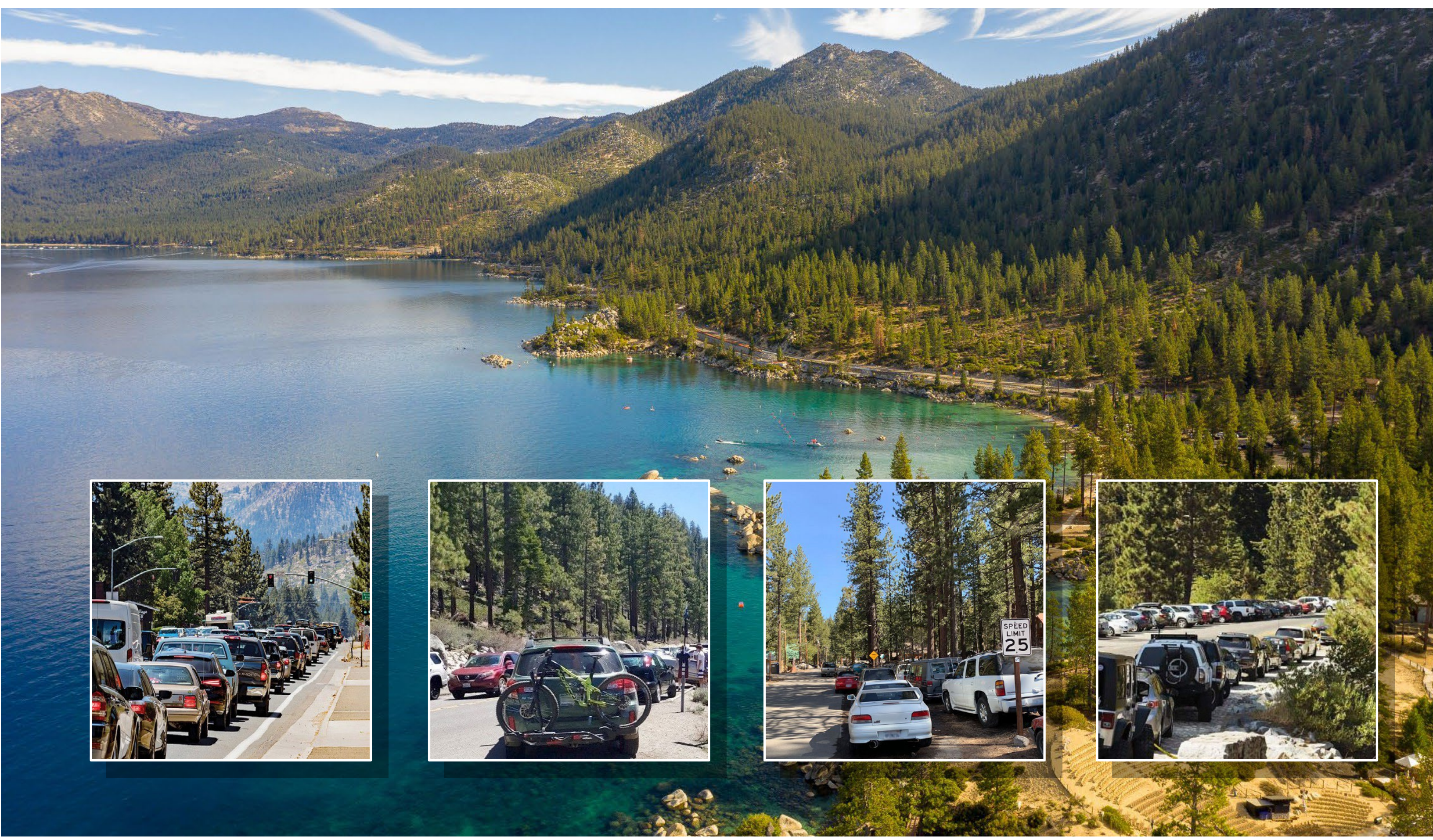
Tahoe Transportation District

STAGE 1 – FINAL IMPLEMENTATION REPORT

Intelligent Sensor Integration on Rural Multi-Modal System

FY 22 Strengthening Mobility and Revolutionizing Transportation (SMART)
SEPTEMBER 2023 TO OCTOBER 2025
Submitted on: 11/04/2025



SMART

NEVADA DOT SAFE AND CONNECTED

TAHOE REGIONAL PLANNING AGENCY

Caltrans

Table of Contents

Part 1: Executive Summary 6
Project Goals and Objectives 6
Location 6
Key Partners 6
Prototype Scope and Deliverables/Outcomes 6
Stage 1 Results 6
Stage 1 Lessons Learned and Stage 2 Outlook 7
Part 2: Introduction and Project Overview 8
Overview 8
Issues To Be Addressed 10
The Technologies Being Deployed 11
Project Team And Stakeholders 14
Stage 1 Deployment 16
Deployments and Evaluations 17
Online Data Platform 18
Stage 1 Project Activities Milestones 19
Stage 2 Deployment (At Scale Implementation) 21
Stage 2 Scope 21
Goals and Desired Outcomes 22
Project Visibility 23
Part 3: Proof-of-Concept or Evaluation Findings 26
Performance Metrics and Data Collected 26
Approach 27
Evaluation Findings 28
Accurate Multimodal Traffic Data Collection 28
Accurate Multimodal Safety Data 30
24 X 7 X 365 Multimodal Traffic Data Collection 32
Collect and Store Multimodal Speed Data 34

Online Data Storage and Management ... 35
Data Presentation, Analytics and Reporting Features ... 36
Traffic Insights ... 38
Safety Insights ... 42
Evaluation Against Original Project Goals ... 44
Statutory Outcomes Demonstrated During Stage 1 ... 45
Benefits and Challenges by Configuration Type ... 47
Key Findings and Lessons from Stage 1 ... 48
Part 4: Anticipated Costs and Benefits of At-Scale Implementation ... 50
Anticipated Impacts by Key Goal Area ... 50
Anticipated Costs of At-Scale Implementation ... 51
Cost-Benefit Comparison ... 51
Preliminary Baseline Data for Evaluation ... 52
Part 5: Challenges & Lessons Learned ... 53
Procurement and Budget ... 53
Partnerships and Coordination ... 53
Technology Suitability and Field Deployment ... 53
Camera Performance and Deployment ... 53
System Monitoring and Maintenance ... 54
Legal, Policy, and Regulatory Requirements ... 54
Data Governance and Cybersecurity ... 54
Workforce Capacity and Community Impact ... 54
Public Awareness and Acceptance ... 54
Part 6: Deployment Readiness ... 57
Part 7: Wrap-Up ... 59
Reflections on Stage 1 Implementation ... 59
Lessons Learned and Recommendations for Stage 2 ... 59
Expectations for At-Scale Implementation ... 60
Advice for Other Communities ... 60
Next Steps ... 60
Appendix A: Anticipated Costs and Benefits of At-Scale Implementation ... 62

List of Tables

Table 1: Project Stakeholder List ... 15
Table 2: Qualitative Description by Program Benefit Area ... 26
Table 3: Evaluation Performance Measures and Methodology ... 27
Table 4: Validation of Traffic Insight Accuracy by Configuration Type ... 30
Table 5: Validation of Safety Data Reporting ... 31
Table 6: Sensor Capture Rate by Configuration Type ... 33
Table 7: Sensor Health & Status by Configuration Type ... 34
Table 8: Traffic Counts by Vehicle Type (7/7/2025 – 7/13/2025) ... 40
Table 9: Evaluation of Stage 1 Outcomes Against Project Goals ... 45
Table 10: Benefits and Challenges by Configuration Type ... 47
Table 11: Projected Impacts of At-Scale Implementation by SMART Statutory Goal ... 50
Table 12: At-Scale Implementation Costs (Stage 2) ... 51
Table 13: Summary of Costs and Benefits ... 52
Table 14: Stage 1 Baseline Data for Evaluating At-Scale Implementation ... 52
Table 15: Challenges and Lessons Learned ... 55

List of Figures

Figure 1: Stage 1 Pilot Sensor Deployment Locations in the Lake Tahoe Basin ... 9
Figure 2: AI Edge Processing (Fixed) Schematic ... 13
Figure 3: AI Edge Processing (Mobile Trailer) Schematic ... 13
Figure 4: AI Centralized Server Processing Schematic ... 14
Figure 5: AI Cloud Processing Schematic ... 14
Figure 6: Project Locations ... 17
Figure 7 Project Key Activities and Milestones Timeline ... 20
Figure 8: Proposed Stage 2 Deployment Locations ... 21
Figure 9 Weekday Variation of Total Traffic – US 50 at Lake Parkway ... 40
Figure 10 Weekday Variation of Total Traffic – Mount Rose Summit ... 41

Acronyms

Acronym	Definition
AI Sensors	Artificial Intelligence Sensors
API	Application Programming Interface
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
Caltrans	California Department of Transportation
CA	California
CHP	California Highway Patrol
DOT	Department of Transportation
FHWA	Federal Highway Administration
FY	Fiscal Year
GIS	Geographic Information System
ITS	Intelligent Transportation System
NDOT	Nevada Department of Transportation
NHP	Nevada Highway Patrol
NIST	National Institute of Standards and Technology
NPV	Net Present Value
OD	Origin-Destination
O&M	Operations and Maintenance
PDU	Power Distribution Unit
PHB	Pedestrian Hybrid Beacon
RFP	Request for Proposals
SR	State Route
STARLINK	Satellite Communications Provider (SpaceX)
TMC	Traffic Management Center
TRPA	Tahoe Regional Planning Agency
TTD	Tahoe Transportation District
TSMO	Transportation Systems Management and Operations
USDOT	United States Department of Transportation
VRU	Vulnerable Road User

Part 1: Executive Summary

The Intelligent Sensor Integration on Rural Multi-Modal System project, funded by the FY22 Strengthening Mobility and Revolutionizing Transportation (SMART) Stage 1 grant, aims to enhance transportation safety, mobility, and reliability in the Lake Tahoe Basin by deploying cloud-based mobility data collection and analysis platform supported by AI-powered sensor technologies (AI Sensor). Stage 1 of the project focused on proof-of-concept implementation.

Project Goals and Objectives

The project is intended to:

- Deliver accurate, accessible open-source data
- Enhance safety for all roadway users
- Improve congestion management and travel-time reliability
- Support long-term economic competitiveness
- Expand access to essential services
- Strengthen resiliency and emergency response coordination
- Improve efficiency and reduce congestion by supporting transit and active transportation

Location

Located on the border of California and Nevada, the Lake Tahoe Basin supports a full-time resident population of approximately 55,000 people. Visitation is the main driver of the Tahoe Region's $5 billion annual economy, based largely on seasonal tourism and outdoor recreation. This influx of visitors puts metropolitan-level travel demands on the region's largely rural transportation system. Tahoe Transportation District's (TTD) jurisdiction is the Lake Tahoe region, which includes portions of two California counties and three Nevada counties.

Key Partners

Key partners included TTD, Tahoe Regional Planning Agency (TRPA), the states of California and Nevada Departments of Transportation (Caltrans/NDOT), Highway Patrols in California and Nevada (CHP/NHP), local jurisdictions, the Washoe Tribe, and consultants Parametrix and Derq.

Prototype Scope and Deliverables/Outcomes

- AI-powered sensors were deployed at 13 key intersections and highway locations to capture real-time traffic activity and safety conditions. In addition, one mobile AI-powered sensor mounted on a solar trailer was deployed at three locations.
- A cloud-based dashboard was developed to provide real-time access to traffic and safety data.

Stage 1 Results

- Analytics Accuracy: Stage 1 validated the system's ability to generate accurate multimodal traffic and safety data, achieving over 90% accuracy across successful installations.
- Safety Impact: The system reliably identified near misses, wrong-way driving, and other high-risk behaviors, providing actionable insights that informed countermeasures.

Stage 1 Lessons Learned and Stage 2 Outlook

Stage 1 validated the feasibility and value of AI-powered, cloud-based traffic technologies, providing planners with new tools to improve safety and efficiency. Building on these lessons, Stage 2 will implement Basin-wide sensor coverage, integrate multimodal data, enhance safety at crossings, support mode shift, strengthen resiliency with satellite communications, improve regional coordination, and generate over $20 million in benefits while creating local workforce and economic opportunities.

Part 2: Introduction and Project Overview

Overview

Project title: Intelligent Sensor Integration on Rural Multi-Modal System

Recipient: Tahoe Transportation District (TTD)

Fiscal year of award: FY 22

Period of performance: September 2023 – October 2025

Report Prepared by: TTD

Date of Report Submission: 11/4/2025

The Lake Tahoe Region is home to the largest alpine lake in North America, spanning the California and Nevada border at 6,225 feet above sea level. The Lake Tahoe Region supports a full-time population of 55,000 residents across two states, five counties, and one city. In 1969, California and Nevada legislators established the Bi-State Compact for sharing Lake Tahoe resources and responsibilities. The Compact, amended in 1980 by Public Law 96-551, also established TTD, which is responsible for implementing safe, environmentally positive, multimodal transportation solutions for the Basin, including transit operations and parking management.

The Lake Tahoe Basin has a unique transportation situation in an environmentally sensitive ecosystem. Seventy-nine percent of the land in the Basin is federally owned with limited infrastructure. As a world-class recreation destination, the region attracts millions of visitors each year, including extended-stay visitors from across the U.S. and international markets, as well as day visitors from surrounding metropolitan areas. Seasonal demand produces significant fluctuations in travel patterns, with summer lake access and winter ski resort demand creating recurring congestion and safety issues. At the same time, the region's constrained right-of-way, extreme weather, topography, and lack of broadband infrastructure limit roadway expansion. These conditions create an imperative to optimize the existing system using intelligent transportation solutions in a unique setting.

In addition to the unique transportation situation, the Basin faces long-standing challenges in collecting and managing reliable multimodal transportation data due to its rural context, limited broadband connectivity, and fragmented Intelligent Transportation System (ITS) infrastructure managed by multiple jurisdictions across two states. Existing traffic management systems in the region are largely legacy technologies with inconsistent coverage and limited data-sharing capabilities. As a result, regional agencies have lacked the ability to monitor real-time travel conditions, evaluate safety performance, and coordinate across state lines. This project was initiated to bridge these data and technology gaps by piloting a unified, AI-driven sensing and data platform capable of operating under the Basin's complex geographic, organizational, and connectivity constraints. The deployment represents not only a first step toward an integrated bi-state transportation data management system for the Tahoe Basin, but also a model for other rural and recreation-focused regions facing similar limitations in infrastructure and data-driven decision-making.

The Intelligent Sensor Integration on Rural Multi-Modal System project is implementing a cloud-based mobility data collection and analysis platform supported by AI-powered sensors deployed at multiple locations within the Lake Tahoe Basin (see Figure 1). The Stage 1 deployment included 13 fixed locations and three mobile locations. Collectively, the intelligent sensor-based infrastructure generates multimodal traffic and safety data to support planning, resource management/allocation, operational decision-making, and interagency coordination. The system enhances roadway safety, improves situational awareness, and provides a foundation for stakeholder engagement and data-driven investment strategies.

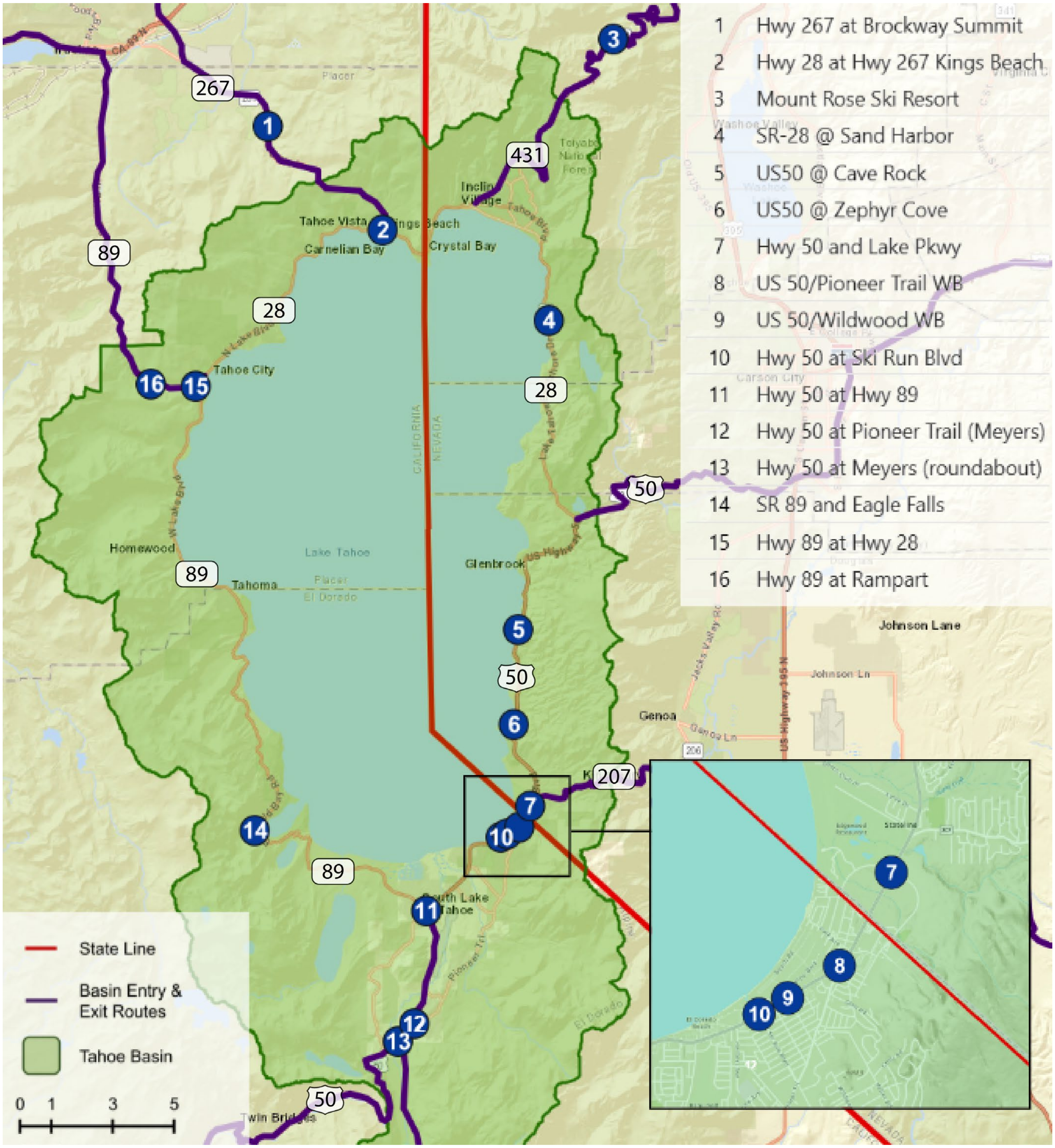


Figure 1: Stage 1 Pilot Sensor Deployment Locations in the Lake Tahoe Basin

Issues To Be Addressed

Current Issues to be addressed include:

1. Lack of Reliable Data for Planning and Operations: The region lacks the infrastructure to provide accurate real-time and historical traffic, safety, and congestion data. Existing "big data" sources have been met with skepticism by decision-makers and the public due to concerns about accuracy and consistency. A reliable and transparent data foundation is needed to support planning, operations, and performance measurement.
2. Managing Heavy, Seasonal Travel Demand: Expanding roadway capacity in the Basin is not feasible due to right-of-way constraints. To improve mobility and safety, investments must focus on multimodal approaches — enhancing public transit, active transportation, and optimizing existing paved areas. Innovative technology solutions are critical for managing peak seasonal demand.
3. Safety for All Road Users: Accessing federal lands with congested access, limited parking, and unsafe conditions on rural highways create risks for pedestrians, bicyclists, and motorists. Illegal parking and unsafe crossing behaviors are common near recreation areas and in town centers. Data is needed to identify high-conflict areas, problem intersections, and near misses to inform targeted safety improvements for vulnerable roadway users (VRUs).
4. Advanced Mobility Analytics and First Responder Support: Current safety analysis is reactive, relying on historical crash data that may take months to become available. AI video analytics can detect emerging trends in real time, allowing proactive interventions that improve safety and efficiency. First responders can also use this data to target efforts, such as wrong-way driving, speeding, and unsafe pedestrian crossings, to focus limited resources more effectively.

Evacuation traffic during the Caldor Fire in 2021; *the fire burned roughly 10,000 acres in the Lake Tahoe Basin.*

5. Parking and Traveler Information: While parking management was not included within the scope of this project, the deployment of AI-powered sensors and cloud-based analytics establishes a data foundation that can support such systems in the future. By capturing real-time traffic volumes and travel patterns at key recreation access points, the system can provide insights into parking demand and congestion, informing future strategies and real-time information for travelers.
6. Mode Shift: Integrating multimodal data feeds, including transit and parking, into an open platform will enable a holistic view of Basin-wide mobility. Public-facing tools can help travelers compare driving, transit, bicycling, or multimodal options, supporting mode shift, and reducing congestion.

7. Emergency Management and Resiliency: The region is highly vulnerable to wildfires and extreme weather events. Though the region has made significant progress in fuels management, AI Sensors, dynamic message signs with real-time information, advance warnings, and integrated data platforms can enhance agency coordination, improve emergency response efficiency, and support safe and effective evacuation of residents and visitors during critical events.

The Technologies Being Deployed

The Intelligent Sensor Integration on Rural Multi-Modal System project leverages a suite of innovative, cloud-based and AI-driven technologies to modernize data collection and enhance transportation safety and planning in the Lake Tahoe Basin. The Stage 1 deployment focused on multimodal data collection and open-data integration, aligning with the SMART grant deployment categories as described below:

- Intelligent Sensor-Based Infrastructure: The project deploys AI-powered video sensors at multiple locations throughout the Lake Tahoe Basin to capture multimodal traffic activity, including vehicle counts and movements, pedestrian movements, bicyclist volumes, travel speeds, and roadway safety events. These sensors operate in four different technical configurations:
    - AI Edge Processing (Fixed): Video feeds are analyzed directly in the field using AI processors connected through commercial cellular networks. This configuration was used at two transit bus shelter locations along Highway 50 in South Lake Tahoe, (see Figure 2). Additionally, the mobile trailer utilized a cellular network at one location: Hwy 50 and Lake Parkway.
    - AI Edge Processing (Mobile Trailer): Video streams are analyzed directly in the field using AI processors connected through a commercial satellite network at two temporary locations (see Figure 3) and cellular communications at one location.
    - AI Centralized Server Processing: Video feeds from eight locations are transmitted to an AI server located at the California Department of Transportation's (Caltrans) Traffic Management Center (TMC), where advanced analytics extract multimodal data (see Figure 4).
    - AI Cloud Processing: Video feeds from three Nevada Department of Transportation's (NDOT) camera locations were analyzed using cloud-based machine learning platforms for scalable data extraction (see Figure 5).
- Cloud-Based Data Management and Analytics: All collected data is aggregated in a secure, cloud-hosted platform for storage, processing, and integration. The system uses Microsoft Fabric with

Cabinet assembly: *AI Edge Processing and AI Mobile Edge Processing, includes a wireless 4G/5G router, AI edge processor unit, and web-managed power strip.*

Power BI visualization tools to enable real-time dashboards, analytics, and reporting. This infrastructure supports data sharing across agencies and lays the foundation for integration with additional datasets such as transit, parking and origin and destination data in future stages.

- Systems Integration and Open Data portal: The project emphasizes interoperability and accessibility by developing an online open-data portal, Tahoe Open Data, in collaboration with the TRPA. Tahoe Open Data is an existing resource familiar to stakeholders. The new Transportation Patterns page provides authenticated access for partner agencies to visualize, download, and analyze multimodal traffic and safety data. Future expansions will allow integration with additional data streams, such as transit operations and parking information, origin and destination, creating a holistic view of transportation system performance.
- Resiliency Considerations: The Intelligent Sensor Integration on Rural Multi-Modal System project is designed to support resiliency goals in the Lake Tahoe Basin, consistent with the SMART grant program objectives.
  - Equal Accessibility Considerations: Transportation challenges in the Basin disproportionately affect underserved and disadvantaged populations, including residents who rely on public transit, seasonal workers, and visitors without access to private vehicles. By improving the accuracy, consistency, and availability of multimodal data, this project provides a foundation for planning investments that expand equitable access to jobs, education, health care, and recreation. The system's open-data platform ensures that agencies and community stakeholders have transparent access to information, building trust and enabling inclusive decision-making. Future integration with transit and parking data will further enhance mobility options for transit-dependent users.
  - Resiliency Considerations: The region faces significant risks from wildfires and extreme weather. The AI-powered sensor network and integrated data platform contribute to resiliency by:
    - Improving situational awareness for agencies during peak congestion, weather disruptions, or emergencies.
    - Providing real-time multimodal data to support coordinated evacuation strategies and emergency response.
    - Improving travel demand management to reduce congestion.

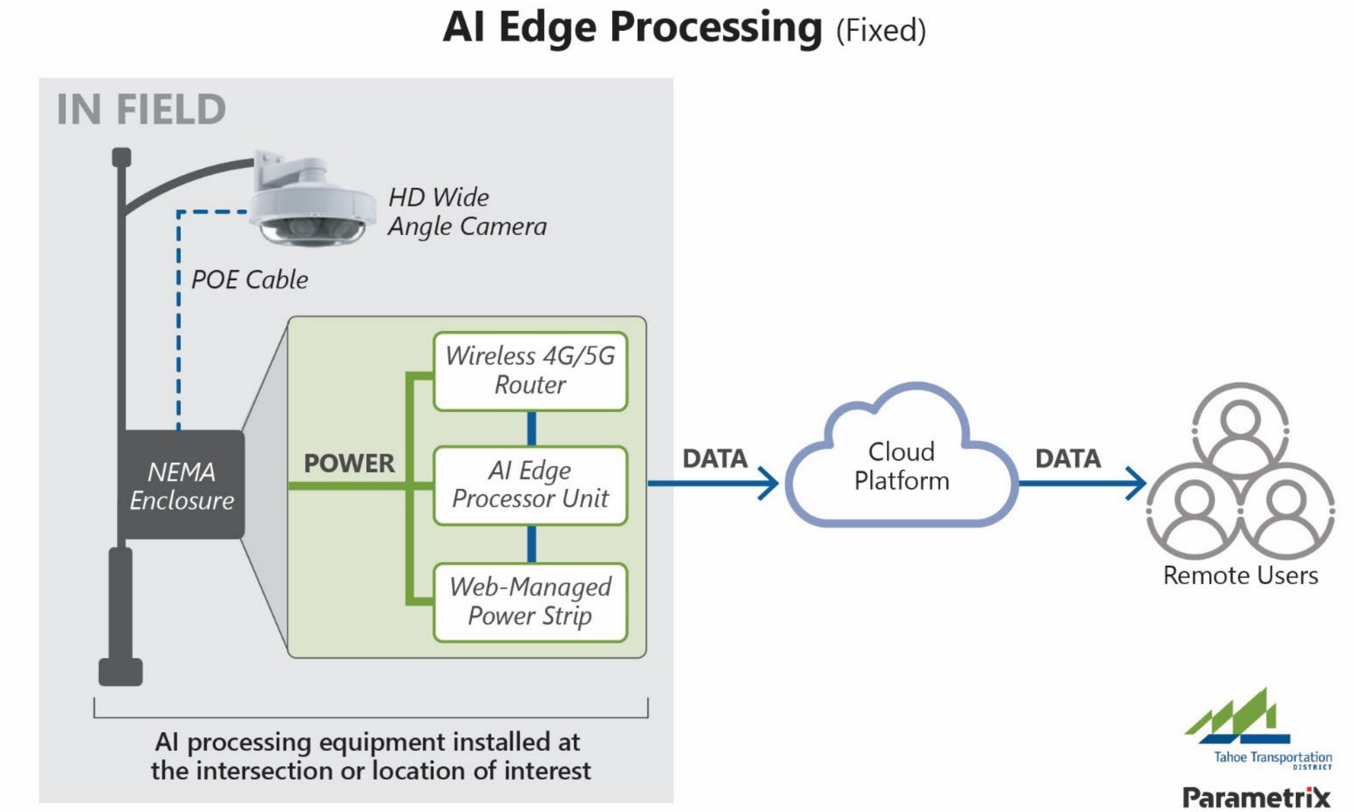


Figure 2: AI Edge Processing (Fixed) Schematic

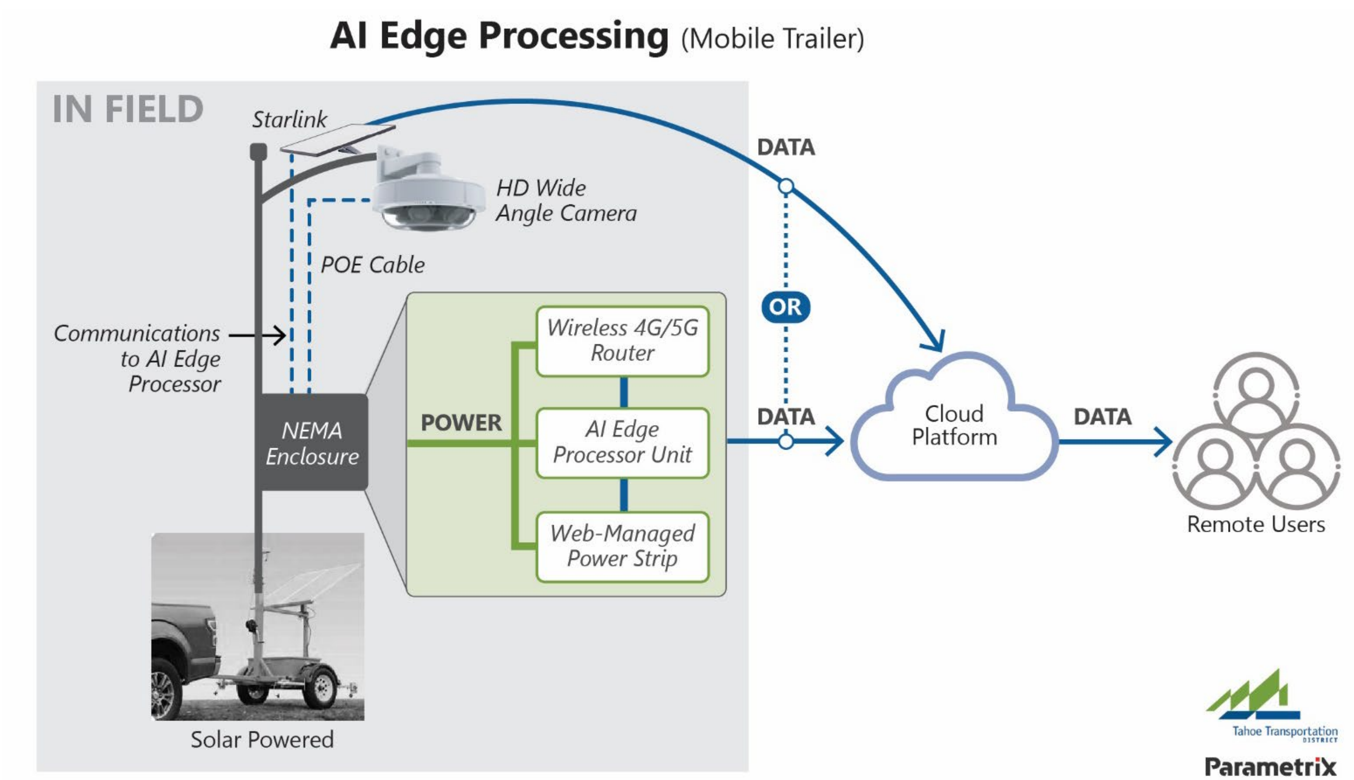


Figure 3: AI Edge Processing (Mobile Trailer) Schematic

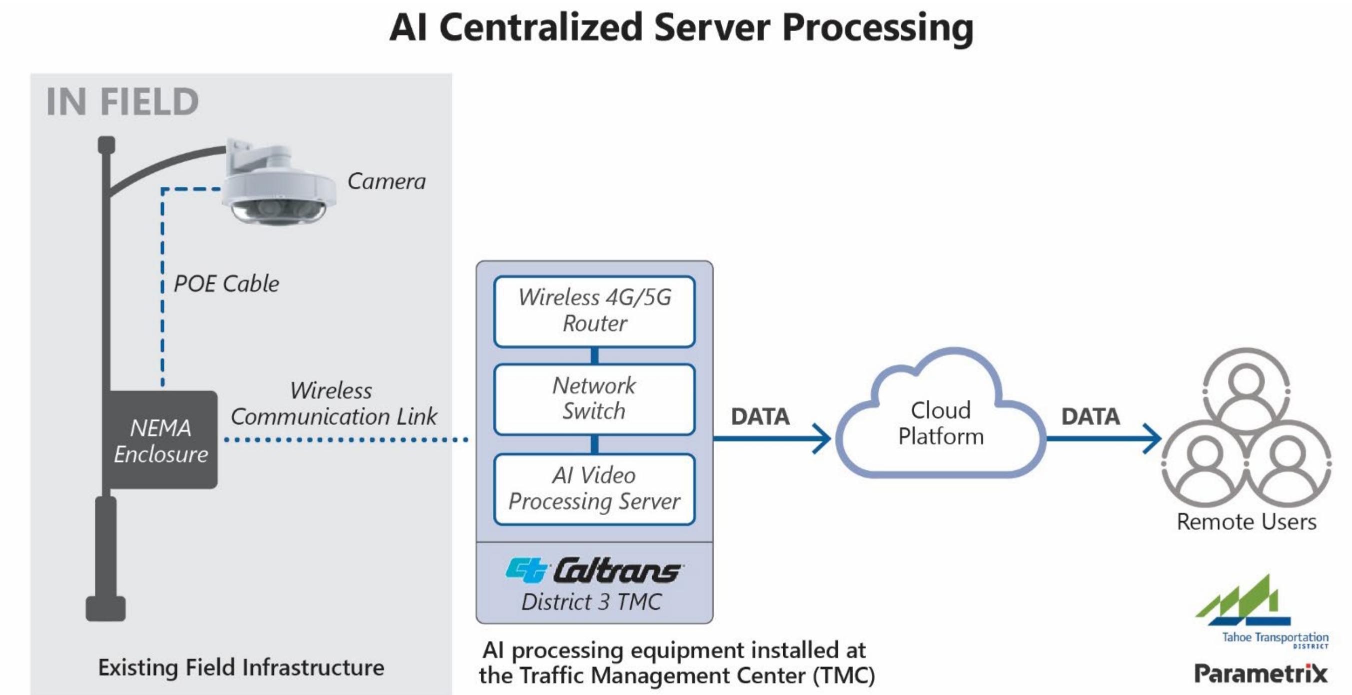


Figure 4: AI Centralized Server Processing Schematic

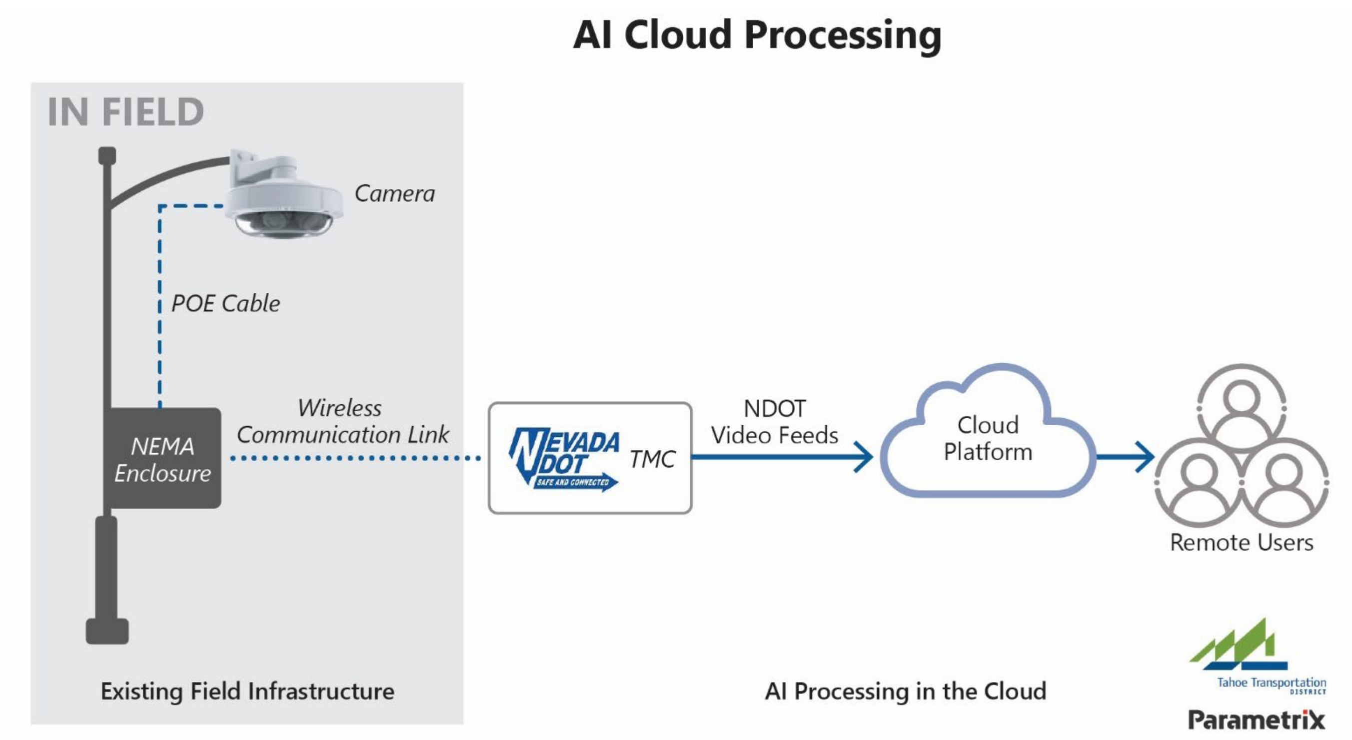


Figure 5: AI Cloud Processing Schematic

Project Team And Stakeholders

The project team is comprised of TTD and TRPA staff. TTD is the grant recipient and the Stage 1 project manager. TRPA is the Metropolitan Planning Organization for the Lake Tahoe Basin. Caltrans and NDOT are project partners and end users. TTD also received support from several local agencies for coordination and installation requirements. These agencies are also anticipated to be end users of the completed system. Table 1 below lists roles and responsibilities of project stakeholders that are engaged in this project.

Table 1: Project Stakeholder List

PROJECT STAKEHOLDERS		
Organization	**Role**	**Responsibilities**
TTD	▪ Project management ▪ Stakeholders and community outreach	▪ Project management ▪ Stage 1 grant compliance and reporting ▪ Stakeholder engagement ▪ Community outreach/Project visibility ▪ RFP solicitation and contracting for consultant and vendor services ▪ Environmental documentation ▪ Prepare implementation reports
TRPA	▪ Data management, Regional Transportation Planning	▪ Data management ▪ Transportation planning analytics ▪ Open data portal
Caltrans	▪ Project partner ▪ Owner of traffic cameras ▪ Project end user	▪ Provide project support/coordination ▪ Participate in all project meetings ▪ Assist during field deployments ▪ Provide technical support ▪ Provide feedback on dashboard and performance metrics ▪ Implement mitigation measures
NDOT	▪ Project partner ▪ Owner of traffic cameras ▪ Project end user	▪ Provide project support/coordination ▪ Participate in all project meetings ▪ Assist during field deployments ▪ Provide technical support ▪ Provide feedback on dashboard and performance metrics
California Highway Patrol (CHP)	▪ Project support / Safety partner	▪ Provide feedback on safety insights (e.g., wrong-way driving), and support interagency coordination.
Nevada Highway Patrol (NHP)	▪ Project support / Safety partner	▪ Review safety data from Nevada sites and participate in cross-jurisdictional safety planning.
City of South Lake Tahoe, CA	▪ Project support ▪ Project end user	▪ Provide project support/coordination ▪ Assist during field deployments
Douglas County, NV	▪ Project support ▪ Project end user	▪ Provide project support/coordination ▪ Assist during field deployments
Carson City, NV	▪ Project support ▪ Project end user	▪ Provide project support/coordination ▪ Assist during field deployments
Placer County, CA	▪ Project support ▪ Project end user	▪ Provide project support/coordination ▪ Assist during field deployments
El Dorado County, CA	▪ Project support ▪ Project end user	▪ Provide project support/coordination ▪ Assist during field deployments

PROJECT STAKEHOLDERS		
Organization	**Role**	**Responsibilities**
Washoe Tribe	▪ Project support ▪ Project end user	▪ Provide project consultation.
Parametrix, Inc.	▪ Professional consultancy and data	▪ Project management ▪ Community outreach support ▪ Stakeholders outreach support ▪ Project planning and system engineering support services ▪ Provide technical assistance during field deployments and evaluation performance period ▪ Data development and integration ▪ Evaluation project and performance measures
Derq	▪ Technology and data services	▪ Provide hardware and software equipment and technical support

Stage 1 Deployment

Through close coordination with project partners, TTD identified multiple sites across the Lake Tahoe Basin to pilot and evaluate advanced data collection platforms (Figure 6).

Extensive engagement with stakeholders ensured that equipment was placed at locations most valuable for testing and aligned with program goals. Regular coordination meetings with partner agencies were established. Multiple interagency draft agreements are in various stages of execution pending Stage 2 implementation.

Deployment in the Lake Tahoe Basin presented significant challenges due to the region's mountainous topography, limited right-of-way space, and constrained infrastructure in recreation and summit zones. Many sites lacked reliable power supply and communications access, requiring creative deployment solutions and the use of mobile or solar-powered systems. These factors underscored the importance of developing resilient, low-footprint technologies that can operate effectively in remote and challenging areas.

As part of this collaboration, technical solutions were explored and system engineering reports, including detailed system requirements, were developed and tailored with each participating agency. To avoid costly infrastructure upgrades and lengthy permitting processes with state DOTs during phase 1, alternative deployment approaches were pursued. This provided the added benefit of testing several data collection and analysis methods, allowing comparison of benefits, challenges, and scalability.

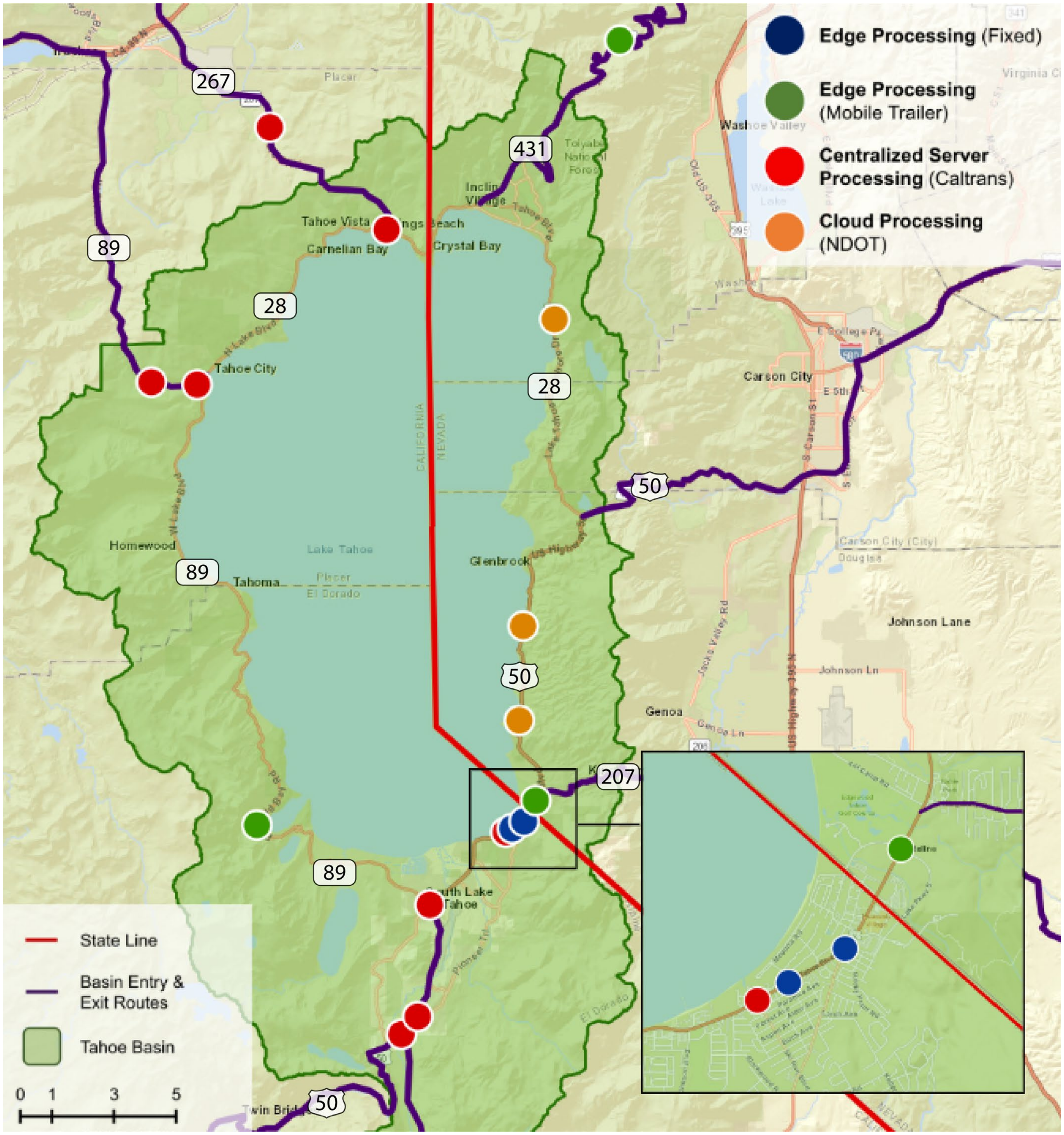


Figure 6: Project Locations

Deployments and Evaluations

Stage 1 tested four distinct technological configurations to assess effectiveness from both technical and operations/maintenance perspectives:

1. AI Edge Processing (Fixed): Deployment of field-based AI Sensors with AI-powered edge devices,

transmitting processed data via commercial cellular networks.

2. AI Edge Processing (Mobile Trailer): Temporary deployment of field-based AI Sensors on a solar-powered mobile trailer equipped with AI edge processing devices. The system transmitted processed data using either cellular or satellite communications, one site operated on cellular connectivity, while two sites utilized satellite.
3. AI Centralized Server Processing: Deployment of an AI video server at the Caltrans TMC, ingesting video streams from existing roadway cameras. Data was analyzed with AI techniques and transmitted to a cloud-based solution (eight locations).
4. AI Cloud Processing: Analysis of NDOT video streams in a cloud environment with multimodal traffic and safety data collected and stored online (three locations).

The edge processing configurations, both satellite- and cellular-based, were equipped with a web-managed power distribution unit (PDU) that allowed the vendor to remotely access, monitor, and reboot the field equipment when needed. This feature proved critical for maintaining uptime and minimizing on-site maintenance requirements, particularly at remote or difficult-to-access locations. The ability to remotely manage system power and network connections provided additional resilience against temporary communication disruptions and ensured faster system recovery following outages.

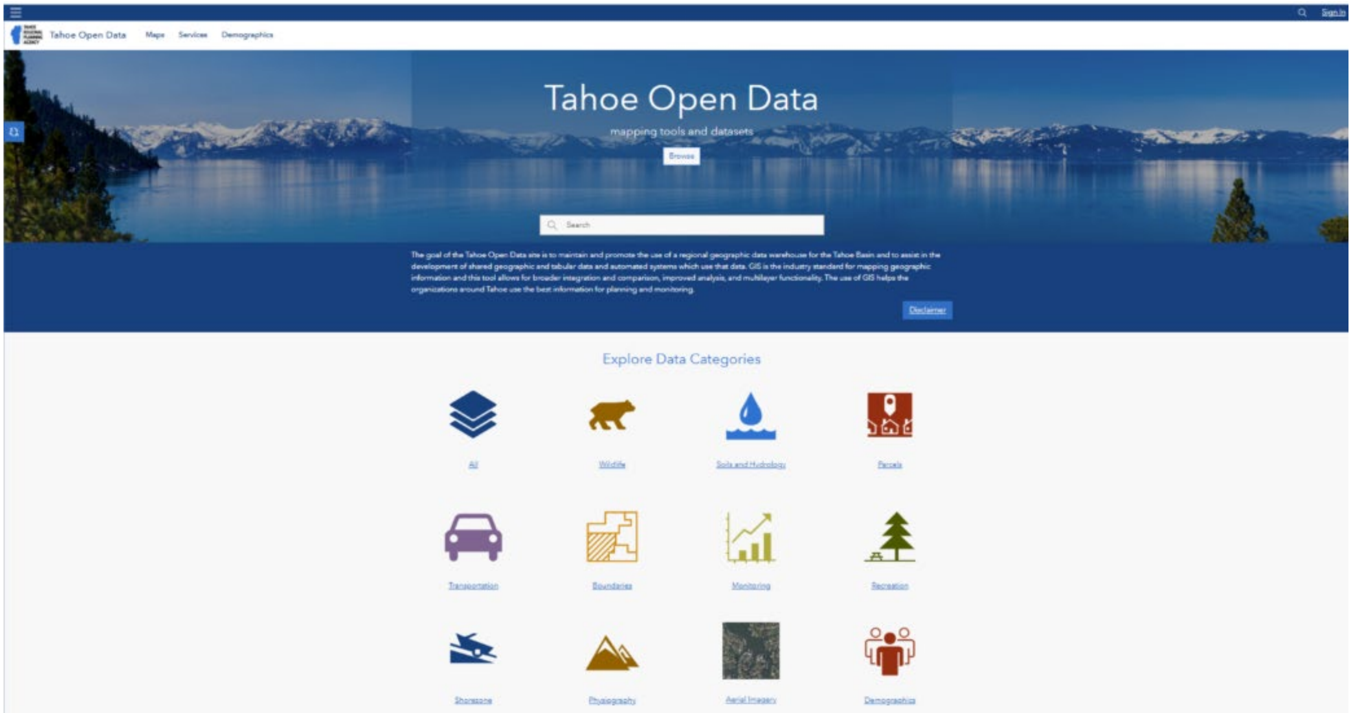
These configurations also provided valuable insight into operational performance, cost-effectiveness, and long-term reliability under varied site conditions and communication environments. The comparison between the two setups demonstrated that edge systems with integrated power and network management capabilities can operate autonomously for extended periods, while maintaining consistent data collection and performance reporting across both cellular and satellite links. These configurations provided valuable insight into performance, cost-effectiveness, and reliability under different site and communication conditions.

Online Data Platform

As part of Stage 1, TRPA began developing an online data platform to make multimodal traffic and safety data collected from the AI Sensor system publicly accessible through the Tahoe Open Data portal. Tahoe Open Data serves as a regional geographic data warehouse for the Tahoe Basin that shares publicly accessible data, maps, and interactive apps. The site includes a wide range of data from authoritative sources, including transportation, wildlife, soils and hydrology, parcels, shore zone, recreation, and demographics data.

By leveraging this trusted and widely used platform, TRPA ensured that the new system was built on a strong foundation. In addition to its broad use and credibility in Tahoe, a benefit to Tahoe Open Data is that the SMART grant data is housed with contextual data to provide a bigger picture on transportation patterns. For example, users can view safety insights from the SMART cameras and authoritative crash data in the same location to understand the short-term and long-term trends for a particular location.

TRPA data staff established a direct application programming interface (API) connection to the vendor's cloud environment, allowing validated datasets, such as vehicle counts, speeds, and safety events, to be automatically imported, stored, and updated. The system enables regional partners, researchers, and the public to explore and download current and historical traffic and safety information in an open, transparent format. This effort advances TRPA's broader goal of promoting data-driven decision-making, regional collaboration, and public access to transportation system insights across the Lake Tahoe Basin.



Tahoe Open Data Website

Stage 1 Project Activities Milestones

The following Figure 7 provides an overview of the key milestone activities completed.

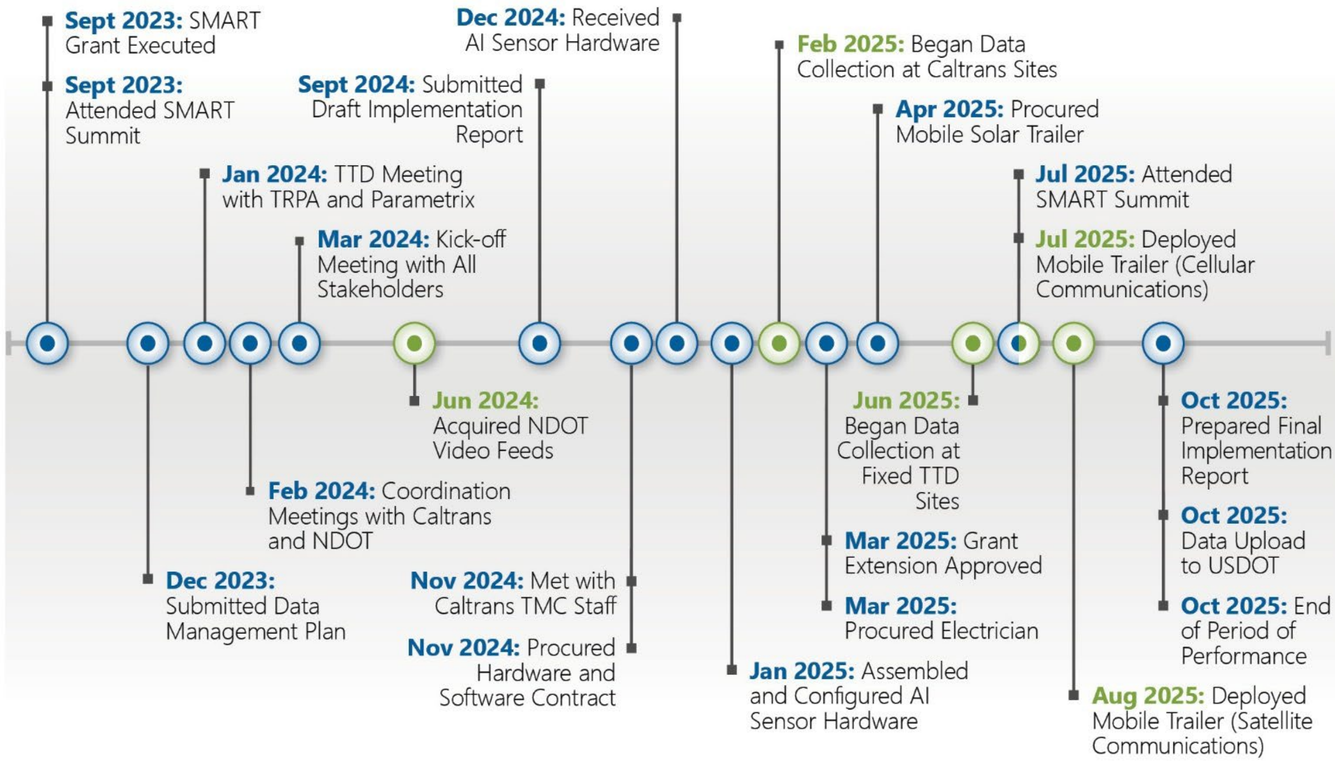


Figure 7: Project Key Activities and Milestones Timeline

Stage 2 Deployment (At Scale Implementation)

Stage 2 Scope

The Stage 2 deployment will build on the successful proof-of-concept completed in Stage 1 by scaling AI-powered and cloud-based technologies across the entire Lake Tahoe Basin. This phase will significantly expand system coverage, integrate multimodal data, and strengthen interagency coordination, delivering measurable safety, mobility, and resiliency benefits across the regional transportation network.

Implementation of Stage 2 is anticipated to occur over a three-year period. Upon completion, TTD and project partners will operate a permanent AI sensing and information network across the Basin (see Figure 8). Collectively, these technologies will generate continuous multimodal data and analytics to support planning, operations, and traveler information services.

The Stage 2 implementation will include:

- AI Sensors Stations: Deployment of 21 stations at critical intersections and highway locations to capture multimodal traffic volumes, speeds, near misses, and other roadway safety events.
- Pedestrian Crossings with AI Detection: Installation of 10 AI-enabled pedestrian detection systems at mid-block crossings to provide automated safety alerts and activate warning beacons for drivers.
- Dynamic Traveler Information Signs: Placement of seven dynamic message signs at strategic corridors to provide real-time traveler information on traffic, travel times, and parking availability.
- Data Integration, Warehousing, and Analytics: TTD, in partnership with TRPA, will continue to expand the Transportation Patterns page on Tahoe Open Data. Data will continue to be aggregated into a secure, cloud-based platform and made accessible through APIs and dashboards. The Tahoe Open Data platform summarizes key performance, safety, and multimodal mobility metrics, offering valuable insights for regional planners, operators, partner agencies, and the general public.

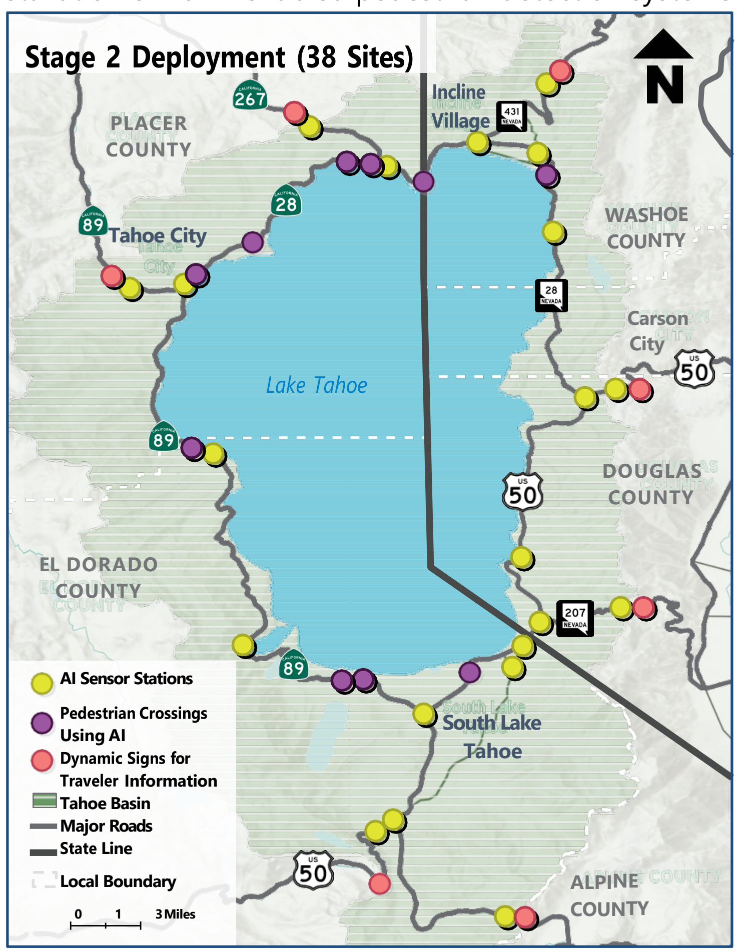


Figure 8: Proposed Stage 2 Deployment Locations

Goals and Desired Outcomes

The Stage 2 deployment is expected to deliver measurable outcomes across safety, mobility, and resiliency, supporting the statutory goals of the SMART grant program. By expanding coverage to 21 AI video data stations, 10 AI-enabled pedestrian crossings, and seven dynamic traveler information signs, the system will generate new insights and improve real-time decision-making for agencies and the traveling public.

The project also addresses the unique challenges of implementing an ITS in a rural, high-altitude environment with limited broadband connectivity, constrained power infrastructure, and narrow right-of-way corridors. Many locations within the Tahoe Basin, particularly recreation areas and summit zones, currently lack access to continuous power or communications networks, making this deployment a model for advancing rural ITS solutions in remote and challenging areas.

Anticipated outcomes, which along with statutory language, include:

- *Reduce Congestion and Delays for Commerce and the Traveling Public (I):* Dynamic message signs will deliver real-time travel information, helping visitors and residents adjust routes, prepare for parking availability, and avoid bottlenecks. Agencies will use AI-generated data to manage traffic flow during peak periods, reducing delays for commerce, recreation, and commuters.
- *Improve Safety and Integration of Transportation Facilities and Systems for Pedestrians, Bicyclists, and the Broader Traveling Public (II):* AI video sensor stations will provide continuous detection of multimodal traffic, near misses, speeding, and wrong-way driving. Eventually, AI-enabled pedestrian crossings will automatically activate beacons when pedestrians are detected, reducing crash risk at unsignalized crossings and improving safety for vulnerable users.
- *Improve Access to Jobs, Education, and Essential Services, including Health Care (III):* By improving the reliability of multimodal data, the project supports planning investments that will make transit and active transportation more viable, improving access for residents, seasonal workers, and disadvantaged populations. Camera sensor placement will consider essential services such as schools, medical centers, and other points of interest to improve travel options.
- *Connect and Expand Access for Underserved or Disadvantaged Populations and Reduce Transportation Costs (IV):* Transparent, open-data tools provide agencies and community partners with equitable access to information, enabling more inclusive decisions that address historically underserved groups in the Basin.
- *Contribute to Promote Medium- and Long-Term Economic Competitiveness (V):* Improved traffic operations, reduced delays, and safer corridors will enhance the region's tourism-based economy and strengthen workforce mobility.
- *Improve Reliability of Existing Transportation Facilities and Systems (VI):* Continuous multimodal monitoring enables more predictable operations, informs roadway maintenance needs, and provides situational awareness during peak demand periods and during extreme weather events. The project also strengthens reliability in areas where traditional ITS infrastructure is limited by power availability, broadband access, and challenging topography.
- *Promote Connectivity Between and Among Connected Vehicles, Roadway Infrastructure, Pedestrians, Bicyclists, the Public, and Transportation Systems (VII):* Data will be shared via Tahoe

Open Data, the cloud-based open platform, ensuring interoperability across Caltrans, NDOT, TRPA, and local jurisdictions. The open-data platform lays the foundation for future integration with transit operations, parking management, and connected vehicle applications, creating a comprehensive multimodal management system. In a region with minimal existing communications infrastructure, this open-data network creates a foundational step toward establishing ITS connectivity in rural and mountainous areas.

- *Incentivize Public-Private Investments or Partnerships, Including Working with Mobile and Fixed Telecommunication Service Providers, to the Extent Practicable (VIII):* The project engages private technology vendors providing AI Sensors, cloud services, and analytics platforms, demonstrating scalable public-private collaboration in support of long-term deployment.
- *Improve Energy Efficiency and Reduce Pollution (IX):* The AI Sensors will be used to provide real-time travel and parking information to travelers well in advance so they can make decisions about alternative modes or changes to their destination prior to becoming part of the congestion problem. By reducing congestion and supporting mode shift the project will help improve travel in the Basin.
- *Increase the Resiliency of the Transportation Systems (X):* Real-time multimodal data enhances preparedness and response during wildfires, severe weather, and other emergencies, improving coordination among agencies, and ensuring safer evacuation. The system's ability to operate in low-power and limited-connectivity environments supports year-round resiliency in remote mountain summits and recreation zones.
- *Improve Emergency Response (XI):* Enhanced situational awareness supports emergency responders in prioritizing limited resources and improving response times during high-demand or emergency conditions.

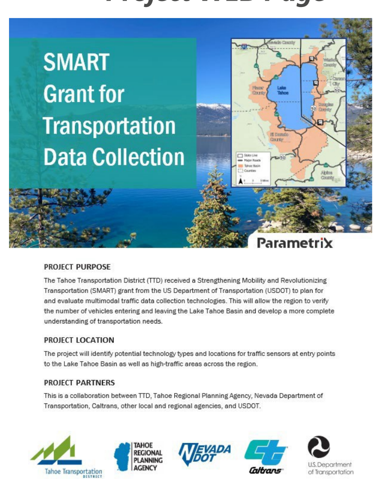
Project Visibility

TTD and its partners have actively promoted the SMART grant project through events, outreach, and publications. Since the initial award announcement, the project has gained significant visibility across multiple channels, showcasing its progress and importance to the Lake Tahoe region.

The following is a list of project visibility:

1. Dedicated Project Webpage Established: A [TTD SMART Grant for Traffic Data Collection webpage]() provides public information about the SMART project, including its purpose, partners, and status.
2. TTD has taken advantage of several opportunities to promote and celebrate the SMART grant award received for Stage 1 through media alerts and social media.
3. Announcement at 2024 Lake Tahoe Summit: The project was formally announced by former U.S. Secretary of Transportation Pete Buttigieg during the 28th Annual Lake Tahoe Summit on August 14, 2024. Continued

Project WEB Page



updates were provided to both California and Nevada legislative staff.

U.S. Secretary of Transportation Pete Buttigieg speaking at the 2024 Lake Tahoe Summit

"Congratulations on an almost $2 million award... for technology to analyze visitor travel patterns and deploy strategies to reduce congestion, particularly in emergencies. We are proud to support you in your work on resiliency in this community.

4. Regular Updates to TTD Leadership: SMART grant progress is routinely presented to TTD's Regional Transit and Capital Program Committee and the Board of Directors.

5. Community and Planning Engagement: A project status update was shared with the Tahoe Transportation Implementation Collaborative on May 6, 2025.

6. Safety Planning Forum Presentation: TTD staff presented project insights to the Nevada Strategic Highway Safety Plan Vulnerable Road Users Taskforce on June 12, 2025.

7. Solar Trailer Deployment Highlight: On July 2, 2025, TTD posted stories showcasing the solar-powered sensor trailer deployment on its external communication channels.

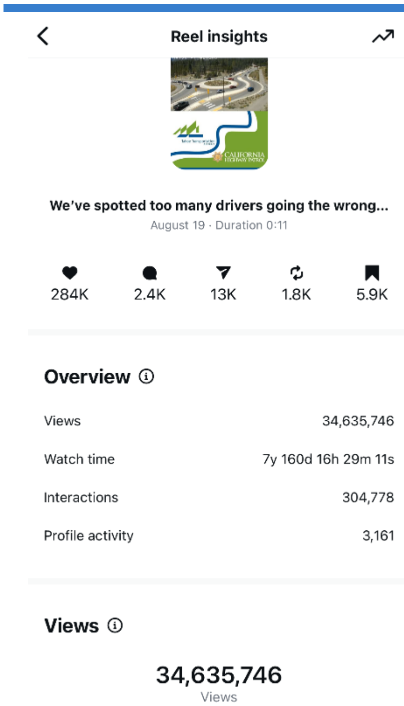
8. 2025 Tahoe Summit Highlight: The project was featured during the Lake Tahoe Summit Transportation Roundtable on August 5, 2025.

9. Senator Rosen Transportation Tour: The SMART project was also highlighted during Senator Rosen's Transportation Tour on August 6, 2025.

10. September Tahoe Transportation E-news: Collecting Traffic Data Around the Lake (September 29, 2025).

11. Participation in SMART Summit, Washington D.C. – TTD staff attended the 2025 SMART Summit in Washington, D.C., where the project was introduced to national peers.

12. Social Media Reach: A social media public safety announcement (PSA) post featuring the Hwy 50 and State Route (SR) 89 roundabout in Meyers, with CHP as collaborators, generated 34.6 million views, 284,000 likes, 13,000 shares, 1,800 reposts, and 2,400 comments. The post was also picked up by a transportation influencer, which increased its reach and effectiveness. Two follow-up posts were used to provide additional education and discuss the mitigation efforts put in place by Caltrans and CHP to increase safety in the roundabout.



Meyers roundabout PSA

13. October 2025- Shared press release, with the League to Save Lake Tahoe and Tahoe Fund, showcasing the Emerald Bay Shuttle Pilot, which included vehicle counts and safety event data collected with the mobile trailer and satellite (SR 89 and Eagle Falls).

14. Conference Exposure – The project was shared with peer transportation agencies at the CalACT Fall 2025 Conference.

15. The project will be promoted in the fall 2025 edition of Tahoe In Depth – a biannual publication for the Tahoe Basin.

Part 3: Proof-of-Concept or Evaluation Findings

The Stage 1 deployment of the Intelligent Sensor Integration on Rural Multi-Modal System project served as a proof-of-concept to validate the performance and feasibility of cloud-based AI-powered sensor systems in rural/remote areas with limited to no infrastructure. These technologies were tested to determine their potential for improving safety, efficiency, and accessibility across regional deployment. The findings discussed below are informed by the performance metrics identified in the Data Evaluation Plan and reflect both the strengths and limitations of the prototype system.

Performance Metrics and Data Collected

The proof-of-concept was evaluated using a series of performance metrics developed to align with the project goals and SMART grant program objectives, as outlined in Tables 2 and 3.

Table 2 below lists the project's performance measures by SMART grant Program Benefit Area, providing qualitative description of anticipated at-scale impacts and identifying historical data sources used to inform this evaluation.

Table 3 defines the specific quantitative performance targets established to measure progress towards these goals.

Table 2: Qualitative Description by Program Benefit Area

MEASURE	QUALITATIVE DESCRIPTION	HISTORICAL DATA AVAILABLE
Safety and Reliability	AI-powered sensors capture multimodal traffic volumes, speeds, near misses, and wrong-way driving. Pedestrian detection systems provide real-time safety alerts at crossings, improving safety for VRU. Continuous monitoring also improves reliability of travel-time data for system management.	Crash and injury records from Caltrans, NDOT, and local law enforcement; historic speed studies and limited congestion monitoring data.
Resiliency	Real-time traffic and safety data improves situational awareness during wildfires, winter storms, and peak congestion. Use of satellite communications ensures reliable data transmission where cellular coverage is limited, strengthening emergency response and evacuation planning.	Historic weather-related closures, wildfire evacuation records, and traffic incident logs from Caltrans, NDOT, and local agencies.

MEASURE	QUALITATIVE DESCRIPTION	HISTORICAL DATA AVAILABLE
Access	Open-data platform provides transparent access to multimodal information, supporting planning for underserved populations, seasonal workers, and residents without private vehicles. Integration with real time transit information will enhance service planning and improve access to jobs and essential services.	Census data on disadvantaged populations; existing TRPA/TTD ridership reports; regional travel behavior studies. Annual Unmet Needs Analysis.
Integration	AI-powered sensors capture multimodal traffic volumes, speeds, near misses, and wrong-way driving. Pedestrian detection systems provide real-time safety alerts at crossings, improving safety for vulnerable road users. Continuous monitoring also improves reliability of travel-time data for system management.	Crash and injury records from Caltrans, NDOT, and local law enforcement; historic speed studies and limited congestion monitoring data.

Table 3: Evaluation Performance Measures and Methodology

Evaluation Question	Performance Metric	Target
Does the AI smart sensing solution detect, classify, and count multimodal traffic and safety data?	Accurate multimodal traffic data collection	94% accuracy for all multimodal traffic data (detection, classification, counts)
Is the solution capable of collecting multimodal traffic and safety data 24x7x365 (real-time)?	24x7x365 multimodal traffic data	Accurate (per measure 1) real-time data collection
Does the solution provide multimodal speed data?	Collect and store multimodal speed data	Accurate (per measure 1) real-time data collection
Does the solution provide online data storage and central management capabilities?	Online data storage and management	An online database management and reporting system with 98% availability
Does the solution include a front end for data filtering, selection, graphing, visualization, reporting, analytics, and data download?	Data presentation, analytics, and reporting features	Multimodal safety presentation and analytics portal

Approach

To evaluate the performance of the AI-powered analytics system, four distinct configurations and processing configurations across multiple sites in the Lake Tahoe Basin were tested during Stage 1:

- Edge Processing (Cellular): Video streams analyzed directly in the field using AI processors connected through commercial cellular networks.
- Edge Processing (Satellite): Video streams analyzed in the field with AI processors connected via Starlink satellite communications to overcome limited cellular coverage in remote areas and as a mobile system setup.
- Centralized Server Processing at TMC: Video feeds transmitted to an AI server located at the Caltrans TMC, where advanced analytics extracted multimodal data.
- Cloud Processing (NDOT feeds): Video streams provided by NDOT were processed in a cloud-based machine learning platform for scalable data extraction and storage.
- The evaluation was designed to assess how each configuration performed under varied communications, environmental, and operational conditions. Validation focused on measuring the accuracy, precision, and recall of the system's video analytics across both traffic and safety insights.

Ground Truth Establishment:

To ensure objectivity, ground truth data was established by manually verifying recorded video footage from each configuration type. Teams reviewed hours of video data to independently count vehicles, pedestrians, and bicyclists, and to confirm the presence of safety events such as near misses, speeding incidents, or wrong-way driving. These manual counts were then compared against the system outputs from the vendor platform.

Key Performance Metrics:

- Traffic Insight Accuracy: Correct identification and classification of vehicles, pedestrians, and bicyclists compared to manual counts.
- Safety Insight Precision and Recall: Correct detection and classification of safety-related events, including near misses (vehicle to vehicle and vehicle to VRU), illegal crossings, crashes, stopped vehicles, illegal turning movements, and wrong-way driving, while minimizing false positives or missed detections.
- System Reliability: Assessment of uptime and resilience of each configuration's communications network (cellular, satellite, cable).
- Scalability and Maintainability: Observations of operational ease, maintenance requirements, and suitability of each configuration for permanent deployment.

This structured validation approach allowed the project team to objectively compare the performance of each configuration type, identify strengths and limitations, and provide actionable recommendations for scaling the most effective technologies into Stage 2.

Evaluation Findings

Accurate Multimodal Traffic Data Collection

One of the primary technology objectives in Stage 1 was to evaluate the performance of AI-powered video sensors in capturing accurate multimodal traffic and safety data across a variety of configuration types. The video analytics platform, utilizing both edge-based computing and cloud-hosted dashboards, was deployed to test different configurations of infrastructure and communications.

The four configuration types evaluated were:

1. Edge Units with Cellular Connectivity (fixed sites)
2. Edge Units on Mobile Trailer with Satellite Connectivity (Starlink)
3. NDOT Camera Feeds with Cloud Processing
4. Caltrans Camera Feeds with Processing at their TMC

The system captured vehicle counts, pedestrian activity, near-miss events, wrong-way driving, and vehicle speeds and classifications. To assess accuracy and reliability, ground truth data was manually established through video review at selected intersections and times, providing an objective comparison against AI-detected events.

Key performance metrics assessed included Traffic Insight Accuracy (vehicle and VRU counts), Safety Insight Precision and Recall (detection of near-miss events and violations), and System Reliability (uptime and communications performance across the four configuration types).

While the Evaluation Plan set a module accuracy threshold of 94 percent, Stage 1 did not consistently achieve this target. Accuracy levels generally exceeded 90 percent for the successfully installed edge units using both cellular and satellite connectivity, which is still effective for identifying trends and supporting countermeasures. The shortfall is attributed to factors summarized in the Benefits and Challenges by Configuration Type and Lessons Learned sections, including single-camera placement, reduced nighttime visibility, limited resolution of existing cameras, and intermittent communications at remote sites.

Despite these constraints, the Stage 1 results demonstrate the system's practical value. With planned refinements in Stage 2, including higher-specification cameras, multi-camera coverage, and more resilient communications infrastructure, accuracy performance is expected to consistently meet or exceed the 94 percent target. Stage 2 validation will also include expanded ground truth sampling to confirm improvements in recall, precision, and overall accuracy.

Highlights from the validation of the four configuration types are shown in Table 4 below.

Table 4: Validation of Traffic Insight Accuracy by Configuration Type

Configuration Type	Vehicle Accuracy	VRU Accuracy	Notes
Edge Units with Cellular Connectivity	94.03%	80.09%	Deploying two cameras at selected sites would enhance detection accuracy by improving field-of-view coverage. Fixed site deployments should be at higher heights for better visibility; some connectivity drops due to poor cellular coverage.
Edge Units on Mobile Trailer with Satellite Connectivity	84.75%	Not included in the validation	Recommendation of two cameras to improve accuracy instead of the one camera setup which was beta tested. Vendor equipment was not originally designed for mobile trailer setups, which provided another configuration to test and ultimately proved feasible. Reliable satellite connectivity; flexible site testing.
NDOT Camera Feeds with Cloud Processing	Accuracy was not validated*	Accuracy was not validated*	Limited by poor resolution and communications quality of existing cameras.
Caltrans Camera Feeds with TMC Processing	86.82%	Not included in the validation	Acceptable performance with centralized server, but limited by communications to cameras, existing camera specifications and placement. Pan Tilt and Zoom (PTZ) cameras were frequently repositioned without advance notice (as part of normal Caltrans operations), requiring periodic readjustment of detection zones to maintain accurate analytics. Deploying dedicated two cameras at selected sites would enhance detection accuracy by improving field-of-view coverage.

*Note *: NDOT sites showed sensor capture rates below 90%, so ground truth validation was not performed; low camera specifications and cloud connectivity issues were the primary causes.*

Accurate Multimodal Safety Data

The AI Sensor system captured a variety of safety metrics, including crashes, vehicle and pedestrian near misses, stopping behavior, illegal lane use, and wrong-way driving. To evaluate the accuracy of these detections, a validation exercise was performed using video footage from selected intersections, comparing the system's reported events with manually reviewed ground truth data collected for the same time periods.

For each validation sample, ground truth events were manually identified by reviewing recorded videos. These observed events were then compared to the safety events reported by the AI Sensor dashboard. The comparison was structured around standard performance metrics:

- True Positives (TP): Events correctly identified by the system that matched the ground truth observations.

- False Positives (FP): Events reported by the system, but were not confirmed in the ground truth review.
- False Negatives (FN): Real events observed in the video, but missed by the system.
- Recall (True Positive Rate): The percentage of real events correctly captured (TP ÷ [TP + FN]).
- Precision: The percentage of reported events that were accurate (TP ÷ [TP + FP]).
- Overall Accuracy: A composite measure of correct detections across all observed and reported events.

The results of this validation exercise are summarized in Table 5, which provides counts and percentages for TP, FP, FN, recall, precision, and overall accuracy. This format ensures a transparent assessment of how reliably the AI Sensor system identifies real-world safety events.

Table 5: Validation of Safety Data Reporting

Metric	Count	% of Total Events
True Positives (TP)	139	86.34%
False Positives (FP)	7	4.79%
False Negatives (FN)	22	13.66%
Recall (TP Rate)	—	86.34%
Precision	—	95.21%
Overall Accuracy	—	82.74%

The validation results demonstrate that the AI Sensor system achieved a recall rate of 86.34% and a precision rate of 95.21%, indicating that the majority of real-world safety events were correctly detected and that most reported events were valid. The overall accuracy of 82.74% reflects strong system performance in identifying and classifying safety-related activities, particularly given that only a single camera was used instead of the vendor's recommended two-camera configuration.

The analysis confirmed that the system was highly effective at detecting prominent safety events, such as wrong-way driving and vehicle near misses, while more complex or low-visibility events, such as pedestrians near misses at night or partially obscured incidents, presented greater challenges.

These results verify the system's capability to produce reliable and actionable safety insights that can inform countermeasure planning, and safety monitoring across the Basin. In Stage 2, expanded validation across more sites and conditions will further refine detection algorithms, enhance accuracy, and ensure consistent performance across all roadway environments.

System Detection Limits, Meyers Roundabout Case

On September 21, 2025, a crash occurred at the Meyers roundabout (US 50 at SR 89). While the event was not flagged on the vendor dashboard, TTD was notified by CHP and requested clarification from the vendor.

The vendor's review determined that the crash involved a sudden U-turn by a vehicle, followed by a rear-end collision with a motorcycle. Because "rear-end near misses" and "lane-change interactions" were not part of the deployed safety analytics product, the incident was not classified or displayed on the live dashboard. However, the vendor was able to retrieve and share a post-processed video clip showing the crash dynamics.

In addition, the single-camera setup at this location limited the field of view. The motorcycle was blocked from view when the crash occurred because the rear-ending vehicle obscured it, highlighting the importance of using a minimum of two cameras per intersection for comprehensive coverage.

Key Takeaways:

- The system successfully captured the raw event data, but it was not flagged under the current safety event categories.
- Certain crash types (e.g., rear-end or lane-change collisions) are not yet included in the near-miss and safety analytics modules.
- Single-camera deployment reduced visibility of the incident, preventing full detection of the motorcycle in the crash sequence.
- Vendor support allowed post-processed video recovery and interpretation of the incident, ensuring the event was not lost.

Implications for Stage 2:

- Expand safety analytics to include a broader set of crashes and near-miss scenarios (rear-end, lane-change).
- Deploy at least two cameras per intersection to ensure full field-of-view coverage.
- Clarify with vendors the scope and limits of live dashboard detection categories.
- Establish protocols for cross-verification between reported incidents and sensor analytics to ensure full coverage.

24 X 7 X 365 Multimodal Traffic Data Collection

A key objective of the Stage 1 proof-of-concept was to evaluate the ability of the deployed systems to continuously collect, process, and transmit multimodal traffic data under real-world conditions. The evaluation compared the performance, communications reliability, and operational challenges across the four configurations tested during the project:

1. Edge Processing (Fixed)– Cellular Connectivity
2. Edge Processing – (Mobile Trailer) – Satellite or Cellular Connectivity
3. Centralized Server Processing – Caltrans TMC
4. Cloud Processing – NDOT Camera Feeds

Evaluation Metrics

Two primary metrics provided by the vendor were used to assess system uptime and reliability:

- **Sensor Capture Rate:** The percentage of video frames successfully captured and processed by the system out of every 100 frames in the incoming video stream. This measure reflects both video signal quality and communication stability between the cameras and the processing units.
- **Health and Status Summary:** Indicates the operational connectivity of each sensor over time, aggregated at five-minute intervals. This metric tracked whether a sensor remained connected to its processing unit, either locally (edge units), centrally (Caltrans TMC), or remotely (vendor cloud).

Performance varied across configuration types due to differences in communication architecture and processing location. In edge processing configuration (cellular and satellite), data collection continued even when network connectivity was temporarily lost, as the system stored data locally and uploaded it once connectivity was restored. In contrast, the Caltrans TMC and NDOT cloud setups depended on live video streams, resulting in permanent data loss when connections dropped. Offline periods typically resulted from power outages, communication interruptions, or hardware and cabling issues that affected data transmission.

The sensor capture rate provides an indication of data quality and consistency across configurations. Lower capture rates were linked to degraded cables, limited camera resolution, network instability, and frame loss in live video streams. In the Caltrans and NDOT setups, existing camera specifications and unstable connectivity contributed to intermittent frame drops and reduced performance.

Table 6 summarizes the average Sensor Capture Rate for each configuration type and highlights the primary factors affecting performance.

Table 6: Sensor Capture Rate by Configuration Type

Configuration Type	Average Capture Rate (%)	Notes / Observations
Edge Processing – Fixed with Cellular	100%	Stable capture with minor cellular signal interruptions. Buffered uploads after offline periods.
Edge Processing – Mobile Trailer with Satellite	100%	Reliable capture; buffered uploads after offline periods.
Centralized Processing – Caltrans TMC	92.4%	Some data loss due to video frame drops.
Cloud Processing – NDOT Feeds	93.2%	Reduced performance; impacted by video feed quality and resolution.

The Health and Status Summary, presented in Table 7, provides a comparison of the percentage of time each sensor remained online, as well as how data was handled during offline periods. Edge-based systems, both cellular and satellite, showed the highest resilience, continuing to collect data even during temporary connectivity losses. By contrast, the Caltrans and NDOT setups experienced full data loss during network outages due to their reliance on remote streaming and centralized processing.

Table 7: Sensor Health & Status by Configuration Type

Configuration Type	% of Time Sensor Online	Offline Data Handling	Primary Causes of Downtime
Edge Processing – Fixed with Cellular	99.7%	Data buffered and uploaded when reconnected.	Signal loss or power drop.
Edge Processing – Mobile Trailer with Satellite	100%	Data buffered and uploaded when reconnected.	Weather interference or power issues.
Centralized Processing – Caltrans TMC	100%	Data lost during outages.	Feed loss or network drop.
Cloud Processing – NDOT Feeds	100%	Data lost during outages.	Network latency or low camera resolution.

The continuous 24x7x365 monitoring evaluation confirmed that edge-based configurations provide the most consistent and resilient performance in varied field conditions, particularly in remote or low-connectivity areas. Although the centralized and cloud-based systems offered streamlined integration with existing infrastructure, their dependence on live video feeds made them more vulnerable to temporary communication failures and resulting data loss.

These findings demonstrate that distributed edge processing, supported by redundant cellular and satellite communications, represents the most reliable and adaptable architecture for permanent deployment within the Lake Tahoe Basin.

Collect and Store Multimodal Speed Data

The multimodal speed data collected by the AI-powered sensors has been continuously stored and managed on a secure cloud-based platform. This allows authorized project partners to access the information in real time for presentation, visualization, and further analysis.

TRPA successfully connected to the vendor system through an API, enabling automated integration of the speed datasets into the Tahoe Open Data portal. This connection ensured that validated speed data could be directly queried, downloaded, and used alongside other regional datasets, such as land use, traffic volumes, and safety performance measures.

Through the API integration, TRPA staff were able to:

- Access real-time and historical speed data for multiple deployment sites.
- Filter and analyze data by location, date, and mode (vehicles, buses, bicycles, pedestrians).
- Integrate speed data into ArcGIS dashboards and planning tools, providing planners with actionable insights into congestion patterns and travel-time reliability.
- Automate reporting and visualization, reducing manual data handling and ensuring transparency through public-facing dashboards.

This capability demonstrates the value of open data integration in supporting regional planning. By making sensor data available through TRPA's open platform, agencies and stakeholders can have direct access to multimodal speed insights that were previously unavailable in the Lake Tahoe Basin.

Online Data Storage and Management

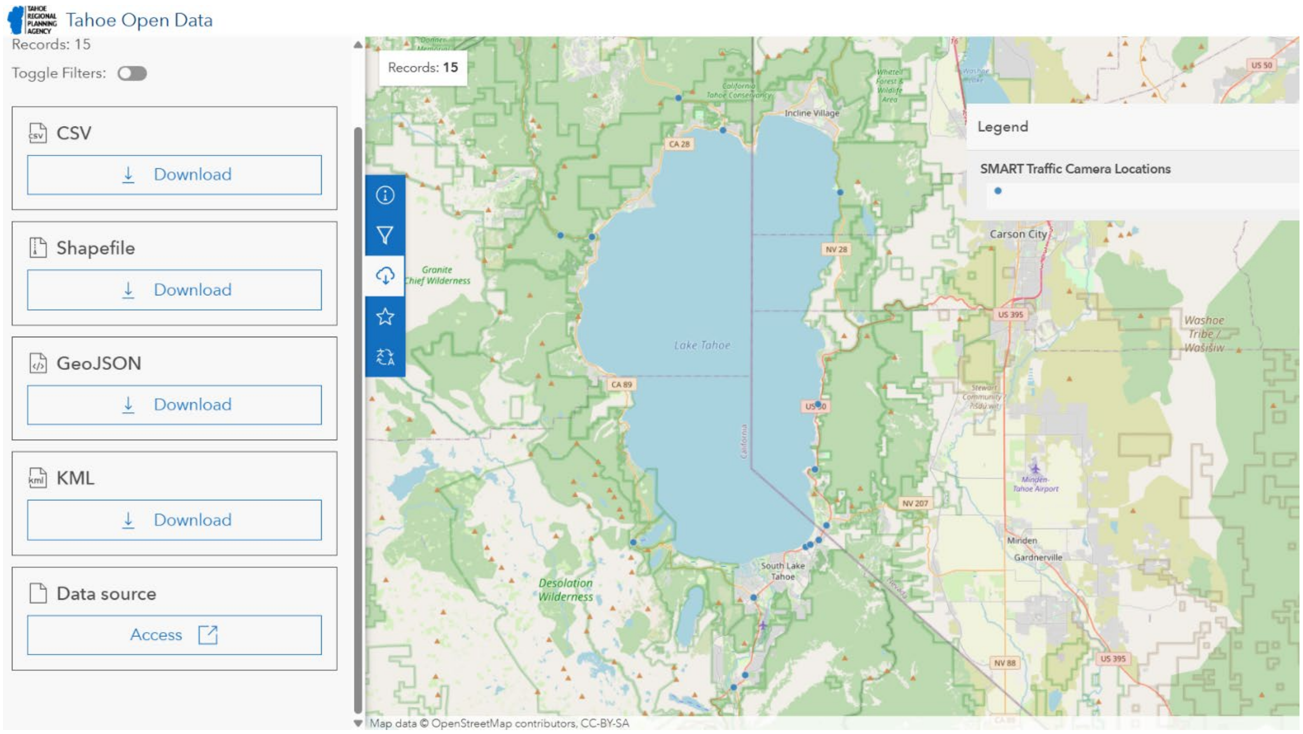
All multimodal traffic and safety data collected during Stage 1 is securely stored in the vendor's cloud environment. The vendor platform provides a web-based interface that allows authorized users to access the data in real time. Users can filter the data by mode, data type, and time period, enabling quick visualization of trends, such as vehicle volumes, pedestrian activity, near-miss events, and speeds.

To enhance transparency and ensure long-term availability, TRPA implemented an automated API connection between the vendor's cloud platform and the Tahoe Open Data portal. This integration allows raw and processed datasets to be automatically pulled from the cloud platform and downloaded into TRPA's Tahoe Open Data portal. Once published, the data becomes publicly accessible through TRPA's open data website, where users can filter, download, and visualize multimodal information alongside other regional datasets.

This dual-platform approach offers several advantages:

- Vendor Cloud Platform: Supports real-time monitoring, partner access, and system performance evaluation.
- TRPA Open Data portal: Provides a public-facing repository that ensures open access, fosters regional collaboration, and allows the data to be integrated with TRPA's planning and GIS tools.
- Automated Data Flow: API connections minimize manual handling, reduce error potential, and streamline reporting workflows.

Together, these platforms create a transparent, accessible, and sustainable framework for managing transportation and safety data in the Lake Tahoe Basin. They ensure that both project partners (for operations and evaluation) and the general public (for awareness and research) can benefit from the insights generated by the Stage 1 deployment.



Tahoe Open Data Website

Data Presentation, Analytics and Reporting Features

The data collected by the AI Sensors is securely processed, cleaned, and analyzed within the cloud platform. Authorized users can access a secure dashboard where traffic and safety insights are displayed in tabular form. The dashboard supports filtering by location, time, and mode, allowing partners to review detailed counts of vehicles, pedestrians, bicyclists, and safety events, such as near misses or wrong-way driving.

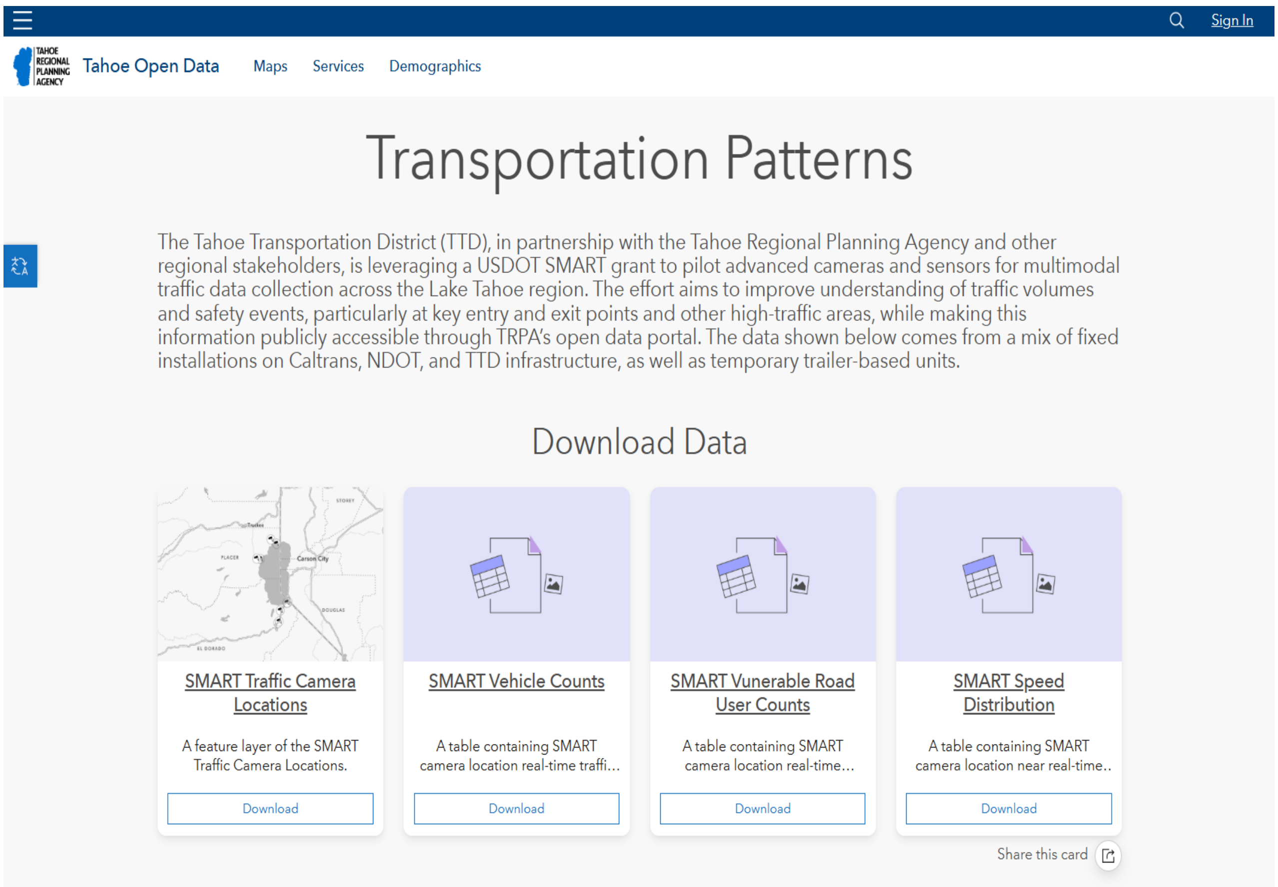
As part of Stage 1, TRPA established a direct API connection to the vendor's dashboard and enabled staff to download raw datasets for local storage, quality control, and independent analysis. This integration ensures that TRPA can preserve validated datasets beyond the vendor environment and publish them through the Tahoe Open Data portal. While the initial focus has been on publishing data in structured tables, TRPA has also developed interactive visualizations that allow agencies, stakeholders, and the public to interpret trends more intuitively.

Looking forward, the project team intends to continue the transition from the current vendor dashboard outputs into the more open and flexible data warehousing and analytics environment the Tahoe Open Data platform provides. Using available tools such as ArcGIS Online and open-source Python libraries, TRPA will enhance the data presentation layers to include more interactive dashboards, charts, and geospatial visualizations. These enhancements will make it easier to:

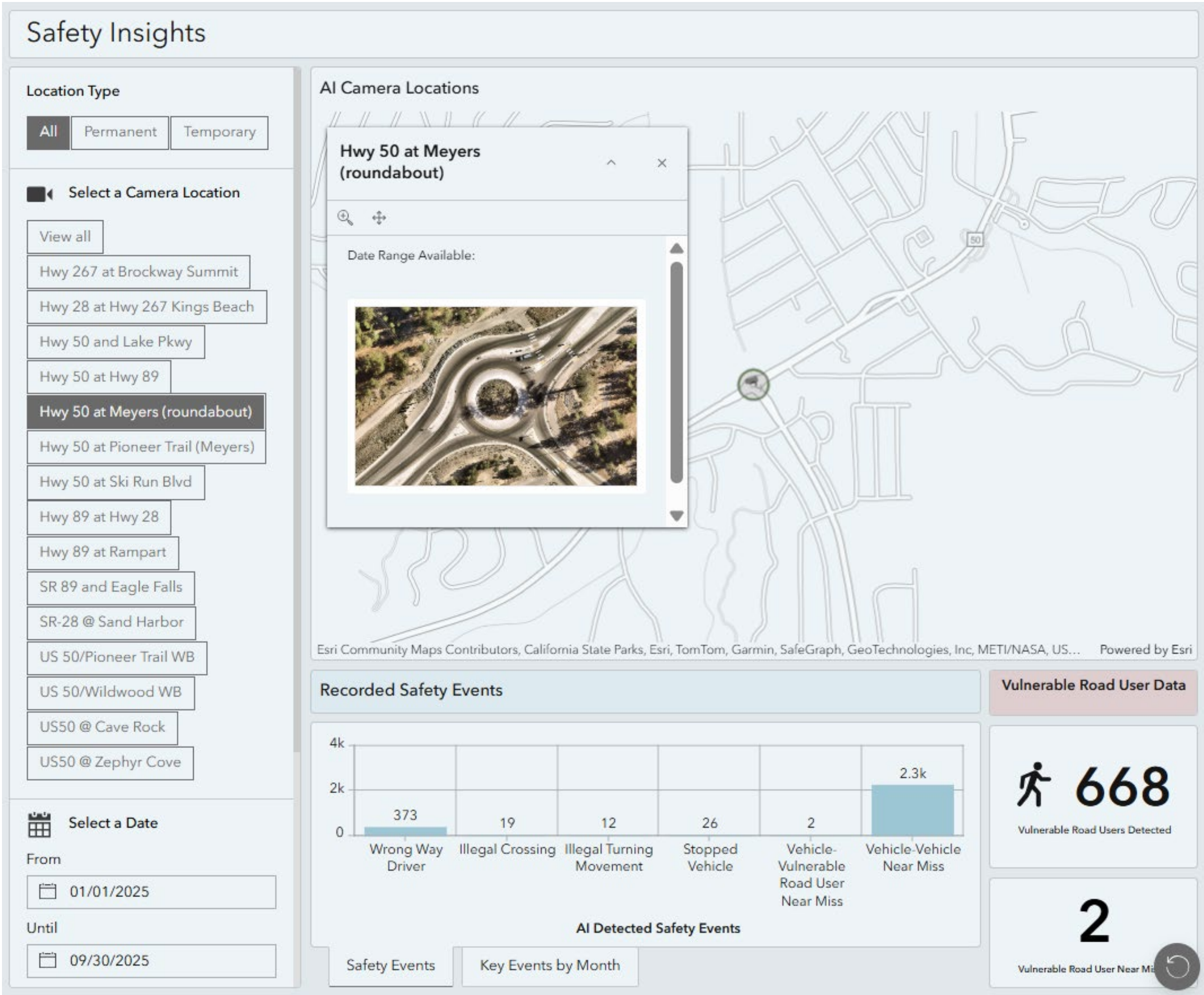
- Compare multimodal travel patterns across corridors, time-periods, and seasons.
- Monitor real-time conditions and identify anomalies through visual alert systems.
- Generate automated performance reports for partner agencies.

- Engage the public through user-friendly dashboards that enhance transparency and build trust.

In Stage 2, this open online platform will be expanded to include additional data sources, such as transit operations, parking availability, and roadway safety countermeasure performance. With proper authentication, project stakeholders will have access to a centralized online data warehouse and presentation dashboards to support regional planning, operational decision-making, and performance monitoring.



Tahoe Open Data Website: *Transportation Patterns*



Tahoe Open Data Website: *Safety Insights*

Traffic Insights

Seasonal Traffic Impact

Location: Hwy 28 at Hwy 267

The AI-powered sensor deployed at the Hwy 28 and Hwy 267 intersection in Kings Beach provided a detailed multimodal profile at one of the primary access points into the Lake Tahoe Basin. By comparing 31 days of off-peak operations (March 1–31) to 31 days during the seasonal peak (August 18–September 17), the system revealed several actionable insights.

<u>Key Findings</u>

- **Overall Growth in Vehicle Volumes**: Passenger vehicle counts increased from 118,087 in March to 157,158 in August (+33%). This underscores the seasonal surge in visitor travel demand into the Basin.

- **Sharp Increase in Motorcycle Activity**: Motorcycle volumes rose from only 25 in March to 316 in August (over 12 times increase). This highlights a strong recreational component in peak-season travel that is often missed in traditional counts.
- **Growth in Freight Movements**:
  - Articulated trucks grew from 564 to 1,462 (+159%).
  - Single unit trucks rose from 1,319 to 2,274 (+72%).
  - This suggests heavier freight and delivery activity during the visitor season, reflecting both supply needs and goods movement tied to tourism demand.
- **Bus and Shuttle activity**: Bus (transit, shuttles and tour bus) counts increased from 726 in March to 1,148 in August (+58%), reflecting higher activity from both public transit and private tour or shuttle services during peak periods and supporting the case for coordinated seasonal operations.
- **Dramatic Increase in Active Modes**: Bicycle crossings increased from 19 in March to 448 in August (over 23 times) at the Hwy 28 / Hwy 267 intersection in Kings Beach. This shows that cycling activity at Kings Beach is highly seasonal, aligning with summer recreation patterns and reinforcing the need for safe multimodal facilities.

Implications for Planning and Operations

- **Seasonal Demand Management:** The data confirms the magnitude of seasonal variation at this key access point, supporting targeted demand management strategies and seasonal traffic operations planning.
- **Freight and Visitor Interface**: The increase in truck volumes during visitor peaks underscores the importance of balancing freight needs with recreational travel demand, particularly along constrained corridors.
- **Transit Investment**: Evidence of higher seasonal bus ridership justifies planning for expanded peak service and better multimodal integration at the Hwy 28 / Hwy 267 intersection in Kings Beach.
- **Active Transportation Infrastructure**: The sharp increase in bicycle volumes highlights the importance of prioritizing safe facilities for cyclists, especially during high-volume visitor seasons.

High Volume Intersection Traffic Insights

Location: Hwy 50 and Lake Parkway

The intersection of US 50 and Lake Parkway, located in the Stateline NV corridor, in a town center, is one of the busiest and most critical intersections in the Lake Tahoe Basin. This fully signalized four-leg intersection serves as a key gateway between California and Nevada, accommodating a diverse mix of local, commuter, commercial, and visitor traffic. Its proximity to major hotels, resorts, casinos, a 5,000-person event center, and recreational areas results in high travel demand across all modes.

The AI-powered mobile trailer was deployed at this intersection for 10 days, from Monday, July 3, 2025 through Sunday, July 13, 2025, capturing multimodal traffic data. The system automatically classified traffic by vehicle type, as shown in the table below. The configuration was calibrated for the first four days, resulting in seven days of data.

Table 8: Traffic Counts by Vehicle Type (7/7/2025 – 7/13/2025)

Date	Passenger Vehicle	Motorcycle	Articulated Truck	Single Unit Truck	Bus	Bicycle
Mon-7/7/2025	31,245	141	210	594	102	43
Tue-7/8/2025	26,707	106	214	570	133	32
Wed-7/9/2025	25,589	94	157	508	193	29
Thu-7/10/2025	34,343	124	190	628	338	73
Fri-7/11/2025	37,737	135	186	656	396	76
Sat-7/12/2025	37,677	275	40	411	352	77
Sun-7/13/2025	33,767	185	60	446	350	51

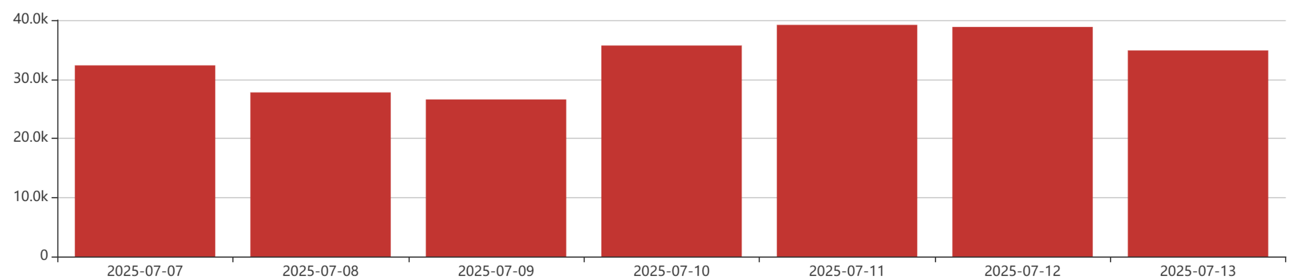


Figure 9 Weekday Variation of Total Traffic – US 50 at Lake Parkway

The following are key insights and observations:

- High Traffic Volumes: Total vehicle volumes ranged from about 25,500 to 37,700 per day, with the highest volumes on Friday and Saturday.
- Weekday versus Weekend Patterns: Traffic increased by roughly 40 percent later in the week, reflecting visitor travel demand.
- Vehicle Mix: Passenger vehicles made up over 95 percent of all traffic, with trucks and buses accounting for the rest.
- Motorcycles and Bicycles: Motorcycle counts peaked on Saturday (275), while bicycle crossings also rose toward the weekend.
- Bus Activity: Bus counts grew from 102 on Monday to 396 on Friday, showing increased shuttle and transit activity.

This dataset demonstrates the value of AI-enabled, short-duration multimodal monitoring for understanding travel patterns at critical intersections. Unlike traditional manual counts, the continuous classification data provides high-resolution insights for congestion management, signal timing, and multimodal planning. It also reveals tourism-driven traffic surges that inform parking, transit, and demand management strategies, supporting both real-time operations and long-term planning for the Lake Tahoe Basin.

Testing Satellite Functionality and Extreme Weather

Location: Mount Rose Summit

The solar trailer was deployed near the summit of Mount Rose, NV to test satellite functionality under more extreme weather conditions. At nearly 9,000 feet, Mount Rose is the highest all-season pass in the Sierra Nevada mountain range. TTD intends to partner with NDOT to install permanent sensor infrastructure on nearby facilities. Positioning the trailer at this location provided valuable insight into potential challenges for a future permanent installation. Vehicle counts were the primary objective of this deployment.

AI Sensor detecting pedestrian activity in snow and low visibility conditions

The system was deployed at this location and collected data between October 9, 2025 and October 15, 2025. The first snowstorm of the season occurred on October 14, 2025 leaving five inches of snow, which provided an opportunity to test the system during severe weather and low visibility conditions.

Key findings Include:

- The system successfully collected vehicle data; noting a considerable drop on the snow day (October 14, 2025).
- AI Sensor was able to detect pedestrian activity in snow and low visibility conditions
- AI Sensor was able to detect wrong way driving in snow and low visibility conditions

AI Sensor detecting wrong way driving in snow and low visibility conditions

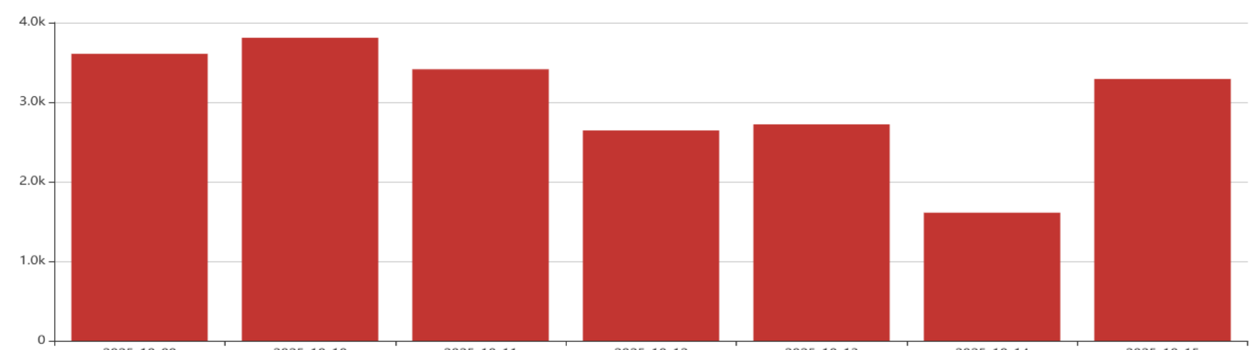


Figure 10 Weekday Variation of Total Traffic – Mount Rose Summit

Safety Insights

The AI Sensor system proved valuable in identifying and addressing critical safety issues at high-risk intersections. Continuous video analytics and real-time data processing enabled detection of high-precision safety violations, including frequent pedestrian near misses, speeding incidents, and wrong-way driving events. These insights informed targeted countermeasures designed to improve both pedestrian and vehicular safety around the Basin.

Wrong-Way Driving and Countermeasures

Location: Highway 50/State Route 89 Roundabout

One of the most significant Stage 1 findings was the high frequency of wrong way driving violations at the Highway 50/State Route 89 roundabout in Meyers, CA, where 103 incidents were recorded between February 20, 2025 and May 9, 2025. This led to a collaborative meeting on May 22, 2025, between TTD, TRPA, Caltrans, CHP, and El Dorado County to review sensor videos and identify mitigation strategies. Caltrans had restriped the roundabout in early May as part of their seasonal maintenance, which resulted in a decline in the number of safety incidents identified on the cloud-based platform. In response to the meeting, they updated signage, which further contributed to the decline in wrong-way events. El Dorado County committed to applying the same signage approach at a new roundabout under construction less than a mile away, extending the safety benefits and providing continuity along the transportation corridor. This is incredibly valuable in a rural area with limited resources supporting high influxes of visitation.

AI Sensor detection of wrong way driving

Roundabout after Signage improvement

SR 89 at Eagle Falls – Safety and Operational Insights

In the summer of 2025, TTD along with several other partner agencies, conducted the Emerald Bay Shuttle Pilot project in the popular recreation area. The pilot included parking barriers to prevent dangerous shoulder parking, a roadway safety audit conducted by Caltrans, and shuttle that provided an alternative to driving. To complement this effort, TTD staged the mobile solar trailer between August 20 and September 22, 2025, along SR 89 at the entrance to the Eagle Falls trailhead parking lot. This intersection provided valuable observations over the monitoring period. This location is a curved segment of SR 89 with an access road to the Eagle Falls parking lot that serves as a popular trail access point. There are no marked pedestrian crossings on SR 89 or on the parking lot access road. The speed limit at this location is 40 mph.

Solar trailer located at Eagle Falls (Emerald Bay)

Key findings include:

- High Pedestrian Activity: 20,513 pedestrians over 32 days (641 per day) were recorded crossing SR 89, all at unmarked locations and within the radius of the curve due to the absence of designated crosswalks.
- Pedestrian Safety Risks: Eight near-miss events between vehicles and VRUs were detected, highlighting elevated conflict risk in an area with substantial pedestrian demand.
- Vehicle Maneuvers: 759 "wrong-way" driving events were initially flagged by the system. After video review, these were determined to be vehicles performing U-turns in the middle of SR 89 or vehicles crossing the double yellow line to go around traffic. The U-turns reflect a substantial demand for turning movements in an area with no nearby intersections to accommodate them.

Implications:

- The data suggests that this intersection requires geometric improvements to better serve both pedestrians and motorists. The Caltrans road safety audit conducted in summer 2025 recommended a protected pedestrian crossing, or pedestrian signal at Eagle Falls, as well as the removal of shoulder parking on the lakeside to allow for a pedestrian path.

Overall Impact of AI Sensors on Safety Strategy

Although before-and-after data periods remain limited and occasional gaps occurred due to site-specific sensor challenges, AI Sensors has clearly demonstrated its value in enhancing roadway safety. By revealing real-time safety challenges, prioritizing high-risk intersections, and enabling data-driven countermeasure design, AI Sensors provided actionable intelligence that directly supported infrastructure improvements.

An integral part of this approach was the development of an online data integration and warehousing platform managed in partnership with TRPA. This system allowed multimodal safety and traffic insights to be shared across agencies, supported public-facing transparency through TahoeOpenData.org, and established a scalable framework for ongoing evaluation. These early Stage 1 efforts have already delivered tangible safety benefits and are expected to yield broader, measurable improvements across the Basin as the system expands in Stage 2.

Evaluation Against Original Project Goals

The Stage 1 implementation met or exceeded seven of the project's original goals from the grant proposal:

Table 9: Evaluation of Stage 1 Outcomes Against Project Goals

Goal from Grant Proposal	Evaluation Summary
Improve roadway data accuracy, consistency, and accessibility for planning and operations	Stage 1 successfully deployed AI-powered sensors at fixed and mobile sites, demonstrating reliable multimodal traffic counts, speed data, and safety event detection. An open-data platform, Tahoe Open Data – Transportation Patterns, was developed with TRPA, accessible to planners, operators, and the public.
Enhance safety for all road users, particularly vulnerable users such as pedestrians and bicyclists	Continuous video analytics identified pedestrian near misses, speeding, and over 100 wrong-way driving violations at a key roundabout. Findings led to restriping, and new signage installation, directly improving roadway safety.
Reduce congestion by supporting mode shift to transit and active modes	Stage 1 established multimodal data integration and traveler information foundations. These will support future mode shift strategies in Stage 2.
Improve congestion management and travel-time reliability	Real-time traffic monitoring provided insights into seasonal peaks and congestion hotspots. Dynamic information capabilities were piloted and will be expanded in Stage 2 to support congestion mitigation.
Expand equitable access to jobs, education, and services, particularly for underserved populations	The open-data platform increased transparency and accessibility of multimodal information. Five cameras are located in Community Priority Zones, which are regionally defined disadvantaged communities within the Lake Tahoe Basin. Collecting safety insights and traffic count data in these communities supports planning.
Increase communication resiliency and improve coordination for emergency response and evacuation	Deployment of satellite connectivity (i.e., Starlink) addressed cellular coverage gaps at rural sites, enhancing communications resiliency. Real-time monitoring improved situational awareness during severe weather and emergencies.
Support long-term economic competitiveness in a recreation-based regional economy	By improving data for safety, congestion, and mobility planning, Stage 1 provided tools to enhance the visitor experience and workforce reliability, supporting Tahoe's tourism-based economy.

Statutory Outcomes Demonstrated During Stage 1

The Stage 1 deployment supports key national priorities, demonstrating improvements in the statutory areas listed below with the potential for broader regional and national benefits:

- Reduce Congestion and Delays for Commerce and the Traveling Public (**I**): Real-time traffic data provided insight into seasonal peaks, bottlenecks, and circulation patterns. These insights will enable agencies to better manage congestion and inform demand management strategies. The Stage 1 technology successfully counted vehicles and identified congestion and seasonal peaks.

This information can be used in the TRPA Lake Tahoe Resilience Improvement Plan and Regional Emergency Communications and Transportation Strategy.

- Improve Safety and Integration of Transportation Facilities and Systems for Pedestrians, Bicyclists, and the Broader Traveling Public (**II**): AI analytics enabled real-time detection of wrong-way driving, near misses, and pedestrian risk areas, directly supporting safety initiatives such as intersection improvements and pedestrian crossing enhancements.
- Improve Access to Jobs, Education, and Essential Services, Including Health Care (**III**): Multimodal data highlighted travel challenges faced by commerce/freight, emergency response, residents, workers, and visitors. Many of the cameras are located at entrance points into the Lake Tahoe Basin and the vehicle counts collected by the AI Sensors were validated by the consultants. This information can be used to inform the TRPA Transportation Systems Management & Operational Plans, which aims to use multimodal transportation strategies and technologies to maximize network efficiency, safety, and reliability, while emphasizing optimization of existing infrastructure over expansion – a critical consideration given the Tahoe region's goal of making more effective use of existing transportation modes.
- Connect or Expand Access for Underserved or Disadvantaged Populations and Reduce Transportation Costs (**IV**): Open-data tools demonstrated the ability to share multimodal insights with regional partners, improving planning capacity for disadvantaged populations. Five cameras are located in Community Priority Zones, which are regionally defined disadvantaged communities within the Lake Tahoe Basin. These cameras are US 50/89, US 50 at Ski Run, US 50/Wildwood WB, US 50/Pioneer Trail WB, and Hwy 28 at Hwy 267. Collecting safety insights and traffic count data in these disadvantaged communities supports planning capacity. Especially the VRU counts and near misses, as these communities have higher concentrations of people without vehicles, seniors, people with disabilities.
- Contribute to Medium and Long-Term Economic Competitiveness (**V**): By providing reliable data on traffic and visitor travel patterns, Stage 1 supported planning efforts that improve workforce mobility and enhance the visitor experience are crucial to Tahoe's tourism economy.
- Improve the Reliability of Existing Transportation Facilities and Systems (**VI**): Continuous monitoring of roadway and travel conditions demonstrated the value of real-time analytics for improving system performance and reliability, especially during peak demand and weather disruptions.
- Promote Connectivity between and among Connected Vehicles, Roadway Infrastructure, Pedestrians, Bicyclists, the Public, and Transportation Systems (**VII**): Stage 1 integrated feeds from roadway video sensors with cloud analytics establishes a foundation for linking multimodal data sources, including transit and parking, in Stage 2.
- Incentivize Private Sector Investments or Partnerships, Including Working with Mobile and Fixed Telecommunication Service Providers to the Extent Practicable (**VIII**): Collaboration with vendors demonstrated the value of cloud-based analytics and strong public-private partnerships that can be scaled for broader deployments. The collaboration with the vendor in Stage 1 expanded their typical configuration to use a mobile trailer with satellite communications.

- Improve Energy Efficiency (**IX**): The Stage 1 deployment demonstrated the capability to generate multimodal traffic and safety data that could support such evaluations in Stage 2. Future integration with travel demand and traveler information applications will be necessary to quantify benefits in this area.
- Increase the Resiliency of the Transportation System (**X**): The deployment of Starlink satellite connectivity proved effective in overcoming limited cellular coverage in rural areas, enhancing resiliency during emergencies and environmental disruptions.
- Improve Emergency Response (**XI**): Real-time traffic and safety data provided new situational awareness tools that can support emergency responders in prioritizing resources and improving response during wildfire events, winter storms, or other emergencies.

December 29, 2021 Nevada Governor Sisolak declared a State of Emergency; NDOT turned away traffic trying to enter Lake Tahoe due to dangerous road conditions and oncoming storms.

Benefits and Challenges by Configuration Type

Table 10 below summarizes the benefits and challenges observed across the four installation and processing configurations tested during Stage 1, including Edge Processing (cellular and satellite), Centralized Server Processing at the Caltrans TMC, and Cloud Processing of NDOT feeds.

Table 10: Benefits and Challenges by Configuration Type

Configuration Type	Benefits	Challenges
Edge Processing – Cellular, (Fixed sites and Mobile Trailer)	• Local processing reduces latency. • Less reliance on central infrastructure. • Works well in areas with strong cellular coverage.	• Connectivity drops in weak coverage zones. • Equipment at roadside shelters vulnerable to vandalism/graffiti. • Higher maintenance burden for distributed edge units.
Edge Processing – Satellite (Starlink, Mobile Trailer)	• Reliable connectivity in rural/remote sites without cellular service. • Mobile trailer allows flexible testing at multiple sites. • Demonstrated strong performance during field validation.	• Requires careful setup of detection zones for line-of-sight and weather resilience. • Power supply logistics for mobile/remote sites. • Higher subscription/operating costs.
Centralized Server Processing – Caltrans TMC	• Leverages existing camera infrastructure and fiber	• Dependent on quality/ placement of existing cameras;

Configuration Type	Benefits	Challenges
	backbone. • Centralized processing reduces field equipment needs. • Easier for partner agencies to monitor/manage data.	all locations were limited to one camera. • Some cameras not optimized for AI analytics (frame rate, resolution). • Requires coordination with Caltrans IT/ops staff. • Requires good communications infrastructure.
Cloud Processing – NDOT Feeds	• Scalable platform for multiple locations. • Reduces need for new roadside hardware. • Rapid deployment where video feeds exist.	• Poor video quality and frequent communication drops. • Existing cameras not suitable for AI validation. • Limited ability to conduct ground-truthing; only sensor health metrics available.

Key Findings and Lessons from Stage 1

The Stage 1 proof-of-concept validated the effectiveness, scalability, and real-world applicability of AI-powered sensor technologies in the Lake Tahoe Basin. The deployment demonstrated that these systems could enhance roadway safety, improve multimodal traffic monitoring, and support data-driven decision-making for future smart infrastructure investments.

The following is a summary of key findings and lessons learned from Stage 1:

- System Performance: Stage 1 confirmed the functionality of AI-based video analytics across multiple configurations (edge, centralized, and cloud). Edge-based systems with cellular and satellite connectivity achieved over 90 percent accuracy and showed the highest reliability in continuous 24x7 data collection.
- Safety Insights: The system detected a wide range of safety events, including near misses and wrong-way driving, with a precision rate exceeding 95 percent. These insights directly supported design countermeasures, such as signage and restriping at high-risk locations.
- Data Integration and Accessibility: The successful API connection with TRPA's Tahoe Open Data portal demonstrated the feasibility of automated data sharing and open-access publication of validated traffic and safety data.
- System Resiliency: Satellite connectivity (Starlink) effectively bridged communication gaps in rural and mountainous areas, improving system uptime and enabling data continuity during network outages.
- Operational Insights: Multimodal counts and speed data provided agencies with detailed visibility into seasonal variations, visitor patterns, and modal behavior that traditional short-duration counts cannot capture.

Lessons Learned:

Improved results in Stage 2 will depend on enhanced camera specifications, multi-camera coverage (minimum of two cameras at each intersection), and optimized placement at intersections to improve visibility and accuracy.

- Future systems should expand the safety analytics modules to include additional crash and near-miss types, such as rear-end and lane-change interactions.
- Speed validation requires access to detailed raw speed data by vehicle type through the vendor API for comprehensive analysis.
- Long-term success depends on strengthening local support capacity, streamlining interagency coordination, and maintaining resilient communications infrastructure across all deployment environments.

These findings position the project for successful regional expansion in Stage 2, advancing a scalable, data-driven approach to multimodal safety and mobility management in the Lake Tahoe Basin.

Part 4: Anticipated Costs and Benefits of At-Scale Implementation

Anticipated Impacts by Key Goal Area

Based on findings from Part 3 and performance results from Stage 1, the following qualitative assessments outline expected impacts from full-scale deployment across the statutory SMART grant goals:

Table 11: Projected Impacts of At-Scale Implementation by SMART Statutory Goal

SMART Statutory Goal	Expected Impact of At-Scale Implementation
(I) Reduce congestion and delays for commerce and the traveling public	Real-time monitoring of traffic entering, exiting, and circulating within the Basin will provide agencies with actionable insights to manage peak demand, reduce bottlenecks, and support visitor mobility. Traveler information tools based on sensor data will help reduce delays for residents, visitors, and commerce-related traffic.
(II) Improve safety and integration of systems for all users	AI Sensors detect near misses, speed trends, and wrong-way driving in real-time. Data-driven safety insights will guide countermeasures for pedestrians, bicyclists, and drivers, improving safety and integration of transportation facilities across jurisdictions.
(III) Improve access to jobs, education, and essential services	More reliable multimodal data will inform investments in transit and active transportation, improving access for Basin residents, seasonal workers, and disadvantaged populations who rely on transit or non-driving modes.
(IV) Expand access for underserved populations and reduce transportation costs	Open-data tools provide transparent information to agencies and community stakeholders, supporting inclusive planning and lowering costs by enabling more efficient use of existing infrastructure rather than costly new road expansion, which is highly unlikely to be approved in the Lake Tahoe Basin.
(V) Contribute to economic competitiveness	Reduced travel delays, safer roadways, and improved visitor experience enhance the competitiveness of the region's tourism-based economy. Better mobility supports workforce reliability and local business vitality.
(VI) Improve system reliability	Continuous multimodal monitoring enables more predictable traffic management. Cloud-based data systems ensure consistent performance and rapid adaptation to changing conditions, reducing downtime and uncertainty.
(VII) Promote connectivity among users and infrastructure	The project's open-data platform integrates multiple agency data streams (Caltrans, NDOT, TRPA, local jurisdictions). It provides the foundation for future integration with transit feeds, parking management, and connected vehicle systems.

(VIII) Incentivize private sector investment	Vendor partnerships for AI Sensors, cloud services, and analytics demonstrate scalable public-private collaboration. The project positions the region to expand partnerships with technology and telecommunications providers.
(IX) Improve energy efficiency	Real-time data supports demand management strategies that reduce congestion, encourage a mode-shift to transit, biking, and walking.
(X) Increase resiliency of the transportation system	Real-time situational awareness during wildfires, severe winter storms, and other hazards improves coordination and response. Starlink satellite communications ensure reliable data transmission in rural areas with poor cellular coverage.
(XI) Improve emergency response	Continuous monitoring provides emergency responders with better situational awareness of traffic volumes and speeds, supporting more efficient resource allocation and safer evacuation during critical events.

Anticipated Costs of At-Scale Implementation

The total estimated cost for full-scale deployment (Stage 2) is based on vendor quotes, operational planning, and lessons learned from the Stage 1 proof-of-concept pilot. A summary of the major cost elements is presented in Table 12, with additional details and cost assumptions provided in Appendix A: Benefits–Cost Analysis.

Table 12: At-Scale Implementation Costs (Stage 2)

Cost Element	Estimated Value
Infrastructure Investments (sensors, edge devices, cloud systems)	$19,480,000
Annual Operations & Maintenance (O&M)	$5,500,000/year (28.2% of capex assumed for tech updates and replacement) *
15-Year Discounted Total Cost (including O&M)	$57,364,131

*Assumes a 15-year analysis period with equipment replacement after seven years; higher annual O&M accounts for technical updates.

Cost-Benefit Comparison

A Benefit-Cost Analysis (BCA) conducted for Stage 2 projects a Benefit-to-Cost Ratio (BCR) of 3.07, indicating that benefits far exceed anticipated costs, over 15 years (the use of 15 years period for the analysis is justified in Appendix A):

Table 13: Summary of Costs and Benefits

BCA Summary	Value
Total Discounted Benefits	$176,312,617
Total Discounted Costs	$57,364,131
Net Benefits	$118,948,486

Major monetized benefits include:

- Approximately $19.6M annually in reduced emergency response fatalities (using Value of Statistical Life methodology)
- Approximately $4.1M annually in time savings for transit riders

Non-monetized benefits include:

- Congestion Reduction Impact: An improved roadways communications network will decrease congestion and enhance safety
- Economic Gains: Long-term benefits include cost savings from reduced travel times, lower vehicle operating costs, and increased productivity. This benefit was not ignored but was not estimated for this analysis.

Preliminary Baseline Data for Evaluation

The following baseline data was collected during Stage 1 to support Stage 2 evaluation:

Table 14: Stage 1 Baseline Data for Evaluating At-Scale Implementation

Metric Area	Baseline Level (Pre-Stage 1)
AI Sensors Safety Violations	Two to five wrong way driving violations observed per day at select locations
AI Sensors System Accuracy	Vehicle counts: 94%, VRU counts 80%, Safety precision: 90%

Part 5: Challenges & Lessons Learned

The Stage 1 implementation revealed a range of technical, institutional, and logistical challenges that provided valuable insights for improving readiness, execution, and scalability in Stage 2. These lessons will help refine procurement practices, strengthen partnerships, and enhance the technology's long-term sustainability and integration within the Lake Tahoe Basin.

Procurement and Budget

- Challenge: Stage 1 experienced delays in developing scopes of work and executing interagency agreements, which impacted the initial deployment schedule.
- Lesson Learned: Early coordination and drafting of procurement documents are essential to maintain momentum.
- Recommendation: Initiate procurement planning immediately upon execution of the grant agreement, with pre-approved templates for RFPs and interagency agreements to streamline contracting in Stage 2.

Partnerships and Coordination

- Challenge: The bi-state nature of the Lake Tahoe Basin introduced complexity in managing multiple jurisdictions, agencies, and regulatory processes.
- Lesson Learned: Strong coordination among TTD, TRPA, Caltrans, NDOT, and local governments was critical to determine locations, permitting, and technical integration.
- Recommendation: Establish formal governance structures and recurring coordination meetings with all partner agencies early in Stage 2 to maintain consistent communication and decision-making.

Technology Suitability and Field Deployment

- Challenge: Deploying technology in a rural, mountainous environment presented significant obstacles, including lack of broadband connectivity, limited power availability, minimal right-of-way space, and exposure to harsh weather conditions.
- Lesson Learned: Satellite connectivity (Starlink) proved effective where cellular service was unavailable and leveraging existing NDOT and Caltrans power sources reduced costs and permitting delays.
- Recommendation: Continue using resilient hybrid communications systems (cellular and satellite) and plan for solar power or battery backup options at off-grid sites.

Camera Performance and Deployment

- Challenge: Single-camera setups limited accuracy for vehicle and VRU detection, particularly at wide intersections and locations without marked crossings or sidewalks.
- Lesson Learned: Using two cameras per intersection improves accuracy and reduces blind spots, particularly under low-light or obstructed conditions.

- Recommendation: Standardize two-camera configurations at key intersections and other locations in Stage 2 to enhance coverage, visibility, and detection reliability.

System Monitoring and Maintenance

- Challenge: Some sites experienced data gaps or delayed uploads due to power interruptions or connectivity loss.
- Lesson Learned: Continuous remote access and real-time system health monitoring are vital for proactive maintenance.
- Recommendation: Implement automated alert systems and maintain web-managed power units for remote troubleshooting and equipment rebooting.

Legal, Policy, and Regulatory Requirements

- Challenge: Navigating permitting and coordination with Caltrans and NDOT extended timelines, though federal requirements such as National Environmental Protection Act and Build America, Buy America Act were not triggered for this pilot phase.
- Lesson Learned: Early communication with regulatory agencies helps anticipate permitting requirements and streamline reviews.
- Recommendation: Establish clear roles and early interagency agreements for Stage 2 to address potential permitting and regulatory obligations before deployment.

Data Governance and Cybersecurity

- Challenge: Managing data security, privacy, and sharing across multiple agencies required careful planning and alignment with federal data standards.
- Lesson Learned: The TRPA Open Data portal and API integration established a strong foundation for transparent data access and management.
- Recommendation: In Stage 2, formalize a data governance policy outlining ownership, access control, and cybersecurity protocols consistent with NIST and Zero Trust principles.

Workforce Capacity and Community Impact

- Challenge: The specialized nature of AI and ITS technologies required new technical skills among local staff and contractors.
- Lesson Learned: Hands-on training during Stage 1 helped local staff build foundational knowledge in equipment management, monitoring, and troubleshooting.
- Recommendation: Continue workforce development and on-site training programs in Stage 2 to strengthen local expertise and reduce reliance on vendor support.

Public Awareness and Acceptance

- Challenge: The public was not aware of the project’s purpose and benefits at the beginning of Stage 1.
- Lesson Learned: Increased outreach and communication, particularly social media, improved

understanding of the system's role in enhancing safety, mobility, and data-driven planning.

- Recommendation: Build on the success of the roundabout posts on social media and create a routine PSA post to keep the community engaged during Stage 2, highlighting the system's value for residents, visitors, and emergency response.

To improve future planning and execution for Stage 2, Table 15 summarizes the major challenges and corresponding lessons learned.

Table 15: Challenges and Lessons Learned

Challenge	Lesson Learned
Late start in preparing scope of work requirements for RFP solicitation.	Ensure project continuity by preparing draft scope materials and assigning dedicated staff as soon as possible to support timely solicitation and contract execution.
Late start in preparing and executing interagency agreements.	Start preparing and negotiating draft interagency agreements as early as possible and build on prior Stage 1 conversations.
Some sites experienced intermittent sensor failures due to communication drops between field equipment and the control center.	Deploy more resilient communications infrastructure (including satellite where appropriate) and improve calibration to ensure consistent connectivity. This underscores the importance of Stage 2, including permanent installation on existing or new infrastructure.
Lack of adequate cellular communication at very rural site locations.	Look into alternative communication solutions, namely satellite systems such as Starlink.
The high cost of providing power at some locations.	Leverage existing NDOT and Caltrans field infrastructure at remote locations by deploying AI processing at their respective TMC's, instead of new field infrastructure at the locations. Alternatively, deploy solar at locations where existing infrastructure is unavailable.
AI-powered sensors lacked system and communications failure alerts.	Develop and implement real-time monitoring and alert features to flag system disruptions and data irregularities early.
Detection accuracy was reduced at some sites due to low-light conditions.	Deploy higher-specification cameras with improved low-light capability.
Existing cameras at some sites had limited resolution and frame rates.	Install new cameras designed specifically for AI analytics.
Many intersections would have benefited from a minimum of two cameras, which were not available.	Ensure deployment of at least two cameras at each intersection to improve coverage and accuracy.
CCTV cameras were often repositioned.	When cameras are moved or repositioned, the established detection zones are no longer in the correct placement. Each time the cameras were moved, the location had to be reconfigured by the vendor.

At several sites, cameras were located farther from intersections than ideal, reducing detection precision.	Optimize camera placement during Stage 2 design to ensure appropriate proximity and coverage. Consider adding another camera at some locations to capture the entire intersection.
The vendor was unaware of cellular limitations for specific locations and they were unfamiliar with utilizing satellites for communications.	Local understanding of cellular limitations supported the use of the satellite. The vendor wanted to rely on cellular communications, but local experience indicated that it would not be productive. Similarly, the vendor team had not used satellite in lieu of cellular communications. This resulted in a slight delay and troubleshooting in the field for TTD staff.
The vendor unfamiliar with intersections, motorist, and pedestrian behaviors.	Project team worked with the vendor to develop realistic detection zones in the temporary locations.
Road construction	Lack of pavement markings and detours cause false positive safety events. Construction detours resulted in false positive safety events.
The vendor had no prior experience with their equipment being installed on a mobile unit.	The mobile deployment challenged the vendor as the system needed to be reconfigured at each remote location, usually with satellite.

Part 6: Deployment Readiness

TTD identified several institutional, technical, labor, and data governance components that must be addressed to ensure a successful Stage 2 deployment.

1. Legal, Policy, and Regulatory Requirements:
   - Engage all stakeholders early, including emergency services, municipal traffic agencies, and regional partners (Caltrans, NDOT, TRPA, local jurisdictions).
   - Prepare RFP scopes of work and interagency agreements quickly after the grant agreement is executed to avoid procurement and contracting delays.
   - Establish recurring coordination meetings and clear governance roles to ensure accountability across jurisdictions.
   - Explore coordinating with the NDOT's SMART FY 2024 Stage 1 project, Enhancing Corridor Communication Roadmap
2. Technical Readiness:
   - Ensure reliable communications at all sensor sites, using satellite (Starlink) as a proven alternative in locations with limited cellular coverage.
   - Plan for equipment lifecycle management, by budgeting for replacement or upgrades of AI Sensors and dynamic signs in years seven through ten.
   - Implement real-time monitoring and alert protocols to detect video loss, latency, or abnormal traffic trends.
   - Standardize camera deployment with AI-optimized, high-resolution, low-light cameras, ensuring at least two per intersection and proper mounting heights to maximize visibility and detection accuracy.
3. Workforce and Labor Considerations:
   - Assess workforce needs to provide training and reskilling strategies tailored to Stage 2 technologies.
   - Prepare for project team transitions and keep notes to ensure new team members can pick up where others left off.
   - Deliver hands-on training for local staff in operating vendor dashboards, analytics platforms, and troubleshooting tools.
   - Build local technical support capacity to reduce reliance on remote vendor services.
   - Expand opportunities for businesses through training, contracting, and workforce development programs.
   - Incorporate new skill-building opportunities in AI, data analytics, and smart infrastructure management to strengthen regional workforce capacity.

4. Data Governance and Privacy:
   - Develop and implement a comprehensive data governance policy covering data storage, access controls, retention timelines, and audit procedures.
   - Establish protocols for secure data transmission and adherence to industry cybersecurity standards (e.g., National Institute of Standards and Technology (NIST), Zero-Trust policies[1]).
   - Ensure safeguards for privacy by excluding license plate data, facial recognition, or any personally identifiable information.
   - Promote transparency by providing agencies with open-data access, while maintaining strict privacy and security protections.

[1] A cybersecurity approach based on "never trust, always verify," requiring continuous authentication, strict access controls, and encryption to protect data and systems regardless of user location or network.

Part 7: Wrap-Up

Reflections on Stage 1 Implementation

Stage 1 demonstrated the feasibility and value of deploying AI-powered sensors and cloud-based platforms to collect and analyze multimodal traffic and safety data across the Lake Tahoe Basin. The project met its core objectives of validating system functionality, testing communication reliability, and building a foundation for scalable smart mobility infrastructure.

Key achievements include:

- Successful testing of four system configurations — edge processing (cellular and satellite), centralized processing at the Caltrans TMC, and cloud-based processing using NDOT feeds.
- Verification of satellite communications (Starlink) as a reliable and, in some cases, superior connectivity solution for rural and remote areas with limited cellular coverage.
- Establishment of a cloud-based, open-data platform for multimodal analytics integrated with the TRPA Tahoe Open Data portal.
- Strong interagency collaboration across two states, five counties and the Washoe Tribe, enhancing regional coordination and data sharing.
- Increased project visibility through engagement with partners, public agencies, and USDOT, showcasing Tahoe's leadership in rural ITS.

Lessons Learned and Recommendations for Stage 2

Stage 1 exceeded expectations in demonstrating the system's operational viability; however, it also revealed several technical and institutional improvements needed for at-scale deployment.

Key lessons and adjustments for Stage 2 include:

- Early Coordination: Begin considering scopes of work, RFPs, and interagency agreements as soon as the grant agreement is executed to avoid procurement delays.
- Infrastructure Reliability: Maintain redundant communications, including both cellular and satellite links, to ensure data continuity in all environmental conditions.
- Camera Deployment Standards: Use higher-specification cameras with dual-camera setups at intersections to improve detection accuracy and expand the field of view.
- Real-Time System Monitoring: Implement automated health and alerting tools to promptly identify data anomalies and ensure consistent performance.
- Emergency Operations Testing: Stage 1 coincided with the summer season with mild weather conditions and no major emergency events; full-scale implementation should include testing under severe winter weather or emergency scenarios to evaluate system resiliency.

Expectations for At-Scale Implementation

The proposed Stage 2 deployment will expand coverage Basin-wide, connecting data from all key corridors and intersections. With refinements identified during Stage 1, the project is expected to:

- Improve detection and reporting of safety events, including near misses, crashes, illegal movements, and wrong-way driving.
- Provide reliable, high-quality data to support planning, operations, and performance monitoring.
- Enhance traveler information, congestion management, and dynamic communication with road users, including real-time parking availability information.
- Strengthen resiliency by maintaining situational awareness during wildfires, storms, and other hazards.
- Reduce congestion by supporting mode shift and optimizing resource allocation.

Advice for Other Communities

Communities considering similar AI Sensor technologies should:

- Start with small-scale pilots to validate communication, sensor accuracy, and agency workflows before scaling up.
- Engage stakeholders early to define data-sharing protocols, ownership, and governance policies.
- Prioritize system flexibility, including modular hardware, open APIs, and multiple communications options, to adapt to varied field conditions.
- Establish an ongoing funding source. as well as local technical capacity and partnerships to sustain operations beyond the pilot phase.

Next Steps

To prepare for Stage 2 implementation, TTD will:

- Secure a local funding source to maintain the license renewal beyond the initial pilot (Stage 1) and maintain access to the vendor platform. TTD is currently working with local agencies to help support the license renewal to cover costs until Stage 2, or another funding source, is awarded for an at-scale implementation.
- Develop the Stage 2 SMART grant application.
- Develop a Transit and Intercity Rail Capital Program (TIRCP) grant proposal for at-scale implementation for the California portion of the Tahoe Basin.
- Seek other state funding opportunities to support an at-scale implementation.
- Refine RFP scopes and interagency agreements to streamline contracting.

- Conduct before-and-after studies to measure safety and operational benefits.
- Expand data sharing and interoperability among regional partners.
- Continue building local capacity through training and workforce development.
- Finalize and adopt a comprehensive data privacy and governance policy.

Stage 1 has positioned the Tahoe Basin to advance toward a fully integrated, data-driven transportation system that enhances safety, mobility, and resiliency for residents and visitors alike.

Appendix A: Anticipated Costs and Benefits of At-Scale Implementation

At-Scale Deployment

The at-scale implementation will deploy an advanced data collection and management system, coupled with an integrated multimodal online data archive, to enhance the accuracy, consistency, and ease of analyzing roadway data in the Lake Tahoe Basin. This system will leverage AI-powered video sensors for comprehensive data collection, providing valuable insights into travel patterns within and around the Basin.

Additionally, these AI Sensors will detect pedestrians at crossings and automatically activate Pedestrian Hybrid Beacons (PHB) to alert approaching vehicles, enhancing safety at critical locations.

The implementation of Stage 2 is planned to span three years. Upon completion, TTD and its project partners will establish a permanent network of AI-powered sensors across the Lake Tahoe Basin, as depicted on the project location map in Figure A1.

This network will enable a wide array of data analytics, supporting TTD and its agency partners in planning and operational decision making. This information can be used to evaluate a traffic management center for the Lake Tahoe Basin.

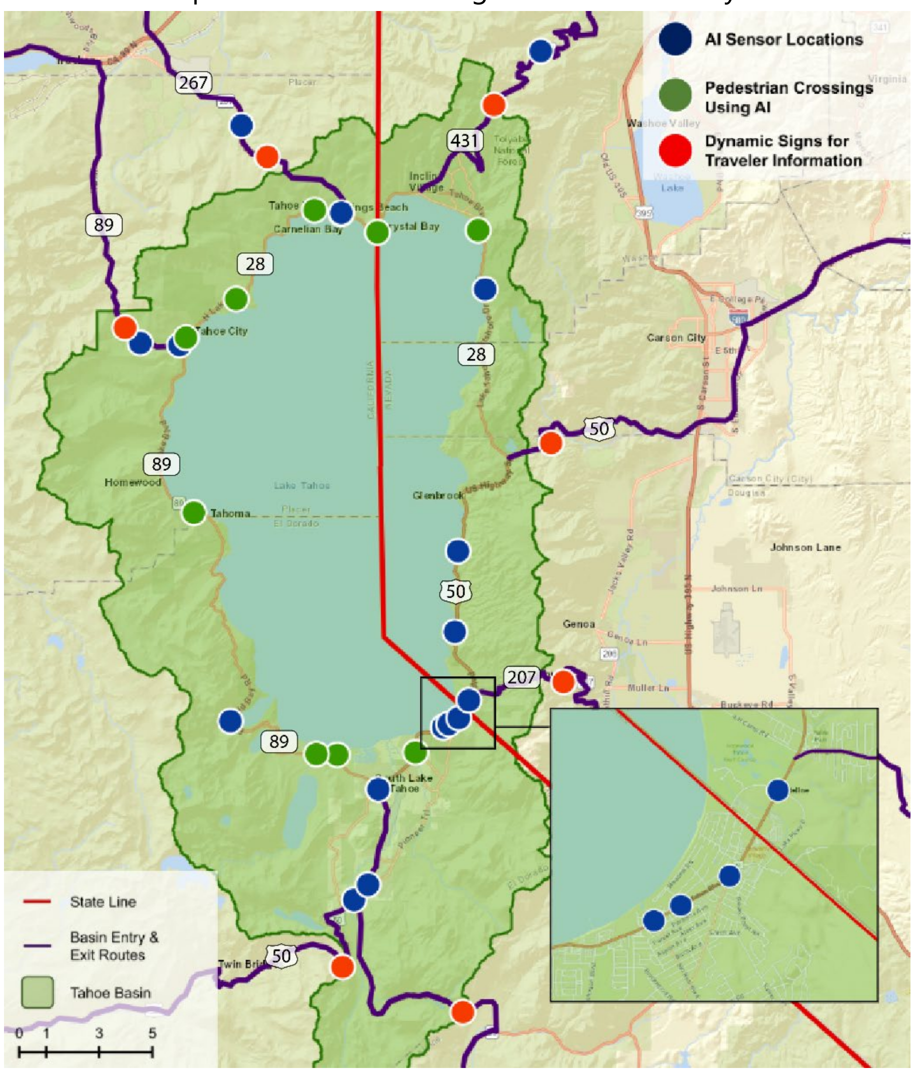


Figure A1: Stage 2 Deployment Locations

Anticipated Stage 2 Outcomes

The at-scale implementation of an advanced data collection and management system, along with integrated multimodal online data archiving, is expected to deliver several direct and indirect benefits, operational efficiencies, and cost savings, including:

- Reduction in Traffic Incidents and Associated Costs: Transportation safety will see significant improvements through real-time collection and analysis of near-miss and crash data. Additionally, monitoring speed, travel times, and parking availability will help reduce the number of vehicles parked informally or illegally along narrow recreation corridors, thereby mitigating risky motorist and pedestrian behaviors. Data will continue to be available to first responders so they can direct resources to areas with higher rates of traffic incidents. Smart PHBs will further enhance pedestrian safety by alerting drivers to crossing activity.

- Enhanced Planning and Operational Efficiency: The availability of enhanced planning, programming, and operational data will enable regional agencies to manage the existing transportation network more effectively and identify and prioritize infrastructure investments. Automated data collection will lower data collection costs for all participating agencies.

- Improved Traffic Flow and Reduced Congestion: By managing travel demand through the connected network, partner agencies and the public will gain access to critical information on travel times, parking availability, and emergency response activities. This will promote mode shifts and enhance resiliency by providing real-time information on public transit options, leading to reduced traffic congestion. The transit network will be fully integrated into the system, offering real-time passenger information along fixed routes and micro-transit.

- Integration with Regional Planning: Outcomes from the SMART Stage 1 pilot will be integrated into TRPA's Transportation Systems Management & Operations (TSMO) Plan. The Plan aims to assess existing conditions and develop a set of integrated strategies to optimize the performance of the transportation system. The Plan will maximize network efficiency, safety, and reliability, while emphasizing optimization of existing infrastructure. The Stage 1 results are critical elements to inform the TSMO Plan, which will invite other opportunities for the full implementation in Stage 2.

Derived from the above benefits, the following performance measures can be quantified to develop the benefits of at-scale implementation:

1. Reduction in data collection costs.
2. Reduction in traffic incidents and associated costs.

Data from Stage 1 deployment and the proposed technology systems for Stage 2 will be used to quantify these specific metrics and estimate the anticipated costs and benefits of at-scale implementation. Some assumptions and references are included where current data was not available from Stage 1 implementation.

Approach and Assumptions

Benefits from Reduction in Data Collection Cost

The advantages of transitioning from manual to automated traffic data collection are well-documented in various studies. For example, a Planning for Operations Case Study by the Metropolitan Transportation Commission in San Francisco[2] highlighted that using archived data for "existing conditions" analysis is both more time-efficient and cost-effective than the repeated collection of new data.

Similarly, an evaluation of the SmartBus ITS implementation program for the Chattanooga Area Regional Transportation Authority[3] demonstrated that data archive warehousing can pay for itself in less than eighteen months, while scheduling software saved planners nearly four weeks of work annually.

Manual Data Collection Costs

Across the U.S., transportation planning organizations invest substantial resources into manual traffic data collection. In states like California, Washington, and Oregon, large metropolitan areas and transportation agencies typically spend between $800,000 and $2 million annually on a mix of manual counts, automated sensors, and advanced technologies like video analytics.

At the site level, conducting manual data collection at a single intersection throughout the year—factoring in seasonal, monthly, and daily variations, along with multimodal counts (vehicles, bicycles, pedestrians)—can cost approximately $15,000 to $25,000 per site per year. This estimate includes:

- Frequency of Data Collection: Data collection needs to be conducted multiple times across various seasons and times of day to capture a full range of traffic patterns.
- Labor Costs: With labor rates typically ranging from $75 to $150 per hour and each session lasting several hours, the sessions must be repeated across the year for different modes of transportation.
- Data Processing and Reporting: The additional costs of entering, analyzing, and reporting multimodal data add to the overall expense.

Estimate for BCA

Given these considerations, a $22,400 per site estimate is a conservative figure to use when evaluating the costs of manual data collection. For the 38 sites in question, this results in an annual cost estimate of $850,000 for manual traffic data collection. This estimate will serve as the basis for comparing the potential savings offered by automated data collection systems in the subsequent BCA.

---

[2] https://www.itskrs.its.dot.gov/2011-b00732

[3] https://www.itskrs.its.dot.gov/2011-b00713

Benefits from Reduction in Traffic Incidents

Reduction in Crashes

Reduction in traffic incidents are, potentially, due to improved data-driven decision-making and from the deployment of pedestrian safety warning systems using AI.

Estimating the percentage reduction in traffic incidents due to improved data-driven decision-making can be challenging, as it depends on various factors, such as the quality of the data, the effectiveness of the interventions, and the baseline safety conditions. The following provides context to the safety benefits resulting from the Stage 2 deployment and the resulting data-driven decision-making:

- Traffic Signal Optimization: Signal retiming can reduce crashes at intersections by improving traffic flow and reducing conflict points.
- Safety Campaigns and Public Awareness: Data-driven public safety campaigns can achieve a 5 to 10% reduction in incidents by targeting specific risky behaviors[4].

Additionally, the project includes the deployment of pedestrian safety warning systems using AI at 10 pedestrian crossing locations. A recent study in Arizona[5], found that PHBs reduced pedestrian-related crashes by 46%.

Based on these examples, a reduction in crashes could range from 5% to 46%. For the Stage 2 deployment, a conservative estimate of a 20% reduction in crashes is reasonable, given the combination of data-driven decision-making and AI-powered pedestrian safety systems.

In the Lake Tahoe Basin, between 2013 and 2021, there were 3,355 crashes, including 41 fatal crashes and 183 severe injuries. Among these, six fatalities were pedestrian-related and five involved bicyclists.

For the locations identified for Stage 2 deployment, there were 329 crashes, resulting in two fatalities and 14 serious injuries. The projected 20% reduction in crashes at these deployment locations could significantly improve safety outcomes.

Estimates for BCA

The U.S. Department of Transportation (USDOT) provides guidance on the Value of Statistical Life (VSL) [6]. This document provides guidelines for estimating the value of reducing fatalities and injuries. Based on the methodology adopted in the guidance, an estimated value of $13.2 million will be used to represent the VSL for the analysis base year of 2024. Other values of crash injuries and no injury crashes can be derived from the document "DOT VSL Guidance - 2021 Update.pdf"[7]

---

[4] WHO global status report on road safety 2013: supporting a decade of action

[5] Evaluation of Pedestrian Hybrid Beacons on Arizona Highways, 09/01/2019.

[6] https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-on-valuation-of-a-statistical-life-in-economic-analysis

[7] DOT, Departmental Guidance Treatment of the Value of Preventing Fatalities and Injuries in Preparing Economic Analyses, 2021

The table below presents the estimated potential costs of crashes at the sensor locations over the eight-year period from 2013 to 2021.

Cost due to	Number	Unit Value	Total Cost
Fatalities	2	$13,200,000	$26,400,000
Serious Injuries	14	$3,510,000	$49,140,000
Damages	329	$4,000	$1,316,000
Total			**$76,856,000**

The total cost of crashes at the project locations over the eight-year period from 2013 to 2021 is estimated at $76,856,000, averaging approximately $9.6 million per year. Applying a 20% reduction factor results in an estimated annual cost savings of $1,921,000. This provides a rough estimate of the economic value generated each year in the deployment area due to the projected reduction in crashes.

Benefit / Cost Analysis

This section outlines the projected costs and benefits associated with deploying smart intersections in a city over the next 15 years. This analysis includes calculations of net present value (NPV) and sensitivity analysis to assess the impact of potential variations in costs and benefits.

Projected Costs

The total project costs include initial installation, annual maintenance, and operational costs. These costs are projected over a 15-year period, considering inflation and technological upgrades.

Stage 2 At-Scale Implementation Costs:

- AI Video Sensor Stations: $1,600,000
- Dynamic information signs: $1,400,000
- Ped crossing Alert Systems: $800,000
- Communications (36 months): $105,000
- Data Platform Development (6 months): $300,000
- Data Platform O&M (36 months): $360,000
- Consulting, Contracting and Software subscriptions: $4,300,000
- Total Stage 2 At-Scale Cost $8,865,000

Lifecycle and Replacement Assumptions

Consistent with federal guidance for ITS equipment (recommended lifecycle of 7 to 10 years), this analysis assumes a 7-year lifecycle for critical equipment. A full replacement cycle is assumed after Year 7 of deployment, at an estimated cost of $3,800,000. This replacement cost covers AI video sensors, dynamic information signs, and pedestrian crossing alert systems, ensuring technology remains current and operational throughout the 15-year analysis horizon.

The inclusion of lifecycle replacement costs ensures that the Benefit/Cost analysis provides a more realistic long-term view of financial requirements for maintaining the system in a state of good repair.

In addition to the above, Operations and Maintenance costs are assumed to be $500,000 per year. The following table provides the undiscounted project costs.

Project Costs (Undiscounted - 2025 $)			
Year	Capital Costs	O&M Costs	Total Costs
2025			$-
2026	$2,955,000		$2,955,000
2027	$2,955,000		$2,955,000
2028	$2,955,000		$2,955,000
2029		$500,000	$500,000
2030		$500,000	$500,000
2031		$500,000	$500,000
2032		$500,000	$500,000
2033		$500,000	$500,000
2034		$500,000	$500,000
2035	$1,266,667	$500,000	$1,766,667
2036	$1,266,667	$500,000	$1,766,667
2037	$1,266,667	$500,000	$1,766,667
2038		$500,000	$500,000
2039		$500,000	$500,000
2040		$500,000	$500,000
2041		$500,000	$500,000
2042		$500,000	$500,000
2043		$500,000	$500,000

Projected Benefits

The benefits from the smart intersections include reductions in emergency response times, improvements in transit on-time performance, and potential reductions in traffic-related fatalities. The following table projects these benefits over the next 15 years.

Year	2025 $ (Undiscounted)			
	Costs	Benefits		
	Total Costs	Reduced Cost Savings	Safety	Total Benefits
2025	$-	$-	$-	$-
2026	$2,955,000	$-	$-	$-
2027	$2,955,000	$-	$-	$-
2028	$2,955,000	$-	$-	$-
2029	$500,000	$850,000	$1,921,000	$2,771,000
2030	$500,000	$850,000	$1,921,000	$2,771,000
2031	$500,000	$850,000	$1,921,000	$2,771,000
2032	$500,000	$850,000	$1,921,000	$2,771,000
2033	$500,000	$850,000	$1,921,000	$2,771,000
2034	$500,000	$850,000	$1,921,000	$2,771,000
2035	$1,766,667	$850,000	$1,921,000	$2,771,000
2036	$1,766,667	$850,000	$1,921,000	$2,771,000
2037	$1,766,667	$850,000	$1,921,000	$2,771,000
2038	$500,000	$850,000	$1,921,000	$2,771,000
2039	$500,000	$850,000	$1,921,000	$2,771,000
2040	$500,000	$850,000	$1,921,000	$2,771,000
2041	$500,000	$850,000	$1,921,000	$2,771,000
2042	$500,000	$850,000	$1,921,000	$2,771,000
2043	$500,000	$850,000	$1,921,000	$2,771,000
Total	**20,165,000**	**$12,750,000**	**$28,815,000**	**$41,565,000**

Net Present Value (NPV) Calculation

The Net Present Value (NPV) is calculated to determine the project's financial viability. NPV considers the time value of money by discounting future cash flows to present value using a specified discount rate. A positive NPV indicates that the projected benefits exceed the costs, justifying the investment.

Formula:

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Benefits}_t - \text{Costs}_t}{(1+r)^t}$$

Where:
- t is the year (from 1 to n).
- Benefits_t is the total benefits in year t.
- Costs_t is the total costs in year t.
- r is the discount rate (7%).
- n is the total number of years (15 years in this analysis).

Year	2024 $ (Discounted)				NPV
	Costs	Benefits			
	Total Costs	Reduced Cost Savings	Safety	Total Benefits	
2025	-	-	-	-	-
2026	$2,761,682	-	-	-	($2,761,682)
2027	$2,581,011	$-	$-	$-	($2,581,011)
2028	$2,412,160	$-	$-	$-	($2,412,160)
2029	$381,448	$648,461	$1,465,522	$2,113,983	$1,732,535
2030	$356,493	$606,038	$1,369,646	$1,975,685	$1,619,192
2031	$333,171	$566,391	$1,280,043	$1,846,434	$1,513,263
2032	$311,375	$529,337	$1,196,302	$1,725,640	$1,414,265
2033	$291,005	$494,708	$1,118,039	$1,612,747	$1,321,743
2034	$271,967	$462,344	$1,044,897	$1,507,240	$1,235,274
2035	$898,084	$432,097	$976,539	$1,408,636	$510,552
2036	$839,331	$403,829	$912,653	$1,316,482	$477,152
2037	$784,421	$377,410	$852,947	$1,230,357	$445,936
2038	$207,482	$352,720	$797,147	$1,149,866	$942,384
2039	$193,909	$329,645	$744,997	$1,074,642	$880,733
2040	$181,223	$308,079	$696,259	$1,004,338	$823,115
2041	$169,367	$287,924	$650,709	$938,634	$769,266
2042	$158,287	$269,088	$608,139	$877,228	$718,940
2043	$147,932	$251,484	$568,355	$819,839	$671,907
Total	**$13,280,348**	**$6,319,555**	**$14,282,195**	**$20,601,750**	**$7,321,402**

Discount Rate =	7%
Total Discounted Costs	$13,280,348
Total Discounted Benefits	$20,601,750
NPV	$7,321,402
BCR	1.55

Sensitivity Analysis

A sensitivity analysis examines how the uncertainty in the input variables (costs and benefits) impacts the NPV. This analysis considers scenarios where project costs and benefits vary by ±20%. The results provide insight into the project's robustness against potential fluctuations, with the resulting Benefit-Cost Ratio (BCR) ranging from 1.03 to 2.33.