attain a Benefit-Cost Ratio of 1.0
Fatal	$14,806,000	0.02	64 years
Injury	$329,500	0.69	17 months
Property Damage Only	$9,500	24.05	2 weeks

VDOT also incurs some direct costs from truck crashes. On Interstate freeways in the Bristol, Fredericksburg, Richmond, Salem, and Staunton districts, VDOT manages a towing and recovery incentive program (TRIP) where tow companies receive monetary incentives for clearing commercial vehicle crashes within 90 minutes of notification. The program operates on 633 Interstate centerline miles on sections of I-95, I-64, I-85, and I-66, as well as the entire Virginia lengths of I-81, I-77, I-381, I-581, I-295, and I-195 (Parsons 2023). Between 2022 and 2023, VDOT paid $3.6 million in incentives to tow companies across 1,292 commercial vehicle crashes. The average incentive costs borne by VDOT is $2,787 per TRIP-activated event. Therefore, each TRIP-activated event prevented by the in-cab alert system would improve the benefit-cost ratio by 0.012. As an example, if the economic costs generate a benefit-cost ratio of 1, and the in-cab alerts prevent an additional 4 crashes annually, the new benefit-cost ratio would be 1 + (0.012 x 4) = 1.048.

CONCLUSIONS

- *Field testing revealed generally consistent alert delivery with some timing concerns at complex intersections.* While alerts were delivered reliably at the same locations across multiple test runs, testing identified cases where alerts were triggered during turning maneuvers at intersections. This suggests a need for more careful placement of geofencing boundaries near complex roadway features to avoid delivering alerts during challenging driving maneuvers.

- *The estimated market penetration rate of the in-cab alert system varies across interstate corridors, generally ranging from 6% to 12%.* Using FHWA Class 8 and above as a proxy for the truck fleet, I-64 shows a penetration rate between 10–12%, I-95 between 8–12%, and I-81 between 6–8%. Despite variations across interstates, the month-to-month penetration rates remain relatively stable. These findings indicate that while a portion of trucks on Virginia's highways are receiving alerts, there is potential for further expansion to enhance system coverage and effectiveness.

- *A congestion alert typically notifies 2 to 7 trucks per event (median), while DSD alerts usually notify only 1 truck.* On average, I-81 (10.24 trucks), I-95 (9.32 trucks), and I-495 (7.65 trucks) have the highest truck alert counts per congestion event across interstates, with median values of 7, 6, and 4 trucks, respectively. For DSD events, the average number of alerted trucks remains lower, with I-95 (2.33), I-81 (2.09), and I-77 (2.06) report the highest truck alert counts per event. The median for DSD alerts remains 1 or 2 trucks across all interstates, reinforcing the trend that longer congestion events notify more vehicles than transient DSD events.

- *Drivers respond differently to safety alerts based on their initial speed and traffic conditions.* Trucks generally maintain their initial speed immediately after receiving an alert (T = 10 seconds), with over 91% experiencing a speed drop of less than 3 mph. However, as time progresses, the proportion of trucks slowing down increases. Trucks traveling at lower initial speeds (50–55 mph) are more likely to reduce their speed compared to those at higher speeds. This suggests that that lower-speed trucks may already be operating in denser traffic conditions or closer to congestion, and therefore either respond more promptly to alerts or adjust their speed in response to prevailing traffic speeds.

- *The in-cab alert system provides an effective platform for emergency weather notifications*. VDOT successfully uses the system to notify trucks of weather hazards, construction events, and emergency closures, with alerts reaching beyond state borders to warn approaching vehicles. However, the 90-day data retention policy and lack of centralized logging make it difficult to assess long-term effectiveness. While the system reaches 6–12% of trucks during weather events, the impact on driver behavior is harder to quantify than for congestion alerts since emergency notifications do not trigger trajectory tracking.

- *Large carriers utilize in-cab alerts along with other safety technologies and report positive initial results, though alert redundancy may limit additional safety benefits.* Interviews with two major carriers (operating 10,500 and 14,000 trucks respectively) revealed successful integration of in-cab alerts with electronic logging devices and driver tablets, alongside advanced driver assistance systems (ADAS). While carriers report positive behavioral changes and fewer near-misses, the concentration of in-cab alert systems among ADAS-equipped fleets suggests its safety benefits might be partially redundant. Given that consortium members representing 6% of national truck VMT widely use both systems, expanding in-cab alert systems to carriers without ADAS could yield greater safety improvements.

- *Transportation agencies generally support the use of in-cab alerts despite concerns about penetration rates and costs, with early effectiveness data showing promising results.* While agencies report penetration rates of only 8–10%, experiences have been generally positive with measurable speed decreases for alerted vehicles. Agencies are exploring solutions to improve market penetration, including the Eastern Transportation Coalition's consideration of a data portal that would allow other ELD developers to access congestion data.

- *Conversations with other transportation agencies suggest opportunities for coordinated purchasing to reduce costs.* In-cab alerts are currently purchased by individual states. Most of the transportation agencies interviewed, when asked about the possibility of negotiating group pricing for in-cab alert systems, expressed interest in potentially using collective negotiation to further reduce contract costs. The Eastern Transportation Coalition already serves as the primary procurement avenue through which multiple (but not all) member states, including VDOT, purchase in-cab alerts. A coordinated approach through existing partnerships could potentially reduce the current contract costs.

RECOMMENDATIONS

1. *VDOT's Traveler Information Program Manager should continue providing congestion alerts to trucks via Drivewyze at current costs and system characteristics.* Drivers appear to maintain or lower speeds after receiving alerts, either in response to the alerts or upon encountering congestion. Issuing in-cab alerts supports drivers' requests for additional in-cab information as documented in the 2019 VTRC report *Traveler Information for the Commercial Vehicle Operations Community*. At the current amount VDOT pays to issue Drivewyze alerts, a reduction of one injury crash every 17 months would offset system costs.

2. *VDOT's Traveler Information Program Manager should investigate the potential for partnering with other states for reduced pricing.* Since VDOT has partnered with Drivewyze, five additional agencies have begun issuing alerts. As more states grow, there may be opportunities to renegotiate the contract via coordination with other agencies or through coordination among Eastern Transportation Coalition member agencies.

IMPLEMENTATION AND BENEFITS

The researchers and the technical review panel (listed in the Acknowledgments) for the project collaborated to craft a plan to implement the study recommendations and to determine the benefits of doing so. This is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, VDOT's Traveler Information Program Manager will within one year of publication of this report extend the contract with Drivewyze contingent on a reasonable price increase and no significant reduction in market share of commercial vehicles receiving Drivewyze congestion alerts. The Virginia Transportation Research Council will assist with estimating Drivewyze market penetration upon request.

With regard to Recommendation 2, VDOT's Traveler Information Program Manager will within two years of the publication of this report, investigate the potential for renegotiating a lower price for issuing alerts, potentially through a partnership with other transportation agencies or groups such as the Eastern Transportation Coalition. These discussions are contingent on the relative changes in Drivewyze market penetration, as measured by the Virginia Transportation Research Council upon request.

Benefits

The benefit of implementing Recommendation 1 is continued access to a system that demonstrates positive safety impacts while being cost-effective. Economic breakeven analysis shows that avoiding just one injury crash every 17 months would justify the system costs. Commercial vehicle operators have specifically requested this type of in-cab information, suggesting the system addresses an identified need in VDOT's traveler information program.

The benefit of implementing Recommendation 2 is potential cost savings through coordinated purchasing power. With eleven state transportation agencies now using Drivewyze for congestion alerts, there may be opportunities to negotiate lower prices through partnerships. The Eastern Transportation Coalition currently negotiates contracts for several member states including VDOT, which may serve as a framework for coordination. A contract that reduces costs by 25% would save VDOT $57,000 per year.

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