Tapping into Autonomous Trucking Data

An Intelligent Routine Maintenance Framework for Texas

TxDOT Project No. 0-7129

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THE UNIVERSITY OF TEXAS AT AUSTIN
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16. Abstract

Texas has become a major hub for autonomous trucking activity, with companies operating routes daily and continuing to expand operations onto new roadways. Equipped with high-definition cameras and sensor suites, autonomous trucks present a new data opportunity for the Texas Department of Transportation (TxDOT) to improve its routine maintenance operations. Partnering with two autonomous trucking companies and three TxDOT Districts, the University of Texas at Austin Center for Transportation Research (CTR) developed an intelligent routine maintenance framework (IRMF) and prototype. The IRMF establishes workflows for detecting, assigning, and resolving routine maintenance events. Based on public- and private-stakeholder input, the research team prioritized six routine maintenance events for inclusion in the protype: potholes, striping and pavement markers, guardrails and cable barriers, debris, and work zones. The prototype leveraged TxDOT's Nighttime Inspection Suite to enable participating Districts to access 411 autonomous trucking events and compare with traditional TxDOT inspections. Additionally, the research team created a dashboard for mapping and visualizing the routine maintenance events by type, roadway, and District. Finally, the research team formulated a growth and sustainability plan that includes complementary artificial intelligence (AI) solutions, a cost-benefit analysis, and procurement pathways. Overall, the project establishes a proof of concept upon which TxDOT can build, automate, and ultimately scale statewide. By integrating data from autonomous trucks and other third-party data sources, TxDOT can improve the coverage, resolution, and timeliness of its routine maintenance data; reduce response times; and increase the safety of its roadways for automated and traditional vehicles alike.

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Jeremiah Kuntz, Senior Manager – Government Relations, Aurora

Leslie Keaveney, Senior Manager, Policy, Aurora

Dedication

The research team dedicates this project to Dr. Zhanmin Zhang. As a professor, researcher, and mentor, the research team is forever grateful for the wisdom and patience that he imparted. His resilient spirit carries on as inspiration.

Table of Contents

Table of Figures

Table of Tables

TAPPING INTO AUTONOMOUS TRUCKING DATA

An Intelligent Routine Maintenance Framework for Texas

EXECUTIVE SUMMARY

Texas has become a major hub for autonomous trucking activity, with companies operating routes daily and continuing to expand operations onto new roadways. Equipped with high-definition cameras and sensor suites, autonomous trucks present a new data opportunity for the Texas Department of Transportation (TxDOT). The data offers a particular opportunity to improve routine maintenance operations by detecting and resolving maintenance events such as potholes, faded striping, or guardrail damage.

The research team designed an Intelligent Routine Maintenance Framework (IRMF) for detecting, assigning, and resolving routine maintenance events. Based on public- and private-stakeholder input, the research team prioritized six routine maintenance events for inclusion in the IRMF: 1) potholes, 2) striping and pavement markers, 3) signs, 4) guardrails and cable barriers, 5) debris, and 6) work zones. The research team crafted a data management plan and performance measures for each event type.

The research team then developed and tested a prototype of the IRMF. Two autonomous trucking companies—Kodiak Robotics and Aurora—contributed one week of data to the project. The data included:

- 411 total events
- 70 potholes and 58 instances of debris
- Coverage across five major TxDOT roadways and thirteen TxDOT districts

Leveraging TxDOT's Nighttime Inspection Suite, the research team worked with TxDOT ITD to upload the data and create a feature layer alongside traditional TxDOT inspection data. The Odessa, Houston, and Dallas Districts accessed the data and provided input to refine the IRMF and prototype. The research team developed a Tableau dashboard to enable maintenance personnel to visualize maintenance events and see key performance indicators such as the number of routine maintenance events by type, roadway, and district.

Finally, the research team developed a sustainability and growth plan. Included are a catalog of complementary AI solutions, a cost/benefit analysis, and procurement documents to support TxDOT in expanding the IRMF beyond the scope of the research project.

This research report captures the highlights from TxDOT Project 0-7129: *Working with Autonomous Trucks to Improve Routine Maintenance Operations*. Overall, the project establishes a proof of concept upon which TxDOT can build, automate, and ultimately scale. By integrating data from autonomous trucks and other third-party data sources, TxDOT can improve the coverage, resolution, and timeliness of its routine maintenance data; reduce response times; and increase the safety of its roadways for automated and traditional vehicles alike.

1 | INTRODUCTION

Automated Trucking in Texas: An Untapped Data Source

Texas has become a major hub for autonomous trucking activity, with companies operating routes daily and continuing to expand operations onto new roadways. Equipped with high-definition cameras and sensor suites, autonomous trucks present a new data opportunity for the Texas Department of Transportation (TxDOT). In particular, the data may be used to improve routine maintenance operations by detecting and resolving maintenance events such as potholes, faded striping, or guardrail damage.

Routine Maintenace Challenges

Traditional routine maintenance data is sparse and lacks precision, relying heavily on TxDOT district- and section-office personnel. Typically, TxDOT districts perform a complete system inspection on a quarterly basis and conduct partial inspections during daily routines; this scheduling creates the need for leveraging supplemental real-time maintenance data.

TxDOT's routine monitoring is supplemented by reporting tools available for the traveling public, some coordination with law enforcement, and information from other public agencies in a region. These supplemental reports, however, are neither uniform across districts nor automated. New strategies are needed for developing a statewide intelligent routine maintenance framework that enables districts to tap into real-time, accurate, and complete routine maintenance information.

The Opportunity for Data Integration

The proliferation of data sources has unlocked new opportunities for transportation agencies to access real-time asset condition information. As autonomous trucking expands across Texas and nationally, TxDOT must seize the momentum to establish a collaborative data-sharing environment. Autonomous trucks are capable of providing high-resolution, near-real-time data on routine maintenance events occurring on key freight corridors. Furthermore, there are new private-sector solutions that are leveraging sensors, cameras, and other devices and applying artificial intelligence (AI) to develop asset inventories, automate detection, and enable proactive maintenance. By partnering with autonomous trucking companies and the private sector, TxDOT can develop a strategy for integrating emerging data sources into routine maintenance operations.

Project Overview

The University of Texas at Austin Center for Transportation Research (CTR) designed, developed, and tested a prototype of an Intelligent Routine Maintenance Framework (IRMF) for TxDOT. Key objectives included:

- **Detecting** maintenance events through traditional TxDOT inspection, autonomous trucks, or third-party data sources;
- **Assigning** maintenance events to be addressed through in-house maintenance crews or external contractors; and
- **Resolving** maintenance events by performing the appropriate work and recording the time of completion.

Overall, the IRMF enables TxDOT to leverage data from autonomous trucks as well as other third-party data sources. Tapping into emerging data sources can supplement or replace labor-intensive inspection methods, generating valuable cost-savings for TxDOT. Additionally, TxDOT can improve the coverage, resolution, and timeliness of its routine maintenance data; reduce response times; and increase the safety of its roadways for automated and traditional vehicles alike. Project 0-7129 establishes a strong proof of concept upon which TxDOT can build, automate, and ultimately scale into a statewide intelligent routine maintenance program.

Working with Autonomous Trucks
to Improve Routine Maintenance Operations

Project Overview

Autonomous trucks present a new data stream to detect routine maintenance events, including potholes, damaged signs, and debris. Research Project 0-7129 develops an Intelligent Routine Maintenance Framework and prototype that integrates data from autonomous trucks into TxDOT's routine maintenance workflow. As a result, TxDOT can harness more timely, accurate, and detailed information to address routine maintenance events.

1 Detect

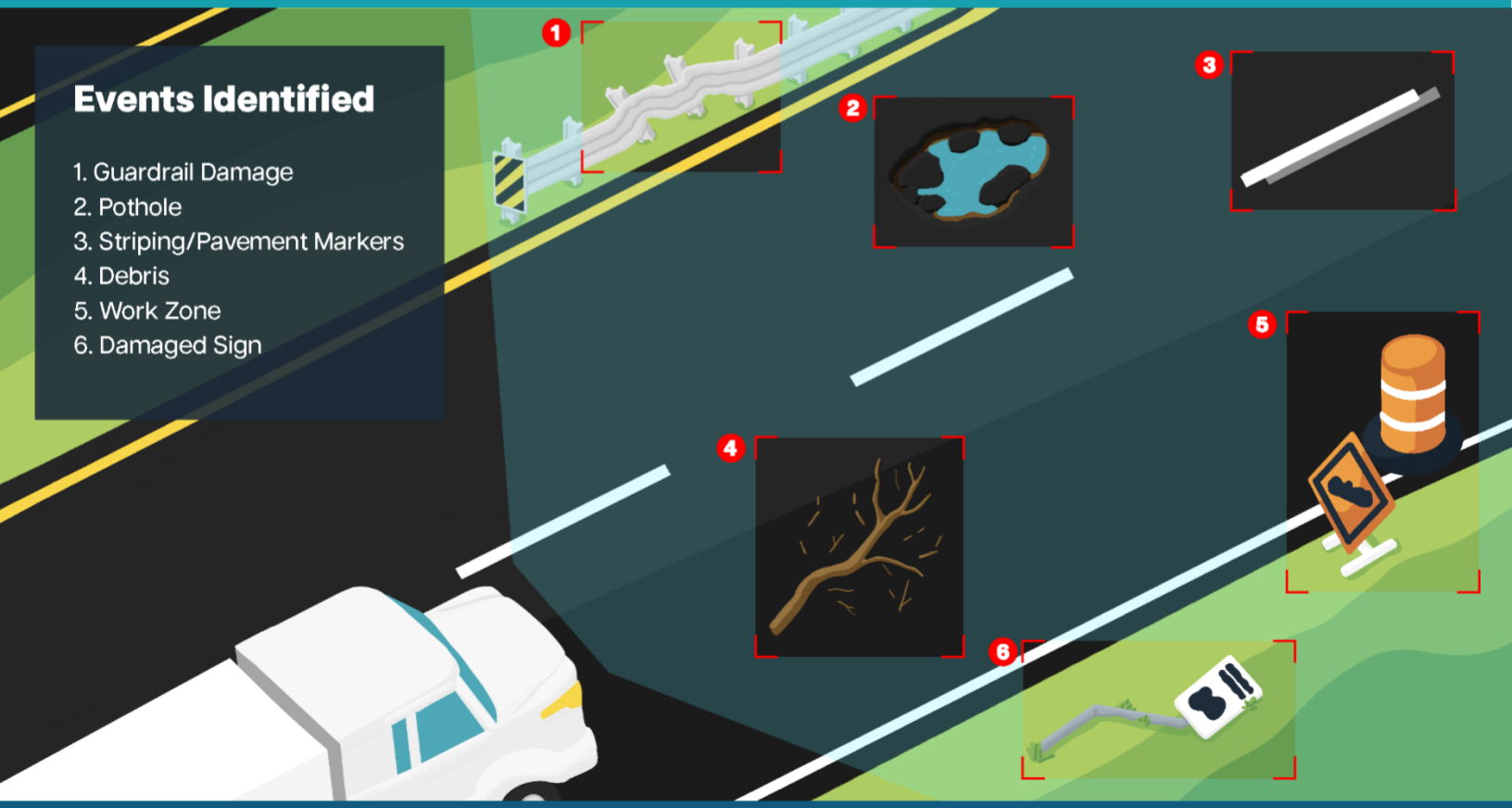
Maintenance events may be detected through traditional TxDOT inspections, autonomous trucks, or third-party data sources.

2 Assign

TxDOT Districts prioritize maintenance events to be addressed through in-house teams or external contractors.

3 Resolve

Maintenance crews and/or external contractors perform the requested work and record the event resolution.



Project Outcomes

1. **Faster detection of maintenance issues**
2. **More accurate, detailed location data**
3. **Improved response times**

Project 0-7129

2 | PROCESS

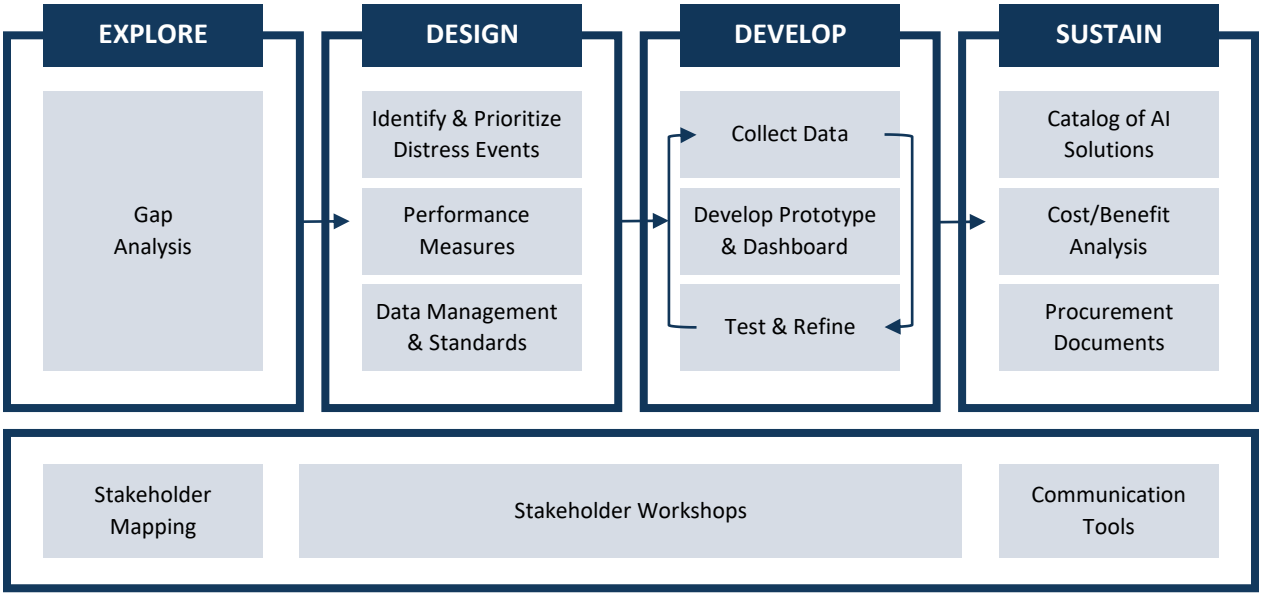


Figure 1: Project Components & Process

Launched in September 2021, Project 0-7129: Working with Autonomous Trucks to Improve Routine Maintenance Operations included four major stages (Figure 1):

Explore

First, the research team reviewed current TxDOT routine maintenance practices and conducted key person interviews. Gaps included opportunities to improve the coverage, resolution, and timeliness of routine maintenance data. Following, the research team outlined a method for TxDOT to ingest high-resolution, real-time data on damage to and deterioration of key assets that can supplement existing routine maintenance operations.

Design

Next, the research team organized a stakeholder workshop with public and private sector representation in order to identify and prioritize maintenance events. Six events were prioritized, including potholes, signs, guardrail and cable barrier damage, striping/pavement marker deterioration, debris, and work zones. Performance measures and a data management strategy were formulated based on each of the priority maintenance events.

Develop

To test the IRMF, the research team partnered with two autonomous trucking companies—Kodiak Robotics and Aurora—in order to collect routine maintenance data. The research team worked with the TxDOT to ingest the data into the Nighttime Inspection Suite and compared the autonomous trucking data with traditional TxDOT inspections in the Odessa, Houston, and Dallas Districts. Furthermore, the research team developed a dashboard in order to enable TxDOT to readily visualize and analyze the results.

Sustain

Finally, the research team created several supplementary tools that would enable TxDOT to grow and ultimately sustain the IRMF beyond the scope of the research project, including a catalog of complementary AI solutions, cost/benefit analysis, and procurement documents.

Gap Analysis

The initial gap analysis reviewed TxDOT's current routine maintenance operations. Examining the routine maintenance process from reporting through resolution, the research team reviewed maintenance manuals and noted existing data sources, software requirements, and standard workflows. The research team compiled a list of common distress events sorted by asset type, and their associated impact on roadway conditions.

Additionally, the research team conducted interviews with key representatives within division, district, and section offices to assess the strengths and weaknesses of these procedures and practices. These discussions confirmed the need for an intelligent routine maintenance framework and identified three major routine maintenance data gaps: 1) geographic coverage, 2) location accuracy, and 3) time frequency.

Stakeholder Mapping & Workshops

To align project goals with user needs, the research team developed a stakeholder mapping plan—comprising representatives across the public sector, private sector, and research institutions—which informed two stakeholder workshops.

First Stakeholder Workshop

Held in April 2022, the goal of the first stakeholder workshop was to collect input on the IRMF in three primary areas: 1) priority maintenance needs, 2) opportunities for data sharing, and 3) recommended data standards and management practices. Nearly thirty stakeholders took part in the first workshop, and included presentations from TxDOT, Kodiak Robotics, and the Texas A&M Transportation Institute. Balancing priority maintenance event data needs with the availability of autonomous trucking data, six priority events were selected: 1) potholes, 2) striping and pavement markings, 3) signage, 4) guardrail and cable barrier damage, 5) roadway debris, and 6) work zones.

The research team outlined the three major phases of the IRMF for input: detection, assignment, and resolution. Beginning with event detection, the research team gathered additional details regarding each of the six priority maintenance events. Following, the research team focused on how maintenance events were assigned to either in-house maintenance crews or to external contractors. Finally, the research team collected feedback on resolution, noting key performance indicators such as asset repair time and pavement condition score where applicable. Stakeholders recommended future technologies that may influence the long-term sustainability of the IRMF as well as the possibility of aligning this project alongside other ongoing TxDOT efforts.

Second Stakeholder Workshop

The second stakeholder workshop was in April 2023, following significant development of the IRMF and testing of the prototype. The goal was to receive feedback from participating TxDOT Districts and autonomous trucking partners on five primary criteria: 1) alignment with TxDOT's goals, 2) product usability, 3) ability for integration into existing data management systems, 4) overall product satisfaction, and 5) ability to scale and sustain long-term.

The research team demonstrated the Tableau dashboard, where users can digitally view and interact with maintenance event data. Furthermore, the research team described prototype development process, including data collection, data transmission, uploading and access to the Nighttime Inspection Suite, and evaluation. Stakeholders responded positively to the project progress and agreed to the benefits of aligning with the Nighttime Inspection Suite. Stakeholders provided suggestions for improvement and agreed to participate in the evaluation of the prototype.

Priority Distress Events

The research team identified more than twenty routine maintenance events that were of interest to TxDOT personnel. Based upon stakeholder input and availability of autonomous trucking data, the research team ultimately prioritized six for inclusion in the IRMF and prototype.

Potholes

Taking various forms, pothole pavement maintenance events are subject to rapid enlargement resulting in potential pavement loss, vehicle damage, and potential restrictions to vehicle control. Position and size of the pothole are particularly important, as they can impact safety and traffic flow.

Striping & Pavement Markers

Lane striping and pavement markers are used to guide traffic safely on roadways and are used to aide in the positioning of AVs. Faded/missing striping, degraded retroreflectivity, or confusing patterns that may occur in work zones are important to capture and address.

Signage

Temporary or permanent signs are used to direct traffic, post regulatory information such as speed limits, or provide navigation information. When signs and/or their supports are damaged, leaning, missing, faded, or have reduced retroreflectivity, road users may be unaware of critical information.

Guardrail & Cable Barriers

Guardrail and cable barriers are used to separate vehicles from potential hazards and are designed to save lives in the event of a crash. When guardrail and cable barriers are damaged, it is of highest priority to fix in order to restore safety for road users and minimize liability to TxDOT.

Debris

Debris is considered any unwanted object in the right-of-way. The nature (size, weight, material) and location (shoulder or roadway) of the debris affects the level of urgency with which it needs to be removed.

Work Zones

Autonomous trucking companies identified work zones as a high priority. Autonomous trucks require advance warning, clear signage, and simple striping to navigate unique road environments.

Figure 2: *Priority Distress Events*

Performance Measures

To develop the most impactful IRMF, the research team developed a series of performance measures, targets, and baselines for each maintenance event. Metrics were informed using TxDOT documentation including some instances where standards are referred to the Federal Asset Management Plan.

Potholes. The Pavement Condition Score is a combined index of ride quality and pavement surface distress adjusted for traffic speed, where a score of between 70–100 is considered "good or better condition." TxDOT currently reports 89.3 percent of its roadways in "good or better condition," this project targets 90 percent or higher.

Striping. Two measurements influence the score index of striping assets, including daytime visibility and retroreflectivity. Striping visibility can be inhibited via deterioration or dirt buildup, which may also factor into retroreflectivity capability. A stripe is considered "passing" when it maintains smooth and uniform visibility and retroreflectance. Measured in one-mile segments, a target measure is for 70 percent, or more, or striping to meet "passing" criteria."

Pavement Markings. This asset is to meet equal standards to daytime visibility and retroreflectivity measurements outlined in striping events.

Signage. These assets should target 100 precent "passing" criteria for daytime visibility and retroreflectivity standards, as fully legible and without hindrance from fading or dirt buildup. Additionally, no obstructions can limit the functionality of messaging, including fallen or leaning positions.

Cable Barriers and Guardrails. To best enable roadway safety these assets should remain upright and staked into the ground, without any gaps from roadside protection.

Debris. The goal is to encounter as little debris as possible, ideally no more frequent than one item per roadbed mile.

Data Management & Standards

The research team reviewed TxDOT documentation and national best practices to guide the collection, transfer, reporting, evaluation, privacy, and security of IRMF data.

Event ID. A unique identifier for each routine maintenance event detected. Identification schemas may be developed to distinguish and anonymize different AV companies.

Latitude and Longitude. Location information to at least five decimal points.

Roadway Location. Indication of where in the right-of-way the maintenance event is located to assist with determining the urgency of response.

__Table 1__: Roadway Location Classifications

Roadway Location
Travel Lane
Shoulder
Roadside

Timestamp. Information regarding when the routine maintenance event is detected, reported in Greenwich Mean Time (GMT).

Event Category and Event Type. Classification of the routine maintenance event according to the following structure:

__Table 2__: Event Category and Type Classifications

Event Category	Event Type
Roadway	Striping
	Pavement Markers
Roadside	Signs
	Guardrail & Cable Barrier Damage
Pavement	Pothole
Hazard	Debris
	Work Zone Safety

Image. A visual of the routine maintenance event at time of detection.

Description. Additional information that may be useful to routine maintenance personnel.

5 | DEVELOP

As part of the 0-7129 effort, the research team developed a Tableau dashboard to summarize and visualize maintenance event data provided by AV trucking companies. The dashboard is intended to provide a high-level overview of the data that can support planning, resource allocation, and understanding of maintenance needs. The dashboard can be accessed using this link: https://public.tableau.com/app/profile/anna.mcauley/viz/0-7129/OverallDashboard.

Data Collection

Two autonomous trucking companies, Kodiak Robotics and Aurora, provided sample data sets of roadway maintenance events that their trucks detected. Preliminary sample data was collected in June 2022 and November 2022 to inform the prototype development. Once a data schema was established, official data was collected from June 12-21, 2023. 411 events were shared with the research team in .csv files.

Kodiak Robotics

The Kodiak data featured 388 total events. Each data point included the date, timestamp, latitude, longitude, comment, and severity. Some but not all included an image. 69 (18 percent) of the maintenance events detected were potholes. Of note were 161 (41 percent) lighting events. While this information was not part of the original data request, the information was found to be valuable. Debris and guardrail damage were the third and fourth most reported events. The majority of events were identified on IH-45 in the Dallas and Bryan districts and IH-35 in the Austin district.

Aurora

The Aurora data featured twenty-three total events. Each data point included the date, timestamp, latitude, longitude, comment, and image. The majority of events were identified on IH-45 and IH-20. Most events detected were related to debris and signs.

Prototype & Dashboard

Data Cleaning

For the prototype, autonomous trucking companies shared .csv files alongside zip files of corresponding .jpg images with the research team. The research team removed duplicates that were reported within two days and 360 feet of each other. Furthermore, the research team manually assigned an event category and type to missing fields based on the description provided by the autonomous trucking company. The research team then provided the files to TxDOT ITD, who merged the data from both companies and made appropriate adjustments to latitude/longitude, standardized times, and created unique event IDs.

Uploading to the Nighttime Inspection Suite

Next, TxDOT ITD staff batch uploaded the autonomous trucking data to the Nighttime Inspection Suite. The data was added as a layer, labeled “Autonomous Vehicles,” and was visible alongside traditional TxDOT inspection data. The base map includes detailed outlines of TxDOT districts and maintenance sections as well as all roadways on- and off-system. Each maintenance event type has a unique symbol, enabling for easy filtering by event category and type.

Performance Dashboard

The research team also developed a dashboard where TxDOT maintenance personnel can access overviews and summaries of reported events. The dashboard was developed using Tableau, a data visualization tool that TxDOT also uses internally. The dashboard enables events to be summarized and filtered by district, roadway, event type, and autonomous trucking company. Figure 3 shows the visualizations, summaries, and event information accessible through the Tableau dashboard using the preliminary sample data. This information is intended to provide a high-level overview of event reports that can support planning, resource allocation, and understanding of maintenance trends.

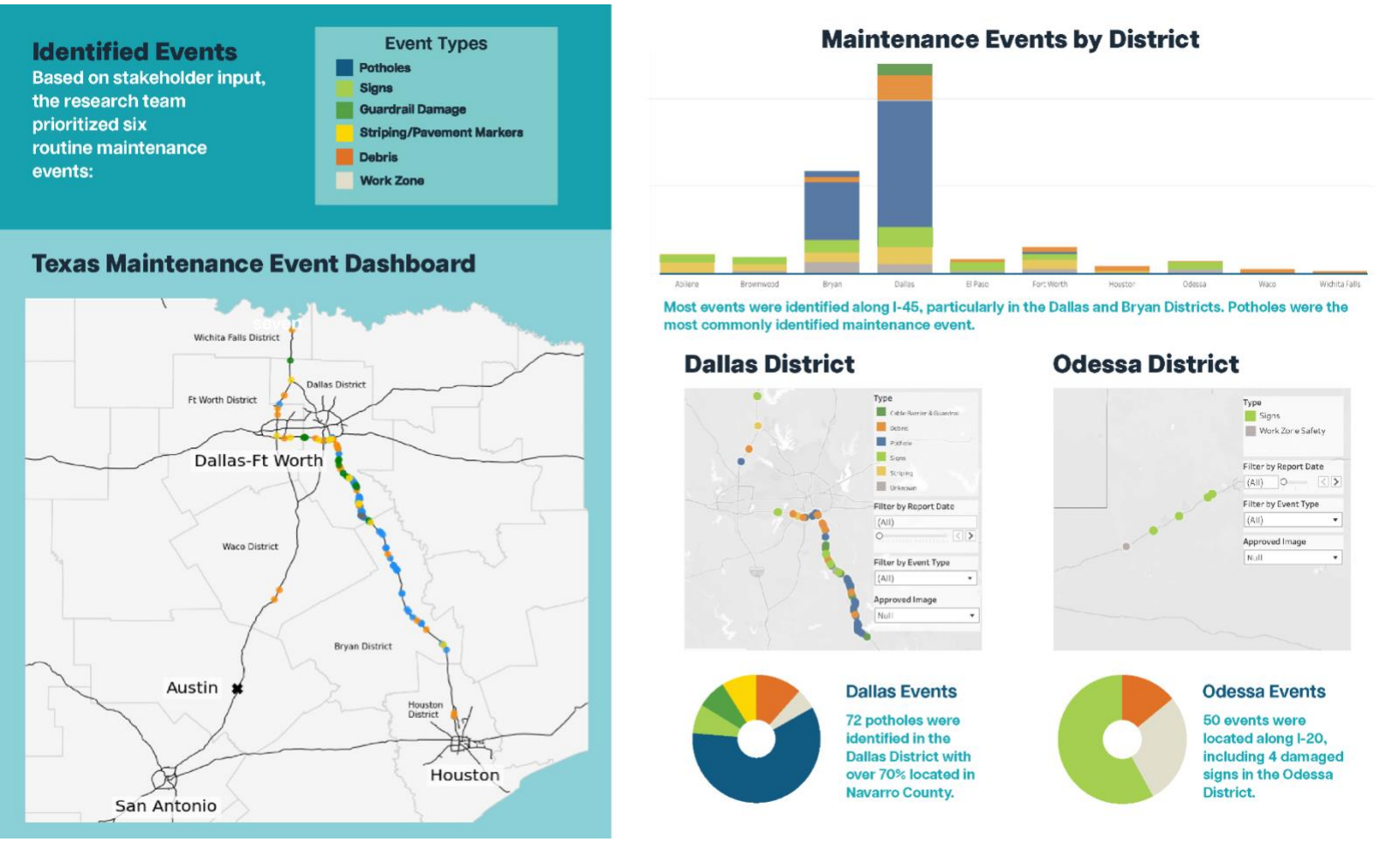


Figure 3: Tableau Dashboard Event Map Using Preliminary Sample Data

Test & Refine

TxDOT Odessa, Dallas, and Houston Districts participated in the testing and refinement of the prototype. Maintenance personnel were asked to monitor autonomous trucking data through the Nighttime Inspection Suite and report on the impacts to their maintenance operations.

In the Odessa District, four damaged sign events were found in the preliminary sample data period. Unfortunately, no events were recorded during the official prototype data period. While there were a limited number of reports, autonomous trucks can still provide valuable information in rural areas.

In the Houston District, six events were recorded during the prototype data period. Three events were debris. Due to either their small size and/or location on the shoulder, the items were flagged for pick up during the next debris/sweeping cycle. Two other maintenance events, namely a pothole and guard rail damage, were identified by the autonomous trucking data. While they did not include images, their coordinates were used to generate work orders. The final event required no action; the autonomous vehicle identified a sign that was attached to a maintenance vehicle on the shoulder. The Houston District provided valuable input, noting the importance of images in improving response time and the need to automate notifications

In the Dallas District, 86 events were recorded across eight maintenance sections, revealing insights into urban and rural areas. A high percentage were potholes, and most events were located along the IH-45 corridor, presenting an opportunity to align with TxDOT's innovation corridor initiative.

Major Findings

TxDOT can leverage the Nighttime Inspection Suite.

TxDOT's existing Statewide Nighttime Inspection Suite provides a strong framework that can be leveraged to incorporate AV trucking data into TxDOT's maintenance processes. Many districts already use the Statewide Nighttime Inspection Suite and are familiar with the tools and capabilities. Stakeholders from Odessa, Dallas, and Houston indicated that they were supportive of expanding the tools to support the ingestion of AV trucking data.

Autonomous trucking companies want to collaborate.

Stakeholders from autonomous trucking companies are very open to collaboration in an effort to improve roadway conditions for all roadway users while benefiting their operations. Stakeholders suggested developing either an FTP site or API that would allow their teams to upload batches of event data to TxDOT, rather than transmit the data manually as they did with sample data.

Data standardization is key.

The research team developed data format and standardization schemas that provide guidance for how autonomous trucking companies should share their maintenance event data. While these guidelines were beneficial, there were still variations in the data that made integration to the Nighttime Inspection Suite challenging. Specifically, Event ID formats and timestamp formats were different between Kodiak and Aurora. Executing a Data Sharing Agreement could help in the future.

Latency impacts maintenance response.

For some events in the Houston District, reports from autonomous trucking companies were not received until approximately a week after the event was detected. The Houston District's maintenance personnel had already responded to the event, so the AV trucking data was no longer useful. A data sharing agreement would help outline when and how often trucking companies should share time-sensitive data.

Images streamline maintenance response.

Only a limited number of maintenance events included an image. For the events where an image was included, TxDOT was able to readily assess the severity of the event and take the appropriate action. For reports that did not include an image, TxDOT maintenance teams were required to make a field visit to verify and assess the report. Ensuring that autonomous trucking companies include an image would minimize the need for these field visits.

Auto-notification would benefit maintenance staff.

TxDOT's existing Statewide Nighttime Inspection Suite is useful for maintenance staff, but it could be improved by auto-notifying staff of safety-critical events, such as debris in the lane of travel or guardrail damage. In the future, TxDOT could establish an FTP site or API where AV trucking companies could automate the uploading process.

Takeaways

The prototype provided a strong proof of concept:

- Autonomous trucking companies want to collaborate to improve roadway conditions, as it also benefits their operations.
- Potholes, signs, and work zone safety were the most reported events.
- The Nighttime Inspection Suite provides a strong foundation for ingesting AV data.

Catalog of AI Solutions

The research team compiled a catalog of complementary AI technology solutions that may supplement data collected from automated trucks. The catalog inventoried twenty-nine solution provides in three categories: infrastructure, vehicle, and user-related applications. The solution providers were mapped to use cases and included an assessment of the technology maturity as well as any existing partnerships with public agencies. Based on the catalog, the research team identified research and deployment opportunities that would enable TxDOT to magnify its return on investment and extend benefits to divisions, districts, and public agencies across the state.

Research Opportunities

The research team identified the following research opportunities:

Create a TxDOT-driven Research Agenda. In addition to existing TxDOT problem statement requests, RTI could solicit input from all TxDOT districts and divisions to create a specific research data agenda and channel research expertise towards highest priority needs.

Make Data Available to the Research Community. By building out data sharing agreements, TxDOT could expand its capacity and capability for analysis via extended access by the research community.

Generate Prototypes for TxDOT Districts and Divisions. In coordination with TxDOT districts, researchers could develop a prototype prior to larger-scale deployment.

Deployment Opportunities

The research team identified the following deployment opportunities:

Automate the Road Inspection Process. Referencing Utah DOT's experience equipping fleet vehicles with Blyncy's Payver technology for construction zone detection and paint-line visibility, garnering successful results and already considering further expansion. TxDOT could equip fleet vehicles with inexpensive AI technology to improve the efficiency and frequency of maintenance event detection.

Leverage Existing Traffic Cameras. Utilizing existing infrastructure, applying AI capabilities to roadside cameras is an opportunity to harness machine vision capabilities without expensive additional infrastructure investments.

Invest in Smart Asset Management. TxDOT's vast infrastructure and asset inventory, expanding due to rapid population growth, raises the opportunities improved asset management solutions will provide. AI tools may be used to optimize performance goals, and inspection capabilities, and streamline maintenance investments.

Procure a Connected Vehicle Data Set. Expanding partnerships with AI-enabled connected vehicles, to harness data insights could be used to inform transportation planning needs and emergency response strategies.

Trial a Traffic Management Platform on a Regional Basis. Expanding coordination and collaboration efforts at a regional scale may support experience building at a district, municipal, and local independently and between agencies. A regional platform may inform decision-making in emergency management, improve the accuracy of travel time predictions, and strengthen corridor management strategies.

Takeaways

AI is a powerful tool that may be applied to routine maintenance operations:

- Start at the district level to pilot before scaling statewide.
- Implement a portfolio approach.
- Decide on latency and granularity based on the maintenance event type.

Cost/Benefit Analysis

The research team developed a cost-benefit analysis comparing the use of a twelve-month data sharing package with Blyncsy to TxDOT's existing routine maintenance practices. This deliverable offered more robust and nuanced insights into the feasibility of supplementing TxDOT's existing maintenance operations with incorporated AI solutions. These insights are useful in assisting the development of a thoroughly planned and scalable IRMF. This first analysis predicted the associated labor and vehicle costs, specifically within TxDOT's Odessa District, over a twelve-month period that accounted for all centerline miles within the district. This analysis was developed in consultation with representatives within TxDOT's Odessa District and from Blyncsy.

Methodology

This specific calculation was made with the assumption of Blyncsy as the primary AI organization, although others such as Roadbotics, Mobileye, or One.Network may also be considered. Blyncsy is a service that utilizes vehicle dashcam footage from vehicles already equipped with dashcams to identify and aggregate roadway maintenance conditions and condition severity. Their Payver platform is currently capable of identifying the five primary maintenance events outlined within the scope of this project, with the exception of official standardized retroreflectivity readings. Further, Blyncsy is capable of integrating data into TxDOT's existing ESRI platform. As dashcam data is collected on an ongoing basis, TxDOT can choose the frequency of data collection requests and reporting latency requirements. Blyncsy's costs are influenced by the number of maintenance events observed, the distance covered, and the frequency of requested data reports.

Major Findings

As TxDOT moves forward in developing a portfolio of third-party data streams, the research team recommends harnessing connected and automated vehicles for real-time and daily data needs and focusing on AI solutions to supplement at greater (i.e., weekly, monthly, or quarterly) intervals. By optimizing each data stream, TxDOT can best allocate its limited resources. Notable benefits realized by procuring an AI solution are reduced labor costs, lower vehicle costs in fuel and maintenance, and fewer emissions. Furthermore, the advanced detection of maintenance issues enables TxDOT to repair assets in a timelier manner and reduce safety risks.

***Table 3**: Proposed Frequency of Inspection by Solution*

Feature	TxDOT Inspection Process	Proposed AI Solution
Potholes	Quarterly	Weekly
Striping	Quarterly	Quarterly
Pavement Markers	Quarterly	Quarterly
Signs	Quarterly	Weekly
Cable Barrier & Guardrail	As part of daily routine	Weekly
Debris	As part of daily routine	None
Work Zones Maintenance Construction	 Hourly Monthly	Weekly

Takeaways

AI solutions can result in cost savings.

- AI tools can be used to develop asset inventories and condition reports.
- Using dashcam footage can minimize the emissions impact from TxDOT inspection vehicles.
- High-intensity quarterly inspections can be supplemented with AI tools.

Procurement Documents

The research team identified procurement pathways for four major components of the IRMF.

Automated Trucking Data

Purpose: Identify routine maintenance events
Procurement Pathway: Data sharing agreement

The research team recommends entering into data sharing agreements with autonomous trucking companies to facilitate the exchange of information pertaining to routine maintenance operations. A data sharing agreement would enable TxDOT to grant rights to autonomous trucking partners to transmit, receive, and use transportation-related information regarding asset condition, safety, and mobility data ("Routine Maintenance Data") for the benefit of TxDOT's intelligent routine maintenance program. The research team drafted specifications based on TxDOT's Texas Connected Freight Corridors data sharing agreement template, which may be found in the Appendix of TM 7.3.

Nighttime Inspection App and/or ArcGIS Workforce

Purpose: Collect, characterize, map, assign, and resolve routine maintenance events
Procurement Pathway: Task order

The IRMF leverages TxDOT's existing Nighttime Inspection Suite to combine traditional TxDOT inspection data with autonomous trucking data. The Nighttime Inspection Suite currently maps routine maintenance events; however, it is limited in its ability to assign and mark resolved events across internal and external maintenance personnel. The research team recommends conducting an internal assessment across TxDOT Districts and then working with ESRI to add the appropriate functionality to the Nighttime Inspection Suite and/or ArcGIS Workforce to create a statewide solution.

Dashboard

Purpose: Analyze data and visualize key performance indicators
Procurement Pathway: Develop in-house

The IRMF includes a dashboard that enables TxDOT maintenance sections, districts, and divisions to readily visualize routine maintenance events and key performance indicators. Leveraging TxDOT's existing contract with Tableau, the research team recommends that TxDOT ITD build out a dashboard in-house to complement the Nighttime Inspection App. The dashboard would map and capture key performance indicators such as the number of routine maintenance events by type, roadway, and TxDOT district.

Third-Party Data Services

Purpose: Identify routine maintenance events and provide asset management information
Procurement Pathway: Request for proposal

The research team recommends issuing a request for proposal (RFP) to solicit multiple vendors for a statewide contract. Vendors who meet the criteria may be awarded contracts and could be made accessible to all TxDOT districts and divisions as well as other public agencies. The research team recommends modeling the RFP after the one issued for location-based services, which resulted in statewide contracts with INRIX, Wejo, and Replica. The research team drafted minimum core requirements, which may be found in TM 7.3.

Takeaways

The research team identified four procurement pathways:

- A data sharing agreement is necessary to receive AV trucking data at scale.
- Functionality can be added to the Nighttime Inspection Suite through existing contracts.
- TxDOT can develop dashboards and performance tools in-house.

7 | RECOMMEND

Growth Opportunities

The research team has identified several opportunities to supplement the growth and scaling of the IRMF.

Automate and Integrate the Prototype into TxDOT Routine Maintenance Practices. For the prototype, AV trucking companies flagged events manually, emailed the to the research team, and the events were uploaded to the Nighttime Inspection Suite by TxDOT ITD staff. In the future, there are opportunities to automate each step in this process.

Expand the IRMF to Include Additional Automated Vehicle Developers. This project included data from two AV trucking companies. While the partnerships with these two companies were successful, there are opportunities to expand to other developers including other freight partners, passenger companies, and last mile.

Increase TxDOT District Participation. Houston, Odessa, and Dallas Districts participate in the prototype development and testing process. There are opportunities to scale the deployment along the Texas Triangle in alignment with autonomous vehicle deployments. To reach other districts where AV trucking companies are not operating, data could be sourced from other AI solutions and vendors.

Strategic Recommendations

The research team has also identified several strategic recommendations:

Support the Texas Connected and Automated Transportation (CAT) Program. The CAT Program is a TxDOT initiative that works to integrate emerging transportation technologies, including AVs and CVs, into the state's transportation system. This program serves to uplift necessary policy and procedural decisions that will maximize the benefit these technologies bring. The CAT Plan specifically works to implement these technologies that can offer benefits to roadway safety, transportation reliability, economic vitality, response agility, and an accessible and comprehensive mobility system. The IRMF aligns with many of the primary goals for the CAT Program, including transportation reliability, economic vitality, and an overall improved mobility system. The CAT Program could serve as a formal body to secure and align necessary coordination that paves the foundational policies and procedural needs to sustain and amplify the impact of this project.

Strengthen Digital Asset Management Techniques. Transportation systems management and operations (TSMO) drive methodology for embracing and harnessing emerging technology solutions, of which digital asset management is a foundational piece. Effective asset management systems improve tracking work orders, viewing and organizing data, and assigning appropriate labor and response resources. The output of the IRMF closely aligns with the goals and benefits from automating asset cataloging and maintenance conditions reporting. Strengthening this partnership enhances the benefits of effective TSMO, without unnecessary duplication of efforts.

Launch an Artificial Intelligence & Maintenance Program (AIM). The research team recommends establishing the Artificial Intelligence & Maintenance (AIM) Program. The objective of the AIM Program is to leverage emerging data sources, artificial intelligence, and machine learning to improve routine maintenance operations. In particular, the AIM Program will enable TxDOT to provide safe roadway surfaces, preserve the state's capital investments in its roadway/roadside assets, maintain a riding quality satisfactory to the traveling public, alleviate congestion, and optimize return on investment.

VALUE OF RESEARCH

Table A-1 presents the summary of the value of research (VoR) estimation for Project 0-7129 based on the functional areas selected by the research team and TxDOT. The functional areas deemed relevant and noted in the project contract include both qualitative and economic components.

Table A-1: 0-7129 Value of Research Benefit Areas

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both
Level of Knowledge	X			X		
Expedited Project Delivery		X		X		
Safety			X			X
Traffic and Congestion Reduction		X			X	
System Reliability		X		X		
Reduced Construction, Operations, and Maintenance Cost		X			X	
Materials and Pavements		X			X	
Infrastructure Condition		X				X
Freight movement and Economic Vitality		X				X
Intelligent Transportation Systems		X				X

Economic Benefits

Level of Knowledge

This research developed a proof of concept for a data-sharing partnership between autonomous trucking companies and TxDOT. The research identified data needs for TxDOT maintenance staff, high-priority roadway condition incidents for autonomous operations, and feasible data exchange partnerships. This research developed knowledge about applications of CAV data, public-private data sharing, recommended standards and sharing guidelines, and maintenance data needs. This research improved knowledge for successful implementation of data-sharing for maintenance operations by providing recommendations based on a prototype pilot and key stakeholder input.

Qualitative Benefits

Safety, Traffic and Congestion Reduction, and System Reliability

During the one-month data collection period, autonomous trucks detected 70 potholes, 25 striping events, and 53 guardrail and cable barrier damage events. Early detection of these maintenance events will improve roadway condition, reduce roadway-related crashes, and reduce congestion and travel time variability. Assuming detection rates remain similar month to month, estimated events detected per year by autonomous trucks is calculated in Table A-2 below. Annual crashes related to potholes, striping, and

guardrail and cable barrier damage were queried from the C.R.I.S. database for 2022, and annual costs were calculated based on severities and according to Table A-3. Crash reduction factors associated with improving each defect are noted below and were retrieved from TxDOT's Highway Safety Improvement Program guidelines. Reduction in crashes due to improved maintenance not only improves safety, but also congestion and reliability. To calculate economic benefits of reduced congestion and improved reliability, value of personal travel time was assumed to be $19.64[1], and average incident clearance time was assumed to be 30 minutes[2].

Table A-2: *Crash Reductions*

Event Type	Estimated Events Detected per Year	Annual Defect-Related Crashes (2022)	Cost of Annual Defect-Related Crashes	Crash Reduction Factor[3][4]
Potholes	840	329	**$6,431,700**	3%
Striping	300	87,894	**$3,314,751,400**	20%
Guardrail & Cable Barrier	636	2,088	**$340,459,900**	35%

Table A-3: *Average Economic Cost by Injury Severity or Crash*

Crash Severity	Cost
Death (K)	$1,778,000
Disabling (A)	$155,000
Evident (B)	$40,000
Possible (C)	$24,000
Not Injured (N)	$6,700

Freight Movement and Economic Vitality.

Freight impacts were calculated similarly; better roadway conditions and fewer crashes will improve travel times, reliability, and efficient operations for freight carriers in Texas. The analysis used a 2022 statistic from the Texas Comptroller that reported 200,000 issued commercial driver's license holders. Valuation

[1] Texas A&M Transportation Institute, Urban Mobility Report 2021: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2021-appx-c.pdf
[2] Federal Highway Administration Focus States Initiative: Traffic Incident Management Performance Measures Final Report: https://ops.fhwa.dot.gov/publications/fhwahop10010/index.htm#toc
[3] TxDOT HSIP Program Guidelines: https://ftp.dot.state.tx.us/pub/txdot-info/trf/hsip/hsip-guidance.pdf
[4] CMF Clearing House: https://www.cmfclearinghouse.org/

of time for commercial drivers was assumed to be $55.24 when calculating impacts of incident-related delays[5].

Intelligent Transportation Systems.

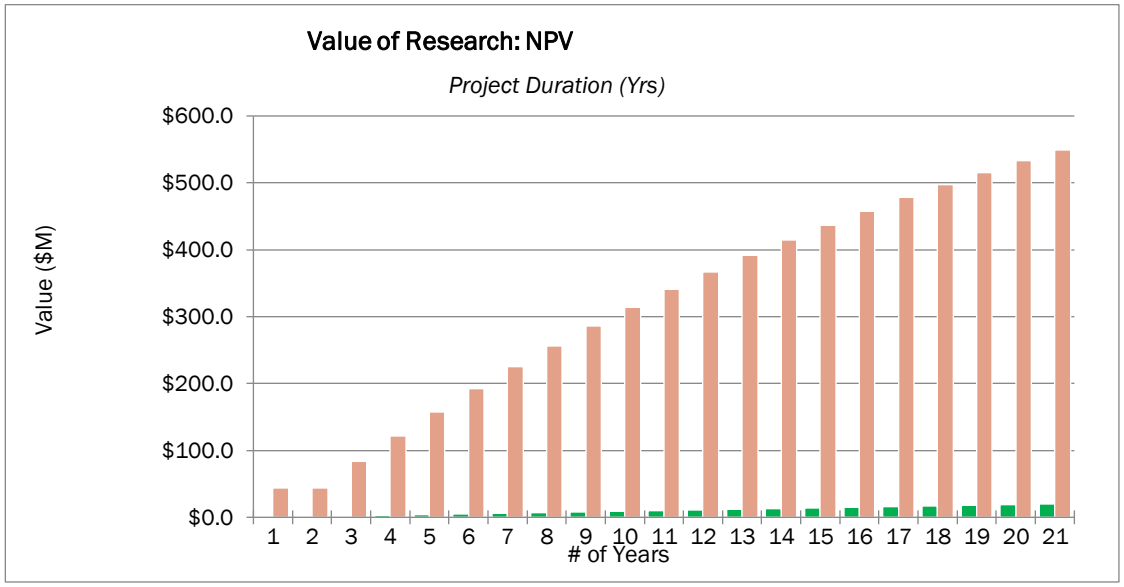
In TxDOT's TSMO Strategic Plan, it is noted that increased ITS systems support to the districts will help improve asset uptime[6]. Incident detection from autonomous trucks can help reduce the need for districts' incident detection monitors, which cost $2800 per device[7].

Reduced Construction, Operations, and Maintenance Cost, Expedited Project Delivery, Materials and Pavements, and Infrastructure Condition.

As part of this research effort, a cost/benefit analysis was performed that considered maintenance operations, project delivery, materials and infrastructure conditions costs for each district's annual maintenance program. The annual cost to districts was calculated as $664,336 and it was assumed that autonomous trucking data can reduce costs by 10%.

Net Present Value Results

Net present value with 5% discount rate over a payback period 20 years was found to be $341,022,205. The cost benefit ratio was calculate to be 1,050:1. Annual expected value was calculated to be $46,129,726.



[5] Texas A&M Transportation Institute, Urban Mobility Report 2021: https://static.tti.tamu.edu/tti.tamu.edu/documents/mobility-report-2021-appx-c.pdf

[6] TxDOT TSMO Strategic Plan, 2021 https://ftp.txdot.gov/pub/txdot-info/trf/tsmo/statewide-strategic-plan.pdf

[7] TxDOT Statewide TSMO Benefit-Cost Analysis https://ftp.txdot.gov/pub/txdot-info/trf/tsmo/benefit-cost-analysis.pdf

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