CV Safety Alert and Predictive Crash Location Integration
Final Implementation Report

Version: 3

Ohio Department of Transportation (DriveOhio)
FY2022 Award
Period of Performance: September 1, 2023 to December 1, 2025

Prepared by: Ohio Department of Transportation, Jacobs, and Etch

Submitted
January 12, 2026

CV Safety Alert and Predictive Crash Location Integration Final Implementation Report

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Project name: CV Safety Alert and Predictive Crash Location Integration

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Version: 3

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Date: January 12, 2026

File name: Ohio Dept of Transportation - SMART Final Implementation Report_rev3

Document history and status

Version	Date	Description	Author	Checked	Reviewed	Approved
Draft 1	08/29/2024	Implementation Report	Nick Hegemier (ODOT),Treea Sekela (Jacobs), Darlene Magold (Etch)			
Final	12/1/2025	Final Implementation Report	Nick Hegemier (ODOT), Andy Wolpert (Jacobs), Darlene Magold (Etch)			
Final revised	1/12/2026		Andy Wolpert			

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Executive Summary

The Ohio Department of Transportation's (ODOT) number one priority is ensuring the safety of everyone using its transportation system. Vision Zero is at the core of ODOT's and the Ohio State Highway Patrol's highway safety program, and transportation systems management and operations (TSMO) strategies are integral to its efforts. Currently, when crashes do occur, emergency and traffic management services receive crash notifications through a variety of sources, and not all are accurate or timely. Preventing crashes and achieving ODOT's goal of Vision Zero can only be accomplished when traffic and incident management make the transition from a reactive state to a proactive state. ODOT has created an Event Streaming Platform (ESP) in order to disseminate live data directly from data producers (i.e. Original Equipment Manufacturers (OEMs)). The two use cases in Stage 1 of the SMART grant illustrate how ODOT can improve safety throughout Ohio.

- **Use Case 1 is "Incident Detection and Response Initiation."** ODOT receives connected vehicle (CV) airbag deployment alerts directly from OEMs, or third-party data sources to automatically provide crash location information to the ODOT TMC and emergency responders.
- **Use Case 2 is "Crash Prediction and Proactive Mitigation."** ODOT collects historic and real-time data to analyze roadway segments and assign an associated real-time Road Risk Score. by using machine learning (ML) to accurately model the state's transportation network and infer the most at-risk portions based on live information.

The Stage 1 prototypes provide meaningful and actionable alerts from real-time and historical data and integrate and use OEM data to improve emergency responses and assist with the implementation of proactive traffic management strategies to reduce the risk of primary and secondary crashes. Stage 1 activities focused on stakeholder engagement, data ingestion from OEMs and other sources, user need identification, systems engineering documentation, data and systems requirements, and prototype development and testing of the two use cases. ODOT had a robust stakeholder engagement approach because of the wide variety of participants including traffic management, emergency systems and response, law enforcement, safety professionals, OEMs, and information technology leadership and staff.

Stage 1 focused on development and testing of the protypes in ODOT Districts 5 and 6 (central Ohio), this area consists of both urban and rural areas to test that the technology is consistent and reliable regardless of the environment. Stage 2 will upscale the projects for statewide implementation on ODOT owned and maintained roadways. Both cases provide solutions to the public by receiving accurate information in rural and urban areas. The ODOT SMART Grant aligns with USDOT's goals and desired outcomes. ODOT will use advanced data, technology, and applications to provide significant benefits to the state, and provide a scalable and replicable system that can be used across the country. Outcomes of the program include:

- Improve public safety and emergency response times
- Improve ODOT TMC response and operations
- Improve ODOT freeway service patrol services
- Improve information provided to the traveling public
- Provide consistent and reliable data to all parties for coordinated responses
- Assess risk and identify countermeasures to reduce the risk of primary and secondary crashes
- Enable OEMs to share data with Infrastructure Owner and Operators (IOOs) across the nation

Prototype development for both use cases has met ODOT and stakeholder expectations to illustrate that data from multiple sources, including OEMs can be accurately ingested into the ESP to process, disseminate, and display data. This will improve crash identification and emergency response (use case 1) and identify high crash risk areas for countermeasure deployment/activation (use case 2). Through the input from stakeholders, ODOT has created a scalable and replicable approach which will allow other state transportation agencies to deploy similar applications. ODOT has identified primary tasks for Stage 2.

Introduction and Project Overview

On November 14, 2023, a commercial truck was traveling west on I-70 near Columbus, Ohio, when it failed to slow for a line of traffic caused by an earlier minor crash. The truck collided with the rear of the queue, resulting in a fatal crash involving two passenger vehicles, a chartered motorcoach carrying school children and another truck. Three students on the motorcoach and three people in a passenger vehicle were killed. More than 40 other people were injured.

In September 2025, the National Transportation Safety Board (NTSB) completed its findings and issued its report on the tragedy. NTSB has issued eight new safety recommendations, including the following:

- Federal Highway Administration (FHWA) issues guidance to states on ensuring that incident classification accounts for all affected roadway conditions and that communications occur between responding and transportation agencies for all incidents in which a queue has formed or is likely to form.
- FHWA updates its Proven Safety Countermeasures publication to incorporate end-of-queue protections and effective communication strategies to provide advance warning to drivers approaching traffic queues.
- ODOT implement a statewide strategy for the use of Variable Speed Limits (VSLs).

The ODOT SMART Grant use cases and prototypes for Stage 1 can serve as tools to assist in applying these recommendations. Use Case 1 demonstrates how ODOT can receive airbag deployment alerts from OEMs, which will enhance timely communication between ODOT, emergency responders, and traffic management. Use case 2 showed how analyzing both historic and real-time data can assess the risk of a crash occurring, which will be used to deploy real-time countermeasures such as VSLs, ramp metering, and deploying ODOT's safety patrol. These deployments will further improve communications to the traveling public through ODOT's systems, and third-party systems, to provide information to increase safety, particularly around traffic queues.

Currently, emergency and traffic management services receive crash notifications through calls from observers or those involved, calls to 911, visual detection from Closed Circuit Television (CCTV) feeds, ODOT's Freeway Safety Patrol (FSP) and third-party notification systems. ODOT's Traffic Management Center (TMC) operators and emergency responders are reliant on these various sources to notify them. Latency and accuracy are challenges of incident detection and location. The TMC will receive incident information from local police departments and the Ohio State Highway Patrol, typically via email. ODOT's Freeway Safety Patrol uses an application to create a log. ODOT receives WAZE incident data; however, not every WAZE event comes through. Information may indicate an incorrect route, direction, or mile marker, which often results in multiple resources being dispatched. If a crash occurs and is not identified, managed, and cleared in a timely manner, this often leads to secondary crashes. Opportunities exist to improve crash responses, particularly in rural areas, where services face challenges in receiving timely and accurate location data.

ODOT and emergency responders also face challenges in reducing the risk of crashes based on existing conditions. ODOT's goal of achieving Vision Zero can only be accomplished when traffic management transitions from a reactive state to a proactive state. Operators need assistance in identifying where congestion and crashes are most likely to occur given current conditions. To date, no predictive system is available to identify elevated crash risks, provide risk factors, suggest response plans, recommend proactive crash mitigation measures, or make any other meaningful predictions to reduce the risk of crashes from occurring.

ODOT created an Event Streaming Platform (ESP) that processes high volumes of real-time data streams to generate new streams, historical datasets, and map layers. ODOT's intention is to make the outputs accessible to public and private entities by providing self--service discovery and consumption, leading to quicker insights and decisions. In 2022, ODOT completed a study which initially identified six possible efficiencies and use cases of the ESP. ODOT identified two of those use cases involving connected vehicle (CV) data and systems integration to develop as part of the USDOT's SMART Grant program. The ESP will assist ODOT and emergency responders in reducing the challenges related to crash detection/response and risk mitigation by collecting, fusing, and processing Connected Vehicle (CV), real-time, and historical data. The ESP has allowed ODOT to successfully develop Stage 1 prototypes and create the foundation for Stage 2 implementation for the following two use cases:

Use Case 1 is "Incident Detection and Response Initiation." ESP receives CV airbag deployment alerts directly from OEMs, or other potential data sources to automatically provide crash location information to the ODOT TMC and emergency responders. This offers ODOT and emergency personnel an enhanced capability to detect, react, and respond in areas where traffic cameras and roadside units are not available.

Emergency responders are responsible for the on-site response to crashes that occur on Ohio's roadways. Incident response typically begins at the local 911 call center when a call is received from someone involved in or who observed the crash. This data is often disparate and may cause confusion to responders. Multiple callers reporting the same accident from different perspectives give conflicting locations especially on highways if people often cannot see mile markers and estimate poorly. Rural accidents on unmarked roads are especially difficult to pinpoint. Some 911 call centers use third-party systems (for example, RapidSOS) for crash notifications, by receiving notifications from cell phones, connected devices, and data sources in the event. However, this does not include airbag deployment data and data can be delayed or inaccurate. Based on the information provided from a variety of sources, the incident is routed to the appropriate dispatch center, whether it be local or State Highway Patrol. This is the stage where the Highway Patrol is first notified of an incident. Use Case 1 streamlines information getting to the appropriate emergency response team by enriching the data coming directly from the OEM with an accurate location and other characteristics within seconds.

Currently, the TMC has various methods to detect, verify, and respond to traffic incidents. Detection methods are widely reactive and require one or more reported conditions. Historically, incidents are only detected after a large impact to traffic has occurred. Current verification methods are typically handled via live CCTV cameras or FSP verification (via either radio or truck-mounted cameras). There is very limited or no aggregation of this data to improve the accuracy of incident detections. The TMC is also heavily dependent on one of the sources notifying them of an incident. If a partner agency forgets to call the TMC, the alert is missed, or the WAZE incident is never reported, the TMC may never detect the incident, until it has had a major impact on the motoring public. The further away from highly traveled roadways, the less likely ODOT is to have a CCTV or patrolling FSP.

Use Case #1

Incident Detection and Response Initiation

WHAT IS IT?
ODOT will receive air bag deployment alerts directly from OEMs and third-party data providers. ODOT's ESP will automatically provide crash location to emergency responders, TMC, and ODOT services.

WHY ARE WE DOING IT?

- Work towards Vision Zero - Improve public safety and emergency response times
- Improve ODOT TMC response and operations
- Improve ODOT freeway service patrol services
- Improve information provided to the traveling public
- Provide consistent and reliable data to all parties for coordinated responses
- Develop data standardization

TMC operators and emergency responders are reliant on the various sources to notify them. Accuracy of incident detection is imperfect. Initial incident reports may indicate an incorrect route, direction, or mile marker, and rely heavily on those involved to initially report the incident. Without data generated from vehicle systems, the verification phase is necessary to validate exact location information before acting. Emergency responders have issues receiving reliable information for the direction of travel of the crash on freeway facilities. 911 systems need to receive reliable information to limit the time to verify crash details. The goal of 911 dispatchers is to notify responders within 60 to 90 seconds of an alert. Every second counts when trying to respond with lifesaving medical services and minimizing the risk for secondary, sometimes more serious, crashes from occurring. **Use Case 1 will create safety benefits by providing faster and accurate crash information to the TMC and emergency services, which will improve traffic management and response times. Stage 2 will upscale the project for statewide implementation on ODOT owned and maintained roadways.** In Stage 2, ESP will provide data connections to disseminate information to the TMC's Advanced Traffic Management System (ATMS) and go live with connections to emergency services through the National Law Enforcement Telecommunications System (Nlets) and the Ohio Law Enforcement Automated Data System (LEADS).

Use Case 2 is "Crash Prediction and Proactive Mitigation." ODOT can detect roadway segments with an elevated crash risk by using machine learning (ML) to accurately model the State's transportation network and infer the most at-risk portions in real-time based on live information. ODOT is using a model that seamlessly integrates datasets and extracts unique insights to help agencies understand safety and sustainability issues on their roadway network. Data used to assess current crash risks include speed, traffic volumes, weather, pavement conditions, and work zones. The development team used ML techniques to efficiently ingest, process, store, and analyze massive amounts of data. Detailed analyses of vehicle speed, instances of hard braking, the intricacies of road curvature, and advanced intersection analysis are vital for understanding and enhancing road safety, as well as determining Risk Rating to quantify relative real-time risk of a crash. Risk Rating scores were developed and then ingested into ESP for Use Case 2.

Risk Rating scores are developed using advanced data analytics to identify and prioritize high-risk areas by synthesizing multiple data sources, including connected vehicle data, road characteristics, historical crash events, and weather conditions. These inputs are monitored and updated to continuously improve the model and highlight the most critical areas that receive attention for mitigation strategies. Priority is assigned using a scoring system that factors in the frequency and severity of traffic volume, and environmental conditions. This prioritization allows the user to see the most influential factors at that moment the risk was calculated. For example, on an icy, snowy day, the weather factor will have a higher weight than the accident history in that specific area. Data sets used in Stage 1 include:

Use Case #2

Crash Prediction and Proactive Mitigation

WHAT IS IT?
ODOT will use historic and real-time data to assess crash risk on corridors. ODOT will identify countermeasures to reduce the risk of crashes.

WHY ARE WE DOING IT?
This is a proactive step towards achieving Vision Zero. Allows for planning, near real-time information for emergency services, and deployment of countermeasures to mitigate crash risks. Reduce the risk of primary and secondary crashes.

- **Vehicle Data:** Speed, congestion, and hard braking events
- **Weather Conditions:** Rain, snow, sleet, aquaplaning, icy roads, and road slipperiness.
- **Map Data:** Road classifications, road types, gradients, curvature, lanes, speed limits.

- **Incident Data**: Traffic incident data pulled from Waze and ODOT (feed)
- **Crash Data:** Vehicle crash data from ODOT

The TMC is responsible for providing travel information. The sooner traveler information is released, the quicker potentially life-saving information can be distributed via road-side message signs, in-vehicle navigation systems, traveler information websites, and mobile applications and real-time countermeasures can be deployed. For example, ODOT currently has three variable speed limit (VSL) corridors, with the legislative authority to add more. Along the I-90 corridor, the TMC adjusts speed limits based on weather conditions and incidents. Along I-670, the TMC will observe volumes and traffic speeds at various stations which typically results in the VSP adjusted from 3:00pm to 6:00pm. Having a real-time system in place to help inform the TMC of crash risks will help with decision making. ODOT's goal of achieving Vision Zero can only be accomplished when traffic management transitions from a reactive state to a proactive state. Operators need assistance in identifying where congestion and crashes are most likely to occur given current conditions.

To date, no predictive system is available to identify elevated crash risks, provide risk factors, suggest response plans, recommend proactive crash mitigation measures, or make any other meaningful predictions to reduce the risk of crashes occurring. Statewide deployment will offer an opportunity to collect anecdotal evidence regarding the effectiveness of the predictive capabilities of the ESP through continued engagement with operators. Understanding how operators leveraged the system and changed their approaches based on data will be a valuable measurement of its potential.

This Use Case and prototype illustrated the following in Stage 1:

- Development of a real-time crash prediction system using machine learning to identify roadway segments with elevated crash risk, enabling ODOT to shift from reactive to proactive traffic management
- Supports ODOT's Vision Zero goals by enabling prevention rather than just response
- Provides operators with data-driven insights rather than relying solely on instinct

In Stage 2, the risk analysis will be integrated with the TMC, county law enforcement, and 911 dispatch centers to allow for planning, near real-time information for emergency services, and deployment of countermeasures to mitigate crash risks. The ESP is prepared to deliver the Road Risk Scores to the ODOT ATMS, where Stage 2 developed countermeasures will be implemented to allow the ATMS to automatically respond to high-risk roadways appropriately. ODOT will incorporate additional data sources to develop a comprehensive road risk score that enhances the capabilities of the machine learning (ML) model.

Figure 1. Study Area

Project Location

For Stage 1, both use cases were tested and deployed in ODOT Districts 5 and 6 (central Ohio). The prototype proved the solution is appropriate for urban and rural environments. Stage 2 will upscale the projects for statewide implementation on ODOT owned and maintained roadways.

Technologies Deployed

As previously described, the ODOT SMART Grant use cases and prototypes are deploying technologies that align with the USDOT's vision for improved safety and mobility.

- Connected Vehicles: The developed prototypes extensively deploy connected vehicle technologies, receiving airbag deployment data, eCall alerts, hard braking events, and traction control activations directly from OEM and third-party data providers. These CV data streams provide real-time crash detection and risk assessment inputs. ODOT is using connected vehicle data to constantly update the machine learning model used for the crash risk assessment.
- Systems Integration: The ESP serves as the central integration backbone, fusing data from multiple sources (historic and live data) and distributing it to stakeholder systems. Current and future integration points include ODOT's ATMS, Nlets, Ohio Law Enforcement Automated Data System (LEADS), county 911 dispatch centers, Public Safety Answering Points (PSAP), Freeway Safety Patrol systems, and third-party platforms like WAZE and RapidSOS.
- ODOT is using existing sensor-based infrastructure to collect data used for the crash risk assessment.
- Intelligent Sensor-Based Infrastructure: The system leverages existing ODOT infrastructure including CCTV cameras for incident verification (via dashboard), weather sensors providing precipitation and temperature data, and will be able to use roadside unit data when ODOT builds its network.

Goals and Desired Outcomes for At-Scale Implementation

The ODOT SMART Grant project aligns with USDOT's goals and desired outcomes. ODOT will use advanced data, technology, and applications to provide significant benefits to the state, and provide a scalable and replicable system that can be used across the country. The vast majority of benefits described in the federal statutory language are goals of ODOT's program.

- Reduce congestion and delays for commerce and the traveling public – By receiving airbag deployment alerts, ODOT can share information immediately with emergency responders and the TMC to quickly mitigate the situation and manage traffic. Information will be communicated to the public to seek alternative routes and avoid traffic delays. Identifying roadways with elevated crash risks can allow ODOT to proactively deploy real-time countermeasures to reduce risks and avoid delays.
- Improve safety and integration of transportation facilities and systems – Airbag alerts and additional CV data are received by the ESP. In Stage 2, the ESP will provide data connections to disseminate information to the TMC's Advanced Traffic Management System (ATMS) and relevant emergency response systems, to provide a complete integrated system. In addition, the crash risk assessments for roadways will be sent from the ESP to ODOT's ATMS. Both projects can improve safety and mobility by providing reliable information to emergency responders, disseminate information to the public to avoid secondary crashes and find alternative routes, and proactively deploy countermeasures.
- Improve the reliability of existing transportation facilities and systems - By identifying high risk crash areas and deploying real-time countermeasures, in addition to being alerted to crashes through OEM CV data, ODOT can improve the reliability of the transportation network for the travelling public.
- Improve access to jobs, education, and essential services – Improving the reliability of the transportation network allows the public to access jobs, goods, and services more efficiently.
- Promote connectivity between and among connected vehicles and transportation systems – ODOT is receiving CV data from OEMs through the ESP, which is shared with other transportation systems to improve safety and mobility for drivers.

- Incentivize private sector investments and partnerships – ODOT has partnered with OEMs in Stage 1 with a common goal of improving safety. ODOT will continue OEM partnerships in Stage 2 and help create standards for airbag deployment consumption within the ESP and for the use of other public entities interested in similar use cases across the country.
- Improve emergency response – Receiving airbag alerts from OEMs will create safety benefits by providing faster and accurate crash information to the TMC and emergency services, which will improve traffic management and response times.

Stage 1 Activities and Deployment

Stage 1 activities focused on stakeholder engagement, user need identification, data and systems requirements, and prototype development and testing of the two use cases in ODOT District 6 (central Ohio). Stakeholder engagement focused on user and system needs identification. ODOT had a robust stakeholder engagement approach because of the wide variety of participants involved in traffic management, emergency systems and response, law enforcement, and data collection and dissemination. Key stakeholders included the following:

- ODOT Office of Safety
- ODOT Office of TSMO
- ODOT Division of IT
- ODOT Statewide TMC
- Ohio Department of Public Safety (ODPS)
- Ohio State Highway Patrol
- DriveOhio
- County Sheriff's Offices and 911 Centers (Delaware, Hamilton, and Union Counties)
- OEMs (Honda, Ford, Audi, Stellantis, Toyota, GM)
- Third-party alert systems (RapidSOS)
- 911 CAD Systems consultant (CommSys)
- National Law Enforcement Telecommunications System (Nlets)

Multiple interviews were held with representatives from each stakeholder group to identify the challenges currently faced and the opportunities to improve the existing conditions. The input received during discussions identified how ODOT's ESP could provide the direct benefits being sought by stakeholders. This feedback served as the foundation of the systems engineering process. User needs for the stakeholders and systems in place were used to create a Concept of Operations for each use case. For Use Case #1, Table 1 summarizes the user needs identified through stakeholder engagement.

Table 1. Use Case #1 Summary of User Needs

Need Identifier	User Need	Stakeholder Group(s)
UN-1	Identify crash locations including route name, mile-marker, reference street, location within the roadway, and whether the vehicle remains on or off the road.	• ODOT • Emergency responders
UN-2	Real-time identification when crashes occur.	• ODOT • Emergency responders
UN-3	Identify unreported crashes.	• ODOT • Emergency responders

Need Identifier	User Need	Stakeholder Group(s)
UN-4	Identify crash severity.	- ODOT - Emergency responders
UN-5	Identify the number of vehicles involved in a crash.	- ODOT - Emergency responders
UN-6	Automated crash notification and crash updates.	- ODOT - Emergency responders
UN-7	Identify manner of impact.	- ODOT
UN-8	Identify influencing factors.	- ODOT
UN-9	Identify secondary crashes and tie them to the influencing primary crash.	- ODOT
UN-10	Include connected vehicle data in influencing factors (hard braking, airbag deployments, etc.).	- ODOT
UN-11	More frequent crash data updates with an improved performance dashboard.	- ODOT
UN-12	Identify the number of vehicle occupants.	- Emergency responders
UN-13	Identify the vehicle powertrain.	- Emergency responders
UN-14	Access to ESP.	- OEMs
UN-15	ODOT data formatting requirements.	- OEMs
UN-16	Protection of PII.	- OEMs

For Use Case #2, Table 2 summarizes the user needs identified through stakeholder engagement.

Table 2. Use Case #2 Summary of User Needs

Need Identifier	User Need	Stakeholder Group(s)
UN-1	Identify locations which require repetitive implementation of crash countermeasures.	• ODOT
UN-2	Ability to quantify the impacts of deployed countermeasures.	• ODOT
UN-3	Ability to integrate into current processes without the need for additional staffing.	• ODOT
UN-4	Visual interface that shows high risk areas in real-time and historically.	• ODOT
UN-5	Ability to predict and implement countermeasures that reduce roadway departure crashes.	• ODOT
UN-6	Ability to differentiate the risk of crashes by crash severity.	• ODOT • Emergency responders
UN-7	Ability to integrate with the ATMS and its existing tools including, but not limited to, speed monitoring, variable speed limits, queue detection, queue warning, video feeds, and traveler information tools like dynamic message signs and Drivewyze.	• ODOT
UN-8	Ability to prioritize priority locations for countermeasure deployment.	• ODOT • First responders
UN-9	Inclusion of a crash probability threshold that should be met before notifications are sent.	• ODOT • First responders
UN-10	Ability to send notifications through state and county government emails.	• ODOT • First responders
UN-11	Ability to log high crash probability occurrences as they are identified in real-time for later analysis and layering with historical data.	• ODOT • First responders
UN-12	Advanced notification of locations requiring patrol or officers both in near-real time and with a five-day outlook.	• First responders
UN-13	Description of locations using mile markers and exit numbers for officers being dispatched and the risk prompting their dispatch.	• First responders

If these user needs are not addressed, then ODOT and emergency responders will continue to face these challenges. The identified user needs led to the creation of the System Requirements document for the prototypes and statewide deployment. The team had several meetings with OEMs to understand their safety initiatives and available data to enhance public safety. OEMs have vast amounts of data and enabling their systems to share data without PII is a task some OEMs have completed, and others are still developing. The Stage 1 prototype allows any OEM to securely share data. OEMs are excited about ODOT's vision for including CV data to improve safety. For Stage 2, ODOT will set aside minimal funding for OEMs to update existing internal systems to share data with ODOT and future DOTs. Obtaining a variety of OEM data will help create standards for airbag deployment consumption within ESP and for the use of other public entities interested in similar use cases across the country. OEMs also need assistance to update agreements with their customers to "opt-in" to sharing airbag data. ODOT, through DriveOhio, continues to have these types of conversations with OEMs to help facilitate motorist data sharing capabilities.

Stakeholder input was critical in helping ODOT shape Stage 1 work to ensure that prototype development would lead to improvements over the status quo and easily allow use cases to be scaled and deployed statewide and to each county, regardless of roadway or population density. **The communication and data workflows to ensure successful scalability within Ohio in Stage 2, and throughout the country beyond Stage 2, were developed through collaboration and direction from the project's stakeholders.**

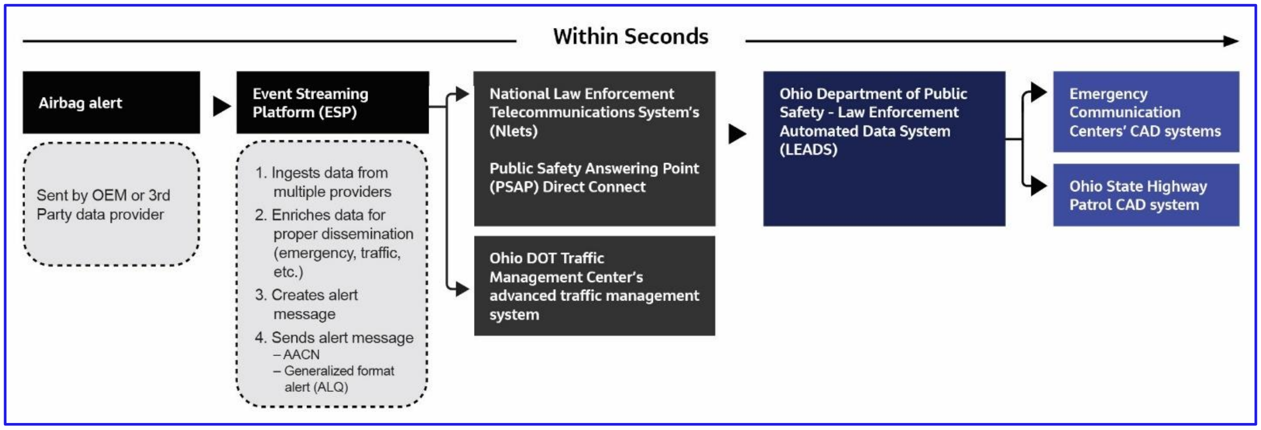
Use Case 1—Incident Detection and Response Initiation In Stage 1, Honda, Stellantis, and Audi provided ODOT with its schema for Airbag Deployment Event Alerts that would be generated from a production level vehicle. Using these schemas, the project team simulated airbag deployments based on historic crash data, enabling validation of system functionality in a controlled environment. The ESP processed this simulated data in under one second per event, demonstrating its ability to handle high volumes of safety-critical information with speed and precision. This data was visualized on a near real-time dashboard, giving stakeholders clear, actionable insights.

In parallel, ODOT received deidentified airbag deployment, Automatic Emergency Call (eCall) data from Stellantis covering January 2024 through April 2025, including location and timestamp details directly from impacted vehicles. A direct API connection was established to receive this data every 24 hours, marking a significant step in integrating near real-time OEM data into the ESP. Stellantis has committed to transitioning this feed to true near real-time access, and with some of the API framework already in place, that upgrade will be straightforward to implement.

Both historical and 24-hour eCall data have been incorporated into the ESP, enriched with PSAP and other location data streams from the ESP, as a unified geographic layer, with events clearly classified by their time frame. This data provides the team with awareness of current incidents, supporting more effective decision-making, rapid response, and the potential for statewide scalability.

The development team has also created a connector for Nlets alarm and roadway event messages, to be consumed by the Ohio Department of Public Safety. Nlets is a private not for profit corporation owned by the States and was created more than 55 years ago by the nation's 50 state law enforcement agencies. It is a computer-based message switching system that links together and supports every state, local, and federal law enforcement, justice, and public safety agency for the purposes of sharing and exchanging critical information. Through stakeholder meetings and input, Figure 2 illustrates the workflow developed for statewide deployment in Stage 2.

Figure 2. Use Case #1 Workflow



The results of this prototype showed success with both data and OEM participation. The data from multiple OEM providers enabled the development team to understand the variability of each OEM to streamline the service provided in the ESP. This proved that information from multiple OEMs can be disseminated instantly and seamlessly to a variety of interfaces. The simulated data was disseminated in the project area using Elasticsearch for historic query and websockets for live dashboard streaming. Testing proved that scaling can easily occur on a statewide basis. The system can ingest and process on the order of 100 airbag alerts per second, and auto-scales by adding additional worker nodes as processing units (the limiting resource) become overloaded.

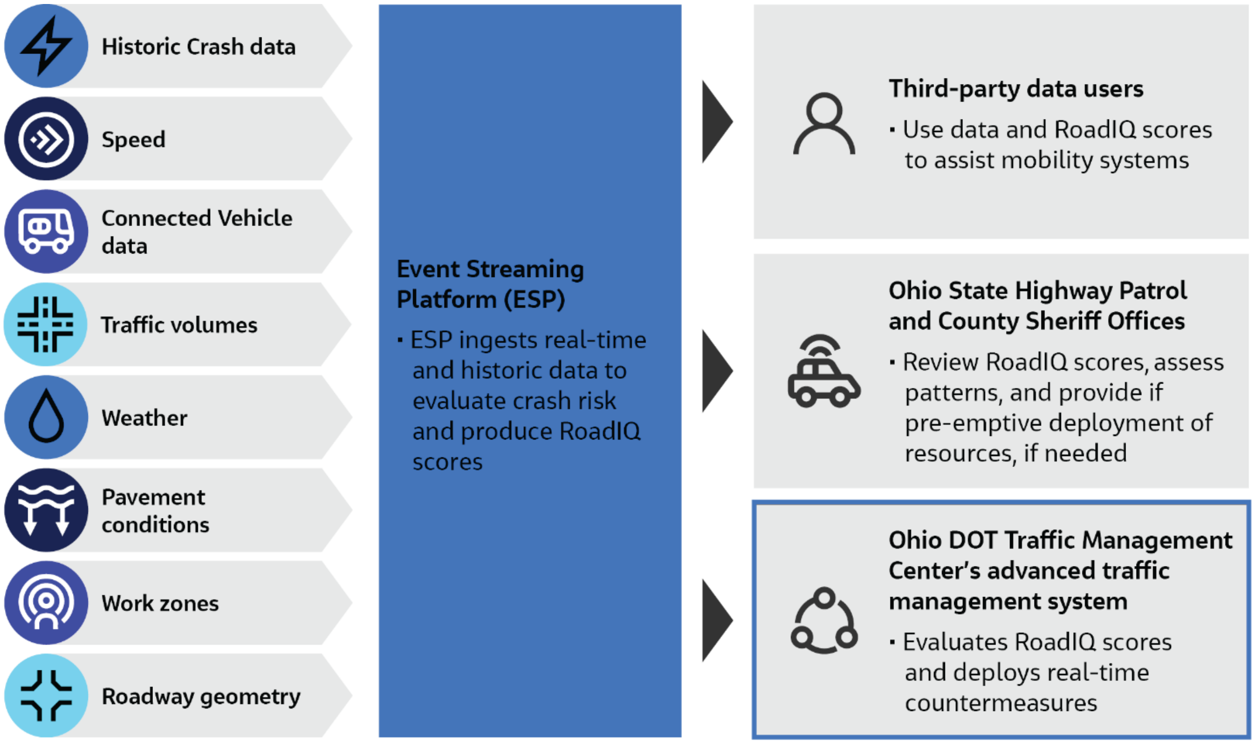
By meeting with multiple OEMs and data providers that work with OEMs, the team learned that Ohio is one of the first states to try and isolate airbag deployment data. There are many data sets that are available to DOTs from third parties that have contracts with OEMs, such as the partnerships between Streetlight / GM, etc., but airbag deployment data is not one of the data elements that is currently available. Largely this is due to the fact that OEMs are not specifically set to collect this data themselves and have that data sent directly from the vehicle to a third-party call center. These call centers are limited to data based on an individual provider where the ESP can provide multiple OEM data in one seamless feed within seconds. OEM data provided to the ESP will connect ODOT's TMC operators and emergency responders to reliable real-time data. The current latency and accuracy challenges of incident detection and location, along with reliance on disparate systems, will be removed from the equation. In particular, this will be of great value in rural areas, where emergency services have expressed difficulties of being notified in low density and low traffic volume areas.

ODOT successfully tested Use Case 1 by receiving OEM airbag alert data through the ESP and then sending the data through LEADS to the Delaware County Sheriff's 911 dispatch center. An alert was triggered in Delaware County which generated an APCO-standard alarm message. This message was automatically mapped to the Delaware County PSAP area. The message was tagged with the identifier for the Delaware Public Safety Answering Point and forwarded from the ESP to the ODPS internal network. From there, LEADS was able to read the message header and forward it to the Delaware County local PSAP switch. This same pattern would apply to any Ohio PSAP with the ability to receive APCO alarm queries (ALQs).

Use Case 2—Crash Prediction and Proactive Mitigation's goal is to design, build, and deploy a crash risk assessment system that can serve as an informational tool to support countermeasures that reduce crashes in areas identified as having higher risk of a crash. Once areas are identified as having a high probability of a crash occurring and countermeasures are recommended by the system, the ESP will push this information to traffic management, emergency management, and law enforcement personnel who can then make decisions about what countermeasures that each can implement and prevent crashes before they occur.

In Stage 1 prototype development, ODOT worked with the development team to develop an ML model that uses datasets and training infrastructure to bootstrap a pilot model. The project team created a map-focused, password-protected dashboard with ESP that can be displayed on large screens or used interactively on a desktop computer. It provides a combined visualization for both use cases, avoiding the need for separate views. The site displays incidents and predicts high-risk locations with no required user input or browser refreshing for the passive display mode of operation. The application can communicate issues around ODOT's roadways, and users can interact with incidents to determine countermeasures. ODOT identified countermeasures that will be used by the TMC to reduce crash risks, including variable speed limits, ramp metering, dynamic shoulder lanes, Freeway Safety Patrol deployment, and traveler information dissemination. Stage 1 activities validated that one system can process a disparate set of data sets, analyze these sets further to make risk assessments, and provide easy access, in real-time, to new and potentially beneficial data streams. These data streams can, in turn, be leveraged to improve risk assessment, promote real-time countermeasures, and inform preventative incident management efforts for ODOT and other traffic management resources. The prototype demonstrated the ability to rapidly process and analyze real-time data from multiple sources, including historical data, to identify areas with elevated crash risks. See Figure 3 for the data being collected for the Risk Rating and users of the information.

Figure 3. Use Case #2 Workflow



Event Streaming Platform (ESP)

- ESP ingests real-time and historic data to evaluate crash risk and produce RoadIQ scores

Third-party data users

- Use data and RoadIQ scores to assist mobility systems

Ohio State Highway Patrol and County Sheriff Offices

- Review RoadIQ scores, assess patterns, and provide if pre-emptive deployment of resources, if needed

Ohio DOT Traffic Management Center's advanced traffic management system

- Evaluates RoadIQ scores and deploys real-time countermeasures

Throughout the duration of the project, the algorithm and machine learning technology were able to constantly collect multiple factors to improve the model accuracy and consistency. The model baseline was created with historic crash data and was the main factor in a high-risk assessment score. Over the past year, the scores were improved by integrating live traffic volume, hard breaking events, and weather data.

This enabled the team to observe what was happening in the pilot area based on live factors and how they contributed to the actual risk level. The model was continuously improving with live data on a daily basis to gain a better understanding of where crashes may occur. The model was tested against the crash dataset to quantify its ability to focus attention on particular roadway segments by distinguishing high and low risk areas. Despite the fundamental limitations of rare-event prediction, it demonstrated moderate predictive power for separating segments by crash risk.

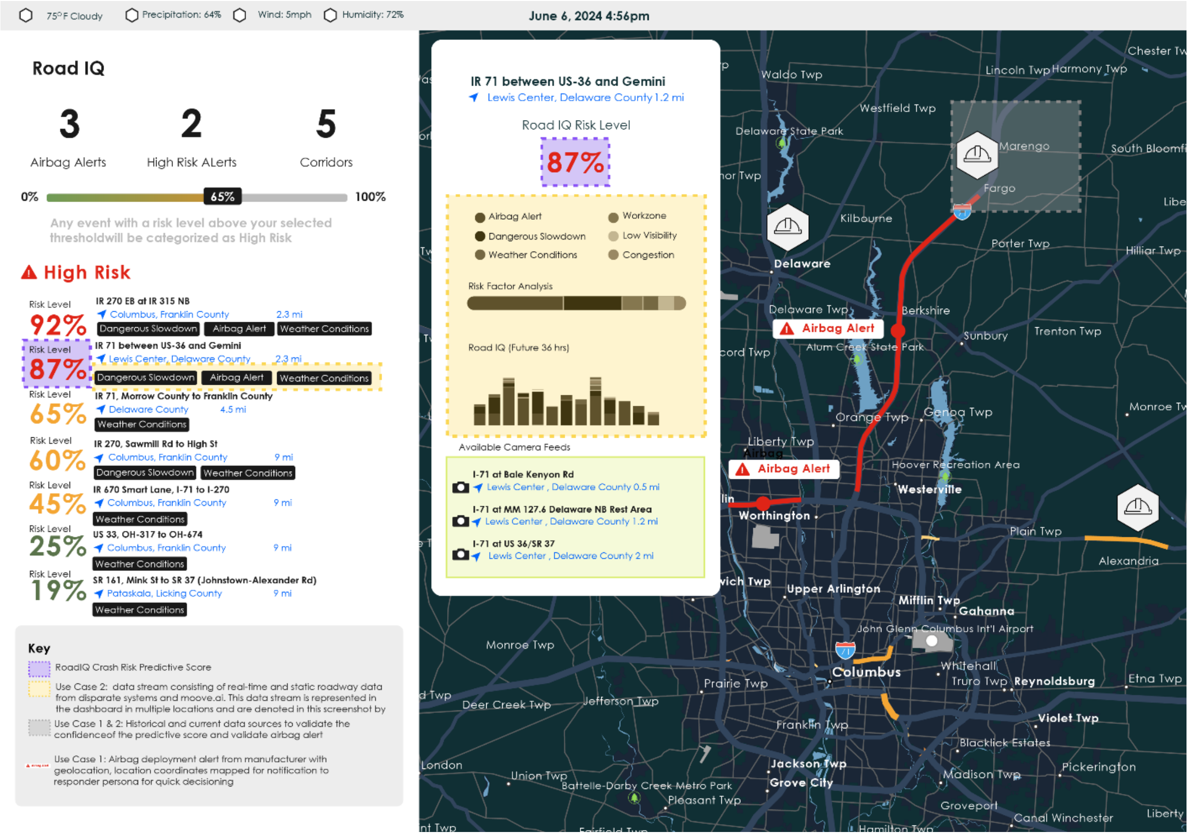
Risk Rating Scores: Risk Rating provides two primary score sets: feature-based scores (e.g. road-slipperiness score) and risk-based scores (e.g. car-driver risk score). Both scores indicate a relationship with risks of crashes, but their meanings, the way they are generated, and their recommended use are somewhat different.

- Feature-based Scores: Risk Rating is created by ingesting data from various sources. For each of those a regularization occurs into a segment score of 0 to 1. For example, a rain score is by default at "0" when there is no rain and at "1" when there is more than 10ml/hr. Rain is localized to a road segment, so the score for the segment corresponds to the estimated rainfall at that segment, which itself is estimated from ODOT sensor data for the model's data ingestion process.
- Risk-based Scores: Risk Rating estimates how likely a crash is to occur on a specific road segment at a given time. These predictive scores are tailored for different purposes—such as evaluating risk for the road itself or for a driver traveling on that road at that moment. Each score represents the probability of an incident happening and is standardized on a scale from 0 to 1:
    - A **score near 0** (e.g., 0 to 0.05) means the road is considered very low risk—typically because it has had very few or no crashes in recent history (such as the past 6 years), or there is very little traffic.
    - A **score near 1** (e.g., 0.95 to 1) indicates very high risk—placing that road segment in the top 1% of risky conditions at that time compared to all other roads and time intervals.

Note that the temporal trends revealed higher Risk Rating scores during evening hours (5–9 PM) and morning commutes (6–9 AM). Monday and Sunday also showed elevated risk levels compared to midweek days. More analysis will be needed to determine the variable speed limit in the I-670 corridor area. This will include more data throughout the project duration and expanding the limits of the actual corridor.

The *Prototype Evaluation Findings* section describes the testing and evaluation of the model. See Figure 4 for the prototype dashboard. The existing technology and infrastructure of ESP, with its built-in data sharing and security capabilities, reduce future efforts and allow for statewide implementation in Stage 2.

Figure 4. Prototype Dashboard



75°F Cloudy | Precipitation: 64% | Wind: 5mph | Humidity: 72%

June 6, 2024 4:56pm

Road IQ

3	2	5
Airbag Alerts	High Risk ALerts	Corridors

0% — 65% — 100%

Any event with a risk level above your selected thresholdwill be categorized as High Risk

High Risk

Risk Level 92% — IR 270 EB at IR 315 NB — Columbus, Franklin County 2.3 mi — Dangerous Slowdown, Airbag Alert, Weather Conditions

Risk Level 87% — IR 71 between US-36 and Gemini — Lewis Center, Delaware County 2.3 mi — Dangerous Slowdown, Airbag Alert, Weather Conditions

Risk Level 65% — IR 71, Morrow County to Franklin County — Delaware County 4.5 mi — Weather Conditions

Risk Level 60% — IR 270, Sawmill Rd to High St — Columbus, Franklin County 9 mi — Dangerous Slowdown, Weather Conditions

Risk Level 45% — IR 670 Smart Lane, I-71 to I-270 — Columbus, Franklin County 9 mi — Weather Conditions

Risk Level 25% — US 33, OH-317 to OH-674 — Columbus, Franklin County 9 mi — Weather Conditions

Risk Level 19% — SR 161, Mink St to SR 37 (Johnstown-Alexander Rd) — Pataskala, Licking County 9 mi — Weather Conditions

Key

- RoadIQ Crash Risk Predictive Score
- Use Case 2: data stream consisting of real-time and static roadway data from disparate systems and moove.ai. This data stream is represented in the dashboard in multiple locations and are denoted in this screenshot by
- Use Case 1 & 2: Historical and current data sources to validate the confidenceof the predictive score and validate airbag alert
- Use Case 1: Airbag deployment alert from manufacturer with geolocation, location coordinates mapped for notification to responder persona for quick decisioning

IR 71 between US-36 and Gemini
Lewis Center, Delaware County 1.2 mi

Road IQ Risk Level
87%

- Airbag Alert
- Dangerous Slowdown
- Weather Conditions
- Workzone
- Low Visibility
- Congestion

Risk Factor Analysis

Road IQ (Future 36 hrs)

Available Camera Feeds

- I-71 at Bale Kenyon Rd — Lewis Center , Delaware County 0.5 mi
- I-71 at MM 127.6 Delaware NB Rest Area — Lewis Center , Delaware County 1.2 mi
- I-71 at US 36/SR 37 — Lewis Center , Delaware County 2 mi

Stage 2 Deployment

Use Case 1 – Stage 2

ODOT will continue developing the baseline data connector for the ESP so that multiple entities can consume air bag deployment data regardless of entity. In Stage 1, the team received schema data from Honda, Stellantis, and Audi. The team also obtained historic and 24-hour data interval eCall data from Stellantis. This has allowed the team to test and verify that multiple data streams can be enriched with spatial elements such as PSAP and linear referencing systems.

By utilizing this foundation, the ODOT team can begin to scale the solution statewide by ingesting larger datasets from Stellantis and other OEMs. This can consist of both near real-time data for accurate response and historic information for detailed analysis. Working directly with the Stellantis development team (Mobilisights) has allowed the team to understand how to work with OEMs to extract air bag deployment data on impact. Discussions with Honda, Ford, Audi, Toyota, and GM have also prepared the development team for Stage 2 implementation statewide with multiple OEM partners. To obtain airbag and other data from the OEM market, ODOT will use Stage 2 funds to procure this information. This also includes a process of how to keep data consistently and accurately flowing through the ESP. This will serve as a model for OEMs as they work with other agencies.

Achieving Vision Zero requires all stakeholders in the traffic ecosystem to work together. A public private partnership approach between transportation agencies, OEMs, and research institutions is necessary. This project is a critical step towards enhancing the relationship between state DOTs and OEMs and improving safety and mobility for all. This procurement process will allow OEMs to update their existing data sharing systems so airbag deployment and associated data can be sent to the ESP. The OEMs realize the importance of providing the critical safety data to ODOT; therefore, it is anticipated there will be minimal additional costs to ODOT from the OEMs to maintain receiving airbag data. ODOT is committed to financially supporting the procurement of airbag data by adding funds to the ODOT annual budget. To allow scalability and replicability, ODOT will work with OEMs to create a standard for OEM data dissemination and set a precedent for providing a seamless dataset for airbag deployment regardless of the OEM provider.

Through the many discussions with stakeholders, ODOT will work with the systems in place to provide a more complete and reliable data set to 911 systems and the TMC. Those identified in Stage 1 include ODOT's ATMS by Arcadis, Automated Secure Alarm Protocol to Public-Safety Answering Point (ASAP to PSAP), and LEADS. ODOT has already created a connector for Nlets to test and provide feedback for Stage 2 deployment. The Nlets connector plugs in to the ESP on the output ("sink") end in order to monitor to the stream of enriched airbag alert information and produce an Nlets Alarm Exchange Query (ALQ) message describing the incident. The message contains the Originating Agency Identifier (ORI) of the Central Ohio PSAP that was identified by the Stage 1 implementation. Because the ESP builds on the proven Kafka and Kafka Connect open-source system, the connector recovers from failure by restarting where it left off in the event stream. This output connector serves as a model of the approach going forward to greatly assist the ODOT team with other connectors forementioned. For Stage 2, Nlets will forward these generated ALQ messages to LEADS to be directed to the appropriate PSAP.

ODOT has also created a Vehicle Manufacturer Air Bag Deployment Source Connector using ESP. The initial connector queries the Mobilisights repository of E-call records on a configurable interval. The current interface is every 24 hours, which matches the current cadence of the E-call update period, and can be lowered as the data update rate increases. ODOT will produce further Vehicle Manufacturer Air Bag Deployment Source Connector implementations built on the existing system. This set of connectors will communicate with other vehicle manufacturer systems to ingest air bag events and translate them into messages on an ESP topic. The exact nature of each connector will depend on the mechanism by which the manufacturers can publish their alerts. If the manufacturers provide web-based REST APIs, for example, the project team will use ESP's built-in REST connector and configure it to poll the API every few seconds. ODOT may also use ESP's push data source capability to generate a push API address and allow the manufacturer to send events to this address, reducing communication delay. There are multiple tools available that may facilitate data ingestion without the need to write specialized code. The connector will be configured like any other published ESP data source. In addition, the password-protected dashboard created in Stage 1 will be available if entities choose to use it. The ESP dashboard can be configured to show data by region, rather than statewide, if requested.

Use Case 2 – Stage 2

For Use Case 2, the model used six years of historical data to create a comprehensive baseline dataset of traffic patterns. This baseline incorporates data sources that provide insights into consistent factors such as roadway geometry and topology, daily and hourly congestion patterns, and average daily traffic counts. The analysis was further enhanced by the integration of historical crash data, which highlights roads with higher crash rates per vehicle and per mile. The system was trained on three years of Ohio crash data from 2020 through November 2022 covering over 1.3 million road segments and more than 760,000 crashes. It combines crash reports with historic data captured every hour for each road segment, which includes the environmental factors like traffic speed or visibility issues.

The primary model output is the expected number of crashes per mile per hour for each segment of road, with hourly numbers over the next 30 days and a breakdown into 15-minute intervals for the next hour.

The design of the model divides the study area into small geographic squares of one-by-one mile each and trains prediction models for each square. These local models look at multiple factors at the same time and the ML training causes them to naturally focus on risk factors that are characteristic to the area. For example, a rural square may weigh blowing snow more heavily as a risk based on conditions during past crashes. The predictions take place on 1/3 of a mile increments so that each segment's score is influenced by multiple nearby squares.

The prototype combined the historical baseline with real-time information, including current congestion data from INRIX traffic, weather updates, work zone notifications, and observed WAZE data feeds. These live data sources, along with other field data (for example, live camera feeds), serve to validate historical patterns, particularly those related to congestion, and bolster confidence in the predictive scoring model used to assess road safety and Risk Rating scores. The live information will be stored and used retroactively to retrain the Risk Rating model's predictive scoring daily. The data from the prototype is georeferenced to ODOT's linear referencing system so that it can easily be extrapolated throughout the state. The continued data collection over the Stage 2 period will help identify hot spot locations throughout the state to determine countermeasures and mitigation actions. Data will be collected to evaluate the effectiveness of countermeasures and help the TMC select the appropriate strategy in given situations. Stage 2 will also be an opportunity to refine and evaluate the ML model's accuracy and sensitivity on a statewide level. Based on the success of the prototype model in terms of leveraging real time data streams and developing intuitive assessments of crash risks for users, Stage 2 can take the modeling a step further by incorporating peer group schema used in statewide network screening to develop comparisons among similar types of roadways. Based on the success of the prototype model in terms of leveraging real time data streams and developing intuitive assessments of crash risks for users, Stage 2 can take the modeling a step further by incorporating peer group schema used in statewide network screening to develop comparisons among similar types of roadways. The main indicator of effectiveness for the underlying model (rather than the integration of data and reporting system) will be the frequency of crashes on high-, medium-, and low-risk roadways. The system is setup for continual improvements to the model as risk assessments are continued to be compared against crashes and traffic incidents. While the system is not intended to accurately predict the exact time and location of each crash occurring on the State's system - it is meant to inform traffic management, emergency services, and law enforcement of areas with elevated crash risk, by providing near real-time information to achieve Vision Zero.

Like Use Case 1, integration with systems identified in Stage 1 will be required. ODOT will create connectors to ESP so users can subscribe to datasets and directly display risk score data in the software they use daily. The password-protected ESP dashboard created in Stage 1 will also be available.

Next Steps

Stage 1 has led the team down a clear path to a scalable solution in Stage 2. Prototype development has proven the ESP can collect, process, generate and display data to improve crash identification and emergency response and identify high crash risk areas for countermeasure deployment. The primary steps include:

1. Procure OEM and Third-Party airbag and related data: ODOT will issue a Request for Proposal (RFP) to contract with OEMs and data providers. The scope of work will include OEMs updating their data sharing systems to enable the ESP to receive critical safety information. Stage 2 funds will be used to compensate OEMs for their time and effort to update data systems. Through stakeholder engagement, OEMs understand the importance of airbag data to public safety and the value it provides to DOTs. Because of these communications, it is anticipated that ODOT will have

minimal costs to receive airbag data in the future. Through discussions with OEMs, costs to update data sharing systems and provide airbag data will range from $200,000 - $500,000 per OEM.

2. ODOT will create ESP connections for OEM airbag data: The existing ESP connector types will be deployed and configured to push or pull OEM events with the lowest ingestion delay that the OEM system supports. Alerts include airbag deployments as well as issues with the OEM API or ESP-side connector. Events will be fed through the existing Stage 1 enrichment pipeline to add ODOT LBRS route and milepost information and will reach the existing output connectors for historic querying and web-based map alerts, plus new ones for ODPS LEADS/Nlets and ATMS.
3. Create ESP connections for ODPS LEADS/Nlets system: Nlets has a direct connection to ODPS' Ohio Law Enforcement Automated Data System (LEADS), along with the other states' public safety departments. LEADS is connected to each of Ohio's 88 county 911 centers. Currently, Nlets and ODPS don't receive airbag alerts. Discussions with ODPS and Nlets has shown that roadway incident alerts can be bundled into the existing message envelopes, as long as they have the appropriate Originating Agency Identifier (ORI) for message passing. Nlets will forward incident data in the appropriate message envelope to the state message switch and on to the county 911 CAD system. The message payload will use the APCO Alarm Exchange Transactions (ALQ/ALR) or the Advanced Automatic Collision Notification (AACN) depending on which format county PSAPs currently receive.
4. Create ESP connection with the TMC ATMS: Stage 1 has shown that control centers must monitor multiple different systems that require separate logins and require a human operator to cross-reference between. This step will reduce information overload and human latency by bringing alerts directly into the ATMS. A web-facing ESP connector will be configured so that Arcadis may pull data into the ATMS. This will include a web endpoint using the Elasticsearch sink connector for flexible querying of generated risk level and alert information, as well as Esri ArcGIS map layers for both use cases.
5. Assist with consumption of ESP data stream into the TMC's ATMS: Using the new ESP connector, the ATMS will overlay the event feed information on the existing map and provide quick access to countermeasure interventions identified in Table 5. The project team will coordinate the new development and provide test messaging from the ESP side.
6. Assist with consumption of ESP data stream into County Sheriff Office systems: The team will inventory all CAD systems in use around the state and will coordinate the effort to raise APCO-standard alerts sent from the ESP via Nlets. This includes verifying compliance with the standards being used, adding compliance as needed, ensuring messages are tagged with the appropriate ORI for each county based on enriched roadway and geofencing information, and generating test messages to validate integration.
7. Collect data to evaluate the effectiveness of countermeasures and help the TMC select the appropriate strategy in given situations: ODOT will document real-time mitigation strategy deployments including time and locations. Post-implementation data related to speed, crashes, and Road Risk Rating score is continuously collected through the ESP and will be leveraged to understand the impacts of countermeasures. The ESP will also allow for an understanding of real-time comparisons between treatment and non-treatment locations as well as exposure metrics for each deployment.

Project Presentations and Coverage

The project concept was presented during ITS America's 2024 and 2025 Annual Conferences and consisted of the project use cases and goals. In addition, the project was presented at the ITS Midwest Conference in Chicago in September 2024, the Ohio Transportation Engineering Conference in October 2024, and the Pennsylvania DOT's Transportation Engineering & Safety Conference held December 11-13, 2024. The presentations consisted of the project history, completion to date, and a demonstration of the prototype for Use Cases 1 and 2 with simulated airbag and live risk scores flowing through the ESP to the live project dashboard.

Information has been provided to the public through the ODOT SMART Grant project website ODOT SMART Dashboard and through LinkedIn: ODOT SMART Grant

Prototype Evaluation Findings

Development of the prototypes has proven the ESP can collect, process, and display data to improve crash identification and emergency response and identify high crash risk areas for countermeasure deployment. ODOT's ESP is cloud-agnostic and uses open-source components that result in a scalable, extensible, portable, and sustainable platform. It can ingest and combine data from diverse sources to enrich understanding of events. ESP provides advanced analytics and visualization tools that unlock deep insights from fused data to inform critical decisions across transportation operations and planning.

Use Case 1: Incident Detection and Response Initiation

Use Case 1 automatically detects the occurrence of a crash using airbag deployment safety alerts from OEM airbag deployment data streams. ODOT and other stakeholders will be notified of crashes in real time. First, the Incident Detection and Response Initiation application prototype involved creating a simulated airbag deployment data stream using historical crash data within ODOT Districts 5 and 6. As previously described, the project team used a schema provided by Honda to simulate air bag deployments using ODOT historic crash data. The team created a simulated air bag deployment event data feed in the ESP to test the consumption and dissemination of data to a dashboard. Through the testing process, ESP can receive a simulated airbag alert, process data, and make it available in under one second. Next, the team worked with Mobilisights to enable the ESP to receive airbag alert data. Mobilisights data exports provide e-call data as an export at 11pm daily. An average day contains 20 manual e-calls and two automated e-calls across the State of Ohio. One day's automated e-calls includes (with actual time and location anonymized):

- Incident 1 (Sept 28, 8:XX PM): Left side collision detected near coordinates 38.XX°N, 83.XX°W
- Incident 2 (Sept 28, 2:XX PM): High severity frontal crash near coordinates 41.XX°N, 81.XX°W with front pretensioner activation

Circumstances of the event which may be included consist of:

- High severity frontal impact
- Low severity frontal impact
- Left side collision
- Right side collision
- General side impact
- Rear-end collision
- Front seatbelt pretensioner deployed
- Rollover detected
- Pedestrian impact detected

When the ESP ingests crash alerts from the OEM source connector, alerts go into an OEM-specific data channel. The first step of processing is to standardize the alert to a JSON message structure that contains the latitude, longitude, timestamp, direction of travel, which airbags have deployed, and the OEM provider name. This results in a combined feed of all alerts in a provider-independent format. The second stage of processing takes the standardized message feed and adds Ohio LBRS fields to it: The standard NLF ID that identifies the route, and the milepost that localize the crash along the route. This provides a new route-enriched feed that is more useful for emergency response. In Stage 1, the county-level stakeholders provided detailed polygonal GIS layers for the current PSAP boundaries. This is used for the final phase of real-time processing, where the latitude and longitude of the crash are matched to a PSAP boundary. The ORI of the responsible organization is added to the message to create a final payload which provides the raw location, route, airbag details, severity, and PSAP ORI. This fully-enriched data topic is then consumed by any interested sink connectors. The current sink connectors are the Elasticsearch search index which provides a searchable API of crash history, the live websocket that streams information to the prototype dashboard, and the Nlets sink connector that produces alarm exchange messages.

An airbag incident simulator was created using real vehicle OEM schemas provided to ODOT. The simulator can replay recorded crash incidents and real OEM data at a desired rate. This simulator was used for testing the display of alerts with the stakeholders and allowed the team to observe the enrichment of real crash events with roadway and PSAP data throughout ODOT Districts 5 and 6. The simulator also enabled stress testing of the system using realistic events. Stress testing showed that the system can instantaneously handle around 100 events per second with full real-time enrichment without needing to scale additional processing power.

The "CV Safety Alert and Predictive Crash Location Integration FY22 SMART Grant Stage 1 Evaluation Plan" prepared by ODOT and submitted to the USDOT SMART Grant Program in December 2023 discussed performance measures designed to aid ODOT in quantifying the impact that the crash alert and detection system has on incident detection and response times. As the project and prototype development evolved, the evaluation criteria were refined and are provided in Table 3.

The proposed solution addresses the challenges and needs identified by stakeholders. The statewide deployment of Use Case 1 will receive CV airbag deployment data/alerts via OEMs or third-party data providers and disseminate airbag information to ODOT's TMC, as well as the relevant emergency response agencies. The team has validated it can receive airbag deployment alerts and has developed a process, with stakeholder input, to provide near real-time airbag deployment data into its incident detection and response process. ESP will provide systems integration through data connections built between ESP and stakeholder systems.

Initial efforts made to leverage CV airbag deployment have the benefit of impacting safety immediately in Ohio while also offering a foundation for safety communication across the state and the country. Ultimately, there are only a small number of vehicle manufacturers and emergency responders that operate on similar platforms and protocols across the country. While the ESP is specifically focused on leveraging data streams in Ohio, the successful expansion of Use Case 1 in Stage 2 establishes the framework other agencies can leverage to harness third-party data for real-time crash communications.

Evaluation performance measures were updated to reflect the goals and desired outcomes for at-scale implementation as outlined in the revised Stage 1 Implementation Report Guidance from April 2025, and feedback from the USDOT.

Table 3. Use Case 1 — Evaluation Performance Measures

Identifier	Evaluation Question	Performance Measure	Performance Measure Target Achieved
PM-1	**Reliability:** Is the ESP able to receive OEM crash data?	Yes/No	Yes
PM-2	**Reliability:** Of the notifications that were expected to be received, what percentage was displayed?	% of airbag alerts that were processed and displayed on a daily basis exceeds 90%	Yes, 100% of crashes were displayed. The team was able to compare the data received to the OEM raw data to verify all crash notifications were received. The data was enriched to include the ORI of the responsible responding agency. The OEM data was also

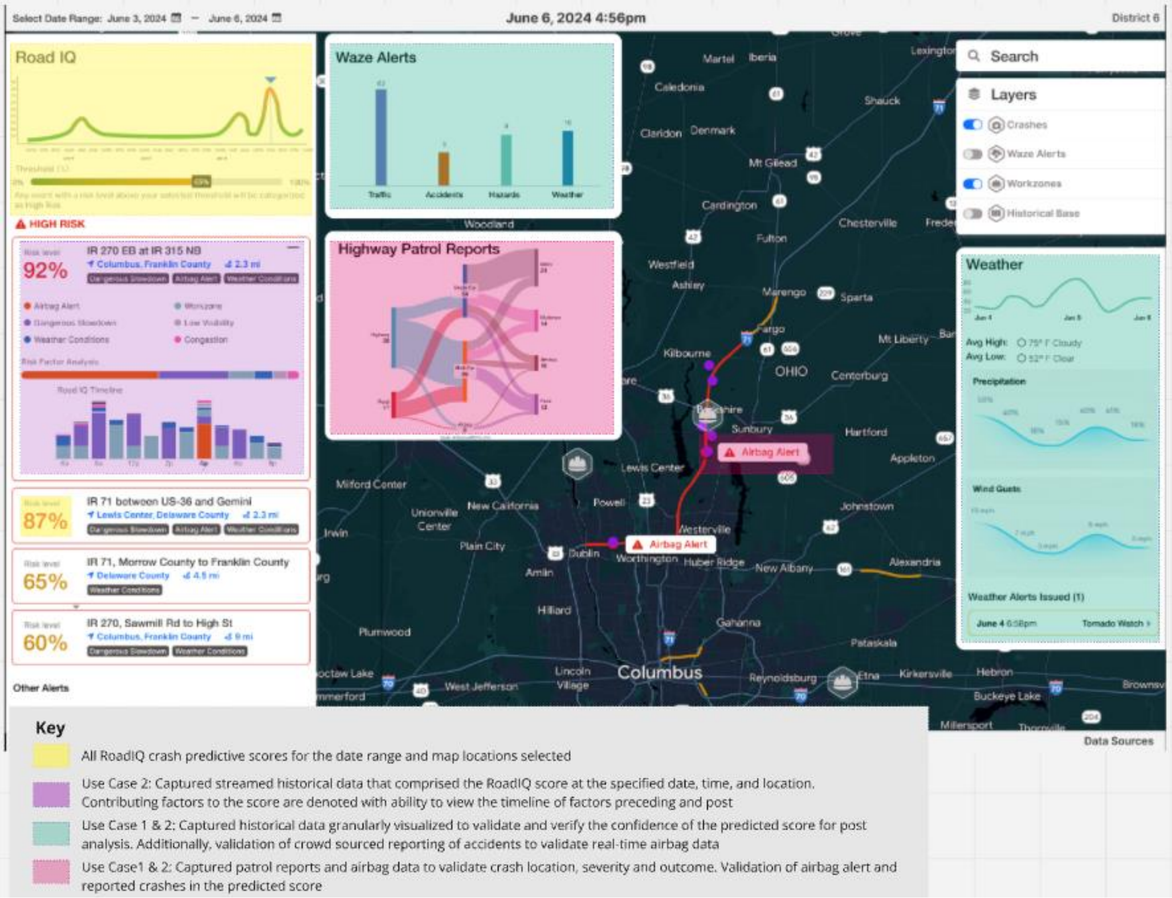
Identifier	Evaluation Question	Performance Measure	Performance Measure Target Achieved
			enriched with log points and geospatial data.
PM-3	**Safety:** Is the ESP able to consume OEM data feeds and determine the proper entities to be notified using geoboundaries throughout the state?	Yes/No	Yes
PM-4	**Safety and Emergency Response:** How quickly can this prototype receive a crash alert and send the message to the responding agencies?	Time between incident occurring to message sent to responding agencies: Stage 1: Time between ESP receiving a test notification and a message being sent to Delaware County Sheriff's Office.	Stage 1 – Yes, the ESP can receive a notification and display information in less than one second.
PM-5	**Safety and Emergency Response:** How quickly can this process initiate a response?	Time between crash and receipt by responding agencies -- As quickly or quicker than the average 911 phone call and response time.	Will be measured in Stage 2
PM-6	**Emergency Response:** How precise is the location of the actual incident compared to the point provided in the alert?	Distance between actual crash and map location from alert.	ESP can ingest and return the location data of airbag deployments within 10 meters/30 feet.
PM-7	**Emergency Response:** How precise is the location of the actual incident compared to WAZE alerts received by the TMC?	Distance between actual crash and map location from ESP and WAZE	Will be measured In Stage 2. When the project is live, ODOT will have WAZE data available to compare the accuracy of each alert.
PM-8	**Safety:** Is there a positive return on investment determined during the prototype stage for an at-scale implementation?	Yes/No	Yes

Use Case 2: Crash Prediction and Proactive Mitigation

Use Case 2 creates a system that analyzes real-time and historical roadway data sources as data inputs, uses them to characterize the risk of crashes occurring at locations along roadways, and initiates preventative measures through ODOT's ATMS and directly by emergency responders. This system will reduce crashes, bringing ODOT closer to achieving Vision Zero and non-recurring delays caused by crashes. The prototype demonstrates the ability to process and analyze real-time and historical data from multiple sources to identify areas with elevated crash risks. A primary source of data for the model is the last six years of ODOT crash history. Individual crashes can be related to contemporaneous environmental conditions at the time and place of the accident. This enriched data allows the model to develop weights for these conditions in computing accident probabilities for future times. This historic data has enabled the development team to analyze factors in the project corridors to determine predictive risks based on 2018-2024 crashes per mile and crashes per vehicle per mile. This baseline analysis enables the team to view live risk scores and compare it to historic data in an instant. ODOT has already identified patterns and new insights from data collected in Stage 1 to inform entities how to invest resources for maximum value, validate or update dangerous segments due to patterns of crashes (primary or secondary) and validate or uncover exceptions to the noise that indicate a new variable or behavior that causes crashes.

The team has created visual representations of high-risk areas on an interactive dashboard, allowing for quick identification of potential problem spots and identification of specific factors contributing to increased crash risks, enabling targeted interventions. See Figure 4 for the historical dashboard.

Figure 5. Use Cases 1 and 2 Historical Dashboard



Key

🟨 All RoadIQ crash predictive scores for the date range and map locations selected

🟪 Use Case 2: Captured streamed historical data that comprised the RoadIQ score at the specified date, time, and location. Contributing factors to the score are denoted with ability to view the timeline of factors preceding and post

🟩 Use Case 1 & 2: Captured historical data granularly visualized to validate and verify the confidence of the predicted score for post analysis. Additionally, validation of crowd sourced reporting of accidents to validate real-time airbag data

🟥 Use Case1 & 2: Captured patrol reports and airbag data to validate crash location, severity and outcome. Validation of airbag alert and reported crashes in the predicted score

As Use Case #2 and prototype development evolved, ODOT added a performance measure to evaluate the Risk Rating model accuracy given current conditions. The evaluation criteria are provided in Table 4. The Phase 1 ML model underwent two different types of evaluation.

Development evaluation. The model was tested during development using December 2022 data that was withheld from the training process. This test showed that the model isolated about 20% of all crashes onto high-risk segments. If a camera is pointed at a segment that is currently labeled as high risk, or a patrol vehicle is nearby, it is 3x more likely to observe a crash than a segment that is not high risk. For the December 2022 test data, a risk level of 0.5 or higher was considered "high risk". At any given hour, about 4% of road segment observations were flagged as high-risk, depending on conditions.

Post-deployment evaluation. After the model had been deployed and running for several months, the team created an evaluation dashboard that takes actual crash reports and compares them to the risk scores witnessed at the time of the real crash. The dashboard allows the time range to be configured and, like the stakeholder dashboard, also allows the high-risk bar to be customized. With a risk threshold of 0.5, and a time period from June 1, 2025 to July 31, 2025, there were 70 severe crashes on roadways with available risk scores, and the risk scores isolated about 1/3 of the real crashes onto high-risk segments.

Table 4. Use Case 2 — Evaluation Performance Measures

Identifier	Evaluation Question	Performance Measure	Performance Measure Target Achieved
PM-1	**Reliability:** Determine a method to compare the accuracy of the predictions with actual crash data.	Yes/No	Yes
PM-2	**Reliability:** Determine if the current roadway conditions validate the predictive risk level of the roadway	Yes/No	Yes – The model used the following real-time data to identify contributing risk factors: • Vehicle Data: Speed, congestion, and hard braking events • Weather Conditions: Rain, snow, sleet, aquaplaning, icy roads, and road slipperiness. The model identifies the major contributing factors to the risk rating.
PM-3	**Safety:** Did crashes occur on previous days where the prototype classified a route as having a high risk of having a crash?	Compare historical crashes to a prototype prediction on a past day	Yes, tests showed that the model isolated about 20% of all crashes onto high-risk segments. At any given hour, about 4% of road segment observations were flagged as high-risk, depending on conditions. Post Deployment - With a risk threshold of 0.5, and a time period from June 1, 2025 to July

Identifier	Evaluation Question	Performance Measure	Performance Measure Target Achieved
			31, 2025, there were 70 severe crashes on roadways with available risk scores, and the risk scores isolated about 1/3 of the real crashes onto high-risk segments
PM-4	**Systems Integration:** Are relevant data sets fully integrated between systems?	Yes/No The data produced by the model is being received by the ESP and traffic management systems (ATMS, etc.)	Stage 1 – Yes, ESP can ingest and distribute data from/to third parties. Stage 2 – ESP will send data to traffic management systems (ATMS, etc.)
PM-5	**Safety:** Has a measure of ranking or probability logically been able to identify the most likely corridor of a crash?	Yes/No	Yes
PM-6	**Safety:** Can the processes developed through the project successfully recommend ODOT identified mitigation strategies using the system data that shows the high probability of a crash?	Yes/No	Stage 1 – Yes, historical comparison of VSL operations to the Risk Rating score. This will be evaluated in Stage 2. ATMS recommends mitigation strategy based on high-risk data received
PM-7	**Safety:** Is there a positive return on investment determined during the prototype stage for an at-scale implementation?	Yes/No	Yes

The proposed solution addresses the challenges and needs identified by stakeholders. The statewide deployment of Use Case 2 will continue data collection, identification of hot spot locations throughout the state, and determine countermeasures and mitigation deployment strategies. Data will also be collected to evaluate the effectiveness of countermeasures.

Per ODOT's Stage 1 SMART Grant application, ODOT achieved the project objectives of: *Identifying applicable data sets; building proofs of concepts and testing them; research and develop a process map and potential workflow for data sharing with state and local 911 systems; and designing subsequent Business Intelligence Analytics, and to create meaning visualizations of the new information resulting in this Proof-of-Concept functionality built with the existing ESP application.*

The prototype validation in Stage 1 has laid the foundation for statewide deployment with active systems in Stage 2. Statewide implementation will meet the USDOT's and ODOT's goals to:

- Reduce congestion and delays for commerce and the traveling public
- Improve safety and integration of transportation facilities and systems

- Improve the reliability of existing transportation facilities and systems
- Improve access to jobs, education, and essential services
- Promote connectivity between and among connected vehicles and transportation systems
- Incentivize private sector investments and partnerships
- Improve emergency response

Anticipated Costs and Benefits of At-Scale Implementation

Project Benefits

Stage 2 will upscale both use cases for statewide implementation on ODOT owned and maintained roadways. For Use Case 1, ODOT will continue to work with OEMs and third-party data providers to procure real-time airbag deployment feeds for dissemination through the ESP. Use Case 1 benefits and outcomes for statewide deployment include the following:

- Improve emergency response: Reducing the time for the proper agency to be notified that a crash has occurred. This will cause an overall reduction in the incident timeline and help save lives. This will significantly improve responses in rural areas because stakeholders expressed the crash notification and location challenges in rural locations.
- Reduce congestion and delays for commerce and the traveling public; improve the reliability of existing transportation facilities and systems; and improve access to jobs, education, and essential services: Reducing the incident timeline allows for crash scenes to be cleared quicker than they otherwise would be, benefiting the overall driving public by reducing the likelihood of secondary crashes as well as congestion. This will aid in reducing congestion and diversion of traffic in urban and disadvantaged communities.
- Improve safety and integration of transportation facilities and systems: Providing alerts for crashes that might otherwise go unreported or unnoticed by motorists. This increases the likelihood that someone who is involved in a crash in a lightly traveled or rural area, can receive the necessary medical attention immediately. This also leads to more accurate crash reporting.
- Promote connectivity between and among connected vehicles and transportation systems: Providing accurate crash location information from CV data improves the reporting of crash data and can help better identify crash hot spots and other locations that may need remediation.
- Incentivize private sector investments and partnerships: Creating a successful public-private-partnership between ODOT and OEMs in integrating airbag deployment data can lead to future partnerships integrating additional useful data such as hard braking data, vehicle telemetry data, windshield wiper activation data and others.
- OEMs participating gain significant strategic advantages including enhanced safety reputation, access to aggregated crash and infrastructure data across Ohio's roadway network that cannot be obtained independently, and the ability to integrate real-time crash and risk rating data into vehicle navigation and driver assistance systems. Early participants help establish technical standards and data formats that will likely influence nationwide implementation, positioning themselves favorably as governments increasingly mandate connected vehicle data sharing. ODOT provides financial support to offset integration costs and assists with customer opt-in and privacy frameworks, reducing barriers to participation. The program strengthens the value proposition of connected vehicle services by enabling automatic emergency response with precise location data, while building crucial regulatory goodwill at state and federal levels.

For Use Case 2, ODOT continues to work with the TMC, ODPS, and County Sheriff Offices to provide crash risk information through ESP. The ESP application displays incidents and predicts high-risk locations with no required user input or browser refreshing for the passive display mode of operation. The application can communicate issues about ODOT's roadways, and users can interact with incidents to determine countermeasures. Table 5 shows the countermeasures identified in Stage 1, with an additional column to show ESP integration actions for deployment statewide. Selected countermeasures focus on the ability to leverage real-time risk across the roadway network. The identified interventions build from past successful implementation of pilot or statewide deployments and range in terms of time and cost to implement. Associated benefits for Use Case 2 (countermeasure deployment) are displayed in Table 5.

Use Case 2 benefits and outcomes for statewide deployment include the following:

- Reduce congestion and delays for commerce and the traveling public and improve safety and integration of transportation facilities and systems: Enhancing proactive traffic management by identifying high-risk areas before incidents occur. This will reduce crashes and congestion along corridors.
- Improve the reliability of existing transportation facilities and systems: Improving resource allocation for emergency responders and safety patrols. Supporting data-driven decision-making for infrastructure and safety improvements.
- Improve access to jobs, education, and essential services: Providing more accurate and timely information to travelers, which will potentially reduce secondary crashes and congestion created by an incident.
- Promote connectivity between and among connected vehicles and transportation systems: Creating a valuable stream of real-world data and making this stream available to any system or entity that wishes to positively impact traffic safety and incident management.
- Incentivize private sector investments and partnerships: Providing crash risk data to OEMs and other third-parties to inform vehicle driver assistance systems. Through our OEM engagement, they envision this data could provide valuable information to drivers and vehicle systems to provide additional insight into existing conditions.

Table 5. Stage 2 Countermeasures and Benefits

Countermeasure/ Strategy	Intended Outcome	ESP Integration
Ramp metering	▪ Reduces crash rate ▪ Improves travel time ▪ Improves traffic speed ▪ Relieves congestion ▪ Controls capacity	Congestion, risk scores, and traffic information in the ESP can be integrated directly into the ATMS enabling the ability to automate the activation of ramp meters.
Variable Speed Limit (VSL)	▪ Reduces crash frequency ▪ Reduces crash severity	The ESP will provide risk scores based on elements such as weather, congestion, incidents, and other sensor information. These scores can further assist with recommending or automating VSL updates across different road segments.
Dynamic Shoulder Lanes **Hard Shoulder Running** **Smart Lane/Smart Corridor**	▪ Reduces congestion ▪ Improves traffic speed ▪ Improves travel time reliability ▪ Reduces motorist stress	Historic traffic data will be used to create a congestion prediction model that will feed into the ESP, allowing traffic engineers to better plan for opening dynamic shoulder lanes thus reducing congestion.
Speed harmonization	▪ Reduces potential for rear-end crashes ▪ Reduces "stop and go" traffic	The ESP provides risk scores to identify areas with potentially dangerous speed transitions. This in turn will allow ODOT to update VSLs to better control the flow of traffic through a given corridor as well as

Countermeasure/ Strategy	Intended Outcome	ESP Integration
		update dynamic message signs and broadcast traveler information.
Freeway Safety Patrol tow truck **Safety Service Patrol**	▪ Reduces congestion ▪ Improves driving conditions	Risk scores supplied through the ESP can help ODOT to better coordinate with enforcement and emergency response to better stage resources for quick response to incidents.
Broadcast traveler information	▪ Reduces congestion ▪ Reduces motorist stress	The ESP risk scores can be used to determine when a message should be sent to drivers on the roads for high-risk road segments. Information such as "High Crash Area, Drive with Caution" can be broadcast to drivers through 3rd party applications, dynamic message signs or through C-V2X communications from RSUs.
Smart Work Zone Systems **Work Zone Traffic Information & Prediction System (TIPS)**	▪ Reduces congestion ▪ Reduces crash likelihood ▪ Improves work zone safety ▪ Encourages drivers to take an alternate route	The ESP risk score data provides insight to where scheduled and unscheduled work zones contribute to high risk. Based on these scores additional safety systems may be added to high-risk work zones to help reduce worker risk and vehicle incidents.

The anticipated costs to upscale statewide deployment of the use cases for a 36-month period include ODOT personnel, travel, contractual, and software. Table 6 summarizes the estimated Stage 2 costs.

- The existing ODOT resources will mentor, coach, provide program oversight, and transfer knowledge on the ODOT Event Streaming Platform (ESP) to other staff and resources.
- Travel cost estimates include three (3) trips with four (4) representatives to Washington DC.
- Contractual services will be used for stakeholder engagement, software development, systems engineering documentation, performance evaluation, and program management for both use cases.
- ODOT will be contracting with original equipment manufacturers (OEMs) and third-party data providers to receive airbag deployment and related transportation data.
- ODOT will integrate the ESP with the Advanced Traffic Management System (ATMS) to enhance existing processes where countermeasures can be identified for deployment. Data will be integrated into the ATMS and then develop automated countermeasures within the ATMS for infrastructure elements that ODOT currently has deployed.
- ODOT will update the connection with Nlets' test environment and integrate the ESP with Nlets' PSAP system.
- Software costs are included for three (3) years of Confluent Cloud which is the core software used by Ohio DOT Event Streaming Platform (ESP) as well as three (3) years of Sysdig, which is the cloud security software.

Table 6. Estimated Stage 2 Costs

Task ID and Description	ODOT Personnel	Travel	Contractual	Other	Total Cost
Task 1 Software development for data ingestion connection	-	-	$2,000,000	-	$2,000,000
Task 2 Software development for data consumer connection and data enhancements for ML model improvement	-	-	$4,000,000	-	$4,000,000
Task 3 Stakeholder engagement	-	-	$300,000	-	$300,000
Task 4 Systems Engineering	-	-	$400,000	-	$400,000
Task 5 Performance measurement	-	-	$300,000	-	$300,000
Task 6 Program Management	$99,620	$12,000	$650,000	-	$761,620
Task 7 OEM data systems updates	-	-	$1,800,000	-	$1,800,000
Task 8 OEM data access			$1,000,000		$1,000,000
Task 9 ATMS integration with ESP	-	-	$2,300,000	-	$2,300,000
Task 10 Software Costs	-	-	-	$1,530,000	$1,530,000
Total					**$14,391,620**

The scope of work for these tasks are as follows:

- Task 1 - This is a continuation from Stage 1 and focuses on developing robust software connections that enable the ESP to receive critical safety data from multiple sources. Using Stellantis' 24- hour connection as a model, the primary objective is to establish direct connections with other major original equipment manufacturers to receive airbag deployment data in real-time. This task involves creating connections for third-party data providers who aggregate and distribute vehicle safety information. The development team will build comprehensive connectors to ingest crash risk data and other safety-related datasets from various sources across Ohio's transportation network. A crucial component of this task is standardizing data formats, as each OEM provides information using different schemas and structures. The team will develop transformation logic to convert these diverse data formats into a unified ESP format, so that consistent processing and distribution is possible regardless of the original source. This standardization effort will create a foundation that allows future data providers to integrate seamlessly into the system.

- Task 2 - This task addresses the output side of the ESP by using software connections that distribute processed data to stakeholder systems throughout Ohio. The team will create robust connections to the TMC's ATMS, enabling traffic operators to receive real-time crash alerts and risk assessments directly within their existing workflow. Finalizing the integration with Nlets and the ODPS's LEADS so to receive immediate notification of airbag deployment events with accurate location information. Establishing connections with County 911 dispatch centers and PSAP systems across all 88 Ohio counties will provide local emergency responders with the critical information they need to respond effectively. The task includes creating comprehensive APIs and web services that allow authorized stakeholders to consume data in formats that suit their specific systems and needs. Building both real-time data feeds for immediate alerting and historical query capabilities for analysis and reporting will provide stakeholders with flexibility in how they access and utilize the information. These data distribution connections will transform raw safety data into actionable intelligence delivered directly to the systems that emergency responders and traffic managers use daily.
  - Data Enhancements for Machine Learning Model Improvement
    - Expanding data sources represents a critical path for enhancing the crash prediction model's accuracy and utility. Adding more granular weather data including road surface temperature, precipitation intensity, and wind speed will provide the model with detailed environmental context that influences crash risk. Including real-time construction and work zone data with specific closure types will help the model understand how maintenance activities affect traffic patterns and safety. Integrating incident reports from multiple sources such as 911 calls, Freeway Safety Patrol logs, and WAZE crowd-sourced data will create a comprehensive view of roadway conditions. Adding OEM telematics data including hard braking clusters and traction control activations will provide early warning indicators of deteriorating conditions before crashes occur. Including time-to-collision warnings from connected vehicles will offer real-time signals of dangerous traffic situations as they develop.
    - Improving temporal resolution will enable more timely and actionable predictions for traffic management centers and emergency responders with more current information that reflects rapidly changing conditions. For Stage 1, the risk model used 15-minute baseline intervals to develop risk scores. For Stage 2, the risk model will increase risk score analysis to near-real time based on the change in data inputs (hard braking, weather, queue detection, etc.). The negative change in data elements and the number of data elements that change in the risk model would increase the rate of updating the risk analysis. Tracking changing metrics will enable the model to identify higher risk segments where conditions are changing, as these transition periods often precede crashes and create the end-

    of-queue scenarios identified in the September 2025 NTSB recommendations. This approach will increase efficiency and have near real-time risk analysis as needed to support processing costs based on traffic management needs.

    - The ESP has been developed to deliver this type of analysis in two ways. First, it receives new predictions in the form of risk score update events that the model could generate at any rate. Each risk score update is at the level of an individual road segment. It can accept more or fewer risk update events on a per-segment basis. Cost management prohibits generating near-real-time safety score updates for the entire state. However, rush hour conditions such as high congestion or changes in speed may necessitate that certain corridors receive more frequent risk updates, and the ESP can scale as needed to receive those. Second, the ability of the ESP to ingest and process event data also means that in Stage 2, it will be used to tell the model when and where to run based on evolving circumstances. The raw input events that signal conditions on the ground, such as pavement temperature readings, work zone locations, or traffic speed, will be fed into a smaller model that decides what areas of the statewide road system need more frequent, potentially near-real-time prediction updates. This rate-controlling model will look at the various inputs together to determine which areas are most dynamic, and therefore require more updating, so that the risk score model can focus on the key segments. It produces a feedback loop where the ESP receives score updates as the model generates them but can also tell the model where it wants to focus the attention. This will save compute costs and transmission bandwidth in areas where baseline intervals are sufficient while serving timely risk score updates for segments that are experiencing changing weather or traffic conditions that exceed the thresholds of the original 15-minute prediction. The adaptive event-driven approach means that the model will have the flexibility to react immediately to new developments for public safety risk where it matters most.
    - **The model will be available for all to consume and utilize at a national level.**

- Task 3 – Stakeholder engagement will continue with regular meetings scheduled with key stakeholders, including OEMs, third-party data providers, departments withing the state of Ohio, county sheriff offices, and Nlets. The team will expand discussions to all county sheriff offices throughout the state.
- Task 4 – Systems engineering documents will be updated and new documents created for Stage 2 system requirements, testing, validation, implementation, and operations & maintenance.
- Task 5 – Performance measurement will include data collection pre-and post-implementation to evaluate effectiveness. Surveys and interviews will be conducted with stakeholders to assess satisfaction with the deliverables.
- Task 6 – Program management will include weekly coordination with the project team, scheduling, budget tracking, risk management, and scope management. The team will develop procurement documents and manage OEM and third-party data providers.
- Task 7 - To integrate with ESP, OEMs must implement data routing that captures airbag deployment events and sends them to ODOT's endpoint either through a push mechanism (OEM actively sends data to ESP as events occur) or pull mechanism (ESP periodically queries OEM systems for new events). This requires OEMs to add data processing middleware that strips

personally identifiable information from raw vehicle data. The Stellantis example in Stage 1 demonstrates this approach, where their Mobilisights platform initially provided 24-hour batch exports of eCall data and is transitioning to near real-time API access, showing how OEMs can phase implementation from historical data validation to live event streaming. System updates also require implementing monitoring and alerting infrastructure to detect transmission failures, logging capabilities for troubleshooting, and scalability provisions to handle potential expansion beyond Ohio's borders. The technical lift varies significantly by manufacturer depending on their connected vehicle architecture maturity—some OEMs like Stellantis already have cloud platforms capable of API-based data sharing, while others may need substantial backend redesign to extract airbag events from their existing call center routing systems and make them available for governmental consumption.

- Task 8 – This task includes a subscription for airbag deployment events and characteristics as available, such as (sensor readings, deployment timestamps, impact severity metrics, pre-crash data, system diagnostic codes, and seatbelt status at time of deployment, etc.). This will be accessed via near-real-time updates or event-triggered notifications. Pricing will be based on each OEM standard pricing model (per vehicle, per event, monthly flat fee, or per API call) for the duration of the grant period.
- Task 9 – This includes meeting with TSMO Office and perform system engineering to document the TMC needs and UI/UX. The system engineering will then be shared with the current ATMS vendor to incorporate the data stream and display it in a manner that aligns with the TMC needs.
- Task 10 - Confluent Cloud and cloud data processing fees.

While a direct quantitative assessment of benefit based on statewide deployment is not available at Stage 1, both prototypes allow for a cost effective upscale bringing increased benefit to ODOT and their traffic safety partners. For Use Case 1, ODOT has commitments with OEMs to share airbag deployment and additional critical public safety data. Connections will be built to receive and disseminate data from/to existing systems. The information will be applicable statewide and there is minimal cost to maintain once connections are in place. The potential benefits far outweigh costs by providing real-time crash information which can provide faster emergency services for those injured during the incident. As noted in Huang et al., 2004, a one-minute increase in EMS response time to motor vehicle collisions resulted in a 2.6% increase in fatality odds. ESP offers significant improvements in severe crash reporting time, location quality, and consistency allowing for improvements to EMS crash response. While average EMS response times vary widely based on a number of factors, the initial time to report a crash and direct EMS response to the appropriate location has the potential to reduce EMS times for a wide variety of circumstances and situations by several minutes and thus reducing the likelihood of fatal outcomes for severe crashes. In addition, the airbag notification will allow traffic management to mitigate congestion more quickly are reduce the risk of secondary crashes. The initial investment pays dividends over time as agencies acclimate to the new information stream and work it into their standard operating procedures.

For Use Case 2, the cost for statewide deployment is minimal. The Stage 1 prototype, while focusing on target locations in the State, was built on a statewide level minimizing any additional rework or further build-out to leverage the Stage 1 system improvements. Some countermeasures such as Highway Safety Patrol, Variable Speed Limits, Ramp Metering, etc., are already deployed; therefore, the statewide deployment will allow for more effective and efficient use of existing investments across the state. As the system operates over time it will also result in a new baseline leveraging the real-time data available in the ESP. ODOT will be able to use this new baseline to evaluate existing countermeasures with an array of metrics not currently available further increasing the benefit of the system. Statewide deployment will also provide enhanced decision making on the location and type of proposed countermeasures that should be deployed, in coordination with current HSIP and TSMO planning, thus optimizing safety and available funding.

The initial model developed to leverage the real-time data stream in the ESP considered three years of crash data covering the entire roadway network in the state of Ohio. The prototype model proved that a crash-risk based approach focused on static and dynamic factors has the potential to indicate roadway segments which show a real-time elevated risk for a crash. The prototype models considered multiple datasets and contributing factors including:

- Average annual daily traffic
- The estimated current number of vehicles passing through a cross-section of the lanes (flow) measured in vehicles per hour
- Traffic density measured in vehicles per mile
- Current congestion, when demand exceeds capacity, in which case traffic volume (flow multiplied by time) exceeds lane capacity for that duration of time
- Current speed in miles per hour
- Free flow speed when there is no congestion present
- The presence of vehicular queuing when congestion occurs
- Sudden speed changes, correlated with an increase in hard braking
- Visibility, measured in miles and affected by darkness, fog, snow, or rain
- Precipitation and temperature which impacts traction and stopping distance
- Time of day which is important for daily patterns like rush hour travel
- Day of week
- Seasonality (month of the year), associated with patterns like school traffic
- Work zones
- Spatial location, which includes local environmental factors which are not directly modeled

Critically, the prototype models establish a baseline for the processing of real-time data for the statewide network. In Stage 2, the models will continue to be refined based on observations and improvements as the ESP continues to operate. Stage 2 will also be an opportunity to align crash risk predictions and real-time countermeasure with other aspects of ODOT's TIMS and Highway Safety Improvement Program as users begin to assimilate the ESP into standard operating procedures. Ultimately, the success of Use Case 2 in Stage 1 makes for a plug and play framework where an improved model in Stage 2 could be developed "offline" and brought into the ESP as an upgrade within the current framework significantly reducing additional deployment costs and offering the benefit of continuous model improvements over time.

As it stands at the end of Stage 1, the ESP can assess and relay real time crash risks to system users. Additional improvements will help to better leverage existing dynamic countermeasures such as variable speed limit corridors and highway safety patrols as additional user connections are established. **As noted, the system is not intended to predict the exact time and location of a crash, however, being able to proactively direct safety patrols, and reduce speed limits at high-risk locations offers a targeted approach to reducing response times, clearing vehicles to reduce secondary crashes, and reducing travel speeds. All of these improvements reduce the likelihood of a crash resulting in a fatality and align**

with core elements and principles of the Safe Systems Approach. Reducing the severity of one crash from a fatality or serious injury to a minor injury is equivalent to more than a $400,000 savings based on ODOT's human capital costs. These costs do not account for savings associated with broader societal impacts. Ohio averaged 1,161 fatal crashes from 2020 through 2024. If stakeholders leverage the ESP to reduce the severity of just five of these crashes per year, the system will show a positive cost benefit within 7 years. Even at these very conservative estimates, the system has the potential to efficiently leverage initial costs to save lives.

Challenges and Lessons Learned

Barriers (Data, Partners)

Through stakeholder and partner engagement, the project identified data source options and sensitivities around data sharing. OEM crash data is vital to the success of both use cases, specifically, airbag deployment data. A significant barrier the team experienced was an existing partner being unable to share real-time airbag data. There are many data sets available to DOTs from third parties that have contracts with OEMs, such as the partnerships between MOOVE.ai / Stellantis, Streetlight / GM, etc., but air bag deployment data is not one of the data elements that is currently available. Largely this is due to the fact that OEMs are not specifically set to collect this data themselves and have that data sent directly from the vehicle to a third-party call center.

Achieving Vision Zero requires all stakeholders in the traffic ecosystem work together. A public-private partnership approach between transportation agencies, OEMs, and research institutions is necessary. This project is a critical step towards enhancing the relationship between state DOTs and OEMs and improving safety and mobility for all.

During stakeholder engagement, the team discovered multiple third-party data providers, such as SiriusXM and moove.ai, work with OEMs to collect and disseminate data, and are interested in participating in Stage 2. Not all OEMs work with third-party providers, so ODOT will be working directly with OEMs and third-party providers to collect safety related data. These additional data streams from third-party providers to the ESP will help expand and diversify the data sources.

Lessons Learned

The model developed in Stage 1 leveraged historical data to create relationships between crashes, static factors, and dynamic inputs. Critically, the system proved that the combination of static factors and dynamic inputs offers a pathway for statewide implementation of Use Case 2. However, model improvements in Stage 2 can improve the effectiveness of the system by considering existing ODOT peer groups to leverage comparatively expected statewide safety performance consistent with the Highway Safety Program's annual network screening efforts. This will allow for a more balanced comparison of similar roadway types rather than a blanket modeling approach for all roadways. Additionally, following a severity weighted baseline would allow for a better understanding of the expectation for severe versus total crashes bringing the ESP in alignment with Vision Zero.

As part of Stage 1, ODOT tested sending OEM airbag data from the ESP through LEADS to the Delaware County Sheriff's Office 911 center. To ensure successful deployment and operation of the ESP at the County level, it is essential to establish comprehensive test environments that accurately replicate the production data reception process. Prior to any production implementation, each County installation site must have a dedicated test environment configured to mirror the production environment's data ingestion workflows. These test environments will enable thorough validation of data connections, transformation logic, and system performance under conditions that closely simulate real-world operations.

Deployment Readiness

OODT has worked with stakeholders to develop a seamless workflow to share data for both use cases, as previously shown in Figures 1 and 2. **ODOT has successfully tested the system to send OEM airbag data to the correct emergency responding entity.** ODOT will move from test environments to production environments in Stage 2. ODOT has identified primary tasks for Stage 2 and developed a 36-month project schedule (Figure 5). Critical path elements involve issuing RFPs and gaining agreements with OEMs and third-party data providers to receive data (including airbag deployment data). Having multiple data sources will provide a more responsive system and include a larger percentage of vehicles in Ohio. ODOT will need access to API documentation and keys, similar to the work performed with Stellantis in Stage 1. ODOT will create connections to the TMC's ATMS by Arcadis and Nlets' PSAP. Since Nlets' PSAP system is connected to the Ohio Department of Public Safety, upscaling for statewide deployment will be seamless. In addition, since Nlets also supports every other state, local, and federal law enforcement organization, the work done for this program will be scalable and replicable across every other state. After these critical tasks, data connections can be built between ESP and stakeholder systems.

Data management, privacy, and cybersecurity are critical elements for successful implementation in Stage 2. The data management plan in the DMP Tool will be periodically updated as projects mature, and new details emerge. To maintain data privacy, all collected data will exclude personal identifiable information (PII) and be aggregated to ensure it does not represent any person or entity. ODOT's Office of Data Governance has a process in place to determine whether data contains PII. While incident alerts will include geospatial data along with time and date information, these details will not be correlated to individuals, instead focusing on severity metrics like acceleration rather than speed to prevent the capture of incriminating factors. Security will be addressed through ESP via its user authentication and roles system and subscriber/publisher access model, ensuring robust data protection and privacy. This approach will safeguard all data and prevent unauthorized access.

The system is defended against cybersecurity threats by adhering strictly to 2025 best practices including the Open Worldwide Application Security Project (OWASP) Top 10 guidelines. Communication between Amazon Web Services data centers (ESP, Stellantis) takes place over end-to-end encrypted connections. The Stellantis data transfer uses an AWS IAM role-based trust relationship. ML data communication takes place directly between the Kafka systems and the ESP, secured by the same SASL/SSL mechanism used by Confluent Cloud. The authentication and encryption methodology protects against untrusted entities injecting false event or risk data. Once data is ingested by the ESP, all information is encrypted at rest by AWS Elastic Block Storage (EBS) and AWS Simple Storage Service (S3) using Amazon-managed keys.

While most of the maintenance and operating requirements have been researched, it is not yet known how well the system will be adopted. The adoption rate for the ESP will determine the rate at which the ESP will need to scale to meet demands. Additionally, the ESP now relies heavily on Confluent as a cloud service provider to streamline data sharing and streaming capabilities. This platform cost is based on the amount of data streaming through the platform. This will need to be additionally vetted to ensure that platform is cost efficient.

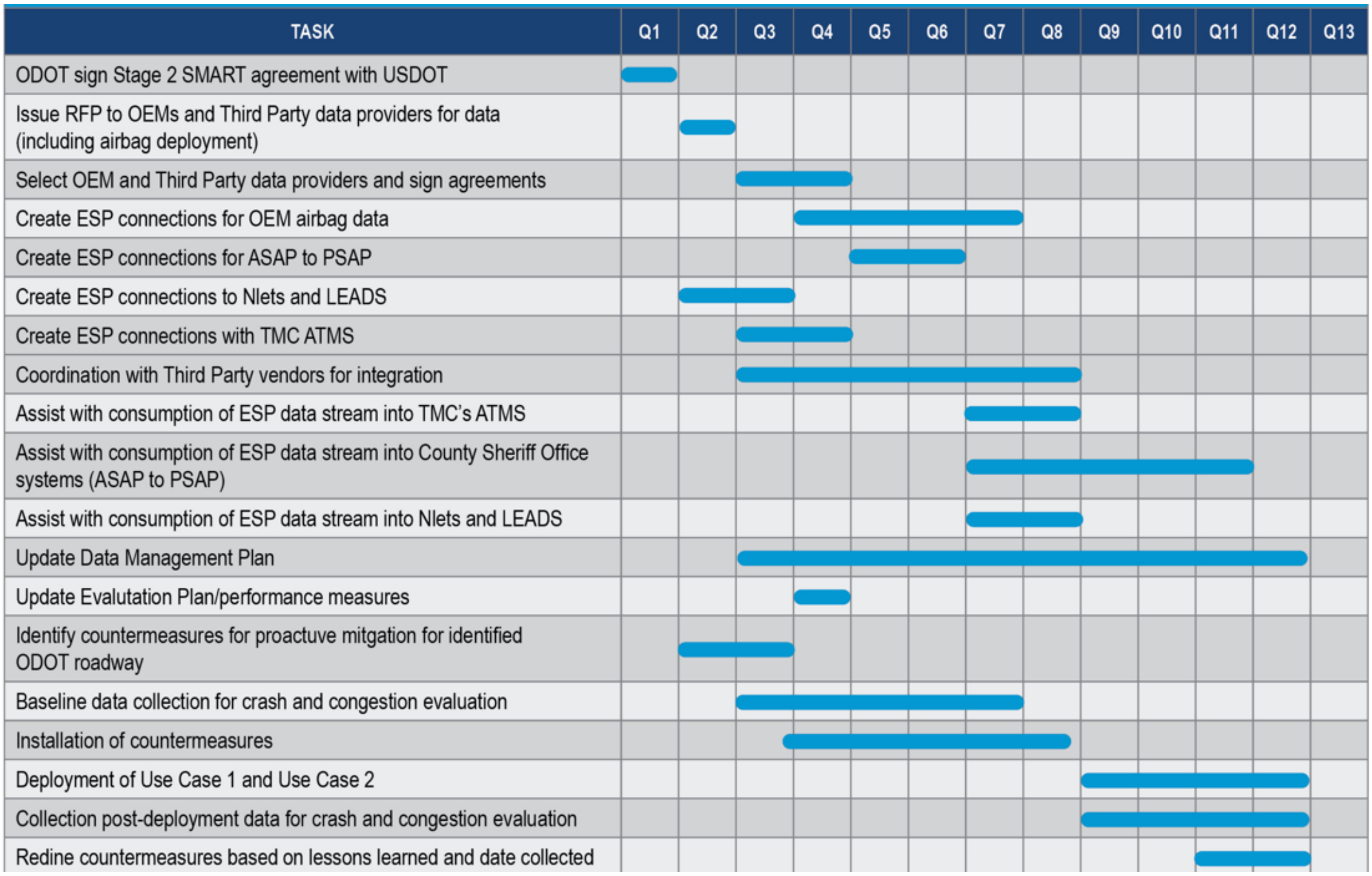
While technical debt won't ever be able to be completely removed from software projects, ODOT can take steps to minimize how much technical debt is created within the project. ODOT plans to minimize technical debt by adding automation to monitor and automatically update components in the source code through widgets such as Dependabot. Additionally, all software is required to be thoroughly unit tested and peer reviewed before approval. DriveOhio has historically committed budget for the development of ESP, future year budgets will retain commitment towards ESP maintenance and improvement, including the applications being supported through the SMART Grant program.

The integration of ESP's real-time and historical data information to help with problem identification and decision making will require training and education for the new systems in place for the TMC operators and emergency services. ESP's tools can help provide reliable and streamlined data, allowing traffic management and incident response staff to focus on solutions rather than verification of information. This can increase productivity and job satisfaction allowing workers to focus on the core aspects of their roles. The efforts related to this SMART grant project also employ the direct use of artificial intelligence (AI) and ML. The initial use of these technologies by ODOT will further progress their usage into the future, thus requiring new skills that will advance the creation of new job opportunities within the public sector. DriveOhio, through its workforce development initiative, is already engaging with the future workforce and introducing them to the ways AI and ML can be utilized within the transportation industry. ODOT will provide training to TMC staff so there is understanding of information being provided through the crash risk analysis and how the risks are developed.

ODOT will be ready to move forward with Stage 2 once authorized. The team has identified the primary tasks for statewide deployment:

- ODOT will issue a Request for Proposal (RFP) to contract with OEMs and data providers to procure airbag and related data. The scope of work will include OEMs updating their data sharing systems to enable the ESP to receive critical safety information.
- ODOT will create ESP connections for OEM airbag data to push or pull OEM events with the lowest ingestion delay that the OEM system supports.
- ODOT will continue coordination with ODPS LEADS and Nlets system to bring connections into the production environment for testing and deployment.
- ODOT will create an ESP connection with the TMC ATMS through a web-facing ESP connector that will be configured so that Arcadis may pull data into the ATMS.
- ODOT will assist with consumption of ESP data stream into the TMC's ATMS. The project team will coordinate the new development and provide test messaging from the ESP side.
- ODOT will assist with consumption of ESP data stream into County Sheriff Office systems. This includes verifying compliance with the standards being used, adding compliance as needed, ensuring messages are tagged with the appropriate ORI for each county based on enriched roadway and geofencing information, and generating test messages to validate integration.
- ODOT will collect data to evaluate the effectiveness of countermeasures and help the TMC select the appropriate strategy in given situations.

Figure 6. Stage 2 Schedule



TASK	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
ODOT sign Stage 2 SMART agreement with USDOT	●												
Issue RFP to OEMs and Third Party data providers for data (including airbag deployment)		●											
Select OEM and Third Party data providers and sign agreements			●	●									
Create ESP connections for OEM airbag data				●	●	●	●						
Create ESP connections for ASAP to PSAP					●	●							
Create ESP connections to Nlets and LEADS		●	●										
Create ESP connections with TMC ATMS			●	●									
Coordination with Third Party vendors for integration			●	●	●	●	●	●					
Assist with consumption of ESP data stream into TMC's ATMS							●	●					
Assist with consumption of ESP data stream into County Sheriff Office systems (ASAP to PSAP)							●	●	●	●	●		
Assist with consumption of ESP data stream into Nlets and LEADS							●	●					
Update Data Management Plan			●	●	●	●	●	●	●	●	●	●	
Update Evalutation Plan/performance measures				●									
Identify countermeasures for proactuve mitgation for identified ODOT roadway		●	●										
Baseline data collection for crash and congestion evaluation			●	●	●	●	●						
Installation of countermeasures				●	●	●	●	●					
Deployment of Use Case 1 and Use Case 2									●	●	●	●	
Collection post-deployment data for crash and congestion evaluation									●	●	●	●	
Redine countermeasures based on lessons learned and date collected											●	●	

Wrap-up

Prototype development has met ODOT's expectations and proved the ESP can collect, process, disseminate, and display data to improve crash identification and emergency response and identify high crash risk areas for countermeasure deployment. Soliciting input and feedback from law enforcement, traffic managers, OEMs, experts in incident alert systems, and third-party data providers confirmed the prototype met user needs and created a clear approach for statewide deployment. Key steps for upscaling in Stage 2 include:

- Procure OEM and Third-Party data
- Create ESP connections for OEM airbag data
- Update ESP connection for Nlets system
- Create ESP connection with the TMC ATMS
- Assist with consumption of ESP data stream into the TMC's ATMS
- Assist with consumption of ESP data stream into County Sheriff Office systems
- Assist with consumption of ESP data stream into ODPS LEADS system/ Nlets system
- Collect data to evaluate the effectiveness of countermeasures and help the TMC select the appropriate strategy in given situations

The ODOT SMART grant program has created a scalable and replicable approach which will allow other state transportation agencies to deploy similar applications. The foundation has been laid and the process will be developed for other transportation agencies to implement. Transportation agencies that wish to develop and deploy a similar program must create a robust stakeholder engagement plan. Stakeholder involvement is critical for success. Working with emergency notification and response systems can be complex; therefore, many discussions and introductions to new stakeholders are needed to fully understand how data can be shared and used to improve safety and mobility. In addition, having access to and understanding historical and real-time data is vital. Creating data specifications to provide descriptions of the data elements, including their types, formats, and any unique characteristics pertinent to the project is important.

Implementing a hybrid project management and development approach, combining traditional waterfall, systems engineering practices and agile software development methodologies, best suits delivering documentation and software. Agile delivery is a risk management tool that delivers early success and identifies early failures to maximize project success. The hybrid approach allows for some of the certainties and confirmation of a waterfall project approach (e.g., agreed upon deliverables, upfront certainty, cost estimates, and timeline schedule), while offering the speed and agility of an agile approach (e.g., iterations, active stakeholder involvement, speed).

The purpose of Stage 1 was to show data can be collected, displayed and analyzed. Stage 1 work efforts have allowed ODOT to collect and disseminate live event data and can be connected and standardized to be integrated in multiple systems. The program is now set to advance the applications to improve public safety in Stage 2.