Determining the Effectiveness of Commercial Vehicle Safety Alerts

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Prepared for:
The Ohio Department of Transportation,
Office of Statewide Planning & Research

Project ID Number: 118084

September 2024

Final Report

Technical Report Document Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/OH-2024/25		
4. Title and Subtitle		5. Report Date
Determining the Effectiveness of Commercial Vehicle Safety Alerts		**September 2024**
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
Emmanuel Kidando, Angela Kitali, Mohammad Jalayer, Panick Kalambay, Jeffrey L'Amoreaux, Amir Ibrahim, Meshack Mihayo, Abdul Ngereza, Deep Patel, Md Sadman Islam		
9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
Cleveland State University 2121 Euclid Avenue Cleveland, Ohio 44115-2214		11. Contract or Grant No. **39166**
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered
Ohio Department of Transportation 1980 West Broad Street Columbus, Ohio 43223		**Final Report**
		14. Sponsoring Agency Code
15. Supplementary Notes		
N/A		

16. Abstract

The Ohio Department of Transportation has partnered with Drivewyze to improve safety and mobility on Ohio's highways, focusing on commercial vehicle safety alerts (CVSAs). Through this partnership, Drivewyze provides commercial motor vehicle (CMV) drivers with real-time alerts via in-cab electronic logging devices (ELDs). The alerts are intended to warn drivers about urgent road conditions, providing them with an opportunity to react proactively to incidents. The primary goal of this research project is to assess the effectiveness of Drivewyze alerts, specifically congestion and sudden slow-down alerts, in enhancing safety and mobility on Ohio's highways. A data-driven analysis was used to quantify the mobility and safety effectiveness of Drivewyze CVSAs. The research team also surveyed commercial vehicle drivers, state transportation agencies, and trucking companies to obtain feedback and opinions on the effectiveness of CVSA systems and identify available alternative CVSA systems. Findings from the effectiveness analysis suggest that the use of the Drivewyze system may yield positive returns on safety and mobility. Furthermore, survey results indicate positive feedback about CVSAs and show that Drivewyze has the highest penetration rate compared to similar technologies such as Global Positioning Systems (Garmin, Rand McNally, etc.), Samsara, PrePass, Motive, Geotab, Trucker Path, etc. This report also provides recommendations for enhancing the effectiveness of CVSA systems based on survey data and data-driven analyses.

17. Keywords	18. Distribution Statement
Drivewyze, Commercial Vehicle Safety Alerts, Congestion, Sudden Slowdowns, Safety, Mobility	**No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	**Unclassified**	**72**	

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

Credits and Acknowledgements

The research team extends its gratitude to the ODOT Technical Advisory Committee, specifically Ms. Stephanie Marik and Mr. Timothy Filla, for their invaluable assistance and significant contributions to the research tasks. We also appreciate Ms. Jacqueline Martindale, Project Manager, for her time and assistance in this project. We acknowledge and thank Ms. Martha Kapitanov and the FHWA officials for their tremendous support in the survey task. We would like to acknowledge our survey participants, including the truck drivers, state transportation agencies, and truck companies.

Prepared in Cooperation with the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration

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List of Acronyms

AADT	Annual Average Daily Traffic
AI	Artificial Intelligence
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
BSW	Blind Spot Warming
CDOT	Colorado Department of Transportation
CEA	Cost Effective Analysis
CMF	Crash Modification Factor
CMV	Commercial Motor Vehicle
CRF	Crash Reduction Factor
CSW	Curve Speeding Warming
CVSA	Commercial Vehicle Safety Alert
DMS	Dynamic Message Sign
DOT	Department of Transportation
EEBL	Emergency Electronic Brake Light
ELD	Electronic Logging Device
FCW	Forward Collision Warning
FMCSA	Federal Motor Carrier Safety Administration
IMA	Intersection Movement Assist
ITS	Intelligent Transportation System
GPS	Global Positioning System
GDOT	Georgia Department of Transportation
LCW	Lane Changing Warning
LDW	Lane Departure Warning
LED	Light-Emitting Diode
MEF	Mobility Enhancement Factors
NCDOT	North Carolina Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NJDOT	New Jersey Department of Transportation
NPV	Net Present Value
ODOT	Oregon/Ohio Department of Transportation
OSM	Onboard Safety Monitoring
PSA	Public Service Announcement
RSC	Roll Stability Control
SCE	Safety Critical Events
TxDOT	Texas Department of Transportation
VDOT	Virginia Department of Transportation
VMT	Vehicle Miles Traveled
VIN	Vehicle Identity Number
WIM	Weigh-in-Motion

1. Problem Statements

The Ohio Department of Transportation (ODOT) has partnered with Drivewyze to improve safety and mobility on Ohio's highways, focusing on commercial vehicle safety alerts (CVSAs). This partnership involves providing real-time alerts to commercial motor vehicle (CMV) drivers via in-cab electronic logging devices (ELDs) messaging to notify them about changing roadway conditions, allowing drivers to react quickly and avoid stopped traffic or major slowdowns. This initiative is part of the ODOT's ongoing efforts to improve safety and mobility on Ohio's roads by offering safety alerts to CMV drivers through effective alternative methods.

Despite the potential of real-time alerts to enhance safety and mobility in highway systems, a literature review showed that no data-driven analysis quantifies the benefits of CVSA systems on highways. It is crucial to conduct a data-driven analysis and utilize the outcomes to make well-informed investment decisions in the system. The overall goal of this research project was to assess the effectiveness of the CVSA system in enhancing the safety and mobility of Ohio's roadways. In addition, the project focused on establishing a repeatable methodological framework and tool for benefit-cost analysis (BCA). This evaluation is envisioned to enable ODOT to effectively make informed strategic decisions regarding the use of CVSA systems to complement overhead and roadside digital message signs, an Intelligent Transportation System (ITS) subsystem. Specifically, the project has accomplished the following objectives:

- Evaluated the cost-benefit of the Drivewyze system. The project assessed the financial implications of implementing the Drivewyze system and analyzed its potential benefits in enhancing the safety and mobility of Ohio's highways.
- Identified and evaluated the scope of Drivewyze's services beyond congestion and sudden slowdown alerts.
- Explored alternative CVSA systems and their potential effectiveness. The research team investigated CVSA systems used in other jurisdictions and examined their effectiveness in improving safety and mobility.

The rest of the current report is structured as follows. Section 2 presents the research background, providing context for the project within the broader CMV safety and mobility landscape. Section 3 outlines the research approach, which includes surveys, data, penetration rate approach, and effectiveness analysis. Section 4 presents the results discussion on current practices by state transportation agencies, and trucking companies, as well as the opinions from CMV drivers regarding CVSAs for mobility and safety. Moreover, this section synthesizes the research findings and presents the results of Drivewyze penetration rate, effectiveness, and BCA. Section 5 provides recommendations based on the study findings.

2. Research Background

Commercial vehicle crashes, such as those involving large trucks and buses[1], have persistently posed a significant safety issue in the United States (U.S.). The latest traffic safety data from the Federal Motor Carrier Safety Administration (FMCSA) highlights the alarming toll of fatal crashes in the U.S. According to the FMCSA 2024 report, there were 156,553 crashes involving large trucks on American roadways in 2023 (FMCSA, 2024). These crashes resulted in 4,807 fatalities and 74,001 injuries. In the state of Ohio, between 2016 and 2021 about 909 fatal crashes involving large trucks occurred each year on average (U.S.DOT, 2023). These crashes have predominantly occurred on interstate highways in rural areas, where lower traffic volumes

[1] In the Fatality Analysis Reporting System (FARS), a large truck is categorized as a truck with a gross vehicle weight rating (GVWR) exceeding 10,000 pounds, and a bus is defined as any motor vehicle primarily designed for the transportation of nine or more persons, including the driver (U.S. DOT, 2022).

contribute to CMV drivers frequently exceeding speed limits (U.S. DOT, 2022). The risk of a severe crash increases when sudden traffic slowdowns because of incidents forcing CMV drivers to suddenly decelerate. This congestion, especially when there is a minimal warning about downstream conditions, often hinders CMV drivers' ability to respond promptly, leading to secondary crashes (Lee et al., 2007). A proactive solution to this issue involves providing drivers with timely information well in advance, encouraging them to approach with caution, reduce their speeds, and make other well-informed decisions, thereby mitigating the risk of additional crashes.

Different conventional methods have been used to alert commercial and passenger vehicle drivers on the highways. The Dynamic Message Sign (DMS) and its variations thereof, is an intelligent Transportation System (ITS) subsystem most commonly used alert systems installed on highways to notify motorists of roadway conditions, incidents, special events, weather, environmental conditions, public safety announcements, and other situations that may affect their travel. However, the DMS may pose some challenges in conveying messages effectively due to the high traffic speeds, installation location, and number of text lines and phases used, resulting in drivers struggling to comprehend the information and making imprecise decisions downstream. Other factors include text height, message duration per phase, and malfunctioning panel sections, but these are either adjustable or require maintenance. While DMS devices are often located and placed strategically and operated with messaging efficiency following established guidelines and industry best practices, they are not always located where they are needed. In addition, the DMS may not provide alerts with sufficient warning or may go unnoticed by drivers depending on their ongoing driving tasks or whether they are cognitively or visually distracted. Recognizing the limitations of these roadways ITS devices, a more dynamic and interactive approach that leverages software systems that provide in-cab safety alerts, such as Drivewyze, PrePass, Samsara, Motive, Geotab, and Trucker Path has emerged. This type of system provides real-time information to vehicle drivers about incidents and changing road conditions miles ahead, enhancing situational awareness and promoting safer driving practices. Therefore, in-cab safety alert systems address the limitations of static traditional methods, enhancing the responsiveness and decision-making capabilities of CMV drivers on the road.

In-cab safety systems leverage probe-based traffic data to provide timely information to CMV drivers. To ensure the effective relay of this information, the system is integrated with the ELDs, interactive devices that deliver pertinent information and recommended courses of action to drivers. The efficiency of in-cab systems has led to increasing adoption by numerous transportation agencies across the U.S. Transportation agencies such as the North Carolina Department of Transportation (NCDOT), New Jersey Department of Transportation (NJDOT), Georgia Department of Transportation (GDOT), Pennsylvania Turnpike, and Ohio Department of Transportation (ODOT) have opted for in-cab safety alert systems, partnering specifically with Drivewyze to enhance safety measures and mobility operations in their respective states. It is important to understand that for Drivewyze system currently provides alerts on congestion, sudden slowdown, and more recently, work zone areas in Ohio. Drivewyze monitors probe-based traffic data from INRIX and partners with state DOTs to obtain these alerts. This system does not offer suggestions to drivers on the best actions to enhance mobility and safety; rather, it increases situational awareness for drivers. For instance, if a Drivewyze congestion alert is disseminated to the CMV drivers, Drivewyze does not suggest an alternate route to take to save travel time.

The review of existing literature as presented in this section and Appendix A has brought to light a significant gap, indicating a scarcity of studies evaluating the effectiveness of in-cab safety systems. This highlights the need for transportation agencies to conduct comprehensive assessments of these systems and their impact on safety and mobility. Therefore, this study emerges as a pioneering initiative focused on performing a BCA of in-cab CVSAs, particularly emphasizing the Drivewyze system. The objective is to provide ODOT with crucial and previously unavailable insights, enabling an informed decision-making process regarding their investment in this technology, since the CVSA companies charge state DOTs fees for their services. Therefore, by addressing this research gap, the study aims to contribute valuable information to the transportation sector, facilitating more effective and informed decisions regarding the adoption of in-cab safety alert systems.

3. Research Approach

The following section presents the major tasks that were carried out to address the research objectives. Figure 1 presents an overview of the project, highlighting two key approaches: surveys and a data-driven method for analyzing both mobility and safety effectiveness. These components were utilized concurrently to develop comprehensive recommendations. Detailed discussions of this section are presented in Appendix B and C.

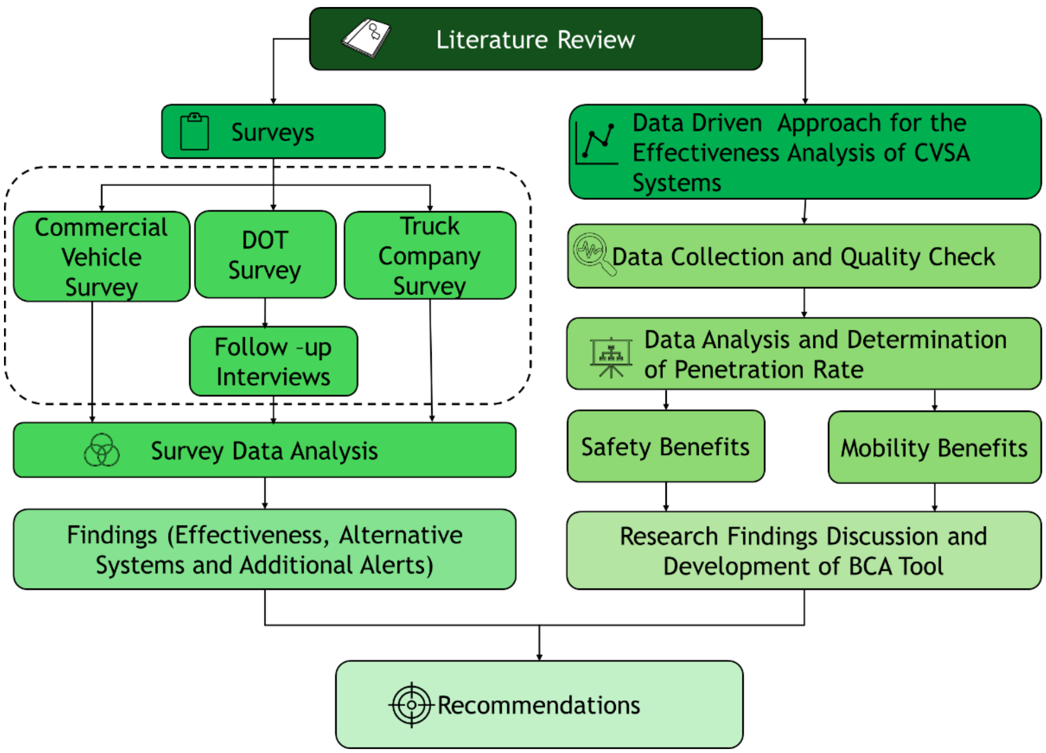


Figure 1: Research Approach Workflow

3.1. Surveys

To obtain feedback and opinions on the effectiveness of CVSA systems and identify available alternative CVSA systems, the research team distributed three surveys using the Qualtrics™ survey tool targeting CMV drivers, state DOT agencies, and trucking companies.

Commercial Motor Vehicle Driver Survey

The research team distributed surveys to CMV drivers at various truck stops along Ohio's freeways to collect drivers' opinions, and usage of the Drivewyze system, and to identify alternative on-board alert systems. The research team statistically estimated a range of about 350 to 450 truck drivers as the sample size. The following steps were taken by the research team to establish the final sample size used for the CMV driver survey.

- The research team obtained truck annual average daily traffic (AADT) of 2022 for freeway segments in Ohio.
- Using the truck AADT, the segments were ranked to identify the top 10 segments (see Table 10 in Appendix B).
- The maximum truck AADT of 2022 was used to estimate the average monthly volume.
- The seasonal adjustment factor (average of urban factors in 7 days) for estimation was obtained from the ODOT website. For the estimation of truck volume for a particular season or month please refer to Equation 10 in Appendix B.
- The team estimated the monthly volume (December, January, and February) for the year 2022 (see Table 11 in Appendix B). The total volume was used as population data to compute the sample size.
- Using the population data above, the estimated number of respondents for the CMV driver survey was 384.

Selection of Truck Stops for Distributing CMV Driver Survey

The state of Ohio has 166 existing truck stops along Ohio's highways. The research team selected 15 (9%) truck stops to distribute the CMV driver survey. The criteria for selection are based on:

- The number of Drivewyze alerts
- Truck volume
- State spatial coverage in the state

Selection Score

The selection was initially done by ranking the 166 existing stops based on a selection score that combined the number of Drivewyze alerts and truck AADT in a segment. The three-mile buffer area around each stop was used to determine the alert counts around truck stops. Other distances of half a mile and one mile were initially selected but did not result in a significant distinction in the number of counts across the stops. Moreover, the truck AADT was assigned to each stop based on the truck AADT of the nearest segment to the stop. The selection score was simply determined by averaging the normalized values of the Drivewyze alert count and truck AADT. Based on the computed score, the 166 stops were ranked, and the top 15 were selected. Equation 1 below describes the formula for computing the score for each stop.

$$selection\ score = 0.5 \times (A + B) \qquad (1)$$

Where A is the normalized Drivewyze alert count within the three-mile truck stop buffer and B is the normalized truck AADT for a segment nearest to the truck stop. The normalization of the Drivewyze alert count and truck AADT was done by subtracting the minimum values from the corresponding value, and then dividing the resulting value by the range of the data.

Spatial Coverage

Following the initial selection, the next step was to account for the spatial coverage of the truck stops. In this step, some of the initially selected stops, particularly those that were closely spaced, were removed, and other replacement truck stops were selected based on their locations. The initial selection resulted in all 15 stops selected close to the cities of Columbus and Cincinnati along I-71 and I-75. To have better spatial coverage in the state, eight of the initial stops were removed, and replaced with locations close to the cities of Cleveland, Toledo, and Akron as well as on the route I-70 in Southeast Ohio. Figure 2 and Figure 3 present the truck stops that were selected for distributing the CMV driver survey.

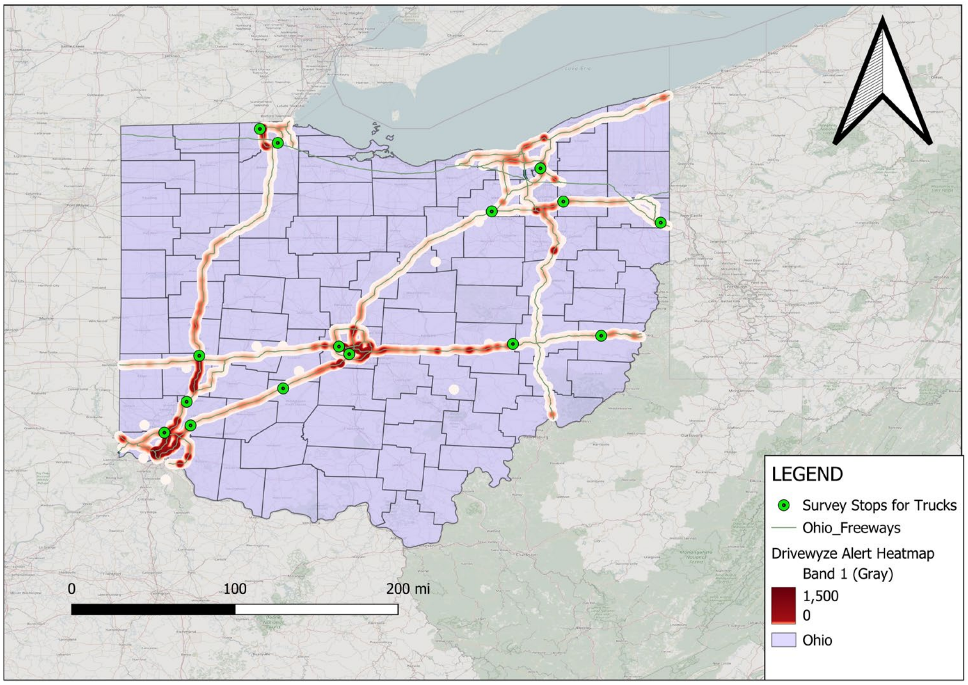


Figure 2: Selected Stops with Drivewyze Alerts Heatmap

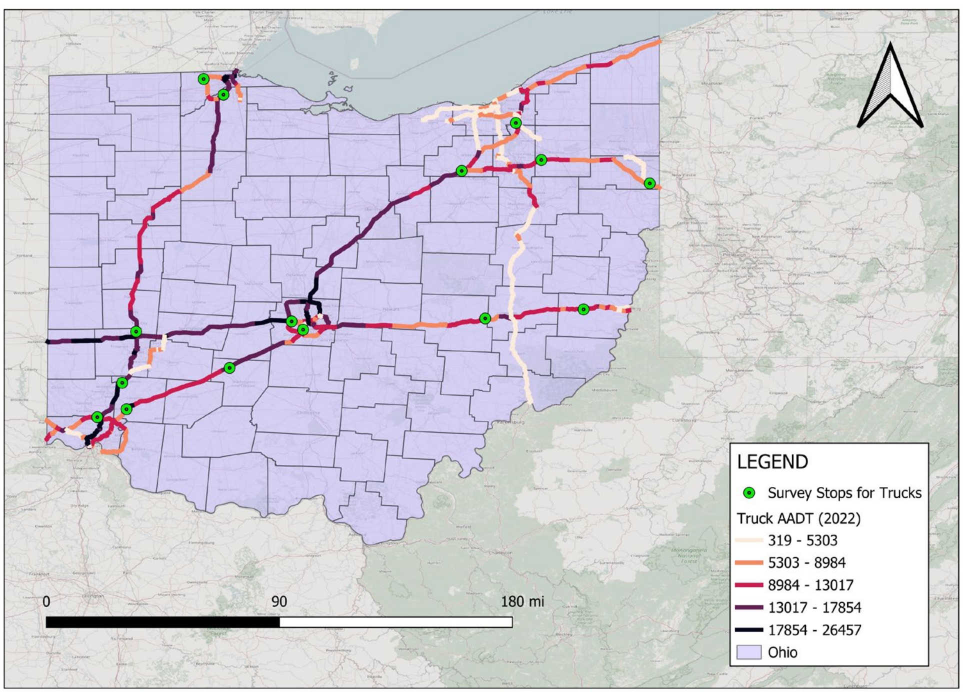


Figure 3: Selected Stops with Truck AADT

State DOT and Trucking Company Survey

The research team developed an 11-question survey, distributed via email to state DOTs, to collect information on in-cab systems used to disseminate mobility and safety alerts to CMV drivers. Follow-up interviews were also requested to obtain more detailed insights into each state's in-house CVSA systems and their effectiveness. The email addresses of key contacts at each state DOT were sourced from their respective websites. Additionally, a separate survey targeting trucking companies was prepared to collect details on the various CVSA systems they use for mobility and safety alerts. The research team collaborated with ODOT and the Federal Motor Carrier Safety Administration (FMCSA) to distribute this survey to trucking companies. Appendix C provides copies of the questions used in the surveys for CMV drivers, state DOT agencies, and trucking companies. These questions were reviewed and approved by the ODOT technical advisory committee before being distributed for data collection.

3.2. Drivewyze Penetration Rate

The penetration rate of Drivewyze in Ohio was determined by analyzing the frequency of congestion and sudden slowdown incident alerts issued for specific roadway segments. This involved computing the ratio of trucks that received these alerts to the total number of trucks that passed through the roadway segments. Specifically, the following data were used in the analysis:

- Drivewyze incident alerts from January 1st, 2022, to January 30th, 2024. The attributes of interest from alert data include:
    - Alert type (congestion or sudden slow down),
    - Start and end timestamps of the incident,
    - Number of vehicles that received the alerts (vehicle/alert counts), and
    - Duration of the incident (minutes).
- Weigh-in-Motion (WIM) data from January 1, 2022, to January 30th, 2024. WIM is an ITS subsystem consisting of sensors installed below a grade of the roadway that records various vehicle characteristics while traveling at normal speed without requiring them to stop. The data collected typically includes axle counts, axle weights, axle spacings, vehicle classification, vehicle length, gross vehicle weights, and vehicle speeds. The WIM data were necessary to provide an exact count of CMVs on a freeway segment. Figure 4 below presents the distribution of the available WIM stations on Ohio's freeways.

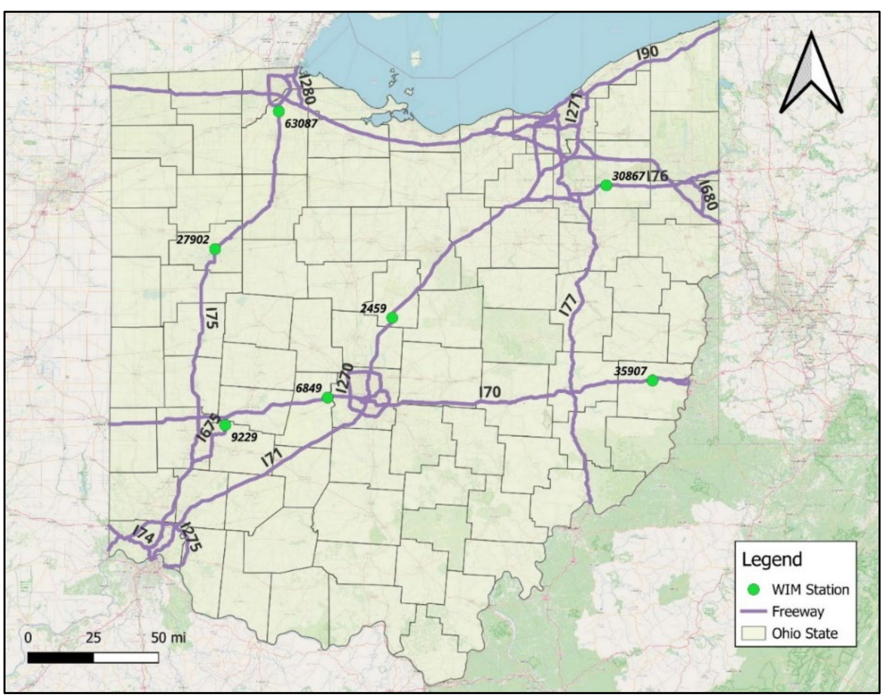


Figure 4: WIM Stations on Ohio Freeways

Penetration rates were estimated for freeway segments where both WIM data and Drivewyze alert data were available. The penetration rate estimation is based on the assumption that CMVs receiving Drivewyze alerts correspond to vehicles classified as class 6 and higher, as defined by the Federal Highway Administration's (FHWA) vehicle classification scheme F. General steps undertaken in computing the penetration rate are summarized in Figure 5.

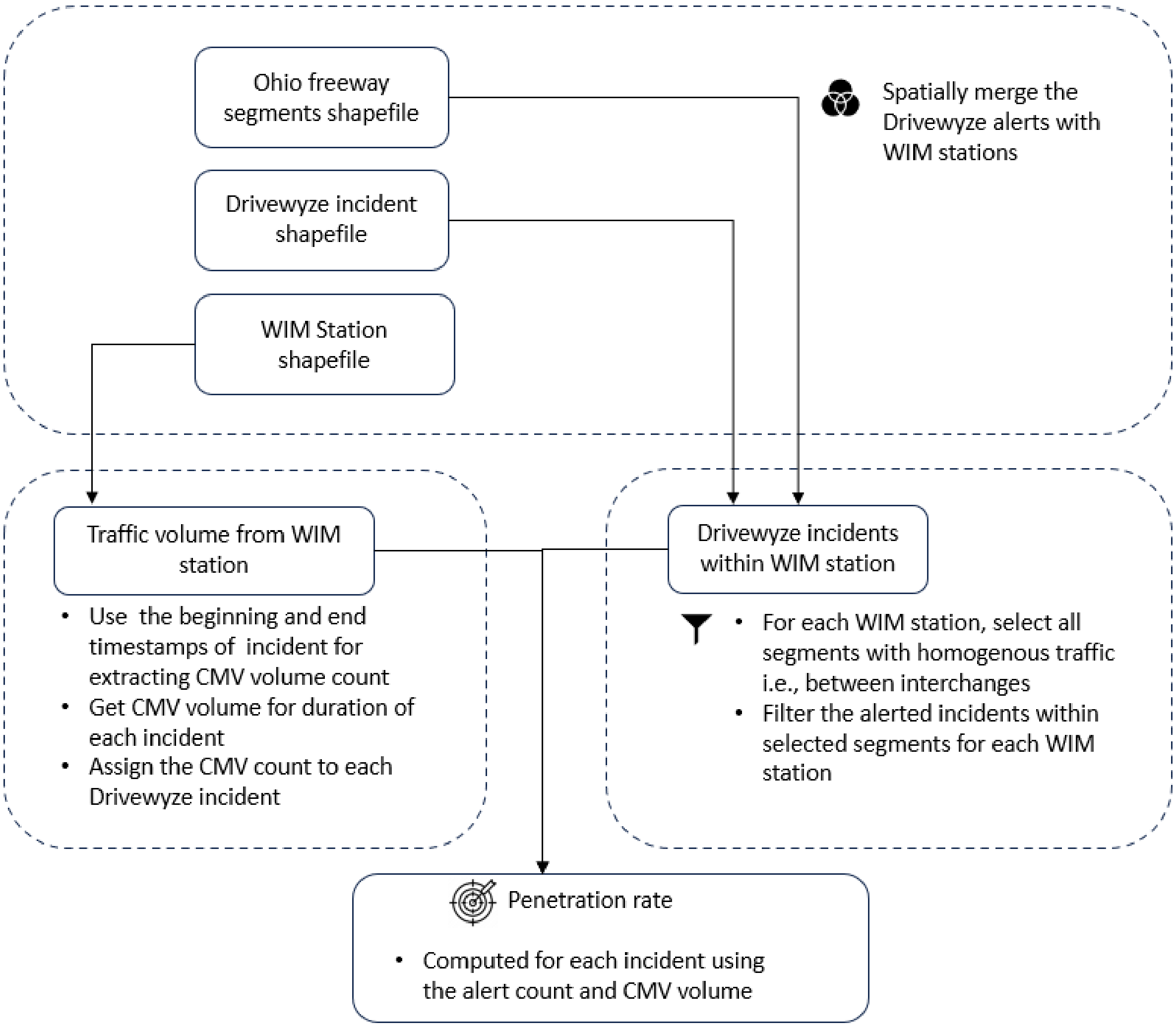


Figure 5: Penetration Rate Computation Workflow

- As illustrated in Figure 5, all WIM stations located on Ohio freeways were identified and mapped in QGIS.
- The locations where CMVs received the Drivewyze alerts were spatially merged with the WIM station locations.
- Drivewyze alerts issued within segments containing WIM stations, defined by entrance and exit ramps, were filtered, and selected as potential counts for the penetration rate analysis.
- Using the beginning and end timestamps of the specific incidents, the CMV counts from individual WIM stations were then aggregated to obtain the total CMV volume.
- The penetration rate (P_r) of the Drivewyze system was calculated for each alert using Equation 2 below.

$$P_r = \frac{\sum V_D}{\sum V_{WIM}} x\ 100\% \quad (2)$$

Where,

V_D is the number of CMVs that received Drivewyze alert(s) for a specific incident, and

V_{WIM} is the number of CMVs that traveled through the WIM count station for the same duration as the incident.

3.3. Safety Effectiveness and Benefit-Cost Analysis

The evaluation of the Drivewyze system's effectiveness and benefit-cost analysis (BCA) involved estimating its impact on CMV congestion-related crashes and secondary crashes. The assumption is the Drivewyze alert system addresses these two types of crashes on freeways. This comprehensive analysis is detailed in the following sections.

3.3.1. Identifying Secondary Crashes

Secondary crashes are crashes that result from the primary crash downstream within a specified incident duration. Crash data for six years from January 1st, 2018, to December 31st, 2023, were extracted from a database. Crashes involving CMVs were identified and verified by reviewing the vehicle identification number (VIN). Using the VIN, vehicle information was scraped from the National Highway Traffic Safety Administration's (NHTSA) VIN Decoder website (https://vpic.nhtsa.dot.gov/decoder).

Identifying secondary crashes, as defined in the literature, extends beyond just the primary crash site and includes evaluating its temporal and spatial impact areas (Hongbing & Asad, 2010; Kitali et al., 2018; Yang et al., 2014). The team employed a static approach using a three-mile distance threshold and the primary crash's duration to identify secondary crashes that occurred in the vicinities of the primary crashes on freeways. Based on previous studies, this distance threshold is adequate in identifying secondary crashes (Hongbing & Asad, 2010; Kitali et al., 2018; Yang et al., 2014). The following steps summarize the procedures undertaken to identify secondary crashes.

- Step 1: Compare the crash report time and crash scene clearance time of each crash with every other crash in the database.
- Step 2: Identify potential secondary crashes by matching crash times that fall within the primary crash duration.
- Step 3: Exclude crashes not in the same direction and that occurred beyond three miles of each other and those that exceeded 180 minutes.
- Step 4: Filter out pairs that crashes were not associated with at least one CMV secondary crash.
- Step 5: Review crash narratives to confirm if CMV secondary crashes were related to stopped traffic downstream and the vehicle at fault.
- Step 6: Select the pair that involved a CMV as the at-fault vehicle type in a crash. These pairs of crashes were assumed to be secondary crashes. If the Drivewyze alert system is effective, it will address this type of crash.
- Step 7: Use mapping software to validate the pair of crashes (primary and secondary crashes) and their sequence.

3.3.2. Identifying Congestion-Related Crashes

Congestion-related crashes were also considered a safety measure of effectiveness for the Drivewyze alert system. CMV crashes and INRIX probe-based speed data from January 2018 to December 2023 were used to identify congestion-related crashes. Speed data were extracted from the INRIX repository for all freeway segments, aggregated at 5-minute intervals. The following procedures were employed to detect CMV congestion-related crashes.

- For each CMV involved in a crash, trace the speed profile 30 minutes before.
- Review each crash, and if there is a 35-mph speed drop compared to the INRIX reference speed within three miles downstream, then label these crashes as potential congestion-related crashes. INRIX reference speed reported in the data was considered as the free flow speed in the calculation.
- For labeled potential congested-related crashes, review the crash narrative to determine if the crash occurred when the CMV was approaching a queue and identify the vehicle at fault.
- For crashes without a narrative, use the manner of collision, particularly rear-end or sideswipe, suggesting that the CMV failed to maintain adequate headway.
- Select crashes where the CMV is identified as the at-fault vehicle, and the crash occurred when the vehicle was joining a stopped queue.

Figure 6 below graphically illustrates how congestion-related crashes were identified following the above procedures. It is based on the assumption that if the Drivewyze alert system effectively provides congestion alerts, then Drivewyze will prevent such crashes by giving drivers sufficient time to react to roadway incidents.

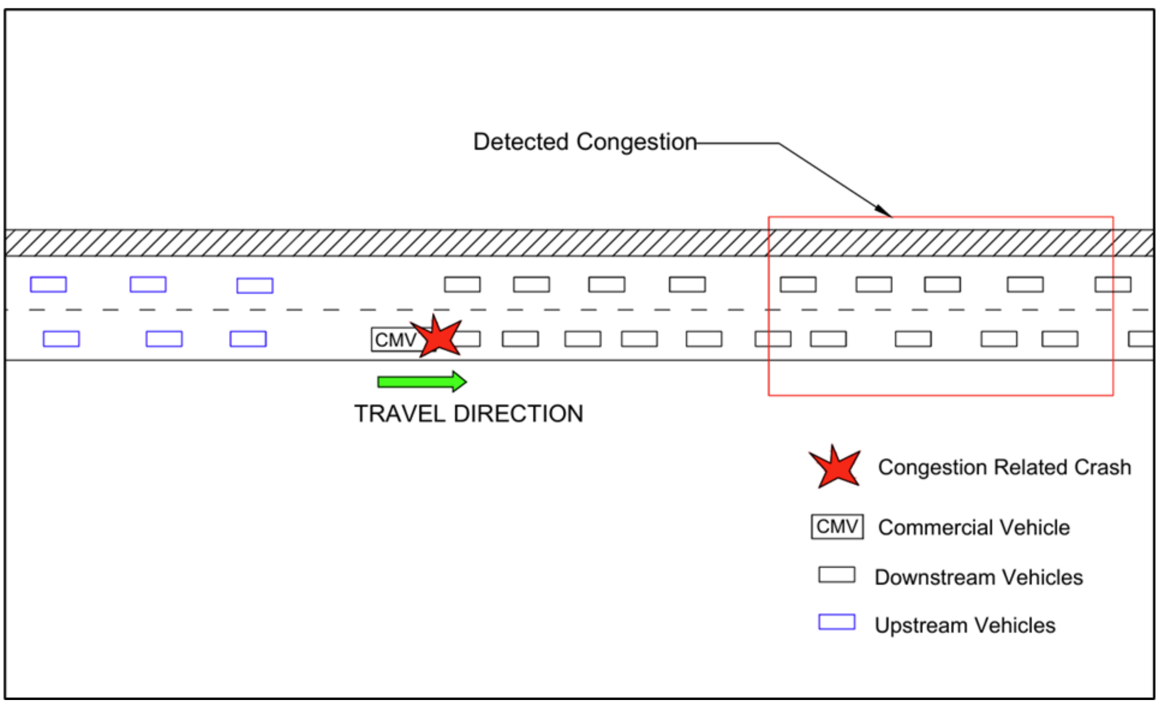


Figure 6: Schematic Presentation of Congestion-Related Crash

3.3.3. Delays from Congestion-Related Crashes

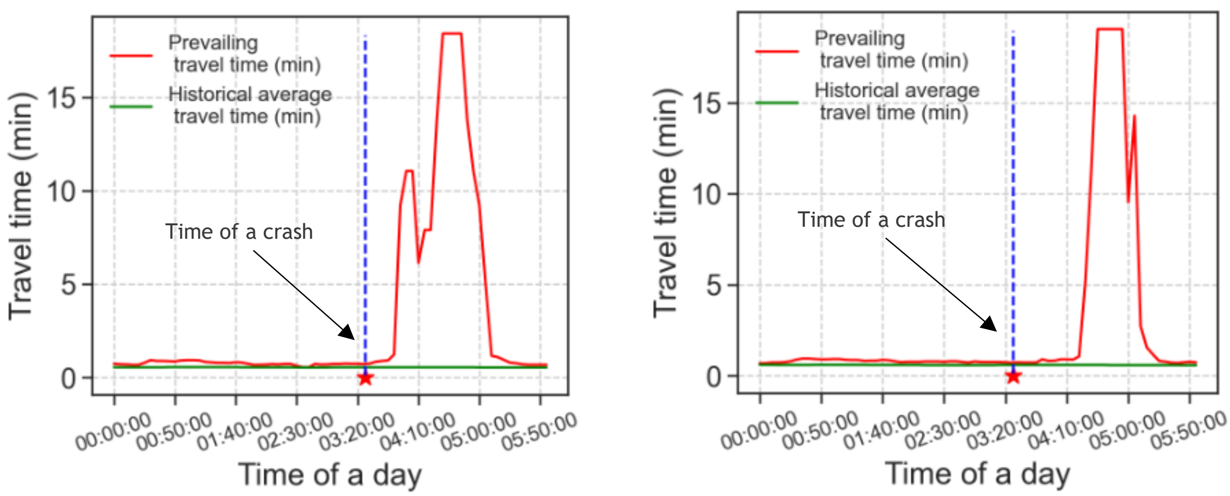
For mobility effectiveness analysis, it is important to note that Drivewyze currently provides alerts to CMV drivers without offering specific actions to improve mobility and safety including suggesting alternative routes to avoid congestion. As a result, directly linking the benefits of Drivewyze alerts to freeway mobility improvements is challenging. To address this, the study evaluated the reduction in travel time delays upstream of congestion-related crashes as an alternative method for assessing the mobility benefits of Drivewyze. The analysis assumed that each CMV-involved crash caused by congestion would lead to increased travel time for upstream traffic. Below are procedures used to estimate these delays.

Procedures for Estimating Delays

- For each congestion-related crash, the travel time/speed profiles of prevailing travel times were compared to the historical average values on upstream XD segments (using INRIX data). The historical average travel time was used as a baseline to account for recurring congestion on segments. It was assumed that in the absence of a crash, the travel time would closely match the historical average for each segment.
- The delay was computed for a distance and time threshold determined by the profile of the actual speed upstream of the crash. More specifically, the time when the prevailing travel time profile reverted to the historical average speed profile was used as the cutoff point (Figure 7) for each segment affected by each crash.
- For each CMV congestion-related crash, the delay was determined by computing the difference between the prevailing travel times and the historical average travel times at each segment (see Equation 3 below).

$$\textit{delay (min)} = \textit{prevailing travel time (min)} - \textit{historical average travel time (min)} \qquad (3)$$

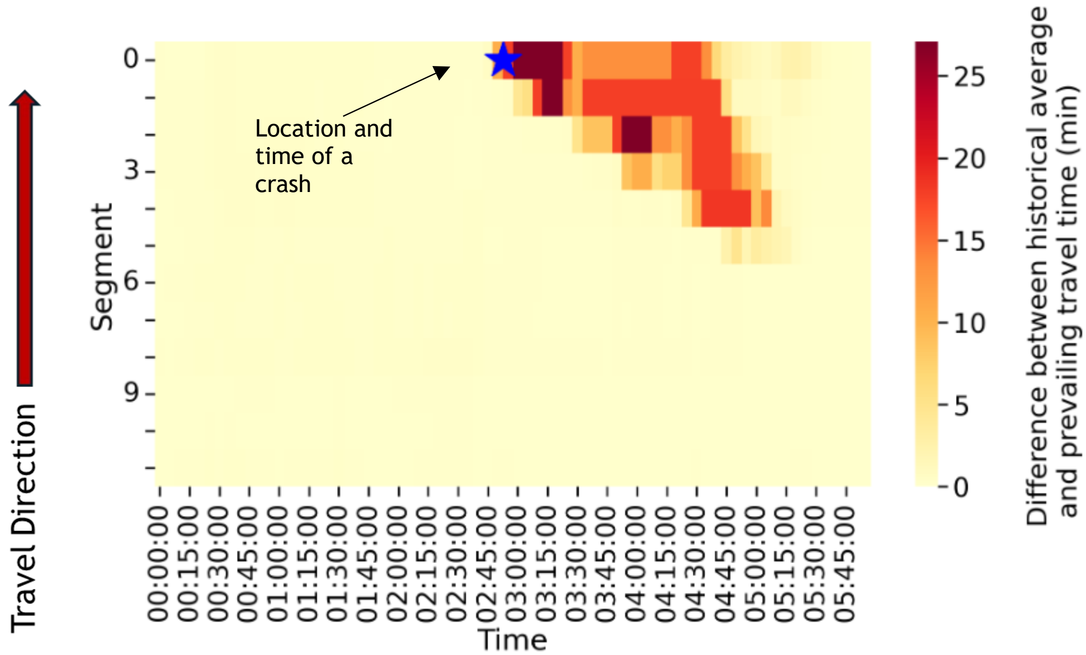
- The delays were accumulated based on the segments affected per each CMV congested-related crash.
- The non-recurrent congestion duration for each CMV crash was also recorded. This duration was determined from the travel time profiles, spanning the period during which prevailing travel time deviated by more than 5% from the historical average value, and higher travel times sustained for at least 15 minutes. The 15-minute threshold was used to account for the typical variations in travel times.



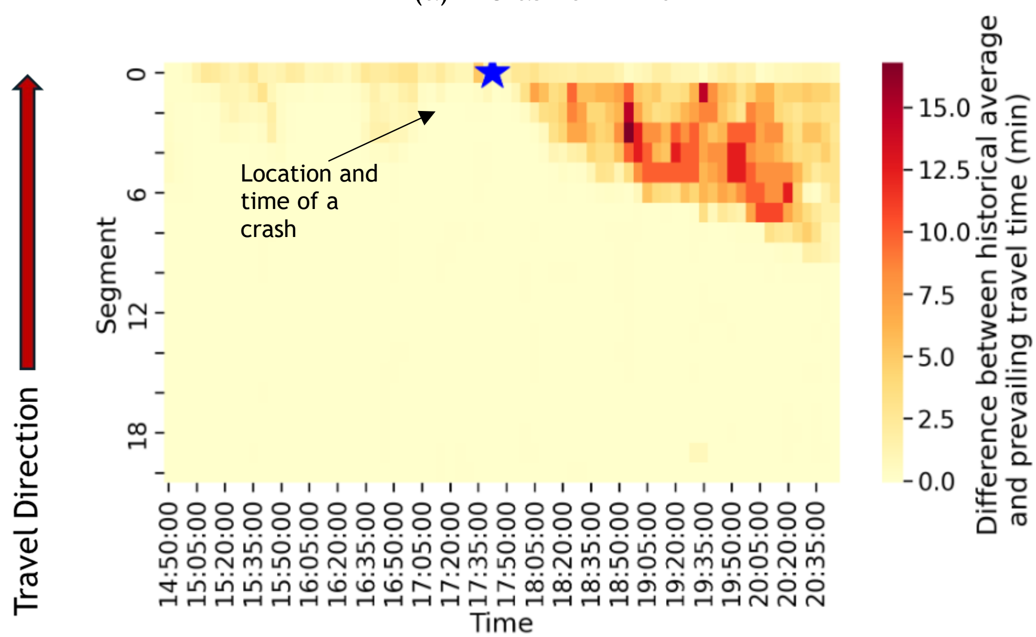
(a) Segment 1 (b) Segment 2

Figure 7: Travel Time Profiles with CMV Congestion-Related Crashes

Figure 8 below demonstrates how delays were detected based on the segment spatial and temporal variation of the difference between the historical average and prevailing travel times after a crash. As indicated in Figure 8 (a) for one of the crashes on the I-470 freeway, the travel time increased from the time and location (segment 0) of the crash and propagated to the upstream segments (up to segment 5) for about two hours. A similar analysis was conducted for all crashes for the before and after periods and the total delays were aggregated by year.



(a) A Crash on I-470



(b) A Crash on I-75

Figure 8: Spatial and Temporal Pattern of Delays Upstream CMV Congestion-Related Crashes

3.3.4. Effectiveness Analysis of Congestion-Related Crashes

For the effectiveness analysis, most of the secondary crashes were associated with congestion-related crashes. Therefore, the research team focused exclusively on the congestion-related crashes in the BCA. A Naïve before-after approach was used to evaluate the effectiveness of the Drivewyze system. This approach was used due to the limitation of the sample size of CMV congestion-related crashes, which constrained the use of more robust techniques like the empirical Bayes method. The empirical Bayes approach with comparison sites requires using untreated sites to develop a safety performance function. However, since Drivewyze alerts can be sent to all freeway segments, categorizing crashes into treatment and comparison groups is challenging and was not pursued further. The research team also explored using existing safety performance functions developed for Ohio freeways and those in the Highway Safety Manual (HSM). However, these safety performance functions are based on all vehicle types and all crash types, whereas this study focuses specifically on CMV congestion-related crashes. Consequently, the existing safety performance functions from Ohio and the HSM were not suitable for this study.

To account for exposure variables, the number of crashes in the Naïve approach was normalized by segment length and AADT. This was achieved by aggregating the congestion crashes to freeway segments, and thereafter selecting segments with at least one Drivewyze alert received and one crash for any of the years (2018-19 and 2022-23) in the analysis. Equations 5 and 6 below present the computation of the freeway segment crash rates per million AADT miles.

$$\textit{Crash rate (per million AADT miles)} = \frac{Total\ crash\ count\ in\ a\ freeway\ segment}{MVM} \quad (4)$$

Where,

$$MVM = \frac{365 \times number\ of\ years \times Segment\ Length \times AADT}{1 \times 10^6} \quad (5)$$

The Naïve approach was used to compute the crash modification factor (CMF), from which the reduction (effectiveness) in congestion-related crashes was determined. The CMF was determined following the procedure below.

- Define the before (B = 2 years, 2018 & 2019) and after (A = 2 years, 2022 & 2023) treatment period
- Compute observed crash rates in the treatment site before (CB) and after (CA) using Equation 6.
- Compute the expected crash rates in the treatment site during the after scenario assuming the treatment was not implemented (EA).

  $$EA = CB \times (A/B) = CB \quad (6)$$

- Compute CMF

  $$CMF = CA/EA = CA/CB = \frac{Observed\ Crash\ rate\ (After\ Scenario)}{Expected\ Crash\ rate\ (After\ Scenario)} \quad (7)$$

- Compute the crash reduction factor (CRF) from the CMF, representing the effectiveness of Drivewyze.

  $$CRF = 1 - CMF \quad (8)$$

The benefits were quantified by considering the reduction in overall crash costs for the after scenario compared to the before scenario. The computation was done for each crash severity outcome.

$$\textit{Benefit} = \sum_s Target\ crashes\ (s) \times\ Effectiveness\ (s) \times\ Crash\ cost\ (s) \quad (9)$$

Where,

s is the crash severity level (KABCO definition),
Effectiveness is the CRF,

Target crashes represent the total crashes for the before scenario, and
Crash cost represents the cost of a crash for each severity outcome.

3.4. Analysis of CMV Trajectory Data

Trajectory data were investigated to assess CMV drivers' actions after receiving alerts, which is crucial for the BCA of the CVSA system. The study utilized Drivewyze data collected from the Tableau dashboard, spanning two-years from January 1st, 2022, to December 31st, 2023. This dataset included important attributes such as incident ID, Drivewyze corridor ID, incident timestamps, CMV geo-location, incident geo-location, duration of the incident, and the number of CMVs receiving the alert. Key inputs for determining the Drivewyze penetration rate were incident IDs, timestamps, and the locations where alerts were sent to each CMV. Figure 9 presents a heatmap showing the spatial location of Drivewyze alerts on the study corridors for 2022 and 2023.

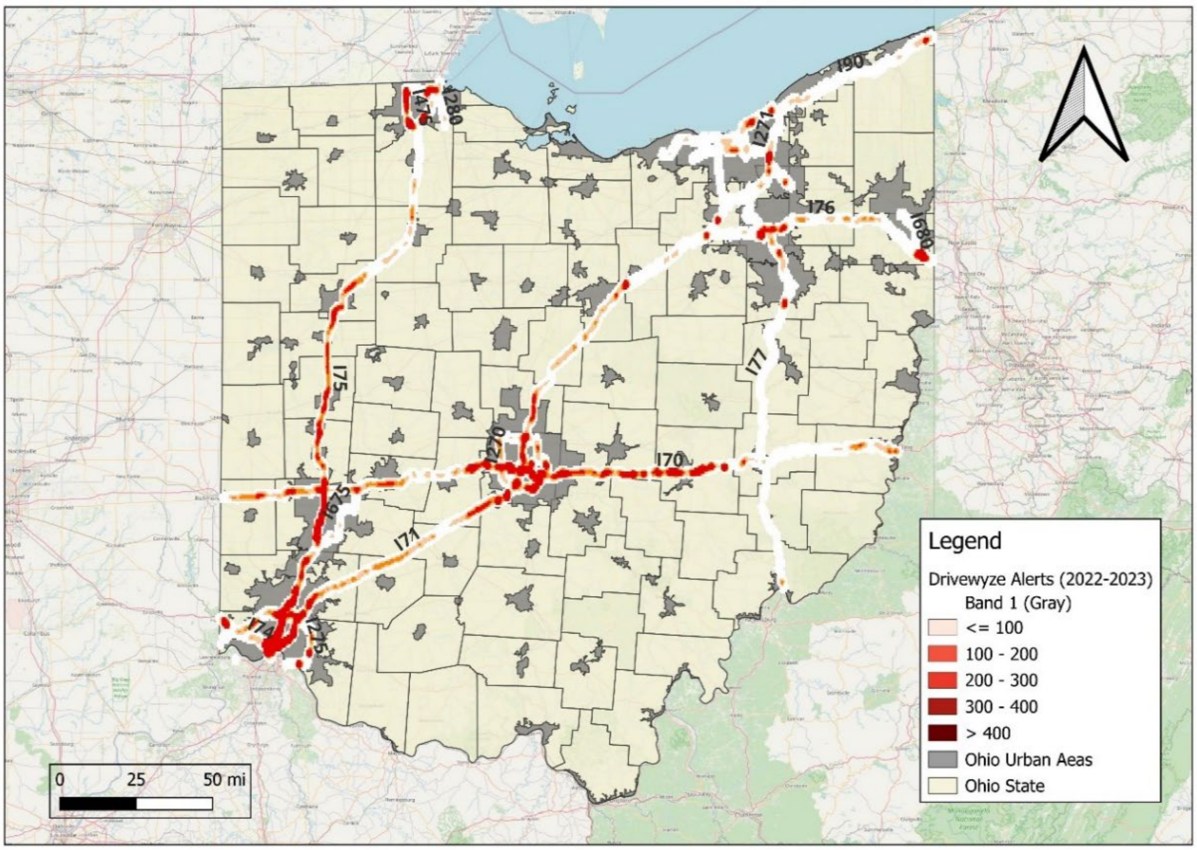


Figure 9: A Heat Map Displaying Drivewyze Alerts

In addition, sample trajectory data representing individual CMV paths and braking behavior upon receiving the alerts were included in the analysis. The only data that Drivewyze made available to the research team were those that involved congestion and sudden slow-down alerts from September 28th, 2023, to February 14th, 2024, four months. The trajectory data were evaluated to understand the CMV driver's response time after receiving the alert for an incident. A total of 6,808 sample trajectories were investigated. Figure 10 shows the proportion of drivers who applied their vehicle brakes in response to the time they received the alerts displayed on ELDs. Based on Figure 10 the majority of CMV drivers (82.3%) applied their brakes before receiving the alerts, and only 17.2% applied their brakes after receiving the alerts. A very small percentage (0.4%) of CMV drivers applied brakes at the same time of receiving alerts while only six drivers (0.1%) did not apply their brakes after receiving the alerts. Furthermore, Figure 11 shows the length of time the brakes were applied to the 1,171 CMV drivers (17.2%) who responded after receiving an alert.

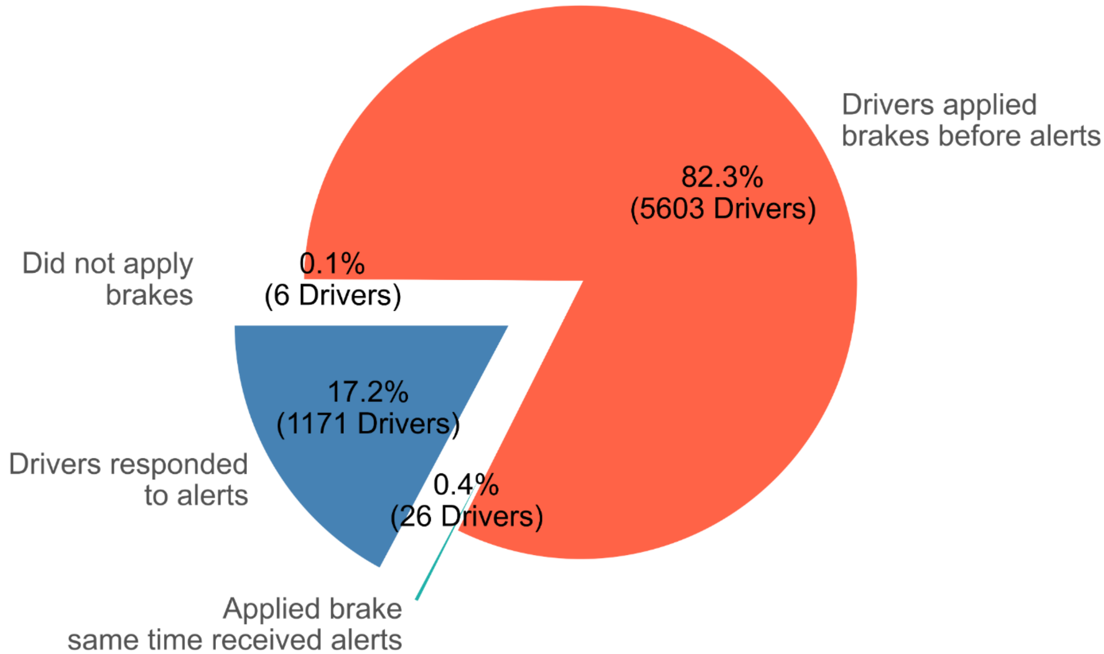


Figure 10: CMV Driver Responses after Receiving Drivewyze Alerts

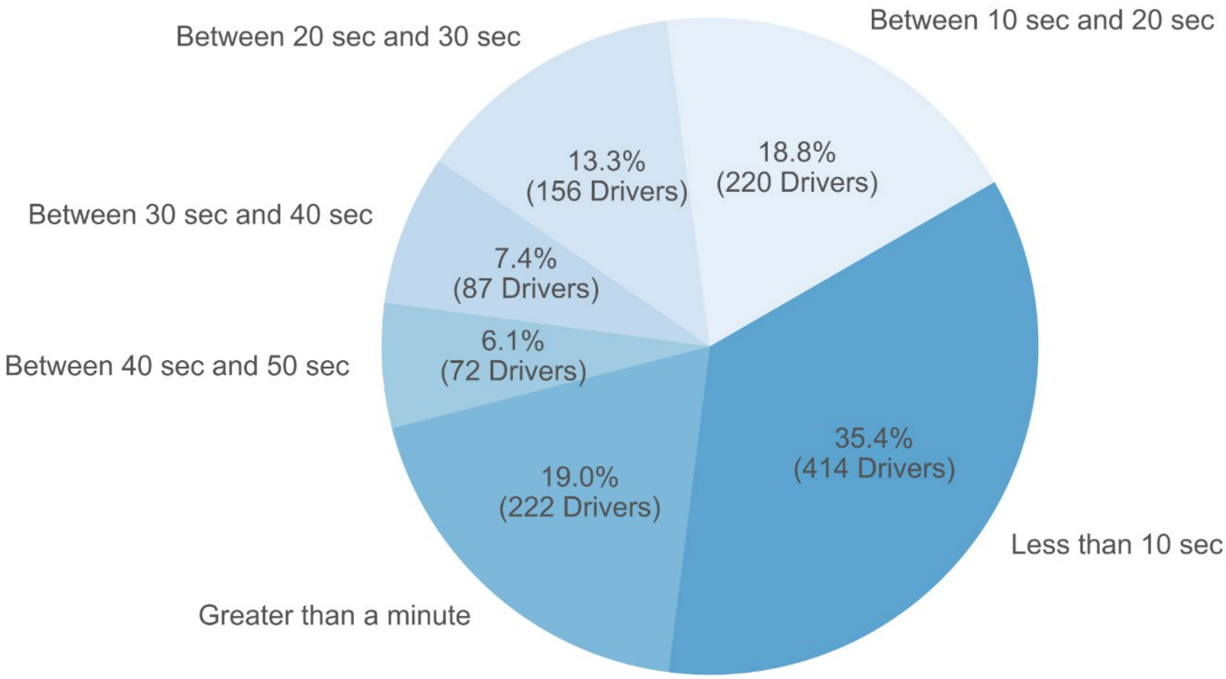


Figure 11: Response Times of CMV Drivers

According to the pie chart in Figure 11, most CMV drivers (949, 81%) responded in less than 50 seconds after an alert was displayed of which 35% responded in less than 10 seconds. Also, there were 222 drivers (19%) who responded more than one minute later after the alert was displayed. Figure 12 presents a histogram of the time distribution of the response time to alerts for CMV drivers who responded within five minutes (300 seconds).

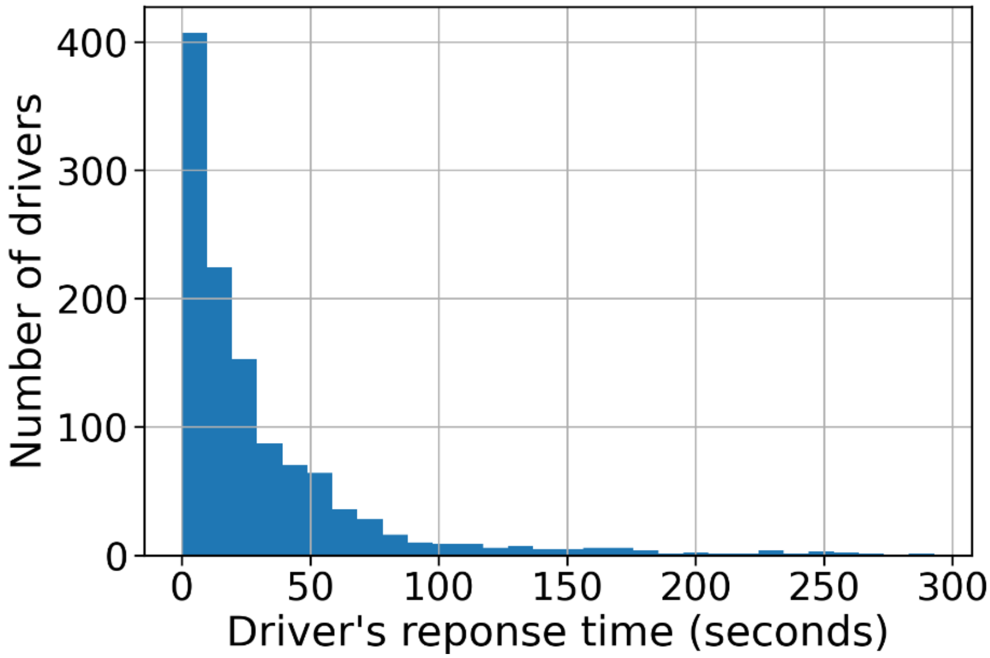


Figure 12: CMV Driver Response Time for Drivers who Responded within Five Minutes

4. Research Findings and Conclusions

This section compiles the results of different project tasks. Specifically, the discussion focuses on survey results, analysis of penetration rate, and effectiveness analysis of the Drivewyze system.

4.1. Surveys Results

The primary objective of conducting surveys was to gather information on the current usage and effectiveness of CMV onboard alerting systems for improving mobility and safety. Follow-up interviews with DOT agencies supplemented the survey responses, focusing on identifying in-house systems that ODOT could potentially utilize to disseminate alerts to CMV drivers. The research team received and analyzed 584 CMV driver survey responses, from 17 transportation agencies, and 24 responses from trucking companies. Eight DOT agencies participated in follow-up interviews.

4.1.1. Available CMV Alert Systems

(a) Truck driver survey

CMV drivers were asked to identify the systems or technologies equipped in their trucks that provide mobility and safety alerts. They were given three options to choose from: “Drivewyze”, “None” and “Other(s)”. The goal of asking this question was to assess the penetration of the Drivewyze system. Survey responses from CMV drivers, as shown in Figure 13, reveal that 26.88% of the drivers used Drivewyze, while 1.37% use Drivewyze alongside other safety alert systems.

Meanwhile, 59.42% of CMV drivers indicated using safety alert systems other than Drivewyze. Additionally, 12.33% indicated they do not use any of the safety alert systems in their CMVs.

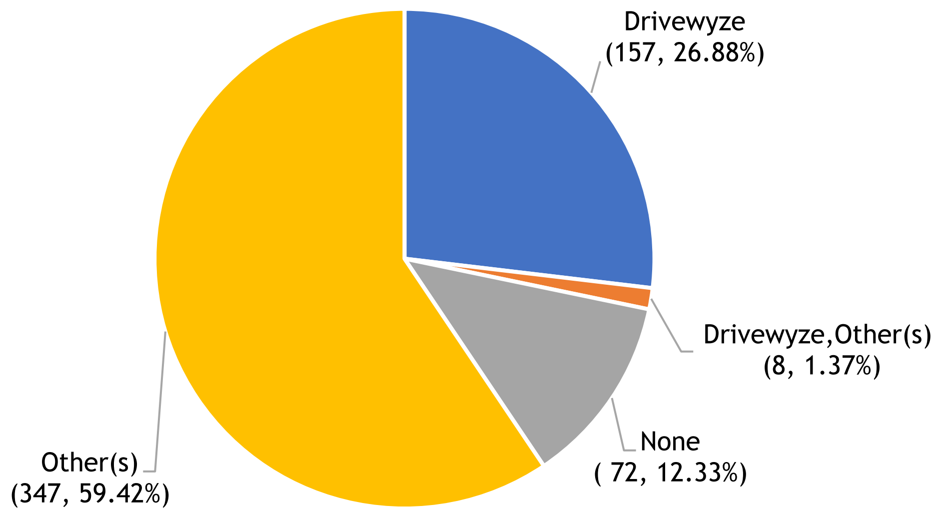


Figure 13: CMV Alert Systems - Truck Driver Survey

From CMV drivers who indicated to use other alert systems, over 110 different CVSA systems or technologies were identified that provide alerts on safety and mobility. Figure 14 presents the top ten technologies in descending order based on the number of responses received. Drivewyze emerged as the most popular alert system among CMV drivers, with approximately 28.25% (in Figure 13, 26.88% + 1.37%) of responses indicating using the technology, either exclusively or alongside other technologies for alerts. About 8.56% of CMV drivers use various global positioning systems (GPS), such as Garmin and Rand McNally, for alerts. Other commonly used systems include Motive (7.88%), Samsara (5.82%), and Omnitracs (3.42%). Notably, about 12.33% of CMV drivers indicated they do not use any commercial vehicle safety alert (CVSA) systems.

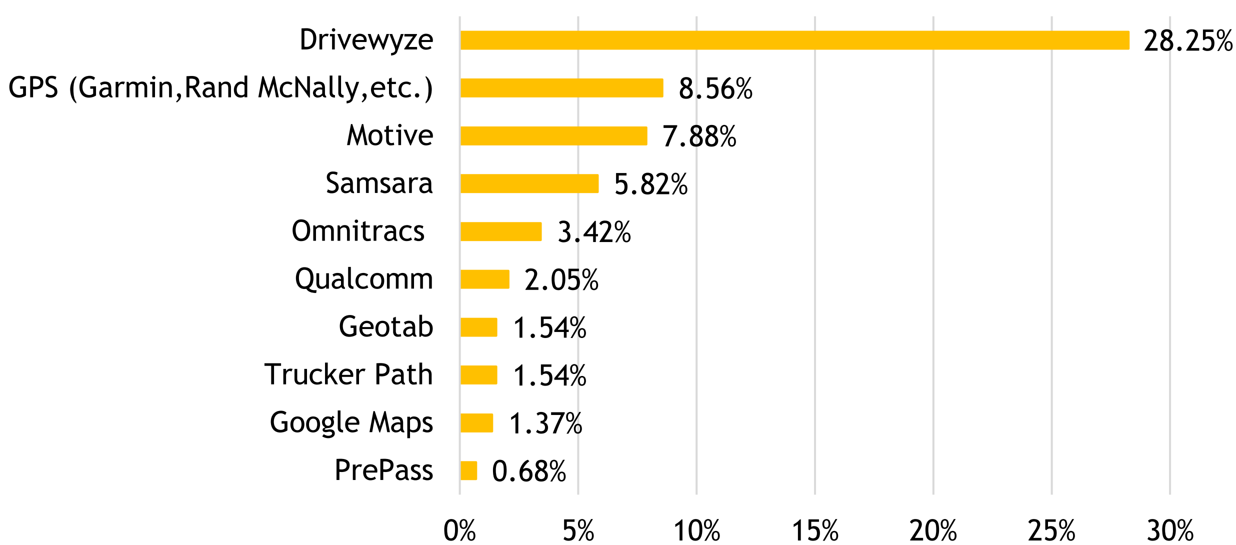


Figure 14: Proportions of CVSA System Based on CMV Drivers' Responses

(b) State DOT survey
According to state DOT shown in Figure 15, about 35.29% of these agencies have partnered with Drivewyze to provide alerts to CMV drivers, with 17.65% of them also using Drivewyze in conjunction with other technologies. The survey also indicated that 17.65% of states use other systems, while 29.41% do not use any CVSA systems. Agencies that use alternative alert systems mentioned platforms like PrePass, Quick Map, and various 511 apps. Some of these 511 mobile apps (available in certain states) operate similarly to Drivewyze by sending geo-targeted, real-time safety and mobility alerts to both truck and passenger car drivers, often with audio notifications.

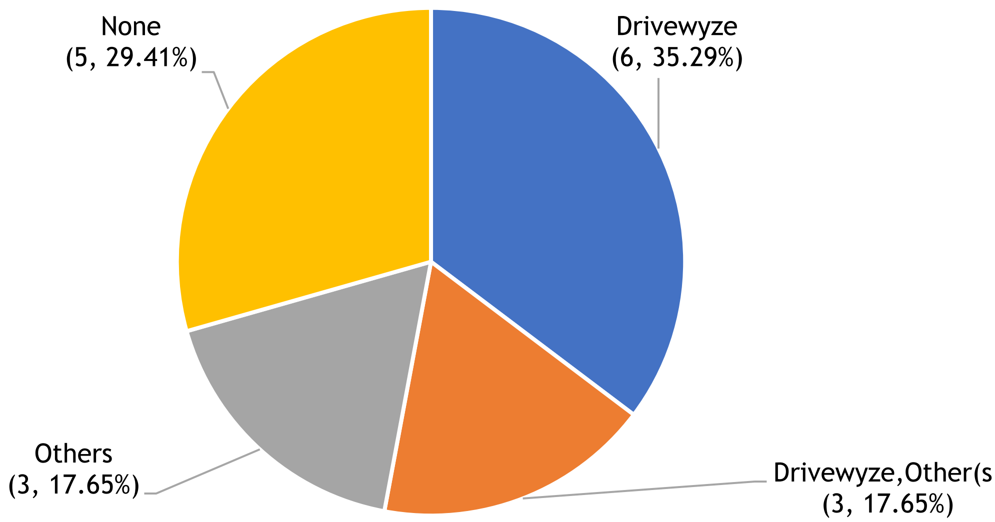


Figure 15: CMV Safety Alert Systems - Agency Survey

These apps allow users to activate GPS functionality on in-cab smart devices such as phones or tablets. Once the GPS is activated, the apps provide geo-targeted notifications, monitoring the device's location and alerting users when they approach a geofenced area. The types of alerts sent to the drivers include work zones, lane closures, dangerous slowdowns, detours, incidents, travel delays, and weather advisories. Examples of 511 systems with these capabilities include 511 South Carolina Traffic, Iowa 511 (with Trucker Mode for CMV), 511PA (advisories from within a 10-mile radius), SDDOT 511, Quick Map, Ontario 511, and others.

(c) Truck company survey
A survey was conducted among various trucking companies as shown in Figure 16, yielding 24 responses, of which 20 companies fully completed the survey. Among the 24 responses, 12.5% indicated they use Drivewyze exclusively, while 16.67% reported using Drivewyze in combination with other systems for mobility and safety alerts. About 54.17% of the companies utilize other CVSA systems, with Samsara being the most popular system, accounting for 33.33% of all responses. On the other hand, about 16.67% of the responses indicated they do not use any CVSA systems.

4.1.1. Alerts Received by CMV Drivers and Proposed Additional Alerts

Survey results also revealed that the majority of CMV drivers reported receiving alerts for harsh vehicle maneuvers, weigh station locations, and real-time incidents. Alerts for sudden slowdowns, traffic congestion, and work zones, were also commonly listed among the drivers who responded. Conversely, alerts for fatigue/drowsiness, truck detours, high theft areas, and public awareness campaigns were less frequently reported. Upon reviewing the alerts provided by various technologies identified from both surveys and the literature review, the research team compiled a list of additional alerts that Drivewyze could consider incorporating into its application to maximize the system's benefits. The recommended alerts include severe weather, snowplows, lane closures, and the availability of parking spots. Additional alerts are presented in Table 12 in Appendix B. Although not all alerts presented have the potential to enhance the mobility and safety of highways, providing a comprehensive alert system in one application could attract more users and potentially increase the application's penetration rate.

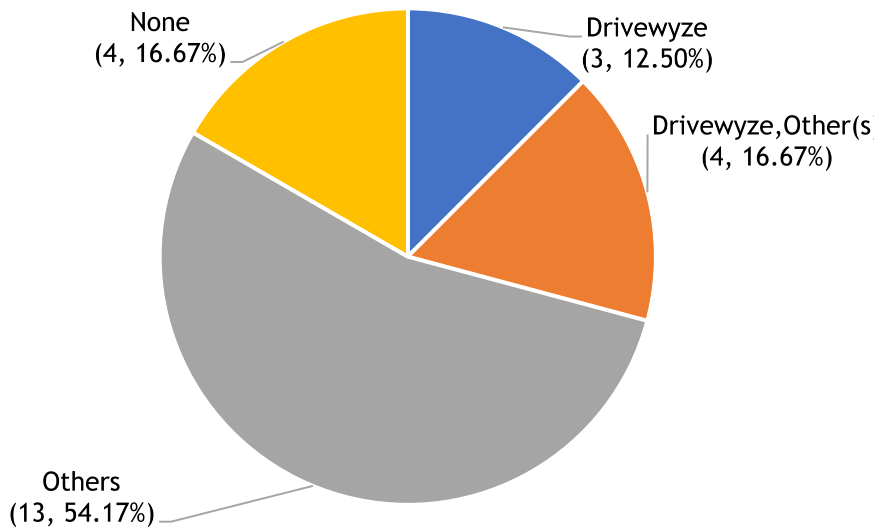


Figure 16: CMV Safety Alert Systems - Truck Company Survey

4.1.2. Effectiveness of CMV Alerts

The CMV drivers were requested to rate the effectiveness of each alert type by choosing from four different options: *"not effective", "slightly effective", "somewhat effective"*, and *"very effective"*. An analysis of the responses received revealed that the weigh station alert received the highest number of "*very effective*" responses (40%) followed by harsh vehicle maneuvers such as speeding (36%). Real-time incidents, toll plazas, sudden slowdowns, traffic congestion, low-clearance bridges, etc., received nearly the same number of "*very effective*" responses (about 30%). Figure 17 provides the effectiveness of other alerts based on CMV drivers' responses.

Further analyses of the open-ended survey question, based on the sentiment analysis and text analysis were conducted to gain insights into drivers' opinions with the use of alert systems. Drivers' opinions were classified as positive, neutral, or negative. The sentiment analysis was conducted on the opinions of all CMV drivers who use any alert system and those who use Drivewyze. Out of the 338 opinions collected from drivers, about 61% were positive, 10% were categorized as neutral, and 29% were negative. When considering only the opinions of drivers who use Drivewyze (76 drivers), 57% provided positive comments about Drivewyze alerts, 14% expressed a neutral sentiment, and 29% a negative sentiment. Based on these observations, overall drivers appear to value the benefits associated with alert systems. Some negative comments that drivers expressed are associated with the accuracy of the alerts, possibly due to system latency issues. Some drivers expressed that the alert system was the source of distraction and presented a safety issue. These comments appeared frequently among the drivers.

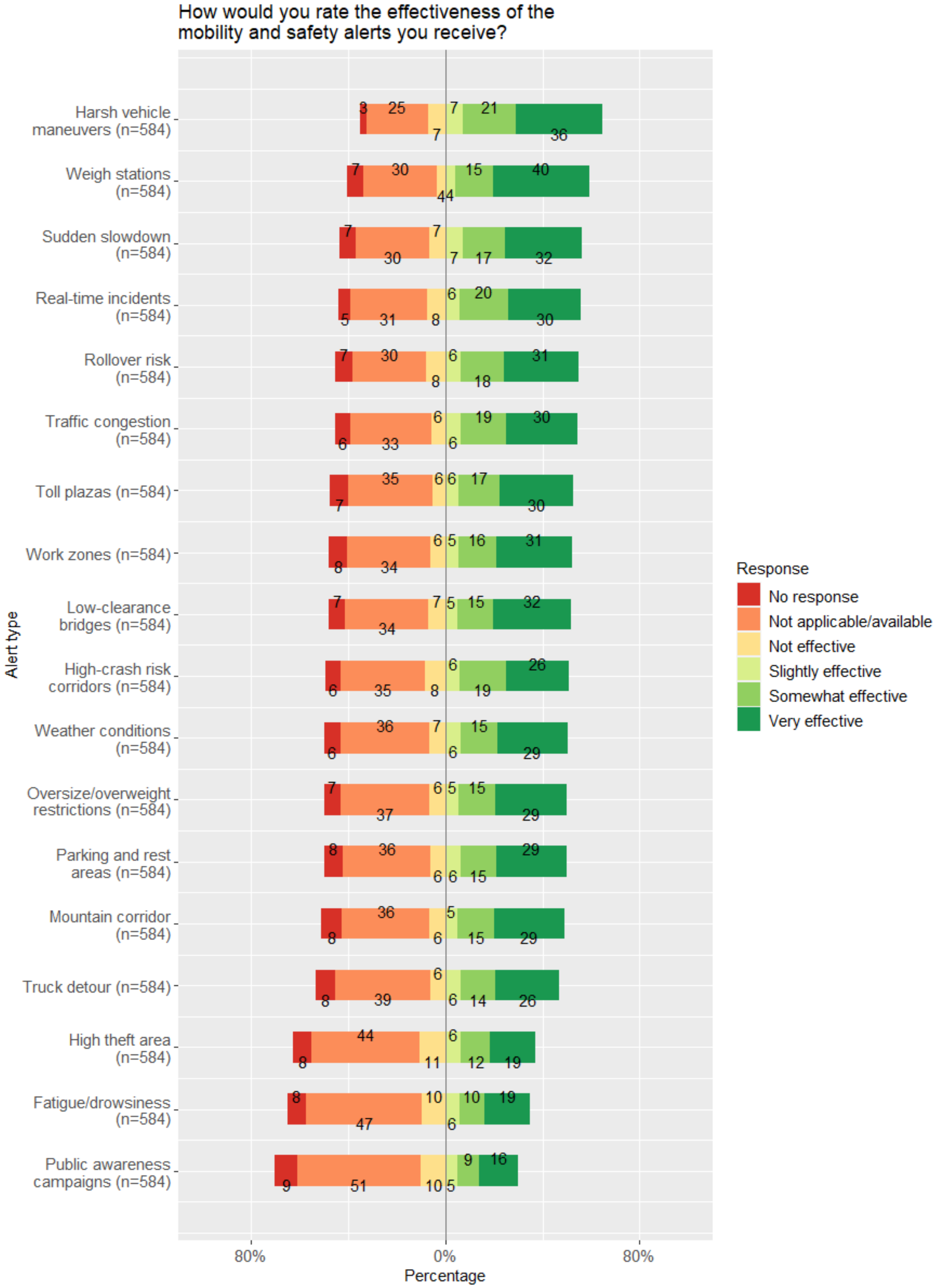


Figure 17: Effectiveness of CMV Alerts

4.1.3. Drivewyze Penetration Rate

The research team compared a data-driven approach with survey results to estimate the penetration rate of the Drivewyze system in Ohio. The data-driven approach utilized Drivewyze incidents, the number of alerts sent to CMV drivers, and weigh-in-motion (WIM) data. Based on 1,230 alerted incidents between January 2022 and January 2024, two years, the average penetration rate using the data-driven approach was estimated at 8.0% with few incidents with a penetration rate greater than 50% (Figure 18). On the other hand, a survey of CMV drivers revealed that 165 out of 584 respondents (approximately 28%) reported using Drivewyze with few drivers using it along with other systems for safety and mobility alerts. However, this figure may overestimate the actual usage of Drivewyze. Many CMV drivers reported using multiple alert systems and it is likely they primarily use Drivewyze for specific features only such as weigh station bypass. Moreover, it is important to note that the survey question did not ask if the drivers use Drivewyze all the time rather drivers were asked to list the type of systems or technologies equipped in the vehicle for receiving mobility and safety alerts. The data-driven approach, which relies on WIM data, likely provides a more accurate estimate of the penetration rate by accounting for the actual number of CMVs using the system relative to total CMV traffic.

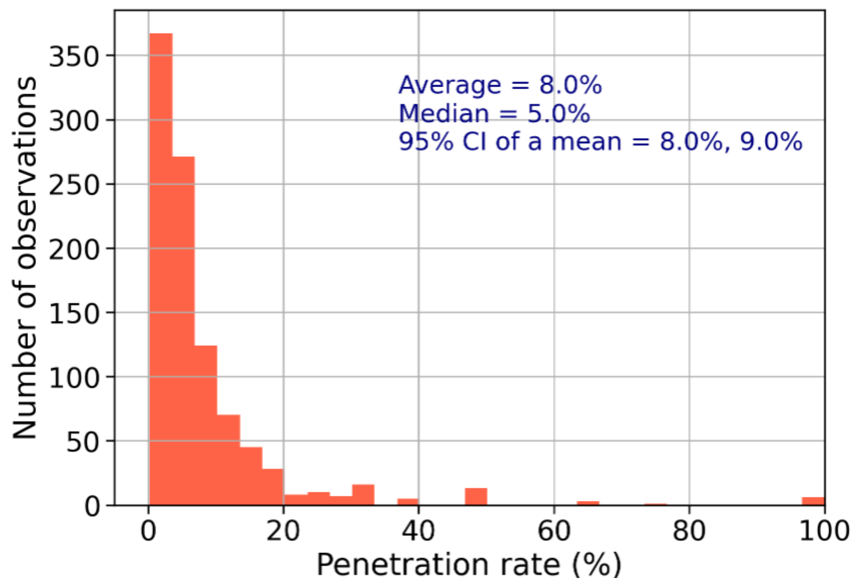


Figure 18: A Histogram Displaying Drivewyze Penetration Rate

4.1.4. Secondary and Congestion-related Crashes

The distribution of secondary crashes after quality checks is depicted in Figure 19 organized by year. The impact of COVID-19 on the number of CMV crashes is evident in this figure, with a significant decrease observed in 2020. As such, the research team selected 2018 and 2019 as the more suitable years to represent the before scenario when compared with the after scenario (2022 and 2023). Figure 19 also indicates a slight decrease in the number of secondary crashes between the 2018-2019 and 2022-2023 periods, with an average reduction of 10 crashes in the after period compared to the before period. Moreover, the review of the injury severity of these crashes (presented in Table 1) revealed that there is an overall reduction in the number of severe crashes, except for serious injury cases.

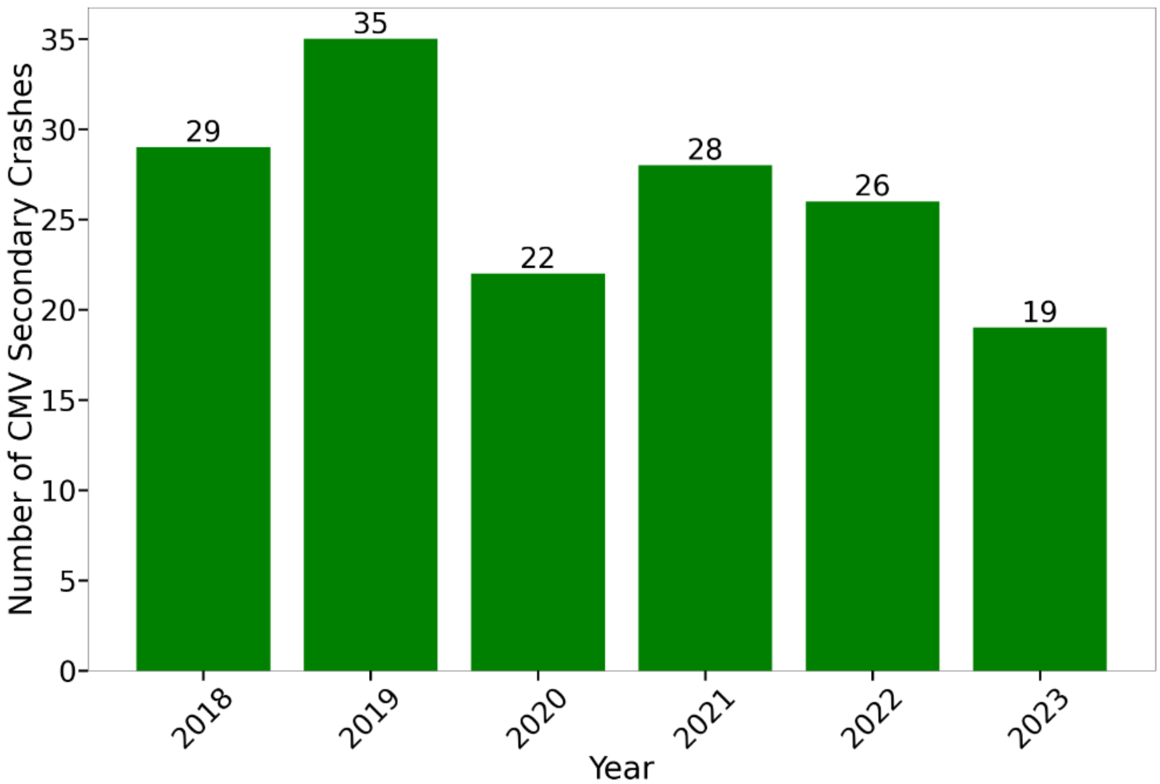
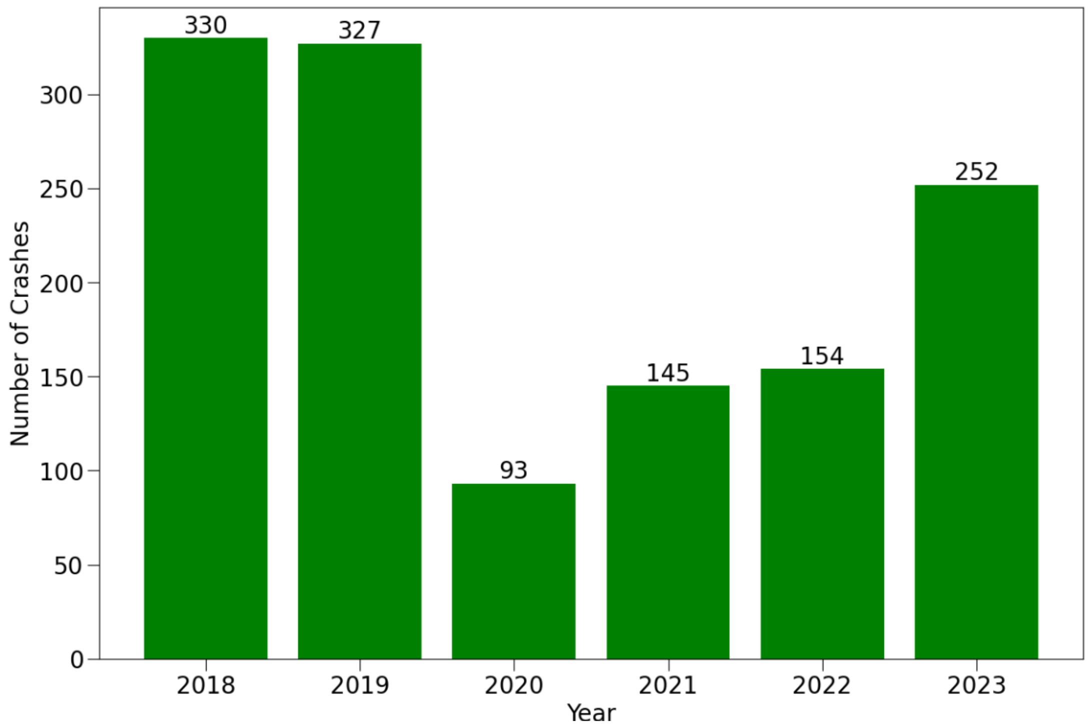


Figure 19: CMV Secondary Crashes on Ohio Interstate Freeways

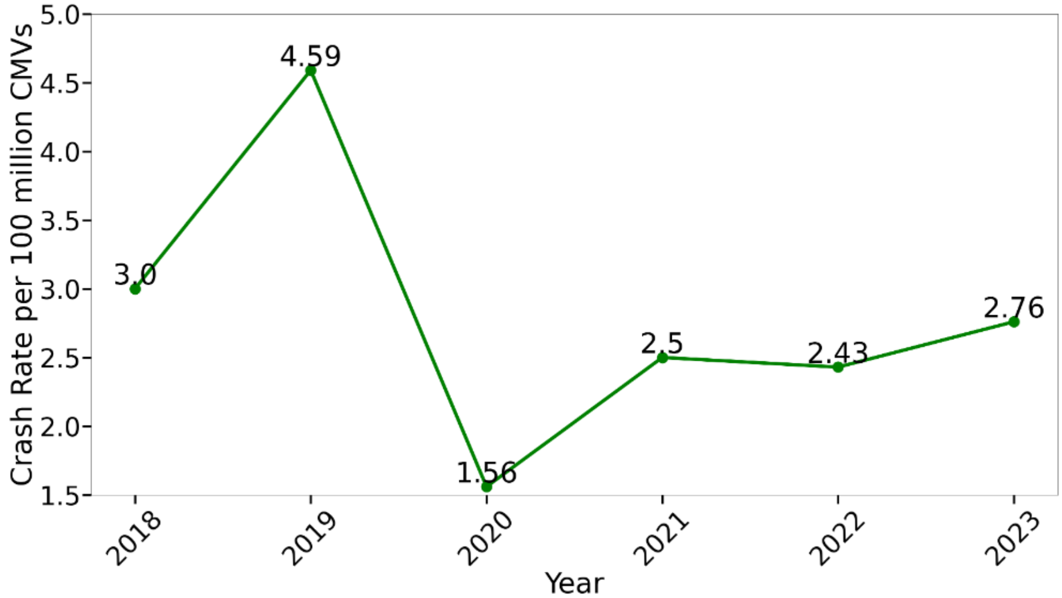
Table 1: Injury Severity Breakdown of Secondary Crashes

Severity Outcome	**Number of Crashes (2018- 19)**	**Number of Crashes (2022-23)**
Fatal	1	0
Serious Injury Suspected	0	3
Minor Injury Suspected	11	6
Injury Possible	10	4
Property Damage Only	42	32
Total	**64**	**45**

Figure 20 presents the number of congestion-related crashes and rates. The crash rates were estimated as the number of crashes per 100 million CMVs. More specifically, it was calculated using the sum of truck AADT and the sum of congestion-related crashes each year. Like secondary crashes, the impact of COVID-19 on the number of CMV crashes can be seen in Figure 20, with the year 2020 experiencing a significant decrease in the number of crashes as well as crash rates.



(a) CMV Congestion-Related Crashes



(b) CMV Congestion-Related Crash Rate per 100 million

Figure 20: CMV Congestion-Related Crashes on Ohio Interstate Freeways

4.2. Benefit-Cost Analysis of Drivewyze System

The evaluation of the Drivewyze system's effectiveness focused on its impact on both safety and mobility. To assess safety effectiveness, the reduction in congestion-related crashes during the system's operational period (after scenario) was compared to the period before its implementation (before scenario). For mobility impact, the analysis focused on delays associated with CMV congestion-related crashes in both scenarios. The following sections detail the results of these effectiveness analyses.

4.2.1. Safety Effectiveness

To evaluate the impact of the Drivewyze system through a BCA, the costs incurred by ODOT to provide alert services on Ohio freeways were compiled. Table 2 below provides a breakdown of the annual costs from fiscal year 2022 to 2025. Each year, ODOT pays $373,500 on its annual contract with INRIX to enable the congestion and sudden slowdown alerts in Drivewyze. For the first fiscal year (2022), when Drivewyze developed and began disseminating these alerts, ODOT compensated Drivewyze at a reduced rate due to the development starting in October 2021, the alerts going live in December 2021, and a data outage for which ODOT received a credit. ODOT has a separate contract with Drivewyze for other types of alerts, amounting to $500,000 for the fiscal year 2024, with a renewal cost of $490,000 in July 2024 for the fiscal year 2025. For the effectiveness analysis, the after scenario was defined using data from 2022 and 2023. Therefore, ODOT's investment in Drivewyze for 2022–23 totaled $622,500 (as shown in Table 2), which was used as cost in the BCA.

Table 2: ODOT Annual Drivewyze Costs

Fiscal Year	Drivewyze via INRIX Contract	Drivewyze Direct Contract	Total
2022	$249,000	n/a	$249,000
2023	$373,500	n/a	$373,500
2024	$373,500	$500,000	$873,500
2025	$373,500	$490,000	$863,500

The total monetary costs associated with congestion-related crashes were quantified for both before and after scenarios using the USDOT-recommended values shown in Table 3. Crash costs were monetized based on the most severe outcome of each crash (USDOT, 2023). The effectiveness, measured as the reduction in overall congestion-related crashes, was computed using Equation 8 following the procedures for the Naïve approach to compute the CMF categorized by injury severity. Table 4 shows the estimated CMF of each injury severity group. These values were then used to compute the benefits using Equation 9 and the crash costs in Table 3.

Table 3: Recommended Crash Monetized Values (2023)

KABCO Scale	Crash Severity	Crash Costs
K	Fatal Injury	$12,500,000.00
A	Suspected Serious Injury	$1,188,200.00
B	Suspected Minor Injury	$233,800.00
C	Possible Injury	$111,700.00
O	No Apparent Injury	$5,000.00

For instance, to compute the benefits for fatal crashes, the analysis used four crashes, a CMF of 0.81, and a crash cost of $12,500,000. The calculation is as follows: 4 x (1 – 0.77) x $12,500,000 = $11,729,331.66. Similar calculations were performed for other injury severity categories. The overall benefit, as shown in Table 4, reflects a saving of $14,043,151.40 in congestion-related crash costs. Based on the costs incurred by ODOT to invest in Drivewyze and this saving, the estimated benefit-cost ratio (BCR) for CMV congestion-related crashes is 22.56. This ratio indicates a return on investment, suggesting that for every dollar invested in the Drivewyze system, there is a return of $22.56.

Table 4: Benefit Estimation for Congestion-Related Crashes

S/N	Crash Severity	Number of Target crashes (2018/19)	CMF	Effectiveness, CRF = (1 - CMF)	Crash Cost	Benefits
1.	Fatal (K)	4	0.77	0.23	$ 12,500,000	$11,729,331.66
2.	Serious Injury (A)	6	0.56	0.44	$ 1,188,200	$3,119,149.28
3.	Minor Injury (B)	28	1.54	-0.54	$ 233,800	- $3,563,161.71
4.	Possible Injury (C)	35	0.36	0.64	$ 111,700	$2,492,645.93
5.	No Apparent Injury (O)	212	0.75	0.25	$ 5,000	$265,186.24
TOTAL						$14,043,151.40
Benefit/cost ratio						$14,043,151.40/$622,500 = 22.56

4.2.2. Mobility Effectiveness Analysis

For mobility effectiveness analysis, the benefits were quantified by calculating the reduction in upstream delay for the after scenario compared to the before scenario. Figure 21 presents the yearly average delay per mile (hours/mile) incurred by the upstream traffic due to congestion-related crashes. This figure also displays that the delay decreased for the after scenario compared to the before scenario and the impact of COVID-19 can be seen. The Drivewyze system is associated with reducing delays by 20.5 hours per mile on average in the after periods.

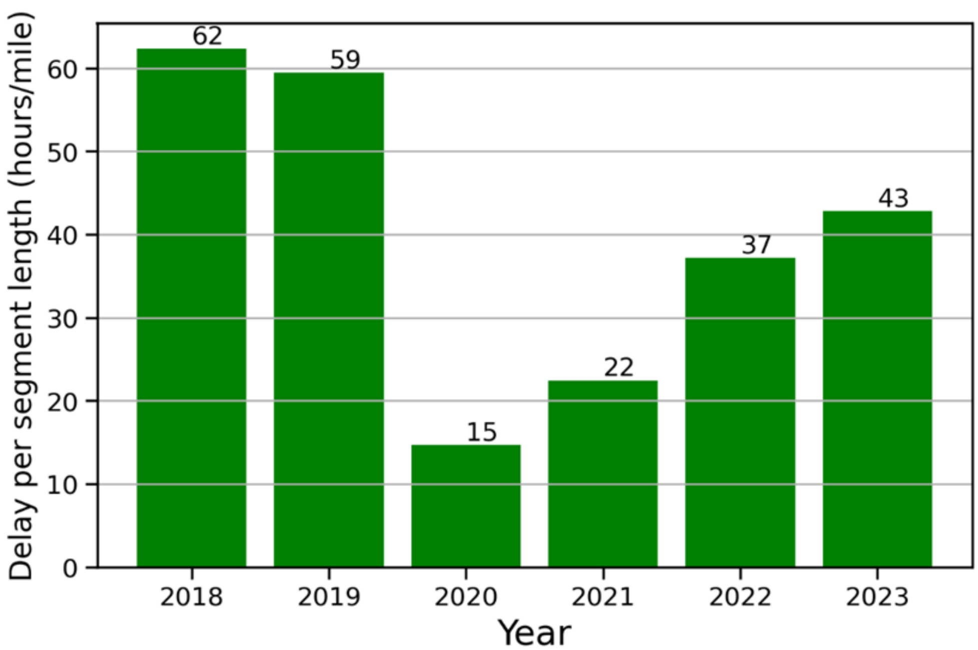


Figure 21: Delay per Mile for Upstream Traffic due to CMV Congestion-Related Crashes

The estimated effectiveness for both mobility and safety was calculated under the assumption that ODOT did not implement any additional countermeasures on freeways to address CMV congestion-related crashes during the study period (2018 – 2023). Moreover, CMV congestion-related crashes typically occur during recurring congestion periods, making it challenging to separate the impact of recurring congestion from the delay caused by a crash. To address this issue, the historical average travel time of the segment was used instead of free flow travel time. However, some crashes showed little to no impact on travel time when speed profiles were analyzed just after the crash.

5. Recommendations for Implementation

This study assessed the mobility and safety effectiveness of the CVSAs disseminated by Drivewyze to CMV drivers. Furthermore, the research team explored alternative CVSA systems and the scope of Drivewyze's services. Based on the research findings and conclusions, the following recommendations are provided.

- **Maintain a cooperative partnership with Drivewyze and INRIX**. ODOT may consider continuing with its cooperative partnership with Drivewyze and INRIX to provide relevant and beneficial mobility and safety alerts to CMV drivers within their roadway network. The benefit-cost ratio of congestion-related crashes was estimated to be 22.56, indicating that for every dollar invested in the Drivewyze system, there is a return of $22.56. Moreover, the estimated delays associated with congestion-related crashes were reduced by 20.5 hours per mile between before (2018-19) and after (2022-23) periods. The analysis of secondary crashes showed an average decrease of 10 crashes in the after period compared to the before period, with reductions in all injury categories except serious injury cases.
- **Enhance the effectiveness and optimize the Drivewyze system for timely alerts and drivers' safety.** To enhance the effectiveness of the Drivewyze system, ODOT could recommend the following to Drivewyze:
    - Minimize the impact of latency in sending out alerts.
    - Evaluate the need to increase the geo-fence radius to give drivers more time to react before reaching incident locations. These recommendations are based on the observations of braking behaviors of CMV drivers from truck trajectories. Among the 1,171 CMV trajectories evaluated, approximately 82% of CMV drivers applied brakes before receiving the alerts, suggesting that latency could be a contributing factor. Additionally, CMV drivers expressed in survey responses that some alerts are not accurate.
    - Incorporating additional alerts, such as weather alerts, snowplows, etc., could attract more users and potentially increase the system penetration rate.
- **Regular assessment of Drivewyze system benefits (ROI).** ODOT could periodically evaluate the benefit of using the Drivewyze system to ensure that the agency continues to benefit from the partnership between Drivewyze, INRIX, and ODOT. The research developed a framework for effectiveness analysis and a calculation tool for benefit-cost analysis to help evaluate the economic feasibility of the system.
- **Upgrade the OHGO system and partner with neighboring state DOTs**. For small trucking companies that might not be able to afford Drivewyze services and other vehicle types, ODOT could consider upgrading the OHGO system and partnering with neighboring states to develop a unified system that optimizes resources and improves the safety and mobility of CMV drivers who frequently cross state boundaries.
- **Share data with the public for innovation and collaboration**. The survey for DOTs and follow-up interviews revealed that many states are partnering or planning to partner with Drivewyze. However, some states are reluctant for various reasons, including subscription costs. States like Wyoming push alerts or notifications about road conditions to the Situation Data Exchange (SDX), where any third party can freely query and share the information with the road users. As part of its vehicle alert strategy, ODOT will be publishing a Workzone Data Exchange (WZDx) feed. ODOT may consider making other data also available to the public to accelerate innovation in alerting systems and allow other freely available alert systems to share road conditions and incidents with road users.

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Appendix

Appendix A: Literature Review

Introduction

Commercial vehicle crashes, such as those involving large trucks and buses[2], have persistently posed a significant safety issue in the United States (U.S.). While much effort has been dedicated to reducing crashes involving commercial vehicles, particularly large trucks, and buses, the Federal Motor Carrier Safety Administration (FMCSA) acknowledges that more work is needed to realize its vision of moving towards zero large truck and bus fatalities (FMCSA, 2019). Alerting commercial vehicle drivers of traffic slowdowns, upstream congestion, and other road conditions ahead is one way to improve their mobility and reduce the likelihood of commercial vehicle-related crashes. Dynamic Message Signs (DMSs) are one of the conventional methods of alerting both commercial and passenger vehicle drivers. However, DMSs are not always located where they are needed to provide alerts. Furthermore, the warnings from these intelligent transportation systems (ITS) roadway devices might go unnoticed by drivers, depending on their ongoing driving tasks or whether they are cognitively or visually distracted. Therefore, providing in-cab alerts that can be received at any location may be more effective.

In response to the limitations potentially posed by DMS alerts, the integration of in-cab safety alerts has emerged as a viable solution in the commercial vehicle sector. These in-cab alerts strive to address the potential oversight of warnings provided by DMS devices by providing real-time critical information to drivers, enhancing situational awareness, and promoting safer driving practices. This part of the report is dedicated to evaluating the effectiveness of commercial vehicle safety alerts (CVSA) from a literature review perspective. This includes a review of various types of commercial vehicle alerts, their effectiveness, and the benefit-cost ratios (BCRs) associated with these alerts. The subsequent sections of the literature review are structured as follows.

- Approaches to disseminate critical road safety and mobility information.
- Effectiveness of alert technologies
- Overview of benefit-cost analysis (BCA)
- Conclusions

Commercial vehicle safety trends

The latest traffic safety data from the Federal Motor Carrier Safety Administration (FMCSA) highlights the alarming toll of fatal motor vehicle crashes in the U.S.

- Compared to 2019, there was an increase in fatal and severe injury crashes in 2020. There were 4,588 fatal crashes involving large trucks or buses, leading to 5,125 lives lost (U.S. DOT, 2022).
- The most recent figures from the FMCSA for 2022 report a further increase, with 5,384 people losing their lives due to fatal crashes involving both large trucks and buses. Approximately 96% of these fatalities are associated with large truck-related crashes

[2] In the Fatality Analysis Reporting System (FARS), a large truck is categorized as a truck with a gross vehicle weight rating (GVWR) exceeding 10,000 pounds, and a bus is defined as any motor vehicle primarily designed for the transportation of nine or more persons, including the driver (U.S. DOT, 2022).

(FMCSA, 2023). Comparing the statistics to 2017 reveals a concerning trend, with a 7.6% increase in lives lost due to fatal crashes involving large trucks and buses.

- In the state of Ohio, for instance, the annual average between 2016 and 2020 showed 164 lives lost in 144 fatal crashes involving large trucks each year (U.S. DOT, 2022). These statistics highlight the need for enhanced safety measures and interventions in commercial vehicle operations.
- According to the National Highway Traffic Safety Administration (NHTSA), nearly 30% of all crashes occur on interstate highways (Lee et al., 2007).
- Of all fatal crashes involving large trucks, approximately 54% occurred in rural areas, 27% on rural interstate highways, and 13% occurred on rural interstate highways (U.S. DOT, 2022).
- Many crashes reported in 2020 were secondary incidents where a truck or car rear-ended a vehicle in a queue resulting from an initial crash, whereas the study by Lee et al., (2007) found queuing to be a significant cause of the rear-end crashes. Rollover crashes constituted the first harmful event in 4% of all fatal crashes involving large trucks and 2% of all nonfatal crashes (U.S. DOT, 2022).
- In 2020, 71.6% of crashes involving large trucks were collisions with vehicles in transport, and 43.6% of all fatal crashes involving large trucks at that time involved trucks traveling 60 mph or more (U.S. DOT, 2022). The combination of commercial vehicle speeding, and collision can be particularly lethal for drivers and occupants of passenger vehicles.
- Tractor trailers weighing over 80,000 pounds and traveling at 65 miles per hour (mph) require twice the stopping length of a passenger car to bring the tractor-trailer to a complete stop, which is equivalent to approximately two football fields (UDOT, 2022).

Statistics highlight the critical importance of proactively reducing speed in anticipation of congestion, abrupt slowdowns, or other hazards including ongoing construction work or roadway emergencies.

- Particularly within work zones, there is a recognized correlation between fatal crashes and commercial vehicles. In 2020, 208 (26.9%) of the 774 fatal crashes in work zones involved a commercial vehicle (U.S. DOT, 2023).
- Between 2018 and 2020, nationwide statistics indicated that commercial vehicles were involved in 30% of fatal work zone crashes, with over 55% occurring on rural highways, often as rear-end collisions with slowed or stopped traffic (ARTBA, 2023).
- A 2019 Pennsylvania Department of Transportation (PennDOT) study revealed that 32% of work zone crashes and 49% of secondary crashes occurred more than two miles from the origin point of congestion. Moreover, 46% of these crashes (both secondary and work zone crashes) occurred more than an hour later (NOCoE, 2021).
- Alerting commercial vehicle drivers about upcoming traffic situations can help prevent crashes and enhance their mobility.

Commercial vehicle safety alert technologies

This section investigates technological solutions designed for in-cab commercial vehicle alerts and the various types of alerts associated with them. This section aims to provide insights into these technologies and the diverse alert systems employed to enhance road safety and overall mobility.

Current commercial vehicle safety alert (CVSA) technologies offer a range of services categorized into operations, safety, and compliance. Operation-related services generally include vehicle tracking systems, fleet insights, and digital workflows (Lytx, 2023b). The safety features include video telematics, Driver scorecards, and fleet maintenance. Compliance services involve ELD solutions, Driver vehicle inspection report (DVIR) applications, and international fuel tax agreement (IFTA) reporting.

Table 5 below lists the existing CVSA technologies, detailing the types of alerts they disseminate and the transportation agencies that have implemented or conducted pilot programs with these technologies. The list offers comprehensive insights into leading alert technologies. Most of the listed technologies are natural driving data systems composed of onboard cameras capturing the vehicle's front view and sometimes its interior, Global Positioning System (GPS) tracking, speed sensors, and, in some cases, facial recognition systems. Recorded data are typically stored on a cloud-based platform, enabling administrators and driver coaches to access driver travel records, including incident information.

Table 5: Commercial Vehicle Technologies for Mobility and Safety Alerts

CVSA Technology	Agency (not exhaustive)	How it Works/characteristics	Main Alerts Disseminated
DMS	• All the state DOTs	• Use light-emitting diode (LED) displays commonly seen on roadways at strategic locations.	• Traffic information (road conditions, incidents, congestion, travel times, alternate routes, etc.). • Special Events. • Weather Information. • Public Service Announcements (PSA).
Azuga[3]	• Oregon Department of Transportation (ODOT) • Colorado Department of Transportation (CDOT)	• Telematics solution • Video clips 10 seconds before and after a hard braking, sudden acceleration, or hard cornering event and attach them to individual driver reports. • May connect with advanced driver assist systems (ADAS) and alert drivers. • Identification of at-fault drivers in need of coaching. • Coaching and reward system.	• Alerts are sent to fleet managers. • Crash or rollover detection. • Emergency button. • Work alone timer. • Seat belt use alert. • Exception alerts. • Vehicle inspection.
Lytx[4]	• Texas Department of Transportation (TxDOT) • Virginia Department of Transportation (VDOT)	• Telematics solution • Dashcams with machine vision and Artificial Intelligence (AI) technologies that detect distracted driving. • Behaviors are self-corrected or tagged for manager review and intervention.	• Visual and audio alerts are sent to drivers. • Driver unbelted. • Following distance under 2s. • Posted speed violation. • Failed to stop. • Incomplete stop.
Mobileye[5]	• City of New York	• Driver assists technologies. • The system (camera sensors and processor unit) monitors	• Visual and audio alerts. • Forward collision warning.

[3] https://www.azuga.com/
[4] https://www.lytx.com/
[5] https://www.mobileye.com/

CVSA Technology	Agency (not exhaustive)	How it Works/characteristics	Main Alerts Disseminated
		the road ahead and utilizes AI to analyze potential hazards.	• Lane departure warning (LDW). • Pedestrian collision avoidance. • Headway monitoring and warning. • Speed limit indicator. • Blind spot detection. • Alerts about the city's dangerous zones.
NetraDyne[6]	• First Student, a leading school transportation provider in North America in San Diego, CA, and Cincinnati, OH	• Telematics solution. • Fleet camera system. • AI technologies detect distractions such as texting while driving. • Visual detection of road signs • Behaviors are self-corrected. • Automated driver coaching is directly available to drivers.	• Audio alerts. • Reports on driver behaviors and video events are sent to the manager. • Following distance. • Hard braking. • Hard acceleration. • Traffic light violation. • Hard turn. • Speeding violation.
Samsara[7]	• Hawaii	• Telematics solution. • AI dash cameras. • Risky behaviors are detected and captured through facial recognition and accelerometer sensors. • No direct alert (alert through coaching system). • Safety report system classifying the near-miss events.	• Voice alert describing the unsafe behavior. • Video events captured. • Preventive in-cab and office coaching. • Inattentive driving. • Tailgating. • Rolling stops. • Harsh driving. • Mobile usage. • No seat belt.
Teletrac[8] Navman	• City of New York	• Full connected cameras. • Onboard Quad camera showing a 360º display and providing. Forward-facing, driver-facing, and left and right-side views. • Coaching and reward system. • No direct alert (alert through coaching system).	• Integrated streamlined coaching application. • Idle alert. • Speed alert. • Maintenance alert. • Off-hours alert. • Geo-fence alert.
PrePass[9]	• Kentucky, Oklahoma, Iowa, Virginia, Washington, Oregon, Idaho,	• In-cab transponders to check a commercial vehicle's safety and credential clearance status one mile before a weigh station (Vehicle length, weight, load distribution, etc.).	• Visual and audible alert. • Green/red lights indicate a bypass. • Red lights indicate the driver must pull into the weigh station.

6 https://www.netradyne.com/
7 https://www.samsara.com/
8 https://www.teletracnavman.com/
9 https://prepass.com/

CVSA Technology	Agency (not exhaustive)	How it Works/characteristics	Main Alerts Disseminated
	South Dakota, and New York		
Drivewyze[10]	• NCDOT • NJDOT • Ohio DOT • GDOT • Pennsylvania Turnpike	• Use of historical travel time, incident events, and road geometry characteristics to alert drivers about potential hazards. • Proactive alert (no need to wait for the event to occur).	• Visual and audible alert. • Congestion and slowdown. • Weather alert. • Rollover alert. • Mountain corridor alert. • Low bridge alert. • Speed citation alert.

Existing technologies primarily focus on detecting naturalistic driving-related data such as driver fatigue, drowsiness, harsh maneuvers, and seatbelt usage. While some alert systems incorporate features such as alerts for slowdown, congestion, lane departure, and following distance, non-naturalistic driving-related alerts are typically sent during or after the event for driver coaching purposes. Drivewyze distinguishes itself through a proactive approach, offering a more extensive range of alerts and actively keeping drivers informed miles ahead. The following subsection discusses the diverse alert solutions provided by Drivewyze and highlights its capacity to provide advanced notifications across a broad spectrum of scenarios.

Types of alerts

Many commercial vehicles are equipped with electronic logging devices (ELDs) that record driver's service hours electronically. ELDs play a crucial role in commercial vehicle alerts by providing real-time monitoring and notifications related to a driver's hours of service compliance and other safety aspects. Beyond this fundamental function, ELDs offer a platform for communication between various entities and drivers facilitated by additional applications. These applications are critical in streamlining operations, including weigh station inspections and bypassing, electronic inspections, and optimizing fleet management. In recent years, certain data providers have enhanced their ELD applications by integrating real-time alerts for congestion and slowdown. These providers maintain a continuous monitoring system that utilizes probe-based traffic data to identify and relay timely information about traffic conditions on specific routes (Drivewyze, 2023).

In this context, transportation agencies such as the North Carolina Department of Transportation (NCDOT), New Jersey Department of Transportation (NJDOT), Ohio Department of Transportation (ODOT), Georgia Department of Transportation (GDOT), and Pennsylvania Turnpike have partnered with companies such as Drivewyze to disseminate alerts to drivers (MacAdam et al., 2023). A slowdown alert is triggered when the speed difference between a commercial vehicle and downstream traffic is 35 miles per hour (mph) or greater. The application automatically establishes a two-mile geo-fenced region upstream of the slowdown location, issuing a warning message to drivers via the ELD in subscribed commercial vehicles entering the geo-fenced region. Moreover, if a route experiences a more than three-minute increase in travel time, the application automatically creates a three-mile geo-fenced region, issuing a traffic congestion warning message to application-enabled ELDs entering that area. The two scenarios are shown in Figure 22 below.

[10] https://drivewyze.com/

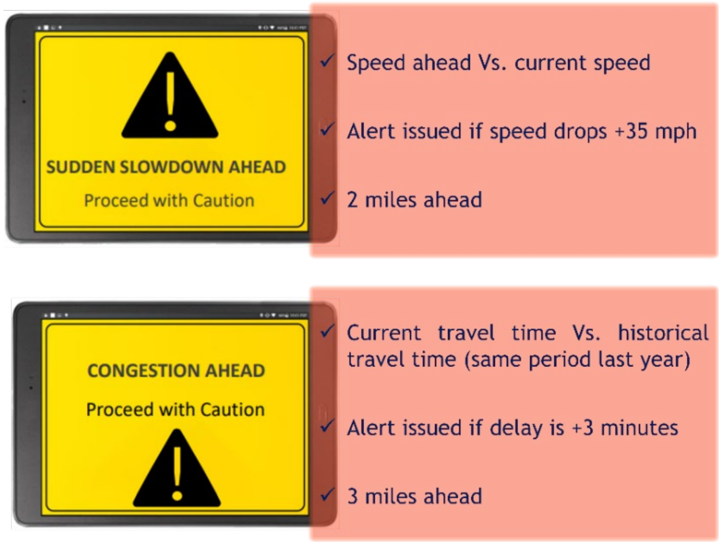
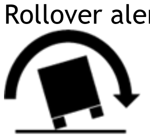


Figure 22: Drivewyze Slowdown and Congestion Alerts (Drivewyze, 2023)

Drivewyze is currently in the process of developing two additional warning scenarios named "Work Zone Ahead – Slow Down" and "Service Vehicle Ahead". It is important to note that Drivewyze safety notifications/alerts were selected based on the criteria of commercial vehicle traffic density and collision history (types of collision that have been regularly occurring). These alerts aim to enhance awareness among commercial vehicle drivers about the traffic situation ahead and encourage positive driver response to minimize the potential occurrence of incidents.

The types of alerts that Drivewyze can provide are listed in Table 6 below. The list includes rollover, real-time slowdown and congestion, mountain corridors, low-bridge, rest areas, severe weather, real-time cargo theft, speed citations, and other alerts (Drivewyze, 2023). The ELD system operates by delivering timely alerts to the device, providing advanced notices/alerts of potential risk zones, accompanied by an audible alert and a visual road sign displayed on the screen. The alert will fade after 10 seconds, or the driver can tap to dismiss it. The third column of Table 6 is the research team's elaboration, providing potential benefits associated with these alerts.

Table 6: Types of Drivewyze Alerts

Type of alert	Description	Potential benefits/effects desired
Rollover alert 	• Notify before sharp exits or curvy roads with a history of rollovers.	• Rollover prevention: drivers adjust their speed, navigate turns more cautiously, or take alternative routes. • Increased awareness: drivers stay vigilant and employ safer driving practices in such high-risk zones.
Real-time slowdown and congestion alerts 	• Notify before congested traffic or locations that require sudden slowdowns.	• Informed decision-making: drivers make informed choices based on real-time traffic updates, allowing route adjustments to avoid congestion and save time.

Type of alert	Description	Potential benefits/effects desired
		• Reduced frustration: drivers anticipate delays, reducing frustration and stress during their commute. • Efficient traffic flow: proactive adjustments by drivers lead to smoother traffic flow, promoting a more efficient road network and enhanced overall mobility.
Mountain corridor alert 	• Notify before brake check stations, steep grades, and runaway ramps.	• Improved preparedness: drivers are more prepared, ensure their vehicle's safety measures are in place before navigating through the corridor, and make informed decisions, reducing the risks associated with mountain corridor travel.
Low bridge alert 	• Notify before railroads, overpasses, tunnels, or bridges with a clearance of 13'6" and lower.	• Heightened awareness and avoidance of damage: drivers reroute or take necessary precautions to avoid low-clearance structures, minimizing the risk of crashes and costly vehicle damage. • Efficient route planning: drivers can plan their routes more efficiently by being aware of low clearance points, ensuring a smoother and safer journey without unexpected height-related obstacles.
Rest area alert 	• Notify before rest areas with available parking stalls.	• Improved planning: drivers plan their rest breaks more effectively and find suitable parking when needed. • Reduced stress: drivers do not stress finding appropriate rest areas with available parking. • Enhanced rest opportunities: drivers can seize the opportunity to rest at open rest areas, promoting safe driving practices and combating driver fatigue.
Severe weather alert 	• Notify within 50 miles of a severe weather event.	• Early warning: drivers make informed decisions to protect themselves and others on the road, alter their routes, or find safe locations to take cover and avoid potential hazards.
Real-time cargo theft alert	• Notify locations with a recent history of cargo theft.	• Cargo protection: drivers and logistics professionals are more vigilant and take necessary precautions to protect valuable cargo during transportation,

Type of alert	Description	Potential benefits/effects desired
		including choosing alternative routes. • Operational efficiency: logistics companies can optimize their operations by planning routes that avoid high-risk areas, minimizing disruptions to the supply chain.
Speed citation alert 	• Notify high-impact sites where citations are common.	• Citation prevention: drivers adjust their speed and driving behavior to avoid potential traffic violations and citations. • Improved compliance: drivers comply with speed limits and traffic rules, promoting safer and legal driving practices. • Cost reduction: The alert system assists in reducing associated fines and legal costs, contributing to financial savings for both drivers and fleet operators.
Other alerts 	• Notify important locations, like high collision areas, work zones, road closures, and more.	• Enhanced preparedness: drivers reroute or adjust their driving behavior accordingly or take any other necessary precautions to minimize risk. • Travel efficiency: drivers optimize their travel routes and plans, avoiding congested areas, work zones, or road closures, ultimately saving time and fuel.

Summary of alert categories

In summary, the research team identified 12 potential alert categories as pivotal factors for enhancing the mobility and safety of commercial vehicle drivers. As shown in Figure 23, the list of these categories relates to various scenarios commercial vehicle drivers may encounter during their journeys. From traffic conditions to route optimization and potential hazards, these categories collectively provide a comprehensive safety and mobility framework that can support commercial vehicle operations.

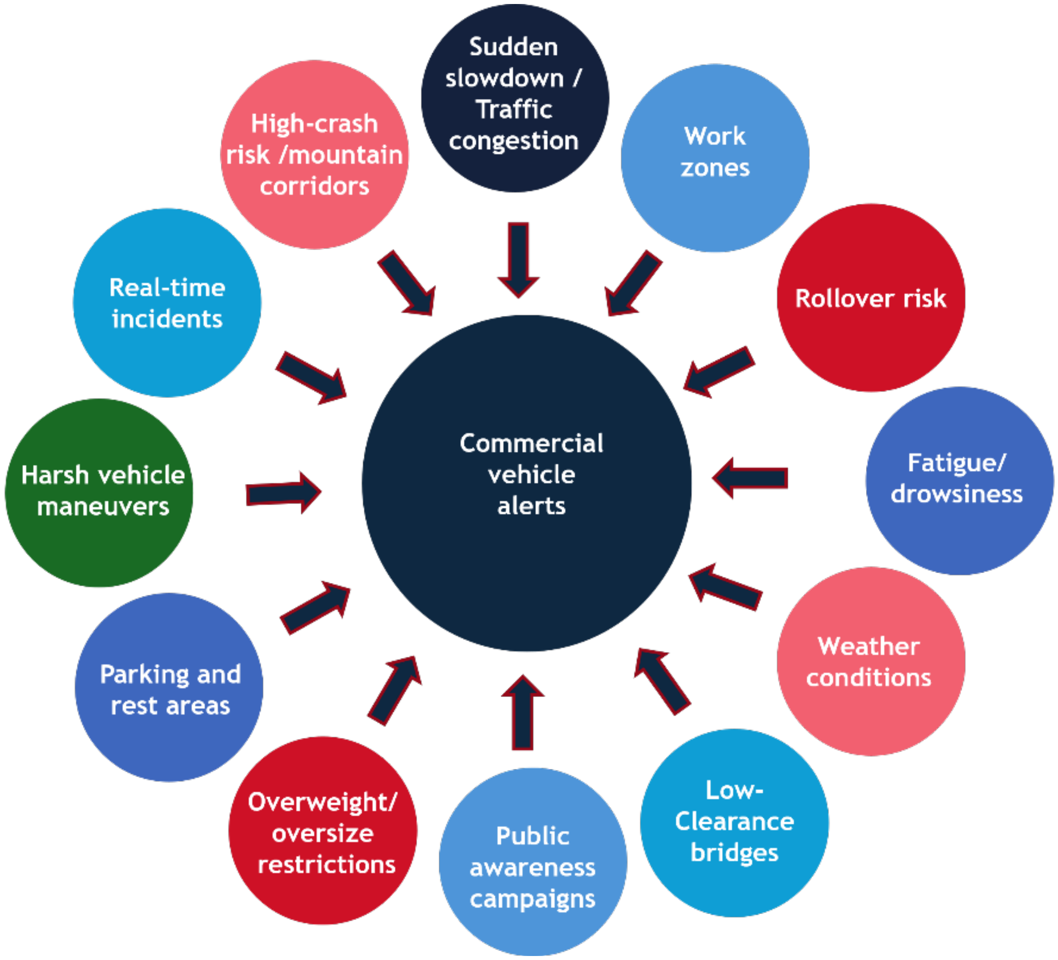


Figure 23: Types of Commercial Vehicle Safety Alert Categories

Effectiveness of alert technologies

Existing literature on the effectiveness of alert technologies for commercial vehicles remains limited (Desai et al., 2024). Only a few studies have offered insights into the efficacy of such technologies or systems. In this section, the research team comprehensively reviewed the available literature, examining both the related work and the specific contexts where these alert technologies have demonstrated their effectiveness.

The Dynamic Message Signs (DMS) system is one of the most widely used and effective ITS for disseminating alerts on highways and influencing driver response. Table 7 below, presents a summary of the literature review findings on DMS.

Table 7: Literature Review on the Dynamic Message Signs

Study	Data	Main findings
Does displaying safety messages on dynamic message signs have measurable impacts on crash risk? (Megat-Johari et al., 2022)	• Safety message data from 202 DMSs on freeways in Michigan between 2014 and 2018. • Roadway geometry, traffic volume, and crash data for segments located downstream of each DMS.	• No significant difference was observed in terms of total crashes. • Declines in nighttime crashes at locations with more frequent messages related to impaired driving. • Significant reductions in speeding-related crashes at locations with higher numbers of messages related to speeding or tailgating. • A 1% increase in the frequency with which safety messages were displayed was associated with a 1.5% decrease in crashes.
Effectiveness of crash facts/safety message signs on dynamic message signs (Savolainen et al., 2021)	• Data includes 333 public comments (emails, Twitter, etc.): Jul. 2013-Jun. 2019. • Opinion surveys (937 respondents): Jun. 2019-Nov. 2019. • Crash statistics: 2012-2018 and Safety message data from 202 DMSs.	• Only 25% of survey respondents indicated that such messages improved their driving behavior. • No significant differences in total or nighttime crashes. • Speeding-related crashes were significantly lower downstream of DMSs.
Effectiveness of Safety and Public Service Announcement (PSA) Messages on Dynamic Message Signs (DMS) (Boyle et al., 2014)	• 2,088 survey responses were collected in 2013 from Chicago, IL; Houston, TX; Orlando, FL; and Philadelphia, PA.	• Male respondents with an income less than $25,000 per year and people aged below 30 years old did not perceive PSA on DMS as effective. • People at least 60 years old and those with graduate school or postgraduate degrees perceived PSAs on DMS as effective.
Evaluating the benefits of dynamic message signs on Missouri's rural corridors (Edara et al., 2012)	• Driver Response to DMS upstream of a work zone (speed data collected in Jun. and Aug. 2010 data from Perryville, Missouri) – 975/962 vehicles upstream/downstream. • Survey data from 151 motorists in Aug. 2011 during the I-57 bridge closure.	• A significant drop in average speeds for private vehicles, trucks, and the combined case. • 1.25 mph to 3.64 mph drop in average speeds for the combined case. • Commercial vehicle drivers tended to be more satisfied with the overall information dissemination process.
Developing Florida-specific mobility enhancement factors (MEFs) and crash modification factors (CMFs) for Transportation Systems	• Speed data upstream and downstream from about 140 DMSs (2016-2019). • Speed ratio was used to estimate MEF. • The speed ratio is the average speed during crash messages to	• The overall MEF was found to be 0.94, implying that there was a 6% reduction in average speeds when the DMSs displayed crash information. • Among messages displaying crash information, if secondary

Study	Data	Main findings
Management and Operations (TSM&O) strategies (Alluri et al., 2020)	the average speed during clear messages). • Coefficient of variation of speeds (CVS) as a surrogate safety measure to quantify the safety benefits. • CVS when the displayed messages did not require drivers to act (clear condition) was compared to the CVS when the DMSs displayed messages about downstream crashes.	information required drivers to "use caution", there were fewer speed reductions compared to lane blockage information. • In other words, drivers were more willing to reduce speeds if lanes were blocked downstream due to a crash. • Displaying crash messages on DMSs was found to result in fewer crashes despite the increase in speed variations.

Despite the wide use of DMSs, multiple limitations hinder its effectiveness. Therefore, employing more advanced safety technology is inevitable.

Camden et al. (2017) listed a variety of advanced safety technologies (ASTs) introduced in the commercial vehicle industry to mitigate risky driving behaviors or errors and prevent commercial vehicle crashes. These ASTs include forward collision warning (FCW), adaptive cruise control (ACC), automatic emergency braking (AEB) systems, lane departure warning (LDW) systems, blind spot warning (BSW), electronic stability control (ESC), roll stability control (RSC), speed limiters, video-based onboard safety monitoring (OSM) systems, kinematic-based OSM systems, vehicle-to-vehicle (V2V) communication, and large truck platooning systems, ELDs, air disc brakes, and brake stroke monitoring systems. OSM systems incorporate several key capabilities, including continuous monitoring of driver behavior and the detection of safety-related events, recordings of safety-related event videos for later review (specific to video-based OSM systems), integration into a fleet's existing back-office software, providing managers with real-time notifications of safety-related events through email and/or text messages, providing drivers with immediate in-cab feedback through visual, auditory, or haptic alerts, enabling wireless or manual retrieval of data (Camden et al., 2015).

The literature review identified four empirical studies that examined the crash reductions associated with CVSA technologies. In addition, eight case studies were found on technology vendor websites. Table 8 outlines the effectiveness of these technologies.

Table 8: Effectiveness of CVSA Technologies

Study	Effectiveness and/or cost
Driver acceptance of collision warning applications based on heavy-truck vehicle-to-vehicle (V2V) technology (Stevens, 2016)	• Approximately 80% of the 112 participants considered intersection movement assist (IMA), forward collision warning (FCW), emergency electronic brake light scenario (EEBL), and blind spot warning (BSW)/lane change warning (LCW) to be highly effective. • Between 58% and 75% of these drivers indicated that auditory and visual alerts were the most valuable features of these collision warning applications. • Among the 112 participants, 84 (75%) stated that monitoring or interpreting the information provided by these safety features was as non-distracting as using their truck's stereo system.

Study	Effectiveness and/or cost
	• About 42 (37.5%) out of the 112 drivers relied to a significant or moderate extent on these safety features as their primary source of alerts for potential hazards in their driving environment.
Independent evaluation of heavy-truck safety applications based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications used in the safety pilot model deployment (Guglielmi et al., 2016)	• FCW, IMA, BSW/LCW, and Curve Speed Warning (CSW) are proven effective in real-world driving scenarios, providing valuable alerts in driving conflicts.
Amerigas propane reduces driver incidents by 55% with Lytx (Lytx, 2018)	• A 55% to 60% reduction in safety-critical events (SCEs), including crashes, was observed. • Reduced risky driving behavior scores. • Reduced costs associated with fewer vehicle collisions.
Cargo transporters reduce fraudulent claims costs with the Lytx driver safety program (Lytx, 2023a)	• 83% decrease in near collisions. • 76% reduction in traffic violations • 33% drop in unbelted drivers
Potential reduction in large-truck and bus traffic fatalities and injuries using Lytx's DriveCam program (Soccolich & Hickman, 2014)	• DriveCam® has the potential to prevent 20.5% of fatal crashes involving large trucks, leading to a 20.0% reduction in fatalities. • DriveCam® can prevent 35.2% of injury crashes involving large trucks and reduce injuries by 35.5%.
Case study: Verst Group Logistics. Preventing the big one (SmartDrive®, 2013)	• Allowed the fleet to avoid $20K-$30K in litigation costs. • Observed a decreasing trend in claims, although the specific percentage reduction was not mentioned. • Achieved a 0% DOT-reportable crash rate (the number of DOT reportable incidents—tow, injury, or fatality—divided by the miles driven) in 2012, although the specific percentage reduction was not specified.
Evaluating the safety benefits of a low-cost driving behavior management system in commercial vehicle operations (Hickman & Hanowski, 2010)	• 38.1%-52.2% reduction in large-truck SCEs. • 44.4%-59.1% reduction in severe SCEs. • Coaching with video reduced severe SCEs by 75.5%.

Overview of benefit-cost analysis methods

A Benefit-Cost Analysis (BCA), a type of economic analysis, is a systematic procedure for quantifying and contrasting the financial benefits and costs of an alert technology. It assesses the soundness and feasibility of an alert technology and gauges its relative merit compared to other alert technologies. Another form of economic analysis is Cost-Effectiveness Analysis (CEA). While similar to BCA, CEA diverges in that it does not express benefits in terms of monetary gains but rather in measurable outcomes. This method is particularly useful for evaluating the cost-effectiveness of different alternatives, especially when the benefits cannot be readily converted into monetary terms. The summary process of BCA is described in Figure 24 below.

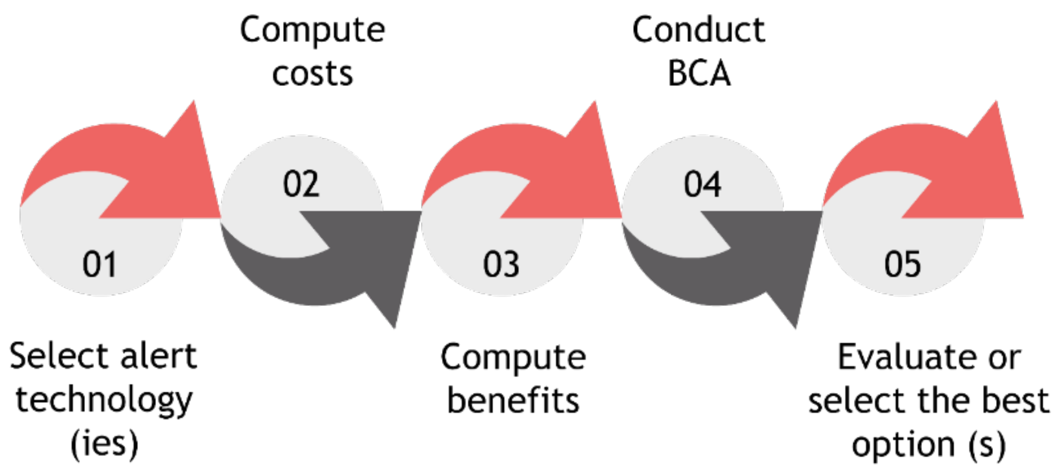


Figure 24: Steps in BCA

To perform the BCA of related alert technologies, the following factors are usually identified (Hickman et al., 2013):

- Technology deployment costs
- Crash costs for the crashes preventable by the specific alert/technology
- Crash benefits as a reduction in the crash rate or expected crash reduction
- Analysis period(s) and discount rate(s)
- Evaluation methodology

Table 9 below summarizes relevant studies that performed BCA on different CVSA technologies. The CVSA methods used, the performance measures considered, and the main findings are presented in this table.

Table 9: BCA Reported in Previous Studies on Safety and Mobility

Study	CVSA Method	BCA Measures	Main Findings
Onboard safety systems effectiveness evaluation final report (Hickman et al., 2013)	• Lane Departure Warning (LDW) • Roll stability control systems (RSC) • Forward Collision Warning (FCW) systems	• Discount rates/costs • Efficacy rates • Net Present Value (NPV) • Benefit-cost ratio (BCR) • Payback periods (PPs)	• Strong and positive safety benefits for LDW and RSC. • LDW system benefits to the carriers outweigh the costs by a BCR of 14.69 to 4.95, depending on annual vehicle miles traveled (VMT) (PP of 4 to 12 months). • LDW system benefits to society would outweigh the costs by a BCR of 5.7 to 1.9 (PP of 11 to 32 months). • RSC system benefits to the carriers outweigh the costs by a BCR of 12.50 to 4.17 (PP of 5 to 14 months). • RSC system benefits to society outweigh the costs by a BCR of 4.2 to 1.4 (PP of 14 to 43 months).
Do the benefits outweigh the costs? Societal benefit-cost	• Automatic emergency braking (AEB) • LDW	• BCR • Efficacity rate, low, average, and high cost	• Equipping trucks with LDW and video-based OSM systems was found to be cost-effective. • All three technologies can be cost-effective for new large trucks provided

Study	CVSA Method	BCA Measures	Main Findings
analysis of three large truck safety technologies (Camden et al., 2018)	• Video-based onboard safety monitoring (OSM)		the current costs and efficacy rates can be maintained or improved upon. • The BCAs showed that every combination of cost (i.e., low, average, or high), efficacy rate (i.e., 20% or 52.2%), and discount rate (i.e., 0%, 3%, or 7%) produced a cost-effective solution when all new and existing large trucks were equipped with video-based OSM systems. • The BCRs ranged from 7.90 to 1.20 when all trucks (new and existing) are equipped and from 10.74 to 1.45 when only new trucks are equipped with video-based OSM systems.
Analysis of benefits and costs of lane departure warning systems for the trucking industry (Houser et al., 2009)	• LDW • Audio alert, similar to the sound of a vehicle driving over a rumble strip • Visual alert	• Discount rates/costs • Efficacy rates • NPV • BCR	• BCR of trucks with LDW to be 6.55 to 1.37 with a 3% to 7% discount (depending on VMT, system efficacy estimates, and technology purchase costs).
Analysis of benefits and costs of roll stability control systems for the trucking industry (Murray et al., 2009b)	• RSC systems • RSC (Wheel speed sensors + lateral accelerometer) • Audible and/or visual alerts	• Discount rates/costs • Efficacy rates • NPV • BCR	• Carrier BCR in RSC deployment to be 9.36 to 1.66 with a 3% to 7% discount (depending on VMT, system efficacy estimates, and technology purchase costs). • PP ranges from 6 to 30 months (depending on VMT, system efficacy estimates, and technology purchase costs. • Regardless of the average VMTs, medium-sized to large motor carriers with an average likelihood of being involved in a rollover crash will achieve positive returns on investment by purchasing and using RSC systems.
Analysis of benefits and costs of forward collision warning systems for the trucking industry (Murray et al., 2009a)	• FCW • Adaptive cruise control (ACC) • Audible and/or visual alerts	• Discount rates/costs • Efficacy rates • NPV • BCR	• Carrier BCR in FCW deployment to be 7.22 to1.33with a 3% to 7% discount (depending on VMT, system efficacy estimates, and technology purchase costs). • PP ranging from 8 to 37 months (depending on VMT, system efficacy estimates, and technology purchase costs). • Regardless of the average VMTs traveled, motor carriers with a typical likelihood of being involved in a rear-end crash will achieve positive returns on investment by purchasing and using the FCW system.

Study	CVSA Method	BCA Measures	Main Findings
Leveraging large-truck technology and engineering to realize safety gains: video-based onboard safety monitoring systems (Camden et al., 2017)	• Video-based OSM systems	• Discount rates/costs • Efficacy rates • NPV • BCR • Cost-effectiveness (CE)	• For equipping all new and old large trucks with video-based OSM systems BCR ranges from 7.90 to 1.20 (for all large trucks), 8.62 to 1.31 (if only Combination Unit Trucks are equipped), and 6.63 to 1.01 (if only Single Unit Trucks are equipped) with a discount rate varying from 0% to 7%. • For only new vehicles with video-based OSM systems, BCR ranges from 10.74 to 1.45 (for all large trucks), 4.20 to 1.48 (if only CUTs were equipped), and 10.24 to 1.39 (if only SUTs were equipped) with a discount rate varying from 0% to 7%. • OSM systems have a high BCR of 10.74 to 10.17 when new large trucks are equipped with the technology (with a 3% to 7% discount rate).
Benefit-cost analysis of lane departure warning and roll stability control in commercial vehicles (Medina-Flintsch et al., 2017)	• LDW • RSC	• Discount rates • NPV • BCR • PP	• Carriers with LDW would experience a BCR of 4.95 to 14.86, an NPV of $3,034 to $10,636, and a PP of 12 to 4 months (from 60,000 to 180,000 VMT/year). • Society would experience a BCR of 1.9 to 5.71, an NPV of $1,008 to $5,260, and a PP of 32 to 11 months (from 60,000 to 180,000 VMT/year). • Carriers with RSC would experience a BCR of 4.17 to 12.50, an NPV of $1,401 to $5,088, and a PP of 14 to 5 months (from 60,000 to 180,000 VMT/year). • Society would experience a BCR of 1.41 to 4.22, an NPV of $252 to $1,989, and a payback period of 43 to 14 months (from 60,000 to 180,000 VMT/year).

In summary, the literature review reveals that the benefits of different alert technologies outweighed their costs. However, the projected BCR is contingent upon variables such as VMT, estimates of system efficacy, and the costs of acquiring the technology. In other words, the cost-effective solution when new and existing commercial vehicles are equipped with these CVSA alerts will depend on the combination of cost, efficacy rate, and discount rate.

Furthermore, there is a noticeable absence of BCA studies on technologies such as Drivewyze or similar technologies in the existing literature. This report serves as a pioneering initiative, aiming to perform a BCA on these innovative technologies. It will provide valuable insights into their potential and suitability for widespread adoption within the commercial vehicle industry, equipping decision-makers with the necessary information for informed choices regarding their adoption and deployment.

Summary of literature review

The literature review that was presented in this report revealed the pressing need to address safety concerns associated with commercial vehicles, particularly in light of the increased crashes involving such vehicles. Of particular concern are work-zone-related crashes, rear-end crashes, secondary crashes, and speed-related crashes, frequently associated with sudden slowdowns and congestion conditions. In alignment with the FMCSA's goal of eliminating fatalities involving large trucks and buses, it is crucial to prioritize the improvement of both mobility and safety for commercial vehicle drivers through the implementation of effective alert systems.

The review of existing literature revealed that many technologies focused on naturalistic driving-related data, including driver fatigue, drowsiness, harsh maneuvers, and seatbelt usage. DMSs, Azuga, Lytx, Mobileye, Netradyne, Samsara, Teletrac Navman, PrePass, and Drivewyze were among the technologies discussed, with Drivewyze standing out for its proactive approach and alert capabilities, which provided advanced notifications miles ahead.

Additionally, the research team reviewed methodologies employed by the past and current literature for benefit-cost analysis that evaluated the effectiveness of commercial vehicle alert technologies, unveiling insights into their cost-effectiveness. Building on this foundation, the project specifically examined the mobility and safety effectiveness of Drivewyze alerts, which contributed to a more nuanced understanding of the role such technologies play in mitigating the risks associated with commercial vehicle operations. This project adopted the benefit-cost analysis (BCA) approach to determine the effectiveness of Drivewyze safety systems by contrasting the benefits against the costs of this system.

Appendix B: Survey Analysis

Truck Driver Survey

Estimation of the sample size for the CMV driver survey

The formula below (Equation 9), proposed by Nishat (2023), was used to estimate the adequate number of respondents to the CMV driver survey the research team can target. Other studies, such as Taherdoost (2017) used this method to estimate the sample size for surveys.

$$\boldsymbol{n} = \frac{\frac{p\,(100-p)}{E^2} \times z^2}{\frac{z^2 \times p\,(100-p)}{E^2 \times N} + 1} \qquad (10)$$

where,

n = the required sample size,
p = 50% (standard deviation),
E = 5% (percentage maximum error),
z = 1.96 (z-score value corresponding to the 95% level of confidence required), and
N = the estimated population.

A standard deviation of 50% was selected since the research team did not know how much variance to expect. In addition, the standard deviation of 50% symbolizes that half of the population survey has characteristics that are considerable for the survey. Table **10** below presents the top 10 freeway segments with the highest truck AADT in Ohio for the year 2022.

Table 10: Estimated Top 10 Maximum AADT in Ohio Interstate Segments in 2022

Rank	ID	Truck AADT
1	76533509	26457
2	76533506	26457
3	76533505	26457
4	76533508	26457
5	76533507	26457
6	76185755	25100
7	76185754	25100
8	76185756	25100
9	76185752	25100
10	76472129	25100

The maximum AADT for interstate route truck volume was **26,457** truck vehicles.
The formula below (equation 15) was used to estimate the truck volume for a particular season or month (Prassas & Roess, 2020).

$$V_{mj} = \frac{truck\ volume}{MF_j} = \frac{26457}{MF_j} \qquad (11)$$

Where,

V_{mj} is the estimated truck volume, and
MF_j is the seasonal adjustment factor.

Table 11 presents the estimated maximum truck volumes for December 2022, January 2022, and February 2022. These months correspond to the period during which the team received responses from drivers. The monthly adjustment factors used represent the average seasonal adjustment factors provided by the Ohio Department of Transportation (ODOT, 2022).

Table 11: Estimated Maximum Truck Volumes for December, January, and February 2022

Month	Monthly Factor (MF)	Monthly Average Daily Traffic	Number of days in a month	Monthly Volume (N)
December, 2022	1.051	25,174	31	780,394
January, 2022	1.241	21,320	31	660,920
February, 2022	1.140	23,208	28	649,824

During the three months, the estimated total number of trucks is 2,091,138.

$$n = \frac{\frac{p\,(1-p)}{E^2}\times z^2}{\frac{z^2+p\,(1-p)}{E^2\times N}+1} = \frac{\frac{0.5(1-0.5)}{(0.05)^2}\times(1.96)^2}{\frac{(1.96)^2+0.5\,(1-0.5)}{(0.05)^2\times 2091138}+1} = 383.85\approx 384$$

Based on the values selected for the parameters described above to determine the required sample size, the estimated number of respondents for the driver survey was **384**.

Truck Driver Survey Analysis Results

Table 12 below presents a list of alternative CVSA systems and their benefits compared to Drivewyze. It should be noted that the technologies listed in this table are systems with a similar operation scheme as Drivewyze, and the potential additional benefits are their distinctive characteristics.

Table 12: List of Potential Alternative CVSA Systems to Drivewyze

Rank	Alert System	Response from the CMV Driver survey	Potential additional benefits
1.	GPS (Garmin, Rand McNally, etc.)	13.89%	• One-time cost (purchase cost) for the user. • In addition to the alerts provided by Drivewyze, the following alerts are provided: - Animal crossing zone. - School zone. - Rest areas and gas station. - Traffic congestion. - CMV detours. • However, alerts and alternative solutions disseminated do not consider truck restrictions.
2.	Motive	12.78%	• Artificial intelligence-oriented technology. • In addition to safety alerts that are mostly similar to those disseminated by Drivewyze, the alerts are focused on detecting drivers (distraction, harsh maneuvers, non-seat belt use, etc.) through facial recognition vehicle collisions, and near misses. • Provide drivers with on-duty hours tracking.
3.	Samsara	9.44%	• Artificial intelligence-oriented technology. • Like Drivewyze, it sends safety and congestion alerts to CMV drivers. • The technology captures drivers’ risky behaviors (distraction harsh maneuvers, non-

Rank	Alert System	Response from the CMV Driver survey	Potential additional benefits
			seat belt use, etc.) through facial recognition vehicle collisions and near misses.
4.	Omnitracs	5.56%	• In addition to safety alerts that are mostly similar to those disseminated by Drivewyze, the system provides crash risk alerts.
5.	Trucker Path	2.50%	• This CVSA system provides severe weather warnings, rest areas warnings, CMV stops, and CMV parking areas.
6.	Geotab	2.50%	• Similar to Drivewyze, this system provides safety alerts to CMV drivers. • In addition, alerts such as backing up while driving and crash risk are provided.
7.	Google Maps	2.22%	• Through public alerts, Google Maps provides alerts such as traffic congestion, detours, weather, crash ahead, and road closures. • However, alerts and alternative solutions disseminated do not consider the truck restriction per road function.
8.	PrePass	1.11%	• This technology is prominently known for bypassing highway weigh stations. • Traffic alerts are an added benefit of utilizing this technology. • Similar to Drivewyze, this CVSA system provides both mobility and safety alerts. • Indicates the rest areas and brake check/chain-up areas.

The research team asked the CMV drivers to specify the types of alerts provided in their trucks. The goal was to identify the most common alerts drivers currently receive and explore additional alerts they would like to have. Table 13 below presents the proportions of the common alerts received by CMV Drivers.

Table 13: Common Alerts Received by CMV Drivers

Alert type	Label	Count	Percentage
Harsh vehicle maneuvers (speeding, etc.)	No response	9	1.54
	No, I don't receive these alerts, and I am not interested in receiving them.	94	16.1
	No, I don't receive these alerts, but I would like to.	124	21.23
	Yes, I received these alerts.	***357***	***61.13***
Real-time incidents (crashes, lane closures, road closures, etc.)	No response	29	4.97
	No, I don't receive these alerts, and I am not interested in receiving them.	86	14.73
	No, I don't receive these alerts, but I would like to.	185	31.68
	Yes, I received these alerts.	***284***	***48.63***
High-crash risk corridors	No response	29	4.97
	No, I don't receive these alerts, and I am not interested in receiving them.	113	19.35
	No, I don't receive these alerts, but I would like to.	194	33.22

Alert type	Label	Count	Percentage
	Yes, I received these alerts.	***248***	***42.47***
Sudden slowdown	No response	34	5.82
	No, I don't receive these alerts, and I am not interested in receiving them.	78	13.36
	No, I don't receive these alerts, but I would like to.	177	30.31
	Yes, I received these alerts.	***295***	***50.51***
Traffic congestion	No response	25	4.28
	No, I don't receive these alerts, and I am not interested in receiving them.	93	15.92
	No, I don't receive these alerts, but I would like to.	185	31.68
	Yes, I received these alerts.	***281***	***48.12***
Work zone	No response	32	5.48
	No, I don't receive these alerts, and I am not interested in receiving them.	95	16.27
	No, I don't receive these alerts, but I would like to.	187	32.02
	Yes, I received these alerts.	***270***	***46.23***
Rollover risk	No response	28	4.79
	No, I don't receive these alerts, and I am not interested in receiving them.	91	15.58
	No, I don't receive these alerts, but I would like to.	177	30.31
	Yes, I received these alerts.	***288***	***49.32***
Fatigue/drowsiness	No response	40	6.85
	No, I don't receive these alerts, and I am not interested in receiving them.	164	28.08
	No, I don't receive these alerts, but I would like to.	***241***	***41.27***
	Yes, I received these alerts.	139	23.8
Weather conditions	No response	27	4.62
	No, I don't receive these alerts, and I am not interested in receiving them.	92	15.75
	No, I don't receive these alerts, but I would like to.	206	35.27
	Yes, I received these alerts.	***259***	***44.35***
Low-clearance bridges	No response	33	5.65
	No, I don't receive these alerts, and I am not interested in receiving them.	88	15.07
	No, I don't receive these alerts, but I would like to.	191	32.71
	Yes, I received these alerts.	***272***	***46.58***
Oversize/overweight restrictions	No response	31	5.31
	No, I don't receive these alerts, and I am not interested in receiving them.	108	18.49
	No, I don't receive these alerts, but I would like to.	198	33.9
	Yes, I received these alerts.	***247***	***42.29***
Parking and rest areas	No response	38	6.51
	No, I don't receive these alerts, and I am not interested in receiving them.	96	16.44
	No, I don't receive these alerts, but I would like to.	208	35.62
	Yes, I received these alerts.	***242***	***41.44***
Weigh stations	No response	31	5.31
	No, I don't receive these alerts, and I am not interested in receiving them.	77	13.18
	No, I don't receive these alerts, but I would like to.	148	25.34
	Yes, I received these alerts.	***328***	***56.16***
Truck detours	No response	43	7.36
	No, I don't receive these alerts, and I am not interested in receiving them.	88	15.07
	No, I don't receive these alerts, but I would like to.	***252***	***43.15***
	Yes, I received these alerts.	201	34.42
High theft area	No response	39	6.68

Alert type	Label	Count	Percentage
	No, I don't receive these alerts, and I am not interested in receiving them.	119	20.38
	No, I don't receive these alerts, but I would like to.	**276**	**47.26**
	Yes, I received these alerts.	150	25.68
Mountain corridor (steep grades, runaway truck ramps, etc.)	No response	40	6.85
	No, I don't receive these alerts, and I am not interested in receiving them.	104	17.81
	No, I don't receive these alerts, but I would like to.	194	33.22
	Yes, I received these alerts.	***246***	***42.12***
Toll plazas	No response	35	5.99
	No, I don't receive these alerts, and I am not interested in receiving them.	99	16.95
	No, I don't receive these alerts, but I would like to.	184	31.51
	Yes, I received these alerts.	**266**	**45.55**
Public awareness campaigns*	No response	47	8.05
	No, I don't receive these alerts, and I am not interested in receiving them.	153	26.2
	No, I don't receive these alerts, but I would like to.	***266***	***45.55***
	Yes, I received these alerts.	118	20.21
Other(s)	No response	***171***	***29.28***
	No, I don't receive these alerts, and I am not interested in receiving them.	143	24.49
	No, I don't receive these alerts, but I would like to.	163	27.91
	Yes, I received these alerts.	107	18.32

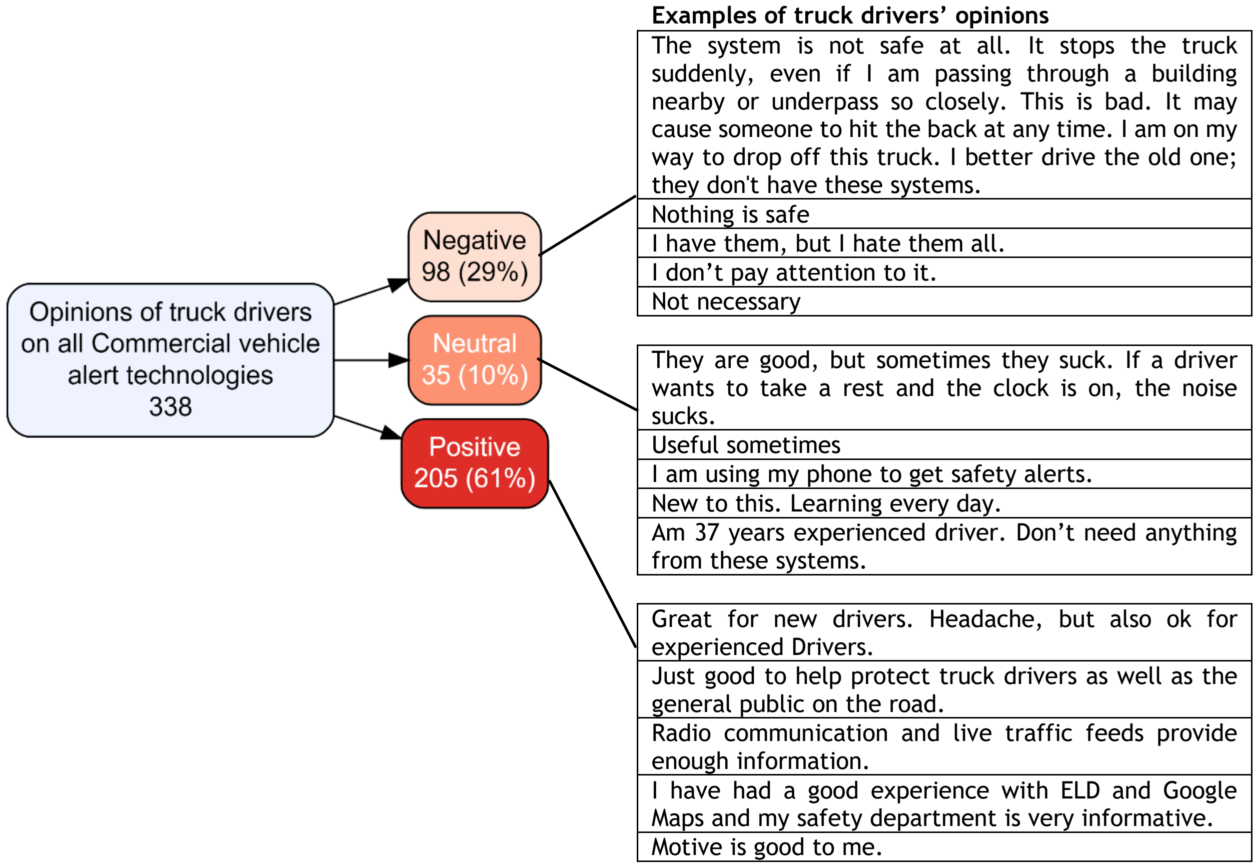
Note: *General messages such as Ohio's distracted driving law enforcement going into effect in October 2023, etc. The highest counts and percentages are highlighted in bold and italic.

Table 14 below shows the additional alerts that improve safety and the reference system that can be used shows how to present these additional alerts.

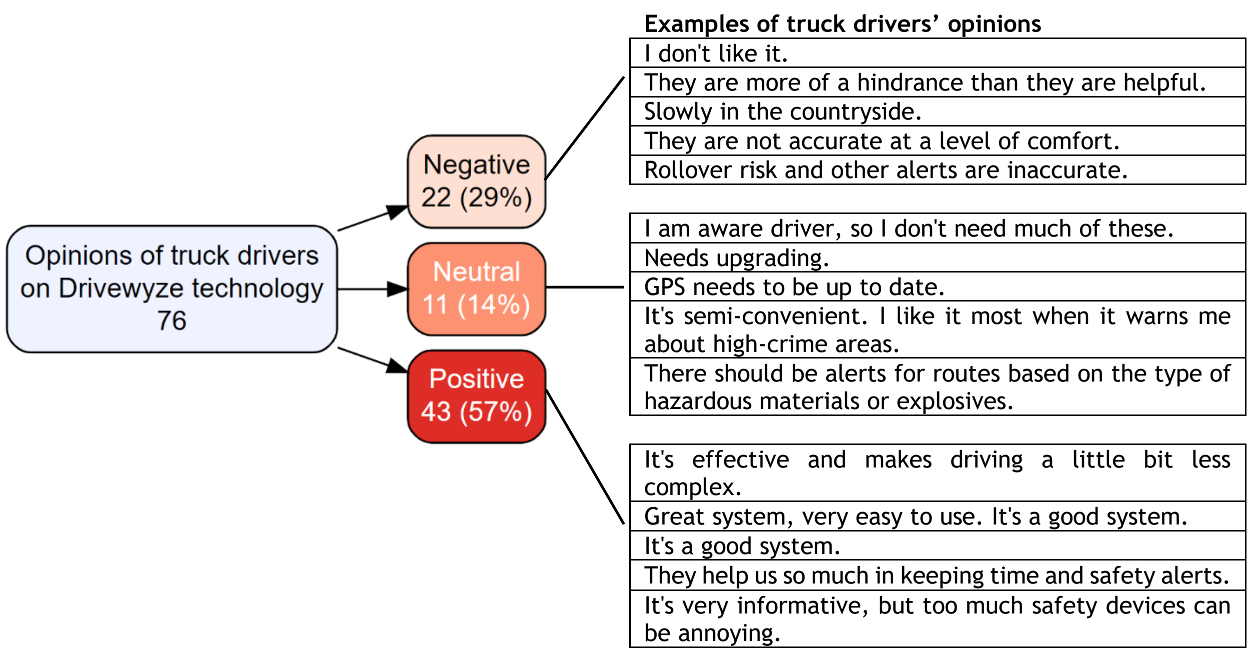
Table 14: Additional Alerts and their Corresponding Reference Systems

No	Additional alerts	Reference System
1.	Severe weather alert/dynamic weather warning	QuickMap, Trucker Path
2.	Lane closure	QuickMap,
3.	Truck detour	Motive
4.	Steep grade and runway truck ramp	
5.	Distracted driving and driver fatigue alerts	Samsara, Motive
6.	High wind area	
7.	Snow-plows operations	COtrip Planner
8.	Animal crossing zones	GPS (Garmin, Rand McNally, etc.)
9.	Rest areas and gas station	Trucker Path, GPS (Garmin, Rand McNally, etc.)
10.	Availability of parking space	
11.	Rest area closure	

The truck drivers were asked an open-ended question to provide their additional perspectives/opinions regarding their experience in using the CVSA systems. Figure 25 shows the summary of the negative, positive, and neutral opinions collected from the drivers.



(a) All CMV Alert Systems



(b) Using Drivewyze System

Figure 25: Sentiment Analysis of Drivers' Opinions

State DOT Agency Survey

Different agencies were requested to fill in an agency survey. 17 states responded to the survey as shown in Figure 26. However, only 11 states completed the survey and 8 agreed to perform a follow-up interview.

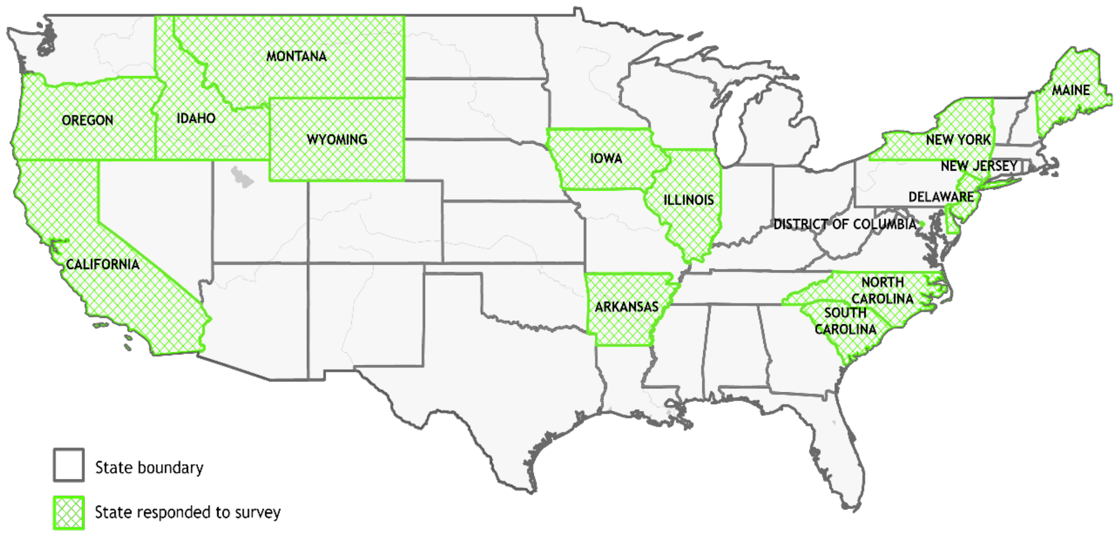


Figure 26: States Responded to Agency Survey

In the survey, the research team asked state DOTs to provide a list of alternative CVSA systems they use for alerts. The results are summarized in Table 15 below.

Table 15: CVSA Systems Identified by State DOTs

State	CVSA system
California Department of Transportation	QuickMap and roadway changeable message signs (CMS)
Iowa Department of Transportation	Not sure if this is what you're looking for, but we send alerts via email or text from our 511 system. We also alert drivers via DMS on the roadway.
New Jersey Department of Transportation	Transcom XML feed to various trucking industries, individual requests to trucking GPS companies, previously used iCone ITS Hazard Beacon.
Oregon Department of Transportation	We are working on developing PrePass systems to operate in Oregon.
Virginia Department of Transportation	Waze, Prepass, and 511 are used for all drivers, not just commercial vehicles.
Wyoming Department of Transportation	We provide our information to any 3rd party who wishes to receive it. Google, TomTom, Sirius XM and recently Drivewyze have agreed to use our data.

The agencies were also asked to specify the alerts disseminated to the CMV drivers, as shown in Table 16. Iowa (IA) was found to provide most of the alerts.

Table 16: Types of Alerts Disseminated by State DOTs

In-cab alert	State										Count per alert
	AR	CA	DE	IA	IL	MT	NJ	NC	OR	WY	
High-crash risk corridors						Yes					1
Sudden slowdown	Yes	Yes					Yes	Yes			4
Traffic congestion		Yes		Yes			Yes	Yes			4
Work zones		Yes		Yes			Yes			Yes	4
Rollover risk	Yes		Yes			Yes					3
Weather conditions		Yes		Yes			Yes			Yes	4
Low-clearance bridges	Yes	Yes	Yes	Yes		Yes					5
Oversize/overweight restrictions		Yes		Yes						Yes	3
Parking and rest areas				Yes						Yes	2
Weigh stations				Yes		Yes			Yes		3
Truck detour				Yes							1
High theft area											
Mountain corridor	Yes					Yes			Yes		3
Toll plazas											
Public awareness campaigns					Yes						1
Total alerts per agency	**4**	**6**	**2**	**8**	**1**	**5**	**4**	**2**	**2**	**4**	

The research team asked DOTs about the criteria they use to select CVSA systems. The purpose was to understand the factors state agencies consider when choosing the most suitable systems. The results for this question are shown in Table 17 below.

Table 17: Criteria for Selecting a CVSA System Revealed by DOT Agencies

State	Criteria
Arkansas Department of Transportation	The system should: reduce secondary crashes; and provide virtual DMS to augment existing real locations.
California Department of Transportation	Safety and easy accessibility
Delaware Department of Transportation	Drivewyze/INRIX seemed the best for a 1-year pilot.
Illinois Department of Transportation, Bureau of Investigations & Compliance	Still being studied -no decision has been made.
Iowa Department of Transportation	We want to get the information to the drivers as quickly as possible. Getting the information into the cab has been the most challenging.
Montana Department of Transportation	None
North Carolina Department of Transportation	We decided to try it (Drivewyze) and see how beneficial it was.
New Jersey Department of Transportation	The system was available. Piloted towards the end of the pandemic, Alerts were recognized as targeted value.

State	Criteria
Oregon Department of Transportation	Request for proposal
Pennsylvania Turnpike Commission	TSMO plan priorities
Virginia Department of Transportation	Drivewyze is a pilot project for now. We are evaluating it.
Wyoming Department of Transportation	We make all of our information freely available and do not pay any vendor to push our data. This includes Drivewyze.

Table 18 shows the responses from different state DOTs on how the CVSA systems improved safety and mobility.

Table 18: Improvement Observed by Agency Incorporating the CVSA System

State	Improvement
Arkansas Department of Transportation	Have not completed implementation
California Department of Transportation	Not applicable (Our agency does not operate commercial vehicles)
Delaware Department of Transportation	Too early to tell
Georgia Department of Transportation	It's reduced crashes and we have used the data to see where we can continue to improve alerts to help improve safety and mobility.
Illinois Department of Transportation, Bureau of Investigations & Compliance	Not Applicable
Iowa Department of Transportation	I don't have any metrics or data for this question.
Montana Department of Transportation	We are not currently analyzing data.
North Carolina Department of Transportation	In a study done in a North Carolina Work Zone, trucks that received the alerts slowed down between 8-11 mph. We attempted to look at truck crash rates on corridors with and without the Drivewyze alerts, but the results were inconclusive.
New Jersey Department of Transportation	Metrics of alerts are available from the Drivewyze platform analytics. Nothing quantitative.
Pennsylvania Turnpike Commission	We are looking into evaluating the product.
Virginia Department of Transportation	We are currently evaluating DriveWyze. It should have results by late 2024.
Wyoming Department of Transportation	We have not analyzed improved safety and mobility through 3rd parties.

The state DOT agencies were also requested to share their experience with CVSA systems through an open-ended question. The responses are summarized in Table 19 below.

Table 19: Additional Opinions from State DOTs

State	Additional Opinions
Arkansas Department of Transportation	Have not completed implementation. Virtual DMS is email-based based would prefer a user interface to simplify use.
California Department of Transportation	Not applicable
Delaware Department of Transportation	We are looking forward to seeing the results.
Georgia Department of Transportation	It's a good start, but I think it could be even better if we turned it into a full-out GPS
Illinois Department of Transportation, Bureau of Investigations & Compliance	Not Applicable
Iowa Department of Transportation	We've been working with PrePass to help them start using the WZDx data feed for their in-cab alerts. I think the key is data standards. We provide open data using data standards, but alerting companies don't seem to be using those yet.
Montana Department of Transportation	MDT would like to move towards driver/carrier notification alerts through our CMV permit system.
North Carolina Department of Transportation	We believe it has good safety benefits. We wish more trucks used the system and have been working to promote it.
New Jersey Department of Transportation	Having alerts that go directly into the cab of commercial vehicles, although restricted to those using the Drivewyze platform is another way to reach our customers.
New York Department of Transportation	NYSDOT will be piloting a project with Drivewyze to distribute alerts soon.
Oregon Department of Transportation	Oregon DOT has applied for a grant to provide commercial vehicles with as many of these safety systems as possible via Drivewyze and PrePass. Currently, Drivewyze costs are very high and annual which Oregon DOT can't support long term. PrePass has initial development fees with no annual costs, but the presence is significantly less than Drivewyze in Oregon.
Virginia Department of Transportation	We will be able to provide additional information in the next few months. The project website is here: https://vtrc.virginia.gov/projects/all-projects/124308/
Wyoming Department of Transportation	We are using a system called the Situation Data Exchange to provide information to any 3rd party or connected vehicle. The SDX is a one-stop shop that can be used by any data provider or data consumer. It does not cost to push information to the SDX. For more information on this system, see https://sdx.trihydro.com/

Figure 27 presents some of the feedback provided by DOT agencies. Most of the responses indicated that agencies are experiencing significant benefits from using their respective safety alert systems.

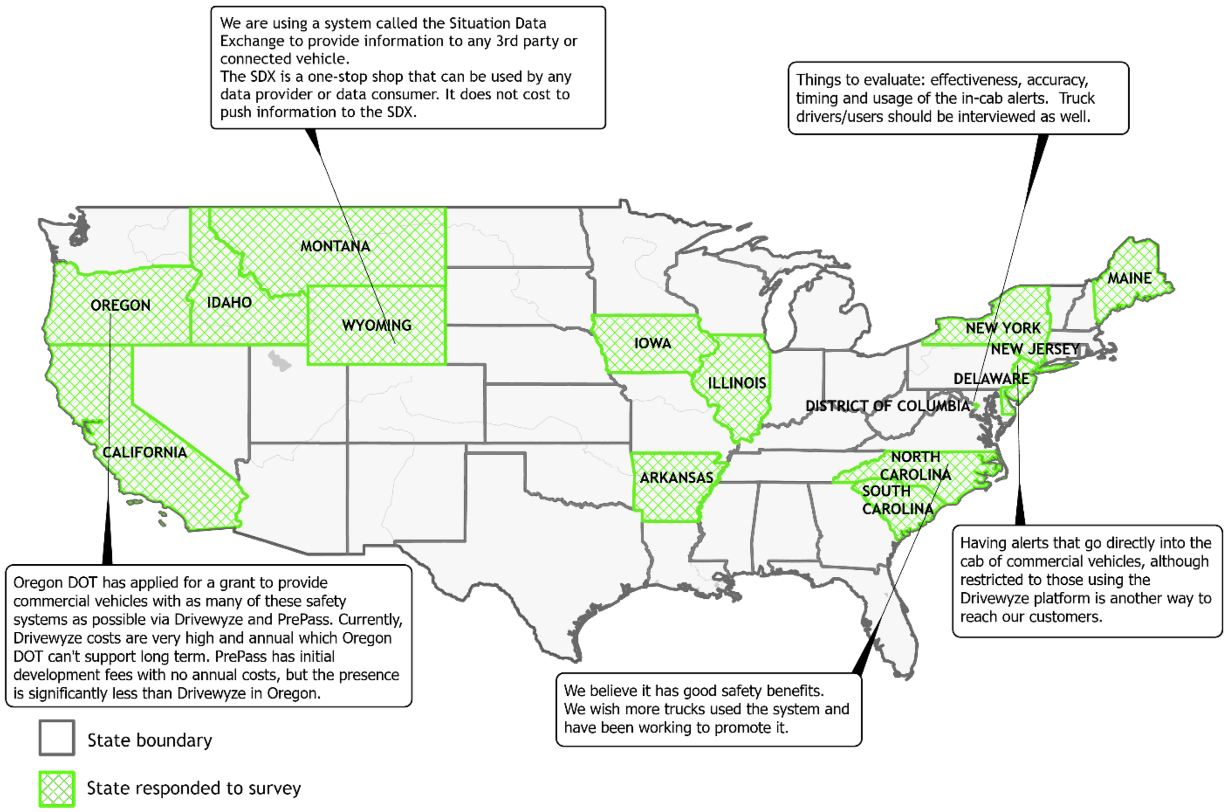


Figure 27: Opinions from State Agencies

Truck Company Survey

Trucking companies were asked to specify the CVSA systems they use, to identify alternative systems employed to disseminate safety and mobility alerts. The responses indicated that Samsara and Lytx are among the most commonly used alert systems, as shown in Figure 28 and Table 20.

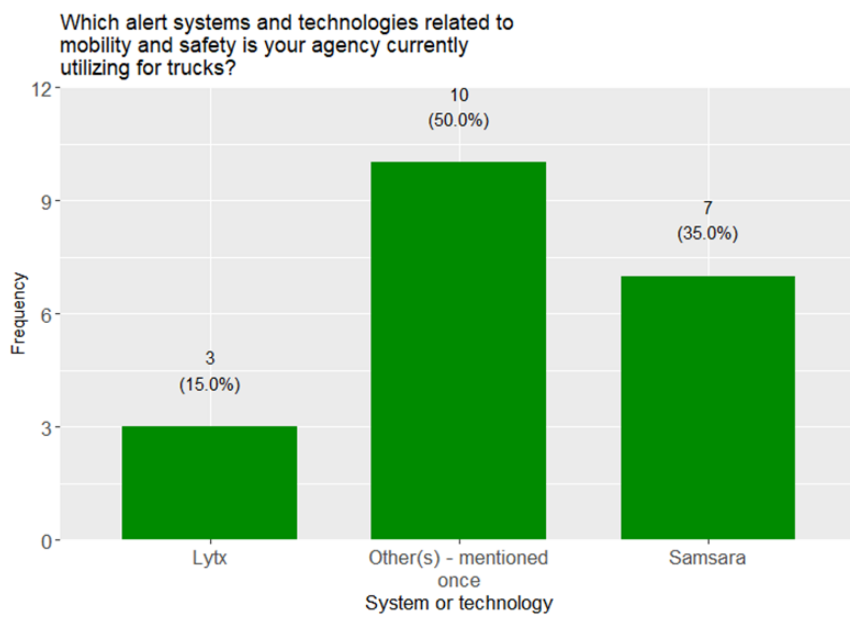


Figure 28: Alert Systems Revealed by Trucking Companies

Table 20: Alert System per Truck Company

Company name	Alert system
Quality Carriers	Collision avoidance (Detroit Assurance) and Lytx
Buchheit Logistics, Inc.	CoPilot Active Traffic on Isaac ELD and Netradyne dash-cam
FLCO Trucking Company	Samsara, Lytx, Bendix
UWC Transportation	Trimble
Sedona Trucking Inc.	Samsara
Capital City Oil	Samba safety
J&H Trucking, Inc.	Samsara & Factory installed front-end-side collision avoidance systems.
Mast Trucking Inc	Samsara
National Enforcement Safety Training LLC	FMCSA and STATES websites
Freeport Transportation	Samsara
RMJK Enterprises Inc.	Collision Mitigation system
Empire Cat	Samsara
Not provided	Lytx
Associated Petroleum Carriers, Inc.	Samsara

Trucking companies were further asked to show the effectiveness of the alerts they subscribed to. Figure 29 highlights the results, with the most effective alerts being related to harsh vehicle maneuvers (such as speeding), real-time incidents (crashes, lane closures, road closures), fatigue/drowsiness, rollover risks, and weigh stations. Notably, 70% of trucking companies reported that their drivers receive alerts about harsh vehicle maneuvers, as shown in Figure 29.

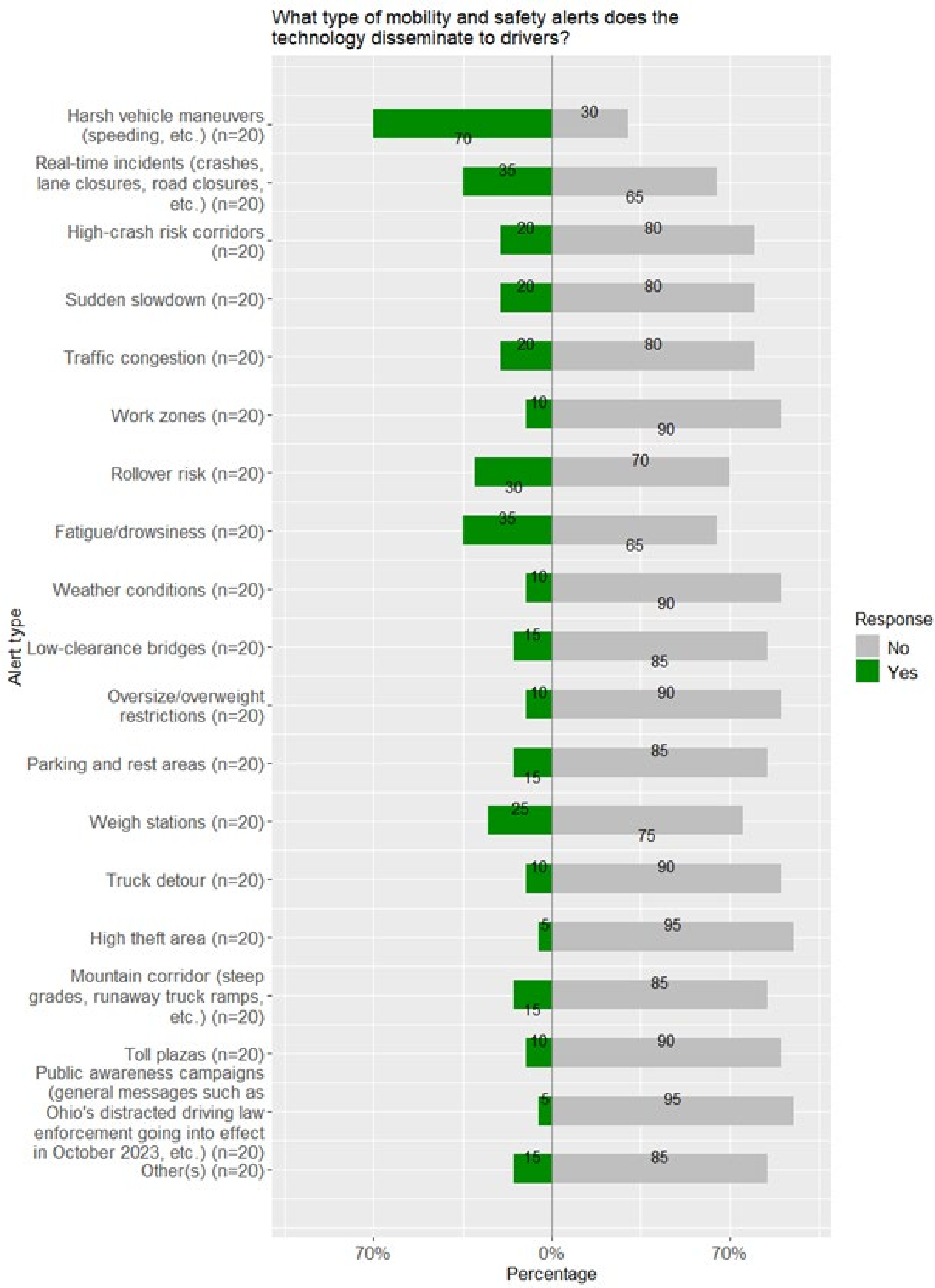


Figure 29: Effectiveness of Alert Revealed by Trucking Companies

Moreover, trucking company survey results revealed additional alerts that are offered to CMV drivers, which include:

- Following distance or adaptive cruise control (ACC) (three mentions)
- Lane change (two mentions)
- Hard braking or braking assist (two mentions)
- Distracted driving
- Smoking in the truck
- Seat belt usage

In the open-ended question, trucking companies revealed additional insights about alert systems. Table 21 provides summarized opinions, suggesting that most alert systems improve the safety and mobility of the fleets.

Table 21: Opinions Provided by Trucking Companies

Company name	Alert system	Response
Quality Carriers	Drivewyze and other(s)	Alerts help us coach driving patterns to improve safety performance.
Buchheit Logistics, Inc.	CoPilot Active Traffic on Isaac ELD and Netradyne dash-cam	Need a comprehensive, uniform system across all states that provides driver information for extreme weather, road hazards, traffic, road closures, and crashes.
Sedona Trucking Inc.	Samsara	We like that our system gives in-cab alerts, so I don't have to call every driver every time they are doing something wrong.
Mast Trucking Inc.	Samsara	Distance alerts and lane departure alerts have significantly reduced our at-fault crashes.
Freeport Transportation	Samsara	Samsara is a great tool we use, working with drivers to show them what they may be doing wrong, how to improve their driving, slow their speeding. Most drivers do not know what they are doing wrong until we show them, not all improve right off the bat but most do.
RMJK Enterprises Inc.	Collision Mitigation System	With the rise in distracted drivers, anything to help the driver be safe in daily operations is a good thing.
Empire Cat	Samsara	They are effective teaching tools.
Belue Trucking Co., Inc.	Drivewyze	The alert systems have been very beneficial, for our drivers, especially regarding high-wind corridors, theft-risk alerts, and rollover zones.

Challenges and opportunities on survey task

Several challenges and opportunities emerged during the surveys. In future studies that involve CMV drivers, researchers may consider the following:

- *Accommodation for Russian-speaking drivers*. The research team encountered Russian-speaking drivers, apart from those who speak Spanish, but did not adequately accommodate them. The team recommends providing future surveys in Russian to better serve these drivers, as they may be well-represented among CMV drivers in the United States, especially in Ohio.
- *Address the language barrier*. Although the survey was also administered in Spanish, it is important to have someone in the field who can communicate in Spanish or Russian to assist drivers who cannot effectively speak English.

- *Increase the sample size for the CMV company survey*. Although the main goal was to collect data from CMV drivers and gain some insights from state transportation agencies, future work could focus on collecting more trucking company survey responses and establishing a required sample size using similar criteria for the CMV driver survey. The team was able to collect responses from only 24 companies. A close ally is the FMCSA which has close working relationships with various trucking associations across the U.S. that could be leveraged to support that collection of CMV company surveys.

Appendix C: Survey Questions

Survey for Truck drivers

Survey for Drivers

Start of Block: SURVEY OBJECTIVE

Thank you for taking this survey. Please use the button at the upper-right corner to choose between Spanish or English.

This survey is part of a project funded by the Ohio Department of Transportation (ODOT). The project seeks to evaluate the effectiveness of commercial vehicle safety alert systems in enhancing the safety and mobility of Ohio roadway infrastructure. Survey questions were designed to collect evidence-based opinions and perceptions on the effectiveness of commercial vehicle safety and mobility alert (high-crash risk corridor alert, congestion alert, etc.) systems and/or technologies from commercial vehicle drivers.

The survey is spread across three multiple-choice questions and three open-ended questions. It will likely take you 10-15 minutes to complete – depending on the level of detail provided in your responses. That being said, the ability for this study to truly have informative and actionable findings relies on input from your input, and we sincerely hope that you will take the time to thoroughly respond to the survey questions.

By submitting your responses, you consent to take part in the study. You can close your browser and return to the place you left off (your responses will be saved) at any point in the survey by following the survey link (https://qualtricsxm4bq4w7ztg.qualtrics.com/jfe/form/SV_dpBYIkLsI5nYmBo). You can also withdraw your participation at any point, including after submission, by emailing the research team. Your survey data will then be withdrawn and deleted. If you have any questions, comments, or concerns regarding your participation in this survey, please contact Dr. Emmanuel Kidando at e.kidando@csuohio.edu or Dr. Angela Kitali at akitali@uw.edu.

This study has been approved by the Institutional Review Boards at Cleveland State University (IRB#FY2024-84) and the University of Washington Tacoma (IRB#STUDY00019063).

If you wish to participate in the survey, select the "I AGREE" button. If you do not wish to participate in this survey, select the "I DISAGREE" button.

- ◯ I AGREE and want to participate in the survey. (1)
- ◯ I DISAGREE and do NOT want to participate in the survey. (2)

Skip To: End of Survey If Thank you for taking this survey. Please use the button at the upper-right corner to choose between... != I AGREE and want to participate in the survey.

End of Block: SURVEY OBJECTIVE

Start of Block: SURVEY QUESTIONS

Question 1 Which systems or technologies are you and/or your truck equipped with to receive mobility and safety alerts?

- ☐ None (1)
- ☐ Drivewyze (2)
- ☐ Other(s) (3)

Question 2 If you chose "Other(s)" in the previous question, kindly specify the names of the systems or technologies.

____

Question 3 For which related topics do you receive mobility and safety alerts?

	Yes, I received these alerts. (1)	No, I don't receive these alerts but would like to. (2)	No, I don't receive these alerts, and I am not interested in receiving them. (3)
Harsh vehicle maneuvers (speeding, etc.) (1)	○	○	○
Real-time incidents (crashes, lane closures, road closures, etc.) (2)	○	○	○
High-crash risk corridors (3)	○	○	○
Sudden slowdown (4)	○	○	○
Traffic congestion (5)	○	○	○
Work zones (6)	○	○	○
Rollover risk (7)	○	○	○
Fatigue/drowsiness (8)	○	○	○
Weather conditions (9)	○	○	○
Low-clearance bridges (10)	○	○	○
Oversize/overweight restrictions (11)	○	○	○
Parking and rest areas (12)	○	○	○
Weigh stations (13)	○	○	○
Truck detour (14)	○	○	○
High theft area (15)	○	○	○

Mountain corridor (steep grades, runaway truck ramps, etc.) (16)	○	○	○
Toll plazas (17)	○	○	○
Public awareness campaigns (general messages such as Ohio's distracted driving law enforcement going into effect in October 2023, etc.) (18)	○	○	○
Other(s) (19)	○	○	○

Question 4 If you chose "Other(s)" in the previous question, kindly specify the name(s) of the alert(s).

____

Question 5 How would you rate the effectiveness of the mobility and safety alerts you receive?

	Very effective (1)	Somewhat effective (2)	Slightly effective (3)	Not effective (4)	Not applicable/available (5)
Harsh vehicle maneuvers (speeding, etc.) (1)	○	○	○	○	○
Real-time incidents (crashes, lane closures, road closures, etc.) (2)	○	○	○	○	○
High-crash risk corridors (3)	○	○	○	○	○
Sudden slowdown (4)	○	○	○	○	○
Traffic congestion (5)	○	○	○	○	○
Work zones (6)	○	○	○	○	○
Rollover risk (7)	○	○	○	○	○
Fatigue/drowsiness (8)	○	○	○	○	○
Weather conditions (9)	○	○	○	○	○
Low-clearance bridges (10)	○	○	○	○	○
Oversize/overweight restrictions (11)	○	○	○	○	○
Parking and rest areas (12)	○	○	○	○	○
Weigh stations (13)	○	○	○	○	○
Truck detour (14)	○	○	○	○	○
High theft area (15)	○	○	○	○	○

Mountain corridor (steep grades, runaway truck ramps, etc.) (16)	○	○	○	○	○
Toll plazas (17)	○	○	○	○	○
Public awareness campaigns (general messages such as Ohio's distracted driving law enforcement going into effect in October 2023, etc.) (18)	○	○	○	○	○

End of Block: SURVEY QUESTIONS

Start of Block: SUBMISSION

Question 6 Please provide any additional perspective/opinion regarding your experience using truck safety alert systems.

____

End of Block: SUBMISSION

Survey for Agencies

Survey for Agencies

Start of Block: SURVEY OBJECTIVE

Thank you for taking this survey.

This survey is part of a project funded by the Ohio Department of Transportation (ODOT). The project seeks to evaluate the effectiveness of commercial vehicle safety alert systems in enhancing the safety and mobility of Ohio roadway infrastructure. Survey questions were designed to collect evidence-based opinions and perceptions on the effectiveness of commercial vehicle safety and mobility alert (high-crash risk corridor alert, congestion alert, etc.) systems and/or technologies from transportation agencies.

The survey is spread across three multiple-choice questions and eight open-ended questions. It will likely take you 15-20 minutes to complete – depending on the level of detail provided in your responses. That being said, the ability for this study to truly have informative and actionable findings relies on input from your input, and we sincerely hope that you will take the time to thoroughly respond to the survey questions.

By submitting your responses, you consent to take part in the study. You can close your browser and return to the place you left off (your responses will be saved) at any point in the survey by following the survey link (https://qualtricsxm4bq4w7ztg.qualtrics.com/jfe/form/SV_1SrovZa3vP1tLYa). You can also withdraw your participation at any point, including after submission, by emailing the research team. Your survey data will then be withdrawn and deleted. If you have any questions, comments, or concerns regarding your participation in this survey, please contact Dr. Emmanuel Kidando at e.kidando@csuohio.edu or Dr. Angela Kitali at akitali@uw.edu.

This study has been approved by the Institutional Review Boards at Cleveland State University (IRB#FY2024-84) and the University of Washington Tacoma (IRB#STUDY00019063).

If you wish to participate in the survey, select the "I AGREE" button. If you do not wish to participate in this survey, select the "I DISAGREE" button.

- ○ I AGREE and want to participate in the survey. (9)
- ○ I DISAGREE and do NOT want to participate in the survey. (10)

Skip To: End of Survey If Thank you for taking this survey. This survey is part of a project funded by the Ohio Department... != I AGREE and want to participate in the survey.

End of Block: SURVEY OBJECTIVE

Start of Block: SURVEY QUESTIONS

Question 1 Please name your agency.

____

Question 2 Which alert systems and technologies related to mobility and safety is your agency currently utilizing for commercial vehicles?

☐ None (1)

☐ Drivewyze (2)

☐ Other(s) (3)

Question 3 If you chose "Other(s)" in the previous question, kindly specify the names of the systems or technologies.

Question 4 Which mobility and safety alerts does your agency send to commercial vehicle drivers?

	Select all that apply. (1)
Real-time incidents (crashes, lane closures, road closures, etc.) (1)	☐
High-crash risk corridors (2)	☐
Sudden slowdown (3)	☐
Traffic congestion (4)	☐
Work zones (5)	☐
Rollover risk (6)	☐
Weather conditions (7)	☐

Low-clearance bridges (8)	☐
Oversize/overweight restrictions (9)	☐
Parking and rest areas (10)	☐
Weigh stations (11)	☐
Truck detour (12)	☐
High theft area (13)	☐
Mountain corridor (steep grades, runaway truck ramps, etc.) (14)	☐
Toll plazas (15)	☐
Public awareness campaigns (general messages such as Ohio's distracted driving law enforcement going into effect in October 2023, etc.) (17)	☐
Other(s) (16)	☐

Question 5 If you chose "Other(s)" in the previous question, kindly specify the name(s) of the alert(s).

Question 6 Do you know other mobility and safety alert systems other agencies use for commercial vehicles? Please list them.

____

Question 7 What criteria did your agency use to establish your preferred systems and technologies?

____

Question 8 How have the alert systems improved safety and mobility for your agency's commercial vehicles? Can you provide any metrics or data to illustrate these improvements?

____

Question 9 Please provide any additional perspective/opinion regarding your experience using commercial vehicle safety alert systems.

____

Question 10 If the research team would like to make a follow-up interview, would you be willing to participate in a virtual 30-minute meeting?

- ○ No (1)
- ○ Yes (2)

End of Block: SURVEY QUESTIONS

Start of Block: SUBMISSION

Question 11 If yes, please provide your contact information (email address and/or phone number).

____

End of Block: SUBMISSION

Survey for Companies

Survey for Companies

Start of Block: SURVEY OBJECTIVE

Thank you for taking this survey.

This survey is part of a project funded by the Ohio Department of Transportation (ODOT). The project seeks to evaluate the effectiveness of commercial vehicle safety alert systems in enhancing the safety and mobility of Ohio roadway infrastructure. Survey questions were designed to collect evidence-based opinions and perceptions on the effectiveness of commercial vehicle safety and mobility alert (high-crash risk corridor alert, congestion alert, etc.) systems and/or technologies from commercial vehicle companies.

The survey is spread across two multiple-choice questions and seven open-ended questions. It will likely take you 15-20 minutes to complete – depending on the level of detail provided in your responses. That being said, the ability for this study to truly have informative and actionable findings relies on input from your input, and we sincerely hope that you will take the time to thoroughly respond to the survey questions.

By submitting your responses, you consent to take part in the study. You can close your browser and return to the place you left off (your responses will be saved) at any point in the survey by following the survey link (https://qualtricsxm4bq4w7ztg.qualtrics.com/jfe/form/SV_cHCN7URCesQASuq). You can also withdraw your participation at any point, including after submission, by emailing the research team. Your survey data will then be withdrawn and deleted. If you have any questions, comments, or concerns regarding your participation in this survey, please contact Dr. Emmanuel Kidando at e.kidando@csuohio.edu or Dr. Angela Kitali at akitali@uw.edu.

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If you wish to participate in the survey, select the "I AGREE" button. If you do not wish to participate in this survey, select the "I DISAGREE" button.

○ I AGREE and want to participate in the survey. (4)

○ I DISAGREE and do NOT want to participate in the survey. (5)

Skip To: End of Survey If Thank you for taking this survey. This survey is part of a project funded by the Ohio Department... != I AGREE and want to participate in the survey.

End of Block: SURVEY OBJECTIVE

Start of Block: SURVEY QUESTIONS

Question 1 Please provide the name of your company.

____

Question 2 Which alert systems and technologies related to mobility and safety is your agency currently utilizing for trucks?

- ▢ None (1)
- ▢ Drivewyze (2)
- ▢ Other(s) (3)

Question 3 If you chose "Other(s)" in the previous question, kindly specify the names of the systems or technologies.

____

Question 4 Do you know any other mobility and safety alert systems other companies use for trucks? Please list them.

____

Question 5 What percentage of your vehicles have alert systems or technologies installed?

____

Question 6 What type of mobility and safety alerts does the technology disseminate to drivers?

	Select all that apply. (1)
Harsh vehicle maneuvers (speeding, etc.) (1)	☐
Real-time incidents (crashes, lane closures, road closures, etc.) (2)	☐
High-crash risk corridors (3)	☐
Sudden slowdown (4)	☐
Traffic congestion (5)	☐
Work zones (6)	☐
Rollover risk (7)	☐
Fatigue/drowsiness (8)	☐
Weather conditions (9)	☐
Low-clearance bridges (10)	☐
Oversize/overweight restrictions (11)	☐
Parking and rest areas (12)	☐
Weigh stations (13)	☐
Truck detour (14)	☐

High theft area (15)	▢
Mountain corridor (steep grades, runaway truck ramps, etc.) (16)	▢
Toll plazas (17)	▢
Public awareness campaigns (general messages such as Ohio's distracted driving law enforcement going into effect in October 2023, etc.) (19)	▢
Other(s) (18)	▢

Question 7 If you chose "Other(s)" in the previous question, kindly specify the name(s) of the alert(s).

____

Question 8 Does your company have any data on how these systems and technologies have reduced crashes and improved driver safety?

____

End of Block: SURVEY QUESTIONS

Start of Block: SUBMISSION

Question 9 Please provide any additional perspective/opinion regarding your experience using truck safety alert systems and their effectiveness or limitations.

____

End of Block: SUBMISSION