March 2024 | Prepared by: Athey Creek Consultants

ENTERPRISE

Comparison of Emerging Traffic Data Collection Methods to Traditional Methods

ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(490)

FINAL REPORT

Technical Report Documentation Page

1. Report No. ENT 2024-1	2. Government Accession No.	3. Recipients Catalog No.	
4. Title and Subtitle Comparison of Emerging Traffic Data Collection Methods to Traditional Methods		5. Report Date March 2024 6. Performing Organization Code	
7. Author(s) Tina Roelofs and Linda Preisen		8. Performing Organization Report No.	
9. Performing Organization Name and Address Athey Creek Consultants 2097 County Road D, Suite C-100 Maplewood, MN 55109		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. 2023-0171	
12. Sponsoring Organization Name and Address ENTERPRISE Transportation Pooled Fund Study TPF-5(490) Michigan Department of Transportation (Administering State) PO Box 30050 Lansing, MI 48909		13. Type of Report and Period Covered FINAL Report 14. Sponsoring Agency Code	
15. Supplementary Notes Final Report: [Insert link to final report]			
16. Abstract Transportation agencies use many traditional data collection methods (e.g., manual counts, pneumatic tubes, in-road sensors, radar sensors) as well as emerging data collection methods (e.g., unmanned aircraft systems, probe data, video image detection and processing) for traffic data collection. While traditional traffic data collection methods have provided trusted data for many years, there may be advantages to using emerging traffic data collection methods to supplement or replace existing methods. For example, emerging traffic data collection methods may reduce resources needed to operate and maintain detection devices in the field, provide more complete coverage and faster access to data, or offer advanced analytics to increase an agency’s ability to glean useful insights from the data. Because tradeoffs likely exist when assessing various traffic data collection methods, it is important to compare emerging data collection options to traditional methods and learn from agency experiences. This Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) TPF Study project gathered traffic data collection methods and details through a literature search and survey of transportation agencies. After information-gathering was complete, a comparison of emerging traffic data collection alternatives to traditional methods was conducted and documented.			
17. Document Analysis/Descriptors Traffic data collection		18. Availability Statement No restrictions.	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 101	22. Price

Comparison of Emerging Traffic Data Collection Methods to Traditional Methods

Final Report

Prepared by:

Athey Creek Consultants

March 2024

Published by:

ENTERPRISE Transportation Pooled Fund Study TPF-5(490)
Michigan Department of Transportation (Administering State)
PO Box 30050
Lansing, MI 48909

Acknowledgements

This *Comparison of Emerging Traffic Data Collection Methods to Traditional Methods* report was prepared for the Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) Transportation Pooled Fund Study Transportation Pooled Fund (TPF)-5(490) program (https://enterprise.prog.org/). The primary purpose of ENTERPRISE is to use the pooled resources of its members from North America and the United States federal government to develop, evaluate, and deploy Intelligent Transportation Systems (ITS).

The cover page image is provided courtesy of RettungsgasseJETZTde on Pixabay.

Project Champion

Charles Tapp from the Texas Department of Transportation was the ENTERPRISE Project Champion for this effort. The Project Champion served as the overall lead for the project.

ENTERPRISE Members

The ENTERPRISE Board consists of a representative from each of the following member entities.

- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Ontario Ministry of Transportation
- Texas Department of Transportation
- Wisconsin Department of Transportation

Project Input

ENTERPRISE would like to thank the many state transportation agencies that provided input to the project through an online survey.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
AZ	Arizona
CCS	Continuous Count Station
CTSO	Committee on Transportation System Operations
DOT	Department of Transportation
ENTERPRISE	Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency
FHWA	Federal Highway Administration
FMCW	Frequency Modulated Continuous Wave
HOT	High-occupancy Toll
HOV	High-occupancy Vehicle
HPMS	Highway Performance Monitoring System
ID	Idaho
IA	Iowa
KS	Kansas
KY	Kentucky
ML	Machine Learning
MI	Michigan
NH	New Hampshire
PA	Pennsylvania
QA	Quality Assurance
QC	Quality Control
RSA	Road Safety Audits
SC	South Carolina

TX	Texas
TMC	Traffic Management Center
TPF	Transportation Pooled Fund
UT	Utah
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
VIP	Video Image Processing
VMT	Vehicle Miles Traveled
WIM	Weigh in Motion

Executive Summary

Transportation agencies use many traditional traffic data collection methods as well as emerging traffic data collection methods. The traffic data is collected for a variety of reasons including to inform traffic studies or other transportation planning efforts, to complete Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) reporting, or to support traffic management efforts. For this project, traditional traffic data collection methods are those that have been used by transportation agencies for many years and are largely understood in terms of performance and maintenance over time. Emerging traffic data collection methods are still evolving and in some cases are showing advantages compared to traditional methods but are not yet fully demonstrated or institutionalized in many transportation agencies.

While traditional traffic data collection methods have provided trusted data for many years, there may be advantages to using emerging traffic data collection methods to supplement or replace existing methods.

Because tradeoffs likely exist when assessing various traffic data collection methods, the Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) Transportation Pooled Fund (TPF) Study members were interested in comparing emerging traffic data collection options to traditional methods and learn from agency experiences. A literature search and survey of transportation agencies were conducted to document details (e.g., benefits, drawbacks) of traditional and emerging data collection methods and compare the emerging methods to traditional traffic data collection methods.

There were 12 traditional traffic data collection methods and 5 emerging traffic data collection methods identified through the literature search and survey of transportation agencies. See Section 2.0.

- Traditional Traffic Data Collection Methods
  - Acoustic Sensors
  - Bluetooth/Wi-Fi
  - Floating Car Survey
  - Inductive Loops
  - Infrared Sensors
  - Magnetic Sensors
  - Manual Counts
  - Microwave Sensors
  - Piezoelectric Sensors
  - Pneumatic Tube
  - Radar Sensors
  - Ultrasonic Sensors
- Emerging Traffic Data Collection Methods
  - Purchasing Sensors as a Service
  - Thermal Imaging Cameras
  - Third-Party Probe Data
  - Unmanned Aircraft Systems (UAS)/ Unmanned Aerial Vehicle (UAV)
  - Video Imaging Detection/Processing

It is important to note that the literature search (See Section 3.0) and survey (See Section 4.0) of transportation agencies for this project was not meant to be exhaustive but to provide a sampling of related documentation available on different traditional and emerging methods for traffic data collection.

From review of the resources and the survey responses, specific types of emerging traffic data collection methods were compared to traditional methods based on categories such as installation and maintenance, safety, data coverage, data analytics, privacy, and other considerations. (See Section 5.0.) Selected key findings from the comparison are presented in Table E.1.

Table E.1 Traditional and Emerging Traffic Data Collection Methods

<table>
<tr><th rowspan="2">Category</th><th colspan="2">Key Findings</th></tr>
<tr><th>Traditional</th><th>Emerging</th></tr>
<tr><td>Installation, Maintenance, and Safety</td><td>• Field installation and maintenance (e.g., lens cleaning) are needed for traditional methods except for conducting manual counts and floating car surveys.
• Some installation methods are pavement invasive (e.g., pneumatic tubes, in-road sensors), and some are noninvasive (e.g., microwave sensors).
• There are safety concerns (e.g., lane closure) with data collection methods that require staff to install and maintain equipment near traffic. However, once installed, there is no disruption of traffic or safety concerns, unless maintenance is needed.</td><td>• Using probe data or UAS/UAVs reduces the number of overall field devices for an agency, reducing installation and maintenance associated with physical detection devices. In addition, there is less agency labor time to collect data with the use of third-party probe data.
• Transportation agencies that purchase sensors as a service may reduce their in-house installation and maintenance effort and costs.
• Field safety is not a concern with probe data since there is no field installation or maintenance needed. However, field safety concerns exist with installation and maintenance of other emerging methods, for example where a lane closure may be required to access field detection devices.</td></tr>
<tr><td>Data Coverage, Availability, and Accuracy</td><td>• Traditional traffic data collection sensors are not deployed statewide (i.e., ubiquitously), they are deployed at specific point locations (e.g., spaced out along corridor, intersection, road segment). Therefore, widespread traffic data is not available as needed for some agency purposes.
• Some traditional methods (e.g., Bluetooth/Wi-Fi) provide data in real-time if there is communication from the sensor back to, for example a Traffic Management</td><td>• Probe data provides broad (e.g., statewide) coverage. However, gaps can exist with obtaining probe data at locations with no cellular service.
• Real-time data can be provided with all emerging traffic data collection methods investigated in this project. Real-time traffic data provides quicker access to the data allowing a faster turnaround for use in studies.
• Video imaging detection/processing can offer a quicker method to provide vehicle and pedestrian counts at intersections.</td></tr>
</table>

Category	Key Findings	
	Traditional	**Emerging**
	Center (TMC). However, some methods such as pneumatic tubes and manual counts will only provide historical data. • Traditional methods (e.g., manual counts, pneumatic tubes) have been proven to provide accurate data. Although human error can impact accuracy (e.g., manual counts) and improper installation will lead to inaccurate data. • Pneumatic tubes, in-road sensors, and radar cannot tell what direction vehicles are traveling from shared lanes. Microwave sensors provide directional traffic data for all types of roadways.	• UAS/UAVs are well suited for sporadic, critical, short term, gathering efforts where flexibility of operation is beneficial. UAS/UAVs also provide a benefit with the ability to use in rural areas or areas with challenging terrain. However, trained staff are needed to pilot UAS/UAV operations when these are used for traffic data collection. • While probe data (e.g., speeds) is suitable for many agency purposes, there are accuracy challenges observed with several conflicting movements (e.g., driveways), times of day with very low traffic volumes (e.g., overnight, rural facilities), and where signals are densely spaced.
Environmental/ Weather Impacts	• Many traditional methods (e.g., acoustic sensors, inductive loops, magnetic sensors, microwave sensors, radar sensors) are not affected by weather conditions. However, some methods (e.g., infrared sensors) can be less effective in conditions such as fog, clouds, shadows, mist, rain, and snow.	• There are no environmental condition challenges with probe data. There are some weather constraints with purchasing sensors as a service, UAS/UAVs, thermal imaging cameras, and video imaging detection/processing. For example, UAS/UAVs cannot fly in extreme weather conditions, and video imaging detection/processing is constrained in dark conditions.
Need for Data Analytics	• Traditional traffic data collection methods can require data analytics. For example, data from point detection devices located around a state may need to be extrapolated to understand volumes for statewide HPMS reporting. • Data from inductive loops or radar may also need to be analyzed to convert to travel times, trigger	• Many transportation agencies utilize vendors or universities to perform data analytics due to the large amount of data produced by some of the emerging traffic data collection methods such as probe data.

Category	Key Findings	
	Traditional	Emerging
	congestion alerts, or show congestion on a map.	

Numerous examples of how emerging traffic data collection methods have complemented or replaced traditional traffic data collection methods were also documented from the resources reviewed and the survey conducted for the project. See Section 5.0. The following are a few examples.

- Third-party data is available statewide in Pennsylvania; therefore, it is generally discouraged to deploy/use physical detectors except in areas where probe data is demonstrably insufficient.
- Automatic processing time for vehicle counts with UAV in Washington was approximately 1.8 hours per hour of video, compared to 6 hours of manual processing per hour of video.
- Probe data as noted by the Texas DOT can replace a radar speed study if there are single lane approaches and high enough probe density in the area, otherwise the probe data complements with providing extra data.
- The use of video imaging detection/process in Idaho has provided counts where every other traditional method is not an option, and it provides a way to remove people from stepping onto roadways in high traffic areas.
- In Texas, use of video imaging detection/processing has removed staff from the road and provides a quick method to count intersections, pedestrians, etc. It is also convenient, saves time, and has replaced the need for manual counts.

Overall, the research conducted for this project provided ENTERPRISE member agencies with details about traffic data collection methods to inform staff about the benefits and drawbacks as traffic data collection methods are considered.

Chapter 1: Introduction

Transportation agencies use many traditional traffic data collection methods as well as emerging traffic data collection methods. The traffic data is collected for a variety of reasons including to inform traffic studies or other transportation planning efforts, to complete Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) reporting, or to support traffic management efforts. For this project, traditional traffic data collection methods (e.g., manual counts, pneumatic tubes, in-road sensors, radar sensors) are those that have been used by transportation agencies for many years and are largely understood in terms of performance and maintenance over time. Emerging traffic data collection methods (e.g., purchasing sensors as a service, probe data, video imaging detection and processing, thermal imaging cameras) are still evolving and in some cases are showing advantages compared to traditional methods but are not yet fully demonstrated or institutionalized in many transportation agencies.

TRAFFIC DATA COLLECTION METHODS

TRADITIONAL*:* Methods that have been used for many years and are largely understood in terms of performance and maintenance over time.

EMERGING*:* Methods that are still evolving and in some cases are showing advantages compared to traditional methods but are not yet fully demonstrated or institutionalized.

While traditional traffic data collection methods have provided trusted data for many years, there may be advantages to using emerging traffic data collection methods to supplement or replace existing methods. For example, emerging traffic data collection methods may reduce resources needed to operate and maintain detection devices in the field, provide more complete coverage and faster access to data, or offer advanced analytics to increase an agency's ability to glean useful insights from the data.

Because tradeoffs likely exist when assessing various traffic data collection methods, the Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) Transportation Pooled Fund (TPF) Study members were interested in comparing emerging traffic data collection options to traditional methods and learn from agency experiences.

This ENTERPRISE Pooled Fund Study project explored emerging methods for collecting traffic data compared to more traditional methods.

1.1 Project Approach

The project gathered information through a literature search and survey of transportation agencies. After information-gathering was complete, a comparison of emerging traffic data collection alternatives to traditional methods was documented, considering factors such as benefits and drawbacks. See Figure 1.1 illustrating the project approach.

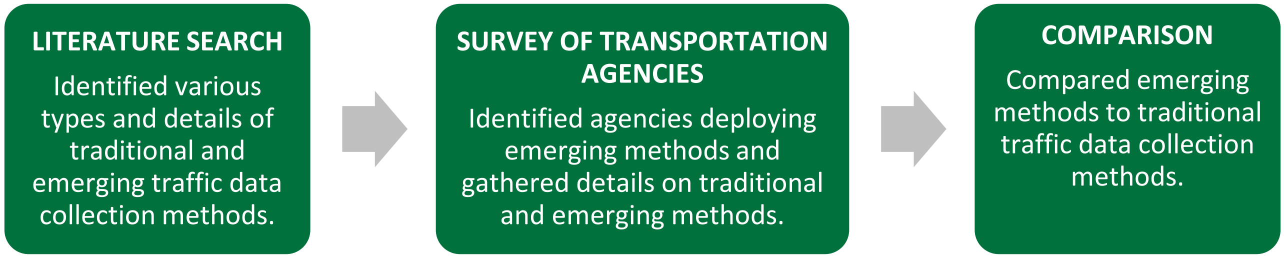

Figure 1.1 Project Approach

1.2 Report Organization

This report includes the following sections:

- Chapter 2 Traffic Data Collection Methods – Defines the traditional and emerging traffic data collection methods that were identified through the literature search or survey of transportation agencies.
- Chapter 3 Literature Search – Presents key findings from the literature search which identified traditional and emerging traffic data collection methods and factors (e.g., benefits, drawbacks).
- Chapter 4 Survey of Transportation Agencies – Provides results from the survey of transportation agencies which identified which state Departments of Transportation (DOTs) have implemented traditional and emerging traffic data collection methods and the details of both methods.
- Chapter 5 Traffic Data Collection Methods Comparison – Presents a comparison of emerging traffic data collection methods to traditional traffic data collection methods.
- Chapter 6 Summary and Implementation – Provides an overall project summary and describes suggested next steps for ENTERPRISE members to consider based on findings and the comparison of emerging and traditional traffic data collection methods.
- Appendix A – Presents details documented from the literature search.
- Appendix B – Presents the survey questions that were distributed to transportation agencies.
- Appendix C – Presents the responses received from the survey of transportation agencies.

Chapter 2: Traffic Data Collection Methods

Through the literature search described in Chapter 3 and the survey of transportation agencies presented in Chapter 4 there were 12 traditional traffic data collection methods and 5 emerging traffic data collection methods identified. See Table 2.1. The results from the literature search and survey for this project were not meant to provide an exhaustive list of traffic data collection methods but to identify overall different traditional and emerging methods for traffic data collection.

Table 2.1 Traditional and Emerging Traffic Data Collection Methods

Traditional	Emerging
Acoustic Sensors	Purchasing Sensors as a Service
Bluetooth/Wi-Fi	Thermal Imaging Cameras
Floating Car Survey	Third-Party Probe Data
Inductive Loops	Unmanned Aircraft Systems (UAS)/Unmanned Aerial Vehicle (UAV)
Infrared Sensors (Active and Passive)	Video Imaging Detection/Processing
Magnetic Sensors	
Manual Counts	
Microwave Sensors	
Piezoelectric Sensors	
Pneumatic Tube	
Radar Sensors (Forward-firing and Side-Firing)	
Ultrasonic Sensors	

As the resources were reviewed from the literature search of traffic data collection methods, definitions from each method were found and are included in this section to assist in understanding each traffic data collection method.

2.1 Traditional Traffic Data Collection Methods: Definitions

Table 2.2 includes definitions for the traditional traffic data collection methods found through the literature search and survey of transportation agencies.

Table 2.2 Literature Search: Traditional Traffic Data Collection Methods – Definitions

Traditional Method	Definition (Source – Noted at end of table)
Acoustic Sensors	Acoustic sensors measure vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety

Traditional Method	Definition (Source – Noted at end of table)
	of sources within each vehicle and from the interaction of vehicle's tires with the road. When a vehicle passes through the detection zone, an increase in sound energy is recognized by the signal processing algorithm and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold, and the vehicle presence signal is terminated. Sounds from locations outside the detection zone are attenuated. Single lane and multiple lane models of acoustic sensors are marketed. Both use a two-dimensional array of microphones to detect the sounds produced by approaching vehicles. (1)
Bluetooth/Wi-Fi	Bluetooth/Wi-Fi can be used as an ITS roadside detection technology to collect travel time and speed data. Examples of applications for this type of information include identifying real-time traffic conditions or speed limit violations. (2)
Floating Car Survey	The purpose of speed test runs is to generate an operating speed profile and ensure that measured spot speeds are representative of speeds throughout the section. Conducting data collection in this manner involves following cars and recording their speeds or journey times. This method allows an assessment of a driver's free-flow speed, and not the desired speed of the person conducting the survey. (3)
Inductive Loop Detector	Inductive loop detectors are a 'loop' of insulated wire installed in the pavement. A detector unit passes an electric current through the loop wire, creating an electromagnetic field. When a conductive metal object moves through this field, a change in energy level occurs, decreasing the inductance of the loop. This increases the oscillation frequency and sends a pulse to the controller, marking the presence of a vehicle. (4)
Infrared Sensors	Active and passive infrared sensors are manufactured for traffic flow monitoring applications. Active infrared sensors illuminate detection zones with low power infrared energy transmitted by laser diodes operating in the near infrared region of the electromagnetic spectrum at 0.85 mm. Passive sensors transmit no energy of their own. Rather they detect energy from two sources: Energy emitted from vehicles, road surfaces, and other objects in their field-of-view and energy emitted by the atmosphere and reflected by vehicles, road surfaces, or other objects into the sensor aperture. (1)
Magnetic Sensors	A magnetic sensor (induction or search coil magnetometer) detects the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) it causes in the Earth's magnetic field. It is placed under or in the roadway to detect the passage of a vehicle over the sensor. Its output is connected to an electronics unit. The two types of magnetic sensors are fluxgate magnetometers and induction magnetometers, referred to as magnetic detectors as described in the Traffic Monitoring Guide. (5)

Traditional Method	Definition (Source – Noted at end of table)
Manual Counts	Manual traffic counts involve employees manually counting the volume of cars they see on the roadway. The count can occur onsite, with the counter watching the roadway in real-time, or offsite, with the counter watching a video recording. To record the data, tally sheets or mechanical counters may be used. Manual counts often require 2 or more employees to collect data for each lane, and to increase accuracy. (4)
Microwave Sensors	A microwave sensor transmits electromagnetic energy from an antenna toward vehicles traveling the roadway. When a vehicle passes through the antenna beam, a portion of the transmitted energy is reflected towards the antenna. The energy then enters a receiver where the detection is made and traffic flow data, such as volume count, speed, and vehicle length, are calculated. Microwave sensors that utilize the Doppler principle analyze the frequency of the received signal. The frequency is decreased by a vehicle moving away from the radar and increased by a vehicle moving toward the radar. Vehicle passage or count is denoted by the presence of the frequency shift. Vehicle presence cannot be measured with the constant frequency waveform since only moving vehicles are detected. (5)
Piezoelectric Sensors	A piezoelectric sensor detects a vehicle axle's passage using a change in the sensor's voltage that is directly proportional to the pressure applied by the vehicle wheel on the sensor. Piezoelectric sensors are used independently to detect and classify vehicles or in conjunction with loop inductors to increase classification accuracy by providing overall (loop) length. Piezoelectric sensors, in combination with passive infrared technologies, are capable of detecting bicycles in mixed pedestrian and bicycle traffic. Piezo sensors are also used for weigh in motion (WIM) sensing. (5)
Pneumatic Tube	Pneumatic tubes are taped down on the surface of the roadway, perpendicular to traffic flow. When a vehicle drives over a pneumatic tube, a burst of air pressure is released and sent through the tube. The pressure burst closes an air switch, which sends an electrical signal to the counting software. The tubes are powered by batteries, lead-acid, or gel, making them easy to move between count sites. (4)
Radar Sensors	Doppler radar sensors transmit microwave signals, and when there is vehicle motion, the frequency of the reflected signal changes, allowing sensors to detect the presence and speed of a vehicle. Frequency Modulated Continuous Wave (FMCW) radars transmit a signal, and upon reception, measure differences in phase or frequency. There are two primary traffic radar technologies: side-firing and forward-firing. Both use radar to detect the presence of moving vehicles on the road and are able to classify vehicles based on vehicle length measurements. (4)

Traditional Method	Definition (Source – Noted at end of table)
Ultrasonic Sensors	An ultrasonic sensor transmits pressure waves of sound energy at a frequency between 25 and 50 kHz, which is above the human audible range. Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information. (1)

(1) Source: Traffic Detector Handbook (Klein et al., 2006)
(2) Source: Data Collection and ITS (ITS JPO, 2022)
(3) Source: Methods and Practices for Setting Speed Limits: An Informational Report (Forbes et al., 2012)
(4) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(5) Source: Traffic Monitoring Guide (FHWA, 2022)

2.2 Emerging Traffic Data Collection Methods: Definitions

Table 2.3 includes definitions for emerging traffic data collection methods found through the literature search and survey of transportation agencies.

Table 2.3 Literature Search: Emerging Traffic Data Collection Methods – Definitions

Emerging Method	Definition (Source – Noted at end of table)
Purchasing Sensors as a Service	A DOT may purchase sensors as service by paying a contractor to install and maintain the desired sensors for the DOT. This allows a DOT to receive traffic data collected by field sensors with less direct agency maintenance and installation effort and cost.
Thermal Imaging Cameras	When a vehicle or pedestrian enters a thermal camera detection zone, traffic data is automatically processed and collected based on dedicated algorithms. Thermal cameras detect heat signatures, allowing them to accurately detect vehicles, pedestrians, and bicycles while measuring speed. Based on the heat signature, vehicles are detected and classified accordingly. (1)
Third-Party Probe Data	Probe data is defined as data that is generated by monitoring the position of individual vehicles (i.e., probes) over space and time rather than measuring characteristics of vehicles or groups of vehicles at a specific place and time. (2)
UAS/UAV	UAVs are multi-purpose aircraft that may operate under the direct control of a remote pilot, or which may be flown autonomously via onboard or remotely located control systems. UAS more broadly include the UAV as well as any supporting systems including pilots, control hardware and software, and ancillary systems such as sensors (e.g., weather, radar) and communication equipment. UAS offer the ability to quickly collect data on temporal disruptions, to fill in data gaps, and to provide more comprehensive and higher quality information to those managing and planning operations. (3)

Emerging Method	Definition (Source – Noted at end of table)
Video Imaging Detection/ Processing	Video imaging detection systems use one or more cameras, a microprocessor-based computer, and software to capture and analyze video footage of a roadway. The cameras are able to differentiate and classify moving vehicles, and unlike manual count video footage, vehicle count and classification is analyzed and processed by the accompanying software. (1) Video imaging processing typically consists of one or more cameras, a microprocessor-based computer for digitizing and analyzing the imagery, and software for interpreting the images and converting them into traffic flow data. (4)

(1) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)

(2) Source: *Work Zone Performance Measurement Using Probe Data (FHWA, 2017)*

(3) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022)

(4) Source: Traffic Detector Handbook (Klein et al., 2006)

Chapter 3: Literature Search

This chapter provides a summary of the literature search completed for this project. The purpose of the literature search was to identify traditional (used by transportation agencies for many years and fully understood) and emerging (still evolving and show great promise but are not yet fully demonstrated or institutionalized in many transportation agencies) traffic data collection methods. The following sections list the resources reviewed (Section 3.1) and note key findings (e.g., benefits, drawbacks) of the traffic data collection methods found in the literature search (Section 3.2).

3.1 Resources Reviewed

The literature search mostly focused on resources published from 2015 to 2023 and included online articles, research reports, related ENTERPRISE projects, and a handbook (published in 2006). A total of 27 resources were reviewed and are listed in Table 3.1. The table provides a link to the resource and identifies which traffic data collection method was included in the resource. It is important to note that the literature search for this project was not meant to be exhaustive but to provide a sampling of related documentation available on different traditional and emerging methods for traffic data collection.

Table 3.1 Literature Search: Traditional and Emerging Traffic Data Collection Methods Included in Each Resource

	Resource	Year		Traditional Methods											Emerging Methods			
			Acoustic	Bluetooth/Wi-Fi	Floating Car Survey	Inductive Loops	Infrared Sensors	Magnetic Sensors	Manual Counts	Microwave Sensors	Piezoelectric Sensors	Pneumatic Tube	Radar Sensors	Ultrasonic	Third-party Probe Data	Thermal Imaging Cameras	UAS/UAV	Video Imaging Detection/Processing
1	Volume & Turning Movement Project (The Eastern Transportation Coalition)	Website													✓			
2	Transportation Data Marketplace (The Eastern Transportation Coalition)	Website													✓			
3	State of the Art Roadway Sensors (Schroeder)	2023				✓	✓	✓		✓			✓	✓		✓		
4	Enhanced Traffic Signal Performance Measures (TPF-5(377)	2023													✓			
5	Data Collection and ITS (ITS JPO)	2022		✓		✓	✓	✓		✓		✓	✓	✓		✓		
6	Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al.)	2022															✓	
7	Integration of Unmanned Aerial Systems Data Collection into Day-to-Day Usage for Transportation Infrastructure – A Phase III Project Final Report, No. SPR-1713 (Brooks et al.)	2022															✓	
8	Traffic Monitoring Guide (FHWA)	2022	✓			✓	✓	✓		✓	✓	✓		✓				✓
9	6 Traffic Counts and Classifications Study Methods (Penny)	2021				✓			✓			✓	✓			✓		✓
10	Innovative Uses of UAV Technology (Leingang and Ryan)	2021															✓	
11	NJDOT UAS/Drone Procedures Manual and Best Practices for Use in New Jersey (Agrawal et al.)	2021															✓	

	Resource	Year		Traditional Methods											Emerging Methods			
			Acoustic	Bluetooth/Wi-Fi	Floating Car Survey	Inductive Loops	Infrared Sensors	Magnetic Sensors	Manual Counts	Microwave Sensors	Piezoelectric Sensors	Pneumatic Tube	Radar Sensors	Ultrasonic	Third-party Probe Data	Thermal Imaging Cameras	UAS/UAV	Video Imaging Detection/Processing
12	Integration of UAS into Operations Conducted by New England Departments of Transportation – Develop Implementation Procedures for UAS Applications (Mallela et al.)	2021															✓	
13	Synthesis on Probe Speed Data for Arterial Operations (Roelofs and Preisen)	2021													✓			
14	Global Benchmarking Program Study on Unmanned Aerial Systems (UAS) for Surface Transportation (Fischer et al.)	2020															✓	
15	Volumes from Probe Data (Preisen and Roelofs)	2020													✓			
16	Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al.)	2019		✓		✓							✓		✓			
17	MassDOT Report 19-010, The Application of Unmanned Aerial Systems in Surface Transportation – Volume I Executive Summary (Knodler et al.)	2019															✓	
18	Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks (Sarasua et al.)	2019																✓
19	Use of Unmanned Aerial Systems (UAS) by State DOTs: February 27, 2018 Peer Exchange (Quinton and Regan)	2018															✓	
20	Assess Speed Data for Traffic Management (Athey Creek Consultants)	2017													✓			

	Resource	Year		Traditional Methods											Emerging Methods			
			Acoustic	Bluetooth/Wi-Fi	Floating Car Survey	Inductive Loops	Infrared Sensors	Magnetic Sensors	Manual Counts	Microwave Sensors	Piezoelectric Sensors	Pneumatic Tube	Radar Sensors	Ultrasonic	Third-party Probe Data	Thermal Imaging Cameras	UAS/UAV	Video Imaging Detection/Processing
21	Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment (Sharma et al.)	2017													✓			
22	An Ultrasonic Sensor System for Vehicle Detection Application (Stiawan)	2017												✓				
23	The Transportation Future Project: Planning for Technology Change (Levinson et al.) Sensors, Monitors & Big Data	2016				✓	✓					✓						
24	I-95 Corridor Coalition Vehicle Probe Project: Validation of Arterial Probe Data (Young et al.)	2015													✓			
25	Methods and Practices for Setting Speed Limits: An Informational Report (Forbes et al.)	2012			✓													
26	Traffic Detector Handbook (Klein et al.)	2006	✓			✓	✓	✓		✓				✓				✓
27	A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems (Mimbela)	2000				✓		✓			✓	✓						

3.2 Summary of Key Findings

There was a considerable amount of information gathered from review of the 27 resources (noted in Section 3.1) on benefits, drawbacks, types of data collected, cost, and how traffic data collection methods replace or complement other data collection methods. Appendix A includes the following tables that document the details found (e.g., benefits, drawbacks) grouped by traditional and emerging traffic data collection methods. See Figure 3.1.

- Benefits
    - Table A.1 Literature Search: Traditional Traffic Data Collection Methods – Benefits
    - Table A.2 Literature Search: Emerging Traffic Data Collection Methods – Benefits
- Drawbacks
    - Table A.3 Literature Search: Traditional Traffic Data Collection Methods – Drawbacks
    - Table A.4 Literature Search: Emerging Traffic Data Collection Methods – Drawbacks
- Types of Data Collected
    - Table A.5 Literature Search: Traditional Traffic Data Collection Methods – Type of Data Collected
    - Table A.6 Literature Search: Emerging Traffic Data Collection Methods – Type of Data Collected
- Cost
    - Table A.7 Literature Search: Traditional Traffic Data Collection Methods – Cost
    - Table A.8 Literature Search: Emerging Traffic Data Collection Methods – Cost
- Replace or Complement Other Traffic Data Collection Methods
    - Table A.9 Literature Search: Traditional Traffic Data Collection Methods – Replace or Complement Other Traffic Data Collection Methods
    - Table A.10 Literature Search: Emerging Traffic Data Collection Methods – Replace or Complement Other Traffic Data Collection Methods

Table A.1 Literature Search: Traditional Traffic Data Collection Methods – Benefits

Benefit	Method	Related Information (Source – Noted at end of table)
Tried and Tested	Inductive Loops	• Well known and commonly used. (1) • Mature, well understood technology. Large experience base. (2)
	Pneumatic Tube	• Well known and trusted. Many agencies and departments already have pneumatic tubes. (1)
Accuracy	Inductive Loops	• Provides best accuracy for count data as compared with other commonly used techniques. (2) • Study in Utah suggested that using data filtering techniques (e.g., Kalman Filtering) on loop detectors that report traffic flow and occupancy data improves the accuracy of queue length and wait time predictions that employ these data. (3)
	Radar Sensors	• Highest count and classification accuracy. Offers the most in metrics and reliability. (1)
Installation and Maintenance	Inductive Loops	• Flexible design to satisfy a large variety of applications. (2)
	Magnetic Sensors	• Some models are installed under the roadway without need for pavement cuts. However, boring under roadway is required. (2)
	Manual Counts	• No installation for onsite counting. (1)
	Pneumatic Tube	• Easy to deploy and retrieve. (1) • Portable, using lead-acid, gel, or other rechargeable batteries as a power source. (4) • Road tube sensors are simple to maintain. (4)
	Radar Sensors	• Compatible with existing infrastructure. (1)
Uses	Acoustic Sensors	• Passive detection. Multiple lane operation available in some models. (2)
	Bluetooth/Wi-Fi	• Real-time traffic conditions. Speed limit violations. (3)
	Inductive Loops	• Multiple lane operation available. (2) • Travel time predictions. Intelligent lane control. Queue warning systems. Adaptive signal control. Ramp metering. (3)
	Infrared Sensors	• Active Infrared: Transmits multiple beams for accurate measurement of vehicle position, speed, and class. (2) • Multiple lane operation available. (2) • Multizone passive sensors measure speed. (2)
	Magnetic Sensors	• Traffic surveillance on freeways, intersections, and parking lots. Truck parking management systems. (3)

Figure 3.1 Screenshot of Table Documenting Traffic Data Collection Methods

The following sections highlight key information found in the literature for traditional and emerging data collection methods.

3.2.1 Traditional Traffic Data Collection Methods

Following are key highlights of information gathered from review of the resources related to traditional traffic data collection methods (acoustic sensors, Bluetooth/Wi-Fi, floating car survey, inductive loops, infrared sensors, magnetic sensors, manual counts, microwave sensors, piezoelectric sensors, pneumatic tube, radar sensors, and ultrasonic sensors) categorized by benefits, drawbacks, types of data collected, cost, and how traffic data collection methods replace or complement other data collection methods. Additional information is included in Appendix A.

TRADITIONAL TRAFFIC DATA COLLECTION METHODS

- Acoustic Sensors
- Bluetooth/Wi-Fi
- Floating Car Survey
- Inductive Loops
- Infrared Sensors
- Magnetic Sensors
- Manual Counts
- Microwave Sensors
- Piezoelectric Sensors
- Pneumatic Tube
- Radar Sensors
- Ultrasonic Sensors

Benefits

The following are benefits noted from the literature review of selected traditional traffic data collection methods. See Table A.1 for additional information and citations.

- *Tried and Tested:* Inductive loops and pneumatic tubes are well known and trusted traffic data collection methods.
- *Accuracy:* Inductive loops provide the best accuracy as compared with other commonly used techniques.
- *Installation:* There is no installation needed for onsite manual counts. Radar sensors can be installed and are compatible with existing infrastructure.
- *Uses:* Inductive loops, acoustic sensors, infrared sensors, and ultrasonic sensors can provide multiple lane operation. Bluetooth/Wi-FI can be used for real-time traffic conditions.
- *Labor Considerations:* After installation, many of the traditional data collection methods do not have labor concerns associated with collecting data.
- *Communication:* Manual counts do not require any communication. Other traditional methods (e.g., acoustic, inductive loops, infrared sensors, magnetic sensors, radar sensors, ultrasonic) require low to moderate bandwidth.
- *Environment Conditions:* Inductive loops work in all lighting and weather conditions. Acoustic sensors are insensitive to precipitation. Magnetic sensors are insensitive to inclement weather conditions such as snow, rain, and fog.

Drawbacks

There were drawbacks noted from the literature review of traditional traffic data collection methods. See Table A.3 for additional details and citations.

- *Safety:* There are safety concerns with traffic data collection methods such as inductive loops and pneumatic tubes that require staff to deploy or retrieve equipment in the field.

- *Labor Intensive:* Manual counts require staff time to complete data collection.
- *Installation and Maintenance:* To maintain inductive loops a lane closure is required. Infrared sensors need periodic lens cleaning and also may require a lane closure to maintain and install. Pneumatic tubes can quickly degrade and can be easily damaged.
- *Accuracy:* Human error with manual counts impacts accuracy. Inductive loop accuracy may decrease when design requires detection of a large variety of vehicle classes.
- *Uses:* Magnetic sensors cannot detect stopped vehicles unless special sensor layouts and signal processing software are used. Some passive infrared models are not recommended for presence detection.
- *Environment Conditions:* Cold temperatures may affect vehicle count accuracy when using acoustic sensors. Infrared sensors are vulnerable to weather conditions such as fog, clouds, shadows, mist, rain, and snow.

Types of Data Collected

Table 3.2 highlights the types of data collected as noted in the sources reviewed for traditional data collection methods. For example, vehicle count was noted in the resources as a type of data collected for acoustic sensors, infrared sensors, manual counts, pneumatic tubes, radar sensors, and ultrasonic sensors. It is important again to note that this table is not meant to be all inclusive but illustrates what type of data is collected by different traditional data collection methods in the resources reviewed for this project. See Table A.5 for additional information and citations.

Table 3.2 Literature Search: Summary of Traditional Traffic Data Collection Methods – Types of Data Collected

Type of Data Collected	Acoustic Sensors	Bluetooth/Wi-Fi	Inductive Loops	Infrared Sensors	Magnetic Sensors	Manual Counts	Piezoelectric Sensors	Pneumatic Tube	Radar Sensors	Ultrasonic Sensors
Bicycle count				✓		✓		✓		
Classification			✓	✓		✓	✓	✓	✓	✓
Count	✓			✓		✓		✓	✓	✓
Direction of motion									✓	
Flow									✓	
Gap			✓							
Headway			✓							
Length				✓					✓	
Multiple lane			✓	✓						
Occupancy			✓	✓	✓	✓		✓		

Type of Data Collected	Acoustic Sensors	Bluetooth/Wi-Fi	Inductive Loops	Infrared Sensors	Magnetic Sensors	Manual Counts	Piezoelectric Sensors	Pneumatic Tube	Radar Sensors	Ultrasonic Sensors
Pedestrian count				✓						
Position				✓						
Presence	✓	✓	✓	✓	✓	✓		✓	✓	✓
Speed	✓	✓	✓	✓	✓		✓	✓	✓	✓
Status (stopped and moving)					✓				✓	
Travel time		✓								
Volume			✓			✓				
Vehicle Weight							✓			

Cost

The cost for traditional traffic data collection depends on the method used as well as location. See Table A.7 for additional information and citations.

- Inductive loops are cost-effective if they are pre-existing, and the cost is low when compared to non-intrusive sensor technologies.
- Manual counts provide low processing costs for low-volume roadways.
- Pneumatic tubes are cost-effective and usually low cost.

Replace or Complement Other Data Collection Methods

From the literature reviewed there were several descriptions on how a traditional traffic data collection method replaced or complemented other data collection methods. In some cases, pavement intrusive detection devices were removed or eliminated and replaced with non-intrusive detection devices. See Table A.9 for additional information.

- A study in Illinois revealed that travel-time prediction models were more accurate using occupancy data from loop detectors when compared to other traffic variables collected and that particular data collection and ITS attention should be paid to malfunctioning loop detectors. This study suggested fusing traffic data from multiple sources to improve the accuracy of traffic prediction models. *Source:* *Data Collection and ITS* *(ITS JPO, 2022).*
- Massachusetts DOT retired their legacy loop detection system for real-time traffic operations. They are using Bluetooth and pursuing an agreement for third-party traffic data. Decision factors included maintenance, less disruption to operations, and improved alternatives. *Source:* *Evolving and Phasing Out Legacy ITS Devices and Systems* *(Preisen et al., 2019).*

- Oregon DOT eliminated in-pavement loop detectors for ITS operations and transitioned to non-intrusive detection devices. Decision factors included alternatives and maintenance. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*
- MTO plans to remove 30-50% of vehicle detection stations and related equipment including in-pavement loop detectors. MTO has installed nonintrusive devices such as radar, microwave, and Bluetooth. Decision factors to move to nonintrusive devices include a longer life cycle, less disruption to operations, alternatives, operational needs, and maintenance cost and effort. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*
- The induction or search coil magnetometer is less susceptible than loops to the stresses of traffic. The induction magnetometer can be used where loops are not feasible (e.g., bridge decks) and some models can be installed under the roadway without the need for pavement cuts. *Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (Mimbela et al., 2000).*
- Oregon DOT eliminated radar speed detection devices and are now using third-party probe data. Decision factors included cost, performance/data quality, maintenance, and alternatives. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*

3.2.2 Emerging Traffic Data Collection Methods

Following are key highlights of information gathered from review of the resources related to emerging traffic data collection methods (probe data, purchasing sensors as a service, thermal imaging cameras, UAS/UAV, and video imaging detection/processing) categorized by benefits, drawbacks, types of data collected, cost, and how traffic data collection methods replace or complement other data collection methods. Additional information is included in Appendix A.

EMERGING TRAFFIC DATA COLLECTION METHODS

Third-party Probe Data

Purchasing Sensors as a Service

Thermal Imaging Cameras

UAS/UAV

Video Imaging Detection/Processing

Benefits

There were a number of benefits noted with the use of emerging traffic data collection methods. Additional information and citations can be found in Table A.2.

- *Accuracy:* With increased probe penetration over the years, spatial, temporal, and incident detection accuracy has increased. Video imaging detection/processing provides more accurate data than manual counts, pneumatic tubes, and inductive loop detectors.
- *Safety:* Once installed there are no disruptions of traffic or safety concerns with thermal imaging cameras and video imaging detection/processing.
- *Uses:* Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground compared to untethered UAS uses. Video

imaging detection/processing provides wide-area detection when information gathered at one camera location can be linked to another.

- *Labor Considerations:* Once installed there are no manual labor concerns with thermal imaging cameras and video imaging detection/processing.
- *Privacy:* There are no privacy issues with video imaging/detection processing since vehicles and pedestrians are not identifiable.
- *Weather Conditions:* There is no sensitivity to light interferences, including darkness, shadow, or sun glare with thermal imaging cameras.

Drawbacks

Drawbacks noted with emerging traffic data collection methods found in the review of resources included the following. See Table A.4 for additional details and citations.

- *Staffing:* In order to fully utilize the analytics tools for probe speed data, staffing time and resources are needed, and some agencies are not able to dedicate staff.
- *Installation:* Thermal imaging cameras and video imaging detection/processing need to be installed at an optimal location/height.
- *Maintenance:* Video imaging detection/processing maintenance includes periodic lens cleaning, requiring a lane closure when a camera is mounted over the roadway.
- *Accuracy:* There are accuracy challenges with probe data when there are several conflicting movements (e.g. driveways), times of day with very low traffic volumes (e.g. overnight), and where signals are densely spaced.
- *Uses:* At night when video imaging detection/processing is utilized vehicle counts are conducted using headlight detection, and classification data may not be possible depending on nearby lighting.
- *Privacy:* Due to the huge volume of raw GPS data and potential privacy issues with probe data, it is important to develop a method for agency interfaces with private sector data providers that avoids massive database requirements and does not introduce privacy concerns associated with capturing raw GPS points that may include origin at residences, work destination, or other intermediate stops. There are also privacy concerns with UAS/UAV and video imaging detection/processing.
- *Environment Conditions:* Some video imaging detection/ processing models are susceptible to camera motion caused by strong winds or vibration of camera mounting structure. Performance may also be affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens.

Types of Data Collected

The types of data collected vary by the emerging traffic data collection method. See Table A.6 for additional details and citations.

- *Probe Data:* Travel time, speed, origin-destination, freight, waypoint, volume, and conflation.

- *Thermal Imaging Cameras:* Vehicle classification, speed, object detection, tracking, traffic flow, license plate recognition, and incident detection.
- *UAS/UAV:* Vehicle counts, classification, speed, trajectory, origin-destination, and volume.
- *Video Imaging Detection/Processing:* Vehicle count, classification, vehicle presence, speed, traffic flow, density, and volume.

Cost

The cost of traffic data collection methods varies as found in the literature review. See Table A.8 for additional information and citations.

- Identifying and documenting the qualitative or quantitative justification for purchasing third-party data can be a challenge. One solution is to compare costs to deploy, operate, and maintain the existing sensor network.
- Thermal imaging cameras are more expensive than invasive methods.
- UAS have the potential to be more time-cost effective than traditional methods.
- Video imaging detection/processing is generally cost effective when many detection zones within the camera field of view or specialized data are required. However, it is more expensive than manual counts, pneumatic tubes, and inductive loop detectors.

Replace or Complement Other Data Collection Methods

The literature search produced several examples of how emerging traffic data collection methods have replaced or complemented other data collection methods. See Table A.10 for additional details.

- Missouri DOT as of 2019 was phasing out radar and Bluetooth/Wi-Fi and transitioning to probe data based on cost (infrastructure and maintenance) and accuracy. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019)*
- As of 2019, Pennsylvania DOT was procuring third-party real-time statewide speed data, with limited deployment of detection equipment. Vehicle detection equipment was being left in place for future connected vehicle applications. The decision factors for this change included effective resource allocation, operational needs, and usage. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*
- There are no significant advantages with using thermal imaging cameras over video imaging detection during regular daytime conditions. *Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021).*
- The existing traffic monitoring system uses cameras mounted on signal mast arms and relies upon highly oblique views of vehicles across multiple lanes of traffic, which often results in visual occlusion. In general, the improved view afforded by UAS data acquisition translated to a more accurate assessment of traffic flow. UAS acquisition also provides more flexibility with respect to deployment and a better, more expansive view of the intersection and approaching traffic. However, the UAS system is very limited with respect to viewing time as battery-powered flights are short, and flights over people and moving vehicles are currently restricted by regulations.

Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground. *Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022).*

- A video imaging detection system is able to differentiate and classify moving vehicles, and unlike manual count video footage, vehicle count and classification are analyzed and processed by the accompanying software. *Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)*.
- A video image processor can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs. *Source: Traffic Detector Handbook (Klein et al., 2006).*

Chapter 4: Survey of Transportation Agencies

An online survey was distributed to State DOTs through the ENTERPRISE members and the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Operations (CTSO). The purpose of the survey was to learn details on traditional and emerging data collection methods. A complete list of questions asked in the survey is included in Appendix B. This section provides a summary of the information gathered from survey responses. Appendix C includes full survey responses.

4.1 Survey Respondents

Seventeen (17) responses were received from the following 11 states. See Figure 4.1.

- Arizona DOT (1 response)
- Idaho Transportation Department (1 response)
- Iowa DOT (1 response)
- Kansas DOT (1 response)
- Kentucky Transportation Cabinet (1 response)
- Michigan DOT (1 response)
- New Hampshire DOT (1 response)
- Pennsylvania DOT (1 response)
- South Carolina DOT (1 response)
- Texas DOT (7 responses)
- Utah DOT (1 response)

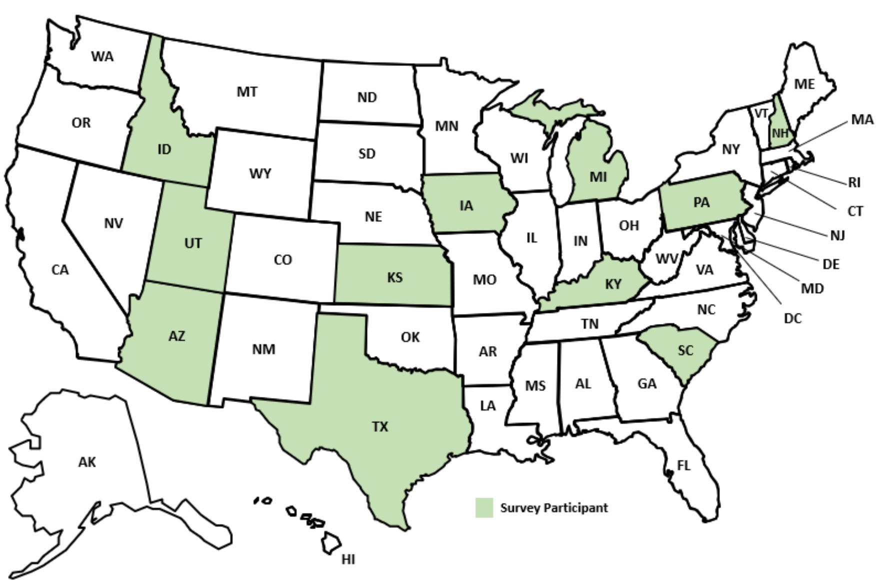

Figure 4.1 Survey Respondents

4.2 Summary of Survey Responses

This section summarizes the information gathered from 11 states the responded to the online survey on their use of traditional and emerging traffic data collection methods.

4.2.1 Traditional Traffic Data Collection Methods

Survey respondents provided information on the traditional traffic data collection methods used by their agency as well as benefits, and drawbacks on these methods.

Methods Used

Current traditional traffic data collection methods used by survey respondents included pneumatic tubes (11 responses), in-road sensors (10 responses), manual counts (9 responses), and radar sensors (8 responses).

Benefits

Benefits noted by respondents with traditional traffic data collection methods were grouped into categories (e.g., tried and tested, accuracy) after reviewing responses. All traditional methods used by the survey respondents (manual counts, microwave sensors, pneumatic tubes, in-road sensors, and radar) were described as tried and tested traffic data collection methods. See Table 4.1.

Table 4.1 Survey Responses Summary: Traditional Traffic Data Collection Methods – Benefits

Benefits	Traditional Traffic Data Collection Method				
	Manual Counts	Microwave Sensors	Pneumatic Tubes	In-road Sensors	Radar
Tried and Tested	✓✓✓	✓✓✓	✓✓✓	✓✓	✓✓
Accuracy	✓		✓	✓Better accuracy than tubes	
Installation		✓Noninvasive			
Collected Data		✓Lane by lane data	✓Lane by lane counts ✓Collect more locations ✓Good axle distance and vehicle class data	✓Lane by lane data (speed, classification, truck counts) ✓Provides the richest data	
Cost			✓Lower cost		
Maintenance			✓ Lower maintenance		
Safety				✓Safer than tubes	
Adjustments					✓To match new conditions

Benefits	Traditional Traffic Data Collection Method				
	Manual Counts	Microwave Sensors	Pneumatic Tubes	In-road Sensors	Radar
Use		✓All types of roadways ✓Year-round operation	✓Local routes	✓Interstates and on/off ramps	✓Great for stop-and-go areas such as urban interstates

✓= Response

Drawbacks

Drawbacks noted by respondents with traditional traffic data collection methods were grouped into categories (e.g., safety, staffing, labor intensive) after review of the responses. For example, one drawback noted with pneumatic tubes was the safety concern with staff installing the tube across traffic out in the field. Table 4.2 shows the drawbacks noted by respondents by category.

Table 4.2 Survey Responses Summary: Traditional Traffic Data Collection Methods – Drawbacks

Drawbacks	Traditional Traffic Data Collection Method				
	Manual Counts	Microwave Sensors	Pneumatic Tubes	In-road Sensors	Radar
Safety	✓✓Staff in or around traffic		✓✓✓Staff in or around traffic		✓
Staffing	✓Limited to availability of personnel				
Labor Intensive	✓		✓Physical exertion to install		✓Physical exertion to install
Power Service Needed		✓		✓✓	
Communication		✓Between the site and the DOT			
Backfilling Data		✓If the system malfunctions			
Maintenance			✓Can be cut or damaged	✓✓Construction may damage ✓Anything in the pavement is dependent on the structural integrity of the roadway	
Installation			✓Invasive	✓Invasive	✓Need a post/pole to mount not always available in rural areas
Data Limitations			✓✓✓Cannot tell what direction vehicles are going from shared lanes	✓Limited by stop and go traffic ✓ Cannot tell what direction vehicles are going from shared lanes	✓Cannot tell what direction vehicles are going from shared lanes ✓Severe limits to classifying vehicles

Drawbacks	Traditional Traffic Data Collection Method				
	Manual Counts	Microwave Sensors	Pneumatic Tubes	In-road Sensors	Radar
Accuracy			✓Not always 100% accurate		
Cost				✓Maintenance and installation cost is higher than tubes	
Reliability					✓Often have to recount due to sensor failing
Use			✓Do not work well in stop and go conditions		

✓ *= Response*

4.2.2 Emerging Traffic Data Collection Methods

Survey respondents provided information on emerging traffic data collection methods used by their agency, type of data that is collected from these methods, uses of the data, analytics process, how the method has replaced or complemented traditional data collection methods, benefits, drawbacks, and cost savings.

Methods Used

Emerging traffic data collection methods used by survey respondents included third-party traffic data (8 responses), video imaging processing (6 responses), and purchasing sensors as a service (3 responses). In addition, one agency described the use of data collection from camera detection to assist in traffic signal retiming and transportation planning studies. Origin-destination data collected and provided by a vendor as described by one responder is also used as an emerging traffic data collection method.

Types of Data Collected

Types of data collected by each emerging method is included in Table 4.3. Seven (7) transportation agencies indicated that third-party traffic data collects vehicle speeds. Among the emerging data collection methods used, video image processing was reported as collecting pedestrian counts and bicyclist counts while the other emerging methods were not used to collect this type of data.

Table 4.3 Survey Responses Summary: Emerging Traffic Data Collection Methods – Types of Data Collected

Types of Data Collected	Emerging Traffic Data Collection Method		
	Purchasing sensors as a service	Third-party traffic data	Video imaging processing
Vehicle Speeds	✓✓✓	✓✓✓✓✓✓✓	✓✓✓
Vehicle Counts	✓✓	✓✓✓✓	✓✓✓✓✓

Types of Data Collected	Emerging Traffic Data Collection Method		
	Purchasing sensors as a service	Third-party traffic data	Video imaging processing
Freeway Truck Counts	✓✓	✓	✓✓✓
Vehicle Classification	✓✓	✓	✓✓✓
Pedestrian Counts			✓✓✓✓
Bicyclist Counts			✓✓✓
Other	✓Weigh in Motion	✓Hard braking, hard accelerating, U-turn movements, cross-over/ intersection directional distribution	✓Truck parking available spaces

✓= Response

Uses of Data Collected

Uses of data collected by each emerging method is included in Table 4.4. Purchasing sensors as a service was reported for uses including transportation planning studies, HPMS reporting to FHWA, real-time traffic management, and in construction and maintenance. Third-party traffic data was reported for multiple uses, with 5 agencies reporting its use for real-time traffic management.

Table 4.4 Survey Responses Summary: Emerging Traffic Data Collection Methods – Uses of Data Collected

Uses of Data Collected	Emerging Traffic Data Collection Method		
	Purchasing sensors as a service	Third-party traffic data	Video imaging processing
Traffic signal re-timings		✓✓✓	✓✓✓✓
Transportation planning studies	✓ ✓Monitor traffic growth, trends and historical patterns. Aids in projecting future traffic.	✓✓✓✓✓	✓✓✓
HPMS reporting to FHWA	✓	✓✓	✓✓✓
Real-time traffic management (e.g., monitoring travel times)	✓ ✓Real time for hurricane evacuation or other disaster reporting; updating databases and calculating Vehicle Miles Traveled (VMT).	✓✓✓✓✓✓	✓✓✓

Uses of Data Collected	Emerging Traffic Data Collection Method		
	Purchasing sensors as a service	Third-party traffic data	Video imaging processing
Other	✓Used in maintenance and construction.	✓Origin destination data: construction alert, inform the public, environmental studies, traffic model calibration, project prioritization ✓Used data to indicate travel times from a particular location through and intersection to determine delays caused by detouring traffic on a TXDOT construction project.	✓Rest area truck counts ✓Traffic Monitoring Guide

✓= Response

Analytics

Most survey respondents utilize a vendor or university to provide data analytics in a usable format. See Table 4.5. No respondents indicated that their DOT provides analytics for video imaging processing.

Table 4.5 Survey Responses Summary: Emerging Traffic Data Collection Methods – Analytics

Emerging Method	Analytics Provider	
	Vendor/University	DOT
Purchasing sensors as a service	✓✓	✓
Third-party traffic data	✓✓✓✓✓✓✓✓	✓✓
Video image processing	✓✓✓✓✓✓✓	

✓= Response

Replace or Complement Traditional Data Collection Methods

Respondents provided details on whether an emerging traffic data collection method has replaced or complemented a traditional traffic data collection method. Purchasing sensors as a service can decrease the frequency/need for other types of sensors and replace in-house installation and maintenance of sensors. The use of third-party traffic data has increased safety, increased data, reduced physical traffic data collection deployments, and reduced staff time. Video imaging processing can replace other traditional sensors (e.g., manual counts, pneumatic tubes, loop detectors). Specific details from respondents are provided in Appendix C.

Benefits

Respondents indicated a number of benefits to using emerging traffic data collection methods compared to traditional methods. Seven (7) respondents noted that third-party traffic data has increased data points and improved data insights. See Table 4.6.

Table 4.6 Survey Responses Summary: Emerging Traffic Data Collection Methods – Benefits

Benefits	Emerging Traffic Data Collection Method		
	Purchasing sensors as a service	Third-party traffic data	Video imaging processing
Less expensive	✓	✓✓	✓
Less maintenance	✓✓✓	✓✓✓✓✓✓	✓✓✓
Better accuracy	✓✓	✓✓✓	✓✓✓
Increased data points	✓✓	✓✓✓✓✓✓✓	✓✓✓✓
Less time needed to collect data		✓✓✓✓✓✓	✓✓✓✓✓
Improved data insights	✓	✓✓✓✓✓✓✓	✓✓✓✓
Other		✓The consultant is able to pull data over a longer period of time than we would have from traditional counting methods. The data is not a complete set and is a sampling at best, so that is a downside – but has been useful for the tasks we have asked them to complete. The old way, with in-house employees would be less expensive, I am sure. ✓Year-round operation, difficult location data such as interstate to interstate traffic data ✓Broader coverage and more system awareness	✓Video allows us to do turning movements, which are incredibly beneficial for RSAs, intersection studies, and signal timing. However, they are more expensive. ✓Video image processing takes longer than manual counts, but the individual(s) that would otherwise be doing a manual count can be doing something else while a contracted person works through the video data.

✓ *= Response*

Drawbacks

Respondents noted drawbacks with using emerging traffic data collection methods. For example, purchasing sensors as a service can involve a slow procurement process. Third-party traffic data can provide a lot of data and big data, latency may be an issue depending on use of the third-party data, and there may not be enough data points for accurate data on low volume roads. Agencies may need to spend a lot of time setting up video imaging processing for accurate data collection and the cost may include subscriptions.

Cost Savings

Respondents reported several examples of cost savings with implementing emerging data collection methods as compared to more traditional methods. Purchasing sensors as a service can reduce staff, improve safety, can be a lower cost and provide better data compared to traditional methods. With the use of third-party traffic data field observations may not be needed, physical speed detectors can be eliminated, maintenance is reduced, and no equipment is needed. With the use of video image processing safety is increased as staff do not need to be in or around traffic. In addition, video imaging processing increases and provides more comprehensive data.

Chapter 5: Traffic Data Collection Methods Comparison

This section provides a comparison of selected emerging traffic data collection methods found in the literature search and survey of transportation agencies described in Chapter 3 and Chapter 4 to traditional traffic data collection methods.

Also included for some of the traffic data collection methods are examples of how the emerging method has complemented or replaced traditional collection methods as well as cost savings.

5.1 Emerging Traffic Data Collection Methods Compared by Category to Overall Traditional Traffic Data Collection Methods

The comparison of emerging traffic data collection methods to overall traditional traffic data collection methods was grouped by the following factors:

- Field installation and maintenance
- Field safety
- Coverage
- Data availability
- Accuracy
- Environmental conditions
- Use
- Data analytics
- Data collected
- Labor considerations
- Privacy

Table 5.1 summarizes the key information in each of these categories that was found in the literature search and survey conducted for this project.

Table 5.1 Emerging Traffic Data Collection Methods Compared to Traditional Traffic Data Collection Methods

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
Field Installation and Maintenance	• There is no field installation or maintenance needed, reducing the overall number of field detection devices. • Less maintenance than traditional data collection methods.	• There is no field installation or maintenance needed, reducing the overall number of field detection devices.	• Field installation and maintenance are needed depending on the sensors utilized. A transportation agency may contract to have installation and maintenance of field sensors conducted by a contractor reducing DOT field staff hours.	• Field installation (at an optimal location/ height) and maintenance (e.g., lens cleaning) are needed.	• Field installation (at an optimal location/ height) and maintenance (e.g., lens cleaning) are needed.	• Field installation and maintenance (e.g., lens cleaning) are needed for traditional methods except for conducting manual counts and floating car surveys. • Some installation methods are invasive (e.g., pneumatic tubes, in-road sensors), and some are noninvasive (e.g., microwave sensors).
Field Safety	• Since there is no field installation or maintenance needed there are no field safety concerns.	• There are field safety concerns with UAS/UAV operating near or around traffic.	• There are field safety concerns (e.g., lane closure) with installing and maintaining sensors near traffic.	• There are field safety concerns (e.g., lane closure) with installing and maintaining thermal imaging cameras near traffic.	• There are field safety concerns (e.g., lane closure) with installing and maintaining video imaging near traffic. • Once installed, there is no disruption of	• There are safety concerns (e.g., lane closure) with data collection methods that require staff to install and maintain

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
			• Once installed, there is no disruption of traffic or safety concerns unless maintenance is needed.	• Once installed, there is no disruption of traffic or safety concerns unless maintenance is needed.	traffic or safety concerns unless maintenance is needed.	equipment near traffic. • Once installed, there is no disruption of traffic or safety concerns unless maintenance is needed.
Coverage	• Probe data may be available statewide to expand coverage and fill in gaps of a sensor network. However, gaps may exist with obtaining probe data in locations with limited or no cellular service in remote or rural areas.	• UAS/UAV are deployed by an agency at a specific location. • There is flexibility with respect to location deployment.	• Sensors are deployed by an agency at a specific location (e.g., corridor, intersection, road segment).	• Thermal imaging cameras are deployed by an agency at a specific location (e.g., corridor, intersection, road segment).	• Video imaging detection/processing cameras are deployed by an agency at a specific location (e.g., corridor, intersection, road segment).	• Traditional traffic data collection sensors are not deployed statewide (e.g., ubiquitously), they are deployed at specific point locations (e.g., spaced out along corridor, intersection, or road segment). Therefore, widespread traffic data is not available as needed for some agency purposes.

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
Data Availability	• Third-party traffic data is available in real-time, which provides quicker access to the data allowing a faster turnaround for studies, etc. The data can also be archived for different agency uses.	• UAS/UAV can provide data in real-time (e.g., camera view from a UAS/UAV can be viewed by incident responders).	• Depending on the type of sensor utilized through purchasing sensors as a service real-time data may be available.	• Thermal imaging cameras provide data in real-time. TMC operators can view the camera displays in real time or be alerted when there is movement in a camera viewing area.	• Data is provided in real-time.	• Some traditional methods (e.g., Bluetooth/Wi-Fi) provide data in real-time if there is communication from the sensor back to, for example, a TMC. However, some methods such as pneumatic tubes and manual counts will only provide historical data.
Accuracy	• With probe penetration continuing to increase over time, spatial, temporal, and incident detection accuracy has increased. • Accuracy challenges are observed with several conflicting movements (e.g.,	• Accuracy of the speed data collected with UAS is comparable with traditional methods.	• Improper installation will lead to inaccurate data.	• Improper installation will lead to inaccurate data.	• Improper installation will lead to inaccurate data.	• Traditional methods (e.g., manual counts, pneumatic tubes) have been proven to provide accurate data. • Human error can impact accuracy (e.g., manual counts). • Improper installation will

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
	driveways), times of day with very low traffic volumes (e.g., overnight, rural facilities), and where signals are densely spaced.					lead to inaccurate data.
Environmental Conditions	• There are no field devices deployed with third-party traffic data, therefore there are not any challenges with weather conditions. • Provides year-round operation.	• There are constraints related to wind, precipitation, and light.	• Depending on the type of sensor utilized through purchasing sensors as a service there may be challenges with weather conditions.	• There are challenges with inclement weather to a thermal imaging cameras lens. • There is no sensitivity to light interference, including darkness, shadow, or sun glare with thermal imaging cameras.	• Performance is affected by inclement weather (e.g., fog, rain, and snow); vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/ road contrast; and water, salt grime, icicles, strong wind, vibration of camera mounting structure, and cobwebs on camera lens.	• Many traditional methods (e.g., acoustic sensors, inductive loops, magnetic sensors, microwave sensors, radar sensors) are not affected by weather conditions. However, some methods can be less effective such as infrared sensors in conditions such as fog, clouds, shadows, mist, rain, and snow.
Use	• Probe data works best on high-	• UAS-based tools are especially well	• Purchasing sensors as a service may	• Use of thermal imaging cameras	• Video Imaging is suitable for arterial	• Inductive loops, acoustic sensors,

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
	volume roadways that do not have super-dense access points and do not have over-saturated conditions. • Third-party probe data may also be used for traffic signal re-timings, transportation planning studies, HPMS reporting to FHWA, and real-time traffic management (e.g., monitoring travel times). • Other uses include construction alerts, informing the public, environmental studies, traffic model calibrations, and project prioritization.	suited for sporadic, critical, short term, data gathering efforts where flexibility of operation is beneficial. • Uses of traffic data from UAS-based data collection can include traffic incident management, parking lot utilization monitoring, weather-related data collection to support traffic, traffic congestion management, traffic monitoring, and incident monitoring.	be used for transportation planning studies (e.g., monitor traffic growth, trends, historical patterns, projecting future traffic), HPMS reporting to FHWA, and real-time traffic management (e.g., monitoring travel times, hurricane evacuation, updating databases, calculating VMT).	may include adaptive signal control, wrong-way detection, crash/ incident detection, road user type classification, red-light violation detection system, and active traffic management strategies.	and freeway applications including congestion and can monitor multiple lanes and multiple detection zones/lanes. • Provides wide-area detection when information gathered at one camera location can be linked to another. • Video imaging may also be used for traffic signal re-timings, transportation planning studies, HPMS reporting to FHWA, rest area truck counts, and real-time traffic management (e.g., monitoring travel times).	infrared sensors, and ultrasonic sensors can provide multiple lane operation. • Radar is great for stop-and-go areas (e.g., urban interstates). • Pneumatic tubes work well on local routes. They don't work well in stop and go conditions. • Pneumatic tubes, in-road sensors, and radar cannot tell what direction vehicles are traveling from shared lanes. Microwave sensors provide directional traffic data for all types of roadways.

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
Data Analytics	• Probe data requires advanced data analytics techniques/ software. • To fully utilize the analytics tools for the large amount of data from probes, staff time and resources are needed. Many transportation agencies utilize vendors or a university to perform data analytics.		• Data analytics with agencies that purchase sensors as a service are typically provided by a vendor or a university.		• Many transportation agencies utilize vendors or a university to perform data analytics.	• Traditional traffic data collection methods typically require data analytics. For example, data from point detection devices located around a state may be extrapolated to understand volumes for statewide HPMS reporting. Data from inductive loops or radar may also be analyzed to convert to travel times, trigger congestion alerts, or show congestion on a map.
Data Collected	• Probe data provides travel time, speed, counts, origin-destination,	• UAS/UAV use examples have produced vehicle counts, classification,	• Depending on the sensor utilized, types of data collected may include vehicle	• Thermal imaging cameras may collect vehicle classification, speed, object	• Video imaging may collect vehicle count, classification, vehicle presence, speed, traffic flow, density,	• The types of data collected (e.g., lane by lane counts) vary by method.

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
	freight, waypoint, volume, and conflation. • Third-party traffic data collected may also include hard braking, hard accelerating, U-turn movements, cross-over/ intersection directional distribution.	speed, trajectory, origin-destination, and volume.	speeds, vehicle counts, freeway truck counts, vehicle classification, and WIM.	detection, tracking, traffic flow, license plate recognition, and incident detection.	volume, freeway truck counts, truck parking, pedestrian counts, and bicyclist counts.	
Labor Considerations	• There is no agency staff time needed to collect data compared to traditional methods.	• Staff are needed to pilot the UAS/ UAV operation.	• There is no manual labor for collecting data after installation.	• There is no manual labor for collecting data after installation.	• No manual labor for collecting data after installation.	• After installation, many of the data collection methods do not have labor concerns associated with collecting data. • Manual counts require staff time to complete data collection and are limited to the availability of personnel.

Category	Emerging Traffic Data Collection Methods					Traditional Traffic Data Collection Methods
	Third-party Probe Data	UAS/UAV	Purchasing Sensors as a Service	Thermal Imaging Cameras	Video Imaging Detection/Processing	
Privacy	• There are privacy concerns with probe data.	• Privacy is a concern with UAS/UAV capturing and monitoring traffic or other road users (e.g., pedestrians) in real-time.	• Depending on the sensors used, there may be privacy concerns.	• Vehicle and pedestrians are not identifiable with thermal imaging cameras.	• There can be privacy concerns with video imaging detection (process includes interpreting images and converting them into traffic flow data).	• There are not any privacy concerns with traditional traffic data collection methods.

5.2 Emerging Traffic Data Collection Methods Complementing or Replacing Traditional Traffic Data Collection Methods

This section describes how third-party traffic data, UAS/UAV, purchasing sensors as a service, and video imaging detection/processing has complemented or replaced traditional traffic data collection methods. The information noted was found from review of the resources reviewed and the survey conducted for this project.

Third-party Probe Data

- As transportation agencies have used arterial probe speed data there have been a variety of practices that have changed. These include revised process for speed studies (Oregon DOT), reduced use of floating car method and resource savings (Oregon DOT, Georgia DOT, RTC of Southern Nevada), improved signal prioritization (Pennsylvania DOT), provided supplemental data in work zones (Wisconsin DOT), more proactive arterial management (Georgia DOT), provided data-driven project prioritization (Georgia DOT and North Carolina DOT), and provided less field detection devices (New Jersey DOT and RTC of Southern Nevada). *Source: Synthesis on Probe Speed Data for Arterial Operations (Roelofs and Preisen, 2021)*
- Missouri DOT as of 2019 was phasing out radar and Bluetooth/Wi-Fi and transitioning to probe data based on cost (infrastructure and maintenance) and accuracy. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019)*
- As of 2019, Pennsylvania DOT was procuring third-party real-time statewide speed data, with limited deployment of detection equipment. Vehicle detection equipment was being left in place for future connected vehicle applications. The decision factors for this change included effective resource allocation, operational needs, and usage. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*
- Oregon DOT eliminated radar speed detection devices and now use third-party probe data. Decision factors included cost, performance/data quality, maintenance, and alternative. *Source: Evolving and Phasing Out Legacy ITS Devices and Systems (Preisen et al., 2019).*
- Sensors may still be used for variable speed limits or to facilitate operations of managed lanes (e.g., high-occupancy toll (HOT), high-occupancy vehicle (HOV), reversible lanes) instead of probe data. *Source: Assess Speed Data for Traffic Management (Athey Creek, 2017).*
- In 2023 Pennsylvania DOT was using third-party data similar to the use of detectors for collecting speed data. Third-party data is available statewide in Pennsylvania; therefore, it is generally discouraged to deploy/use physical detectors except in areas where probe data is demonstrably insufficient. There are certain applications (e.g., VSL corridor in Philadelphia) where detector data is used as the primary data source and third-party data is a backup due to relative latency of probe data. *See Appendix C: Survey Responses*.
- In Texas, third-party traffic data was used to indicate travel times from a particular location through an intersection to determine delays caused by detouring traffic on a construction project.

Third-party traffic data has also just started to be used for signal timing. *See Appendix C: Survey Responses.*

- Purchased traffic counts from connected vehicles are starting to be utilized by the Texas DOT through consultant work. The connected vehicle data is only capturing passenger vehicle and only a percentage. *See Appendix C: Survey Responses.*
- Probe speed data complements data at Texas DOT by providing real-time data and having more data for speed studies. *See Appendix C: Survey Responses.*
- Iowa DOT with use of probe data has eliminated sensors originally deployed for real-time speed monitoring. *See Appendix C: Survey Responses.*
- Probe data use in Utah has decreased the frequency/need for microwave/radar sensors deployed on freeways, and it has decreased the need for people riding in vehicles to provide travel times. *See Appendix C: Survey Responses.*
- There have been many hours of labor saved by New Hampshire DOT staff with the use of probe data in the development of speed studies. *See Appendix C: Survey Responses.*
- Probe data as noted by the Texas DOT can replace a radar speed study if there are single lane approaches and high enough probe density in the area, otherwise the probe data complements with providing extra data. *See Appendix C: Survey Responses.*
- The rich source of probe data has helped in evaluating travel time reliability in Idaho. In corridor studies, the probe data has provided a more comprehensive data set than standard 48-hour counts. *See Appendix C: Survey Responses.*
- Texas DOT through consultant work pull data over a longer period of time than with traditional counting methods. *See Appendix C: Survey Responses.*
- Michigan DOT has found use of probe data beneficial by providing year-round data. *See Appendix C: Survey Responses.*
- Texas DOT has utilized a consultant that has been able to pull data over a longer period of time with third-party traffic data than with traditional counting methods. One downside is the data is not a complete set and is a sampling at best. *See Appendix C: Survey Responses.*
- The use of third-party traffic data has increased safety, increased data, reduced physical traffic data collection deployments, and reduced staff time. *See Appendix C: Survey Responses.*

UAS/UAV

- The existing traffic monitoring system uses cameras mounted on signal mast arms and relies upon highly oblique views of vehicles across multiple lanes of traffic, which often results in visual occlusion. In general, the improved view afforded by UAS data acquisition translated to a more accurate assessment of traffic flow. UAS acquisition also provides more flexibility with respect to deployment and a better, more expansive view of the intersection and approaching traffic. However, the UAS system is very limited with respect to viewing time as battery-powered flights are short, and flights over people and moving vehicles are currently restricted by regulations. Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground. *Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022).*

- The demonstration of a UAS-based traffic flow analysis system in Virginia has shown that it may be used to collect traffic flow data such as vehicle counts and classification as well as speed and trajectory data quickly and efficiently. *Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022).*
- UAS/UAV provide a benefit over current methods in rural areas or areas with challenging terrain. *Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021).*
- UAVs have the potential to reduce hours required to collect speed and volume data. In addition, current methods of data collection can be difficult in rural areas or areas with challenging terrain. *Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021).*
- UAVs have the potential to reduce hours required to collect speed and volume data. In addition, current methods of data collection can be difficult in rural areas or areas with challenging terrain. *Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021).*
- Static camera was 2.3% more accurate than UAS with same data processing. However, much more flexibility with UAS, especially in difficult locations/terrain. *Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021).*
- Automatic processing time for vehicle counts with UAS was approximately 1.8 hours per hour of video, compared to 6 hours of manual processing per hour of video. *Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021).*

Purchasing Sensors as a Service

- Purchasing sensors as a service can decrease the frequency/need for microwave/radar sensors on the freeway. *See Appendix C: Survey Responses.*
- In 2019, South Carolina DOT moved to a pay for data contract for Continuous Count Station (CCS)/WIM sites. The contractor installs the sensors in the roadway (unless a camera is used) and maintains the sensors and all equipment on the side of the road. This has produced less maintenance and installation cost, and better vehicle classification accuracy. South Carolina DOT pays only for data passing QA/QC and marked as good in the software. This process provides more accurate and timely data. *See Appendix C: Survey Responses.*
- Iowa DOT mainly purchases sensors as a service for queue detection related to work zones and occasionally to collect volumes to help plan a future project. *See Appendix C: Survey Responses.*

Video Imaging Detection/Processing

- A video imaging detection system is able to differentiate and classify moving vehicles, and unlike manual count video footage, vehicle count and classification are analyzed and processed by the accompanying software. *(Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021).*
- A connected vehicle camera array application can open up real time traffic surveillance where erratic drivers can be identified automatically and warnings or even shut down commands can be

sent to the erratic vehicles. The active sensing capability of such a system can potentially prevent some incidents from occurring thereby increasing safety and reducing incident induced traffic congestion. *Source: Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks (Sarasua et al., 2019).*

- A video image processor can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs. *Source: Traffic Detector Handbook (Klein et al., 2006).*
- In Idaho, video has allowed the option for turning movements, which are incredibly beneficial for road safety audits (RSA), intersection studies, and signal timing. However, they are more expensive. *See Appendix C: Survey Responses.*
- Video image processing takes longer than manual counts, but the individual(s) that would otherwise be doing a manual count can be doing something else while a contracted person works through the video data. *See Appendix C: Survey Responses.*
- In Texas, use of video imaging detection/processing has removed staff from the road and provides a quick method to count intersections, pedestrians, etc. It is also convenient, saves time, and has replaced the need for manual counts. Video imaging/detection can replace manual counts and pneumatic tubes for turning counts, 24-hour counts, but is not set up to replace continuous Annual Average Daily Traffic (AADT) counts. In practice this complements traditional methods as there can be lag time for obtaining equipment, equipment setup, etc. *See Appendix C: Survey Responses.*
- In Kansas the use of video imaging detection/processing has replaced manual counts, pneumatic tubes, and road sensors. *See Appendix C: Survey Responses.*
- Video imaging detection/processing in New Hampshire has eliminated manual collection of vehicle classification, can be used 24/7, is non-intrusive, and can be portable. *See Appendix C: Survey Responses.*
- Kentucky DOT use of video imaging detection/processing has replaced manual counts, pneumatic tubes, and loop detectors. *See Appendix C: Survey Responses.*
- The use of video imaging detection/process in Idaho has provided counts where every other traditional method is not an option, and it provides a way to remove people from stepping onto roadways in high traffic areas. Thus, it's super important for a safety aspect for field crews. *See Appendix C: Survey Responses.*

5.3 Emerging Traffic Data Collection Methods Cost Savings

This section highlights cost considerations and cost savings found in the review of resources and from the survey conducted for this project with use of emerging traffic data collection methods.

Third-party Traffic Data

- Texas DOT noted savings with not needing to conduct field observations with probe data. *See Appendix C: Survey Responses.*

- Pennsylvania DOT has used third-party probe data to implement virtual queue warning corridors throughout the state. This saves hundreds of thousands of dollars per deployment over traditional systems and allows deployment in areas that might not otherwise be feasible. *See Appendix C: Survey Responses.*
- Probe data use in Utah DOT has reduced maintenance costs and has provided travel times during construction in areas not available before (e.g., rural area). *See Appendix C: Survey Responses.*
- Texas DOT noted cost savings with a fast turnaround in receiving probe data (e.g., no time needed or associated costs with driving to a location), it is a less invasive method to collect data since no equipment is needed, provides greater coverage, and reduced staff time. *See Appendix C: Survey Responses.*
- Idaho Transportation Department indicated that with additional data points, a corridor study will result in a better design. *See Appendix C: Survey Responses.*
- With the use of third-party traffic data field observations may not be needed, physical speed detectors can be eliminated, maintenance is reduced, and no equipment is needed. *See Appendix C: Survey Responses.*
- Third-party traffic data is less expensive than traditional data collection methods. *See Appendix C: Survey Responses.*

UAS/UAV

- Compared to traditional methods, UAS data collection method was found to have a similar capital cost, while UAS has the potential to significantly reduce time, and therefore the operational cost, associated with data collection and processing. It was found that on medium to high volume roadways, UAS have the potential to be more time-cost effective than traditional methods. *Source: MassDOT Report 19-010, The Application of Unmanned Aerial Systems in Surface Transportation – Volume I Executive Summary (Knodler et al., 2019).*

Thermal Imaging Cameras

- Thermal imaging cameras are more expensive than invasive methods. *Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021).*

Purchasing Sensors as a Service

- Purchasing sensors as a service can reduce staff, improve safety, can be a lower cost and provide better data compared to traditional methods. *See Appendix C: Survey Responses.*
- Purchasing sensors as a service is less expensive than traditional data collection methods. *See Appendix C: Survey Responses.*

Video Imaging Detection/Processing

- Video imaging/detection is generally cost effective when many detection zones within the camera field of view or specialized data are required. *Source: Traffic Detector Handbook (FHWA, 2006).*

- Video imaging detection/processing is more expensive than manual counts, pneumatic tubes, and inductive loop detectors. *Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)*
- Safety is a benefit Kansas DOT has found with using emerging data collection methods over traditional methods. With emerging methods staff do not have to be in traffic. *See Appendix C: Survey Responses.*
- New Hampshire DOT has found with the use of video imaging detection/processing it is less invasive for counts and classification and less labor intensive for classification. *See Appendix C: Survey Responses.*
- The biggest benefit Idaho Transportation Department noted was performing partial day manual counts in urban areas prior to using video. Video imaging and detection has provided more accurate and more comprehensive data, which makes the overall data system better. *See Appendix C: Survey Responses.*
- The use of video imaging detection/processing in Kentucky has required minimal staff. *See Appendix C: Survey Responses.*
- Agencies may need to spend a lot of time setting up a video imaging process for accurate data collection, and the cost may include subscriptions. *See Appendix C: Survey Responses.*

Chapter 6: Summary and Implementation

Transportation agencies use many traditional traffic data collection methods as well as emerging traffic data collection methods. The traffic data is collected for a variety of reasons including to inform traffic studies or other transportation planning efforts, to complete FHWA HPMS reporting, or to support traffic management efforts. For this project, traditional traffic data collection methods (e.g., manual counts, pneumatic tubes, in-road sensors, radar sensors) are those that have been used by transportation agencies for many years and are largely understood in terms of performance and maintenance over time. Emerging traffic data collection methods (e.g., purchasing sensors as a service, probe data, video imaging detection and processing, thermal imaging cameras) are still evolving and in some cases are showing advantages compared to traditional methods but are not yet fully demonstrated or institutionalized in many transportation agencies.

While traditional traffic data collection methods have provided trusted data for many years, there may be advantages to using emerging traffic data collection methods to supplement or replace existing methods.

This ENTERPRISE project explored emerging methods for collecting traffic data compared to more traditional methods through a literature search and survey of transportation agencies.

There were 12 traditional traffic data collection methods and 5 emerging traffic data collection methods identified through the literature search and survey of transportation agencies as listed in the table below. See Chapter 2 for definitions of each traffic data collection method reviewed for this project.

Table 6.1 Traditional and Emerging Traffic Data Collection Methods

Traditional	Emerging
Acoustic Sensors	Third-party Probe Data
Bluetooth/Wi-Fi	Purchasing Sensors as a Service
Floating Car Survey	Thermal Imaging Cameras
Inductive Loops	Unmanned Aircraft Systems (UAS)/Unmanned Aerial Vehicle (UAV)
Infrared Sensors (Active and Passive)	Video Imaging Detection/Processing
Magnetic Sensors	
Manual Counts	
Microwave Sensors	
Piezoelectric Sensors	
Pneumatic Tube	
Radar Sensors (Forward-firing and Side-firing)	
Ultrasonic Sensors	

The literature search and survey of transportation agencies also documented details on each traffic data collection method. It is important to note that the literature search and survey of transportation agencies for this project was not meant to be exhaustive but to provide a sampling of related documentation available on different traditional and emerging methods for traffic data collection.

The following sections provide key findings from the comparison of traffic data collection methods and an implementation plan for using the project findings.

6.1 Key Findings

The research results included identifying several key benefits and drawbacks of traditional and emerging traffic data collection methods. There were also examples of how emerging traffic data collection methods have complemented or replaced traditional traffic data collection methods.

From the review of the resources (Chapter 3) and the survey responses (Chapter 4) specific types of emerging traffic data collection methods were compared to traditional methods based on categories such as installation and maintenance, safety, data coverage, data analytics, privacy and other considerations. Selected key findings from the comparison are presented in Table 6.2.

Table 6.2 Traditional and Emerging Traffic Data Collection Methods: Key Findings

Category	Key Findings	
	Traditional	**Emerging**
Installation, Maintenance, and Safety	• Field installation and maintenance (e.g., lens cleaning) are needed for traditional methods except for conducting manual counts and floating car surveys. • Some installation methods are pavement invasive (e.g., pneumatic tubes, in-road sensors), and some are noninvasive (e.g., microwave sensors). • There are safety concerns (e.g., lane closure) with data collection methods that require staff to install and maintain equipment near traffic. However, once installed, there is no disruption of traffic or safety concerns, unless maintenance is needed.	• Using probe data or UAS/UAVs reduces the number of overall field devices for an agency, reducing installation and maintenance associated with physical detection devices. In addition, there is less agency labor time to collect data with the use of third-party probe data. • Transportation agencies that purchase sensors as a service may reduce in-house installation and maintenance effort and costs. • Field safety is not a concern with probe data since there is no field installation or maintenance needed. However, field safety concerns exist with installation and maintenance of other emerging methods, for example where a lane closure may be required to access field detection devices.

Category	Key Findings	
	Traditional	Emerging
Data Coverage, Availability, and Accuracy	• Traditional traffic data collection sensors are not deployed statewide (i.e., ubiquitously), they are deployed at specific point locations (e.g., spaced out along corridor, intersection, road segment). Therefore, widespread traffic data is not available as needed for some agency purposes. • Some traditional methods (e.g., Bluetooth/Wi-Fi) provide data in real-time if there is communication from the sensor back to, for example a TMC. However, some methods such as pneumatic tubes and manual counts will only provide historical data. • Traditional methods (e.g., manual counts, pneumatic tubes) have been proven to provide accurate data. Although human error can impact accuracy (e.g., manual counts) and improper installation will lead to inaccurate data. • Pneumatic tubes, in-road sensors, and radar cannot tell what direction vehicles are traveling from shared lanes. Microwave sensors provide directional traffic data for all types of roadways.	• Probe data provides broad (e.g., statewide) coverage. However, gaps can exist with obtaining probe data at locations with no cellular service. • Real-time data can be provided with all emerging traffic data collection methods investigated in this project. Real-time traffic data provides quicker access to the data allowing a faster turnaround for use in studies. • Video imaging detection/processing can offer a quicker method to provide vehicle and pedestrian counts at intersections. • UAS/UAVs are well suited for sporadic, critical, short term, gathering efforts where flexibility of operation is beneficial. UAS/UAVs also provide a benefit with the ability to use in rural areas or areas with challenging terrain. However, trained staff are needed to pilot UAS/UAV operations when these are used for traffic data collection. • While probe data (e.g., speeds) is suitable for many agency purposes, there are accuracy challenges observed with several conflicting movements (e.g., driveways), times of day with very low traffic volumes (e.g., overnight, rural facilities), and where signals are densely spaced.
Environmental/ Weather Impacts	• Many traditional methods (e.g., acoustic sensors, inductive loops, magnetic sensors, microwave sensors, radar sensors) are not affected by weather conditions. However, some methods (e.g., infrared sensors) can be less effective in conditions such as fog,	• There are no environmental condition challenges with probe data. There are some weather constraints with purchasing sensors as a service, UAS/UAVs, thermal imaging cameras, and video imaging detection/processing. For example, UAS/UAVs cannot fly in extreme

Category	Key Findings	
	Traditional	Emerging
	clouds, shadows, mist, rain, and snow.	weather conditions, and video imaging detection/processing is constrained in dark conditions.
Need for Data Analytics	• Traditional traffic data collection methods can require data analytics. For example, data from point detection devices located around a state may need to be extrapolated to understand volumes for statewide HPMS reporting. • Data from inductive loops or radar may also need to be analyzed to convert to travel times, trigger congestion alerts, or show congestion on a map.	• Many transportation agencies utilize vendors or universities to perform data analytics due to the large amount of data produced by some of the emerging traffic data collection methods such as probe data.

Emerging Traffic Data Collection Methods Complementing or Replacing Traditional Methods

There were also examples of how emerging traffic data collection methods have complemented or replaced traditional traffic data collection methods as described below. See Chapter 3 and Chapter 4 for details and citations as well as additional examples.

- Third-party Probe Data
    - Missouri DOT phased out radar and Bluetooth/Wi-Fi and replaced these data collection methods with probe data.
    - Oregon DOT eliminated radar speed detection devices and now uses third-party probe data.
    - Third-party data is available statewide in Pennsylvania; therefore, it is generally discouraged to deploy/use physical detectors except in areas where probe data is demonstrably insufficient.
    - Probe speed data complements data at Texas DOT by providing real-time data and having more data for speed studies.
    - Iowa DOT with use of probe data has eliminated sensors originally deployed for real-time speed monitoring.
    - Probe data as noted by the Texas DOT can replace a radar speed study if there are single lane approaches and high enough probe density in the area, otherwise the probe data complements with providing extra data.

Probe data as noted by the Texas DOT can replace a radar speed study if there are single lane approaches and high enough probe density in the area, otherwise the probe data complements with providing extra data.

- UAS/UAV
  - UASs provide more flexibility with respect to deployment and a better, more expansive view of an intersection and approaching traffic as documented in Virginia.
  - UAS/UAV provide a benefit over current methods in rural areas or areas with challenging terrain as documented in Washington State.
  - The demonstration of a UAS-based traffic flow analysis system in Virginia has shown that it may be used to collect traffic flow data such as vehicle counts and classification as well as speed and trajectory data quickly and efficiently.
  - UAVs have the potential to reduce the hours required to collect speed and volume data as documented in Washington State.
  - Automatic processing time for vehicle counts with UAV in Washington was approximately 1.8 hours per hour of video, compared to 6 hours of manual processing per hour of video.

The use of video imaging detection/process in Idaho has provided counts where every other traditional method is not an option, and it provides a way to remove people from stepping onto roadways in high traffic areas.

- Purchasing Sensors as a Service
  - Purchasing sensors as a service can decrease the frequency/need for microwave/radar sensors on the freeway as noted by Utah.
  - In 2019, South Carolina DOT moved to a pay for data contract for CCS/WIM sites. The contractor installs the sensors in the roadway (unless a camera is used) and maintains the sensors and all equipment on the side of the road. This has produced less maintenance and installation cost, and better vehicle classification accuracy.
- Video Imaging Detection/Processing
  - The use of video imaging detection/process in Idaho has provided counts where every other traditional method is not an option, and it provides a way to remove people from stepping onto roadways in high traffic areas.
  - A video imaging detection system is able to differentiate and classify moving vehicles, and unlike manual count video footage, vehicle count and classification is analyzed and processed by the accompanying software.
  - A video image processor can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs.
  - In Texas, use of video imaging detection/processing has removed staff from the road and provides a quick method to count intersections, pedestrians, etc. It is also convenient, saves time, and has replaced the need for manual counts.

6.2 Implementation Plan

The research resulted in several resources that ENTERPRISE members agencies can use to inform staff about the benefits and drawbacks of traffic data collection methods including:

- Definitions of traffic data collection methods (Chapter 2)

- Literature search summary (Chapter 3)
- Survey of transportation agencies (Chapter 4)
- Comparison of traffic data collection methods (Chapter 5)

Transportation agencies can implement the results of this research in several ways. Recommended implementation steps could include the following actions:

1. Distribute the report to staff at ENTERPRISE agencies who are responsible for procuring, installing, and maintaining traffic data collection methods. Agency staff who may benefit from the information in this report could include:
    - Transportation planners
    - Traffic signal engineers
    - ITS engineers
    - Traffic management center (TMC) managers
    - Work zone planners and operations staff
2. Review and utilize the comparison table documented in Chapter 5 when assessing and considering traffic data collection methods for various agency uses.
3. Review the agency examples of how emerging traffic data collection methods are complementing or replacing traditional methods in Chapter 5 to consider how these emerging methods could benefit your agency based on other states' experiences and successes.

Overall, the research conducted for this project provided ENTERPRISE member agencies with details about traffic data collection methods to inform staff about the benefits and drawbacks as traffic data collection methods are considered.

References

Agrawal, A.K., Hoomaan, E., Basile, T., & Kamga, C. (2021). *NJDOT UAS/Drone Procedures Manual and Best Practices for Use in New Jersey.* Trenton, NJ: New Jersey Department of Transportation. https://www.njdottechtransfer.net/wp-content/uploads/2021/11/NJ-2021-001.pdf.

Alden, A.S., Druta, C., Park, H., & Coggin, J. (2022). *Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia.* Charlottesville, VA: Virginia Transportation Research Council. https://vtrc.virginia.gov/media/vtrc/vtrc-pdf/vtrc-pdf/22-R24.pdf.

Athey Creek Consultants. (2017). *Assess Speed Data for Traffic Management*. ENTERPRISE pooled fund study. https://enterprise.prog.org/wp-content/uploads/ENT-Speed-Data-Final-Report-FINAL-100217-1.pdf.

Brooks, C., Cook, C., Dobson, R., Oommen, T., Zhang, K., Mukherjee, A., Samsami, R., Semenchuk, A., Lovelace, B., Hung, V., Tan, Y., Yang, Y., Jenkins, A., Graham, J., Lekha, V.C., Billmire, M., & Barber, V. (2022). *Integration of Unmanned Aerial Systems Data Collection into Day-to-Day Usage for Transportation Infrastructure – A Phase III Project*. Lansing, MI: Michigan Department of Transportation. https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Research-Administration/Final-Reports/SPR-1713-Report.pdf?rev=32d57bde7331473a93c428d820ec6223&hash=6E000DEC62CCC02AD2B8C5D6DFF39E37.

Federal Highway Administration. (2022). *Traffic Monitoring Guide*. https://www.fhwa.dot.gov/policyinformation/tmguide/2022_TMG_Final_Report.pdf.

Federal Highway Administration. (2017). *Work Zone Performance Measurement Using Probe Data*. U.S. Department of Transportation Work Zone Mobility and Safety Program. Accessed on February 12, 2024, from https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop13043/ch2.htm.

Fischer, S., Lawless, E., Lu, J., & Van Fossen, K. (2020). *Global Benchmarking Study on Unmanned Aerial Systems for Surface Transportation*. Washington, D.C.: U.S. Department of Transportation. https://www.fhwa.dot.gov/uas/hif20091.pdf.

Forbes, G.J., Gardner, T., McGee, H., & Srinivasan. R. (2012). *Methods and Practices for Setting Speed Limits: An Informational Report*. Washington, D.C.: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/2022-06/fhwasa12004.pdf.

Intelligent Transportation Systems Joint Program Office. (2022). Data Collection and ITS (2022 Executive Briefing). Accessed on February 7, 2024, from https://www.itskrs.its.dot.gov/briefings/executive-briefing/data-collection-and-its.

Klein, L.A., Mills, M.K., & Gibson, D.R.P. (2006). *Traffic Detector Handbook: Third Edition—Volume I.* McLean, VA: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/operations/its/06108/06108.pdf.

Knodler, M., Fitzpatrick, C., Ni, D., Plotnikov, M., Fiondella, L., Mogawer, W., Chen, D., Chigan, T., & Xie, Y. (2019). *The Application of Unmanned Aerial Systems in Surface Transportation – Volume I: Executive Summary.* Boston, MA: Massachusetts Department of Transportation. https://www.mass.gov/files/documents/2020/04/22/dot_plng_Rsrch_FinalReport_UnmannedAir.pdf.

Leingang, T. & Ryan, A. (2021). Innovative Uses of Unmanned Aerial Vehicle (UAV) Technology. Presentation. 16th Annual Western States Forum, Yreka, CA. Accessed on February 8, 2024, from http://www.westernstatesforum.org/Documents/2021/Presentations/WSDOT_UMASS_LeingangRyan_Final2_UAV_NoVids.pdf.

Levinson, D., Boies, A., Cao, J., & Fan, Y. (2016). *The Transportation Futures Project: Planning for Technology Change*. St. Paul, MN: Minnesota Department of Transportation. https://cts-d8resmod-prd.oit.umn.edu/pdf/mndot-2016-02.pdf.

Mallela, J., Wheeler, P., Sankaran, B., Choi, C., Gensib, E., Tetreault, R., & Hardy, D. (2021). *Integration of UAS into Operations Conducted by New England Departments of Transportation – Develop Implementation Procedures for UAS applications*. New England Transportation Consortium. Burlington, VT: University of Vermont. Final report available from https://www.newenglandtransportationconsortium.org/projects/netc-18-3/.

Mimbela, L.E.Y., Klein, L.A., Kent, P., Hamrick, J.L., Luces, K.M., & Herrera, S. (2000). *A Summary of Vehicle Detection and Surveillance Technologies used in Intelligent Transportation Systems*. The Vehicle Detector Clearinghouse. Federal Highway Administration. https://www.fhwa.dot.gov/ohim/tvtw/vdstits.pdf.

Penny, S. (2021). 6 Traffic Counts and Classification Study Methods. Accessed on February 8, 2024, from https://www.smatstraffic.com/2021/07/21/counts-and-classification-study-methods/.

Preisen, L., Helgeson, C. & Deeter, D. (2019). *Evolving and Phasing Out Legacy ITS Devices and Systems*. ENTERPRISE pooled fund study. Lansing, MI: Michigan Department of Transportation. https://enterprise.prog.org/wp-content/uploads/ENT_PhasingOutLegacyITS_Report_FINAL_Oct2019.pdf.

Preisen, L. & Roelofs, T. (2020). *Volumes from Probe Data*. ENTERPRISE pooled fund study. Lansing, MI: Michigan Department of Transportation. https://enterprise.prog.org/wp-content/uploads/ENT-Project-9-Volumes-Probe-Data-FINAL-11-25-20.pdf.

Quinton, D. & Regan, T. (2018). *Use of Unmanned Aerial Systems (UAS) by State DOTs February 27, 2018 Peer Exchange*. Washington, D.C.: U.S. Department of Transportation. https://rosap.ntl.bts.gov/view/dot/43679.

Roelofs, T. & Preisen, L. (2021). *Synthesis of Probe Speed Data for Arterial Operations*. ENTERPRISE pooled fund study. Lansing, MI: Michigan Department of Transportation. https://enterprise.prog.org/wp-content/uploads/ENT_ArterialSpeedProbeData_FINAL_Report_021721.pdf.

Sarasua, W., Zhao, X., & Davis, W. (2019). *Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks.* Center for Connected Multimodal Mobility (C^2M^2). Clemson, SC: Clemson University. https://acrobat.adobe.com/link/review?uri=urn%3Aaaid%3Ascds%3AUS%3A95dea8aa-cac7-44dd-9584-b39b3e3b36f1.

Schroeder, J. (2023). *State of the Art Roadway Sensors – Phase 1.* ENTERPRISE pooled fund study. Lansing, MI: Michigan Department of Transportation. https://enterprise.prog.org/wp-content/uploads/ENT-Roadway-Sensors-Phase-1-Final-Report.pdf.

Sensors, Monitors & Big Data. (n.d.). The Transportation Futures Project. Minneapolis, MN: University of Minnesota. https://minnesotago.org/application/files/9614/6222/6832/SensorsMonitorsBigData.pdf.

Sharma, A., Ahsani, V., & Rawat, S. (2017). *Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment*. Lincoln, NE: Nebraska Department of Transportation. https://dot.nebraska.gov/media/gosporhy/m007-ndot_inrix_evaluation.pdf.

Stiawan, R. (2017). *An Ultrasonic Sensor System for Vehicle Detection Application*. Bandung, Indonesia: Journal of Physics: Conference Series, Volume 1204, 7th Asian Physics Symposium 29–31 August 2017. https://iopscience.iop.org/article/10.1088/1742-6596/1204/1/012017/pdf.

The Eastern Transportation Coalition. (n.d.) Transportation Data Marketplace. Accessed on February 7, 2024, from https://tetcoalition.org/projects/transportation-data-marketplace/.

The Eastern Transportation Coalition. (n.d.) Volume & Turning Movement Project. Accessed on February 7, 2024, from https://tetcoalition.org/projects/volume-turning-movement-project/.

Transportation Pooled Fund. (2023). Enhanced Traffic Signal Performance Measures. TPF-5(377). Indiana Department of Transportation. Accessed on February 7, 2024, from https://www.pooledfund.org/Details/Study/629.

Young, S.E., Hamedi, M., Sharifi, E., Juster, R. M., Kaushik, K. & Eshragh, S. (2015). *I-95 Corridor Coalition Vehicle Probe Project: Validation of Arterial Probe Data*. College Park, MD: University of Maryland. https://tetcoalition.org/wp-content/uploads/2015/02/I-95_Arterial_Validation_Report_July2015-FINAL.pdf?x70560.

Appendix A
Literature Search: Key Information Categorized

BENEFITS

Table A.1 Literature Search: Traditional Traffic Data Collection Methods – Benefits

Benefit	Method	Related Information (Source – Noted at end of table)
Tried and Tested	Inductive Loops	• Well known and commonly used. (1) • Mature, well understood technology. Large experience base. (2)
	Pneumatic Tube	• Well known and trusted. Many agencies and departments already have pneumatic tubes. (1)
Accuracy	Inductive Loops	• Provides best accuracy for count data as compared with other commonly used techniques. (2) • Study in Utah suggested that using data filtering techniques (e.g., Kalman Filtering) on loop detectors that report traffic flow and occupancy data improves the accuracy of queue length and wait time predictions that employ these data. (3)
	Radar Sensors	• Highest count and classification accuracy. Offers the most in metrics and reliability. (1)
Installation and Maintenance	Inductive Loops	• Flexible design to satisfy a large variety of applications. (2)
	Magnetic Sensors	• Some models are installed under the roadway without need for pavement cuts. However, boring under roadway is required. (2)
	Manual Counts	• No installation for onsite counting. (1)
	Pneumatic Tube	• Easy to deploy and retrieve. (1) • Portable, using lead-acid, gel, or other rechargeable batteries as a power source. (4) • Road tube sensors are simple to maintain. (4)
	Radar Sensors	• Compatible with existing infrastructure. (1)
Uses	Acoustic Sensors	• Passive detection. Multiple lane operation available in some models. (2)
	Bluetooth/Wi-Fi	• Real-time traffic conditions. Speed limit violations. (3)
	Inductive Loops	• Multiple lane operation available. (2) • Travel time predictions. Intelligent lane control. Queue warning systems. Adaptive signal control. Ramp metering. (3)
	Infrared Sensors	• Active Infrared: Transmits multiple beams for accurate measurement of vehicle position, speed, and class. (2) • Multiple lane operation available. (2) • Multizone passive sensors measure speed. (2)
	Magnetic Sensors	• Traffic surveillance on freeways, intersections, and parking lots. Truck parking management systems. (3)

Benefit	Method	Related Information (Source – Noted at end of table)
	Microwave Sensors	• Traffic signal management. Signalized intersection counts. Traffic condition identification. (3) • Animal detection and warning systems. (3)
	Piezoelectric	• Weigh in motion applications. (3) • Bicycle counts. Pavement quality monitoring. (3) • Frequently used as part of weigh-in-motion systems. (4)
	Pneumatic Tube	• Travel time predictions. (3) • Intelligent lane control. (3) • Queue warning systems. (3) • Adaptive signal control. (3) • Ramp metering. (3)
	Radar Sensors	• Larger field of view. (1) • Side-firing radar: Ideal for use at intersection stop bars. Highly effective for roadways without high volumes of congestion. (1)
	Ultrasonic Sensors	• Multiple lane operation available. Capable of overheight vehicle detection. (2) • Crash prevention. Intersection collision warning. Parking management. (3)
Labor Considerations	Radar Sensors	• No manual labor concerns. (1)
Communication	Acoustic Sensors	• Bandwidth: Low to moderate (2)
	Inductive Loops	• Bandwidth: Low to moderate (2)
	Infrared Sensors	• Bandwidth: Low to moderate (2)
	Magnetic Sensors	• Bandwidth: Low (2)
	Manual Counts	• No network or connectivity concerns, especially for rural areas (1)
	Microwave Sensors	• Bandwidth: Moderate (2)
	Radar Sensors	• Lowest power consumption (1)
	Ultrasonic	• Bandwidth: Low (2)
Environment Conditions	Acoustic Sensors	• Insensitive to precipitation. (2)
	Inductive Loops	• Insensitive to inclement weather such as rain, fog, and snow. (2) • Work in all lighting and weather conditions. (1)
	Magnetic Sensors	• Insensitive to inclement weather such as snow, rain, and fog. (2)
	Microwave Sensors	• Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications. (2)

Benefit	Method	Related Information (Source – Noted at end of table)
	Radar Sensors	• Work under all weather conditions. (1)
	Ultrasonic Sensors	• Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. (2)

(1) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(2) Source: Traffic Detector Handbook (FHWA, 2006)
(3) Source: Data Collection and ITS (ITSJPO, 2022)
(4) Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (The Vehicle Detector Clearinghouse, 2000)

Table A.2 Literature Search: Emerging Traffic Data Collection Methods – Benefits

Benefit	Method	Related Information (Source – Noted at end of table)
Accuracy	Probe Data	• Increased volume, as measured by AADT, will increase accuracy of probe data, all other factors being equal. (1) • With increased probe penetration over the years, spatial, temporal, and incident detection accuracy has increased. (2)
	UAS/UAV	• Accuracy of the speed data collected with UAS is comparable with traditional methods. (3)
	Video Imaging Detection/ Processing	• More accurate data than manual counts, pneumatic tubes, and inductive loop detectors. (4)
Safety	Thermal Imaging Cameras	• No disruption of traffic or safety concerns. (4)
	Video Imaging Detection/ Processing	• No disruption of traffic or safety concerns. (4) • A connected vehicle camera array application can open up realtime traffic surveillance where erratic drivers can be identified automatically and warnings or even shut down commands can be sent to the erratic vehicles. The active sensing capability of such a system can potentially prevent some incidents from occurring thereby increasing safety and reducing incident induced traffic congestion. (7)
Uses	Probe Data	• Probe data works best on high-volume arterials that do not have super-dense access points and do not have over-saturated conditions. (8)
	Thermal Imaging Cameras	• Adaptive signal control. (9) • Wrong-way detection system. (9) • Crash/incident detection. (9) • Road user type classification. (9) • Red-light violation detection system. (9) • Active traffic management strategies. (9)

Benefit	Method	Related Information (Source – Noted at end of table)

	UAS/UAV	• Longer flight data collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground. (5)
		• Benefit over current methods in rural areas or areas with challenging terrain. (10)
		• Traffic incident management, parking lot utilization monitoring, Weather-related data collection to support traffic and incident monitoring. (11)
		• Planned to be used by responding agencies.
		  ○ Traffic characterization (type, speed, count, etc.)
		  ○ Assessment of road hazards
		  ○ First responder situational awareness
		  ○ Tethered UAV operations
		  ○ Ground vehicle assistance
		  ○ Ad-hoc communications network
		  ○ Roadway emergency alert
		  ○ Illegal or unintended parking assessment (12)
		• Researchers developed algorithms for analyzing live-stream video to provide quantitative data on traffic counts, flow and density. These analyses are applicable to both daily traffic operations and analytical traffic studies. (13)
		• Traffic Congestion Assessment. (14)
		• Traffic Monitoring. (14)

	Video Imaging Detection/ Processing	• Monitors multiple lanes and multiple detection zones/lane. (6) • Easy to add and modify detection zones. (6) • The types of information provided by video image processing (VIPs) makes suitable for arterial and freeway applications. (6) • Provides wide-area detection when information gathered at one camera location can be linked to another. (6) • Better for high-volume or congested roadways than previous methods. (4) • Uses tracking capabilities to improve vehicle tracking in congested traffic and adding a location identification algorithm to map vehicles throughout a network. (15)
Labor Considerations	Thermal Imaging Cameras	• No manual labor time after installation. (4)
	Video Imaging Detection/ Processing	• No manual labor time after installation. (4)

Benefit	Method	Related Information (Source – Noted at end of table)
Communication	Video Imaging Detection/ Processing	• Bandwidth: Low to high (6)
Privacy	Thermal Imaging Cameras	• No privacy concerns since vehicles and pedestrians are not identifiable. (4)
Weather Conditions	Thermal Imaging Cameras	• No sensitivity to light interference, including darkness, shadow, or sun glare. (4)

(1) Source: I-95 Corridor Coalition Vehicle Probe Project: Validation of Arterial Probe Data (Young, 2015)
(2) Source: Synthesis on Probe Speed Data for Arterial Operations (ENTERPRISE, 2021)
(3) Source: MassDOT Report 19-010, The Application of Unmanned Aerial Systems in Surface Transportation – Volume I Executive Summary (Knodler et al., 2019)
(4) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(5) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia(Alden et al., 2022)
(6) Source: Traffic Detector Handbook (FHWA, 2006)
(7) Source: Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks (Center for Connected Multimodal Mobility (C^2M^2), 2019)
(8) Source: Assess Speed Data for Traffic Management (ENTERPRISE, 2017)
(9) Source: Data Collection and ITS (ITSJPO, 2022)
(10) Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021)
(11) Source: Global Benchmarking Program Study on Unmanned Aerial Systems (UAS) for Surface Transportation (Fischer et al., 2020)
(12) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022)
(13) Source: Integration of Unmanned Aerial Systems Data Collection into Day-to-Day Usage for Transportation Infrastructure – A Phase III Project Final Report, No. SPR-1713 (Brooks et al., 2022)
(14) Source: Use of Unmanned Aerial Systems (UAS) by State DOTs: February 27, 2018 Peer Exchange (Quinton and Regan, 2018)
(15) Source: Global Benchmarking Program Study on Unmanned Aerial Systems (UAS) for Surface Transportation (Fischer et al., 2020)

DRAWBACKS

Table A.3 Literature Search: Traditional Traffic Data Collection Methods – Drawbacks

Drawback	Method	Related Information (Source – Noted at end of table)
Safety	Inductive Loops	• During deployment and retrieval. (1)
	Pneumatic Tube	• Safety concerns for counters. (1)
Labor Intensive	Manual Counts	• High manual labor time/costs. (1)
Installation and Maintenance	Inductive Loops	• Improper installation will lead to inaccurate data, can be damaged by water or street maintenance. (1) • Requires lane closure. Subject to stresses of traffic and temperature. (2) • Improper installation will lead to inaccurate data. (1) • Improper installation decreases pavement life. (2) • Requires pavement cut. (2) • Requires lane closure. (2) • Multiple loops usually required to monitor a location. (2)
	Infrared Sensors	• Periodic lens cleaning, requires lane closure. (2) • Requires lane closure. (2)

Drawback	Method	Related Information (Source – Noted at end of table)
	Magnetic Sensors	• Requires lane closure. (2) • Some models require pavement cuts or boring under the roadway. (2) • Improper installation decreases pavement life. (2) • Requires lane closure. (2)
	Pneumatic Tube	• Quickly degrade and can be easily damaged. (1)
	Radar Sensors	• Forward-Firing: Restrictions near large objects (e.g., big signs, bridges) due to signal reflection. (1)
Accuracy	Manual Counts	• Human error impacts the accuracy. (1)
	Inductive Loops	• May decrease when design requires detection of a large variety of vehicle classes. (2)
Uses	Acoustic	• Specific models are not recommended with slow-moving vehicles in stop-and-go traffic. (2)
	Infrared Sensors	• Some passive infrared models not recommended for presence detection. (2)
	Magnetic Sensors	• Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used. (2)
	Manual Counts	• Inefficient for high-volume or multi-lane roadways. (1)
	Pneumatic Tube	• Not ideal for roadways with high-volumes or slow-moving traffic. Cannot be placed where vehicles may park. (1)
	Radar Sensors	• Forward-firing: Less effective when vehicles are stopped. (1)
	Ultrasonic Sensors	• Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds. (2)
Environment Conditions	Acoustic Sensors	• Cold temperatures may affect vehicle count accuracy. (2)
	Infrared Sensors	• Vulnerable to weather conditions such as fog, clouds, shadows, mist, rain, and snow. (3)
	Pneumatic Tube	• Can be less effective in various weather conditions, such as rain. (1)

(1) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(2) Source: Traffic Detector Handbook (FHWA, 2006)
(3) Source: Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment (Nebraska DOT, 2017)

Table A.4 Literature Search: Emerging Traffic Data Collection Methods – Drawbacks

Drawback	Method	Related Information (Source – Noted at end of table)
Safety	UAS/UAV	• Primary public concern of safety. (1)
Staffing	Probe Data	• In order to fully utilize the analytics tools for probe speed data, staffing time and resources are needed, and some agencies are not able to dedicate staff. Staff needs to be trained and educated on the use of arterial probe speed data. This should include learning from signal timing staff to apply their expertise to the potential uses of the data. However, some agencies are unable to dedicate the time to training of arterial probe speed data. (2)
Installation	Thermal Imaging Cameras	• Need to be installed at an optimal location/height. (3)
	Video Imaging Detection/ Processing	• Needs to be installed at an optimal location/height in order to view the road with no potential obstacles. (3)
Maintenance	Video Imaging Detection/ Processing	• Maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway. (7)
Accuracy	Probe Data	• Accuracy challenges are observed with several conflicting movements (e.g. driveways), times of day with very low traffic volumes (e.g. overnight), and where signals are densely spaced. (2)
Uses	Probe Data	• Inconsistent on low-volume rural facilities. (4)
	Video Imaging Detection/ Processing	• At night, vehicle counts are conducted using headlight detection, and classification data may not be possible depending on nearby lighting. (3)
	UAS/UAV	• UAS-based tools are especially well suited for sporadic, critical, short term, data gathering efforts where flexibility of operation is beneficial. (1)
Privacy	Probe Data	• Due to the huge volume of raw GPS data and potential privacy issues, it is important to develop a method for agency interfaces with private sector data providers that avoids massive database requirements and does not introduce privacy concerns associated with capturing raw GPS points that may include origin at residences, work destination, or other intermediate stops. (5)
	UAS/UAV	• Primary public concern of privacy. (1)
	Video Imaging Detection/ Processing	• Privacy concerns. (3)

Drawback	Method	Related Information (Source – Noted at end of table)
Environment Conditions	Probe Data	• AVI accuracy may be reduced by adverse weather conditions and interference from other radiation sources. (6)
	Video Imaging Detection/ Processing	• Some models are susceptible to camera motion caused by strong winds or vibration of camera mounting structure. (7) • Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens. (7) • Adverse weather conditions may obscure video footage. (3)
	UAS/UAV	• Limitations of these types of UAS technologies include short data collection (flight) times when untethered; constraints related to environmental conditions such as wind, precipitation, and light; and regulatory restrictions and uncertainty that may impact the value of apparent benefits. (1)

(1) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022)
(2) Source: Synthesis on Probe Speed Data for Arterial Operations (ENTERPRISE, 2021)
(3) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(4) Source: Assess Speed Data for Traffic Management (ENTERPRISE, 2017)
(5) Source: Enhanced Traffic Signal Performance Measures (TPF-5(377), 2023)
(6) Source: Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment (Nebraska DOT, 2017)
(7) Source: Traffic Detector Handbook (FHWA, 2006)

TYPES OF DATA COLLECTED

Table A.5 Literature Search: Traditional Traffic Data Collection Methods – Type of Data Collected

Method	Type of Data Collected (Source – Noted at end of table)
Acoustic Sensors	• Count, presence, speed (1)
Bluetooth/Wi-Fi	• Travel time (2) • Speed (2)
Inductive Loops	• Presence of a vehicle. (3) • While not all single loops can collect classification data, newer loops or a double loop can classify vehicles and collect speed data. (3) • May not be able to sufficiently classify low metal vehicles such as motorcycles. (3) • Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). (1) • Common standard for obtaining accurate occupancy measurements. (1) • High frequency excitation models provide classification data. (1) • Vehicle count, vehicle presence, speed, vehicle classification. (4)

Method	Type of Data Collected (Source – Noted at end of table)
	• Multiple lane, multiple detection zone data. (4)

Infrared Sensors	• Active Infrared
	  ○ Count, presence, speed, classification (1)
	• Passive Infrared Sensor
	  ○ Count, presence, speed (1)
	• Laser
	  ○ Vehicle speed, position, length, occupancy (2)
	  ○ Traffic flow (2)
	  ○ Pedestrian/bicycle counts (2)
	  ○ Vehicle count, vehicle presence (4)
	  ○ Multiple lane, multiple detection zone data (4)

Magnetic Sensors	• Magnetometer
	  ○ Lane occupancy (2)
	  ○ Vehicle presence and status (stopped and moving) (2)
	• Magnetometer (two axis fluxgate) Sensor
	  ○ Count, presence, speed (1)
	  ○ Vehicle count, vehicle presence, speed (4)
	• Magnetic induction coil Sensor
	  ○ Count, presence, speed (1)
	  ○ Vehicle count, vehicle presence, speed (4)

Manual Counts	• Volume (3) • Classification: When classification data is also being collected, instead of tallying the number of vehicles, counters may make tallies for the chosen classifications, and then use the totals to determine volume afterward. (3) • Limited vehicle classification. (3) • Multiple simultaneous collections possible for data verification. (3) • Lack of speed data. (3) • Vehicle presence, count, and occupancy. (2) • Bicycle counts (dedicated bike lanes/spaces only). (2)
Piezoelectric Sensors	• Vehicle classification, weight, and speed. (2) • Bicycle detection (dedicated bike lanes/spaces only). (2)
Pneumatic Tube	• Pneumatic tubes are best for short-term counting and classification. To capture classification and speed data, a second tube is required to collect axle count and spacing. The tubes should be close enough together that different vehicles will not drive over them simultaneously. This method is one of the most commonly used counts and classification methods. (3) • Vehicle presence, count, and occupancy. (2) • Bicycle counts (dedicated bike lanes/spaces only). (2) • Vehicle count, vehicle presence, speed, vehicle classification. (4) • The road tube is commonly used for short-term traffic counting, vehicle classification by axle count and spacing, planning, and research studies. (5)

Radar Sensors	• Side-firing Radar
	  ○ Count and vehicle classification, dual beams are needed to collect speed by creating a speed trap. (3)
	  ○ Less effective when vehicles are stopped. (3)

Method	Type of Data Collected (Source – Noted at end of table)
	○ Increased risk of obstruction in high-volume roadways. (3) ○ Radar sensors are able to determine vehicle length and use that data to accurately classify vehicles. This allows radar sensors to offer more classes than the previous methods, including pedestrians and bikes. (3) • Forward-firing Radar ○ Vehicle classification. (3) • Microwave Radar Sensors ○ Direct measurement of speed. (1) ○ Continuous wave (CW) Doppler sensors cannot detect stopped vehicles. (1) ○ Vehicle count, flow, speed, direction of motion. (2) ○ Vehicle count, vehicle presence, speed, vehicle classification. (4)
Ultrasonic Sensors	• Count, presence. (1) • Vehicle tracking, presence, and occupancy. (2)

(1) Source: Traffic Detector Handbook (FHWA, 2006)
(2) Source: Data Collection and ITS (ITSJPO, 2022)
(3) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(4) Source: Traffic Monitoring Guide (FHWA, 2022)
(5) Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (The Vehicle Detector Clearinghouse, 2000)

Table A.6 Literature Search: Emerging Traffic Data Collection Methods – Type of Data Collected

Method	Type of Data Collected (Source – Noted at end of table)
Probe Data	• In some cases, cellular coverage by no or only one carrier in remote areas leaves gaps in the speed data. Areas of cellular dead zones with only one or two carriers providing coverage can also increase latency. (2) • Travel Time & Speed, Origin-Destination, Freight, Waypoint, Volume, and Conflation. (3) • Probe-data collection is a set of relatively low-cost methods for obtaining travel time and speed data for vehicles traveling on freeways and other transportation routes. (4)
Thermal Imaging Cameras	• Vehicle classification, speed (5) • Object detection (capable of detecting multimodal traffic counts including pedestrians and bicyclists), tracking, classification. (6) • Traffic flow and speed. (1) • License plate recognition. (1) • Incident detection. (1)
UAS/UAV	• The demonstration of a UAS-based traffic flow analysis system has shown that it may be used to collect traffic flow data such as vehicle counts and classification as well as speed and trajectory data quickly and efficiently. (7) • Traffic data created included origin-destination results and traffic counts. (8) • Traffic Data Collection (UMass Amherst) ○ UAVs have the potential to reduce the hours required to collect speed and volume data. In addition, current methods of data collection can be difficult in rural areas or areas with challenging terrain.

Method	Type of Data Collected (Source – Noted at end of table)
	○ Deep learning framework called "You Only Look Once" (YOLO) v3 was used to identify vehicles. A new model needed to be created due to new perspective. ○ Volume data collection: Recall and precision both averaged 93%. Accuracy worse 7:00-7:20 AM due to lighting. ○ Speed data collection: Average relative error was 6.6%. ○ Static camera was 2.3% more accurate than UAS with same data processing. However, much more flexibility with UAS, especially in difficult locations/terrain. ○ Automatic processing time for vehicle counts was approximately 1.8 hours per hour of video, compared to 6 hours of manual processing per hour of video. (9) • Traffic management (traffic data collection, traffic flow monitoring, qualitative assessment congested interchanges, etc.). (10) • Traffic Analysis (11)
Video Imaging Detection/ Processing	• Vehicle count and classification. (5) • Vehicle count, vehicle presence, speed, vehicle classification. (12) • Interprets images and converts them into traffic flow data. (3) • Rich array of data available. (13) • VIPs can classify vehicles by their length (usually three length classification ranges are available) and report vehicle presence, volume, lane occupancy, and speed for each class and lane. (Page 1-14 - Klein, L.A. Sensor Technologies and Data Requirements for ITS. Artech House, Norwood, MA. 2001.) (13) • Classification data may be limited or not possible at night. (5) • Speed, density, and volume data. (14) • Vehicle count and classification. (5) • Vehicle count, vehicle presence, speed, vehicle classification. (12)

(1) Source: Data Collection and ITS (ITSJPO, 2022)
(2) Source: Assess Speed Data for Traffic Management (ENTERPRISE, 2017
(3) Source: Transportation Data Marketplace (TDM) (The Eastern Transportation Coalition)
(4) Source: Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment (Nebraska DOT, 2017)
(5) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(6) Source: Data Collection and ITS (ITSJPO, 2022)
(7) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia (Alden et al., 2022)
(8) Source: Integration of Unmanned Aerial Systems Data Collection into Day-to-Day Usage for Transportation Infrastructure – A Phase III Project Final Report, No. SPR-1713 (Brooks et al., 2022)
(9) Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021)
(10) Source: NJDOT UAS/Drone Procedures Manual and Best Practices for Use in New Jersey (Agrawal et al., 2021)
(11) Source: Integration of UAS into Operations Conducted by New England Departments of Transportation – Develop Implementation Procedures for UAS Applications (Mallela et al., 2021)
(12) Source: Traffic Monitoring Guide (FHWA, 2022)
(13) Source: Traffic Detector Handbook (FHWA, 2006)
(14) Source: Active Traffic Monitoring Through Large Scale Processing of Aerial Camera Array Networks (C^2M^2, 2019)

COST

Table A.7 Literature Search: Traditional Traffic Data Collection Methods – Cost

Method	Cost (Source – Noted at end of table)
Inductive Loops	• Cost-effective, especially if pre-existing (1) • Sensor cost: $2,500-$4,300 (2) • The equipment cost of inductive loop sensors is low when compared to non-intrusive sensor technologies. (3)
Infrared Sensors	• Active Infrared ○ Sensor cost: $200-$7,000 (2) • Passive Infrared ○ Sensor cost: $2,000-$4,500 (https://www.itskrs.its.dot.gov/node/209796) (2) • Laser ○ Sensor cost: $8,000 (https://www.itskrs.its.dot.gov/node/209796) (2)
Magnetic Sensors	• Magnetometer ○ Sensor cost: $490-$540 (https://www.itskrs.its.dot.gov/node/209796) (2)
Manual Counts	• Low processing costs for low-volume roadways. (1)
Microwave Sensors	• Work zone intrusion alert system ○ Capital costs: $45,845 ○ Yearly O&M costs: $1,908 ○ Per device per year (2) • Sensor cost: $5,000 (https://www.itskrs.its.dot.gov/node/209796) (2)
Piezoelectric	• Sensor cost: $4,400 (https://www.itskrs.its.dot.gov/node/209796 (2)
Pneumatic Tube	• Cost-effective (1) • Sensor cost: $2,200-$2,800 (https://www.itskrs.its.dot.gov/node/209796) (2) • Road tube sensors are usually low cost. (3)
Radar	• Side-firing Radar ○ More expensive than in-road methods (1) • Forward-firing Radar ○ More expensive than in-road methods (1) • Work zone intrusion alert system ○ Capital costs: $6,600 - $31,000 ○ Yearly O&M costs: $1,200 ○ Per work zone area (https://www.itskrs.its.dot.gov/node/209591) (2)

(1) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)

(2) Source: Data Collection and ITS (ITSJPO, 2022)

(3) Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (The Vehicle Detector Clearinghouse, 2000)

Table A.8 Literature Search: Emerging Traffic Data Collection Methods – Cost

Method	Cost (Source – Noted at end of table)

Probe Data	• Identifying and documenting the qualitative or quantitative justification for purchasing third-party data can be a challenge. Potential solutions include:
	  ○ Identify and compare the costs to deploy, operate, and maintain the existing sensor network.
	  ○ Identify and quantify benefits of applications or scenarios using real-time third-party data that are outside of existing sensor coverage areas.
	  ○ Identify other potential users of real-time (or historic) third-party data within your agency to strengthen the case for the purchase.
	  ○ Tailor the procurement to meet specific agency needs.
	  ○ Contact neighboring and peer agencies that use real-time third-party data to get a better sense of the costs and benefits of procuring and integrating the data for operations. (4)
	• Provide multiple vendor offerings at discounted prices. (5)
	• Probe-data collection is a set of relatively low-cost methods for obtaining travel time and speed data for vehicles traveling on freeways and other transportation routes. (6)

Thermal Imaging Cameras	• More expensive than invasive methods. (1)
	• Sensor cost: $4,800 (https://www.itskrs.its.dot.gov/node/209796 (2)
	• Ramp signal video detection system
	  ○ Capital costs: $10,500
	  ○ Yearly O&M costs: $7,000
	  ○ Thermal camera costs $2,800 per unit (https://www.itskrs.its.dot.gov/node/209568) (2)

UAS/UAV	• Compared to traditional methods, UAS data collection method was found to have a similar capital cost, while UAS has the potential to significantly reduce time, and therefore the operational cost, associated with data collection and processing. It was found that on medium to high volume roadways, UAS have the potential to be more time-cost effective than traditional methods. (7)
Video Imaging Detection/ Processing	• Generally cost effective when many detection zones within the camera field of view or specialized data are required. (8) • More expensive than manual counts, pneumatic tubes, and inductive loop detectors. (1)

(1) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(2) Source: Data Collection and ITS (ITSJPO, 2022)
(3) Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (The Vehicle Detector Clearinghouse, 2000)
(4) Source: Assess Speed Data for Traffic Management (ENTERPRISE, 2017)
(5) Source: Transportation Data Marketplace (TDM) (The Eastern Transportation Coalition)
(6) Source: Evaluation of Opportunities and Challenges of Using INRIX data for Real-Time Performance Monitoring and Historical Trend Assessment (Nebraska DOT, 2017)
(7) Source: MassDOT Report 19-010, The Application of Unmanned Aerial Systems in Surface Transportation - Volume I Executive Summary (Knodler et al., 2019)
(8) Source: Traffic Detector Handbook (FHWA, 2006)

REPLACE OR COMPLEMENT OTHER DATA COLLECTION METHODS

Table A.9 Literature Search: Traditional Traffic Data Collection Methods – Replace or Complement Other Traffic Data Collection Methods

Method	Replace or Complement Other Traffic Data Collection Methods (Source – Noted at end of table)
Inductive Loops	• A study in Illinois revealed that travel-time prediction models were more accurate using occupancy data from loop detectors when compared to other traffic variables collected and that particular Data Collection and ITS attention should be paid to malfunctioning loop detectors. This study suggested fusing traffic data from multiple sources to improve the accuracy of traffic prediction models. (1) • Massachusetts DOT retired legacy loop detection system for real-time traffic operations. Using Bluetooth and pursuing an agreement for third-party traffic data. Decision factors: maintenance, less disruption to operations, improved alternatives. (2) • Oregon DOT eliminated in-pavement loop detectors for ITS operations. Transitioned to non-intrusive detection devices. Decision factors: alternatives, maintenance. (2) • MTO plans to remove 30-50% of vehicle detection stations and related equipment including in-pavement loop detectors. Installing nonintrusive devices such as radar, microwave and Bluetooth. Decision factors: Longer life cycle, less disruption to operations, alternatives, operational needs, maintenance cost and effort. (2)

Magnetic Sensors	• Magnetometer (induction coil)
	  ○ The induction or search coil magnetometer is less susceptible than loops to stresses of traffic. The induction magnetometer can be used where loops are not feasible (e.g., bridge decks) and some models can be installed under the roadway without the need for pavement cuts. (3)
	• Magnetometer (two-axis fluxgate)
	  ○ Less susceptible than loops to stresses of traffic. (4)
	  ○ The two-axis fluxgate magnetometer is less susceptible than loops to stresses of traffic. Also some models of the two-axis fluxgate magnetometer transmit data over wireless RF link. (3)

Piezoelectric Sensors	• On an installed cost basis, piezoelectric sensors are only marginally more expensive than an inductive loop but provide significantly more information in the form of improved speed information, the ability to determine the classification of the vehicle, and the capability to determine and monitor the weights of vehicles for WIM systems. (3)
Radar Sensors	• Oregon DOT eliminated radar speed detection devices and is now using third-party probe data. Decision factors: cost, performance/data quality, maintenance, alternative. (2) • Oregon DOT considered traffic cameras with analytics capability rather than radar. Decision factors: alternative, maintenance. (2) • Forward-firing Radar ○ Still relatively new compared to manual counts, pneumatic tubes, inductive loop detectors, video image detection, and thermal imaging cameras. (5)

Method	Replace or Complement Other Traffic Data Collection Methods (Source – Noted at end of table)
	• Side-firing Radar ○ Still relatively new compared to manual counts, pneumatic tubes, inductive loop detectors, video image detection, and thermal imaging cameras. (5)

(1) Source: Data Collection and ITS (ITSJPO, 2022)
(2) Source: Evolving and Phasing Out Legacy ITS Devices and Systems (ENTERPRISE, 2019)
(3) Source: A Summary of Vehicle Detection and Surveillance Technologies used Intelligent Transportation Systems (The Vehicle Detector Clearinghouse, 2000)
(4) Source: Traffic Detector Handbook (FHWA, 2006)
(5) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)

Table A.10 Literature Search: Emerging Traffic Data Collection Methods – Replace or Complement Other Traffic Data Collection Methods

Method	Replace or Complement Other Traffic Data Collection Methods (Source – Noted at end of table)
Probe Data	• Revised process for speed studies. (1) • Reduced use of floating car method and resource savings. (1) • Improved signal prioritization. (1) • Supplemental data in work zones. (1) • More proactive arterial management. (1) • Data-driven project prioritization. (1) • Less field detection devices. (1) • Third-party data expands coverage area and fills in gaps of sensor network. (2) • Agencies contacted for the project indicated that even with a great deal of experience using third-party data still deploy sensors to facilitate operations of managed lanes like high-occupancy toll (HOT), high-occupancy vehicle (HOV), or reversible lanes. Sensors are also used by agencies contacted for this project for variable speed limits. (2) • Pennsylvania DOT procuring third-party real-time statewide speed data, with limited deployment of detection equipment. Vehicle detection equipment left in place for future Connected Vehicle applications. Decision factors: effective resource allocation, operational needs, and usage. (3) • Missouri DOT is phasing out radar, Bluetooth, and Wi-Fi; transitioning to probe data. Decision factors: cost (infrastructure and maintenance), accuracy. (3)
Thermal Imaging Cameras	• No significant advantages over video imaging detection during regular daytime conditions (4)
UAS/UAV	• The existing traffic monitoring system uses cameras mounted on signal mast arms and relies upon highly oblique views of vehicles across multiple lanes of traffic, which often results in visual occlusion. In general, the improved view afforded by UAS data acquisition translated to a more accurate assessment of traffic flow. UAS acquisition also provides more flexibility with respect to deployment and a better, more expansive view of the intersection and approaching traffic. However, the UAS system is very limited with respect to viewing time as battery-powered flights are short, and flights over people and moving vehicles are currently restricted by regulations. Longer flight data

Method	Replace or Complement Other Traffic Data Collection Methods (Source – Noted at end of table)
	collection may be accomplished using tethered UAS where power is provided to the aircraft directly from the ground. (5) • Benefit over current methods in rural areas or areas with challenging terrain. (7)
Video Imaging Detection/ Processing	• A video imaging detection system is able to differentiate and classify moving vehicles, and unlike manual count video footage, vehicle count and classification is analyzed and processed by the accompanying software. (4) • A video image processor can replace several in-ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs. (6)

(1) Source: Synthesis on Probe Speed Data for Arterial Operations (ENTERPRISE, 2021)
(2) Source: Assess Speed Data for Traffic Management (ENTERPRISE, 2017)
(3) Source: Evolving and Phasing Out Legacy ITS Devices and Systems (ENTERPRISE, 2019)
(4) Source: 6 Traffic Counts and Classifications Study Methods (Penny, 2021)
(5) Source: Developing a Plan for Using Unmanned Aerial Vehicles for Traffic Operations Applications in Virginia(Alden et al., 2022)
(6) Source: Traffic Detector Handbook (FHWA, 2006)
(7) Source: Innovative Uses of UAV Technology (Leingang and Ryan, 2021)

Appendix B
Survey Questions

Survey Questions

1. Please provide your contact details. This information will be used if additional information or clarification is needed from this survey.
   - Name
   - Agency
   - Email

Traditional traffic data collection methods have provided trusted data for many years, however there may be advantages to using emerging traffic data collection methods to supplement or replace existing methods.

2. What TRADITIONAL traffic data collection methods does your agency currently use? Select all that apply.
   - Manual counts
   - Pneumatic tubes
   - In-road sensors (e.g., loop detectors)
   - Radar sensors
   - Microwave
   - None of the above
   - Unsure
   - Other. Please describe.

3. Please provide any comments (e.g., uses, benefits, drawbacks) on the TRADITIONAL methods. *(Required)*

4. Which EMERGING methods does your agency use to perform traffic data collection. Select all that apply.
   - Purchasing sensors as a service
   - Third-party traffic data (e.g., probe data)
   - Video image processing
   - Unsure
   - None
   - Other. Please describe.

(Respond to questions #5-#13 for each method selected in question #4)

5. What type of data is collected? Select all that apply.
   - Vehicle speeds
   - Vehicle counts
   - Freeway truck counts
   - Vehicle classification
   - Pedestrian counts
   - Bicyclist counts
   - Additional types of data collected (open-ended)

6. What is the data collected used for? Select all that apply.
   - Traffic signal re-timings
   - Transportation planning studies

- Highway Performance Management System (HPMS) reporting to FHWA
- Real-time traffic management (e.g., monitoring, travel times)
- Additional traffic data uses (open-ended)

7. At what intervals is the data collected?
   - Every second
   - Every 30 seconds
   - Every minute
   - Every 15 minutes
   - Every hour
   - Daily
   - Comments on data collection intervals (open-ended)

8. Do you receive raw data?
   - No
   - Yes

9. If analytics are needed to process and present the data in a usable format, please describe the analytics process including whether your agency and/or vendors provide this functionality. *(open-ended)*

10. Please describe how each emerging method replaces or complements your agency's traditional data collection methods (e.g., manual counts, pneumatic tubes, loop detectors, radar sensors, microwave). *(open-ended)*

11. What are the BENEFITS to using the emerging methods that your agency uses for traffic data collection, especially compared to more traditional methods (e.g., manual counts, pneumatic tubes, loop detectors, radar sensors, microwave). Select all that apply.
    - Less expensive
    - Less maintenance
    - Better accuracy
    - Increased data points
    - Less time needed to collect data
    - Improved data insights
    - Other benefits of emerging methods. Please describe. (open-ended)

12. What are the biggest drawbacks to using these emerging data collection methods? *(open-ended)*

13. Please describe any cost/benefit savings from implementing emerging data collection methods, compared to more traditional methods (e.g., manual counts, pneumatic tubes, loop detectors, radar sensors, microwave). *(open-ended)*

(All respond to question #14)

14. Please provide any additional information that may be relevant on traditional or emerging traffic data collection methods for this project to consider. *(open-ended)*

Appendix C
Survey Responses

Survey Responses

Seventeen (17) responses were received from the following 11 states.

- Arizona DOT (1 response)
- Idaho Transportation Department (1 response)
- Iowa DOT (1 response)
- Kansas DOT (1 response)
- Kentucky Transportation Cabinet (1 response)
- Michigan DOT (1 response)
- New Hampshire DOT (1 response)
- Pennsylvania DOT (1 response)
- South Carolina DOT (1 response)
- Texas DOT (7 responses)
- Utah DOT (1 response)

Question: What TRADITIONAL traffic data collection methods does your agency currently use? Select all that apply.

Table C.1 Survey Responses: Traditional Traffic Data Collection Methods – Currently Used

Traditional Method Currently Used (Answer Options)	# of Responses
Pneumatic tubes	11 (TX, MI, KS, IA, PA, UT, NH, SC, ID, KY, AZ)
In-road sensors (e.g., loop detectors)	10 (TX, MI, IA, PA, UT, NH, SC, ID, KY, AZ)
Manual Counts	9 (TX, KS, IA, PA, UT, NH, ID, KY, AZ)
Radar sensors	8 (TX, NH, UT, PA, IA, KS, ID, KY)
Other*	• Category: Cameras – Miovision Cameras (TX) – Portable Gridsmart camera that can do manual counts, speeds, and volume collections (KS) – Will utilize portable cameras at short term locations not suitable for pneumatic tubes. (SC) • Category: Roadside counters – In the past, we have used on road, portable traffic counters, but have moved away to roadside counters for safety of technicians. On-road - Safety hazard for employee deploying and retrieving counters. (TX) • Category: Other – Video, Loop Signature, Toll Booths (NH)

***Categories added**

Question: Please provide any comments (e.g., uses, benefits, drawbacks) on the TRADITIONAL methods.

Table C.2 Survey Responses: Traditional Traffic Data Collection Methods – Drawbacks

Traditional Method	Drawbacks*
Manual Counts	• Category: Safety – Have to be in the road at some point. (TX) – One has to be working around a lot of traffic for collecting of field traffic data. (KS) • Category: Staffing – Limited to availability of personnel (TX) • Category: Time Consuming – Labor intensive (NH)
Microwave sensors	• Category: Power Service Needed – Power service needed (MI) • Category: Communication – There can be difficulties with communication to DOT servers (MI) • Category: Backfilling data – Difficult to backfill data if the system malfunctions (MI)
Pneumatic tubes	• Category: Safety – Have to be in the road at some point. Safety aspects (TX) – One has to be in the middle of traffic or working around lot of traffic for installation or collecting of field traffic data (KS) – On higher volume roads tubes may be dangerous to set up (NH) • Category: Maintenance – Tubes can be cut or damaged (SC) • Category: Labor Intensive – They require lots of physical exertion to install (KS) • Category: Installation – Invasive (MI) • Category: Frequency of Counts – Semi-year round operation (MI) • Category: Data limitations – Cannot tell what direction vehicles are going from shared lanes (TX) – Cannot separate the turning volumes if the lane is shared by through and turning traffic (TX) – Limits to how many lanes and roadway configurations these can be used on. (ID) • Category: Accuracy – Not always 100% accurate (SC)

Traditional Method	Drawbacks*
In-road sensors (loop detectors)	• Category: Installation – Invasive (MI) • Category: Cost – Cost of maintenance and installation is higher than tubes. (SC) • Category: Maintenance – Construction projects may destroy sensors. (SC) – Anything in the pavement is dependent on the structural integrity of the roadway. (ID) • Category: Power – Battery powered (MI) – Year-round power service needed (MI) • Category: Data Limitations – Limited by stop and go traffic (ID) – Cannot tell what direction vehicles are going from shared lanes (TX)
Radar	• Category: Data Limitations – Cannot tell what direction vehicles are going from shared lanes (TX) – Severe limits to classifying vehicles (ID) • Category: Labor Intensive – Physical exertion to install. (KS) • Category: Safety – Safety concerns. (KS) • Category: Installation – Road side - need to have a post/pole to mount the radar device, not always available in remote/rural locations. (TX) • Category: Reliability issues – Often have to recount due to one sensor failing. (TX)

Categories added

Table C.3 Survey Responses: Traditional Traffic Data Collection Methods – Benefits

Traditional Method	Benefits*
Manual Counts	• Category: Tried and tested – Tried and true. (NH) – Tried and tested. In other words, these methods have been used repeatedly for many years thus any errors incurred in data collection can be found easily. (KS) – Proven technology. (TX) • Category: Accuracy – Tend towards accuracy (TX)
Microwave sensors	• Category: Tried and tested – Tried and true. (NH)

Traditional Method	Benefits*
	– Proven technology, tried and tested. Errors in data can found easily. (KS) – Proven technology. (TX) • Category: Installation – Noninvasive (MI) • Category: Collected data – Provide lane by lane data (e.g., speed, classification, truck counts) (MI) • Category: Duration – Year-round operation (MI)
Pneumatic tubes	• Category: Tried and tested – Tried and true. (NH) – Tried and tested. In other words, these methods have been used repeatedly for many years thus any errors incurred in data collection can be found easily. (KS) – Proven technology. (TX) • Category: Collected data – Provides lane by lane counts (MI) – Ability to collect more locations (SC) – Provide really good axle distance and vehicle class data (ID) • Category: Accuracy – Accurate as long as they are not damaged (TX) • Category: Cost – Lower cost (SC) • Category: Maintenance – Lower maintenance (SC)
In-road sensors (loop detectors)	• Category: Tried and tested – Tried and true. (NH) – Proven technology. (TX) • Category: Collected data – Provides lane by lane data (e.g., speed, classification, truck counts) (MI) – Provides the richest data (ID) • Category: Accuracy – Better accuracy than tubes (SC) • Category: Safety – Safer than tubes (SC)
Radar	• Category: Tried and tested – Tried and true. (NH)

Traditional Method	Benefits*
	– Tried and tested. In other words, these methods have been used repeatedly for many years thus any errors incurred in data collection can be found easily. (KS) • Category: Adjustments – Can easily adjust to match new conditions (TX)

Categories added

Table C.4 Survey Responses: Traditional Traffic Data Collection Methods – Uses

Traditional Method	Uses
Microwave sensors	• All types of roads (MI)
Pneumatic tubes	• Local routes (MI) • Not good in stop and go conditions (ID)
In-road sensors (loop detectors)	• Interstates (MI) • On/off ramps (MI)
Radar	• Great for stop-and-go areas, such as urban interstates (ID)

Question: What EMERGING methods does your agency use to perform traffic data collection? Select all that apply.

Table C.5 Survey Responses: Emerging Traffic Data Collection Methods

Emerging Method (Answer Options)	# of Responses	Comments
Third-party traffic data (e.g., probe data)	8 (ID, KY, TX, NH, UT, PA, IA, MI)	Through consultant work mostly, they are utilizing some of the purchased traffic counts from connected vehicles (TX)
Video image processing	6 (ID, KY, TX, NH, IA, KS)	Third-Party Video Image Processing (MioVision) (TX)
Purchasing sensors as a service	3 (SC, UT, IA)	In 2019, SCDOT moved to a pay for data contract for CCS/WIM sites. Our contractor installs the sensors in the roadway (unless a camera is use) and maintains the sensors and all equipment on the side of the road. Less maintenance and installation cost, better vehicle classification accuracy. (SC)
None	1 (AZ)	
Other	• Streetlight origin destination data for travel time and origin destination data. Data is collected for construction alert, inform the public, environmental studies, traffic model calibration, project prioritization. Provided quarterly. Raw data is not received. Vendor provide interface, but usually requires additional work. Provides improved data insights. Large amount of funding and misunderstanding the data. Provides understanding of behaviors that we could not visualize accurately before or were skewed by device placement of Bluetooth/Wifi devices. (UT)	

Emerging Method (Answer Options)	# of Responses	Comments
	• Camera Detection. Data collected for traffic signal re-timings and transportation planning studies. Detection every 15 minutes. Raw data is received. We use these for timing and counts to pay back the county pass through projects based on ADT. Analytics process - Agency through Next software and Tableau. Safer when set up. (TX)	

Question: What type of data is collected? Select all that apply.

Table C.6 Survey Responses: Emerging Traffic Data Collection Methods – Types of Data Collected

Types of Data Collected (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
Vehicle Speeds	3 (SC, UT, IA)	7 (KY, TX, NH, UT, PA, IA, MI)	3 (TX, NH, KS)
Vehicle Counts	2 (SC, IA)	4 (KY, ID, TX, MI)	5 (ID, TX, NH, KS, KY)
Freeway Truck Counts	2 (SC, IA)	1 (TX)	3 (ID, NH, KS)
Vehicle Classification	2 (SC, IA)	1 (TX)	3 (ID, NH, TX)
Pedestrian Counts	0	0	4 (KY, ID, NH, TX)
Bicyclist Counts	0	0	3 (KY, ID, NH)
Other	• WIM. All data is collected and stored in IVR format (SC)	• Hard braking, hard accelerating, u-turn movements, cross-over/intersection directional distribution (TX)	• Ped counts with miovision video with TMC. (NH) • Image processing is only for live alerts, not reliable enough for stored traffic data (IA) • Also used at truck parking sites to calculate available spaces (KS)

Question: What is the data collected used for? Select all that apply.

Table C.7 Survey Responses: Emerging Traffic Data Collection Methods – Uses of Data Collected

Use of Data Collected (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
Traffic signal re-timings	0	3 (TX, NH, PA)	4 (KY, TX, NH, KS)
Transportation planning studies	2 (SC, UT)	5 (ID, TX, UT, PA, IA)	3 (ID, TX, NH)

Use of Data Collected (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	**Third-party traffic data (e.g., probe data)**	**Video imaging processing**
HPMS reporting to FHWA	1 (SC)	2 (ID, PA)	3 (KY, ID, NH)
Real-time traffic management (e.g., monitoring travel times	2 (SC, UT)	6 (KY, TX, NH, PA, IA, MI)	3 (KY, TX, IA)
Other	• Data used in real time for hurricane evacuation or other disaster reporting; HPMS; updating SCOUT databases and calculating VMT. Used in planning, maintenance and construction functions. Monitor traffic growth, trends and historical patterns. Aids in projecting future traffic. Public and private users. (SC)	• The consultant has just started using signal timing, we do not have any results from this yet. They did use their data to indicate travel times from a particular location through and intersection to determine delays caused by detouring traffic on a TXDOT construction project. (TX)	• Traffic Monitoring Guide (TMG) (NH) • Rest area truck counts for availability information (KS)

Question: At what intervals is the data collected?

Table C.8 Survey Responses: Emerging Traffic Data Collection Methods – Data Collection Intervals

Intervals Data Collected (Answer Options)	**Emerging Method: # of Responses**		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
Every second	0	2 (NH, TX)	1 (KS)
Every 30 seconds	1 (UT)	0	1(IA)
Every minute	1 (IA)	5 (KY, UT, PA, IA, MI)	2 (ID, TX)
Every 15 minutes	0	2 (ID, TX)	0
Every hour	0	0	1 (TX)
Daily	0	0	1(NH)
Other	• Data is collected and stored in IVR format but “rolled” up to 15 minutes (SC)	• The consultant said the connected vehicle data is only capturing	

Intervals Data Collected (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
		passenger vehicle and only a percentage. (TX) • NH uses TomTom for speed, but we are not sure how often. (NH) • Data is collected every minute but traffic management software compiles 15 minute data usage. (MI) • Most of our standard models use data in quarter hour or hourly bins. Also, I believe the NPMRDS in is 5- minutes bins (ID).	

Question: If analytics are needed to process and present that data in a usable format, please describe the analytics process including whether your agency and/or vendors provide this functionality.

Table C.9 Survey Responses: Emerging Traffic Data Collection Methods – Analytics Process

Emerging Method (Answer Options)	Analytics Process*
Purchasing sensors as a service	• Category: Vendor/University – Vendor provides interface (UT) – Drakewell Software is used for download, processing, QA/QC and reporting (SC) • Category: DOT – We rent work zone sensors that feed raw data into our ATMS, just like our permanent sensors (IA)
Third-party traffic data (e.g., probe data)	• Category: Vendor/University – Vendor (TX) – Vendor works with each agency owned software to integrate into a usable format. (MI) – INRIX provides analytics directly and via RITIS; Wejo we are using Iowa State University to help us analyze the data. (IA) – We utilize the University of Maryland's Probe Data Analytics Suite and Trip Analytics platform that they provide as part of their RITIS platform. (PA) – Vendor - data is collected and reported by TomTom (NH) – Vendor provided (ID)

Emerging Method (Answer Options)	Analytics Process*
	– Although unavailable, the consultant provided the end result for which the data was used. They generally include the caveat that this is passenger vehicles only and is only a sampling of the volume. (TX) – Use another vendor (Iteris) to provide interface (UT) • Category: DOT – We also have an internal data team that ingests and processes data for us, and builds reports based in Microsoft Power BI (PA) – Filtering, limiting – agency (TX)
Video image processing	• Category: Vendor/University – Vendor (TX) – We purchased 2 Gridsmart 360 bell cameras that are primarily used for stationary means on a signal light pole to be used for signal light performance measures, signal timings, and some data collection. Instead of a permanent installation of these cameras we placed them on 2 mobile trailers so that we can collect traffic data collection at intersections around the state of Kansas. Gridsmart sends the imagery/traffic data it collects to their own cloud based system and processes the data there. For truck parking counts, I believe the process and algorithms are set up to automatically calculate the results output the end data to availability signs and our database. We have an ongoing contract with UMN and a consulting firm to maintain the system. (KS) – TrafficVision provides all the analytics (IA) – AI algorithm to convert data into classification and counts. Completed by vendor. (NH) – Counting – vendor (TX) – Vendor provided (ID) – Vendors provide this functionality (TX)

Categories added

Question: Please describe how each emerging method replaces or compliments your agency's traditional data collection methods.

Table C.10 Survey Responses: Emerging Traffic Data Collection Methods – Replace or Complement Traditional Data Collection Methods

Emerging Method (Answer Options)	Replace or Complement Traditional Data Collection Methods*
Purchasing sensors as a service	• Mainly used for queue detection related to work zones. Occasionally to collect volumes to help plan a future project. (IA) • Decreases the frequency/need for microwave/radar sensors on freeway. (UT)

Emerging Method (Answer Options)	Replace or Complement Traditional Data Collection Methods*
	• CCS/WIM pay for data replaced our in-house installation & maintenance of sensors. SCDOT had limited staff & resources to continue installing and maintaining CCS/WIM sensors. SCDOT pays only for data passing QA/QC and marked as good in the software. This process provides more accurate and timely data. Adding Rekor cameras to the CCS/WIM pay for data system improves safety, provides more accurate vehicle classification data & reduces cost due to not having to install & maintain sensors in the roadway. (SC)
Third-party traffic data (e.g., probe data)	• This compliments our data by providing real time data. It also allows us to have more data for speed studies, etc. where currently we are making decisions on point surveys. (TX) • Loops detectors, Microwave detectors provide a lane-by-lane data on the interstate. Pneumatic tubes are useful on Michigan routes. Microwave vehicle detection can detect Motorcycles. (MI) • Cannot be used for volumes, but this service lets us eliminate sensors originally deployed for real-time speed monitoring. (IA) • We only use 3rd party data in manners similar to detectors at it relates to collecting speed data. Our 3rd party data is available statewide, and so we generally discourage deployment/use of physical detectors except in areas where probe data is demonstrably insufficient. We do have certain applications (VSL corridor in Philadelphia) where we utilize detector data as a primary source and 3rd party data as a backup, due to relative latency of probe data. (PA) • Decreases the frequency/need for microwave/radar sensors on freeway, decreases people riding vehicles for travel times. (UT) • Saves many hours of labor by DOT staff in the development of speed studies. (NH) • Can replace radar speed study if there are single lane approaches and a high enough probe density in the area, otherwise it complements with extra data. (TX) • Multi roadways data, historical data. (TX) • Manual counts, ltubes (KY) • This rich source of data helps in evaluating travel time reliability. In corridor studies, it provides a more comprehensive data set than our standard 48 hour count. (ID) • First and foremost, it is safer than putting an employee on/in the road. There are things like traffic signal warrants for which we still need to put out counters to get all vehicles, which we do ourselves, mostly. (TX)
Video image processing	• This gets us out of the road and allows us to quickly count intersections, pedestrians, etc. (TX) • The Video Imagery Processing replaces manual counts, pneumatic tubes and road sensors when it is used. (KS)

Emerging Method (Answer Options)	Replace or Complement Traditional Data Collection Methods*
	• Eliminates manual collection of vehicles classification - 24/7- Non intrusive and can be portable. (NH) • Can replace manual counts and pneumatic tubes for turning counts, 24-hour counts, but is not set up to replace continuous ADDT counts. In practice this complements traditional methods as there can be lag time for obtaining equipment, equipment setup, etc. (TX) • Convenient, Time saving (TX) • Manual counts, pneumatic tubes, loop detectors (KY) • We can perform counts where every other traditional method is not an option, and it provides a way to remove people from stepping onto roadways in high traffic areas. Thus it's super important for a safety aspect for our field crews. (ID) • Usually replaces the need for manual counts i.e., pedestrian/pedcycle, intricate turning movements, etc. (TX)

Question: What are the benefits to using the emerging methods? Select all that apply.

Table C.11 Survey Responses: Emerging Traffic Data Collection Methods – Benefits

Benefits (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
Less expensive	1 (SC)	2 (NH, PA)	1 (NH)
Less maintenance	3 (SC, UT, IA)	6 (NH, UT, PA, IA, MI, TX)	3 (TX, NH, KS)
Better accuracy	2 (SC, UT)	3 (IA, MI, TX)	3 (ID, TX, KS)
Increased data points	2 (UT, IA)	7 (ID, TX, NH, UT, PA, IA, MI)	4 (ID, NH, IA, KS)
Less time needed to collect data	0	6 (KY, TX, NH, PA, IA, MI)	5 (KY, ID, TX, NH, KS)
Improved data insights	1 (UT)	7 (ID, TX, NH, UT, PA, IA, MI)	4 (ID, TX, NH, KS)
Other		• The consultants is able to pull data over a longer period of time than we would have from traditional counting methods. The data is not a complete set and is a sampling at best, so that is a downside – but has been useful for the tasks we have asked them to complete. The old way, with in-house employees	• Video allows us to do turning movements, which are incredibly beneficial for RSAs, intersection studies, and signal timing. However, they are more expensive. (ID) • Video image processing takes longer than manual counts, but the individual(s) that would otherwise be doing a

Benefits (Answer Options)	Emerging Method: # of Responses		
	Purchasing sensors as a service	Third-party traffic data (e.g., probe data)	Video imaging processing
		would be less expensive, I am sure. (TX) • Year-round operation, difficult location data such as interstate to interstate traffic data. (MI) • Broader coverage and more system awareness. (IA)	manual count can be doing something else while a contracted person works through the video data. (TX)

Question: What are the biggest drawbacks to using these emerging data collection methods?

Table C.12 Survey Responses: Emerging Traffic Data Collection Methods – Drawbacks

Emerging Method	Drawbacks
Purchasing sensors as a service	• Deployed as projects and need was not as urgent after projects left. (UT) • Initial contract procurement process can be slow & potential adjustments of switching vendors at the end of contract. (SC)
Third-party traffic data (e.g., probe data)	• Big data, lots of it (TX) • Michigan road description segments are difficult to program if the vendor has a 6 month wait period to possibly amend description. If at any time vendor's servers are down, data is may be lost. Lane by lane vehicle count and classification are not possible. Under conditions accuracy depletes, such as night and under large infrastructures. (MI) • For certain application, the latency of ~5 minutes can be a drawback. (PA) • Data sources of the vendor are erratic and renewing probe data contracts. (UT) • Questionable speed accuracy on lower volume roads, subset of traffic captured. (NH) • Cannot provide an actual turning count until there is near 100% probe saturation. (TX) • Cost prohibits (TX) • Accuracy in low volume roads, or not enough points to calibrate against in an area. (ID) • Expensive/data management (KY) • Not a complete data set (TX)

Emerging Method	Drawbacks
Video image processing	• Time spent setting up the trailer and setting up the camera. Also, with creating the zones properly so that accurate counts can be collected (especially in the Kansas wind). (KS) • Cost including subscriptions, Proprietary, Still evolving and improving, new structures for mounting equipment, may need communications, may not work with solar. (NH) • Cost and delay (TX) • Accuracy (TX) • Cost (ID) • Limited accessibility of technology. (KY) • None that I am aware of form the applications we use. (TX)

Question: Please describe any cost/benefit savings from implementing emerging data collection methods, compared to more traditional.

Table C.13 Survey Responses: Emerging Traffic Data Collection Methods – Cost/Benefit Savings

Emerging Method	Cost/Benefit Savings
Purchasing sensors as a service	• Not feasible to put up sensors in time and locations to support project for small timeframe. Cost prohibitive to install other options. (UT) • Less staff, improved safety, lower cost and better data. (SC)
Third-party traffic data (e.g., probe data)	• We wouldn't have to do field observations. (TX) • State of Michigan IT department red tape does not impede quick software improvements, accurate vehicle speeds compare to traditional methods, (MI) • The Wejo data has the potential to unlock new insights into how vehicles are navigating our roadways. (IA) • We have almost completely been able to eliminate physical deployments of speed detectors. Additionally, we have used 3rd party probe data to implement virtual queue warning corridors throughout the state. This saves hundreds of thousands of dollars per deployment over traditional systems, and also allows deployment in areas that might not otherwise be feasible. (PA) • Much less maintenance and provides travel times during construction and in areas not available before that would be cost prohibitive to deploy in rural areas. (UT) • Faster turn around-Better Time Management (TX) • Less invasive, greater coverage, staff time, no equipment (NH) • Better use of time (TX) • Additional data points on a corridor study will result in a better design. (ID) • Accessibility/size of data sets (KY) • Can be quicker to gather, no vehicle, gasoline, time to location etc. (TX)

Emerging Method	Cost/Benefit Savings
Video image processing	• Cost/Benefit savings of using Emerging Data Collection over Traditional ones is Safety! With emerging data collection, one doesn't necessarily need to be out in the middle of a busy highway or city street trying to collect traffic count data. (KS) • Cost (TX) • Less invasive for counts and class, Less labor for classification. (NH) • Better use of time. (TX) • The biggest benefit is that we were performing partial day manual counts in urban areas prior to using video. This allows us accurate and more comprehensive data, which makes our overall data system better. (ID) • Minimal staff required. (KY) • Time and labor cost to process the information and time in the field for manual counts. (TX)

Question: Please provide any additional information that may be relevant on traditional or emerging traffic data collection methods for this project to consider.

- KDOT does not have funds to procure other forms of emerging traffic data collection. We are aware of companies that can provide video image processing for a fee but do not use them due to lack of funding. (KS)
- Signature technology is emerging and may not have realized its full potential, inclusion can be challenging with new camera technologies, greater volume of data to manage, use of a wide variety of equipment/technology, wide selection of new technologies vendors. (NH)
- Traditional methods are better cost-effective than new traffic data collection. (TX)
- Really need accurate automated processes to help free up personnel. (TX)
- Traditional methods will still have their uses even as emerging methods increasingly adjust to consumers needs, and different methods rise to meet different circumstances and opportunities. It's important to not throw away "old" tools, because they do still work and often can be employed quickly. (TX)
- We see the future being emerging data. However, there are limits in areas where things like passive data are not as saturated, and thus have fewer data points. We have large swaths of our state without cell service, and until we become more saturated with cell and vehicle probe data, our low volume roads will not get highly accurate volumes/speeds/etc. Right now, the biggest inhibitor of video data is cost. (ID)