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Synthesis of Automated Pedestrian Data Collection Technologies

Angela Haddad
Lisa Macias
Chandra R. Bhat
Kenneth A. Perrine

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16. Abstract

Through academic research and direct communications with transportation agencies, this project surveys new roadside technologies that can assist in efforts for detecting pedestrians. Reasons for using such technologies include traffic operations enhancements, safety improvements, planning, benchmarking, and eventual connected vehicle integrations. Traditional technologies and many new product offerings are identified. Results of surveys and interviews show that most practitioners use video-based technologies, but thermal imaging, LiDAR, and combinations of these technologies with video are gaining attention. The expense of technologies and their suitability for use in specific environments are important considerations in choosing products. Details about ongoing cost structure and data ownership are also important to analyze, including products that require a recurring subscription to a cloud-based data processing service. Some agencies have designed their own systems or data processing schemes to avoid expenses required by commercial providers. This project delivers a simple decision support framework that assists in identifying products and technologies most appropriate for a set of requirements.

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Kenneth A. Perrine
Angela Haddad
Lisa Macias
Chandra R. Bhat, Ph.D.

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Center for Transportation Research
The University of Texas at Austin
3925 W. Braker Lane, 4^{th} floor
Austin, TX 78759

http://ctr.utexas.edu/

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Products

P1: Decision Support Framework (Microsoft Excel file)

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Chapter 1. Introduction

Cities in the United States have been experiencing a significant increase in pedestrian fatalities even as the intensity of pedestrian movement has increased, in part as a result of this shift. Additionally, as transportation planning and funding become more data-driven, state agencies are required to justify their investments with robust quantitative data and measures. Thus, there is a critical need for accurate, reliable, and comprehensive information about pedestrian travel movements to support the planning, design, and management of pedestrian infrastructure as part of a larger regional surface transportation system. However, advancement in the pedestrian field is persistently challenged by the lack of usage and documentation of the technologies available.

Traditionally, quantitative measures of pedestrian volumes have been used as a baseline that informs planning and funding decisions as departments of transportation (DOTs) aim to build safe, comfortable, and convenient walkable environments. Accurate and relevant pedestrian movement data can provide insights into the mobility patterns of pedestrians and possible conflicts with motorized traffic. This information can be used to make decisions regarding installing and operating traffic signals or beacons, and to determine the need for constructing painted crosswalks, barriers, refuge islands, underpasses, overpasses, or other facilities. Pedestrian data can also be used to examine sidewalk capacity and can influence land-use decisions through the selection of locations for public buildings and through property and land valuation. Another important benefit of pedestrian data collection is that this data allows researchers to conduct exposure and risk analysis for safety-related purposes. These analyses help identify potential areas of concern and relate pedestrian volumes, attitudes, and behaviors to the likelihood of crash incidents. Other applications include before-and-after analyses of infrastructure projects to better understand the safety outcomes of investments like the installation of a pedestrian-hybrid beacon. Collected data can also be developed into historical datasets that researchers can use to assess changes over time, draw conclusions about the impact of new facilities, and promote design reforms for future facilities.

Emerging capabilities around pedestrian data are made possible by AI-based technologies. Artificial intelligence (AI) makes it possible for machines to learn from experience, adapt, and perform tasks that have historically required human cognition, and it is revolutionizing the field of traffic monitoring. Below is a list of functionalities that are facilitated by emerging data collection technologies:

- Near-miss detection
- Touchless crosswalks
- Detection of social distancing in real-time
- Detection of crosswalk violations
- As-needed crosswalk call extension (e.g., for disabled and elderly citizens)
- Call cancellation

- Call abbreviation (e.g., if someone is running or the crosswalk clears quickly)
- Driver notification of pedestrian midblock crossings
- Crosswalk occupancy detection
- Automated and continuous turn counts
- Preemptive traffic signaling calls to protect vulnerable populations, such as the elderly, schoolchildren, and those with disabilities
- Real-time data on what is around the corner for connected vehicle drivers
- Immediate incident detection and response
- Future-proofing infrastructure to integrate with connected and autonomous vehicles (V2X)

Guidance for counting nonmotorized users has been developed at the national level and is available in the Traffic Monitoring Guide (TMG) and NCHRP Report 797, *Guidebook on Pedestrian and Bicycle Volume Data Collection*. Other reports that document best practices for pedestrian and bicyclist traffic monitoring include:

- FHWA's *2016 Traffic Monitoring Guide*;
- NCHRP Web-Only Document 229, *Methods and Technologies for Pedestrian and Bicycle Data Collection: Phase 2*; and
- Report FHWA-HPL-16-026, *Exploring Pedestrian Counting Procedures: A Review and Compilation of Existing Procedures, Good Practices, and Recommendations.*

However, due to the rapid pace of technological advancement, these reports, which only address technologies available at their time of publication, are not up-to-date. This report documents and addresses all emerging technologies of potential interest to TxDOT in the field of pedestrian data collection, while also briefly discussing traditional techniques for the sake of completeness.

In this project, we undertake a comprehensive literature review of the state-of-the-art and the state-of-the-practice of manual and automated pedestrian data collection techniques. The outcome of this review is an assessment of the different automated data collection methods, including well-established and emerging AI- and sensor-based technologies, to evaluate their appropriateness and efficacy in different environments and for supporting data collection and usage efforts. The purpose of this report is to provide important insights regarding different automated pedestrian sensing techniques that will aid TxDOT in evaluating the appropriateness and effectiveness of these technologies based on a set of relevant decision-making variables. This comprehensive review also informed the nationwide surveys and interviews that were conducted as part of this project.

1.1. Motivations and Objectives

Novel technologies that automate the collection of pedestrian data and behavior through AI-enhanced video analytics, thermal identification, and LIDAR sensors are continuously emerging. However, little is known about the potential risks and technical barriers. Therefore, this research delivers a synthesis of automated pedestrian data collection technologies. The ultimate outcomes of this project are twofold:

1. a synthesis that reflects the state-of-the-art and state-of-the-practice in addition to the results of surveying and interviewing relevant transportation entities and vendors, and
2. the development of a decision support system that aids in evaluating the appropriateness and effectiveness of different automated technologies based on a set of relevant decision-making variables.

These outcomes are addressed through the following technical objectives:

1. review the state-of-the-art and available techniques and products in the market for automated pedestrian detection;
2. conduct a survey on nationwide best practices for pedestrian-related data collection and analytics, and their applications to safety and operations; and
3. interview stakeholders who previously adopted such techniques and understand the lessons learned and their expert qualitative opinions of these technologies.

In this report, we compile our findings on manual and automated pedestrian detection systems as well as current market products while exploring their strengths and weaknesses, maturity levels, accuracy, costs, and installation methods.

Chapter 2. State of the Practice Survey Summary

2.1. Overview

An online survey was designed using Qualtrics; its purpose was to determine the extent to which different pedestrian count and detection technologies are being used, these technologies' attributes, use cases, and customer satisfaction levels. The survey was sent to 194 experts within related agencies, institutions, and companies. Out of the 194 recipients, 63 survey responses were submitted. Below is a list of the agencies that responded to the survey:

State DOTs

- Texas DOT
- Florida DOT
- Utah DOT
- Minnesota DOT
- Massachusetts DOT

City DOTs

- Austin, TX
- Detroit, MI

MPOs

- San Diego Association of Governments
- Pima Association of Governments
- Mid-Ohio Regional Planning Commission
- Maricopa Association of Governments
- Mountainland Association of Governments
- Puget Sound Regional Council
- Metropolitan Transportation Commission (Bay Area)
- The Atlanta-Region Transit Link Authority
- Baltimore Metropolitan Council
- East-West Gateway Council of Governments
- Delaware Valley Regional Planning Commission (DVRPC)
- Charlotte Regional Transportation Planning Organization

2.2. Survey Results

2.2.1. Technology Types

Survey respondents reported using a variety of pedestrian count technologies. The proportion of respondents using each type of technology is presented in **Figure 2.1**; 37% reported using passive infrared sensors, 21% used automated video technologies, and 18% used pressure or acoustic pads. Most agencies that reported using automated video technologies indicated that they started adopting them in 2020 or later. However, the proportion of agencies using LiDAR and thermal imaging is significantly lower, where only Utah DOT reported using them. Additionally, less than 5% of the agencies reported that they are implementing experimental programs for evaluating LiDAR (Austin DOT) and camera technologies.

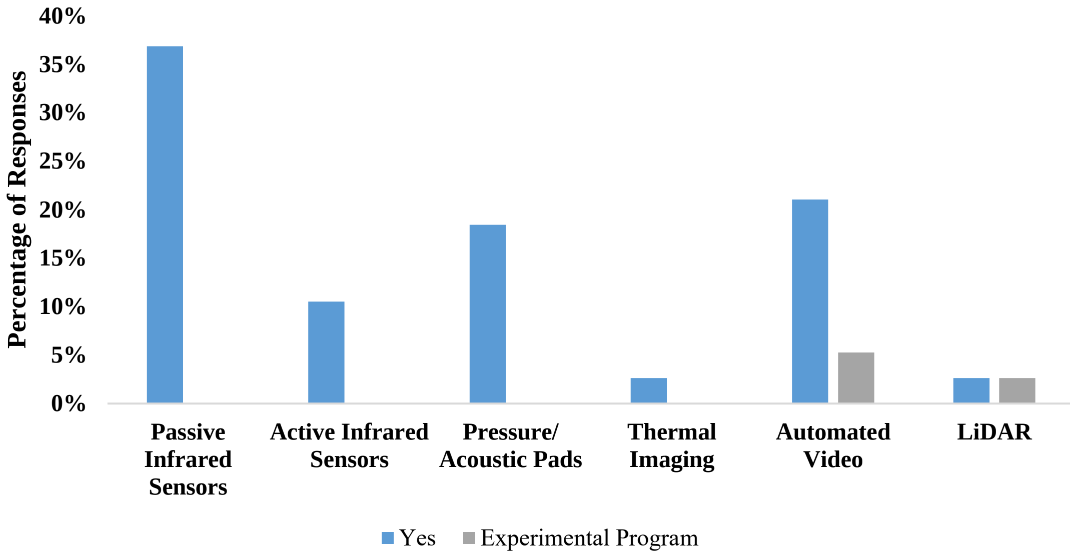


Figure 2.1 Frequency of pedestrian data collection by type of technology

2.2.2. Vendors

The survey asked respondents about the different vendors they use for all pedestrian count and detection technologies. While most respondents elected not to answer this question, some provided the vendors and products they deploy or have heard about, especially for automated video technologies. **Table 2.1 Automated video and LiDAR vendors as reported by survey** respondents lists all the reported vendors providing products that are up to date with emerging technologies. The results show that Miovision products are the most commonly used for pedestrian counts (refer to **Table 2.1** Automated video and LiDAR vendors as reported by survey respondents). Regarding LiDAR technologies, only two respondents provided vendor names, Velodyne and BlueCity.

Table 2.1 Automated video and LiDAR vendors as reported by survey respondents

Vendors	Frequency
Automated Video Technology	
Spack Solutions	1
Currux	1
Miovision	7
GoodVision	1
MicroTraffic	1
AI Agora system	1
Iteris	1
Eco-Counter CITIX3D	1
LiDAR Technology	
Velodyne	1
BlueCity	1

However, no clear answers were provided by respondents when they were asked about product and vendor selection processes. This may indicate a lack of procurement criteria and quality control and assurance measures. The responses included some accuracy, cost, and functionality requirements for vendor selection, while the majority of agencies indicated an inclination to run pilot programs for comparing different equipment prior to deciding on vendors. Some of the answers provided regarding vendor evaluation criteria are presented in **Table 2.2**.

Table 2.2 Vendor evaluation criteria

Criteria	Selected survey responses
Accuracy	• "Send the vendor a video of a location with known counts and compare that with the machine count. Vendors must achieve an accuracy of at least 95%." • "Test vendor's equipment under real-world conditions and compare results against manual counts." • "Our project consultant ran tests on each technology we received an application for to see if they met an 80% accuracy threshold."
Cost	• Lowest price
Country of origin	• Made in the USA
Pilot study	• "Conduct a pilot a study to evaluate counting capabilities of 7 video-based technologies that are already installed at intersections locally. This pilot evaluates their counting accuracy under different conditions." • Formal evaluation with partnering universities
Other	• Functionality provided • Ease of use • Ease of installation • Data analytics platform

Criteria	Selected survey responses
	• Reliability of the equipment in cold temperatures • Ability to sync data standards and formats with the rest of the agency's count data

2.2.3. Technology Evaluation

Survey respondents were also asked to rate the accuracy, ease of implementation, and durability of thermal imaging, automated video, and LiDAR technology based on their experience. The results are summarized in **Table 2.3**. Thermal imaging received only one response, from Utah DOT, which marked it "acceptable" for all three criteria.

Regarding automated video technologies, 50% of the respondents reported excellent accuracy. Five out of the remaining six responses indicated acceptable accuracy, and only one respondent, from Utah DOT, suggested bad accuracy. However, respondents appear to be less satisfied with the ease of implementation of video technologies. Only three out of 11 respondents indicated excellent ease of implementation, while seven scored it merely acceptable. However, respondents reported better hardware durability levels.

Only two respondents ranked the attributes of LiDAR technologies. Interestingly, they had opposite responses regarding the levels of accuracy and ease of implementation. It is difficult to interpret this outcome, especially since LiDAR is still not widely established as a pedestrian detection equipment technology and there are currently no products on the market that are dedicated to this application.

Table 2.3 Technology attribute ranking

Characteristic	Technology	Excellent	Acceptable	Bad	No Answer
Accuracy	Thermal Imaging	1	0	0	37
	Automated Video	6	5	1	29
	LiDAR	1	0	1	36
Ease of Implementation	Thermal Imaging	0	1	0	37
	Automated Video	3	7	1	29
	LiDAR	1	0	1	36
Durability of Hardware	Thermal Imaging	0	1	0	37
	Automated Video	7	2	1	30
	LiDAR	1	1	0	36

2.2.4. Advantages and Disadvantages

Several of the surveyed agencies responded regarding the advantages, disadvantages, and challenges of using emerging pedestrian detection technologies. They reported that the challenges and disadvantages stand in the way of adopting these technologies. In the sections below, we discuss the pros and cons of automated video, LiDAR, and thermal imaging technologies.

2.2.4.1. Automated Video Technology

Table 2.4 summarizes the survey responses on the advantages and disadvantages of automated video technology.

Table 2.4 Advantages and disadvantages of automated video technology

Advantages	Disadvantages
• Covers a larger area where pedestrians are not confined to a narrow path, such as people crossing midblock • Raw video files can be used for safety assessment • Accurate • Placed out of reach of vandalism and away from moving traffic • Easy to install • No need to cut into the road • Easy to audit • Covers all movement • High volume and mode split accuracy • Affordable to procure • Cheaper than the "reduction" method of video review by a technician • Integrated with signal detection equipment	• Pedestrians crossing further from the counter can be missed by automated data processing, so manual processing may be necessary • Battery life is limited • Best suited for short-duration count • Expensive data processing • Long-term deployment feasibility heavily depends on cost, power source availability, and number of cameras • High recurring costs for data • Limited capabilities at night or in locations with high wind • Weather (fog, glare) can thwart devices • Algorithms can be buggy • Generally requires AC power (usually at a signal) • Accuracy and cost depend on the specifics of the installation

2.2.5. LiDAR Technology

Most agencies were not familiar with the advantages and disadvantages of using LiDAR. In particular, many respondents reported that they are unaware of any advantages LiDAR has over video imaging and thermal imaging. **Table 2.5** summarizes the few survey responses on the advantages and disadvantages of LiDAR technology.

Table 2.5 Advantages and disadvantages of LiDAR technology

Advantages	Disadvantages
• Enables the collection of new types of data • Could be cheaper than the "reduction" method of video review by a technician • Accurate	• More commonly used for collecting roadway data and not for pedestrian detection • Not tested yet • High cost of gathering, storing, and processing more refined/granular pedestrian information • MPOs do not need this granular data • There aren't many vendors on the market

2.2.6. Thermal Imaging Technology

Similar to LiDAR, agencies were mostly unfamiliar with this type of technology and its characteristics. **Table 2.6** summarizes the survey results regarding the advantages and disadvantages of thermal imaging technology.

Table 2.6 Advantages and disadvantages of thermal imaging technology

Advantages	Disadvantages
• Detects multiple user types • Enables collection of new types of data • Helps collect data beyond counts • Tracks paths and routes within the sensor area • Counts multiple methods of travel • More accurate than video technology in dark conditions and the presence of occlusion	• Not tested yet • Limited operating temperatures of the equipment • Lack of user familiarity • Not effective in rainy or dark conditions • Costly • Accuracy is not well established

2.2.7. Data Usage

The purpose of pedestrian data collection differed among agencies, though applications relating to safety and planning were commonly observed. **Figure 2.2** summarizes the data uses that were reported by survey respondents. Most agencies use their collected pedestrian data for measuring pedestrian volumes, safety planning, and general non-motorized infrastructure planning applications. A few agencies reported using pedestrian data for assessing the impacts of new developments, inventory assessment, pedestrian phase actuation, and trend monitoring. Only one agency reported using pedestrian data for crash analysis, first and last mile analysis, bridge demand analysis, origin-destination studies, and pedestrian exposure estimation.

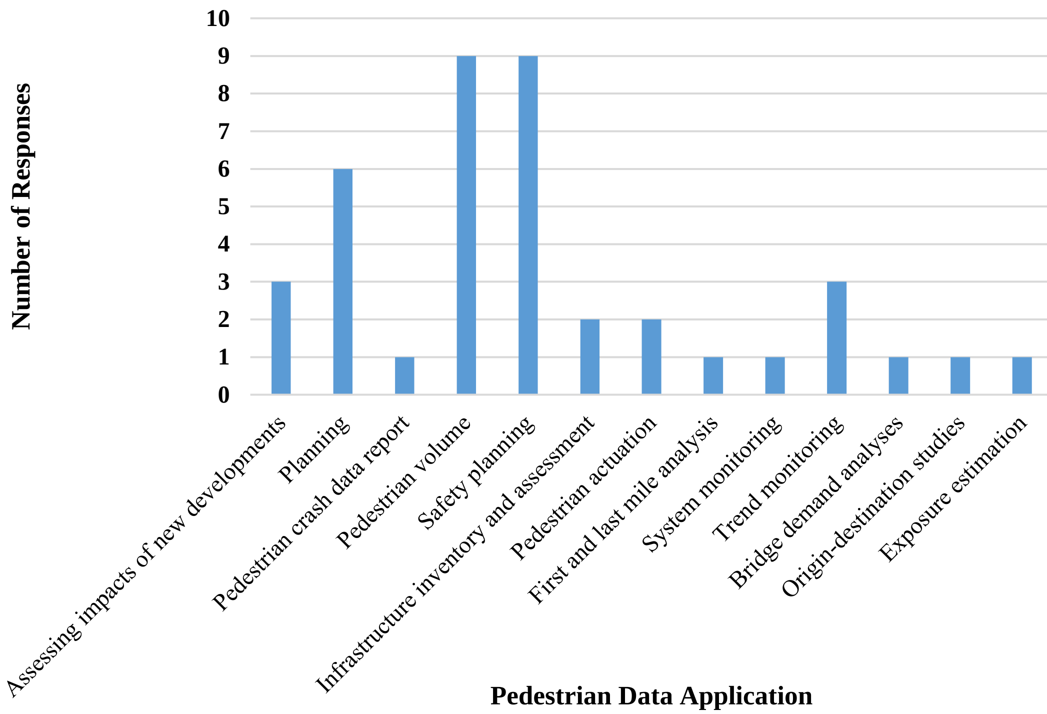


Figure 2.2 Pedestrian data applications reported by survey respondents

Chapter 3. Interview Methodology Overview

3.1. Interviewees

In total, 17 interviews were conducted. **Table 3.1** lists the experts interviewed as part of this study in chronological order.

Table 3.1 List of interviewees

Interviewee Name	Interview Date (MM/DD/YYY)	Position	Organization
Joseph McKenzie	04/02/2022	Project Manager at the Smart Mobility Office	Austin DOT
Peter Ohlms	04/08/2022	Researcher	Virginia Transportation Research Council
Wang Zhang	04/14/2022	Pedestrian Program Manager	Maricopa Association of Governments
Bonnie Sherman	04/15/2022	Bicycle & Pedestrian Program Supervisor	TxDOT
Michael Petesch	04/18/2022	Pedestrian and Bicyclist Data Coordinator	MnDOT
Luke Urie	04/19/2022	Capital Improvement Program Manager	Smart Mobility at Austin DOT
Eric Katz	04/20/2022	Coordinator of Non-Motorized Traffic	FDOT
Patrick Baxter	04/20/2022	Manager of Traffic Department	City of Cambridge
Joshua Rocks	04/27/2022	Manager at the Office of Travel Monitoring	Delaware Valley Regional Planning Commission
Tara Tolford	04/28/2022	Research Associate and Pedestrian Outreach Coordinator	University of New Orleans Transportation Institute
Shawn Turner	05/03/2022	Senior Research Engineer	Texas A&M Transportation Institute
Hao Xu	05/04/2022	Associate Professor	University of Nevada, Reno
Tara Pham	05/09/2022	Co-Founder and CEO	Numina
Alan El-Urfali	05/05/2022	State Traffic Services Program Engineer	FDOT
Chris Kartheiser	05/13/2022	Associate Transportation Planner	City of Minneapolis
Charlene Mingus	05/31/2022	Active Transportation Planner	Baltimore Metropolitan Council
Ben Griffard	06/03/2022	Vice President of Safety	Street Simplified

3.2. Method and Summary

Each interview was conducted as a one-hour informal conversation via teleconferencing to allow researchers to gather the expertise, experiences, and insight each interviewee had to offer. Researchers collected information around the following guiding questions to the best of their abilities, given time constraints and the interests of the interviewees:

- What type of detection are you using? Are you detecting vehicles and bicycles in addition to pedestrians?
- What kinds of features are you looking for: counting? Safety analysis?
- What are the accuracy and price of technologies you're using, and how are they affected by weather?
- How many false detections have you experienced?
- Is anything deterring your agency from using other types of technologies?
- Are you concerned with any privacy issues?
- What kinds of experiences do you have with vandalism?
- Do you have any important lessons to pass on?
- Do you have future goals regarding the use of technologies?

The interviewees' backgrounds ranged from a very experienced team with an advanced pedestrian and bike program that has experimented extensively with different vendors' products to a small program of only two employees satisfied with traditional technologies. It is therefore unsurprising that, the research team noticed significant discrepancies between the levels of technology used by the interviewees. The interviewees provided many insights about specific technologies and products that are summarized in **Section 4.2**.

Chapter 4. Compilation of Findings

4.1. Classical Technologies

This section provides a brief explanation of traditional methods for pedestrian counting to give context to the discussion on emerging technologies and data sources. Classical techniques can be either manual or automated, with manual methods involving trained human data collectors and automatic methods using sensors such as passive/active infrared, pressure mats, and radio beams. Experience has shown that site calibration is required to develop site-specific adjustment factors for automated sensors (Ohlms et al., 2019).

4.1.1. Manual Techniques

Historically, manual data counts have been the most common for determining pedestrian volumes (Johnstone et al., 2017). They are conducted by trained personnel who perform manual field observations or manual observations from recorded videos. This method is still primarily used to collect pedestrian volumes over short durations. Manual counts can be used as standalone data sources or to validate automated counts and develop correction factors.

Field or video observers use tools such as data collection sheets, clickers, count boards, or smartphone applications (Nordback et al., 2016). CounterPoint (https://www.counterpointapp.org/regular-count/) is an example of a mobile application–based counting software that allows users to tap specific buttons representing different traffic categories. They also have more nuanced traffic categories such as "baby in stroller," "oversized bike," and "visually impaired pedestrian." **Figure 4.1** shows an example of CounterPoint's user interface. The main advantages and disadvantages of manual counts are listed in **Table 4.1**.

Video-based manual counts use the same tools as field counts and have similar advantages and disadvantages. The main advantage of using video compared to in-field counts is that video can be reviewed at the staff's convenience, and the footage can be sped up for low-volume areas or slowed down for high-volume locations, which can increase accuracy. On the other hand, the disadvantages of video-based counts are that they require longer installation times and equipment purchase and maintenance. Diogenes et al. (2007) evaluated manual methods for collecting pedestrian data and concluded that field counts underestimated pedestrian volumes by 8–25%. Additionally, their evaluation showed that the accuracy at the beginning and end of the data collection period was inferior. However, video-based manual counts proved to be more accurate than in-field counts.

Figure 4.1. Example of CounterPoint app interface

Table 4.1 Advantages and disadvantages of manual counts (both video and field)

Advantages	• No procurement and installation costs (in-the-field only) • No future maintenance and operation costs • Applicable to all sites and users • Can collect user information beyond volumes such as travelers' behaviors and attributes, e.g., helmet wearing, race, gender, compliance with traffic laws, etc. (Lee & Sener, 2017; Ohlms et al., 2018) • Does not require advanced technical capacities • Does not require any regulatory permissions, unlike deploying automated detectors • Decent accuracy • Provides the ability to slow down or speed up the analysis (video-based only) • Stores data for future analysis (video-based only)
Disadvantages	• Short-term data collection only • Accuracy is subject to human error • Data verification is difficult • Increased inaccuracies at locations with high pedestrian volumes • Requires personnel pre-training programs • Time-consuming and labor-intensive

4.1.2. Signal Actuation Button

4.1.2.1. Concept

Pedestrian signal actuation buttons can be used as a reasonable and cost-effective proxy for determining rough pedestrian demand with the use of some correction factors. Most signalized intersections are equipped with push buttons that grant the pedestrian signal phase when activated (Blanc et al., 2015) (**Figure 4.2**). This is considered a surrogate or proxy measure because only one actuation per signal cycle is recorded, irrespective of the number of crossing pedestrians (Nordback et al., 2016).

Blanc et al. (2015) conducted a pilot study to investigate the use of pedestrian signal actuation as a proxy for pedestrian volume. The investigation involved comparing signal controller logged phase counts with ground truth video counts. The researchers found a linear relationship between pedestrian phase logs and the actual pedestrian volumes with an R^2 value of 0.70. Therefore, their analysis suggests that it is possible to make reasonable estimates of pedestrian volumes from pedestrian actuation if site-specific adjustment factors are used.

The main advantages and disadvantages of using recorded pedestrian phase logs for determining pedestrian volumes are listed in **Table 4.2**.

Figure 4.2 Pedestrian phase actuation button

Table 4.2 Advantages and disadvantages of signal actuation button

Advantages (Blanc et al., 2015)	• Only requires the cost of downloading and evaluating the data • Data collection costs are reduced if a router or wireless data transmission service is available or the controller is on a central signal system • Leverages existing infrastructure
Disadvantages (Lin et al., 2019)	• 40–50% of pedestrians do not use the push buttons • Unnecessary delay for vehicles occurs if pedestrians press the push button but walk away or cross the street before the phase changes • Visually impaired pedestrians have difficulty finding the push button • Push buttons may get stuck or be inoperable • Site-specific adjustment factors are required for estimating pedestrian volumes

4.1.3. Infrared Technology (Active and Passive)

4.1.3.1. Theoretical Background

Pedestrian counters can also employ infrared beams to count people passing a counting point. Two types of infrared sensors exist: active and passive.

The results of the literature review and practitioner survey conducted by Ryus et al. (2017) indicated that passive infrared technology is most commonly used across the U.S. for pedestrian and bicycle counts. Passive infrared sensors detect pedestrians by evaluating the difference between background thermal energy and heat emitted by people as they pass through the detection area. If the reported heat differential and pattern meet predefined criteria, then a positive detection is recorded (FHWA, 2016). Passive infrared sensors are placed facing a fixed object in a location with expected pedestrian movement, and they project an infrared beam from a fixed point. These sensors are usually placed on sidewalks and trails but not at signalized intersections, crosswalks, and bus stops, where pedestrians usually linger (Nordback et al., 2016). TrailMaster, TRAFx, and EcoCounter are three commonly used infrared count device manufacturers.

Alternately, active infrared sensors identify pedestrians by detecting a breakage in the transmitted infrared beam. Active infrared devices are composed of a transmitter and a receiver, and the infrared beam travels in between them. Active infrared sensors have a narrower zone of detection than passive infrared sensors and a more challenging and complex installation procedure. Therefore, active infrared sensors are less commonly used compared to passive ones (FHWA, 2016; Ryus et al., 2017).

Passive infrared sensors are notorious for undercounting, generally due to occlusion errors (Ozan et al., 2021; Ryus et al., 2014). Occlusion errors take place when large groups of pedestrians simultaneously traverse the detection region and the sensor fails to differentiate the individuals. Additionally, the undercounting rate for passive infrared sensors increases with pedestrian volume. Ryus et al. (2014) determined an average undercounting rate of 9.5% and a total deviation of 22.5% based on field testing of several products. They also noticed a large difference in accuracy between products. Another experiment conducted by Ozan et al. (2021) obtained an average deviation ranging between 33% and 44% for different products.

Ryus et al. (2014) obtained a similar undercounting rate of 9.1% and a total deviation rate of 12% for active infrared sensors. On the other hand, Jones et al. (2010) determined undercounting rates ranged between 25% and 48% for pedestrians.

In conclusion, undercounting is a major concern for infrared sensors, and error rates are highly sensitive to the product and the installation site. The main advantages and disadvantages of using infrared sensors are listed in **Table 4.3**.

Table 4.3 Advantages and disadvantages of infrared sensors

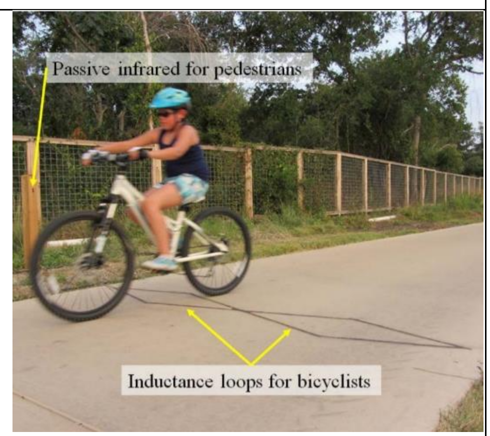
Advantages	• Easy to install • Proven track record • Can be used on shared-use paths and sidewalks • Portable and easy to use • Often does not need electrical service (battery-powered) • Lower equipment costs compared to other methods • Low analysis cost
Disadvantages	**Active and Passive IR** • Cannot determine the number of objects detected • Cannot distinguish different types of users • Background conditions may trigger false detections • Undercounting issues due to occlusion • Worse performance at temperatures approaching that of a human body, due to difficulties distinguishing people from the background • Worse performance on wider facilities, due to a higher incidence of occlusion • Worse performance in heavy rain and snow due to false positives • Cannot capture pedestrians' roadway crossings and intersection turning movements

	• Cannot be used at signalized intersections, crosswalks, and bus stops **Active IR Only** • More difficult to install compared to passive sensors • More prone to false positives due to falling leaves (lower accuracy) • Narrower detection region compared to passive IR

4.1.3.2. Vendors

The most common brand-name infrared technologies are TRAFx and EcoCounter. **Table 4.4** provides a list of common infrared technology products in the market.

Table 4.4 Infrared pedestrian counting products

Manufacturer	Description
Eco-Counter—Multi	**Official Website:** https://www.eco-counter.com/ **Technology:** Passive infrared and inductive loop **User type:** Pedestrian and bike **Cost:** \$4,100–6,600 (depending on range, direction, and housing). \$400/year for data transmission and access software. **Product Features:**  • Distinguishes pedestrians and bicyclists • Difficult to install: may require concrete cuts • Pedestrian detection range options of 4 (1.2), 15 (4.5), or 50 ft (15 m) • Battery life of 10 years • Stores up to 20 months of data • Data extraction is manual (Bluetooth) or automatic (annual fee) • Provides an option for a cellular modem that allows data to be transmitted to Eco-Counter’s online data portal, Eco-Visio • Medium pedestrian detection accuracy • Cannot collect behavioral data

Manufacturer	Description
Eco-Counter—Pyro-Box	 **Official Website:** https://www.eco-counter.com/ **Technology:** Passive infrared **User type:** Pedestrian and bike **Cost:** $2,325–3,825 for no direction detection and $2,925–4,425 for bidirectional detection (Nitesh Shah et al., 2020) **Product Features:** • Does not distinguish between pedestrians and bicyclists • Can determine the direction of travel • Detection range up to 50 ft (15 m) (*PYRO-Box - Permanent/Mobile People Counter*, n.d.) • Battery life of 10 years • Stores up to 18 months of data • Does not require electricity or internet to operate • Uses a cellular connection to transmit count data to the data analysis platform (Eco-Visio) • Clients are generally satisfied with the accuracy of the collected data but encounter some challenges with hardware durability and software performance • This is the company's most popular pedestrian counter (Nitesh Shah et al., 2020)
TRAFx—TRAFx Trail Counter	**Official Website:** https://www.trafx.net/ **Technology:** Passive infrared **User type:** Pedestrian and bike **Cost:** $2,245 (Package including 3 counters, docking station, cables, manual, and CD, a web-based software solution to view and manage data). Additional counters cost $445–545. **Product Features:** • Does not distinguish between pedestrians and bicyclists • Detection range up to 20 ft (6 m) • Battery life of 3–4 years (3xAA) • Stores up to 18 months of hourly data • Commonly used to count pedestrians in parks across North America • Accuracy sometimes does not meet expectations (Ozan et al., 2021) • Directional information is not recorded • Up to 95% accuracy can be expected on narrow sidewalks and trails • Retrieve data manually on-site
TrailMaster	**Official Website:** https://www.trailmaster.com/index.php **Technology:** Active infrared

Manufacturer	Description
	User type: Pedestrian and bike **Cost:** $210 per unit (Ozan et al., 2021) **Product Features:** • Does not distinguish between pedestrians and bicyclists • Portable • Not difficult to install • Battery life up to 1 year • Designed mostly for wildlife applications • Can be set up to photograph users (additional accessories) • Unsuitable for mixed traffic • Some clients were unsatisfied with this technology
CEOS—TIRTL	**Official Website:** https://www.ceos.com.au/ **Technology:** Active infrared **User type:** Pedestrian and bike **Cost:** $760–860 **Product Features:** • Does not distinguish between pedestrians and bicyclists • Portable • Not difficult to install • Battery life up to 1 year • Data storage: 1,000–16,000 events, depending on model • Designed for motor vehicles, but can be used on off-street facilities similar to passive infrared

4.1.4. Radio Beam

4.1.4.1. Theoretical Background

Radio beam counters detect pedestrians when the radio beam between the emitter and receiver is broken. The emitter and receiver are mounted on opposite sides of a walkway or path. Radio beam detectors are suitable for short-term and permanent counting applications. Radio beam detectors are capable of determining the direction of travel if they are configured with a multiple-frequency model. However, this modification results in reducing the detection range from 20 to 13 feet (Ryus et al., 2014).

The sensors that did not distinguish bicyclists from pedestrians were found to have an undercounting rate of 3.63% and a total deviation from actual counts of 28.13%. However, the sensors that distinguished bicyclists from pedestrians were reported to have average undercounting rates of 31.16% when counting bicyclists and 26.27% when counting pedestrians, and total deviations of 72.55% and 52.50%, respectively (Ryus et al., 2014). This indicates that this technology is less accurate compared to IR counters.

Overall, radio beam devices are not commonly investigated in the literature and in practice (Ryus et al., 2014). The main advantages and disadvantages of using radio beam sensors are listed in **Table 4.5**.

Table 4.5 Advantages and disadvantages of radio beam sensors

Advantages	• Radio beams are not optical devices, so temperature, lighting, and rain do not affect performance • Moderate portability (requires installing emitter and receiver) • Minimal site preparation is required • Easy to set up • Does not need electrical service (battery-powered) • Dual beams with different frequencies differentiate between pedestrians and cyclists
Disadvantages	• Subject to occlusion errors • Cannot be placed where pedestrians are expected to linger • Cannot be placed in busy urban settings. Radio beam sensors are fitted for low-volume routes such as rural routes, mountain trails, etc. • The technology is not widely used in North America • High equipment costs • Low accuracy for dual detection technology

4.1.4.2. Vendors

Table 4.6 provides a list of common radio beam products in the market.

Table 4.6 Radio beam pedestrian counting products

Manufacturer	Description
Chamber Electronics—RBBP7	**Official Website:** https://chambers-electronics.com/ **Technology:** Radio beam **User type:** Pedestrian and bike **Cost:** $3,000+ **Product Features:** • Moderate to high portability • Easy to install • Count storage capacity of 1,338 days at 1-hour count intervals • Battery life is 1 year • Counters can differentiate multiple user categories (people, bicycles, horses, cars)

Manufacturer	Description
	• Data extraction is manual
Siemens—Heimdall	**Official Website:** https://www.siemens.com/global/en.html **Technology:** Radio beam **User type:** Pedestrian and bike **Cost:** Not found **Product Features:**  • Operating range in wait areas is up to 4.5 m wide (Siemens, 2019) • Utilizes a "dual antenna" design • Detects pedestrians waiting to cross • Simple software setup • The Standard variant of the Kerbside detector offers a "detect" or "no detect" output, while the Volumetric version uses advanced software to measure the volume occupancy of a pedestrian waiting zone

4.1.5. Pressure and Acoustic Pads

4.1.5.1. Theoretical Background

Pressure sensors (**Figure 4.3**) detect pedestrians and bicycles as they move over a pad using changes in weight. Piezoelectric sensors are a type of pressure sensor that measures changes in pressure by converting them into an electrical charge. Piezoelectric sensors are used in the UK's Pedestrian User-Friendly Intelligent Crossings and the Dutch Pedestrian Urban Safety System and Comfort at Traffic Signals system (Lin et al., 2019). Acoustic sensors detect sound waves caused by feet and bicycle tires.

Pressure pads can distinguish between pedestrians and bicyclists based on the pressure applied to the sensor (Nordback et al., 2016). Pressure pads require users to directly pass over the sensor to report a positive detection. As such, they are only suitable in locations where foot traffic is channeled or restricted. Both pressure and acoustic pads are installed in the ground, either flush or under the surface. Therefore, they are mostly used on unpaved multi-use paths and trails where they can be buried and concealed (Nordback et al., 2016).

Limited accuracy studies regarding pressure and acoustic pads were found. One study reports high accuracy with undercount rates ranging between 3.4% and 5.8% (Ozan et al., 2021). However, it was observed that accuracy decreases as pedestrian volumes increase. The main advantages and disadvantages of using pressure and acoustic pads are listed in **Table 4.7**.

Figure 4.3 Pedestrian pressure sensor

Table 4.7 Advantages and disadvantages of pressure and acoustic pads

Advantages	• Does not need electrical service (battery-powered) • In-ground installation resists vandalism and theft • Relatively accurate • Can distinguish bicyclists from pedestrians • Can capture screenline volumes and roadway crossings
Disadvantages	• Expensive/disruptive for installation under asphalt or concrete pavement • Require users to pass directly above the pads • Acoustic pads can only count pedestrians • Difficult installation • Accuracy information is insufficient • Infeasible for locations with severe winters where the ground freezes • Higher equipment cost compared to other methods • Not widely used in North America

4.1.5.2. Vendors

Table 4.8 provides a list of common pressure and acoustic pad products in the market.

Table 4.8 Pressure and acoustic pad products

Manufacturer	Description
MetroCount—RidePod BP	**Official Website:** https://metrocount.com/ **Technology:** Piezoelectric strip **User type:** Bicycle, e-scooter, and pedestrian **Cost:** $4,400 **Product Features:** • Not mobile • Difficult installation • Battery life is 180 days, or 5 years with back-up solar panel • Measures the direction of travel • Memory storage up to 1 million counts • Remote access to data is optional (remote connectivity via the 3G network) (MetroCount, 2021) • Mean absolute percentage error is 25% 
Eco-Counter—SLAB	**Official Website:** https://www.eco-counter.com/ **Technology:** Pressure pad **User type:** Pedestrian **Cost:** $2,200–3,700 **Product Features:** • Not mobile • Difficult installation • Battery life is 10 years (*SLABs - Robust & Invisible Below-Ground Pedestrian Counter*, n.d.) • Intended for hiking trails, but can also be installed in urban contexts • Data extraction can be manual (Bluetooth) or automatic (annual fee) • Works in all weather conditions • Measures the direction of travel • Up to eight SLABs can connect to a single counting system, allowing for adaptability to varying trail widths 

4.2. Emerging Sensor Technologies

This section summarizes key themes that were apparent throughout multiple interviews. Additionally, **Table 4.9** and **Table 4.10** below present a summary of the interview and survey findings at the technology type and the product/vendor level, respectively. As the information presented in these two tables is sourced from the literature, survey, or interviews, it might not reflect the most up-to-date offerings of each product. Also, the presented information reflects the opinions of the interviewees and survey respondents and may therefore be subject to biases or experiences that differ from the literature's findings.

One of the research team's main questions assessed the interviewees' experiences with technologies. Most interviewees were not aware of the capabilities of LiDAR technology in pedestrian detection, while others did not think that the use of such an advanced and complex technology is justified at intersections. Four practitioners used LiDAR technology and mentioned its high reliability (in that it works consistently in different lighting and weather conditions) and its ability to overcome occlusion and lighting issues, capture multimodal traffic data, and precisely measure the distance between objects for near-miss-detection applications. Other comments included trajectory mapping, satisfaction with cost reductions in using one detector at an intersection (unlike video detection which typically requires more than one camera), and the ability to avoid security concerns associated with collecting video. Implementers noted using LiDAR for real-time traffic control, and for ensuring that pedestrians are clear of a drawbridge prior to its opening. On the other hand, some users had cost-related concerns regarding collecting, storing, and processing the more refined and granular pedestrian information, as MPOs did not need this sort of detailed and voluminous data provided at all hours. Practitioners pointed out other limitations of LiDAR technologies, such as the lack of labeled data for training AI algorithms, the counting of large trucks as two vehicles, and the effect of sensor surface dirt on performance.

Eleven interviewees used camera technologies (i.e., those utilizing automated video detection and analysis). Interviewees were generally satisfied with the technologies' ability to perform multimodal counts. Also, there was a consensus that video is best suited for challenging settings, such as crowded locations and shared paths, where traditional infrared detectors do not work. However, they reported difficulty in evaluating products and deciding on a long-term procurement strategy because agencies do not have the large budgets needed to perform enough experimentation or to establish suitable quality control standards. To overcome recurring cost limitations, some agencies reported offloading collected video to a local third party for processing rather than hiring the product vendor for cost-saving purposes. Some interviewees, who were able to conduct pilot studies, experienced challenges in moving from pilot to procurement, such as the need to understand the interests of different stakeholders, the need to have multiple stakeholders to justify more expensive installments, and the importance of collaboration between agencies. They also mentioned a lack of clarity in determining which agency division is able to move forward with procurement and acknowledged how an agency's roadmap impacts the amount of money available to spend.

In general, most interviewees expressed concerns regarding the technologies' abilities in the presence of glare and occlusion (even for the best cameras). They also identified questionable results in nighttime and bad weather conditions or locations with shadows. For multi-modal detection, some agencies experienced significant undercounting of bicycles in high-bike-volume locations and lower performance due to the noise added by micro-mobility. Other agency concerns were related to the integration of high-tech equipment with existing low-tech infrastructure that is not suitable for smart devices.

Some agencies relied on permanent installations that continuously collect data while others relied on temporary cameras. Regardless of the installation durations, more work needs to be done to define standard quality control and accuracy measures, especially since interviewees reported misleading accuracy definitions (detection versus count accuracy for example). The main concerns associated with temporary products were regarding limited battery options and expensive hourly video processing fees. As for the permanent technologies, agencies were concerned about the recurrent processing, electricity, and communication costs.

Edge computing has been a preferred technology for overcoming security and video storage cost concerns. However, that limits the data usage ability and eliminates the possibility of quality control since the video is not recorded. Other agencies were addressing security and privacy concerns by adopting strict policies for video storage, including deleting the videos after a certain amount of time or after processing, not sharing the camera footage with anyone, and not allowing facial recognition.

An important point highlighted by a couple of the interviewed practitioners is that some commercial products are not very sophisticated and can be easily recreated in-house, which allows similar functionalities and customizations to be achieved at a quarter of the face-value price. However, this requires specialized personnel and a large active transportation program. In addition, acquiring electronic components has been a significant problem recently. Two practitioners mentioned that cloud-enabled communications require service fees that add up quickly.

Two practitioners used thermal imaging technology and mentioned that while it can be more accurate than video technology in dark conditions and the presence of occlusion, it needs more testing and has a limited detection range. Moreover, thermal imaging may need many sensors per approach and does not distinguish between pedestrians and cyclists while working in limited operating temperatures.

Overall, when asked about challenges in using emerging technologies, every interviewee mentioned that either the hardware is expensive or the data processing service is expensive. They also mentioned that the market has not matured yet and there is a rapid technological evolution which results in a continuous need for upgrading. This was especially the case with equipment that became obsolete after telecommunication companies shut down the 3G cell phone service spectrum.

An underlying theme from all of the interviews is that each agency has specific needs and considerations when selecting the most cost-effective yet efficient technology to deploy for pedestrian data collection. There is presently no one size that fits all.

Table 4.9. Summary of findings at the technology type level

Technology	Advantages/Benefits	Disadvantages/Challenges
LiDAR	• Reliable: works in different lighting and weather conditions • Overcomes occlusion • Overcomes lighting issues • Can capture multi-modal traffic data • Non-intrusive technology • 360° view • One LiDAR at the corner of the intersection is enough (which reduces installation and maintenance costs) • Can precisely measure the distance between objects, so it is better suited for near-miss-detection application • Geolocates objects on a map • Simple installation requires ½ to 1 day • More accurate speed data • Can be used to ensure pedestrian safety on movable bridges • Best suited for real-time traffic control • Companies other than Velodyne have cheaper LiDAR sensors that are only 180° • More accurate than video detection • Large detection range • Tracks data without taking pictures • Can differentiate between axles, speeds, and shapes	• Has not been extensively tested yet • Agencies are reluctant to invest due to lack of experience with the technology and its accuracy • High cost of gathering, storing, and processing more refined/granular pedestrian information, which MPOs do not need • There aren't many vendors on the market • Velodyne has the only sensor in the market that has been tested for pedestrian detection and counting • Most agencies don't need 365/24 data • Lack of labeled data for training AI algorithms • Permanent LiDAR may cost over $20,000 • Tradeoff between height and blind spots • Not justified to be used for intersections • AV LiDAR algorithms don't work for roadside LiDAR • Sensor surface dirt can influence performance • Startups have a hard time of getting projects because transportation agencies are not very interested in using LiDAR • Counts large trucks as 2 vehicles • Blind spots with puck sensor • Cannot perform facial recognition • Does not capture license plates
Camera	• Best for multi-modal counts • Most vendors provide shelf-ready solutions • Video can be offloaded to a local third party for processing to save money • Can be used in challenging settings where infrared does not work, such as crowded locations and shared paths • Same technology can be used for detection and counting with a more complex algorithm • Video data can be used for many applications beyond pedestrian detection and counting • Edge computing overcomes storage issues • Edge computing overcomes security issues • Most vendors have clear security and privacy measures	• Expensive compared to traditional IR technology • Difficult to evaluate products and decide on a long-term procurement strategy • Agencies don't have large budgets to perform enough experimentation • Quality control standards are not established • Glare creates occlusions to data collection, even for the best cameras • Questionable accuracy in the dark and bad weather conditions • Shadows result in double-counting pedestrians • Accuracy definitions may be misleading: detection accuracy is different from count accuracy • When connecting to signal timing, multiple stakeholders need to be involved, and agencies need to get the different vendors on board • Significantly undercounts bikes in high-bike-volume locations • Different vendors use a different number of cameras • Micro-mobility adds noise and lowers performance • Edge computing does not allow accuracy checks • The system misses detection in the early morning and in dark/poorly lit conditions • Temporary products have battery limits and expensive hourly video processing fees • Security and political concerns • Existing infrastructure is low-tech and not suitable for smart devices • High recurring and maintenance costs • Permanent installation requires updating the communications network and infrastructure • Most vendors require purchasing new cameras • Video capabilities are not needed to count pedestrians on non-shared paths **Using CCTV and offloading to a third party:** • CCTV cameras do not have a proper field of view at intersections which deteriorates the accuracy and increases the need for off-the-shelf products
Thermal	• Mostly used for pedestrian detection • FLIR has several product offerings • More accurate detection than video technology in dark conditions and in the presence of occlusion	• Agencies are not familiar with this technology for smart traffic monitoring • Needs more testing • Limited detection range • Agencies need many sensors per approach • Does not distinguish between pedestrians and cyclists • Limited operating temperatures of the equipment
In-House Solutions	• Generally cheaper for system management and operation • Quarter the procurement price of off-the-shelf products • Most technologies are not very sophisticated and can be easily replicated in-house • Allow for more customization • If DOT owns the equipment, it can help small municipalities that can't afford consultants • Cheaper units allow spending more money on achieving a spatial distribution	• Require specialized personnel • Need to have a large active transportation program to develop, coordinate, and manage such as effort • Require more time and effort • Acquiring electronic components can be a big problem • Cloud-enabled communications are associated with service fees that add up quickly

Table 4.10. Summary of findings at the product/vendor level

Product	Accuracy	Cost	# Sensors or Cameras	View and Range	Power Source and Infrastructure Requirement	Data Transmission	Online Platform	Edge Processing	Live Feed	Night Vision	Traffic Controller Connection	Application and Output Types	Reputation and Reliability	Advantages	Disadvantages
Velodyne Puck Sensor + Blue City AI LiDAR technology 	• 98.7%	Procurement cost: • Puck sensor: $4,800 Recurring cost: • Unknown, depends on processing algorithms	1–2 / intersection	360º 100 m	• Pole • AC power source • IP addresses	100 Mbps Ethernet connection	✓	✓	✓	✓	✓	• Permanent • Intersection or midblock locations LiDAR sensor: • Cloud of surface points (x,y,z) • Distance between a data pt and sensor • Timestamp • 360º view Blue City AI: • Detection and classification of vehicles, cyclists, pedestrians • GIS trajectory data • Turning movement • Speed of road users • Near-miss detection • Red light violation • Jaywalkers • % of the time a crosswalk is used by pedestrians • Automated traffic signal performance matrix (ATSPM) • Wrong way detection	• Being piloted by CoA	LiDAR sensor: • Very large detection zone • Reliable in all light and weather conditions • High security and privacy • High accuracy • Low number of sensors required per intersection Blue City AI: • Provides surrogate safety analysis platforms to help city planners • Real-time access to signal performance metrics • Real-time access to safety metrics • Very large detection zone • Wide selection of outputs and metrics • AI-based algorithm	• Not widely used • Most agencies don't need 365/24 data
Velodyne Puck Sensor + LiDAR Matrix Inc. AI LiDAR technology 	• 99.5% detection accuracy • >98% traffic count accuracy	Recurring cost: • $1,000–1,500 for one day of data	1 / intersection	360º 90 m	• Traffic signal or light pole • AC power source (optional)	Manual	×	×	×	✓	×	• Temporary (battery life of 3–4 days) • Detection and classification of vehicles, cyclists, pedestrians • GIS trajectory data • Speed • Turning movement	• Developed for Nevada DOT and in use in ~50 locations. Implemented for smart RRFB in Las Vegas.	• LTE wireless connection for system status (battery life, data logging status, available storage space) • High accuracy • Wide range of outputs • Only one sensor is needed to cover an entire intersection • Comparable price to automated video technology	• Uses feature engineering instead of deep learning • Need to change batteries every few days • Sensor surface dirt can influence performance • A permanent arrangement would cost around $20,000
Miovision Scout camera Integrated video technology 	• >95%	Procurement cost: • $5,000 Recurring cost: • $10/hr video processing fee (can also use third-party algorithms)	2 / intersection	90°	• Sign or pole	Manual or 4G/LTE cellular	✓	×	×	×	×	• Temporary (72 hours) • Pedestrian, cyclist, vehicle, and e-scooter counts • Turning movement diagrams • Lane-by-lane volumes	• Trusted and frequently used product	• Portable • Can download video to be analyzed by a third party • Easy to install • Limited paperwork is needed. Can be installed without permission from multiple stakeholders • Miovision allows manual access to the data to avoid annual subscription fees	• Expensive video processing fees • Does not have real-time access • Limited battery life
TrafficLink	• 99% count accuracy	Procurement cost:	1 / intersection	360º 90 m	• Mounting height of 28–30 ft	Manual or 4G/LTE cellular	✓	✓	✓	×	✓	• Permanent • Designed for intersections	• City of Cambridge • CoA	• Only one camera is required per intersection	• Can only view the immediate intersection

Product	Accuracy	Cost	# Sensors or Cameras	View and Range	Power Source and Infrastructure Requirement	Data Transmission	Online Platform	Edge Processing	Live Feed	Night Vision	Traffic Controller Connection	Application and Output Types	Reputation and Reliability	Advantages	Disadvantages
Integrated video technology 	• 97% detection accuracy	• $14,900 (includes hardware and software) Recurring cost (optional add-ons): • $500/yr signal communications • $750/yr continuous counts • $750/yr safety analytics			• Traffic pole • Mast arm • Signal post • AC power							• Stop bar detection • Vehicle, pedestrian, and cyclist count and turning movement count • Pedestrian delay • Occupancy ratio • Vehicle classification • Red light violation • Pedestrian compliance reports • Corridor travel time • ATSPM • Interactions with controller for advance detections	• Ohio DOT	• Can view crosswalks and stop bars on all approaches • Trafficlink web-based portal • Video and detection live stream through the portal • Provides signal phase status for operations • Provides alerts on operations status (power loss, low battery, telemetry unavailable) • Degraded video quality for privacy, storage, and streaming reasons • Local options for video storage that allow troubleshooting • Manually configurable detection zones • Base pricing includes 24/7 detection • If an agency has connectivity at the intersection (through video management systems (VMS)) it can stream in real-time (using RTS protocol) for no extra fee; otherwise, it needs to pay for the signal communications add-on (cellular device connection)	• Doesn't get to the upstream distance (450 ft dilemma zone operation) • Tradeoff between mounting height and coverage range. Needs to be mounted on a high location. • Need to set up communications independently or pay extra fees • Continuous counts are only available for an extra fee
Spack Solutions' countCAM3 Integrated video technology 	Unknown	Procurement cost: • $1,300 • $300 external battery pack (optional) Recurring cost: • ~$300 for 24-hr video	1 / intersection	Unknown	• Sign or pole	Download data over Wi-Fi or hardwired connection	×	×	×	×	×	• Temporary (84 hours) • Intersection • Turning movement counts • Vehicular, pedestrian, and bicycle counts • Vehicular classification	• Tried by Delaware Valley Regional Planning Commission	• Cheap procurement cost • Agency can pre-schedule when the camera records video • 3-day turnaround service • Manual video counts • High accuracy	• Short battery life • Limited functionality
Eco-Counter CITIX – AI Integrated video technology 	95%	Procurement cost: • $10,900 • ~$2,500 for installation assistance (required) • $400 shipping Recurring cost: • ~$400/yr per unit	Unknown	20 m	• 5–7 m mounting height • Traffic pole • AC or DC power (does not come with a battery)	3G/4G connection	✓	✓	✓	✓	×	• Permanent • Designed for intersections • Pedestrian, cyclist, two-wheeler, and vehicle counts	• Clients are generally happy • A pilot study by NCDOT did not recommend it • Will be tested by TxDOT in the summer of 2022	• Self-contained (does not require access to signal) • Less expensive than Miovision • High-precision optical sensor (4K) • High precision for high-volume areas • Wireless data extraction • Has a wide-angle optical sensor that allows the sensor to cover several detection areas on the same site (several counting lines—user-configured) • Suitable for busy urban areas • Access to Eco-Visio online platform • Requires zero calibration	• Not widely used • Limited information available • Difficult installation (requires vendor installation assistance) • Functionality specific to counting

Product	Accuracy	Cost	# Sensors or Cameras	View and Range	Power Source and Infrastructure Requirement	Data Transmission	Online Platform	Edge Processing	Live Feed	Night Vision	Traffic Controller Connection	Application and Output Types	Reputation and Reliability	Advantages	Disadvantages
Numina Integrated video technology 	95%	Procurement cost: • ?? Recurring cost: • $1,500/yr per sensor	1 / approach for large intersections	90° 40 m	• Sign, pole, or building • AC power	Cellular LTE connectivity	✓	✓	×	×	×	• Permanent • Intersections or midblock • Pedestrian, cyclist, and vehicle counts • Location-based activity heatmaps • Speed (categorical) • Accuracy reports	• FDOT and Louisiana DOT pilots indicated low accuracy	• Edge processing, which guarantees privacy • Near-real time • Quarterly retraining of the algorithms • Hardware costs vary based on the number of sensors purchased. More sensors are discounted. • Involved in many pilots	• Rain can damage the units • Extreme weather affected reliability • Low accuracy, especially in crowded and shared paths • Recurring data subscription fees • Lose access to the sensor completely if recurring fees are not paid. The sensor itself does not have storage. • Cannot be used on fast highways and arterials. Cannot detect vehicles above 65 mph very well.
Street Simplified Integrated video technology	• 98% counting accuracy • 90% overall accuracy	Recurring cost: • ~$5,000 per intersection • Price is affected by the complexity of the location and the number of days	2 / intersection	Unknown	• Mounting location	Manual	✓	×	×	×	×	• Temporary (1–7 days) • Intersection or midblock • Counts cars (vehicle classifications), pedestrians, bikes • Vehicle trajectories • Near misses • Red light violation • Speeding • Jaywalkers • Pedestrian and cyclist compliance • Intersection blocking • Safety report	• Worked with the City of Houston and over 200 locations • Caltrans	• High-resolution video • Moving HQ to Austin soon • Can adapt the functioning to the environment • Does not require an external electricity source • Can't read license plates • Can't detect faces • Data is stored on the cloud • Client has full access to data on the cloud • Client can download video • Vendor is responsible for installing the equipment	• The client does not own the equipment • Results of pilot studies are not published yet • Company did not provide details about the equipment used
Boulder AI DNN Node Data processing solution 	Unknown	Unknown	1 / crosswalk	Depends on the camera	• Traffic pole • AC power	SD storage, connected to the internet over a cellular modem	✓	✓	✓	×	✓	• Permanent • Intersections • Multimodal continuous counts, including lane and turning movement analytics • Near-miss detection • Detects pedestrians and bikes at intersections and crosswalks • Speed detection • Red light violation • Turn infractions • Wrong way detection • License plate recognition, make/model • Advance and stop bar detection	• Not recommended by MAG and Massachusetts DOT	• One node supports up to 4 camera feeds • Works with inputs of CCTV cameras • Provides real-time data • Allows remote data management and service configurations • Can be used to implement automated touchless crosswalks, extend or recall crosswalk phase for safer crossings, or inform drivers via changeable or blank out signs	• 1080P resolution required for pedestrian detection • Does not distinguish bikes from pedestrians • Requires one camera per crosswalk • Overcounts by 79% • Counting accuracy is dictated by the lighting conditions, apparel of the pedestrian/bicyclist, and party size • Does not work very well with CCTV cameras due to their low resolution and improper view range
Boulder AI DNN Cam Camera-integrated solution 	Unknown	Unknown	1 / crosswalk	83° 90 m	• Traffic pole • AC power	SD storage, connected to the internet over a cellular modem	✓	✓	✓	×	✓	• Permanent • Intersections • Multimodal continuous counts, including lane and turning movement analytics • Near-miss detection • Detect pedestrians & bikes at intersections and crosswalks • Speed detection • Red light violation • Turn infractions • Wrong way detection	• Not recommended by Massachusetts DOT	• 4k resolution camera • Provides real-time data • Allows remote data management and service configurations • Can be used to implement automated touchless crosswalks, extend or recall crosswalk phases for safer crossings, or inform drivers via roadside or blank out signs	• Does not distinguish bikes from pedestrians • Requires one camera per crosswalk

Product	Accuracy	Cost	# Sensors or Cameras	View and Range	Power Source and Infrastructure Requirement	Data Transmission	Online Platform	Edge Processing	Live Feed	Night Vision	Traffic Controller Connection	Application and Output Types	Reputation and Reliability	Advantages	Disadvantages
												• License plate recognition, make/model • Advance and stop bar detection			
Currux Vision — Autonomous AI Systems Data processing solution	• 98% count accuracy • 97% detection accuracy • Speed with ±2 mph accuracy	Unknown	1 / approach	Depends on the camera	• Traffic pole • AC power	4G/Wi-Fi	✓	✓	✓	✓	✓	• Permanent • Turning movement counts at intersections along with colored dots for different classes of modes (vehicle, pedestrian, bike) • Vehicle classifications and speed studies • Trajectories • Speed • Wrong way detection and notification • Corridor travel time • ATSPM • Real-time near-miss notifications • Red light violation • Speeding • Crosswalk violation • Stop sign violation	• Used in San Jose • Recommended by MAG	• Capable of running a video from a CCTV camera • AI node can be connected to the internet over a cellular modem • Good accuracy • The system is flexible and can operate on highways, intersections, and city streets • Edge capability improves security • Based in Houston, TX	• Counting accuracy is dictated by the lighting position and party size • Missed detections are more likely in early morning and late evening • Requires one camera per crosswalk
Gridsmart Camera-integrated solution 	• 92% detection accuracy • 98% count accuracy	Procurement cost: • ~$18,000 Recurring cost: • $0	1 / intersection	180° 75 m	• Mast arm, off of a luminaire, or off of a strain pole	Data can be stored on the client's server, cloud, or USB	✓	✓	✓	×	✓	• Permanent • Intersections • Vehicle counts on roadway segments • Turning movement counts at intersections • Vehicle classifications • Interactions with controller for advance detections	• Not recommended by MAG	• Only one camera per intersection • Does not require any calibration, ever • Does not have to be aimed or focused • Easy to install • No recurring or licensing fees	• Only works with GRIDSMART cameras
Iteris Vantage Vector with Vantage Next Camera-integrated solution 	• 90% count accuracy • 98% detection accuracy	Procurement cost: • >$12,000 Recurring cost: • ??	1 / crosswalk	50° 120 m	Unknown	Unknown	✓	✓	✓	✓	✓	• Permanent • Intersections • Bi-directional pedestrian, bicycle, and vehicle counts • Pedestrian speed data • Detection alerts • Turning movement counts at intersections • Vehicle classifications • Corridor travel time • ATSPM with pedestrian delay and conflicts • Interactions with controller for advance detections	• Recommended by MAG and FDOT	• Includes video and radar technology • Very accurate • Large detection area • Iteris has multiple product offerings	• Expensive • Results of pilot studies are not available/published
TrafiOne – FLIR Thermal camera solution	• 99% detection accuracy • Not very suitable for counting	Procurement cost: • $6,000–8,000 per approach Recurring cost:	2 / crosswalk	95° 15 m (8 detection zones can be defined)	• Traffic pole • AC power	• Cellular modem • Direct plug-in to the camera • Can be retrofitte	✓	✓	✓	✓	✓	• Permanent • Intersections or midblock crosswalks • Tracks waiting and crossing pedestrians and bicyclists in urban environments • Detects the presence of vehicles and bicyclists at the stop bar	• Integrated with TAPCO's Wrong-Way Alert and Pedestrian Crosswalk Systems	• Online platform for live video visualization and access data and review • Very high detection accuracy of 99% • Very accurate for vehicle counts • Flexible systems architecture	• Not very suitable for counting • Cannot distinguish pedestrians from bikes, but FLIR will be releasing a new module to do this in the future • Stop bar and advanced vehicle and bicycle presence detection require a separate, optional license

Product	Accuracy	Cost	# Sensors or Cameras	View and Range	Power Source and Infrastructure Requirement	Data Transmission	Online Platform	Edge Processing	Live Feed	Night Vision	Traffic Controller Connection	Application and Output Types	Reputation and Reliability	Advantages	Disadvantages
		• $35–50/ month for cellular service • ?? optional license for live feed				d with 5G cellular antennas to integrate with V2X						• Detects pedestrians and bicyclists in the crosswalk or on the curb • Turning movement counts • Wrong way detection and notification • Corridor travel time • ATSPM • Interactions with controller for advance detections	• Used by FDOT		• Need two thermal cameras to cover one crosswalk • System is susceptible to the presence of vehicles on crosswalks • Overcounts elements in the crosswalk • The system overcounts in higher magnitude in the early morning and daytime, compared to evening • Shading affects count accuracy
TrafiSense AI– FLIR Thermal camera solution 	Unknown	Unknown	Unknown	32° 30–90 m	• Traffic pole • AC power	• Cellular modem • Direct plug-in to the camera • Can be retrofitted with 5G cellular antennas to integrate with V2X	✓	✓	×	✓	✓	• Permanent • Detection by lane	• Integrated with TAPCO's Wrong-Way Alert and Pedestrian Crosswalk Systems • Used by FDOT • Sufficiently accurate based on field tests by Oregon DOT	• Similar to TrafiOne by FLIR	• Not able to distinguish between pedestrians and bicyclists • System is susceptible to the presence of vehicles on crosswalks • Only suitable for vehicle, bicycle, and pedestrian presence detection but not volume counts • Overcounts elements in the crosswalk • The system overcounts in higher magnitude in the early morning and daytime, compared to evening • Shading affects count accuracy • Video streaming is not available

Other vendors (products) include:

- Leetron Vision
- Bosch Security Systems, LLC
- Derq Inc.
- Econolite
- Omnibond Systems, LLC (TrafficVision)
- Pelco Corporations
- WTI (Sidewinder/Viper)
- GoodVision Ltd.
- MicroTraffic Inc.

Chapter 5. Decision Support Framework

The survey and interview findings informed the decision criteria included in the decision support framework (DSF). In this chapter we will discuss the decision criteria, the scoring and ranking scheme, and the user interface for the DSF.

5.1. Decision Criteria and Ranking Scheme

The decision criteria are divided into three categories including location conditions, application requirements, and agency considerations. **Table 5.1** summarizes all the decision criteria that was accounted for in the DSF.

We realize that different use cases have varying requirements, and thus different technologies may be suitable for each case. As a result, the user-inputted case-specific considerations are matched with the attributes of different products and technologies as part of the scoring and ranking scheme.

The collected information on each product was aggregated in a matrix that summarizes its attributes. A simple scoring scheme is implemented where a technology scores 1 if its relevant attributes satisfy each of the given decision criterion and 0 if they do not. Finally, the scores are summed and the products are ranked based on the sum of scores in descending order. This sum of scores reflects each product's degree of compliance with the list of inputted criteria. The benefit of this methodology is that it is flexible and allows for the provision of different scores (or weights) to different criteria according to the agency's preferences.

Table 5.1. Decision Criteria Matrix

Location Conditions

Urban vs Rural	Corridor Type	Number of Lanes	Traffic Volume at Location	Location Type	Lighting at Location	Occlusion at Location	Power Supply at Location	Mounting Infra-structure	Want to Use Cameras at Location
• Urban • Rural	• High speed • Medium speed • Low speed	• ≤ 2 lanes • 3–4 lanes • > 4 lanes	• High • Medium • Low	• Intersection • Midblock crossing • Shared path • Trail • Sidewalk	• No • Yes	• No • Yes	• Available • Not available	• Available • Not available	• Yes • No • Maybe

Application Requirements

Time Frame	Study Type	Accuracy Required (Detection)	Real-Time Data Access	Night Vision	Video Internal Storage	Accuracy Required (Count)	Outputs Needed (can select more than one)
• Permanent • Temporary ≤1 day • Temporary > 1 day	• Before/After • Vision Zero • Pedestrian volume counts • Multimodal volume counts • Safety assessment • Real-time operations and signal control	• <80% • 80–90% • 90–95% • >95%	• Yes • No	• Needed • Not needed	• Needed • Not needed	• <80% • 80–90% • 90–95% • >95%	• Counts • Trajectory heat maps on image • Trajectory maps as GIS coordinates • Near-miss and other safety related detection • Red light runner detection • Detection and classification of vehicles, cyclists, pedestrians • Jaywalking detection

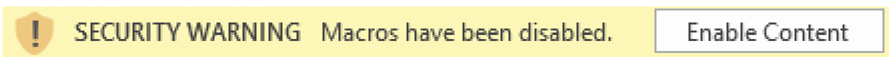
Agency Considerations

Procurement Budget	Recurring Costs Budget	Inter-Division Collaboration	Equipment Ownership	Size of Pedestrian Program	Quality Control Requirement	Public View on Video Detection	Agency Goals	Installation Capacity	Possibility of Manual Data Transmission
• <\$500 • <\$1,000 • <\$2,000 • <\$5,000 • >\$5,000	• \$0 • ≤\$1,000 per sensor per year • ≤\$2,000 per sensor per year • ≤\$10 per hour • ≤\$20 per hour • Not important	• Yes • No	• Agency owned • Not agency owned • Doesn't matter	• <5 employees • 5–15 employees • >15 employees	• Yes • No	• Positive • Negative	• Nationwide counts • Smart corridors • None	• Available • Not available	• Yes • No

5.2. DSF Interface

The DSF is implemented in a Microsoft Excel workbook, and apart from the title page, it consists of three main pages: the "User Input" page, the "Ranking" page, and the "Results" page.

To start the DSF, load the file *DSF P1 0-7126 Final A.xlsm* into Microsoft Excel 2016 or later. When the Excel file loads, the title page should appear. Before any of the functionality will work, macros must be enabled. This can be done by clicking on the "Enable Content" button on the security warning at the top of the Excel user interface:



To enter the DSF, click on the "Begin >>" button.

5.2.1. User Input Page

The interface of the "User Input" page is presented in **Figure 5.1**. For each criterion, there is a drop-down menu that allows the user to select their case-specific decision considerations. The options in the drop-down menu are those presented in **Table 5.1**.

After all decision considerations are selected, the user can scroll down to the "Weighting Matrix" where they can either select the "Default" or "User Input" option, as shown in **Figure 5.2**. The default option provides an equal weight of 4.17% to all the criteria, as presented in **Figure 5.2**. However, the DSF also provides the user with the flexibility to input their desired weight values. The three-step process of incorporating user provided weights is described in **Figure 5.3**. First, the user needs to select the "User Input" option, which will result in deleting the default weights and providing empty cells for all the criteria. Second, the user can enter their desired weights for all the criteria or a subset of the criteria. For example, **Figure 5.3** shows an example where the user is interested in a 50% weight for procurement budget and a 25% weight for the recurring costs budget criterion. The third step involves clicking on the "Autofill empty fields" button to fill the remaining empty cells with weights that ensure a total sum of 100%. In this example, the user inputted weights sum up to 75% and the autofill button provides an equal weight of 1.14% for the remaining criteria to ensure a total of 100%.

After all of the options are set, the user can click on the "Show Results >>" button, which will take them to the "Results" page. Note that if the sum of the weights is more or less than 100%, clicking the "Show Results >>" button will prompt an error message, as shown in **Figure 5.4**.

5.2.2. Ranking Page

After clicking the "Show Results >>" button on the "User Input" page, the "Ranking" page instantaneously performs the backup calculations to match decision criteria with product attributes and calculate the compliance score. Note that the user does not need to modify any inputs on this page and the DSF will operate without the user navigating to this page.

5.2.2.1. Calculating the Compliance Score

The process for calculating the compliance score is as follows:

- For each criterion, the attributes of the product are compared to the user-defined decision considerations.

- If the product attributes match the decision considerations for a given criterion, a value of "1" is set in the compliance matrix. Otherwise, the cell corresponding to the given criterion and product in the compliance matrix is set to a value of "0". This binary classification is indicated by $\mathrm{M_c}$ in the equation below.

- The weight of each criterion, as provided in the "User Input" page, is then multiplied by "1" if the corresponding cell in the compliance matrix has a value of "1". Otherwise, if the corresponding cell in the compliance matrix has a value of "0", the weight is multiplied by "-1". Finally, these values are added for all the considered criteria. In other words, the criterion weight will be added to the total compliance score if the product attributes match the decision considerations, and subtracted if it does not match. This calculation is mathematically formulated in the equation below:

$$\text{Compliance Score} = \sum_{c=1}^{C} \mathbf{1}(\mathrm{M_c}=1).W_c - \mathbf{1}(\mathrm{M_c}=0).W_c$$

where C is the total number of criteria (24), $\mathbf{1}(\mathrm{M_c}=1)$ is an indicator function that outputs a value of one if $\mathrm{M_c}=1$ and a value of zero otherwise, $\mathbf{1}(\mathrm{M_c}=0)$ is an indicator function that outputs a value of one if $\mathrm{M_c}=0$ and a value of zero otherwise, and W_c is the weight corresponding to criterion "c".

5.2.3. Results Page

Finally, the results are automatically displayed on the "Results" page, shown in **Figure 5.5**.

If the user automatically arrives at this page by pressing the “Show Results >>” button on the “User Input” page, the list of products will be sorted in descending order of compliance score. However, if the user does now click on the “Show Results >>” button on the “User Input” page, the product list will not be automatically sorted and the user needs to press the “Sort” button to rearrange the list of products in descending order of compliance score.

In addition to the rank of each product, the results page provides the Compliance Score of each product with each decision criterion. For illustration purposes, **Figure 5.5** shows the results based on a set of example inputs where Miovision TrafficLink has the highest compliance score, satisfying multiple criteria but not the “Want to Use Cameras at Location—yes” criterion.

Afterwards, the user can refer to **Table 4.10**, provided in this report, for detailed information about the products they are interested in.

5.2.4. Modifying the DSF

5.2.4.1. Modifying product attributes

Some of the product attributes in the DSF are set to “??” when the required information is unavailable. If users need to update this information, they should first navigate to the “Ranking” page. There, each product’s attributes are listed in columns BJ to DY. The users can navigate to the required cells and update the relevant information.

5.2.4.2. Procedure for adding new products

The ability to add more products to the DSF has been hard-coded within the “Ranking” page. In column BI in the Excel workbook, rows 17 to 44 are set as *placeholders* to add new products, as shown in **Figure 5.6**. Users can replace the “placeholder” text with the name of the product they are adding followed by inputting the product’s attributes in columns BJ to DY. No other changes are required on the “Ranking” page.

After inserting the product information, users are required to navigate to the “Results” page. In column D titled “Product”, users need to type in the name(s) of the product(s) they added. After that, users need to select columns E till AD of the bottom row of the results table (currently row number 16 referring to the Numina product) and drag the cursor down to apply the formulas to the new products. This process is illustrated in **Figure 5.7**.

Decision Criteria Matrix					
Location Conditions					
Urban vs rural	**Corridor Type**	**Number of Lanes**	**Traffic Volume at Location**	**Location Type**	**Lighting at Location**
Rural	Medium Speed	> 4 lanes	High	Intersection	Yes
Application Requirements					
Time Frame	**Study Type**	**Accuracy Required (detection)**	**Real-time data access**	**Outputs needed**	**Night Vision**
Permanent	Vision Zero	90% 95%	Yes	☑ Counts	Not Needed
				☐ trajectory heat maps on image	
				☐ trajectory maps as GIS coordinates	
				☑ Turning movement	
				☑ Speed of road users	
				☑ Near-miss and other safety related detection	
				☑ Red-light runner detection	
				☑ Jaywalking detection	
				☑ Advanced traffic signal performance metrics	
				☑ Wrong way detection	
Agency Considerations					
Procurement Budget	**Recurring Costs Budget**	**Inter-division Collaboration**	**Equipment Ownership**	**Size of pedestrian program**	**Quality Control Requirements**
<$2000	up to $1,000 per sensor per year	Yes	Doesn't matter	more than 15 employees	No

Occlusion at Location	**Power Supply at Location**	**Mounting Infrastructure**	**Want to Use Cameras at Location**
No	Available	Not Available	Yes
Internal Video Storage	**Accuracy Required (count)**		
Needed	>95%		
Public view on video detection	**Agency Goals**	**Installation capacity**	**Possibility of manual data transmisstion**
Negative	None	Available	Yes

Figure 5.1 DSF user input page – Decision Criteria Matrix

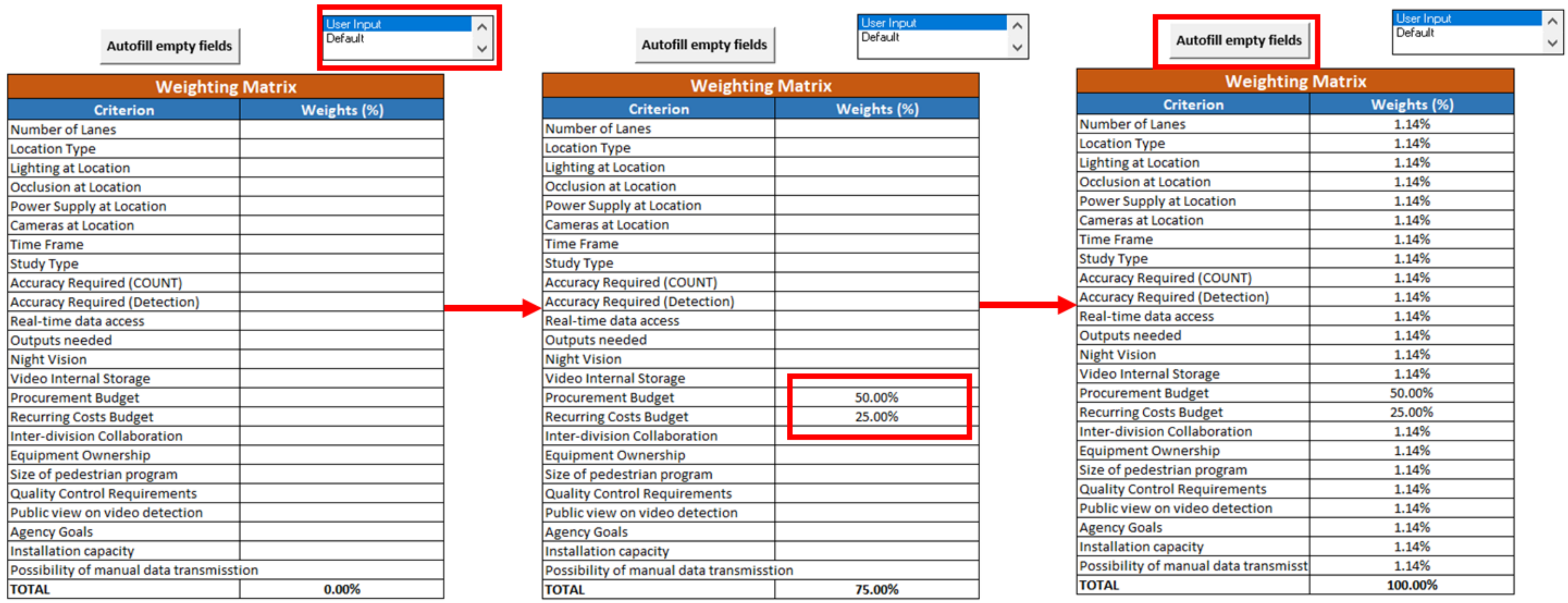
Autofill empty fields

User Input
Default

Show Results >>

Weighting Matrix	
Criterion	**Weights (%)**
Number of Lanes	4.17%
Location Type	4.17%
Lighting at Location	4.17%
Occlusion at Location	4.17%
Power Supply at Location	4.17%
Cameras at Location	4.17%
Time Frame	4.17%
Study Type	4.17%
Accuracy Required (COUNT)	4.17%
Accuracy Required (Detection)	4.17%
Real-time data access	4.17%
Outputs needed	4.17%
Night Vision	4.17%
Video Internal Storage	4.17%
Procurement Budget	4.17%
Recurring Costs Budget	4.17%
Inter-division Collaboration	4.17%
Equipment Ownership	4.17%
Size of pedestrian program	4.17%
Quality Control Requirements	4.17%
Public view on video detection	4.17%
Agency Goals	4.17%
Installation capacity	4.17%
Possibility of manual data transmisst	4.17%
TOTAL	**100.00%**

Figure 5.2 DSF user input page – "Default" Weighting Matrix



Weighting Matrix	
Criterion	**Weights (%)**
Number of Lanes	
Location Type	
Lighting at Location	
Occlusion at Location	
Power Supply at Location	
Cameras at Location	
Time Frame	
Study Type	
Accuracy Required (COUNT)	
Accuracy Required (Detection)	
Real-time data access	
Outputs needed	
Night Vision	
Video Internal Storage	
Procurement Budget	
Recurring Costs Budget	
Inter-division Collaboration	
Equipment Ownership	
Size of pedestrian program	
Quality Control Requirements	
Public view on video detection	
Agency Goals	
Installation capacity	
Possibility of manual data transmisstion	
TOTAL	**0.00%**

Weighting Matrix	
Criterion	**Weights (%)**
Number of Lanes	
Location Type	
Lighting at Location	
Occlusion at Location	
Power Supply at Location	
Cameras at Location	
Time Frame	
Study Type	
Accuracy Required (COUNT)	
Accuracy Required (Detection)	
Real-time data access	
Outputs needed	
Night Vision	
Video Internal Storage	
Procurement Budget	50.00%
Recurring Costs Budget	25.00%
Inter-division Collaboration	
Equipment Ownership	
Size of pedestrian program	
Quality Control Requirements	
Public view on video detection	
Agency Goals	
Installation capacity	
Possibility of manual data transmisstion	
TOTAL	**75.00%**

Weighting Matrix	
Criterion	**Weights (%)**
Number of Lanes	1.14%
Location Type	1.14%
Lighting at Location	1.14%
Occlusion at Location	1.14%
Power Supply at Location	1.14%
Cameras at Location	1.14%
Time Frame	1.14%
Study Type	1.14%
Accuracy Required (COUNT)	1.14%
Accuracy Required (Detection)	1.14%
Real-time data access	1.14%
Outputs needed	1.14%
Night Vision	1.14%
Video Internal Storage	1.14%
Procurement Budget	50.00%
Recurring Costs Budget	25.00%
Inter-division Collaboration	1.14%
Equipment Ownership	1.14%
Size of pedestrian program	1.14%
Quality Control Requirements	1.14%
Public view on video detection	1.14%
Agency Goals	1.14%
Installation capacity	1.14%
Possibility of manual data transmisst	1.14%
TOTAL	**100.00%**

Figure 5.3 DSF user input page – "User Input" Weighting Matrix

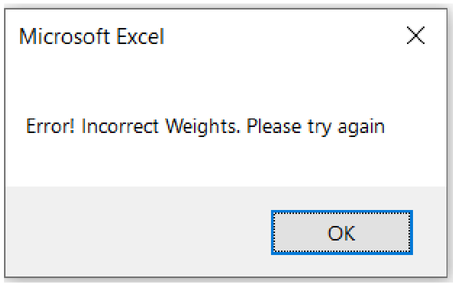


Figure 5.4 DSF user input page – Error message

Sort

<< Show Inputs

Product	Rank	Compliance Score	Number of Lanes	Location Type	Lighting at Location	Occlusion at Location	Power Supply at Location	Want to Use Cameras at Location	Time Frame	Study Type	Accuracy Required (COUNT)	Accuracy Required (Detection)	Real-time data access
Miovision TrafficLink	1	56%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
Boulder AI DNN Cam	2	48%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
Gridsmart	3	46%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
Blue City AI	4	41%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
TrafiOne – FLIR	5	38%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
TrafiSense AI– FLIR	6	35%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
Currux Vision	7	32%	-4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Boulder AI DNN Node	7	32%	-4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%
Iteris Vantage Vector with Vantage Next	9	29%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%
Spack Solutions' countCAM3	10	28%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	-4%
LiDAR Matrix Inc.	10	28%	4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	4%
Miovision Scout camera	12	20%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	-4%
Eco-counter CITIX – AI	13	12%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	4%	-4%
Street Simplified	14	7%	4%	4%	4%	4%	4%	-4%	-4%	4%	-4%	-4%	-4%
Numina	15	3%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	4%	-4%

Outputs needed	Night Vision	Video Internal Storage	Procurement Budget	Recurring Costs Budget	Inter-division Collaboration	Equipment Ownership	Size of pedestrian program	Quality Control Requirements	Public view on video detection	Agency Goals	Installation capacity	Possibility of manual data transmisstion
2%	4%	-4%	-4%	4%	4%	4%	4%	4%	-4%	-4%	4%	4%
3%	4%	-4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	4%	4%
0%	4%	4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	4%	4%
3%	4%	-4%	-4%	-4%	-4%	4%	4%	-4%	4%	-4%	4%	4%
0%	4%	-4%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	-4%
-3%	4%	-4%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	-4%
3%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
3%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
0%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
-1%	4%	4%	4%	-4%	-4%	4%	4%	4%	-4%	4%	4%	4%
-1%	4%	-4%	4%	4%	-4%	-4%	4%	-4%	4%	-4%	4%	4%
-1%	4%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	4%	4%	4%
-1%	4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
3%	4%	4%	-4%	-4%	-4%	-4%	4%	4%	-4%	-4%	4%	4%
-1%	4%	-4%	-4%	-4%	4%	-4%	4%	4%	-4%	-4%	4%	-4%

Figure 5.5 DSF results page, using example criteria

BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	
Product	Website	Sensor Type	Technolog	Number of	≤ 2 lanes	3-4 lanes	> 4 lanes	Midblock	Intersectio	Shared Patl	Trail	Sidewalk	Lighting N	Occlusion	Need powe	Counting A	Detection	Permanent	T
Blue City AI	https://bluecity.ai/	LiDAR	software ar	1 or 2	1	1	1	1	1	1	0	1	0	0	1	98.70%	98.70%	1	
Miovision Scout camera		Video	software ar	2	1	1	0	1	1	1	0	0	1	1	0	95%	95%	0	
Miovision TrafficLink		Video	software ar	1	0	1	1	0	1	0	0	0	1	1	1	99%	99%	1	
Spack Solutions' countCAM3		Video	software ar	1	1	1	0	0	1	0	0	0	1	1	0	??	??	0	
Eco-counter CITIX – AI		Video	software ar	2	1	1	0	0	1	0	0	0	1	1	1	95%	95%	1	
Numina		Video	software ar	4	1	1	0	1	1	0	0	0	1	1	1	95%	95%	1	
Street Simplified		Video	software ar	2	1	1	1	1	1	0	0	0	1	1	0	98	90%	0	
Boulder AI DNN Node		Video	software	4	1	1	0	0	1	0	0	0	1	1	1	??	??	1	
Boulder AI DNN Cam		Video	software ar	4	1	1	1	0	1	0	0	0	1	1	1	??	??	1	
Currux Vision		Video	software	4	1	1	0	1	1	0	0	0	1	1	1	98%	97%	1	
Gridsmart		Video	software ar	1	1	1	0	0	1	0	0	0	1	1	1	92%	98%	1	
Iteris Vantage Vector with Vantage I		Video	software ar	4	1	1	1	0	1	0	0	0	0	1	1	90%	98%	1	
TrafiOne – FLIR		Thermal	software ar	8	1	0	0	1	1	0	0	0	0	0	1	70%	99%	1	
TrafiSense AI– FLIR		Thermal	software ar	8	1	1	0	1	1	0	0	0	0	0	0	70%	99%	1	
LiDAR Matrix Inc.		LiDAR	software ar	1	1	1	1	1	1	0	0	0	0	0	0	98%	100%	0	
Placeholder																			
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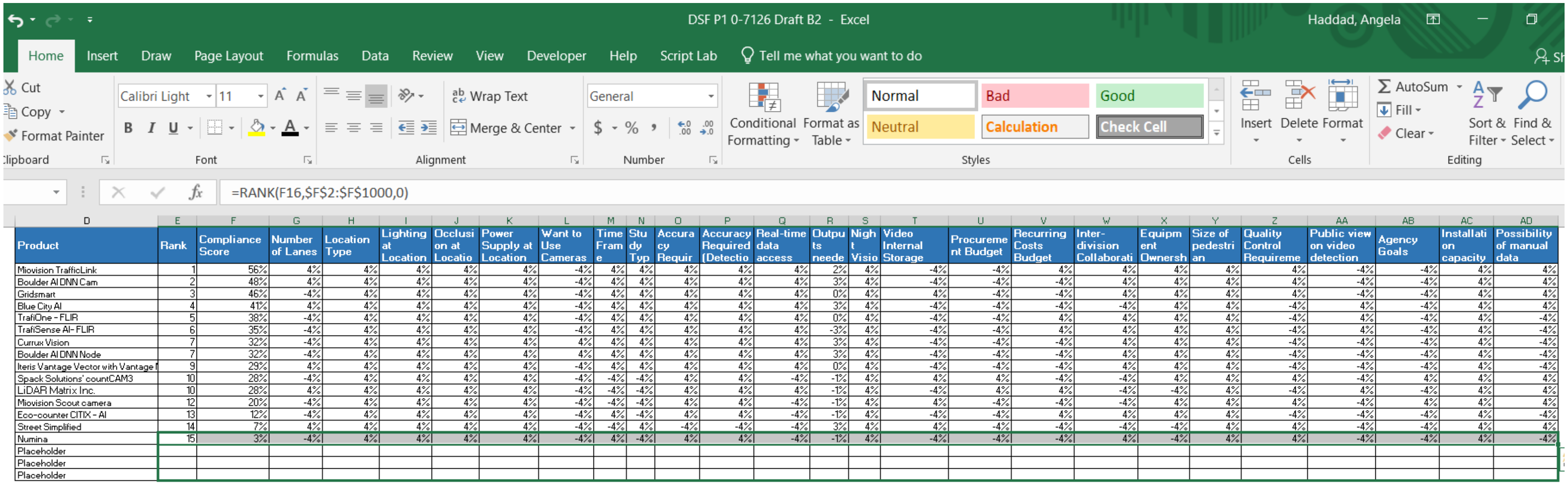
Figure 5.6 DSF Ranking page interface for adding products



Product	Rank	Compliance Score	Number of Lanes	Location Type	Lighting at Location	Occlusion at Locatio	Power Supply at Location	Want to Use Cameras	Time Frame	Study Typ	Accuracy Requir	Accuracy Required (Detectio	Real-time data access	Outputs neede	Night Visio	Video Internal Storage	Procurement Budget	Recurring Costs Budget	Inter-division Collaborati	Equipment Ownersh	Size of pedestrian	Quality Control Requireme	Public view on video detection	Agency Goals	Installation on capacity	Possibility of manual data
Miovision TrafficLink	1	56%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	2%	4%	-4%	-4%	4%	4%	4%	4%	4%	-4%	-4%	4%	4%
Boulder AI DNN Cam	2	48%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	3%	4%	-4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	4%	4%
Gridsmart	3	46%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	0%	4%	4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	4%	4%
Blue City AI	4	41%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	3%	4%	-4%	-4%	-4%	-4%	4%	4%	-4%	4%	-4%	4%	4%
TrafiOne - FLIR	5	38%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	0%	4%	-4%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	-4%
TrafiSense AI- FLIR	6	35%	-4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	-3%	4%	-4%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	-4%
Currux Vision	7	32%	-4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	3%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
Boulder AI DNN Node	7	32%	-4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	4%	3%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
Iteris Vantage Vector with Vantage N	9	29%	4%	4%	4%	4%	4%	-4%	4%	4%	4%	4%	4%	0%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
Spack Solutions' countCAM3	10	28%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	-4%	-1%	4%	4%	4%	-4%	-4%	4%	4%	4%	-4%	4%	4%	4%
LiDAR Matrix Inc.	10	28%	4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	4%	-1%	4%	-4%	4%	4%	-4%	-4%	4%	-4%	4%	-4%	4%	4%
Miovision Scout camera	12	20%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	4%	-4%	-1%	4%	4%	-4%	-4%	-4%	4%	4%	4%	-4%	4%	4%	4%
Eco-counter CITIX - AI	13	12%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	4%	-4%	-1%	4%	-4%	-4%	4%	4%	4%	4%	-4%	-4%	-4%	4%	-4%
Street Simplified	14	7%	4%	4%	4%	4%	4%	-4%	-4%	4%	-4%	-4%	-4%	3%	4%	4%	-4%	-4%	-4%	-4%	4%	4%	-4%	-4%	4%	4%
Numina	15	3%	-4%	4%	4%	4%	4%	-4%	4%	-4%	4%	4%	-4%	-1%	4%	-4%	-4%	-4%	4%	-4%	4%	4%	-4%	-4%	4%	-4%
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Figure 5.7 DSF process of updating results page to accommodate new product

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Appendix A. Interview Summaries

Table B1. Interview Summaries

<table>
<tr><th>Agency</th><th>Summary of Program</th><th>Product Description</th><th>Benefits</th><th>Challenges</th></tr>
<tr><td rowspan="3">City of Austin</td><td rowspan="3">CoA has an advanced ped/bike program and they do extensive experimentation with different vendors and products as part of their Smart Mobility Office.

Interviewed Luke Urie and Josef Mckenzie about CoA's pilot studies.

Austin is going to create a smart corridor. So, they need permanent installations.

<u>Addressing security concerns:</u>
• Do not move forward with technology if it does facial recognition
• Strict policies for video storage
• Video is deleted after a certain amount of time
• Camera footage is not shared with anyone

<u>Areas of interest:</u>
• Pedestrian safety
• Volume counts
• Characterization of all travel modes using same equipment
• Automated traffic signal performance measurements (ATSPM)
• Near misses

<u>Lessons learned:</u>
• Difficult to move from pilot to procurement
• There are multiple stakeholders and we need to see what they are interested in
• There is limited sharing of lessons learned between agencies and teams
• Need to have multiple stakeholders to justify the more expensive installments
• It is not always clear which agency is able to move forward with procurement.
• Collaboration between agencies is essential
• Decision on how much money to spend on equipment depends on the agency's roadmap</td><td><u>LiDAR:</u>

<u>Velodyne Puck Sensor + Blue City AI software</u></td><td>• Covers a larger range than cameras
• Tracks data without taking pictures
• Provide real-time 3D maps of detected objects
• Simple, quick installation that takes 0.5 to 1 day
• Overcomes occlusion issues
• Ability to function in all lighting and weather conditions
• Cheaper 180° sensors can be used for midblock crossing
• Other companies may have cheaper LiDARs. Can see more range than the puck but only give 180° angle.</td><td>• Velodyne does not process the data. Need to work with Blue City AI software.
• The city is responsible for installing the equipment and providing the necessary resources (technician and truck)
• When mounted on a pole, the sensor cannot detect what is directly below it (blind spots)
• Need at least 2 pucks for an intersection to avoid blind spots
• Need to mount LiDAR high enough to avoid vandalism and being hit by large trucks
• Trade-off between height and blind spots
• People's curiosity results in tampering with new technologies
• Need to plan everything ahead of time
• Sometimes the infrastructure does not support the technology. For example, IP addresses may not be available to install at a specific intersection.
• More lanes require more sensors
• Costly
• Problems transmitting data at am and pm peaks. Flickering due to the high volumes.
• Counts large trucks as 2 vehicles</td></tr>
<tr><td><u>NTT Smart Solutions in partnership with Dell Technologies</u>

Uses artificial intelligence and sensors to enable real-time decision-making. It includes HD optical sensors, sound sensors, and IoT devices.</td><td>• Pilots in multiple cities including Austin and Las Vegas
• Data generated by traffic flows is used to route vehicles and reduce congestion
• Advanced facial recognition, when the technology is combined, can help search for missing children</td><td>• The camera sensor took 3 days to install, which added complications</td></tr>
<tr><td><u>Video:</u>

<u>Miovision Sc89qout camera + MicroTraffic algorithm</u>
• At least 3 cameras are needed per intersection</td><td>• Flexibility: can attach it anywhere
• Limited paperwork is needed. Can be installed without permission from multiple stakeholders.
• Most vendors provide shelf-ready solutions
• Can off-load video to a local third party for processing to save money

<u>In-house solution:</u>
• Cheaper to do it in-house if you need it for system management and operation</td><td>• Only suitable for temporary studies
• Battery life is an issue for the portable cameras
• Physical artwork on the roadway may affect performance
• If the camera detects a QR code it actually goes to the website and downloads all the data
• Does not have real-time access
• Does not have nighttime vision
• Glare creates occlusions to data collection, even for the best cameras
• Occlusion issues
• Difficult to evaluate products and decide what to do long term

<u>Using CCTV and offloading to a third party:</u>
• Cameras do not have a proper field of view at intersections
• Flickering, variable frame rate
• Glare issues

<u>Permanent technology:</u>
• Requires updating the communications network: how much data are we going to be sending?
• Requires updating infrastructure
• Much more expensive than temporary deployment
• Not necessary for most applications</td></tr>
</table>

Agency	Summary of Program	Product Description	Benefits	Challenges
Delaware Valley Regional Planning Commission	They have a very experienced team. The agency's main priorities include high-accuracy equipment that can be easily installed and distributed. They want to have access to the raw data, and their objective is to maximize the amount of benefit from the data they collect. Consequently, they prefer developing products in-house. Interviewed Joshua Rocks. Vendors mentioned include Eco-Counter CITIX and Miovision. **<u>Addressing security concerns:</u>** • Do not point at houses • Low-quality resolution, which prohibits facial recognition	**<u>LiDAR</u>**	• Can differentiate between axles, speeds, and shapes. • Can differentiate shapes better than pixelated cameras • Easier to process data by just looking for shapes • No problems with lighting and occlusion • No need to worry about the angle	• Expensive • Processing the data is challenging • Reluctant to invest due to lack of experience with the technology and its accuracy • Unclear how to test accuracy • With third-party services, there is an extra fee to share the data with the public • Provides enormous amounts of data and a lot of it is not very useful. This results in high memory and storage requirements and costs.
		<u>Video:</u> <u>In-house equipment</u> • The cameras used can be installed anywhere. The mounting height is at least 8 ft. Telephone poles are preferred since they move less. <u>Eco-Counter CITIX</u> <u>Spack solutions:</u> • Manually process videos. They charge $300 for every 24 hours of video. They return results in 3 days.	• Can store data for long periods of time. Currently, they archive video for 3 years; the agency is looking to archive it for longer. • Video technology allows counting of different object types **<u>Off-the-shelf products:</u>** • Consultants like Miovision because they take care of processing the data • Eco-Counter CITIX has a very good reputation, and agencies that use it are satisfied **<u>In-house equipment:</u>** • If we own equipment we can help small municipalities that can't afford consultants • Quarter the price of Miovision • Achieves 98% accuracy • Cheaper units allow spending more money on achieving a spatial distribution	• In case of screen-line counts, cannot differentiate between people entering stores or just walking on the sidewalk. • 5–10% increase in operating cost after COVID-19 • In case of permanent installations, we have to pay an electricity fee. Complicated how to decide who pays the electricity cost. • Lighting and occlusion problems • Equipment is stolen in high-crime areas • Technology evolving rapidly. With 3G spectrum being shut down a lot of equipment became obsolete. Need to keep upgrading. **<u>In-house equipment:</u>** • Requires specialized personnel • Requires more time and effort • Have to send a technician out to collect the data manually • Need to think carefully about deployment locations. For example, need to avoid fire hydrants because the equipment will get wrecked by fire trucks • Acquiring electronic components is a big problem • Cloud-enabled communications lead to service fees that add up quickly **<u>Off-the-shelf products:</u>** • We don't trust their accuracy reports • Must pay for outside services and subscriptions • Miovision charges $20/hour • Miovision is only 70% accurate • Miovision will not go outside what they normally do. For example, it is not possible to get information about stop sign violation or if vehicles are yielding for pedestrians at the crosswalk. • Eco-Counter CITIX is very expensive ($13,000/unit)
Virginia DOT	Cheaper, well-tested devices are ideal for counting bikes and pedestrians.	**<u>Video:</u>** <u>Miovision Scout</u>: • Got contractor to put up cameras and send us the videos; had a third party watch the videos because Miovision charges an hourly rate		• Expensive: Miovision charges an hourly processing rate for temporary applications • Lack of trust in Miovision • Equipment will be off if it uses cellular transmission and they run out of money
		<u>StreetLight Data</u>	• Useful big data • Allows wide spatial coverage • A lot of consultants use it • Can use it to get relative pedestrian volumes for different slices of a corridor to plan sidewalk locations	• Not reliable for pedestrian data • Only applicable for trend analysis, not for design purposes
Minnesota DOT	Small program of only 2 employees. They are satisfied with traditional technologies and are not looking into using automated video or LiDAR at the moment. However, many cities in Minneapolis are using Miovision cameras.	**<u>Video</u>**		• Requires having a medium-to-large pedestrian program • More suitable at the county and city level rather than at the DOT level • Limited funding • Limited number of employees • Requires partnering with motor vehicle division to be worth it

<table>
<tr><th>Agency</th><th>Summary of Program</th><th>Product Description</th><th>Benefits</th><th>Challenges</th></tr>
<tr><td>City of Minneapolis</td><td>Relatively large pedestrian and bike program. Over 900 count locations are measured on a 4-year rotating basis.
Only performs temporary 24-hour counts using video technologies. They use infrared technology for permanent counts.
No quality control is performed on the video analysis.

<u>Addressing security concerns:</u>
• Delete the video directly and immediately after processing it</td><td><u>Video:</u>

<u>Miovision Scout</u></td><td>• 1 camera per intersection is sufficient. Only need 2 cameras for complex locations.
• Fairly accurate
• Miovision has an online platform to access all the data
• Miovision's platform can create standard turning movement diagrams
• Miovision allows manual access to the data to avoid annual subscription fees</td><td>• Expensive to buy equipment
• Expensive to process the video. Miovision charges $400–500 per location to process the videos.
• Nighttime visibility issues at intersections with no light poles
• Most data needs can be fulfilled using traditional IR technology
• Difficult to collaborate with the traffic control team to share cameras
• Cannot validate accuracy because the videos get deleted too quickly</td></tr>
<tr><td rowspan="2">Florida DOT</td><td rowspan="2">Florida DOT has a well-developed pedestrian program.

<u>Addressing security concerns:</u>
• Cameras do not point toward private residences
• The view is strictly of the roadway
• Delete videos and photos
• Use software that automatically blurs a person's face
• Use edge processing</td><td><u>Video:</u>

<u>Marlin Engineering in-house camera + GoodVision Algorithm:</u>
• The camera is mounted on a telescopic pole that goes up to 15 ft
• The receiver that is storing the video is a medium-size electrical box that we tie to a sign or pole
• The cameras are programmable but there is no remote access
• GoodVision is used to process video using a machine learning algorithm
• You upload the video to their platform, but the user is responsible for setting up zones properly within their software.

<u>Numina</u>

<u>Miovision</u>

<u>Leetron Vision</u>
• Going to test this soon
• http://leetronvision.com/</td><td>• Accuracy of all technologies is good, the only limit is the price
• Useful in urban and high congestion areas with traffic moving in different directions
• Can use video detection on short-term counts when it is difficult to install other equipment.

<u>Marlin Engineering in-house camera + GoodVision Algorithm:</u>
• Chains for every deployment to avoid being stolen
• GoodVision has a good accuracy track record; better than other companies
• The algorithm can process video footage from any angle or height with the same accuracy
• GoodVision can process thermal images, but they may have lower accuracy
• Manual verification of GoodVision revealed 95% accuracy
• GoodVision can work with footage from any camera
• No vandalism issues because they are mounted high</td><td>• Costly
• Sufficient to use traditional counters on simple roadways with few movements and choke points
• Some sites don't need camera detection, such as trails and low-volume facilities
• Many complexities in installing something permanently due to the required inter- and intra-agency coordination
• Recurring cost for electrical power
• A lot of the locations don't have AC power, but most technologies require it. So, some will need larger solar panels and batteries.

<u>Marlin Engineering in-house camera:</u>
• Remote access is not possible
• Must manually upload the video to GoodVision's platform
• The user is responsible for setting up zones properly within their software
• GoodVision's algorithm requires high-definition cameras and good lighting
• Hourly charge for video processing
• If the camera doesn't see the wheels of a bike it captures it as a pedestrian
• The resolution of some traditional cameras wasn't high enough for GoodVision's AI (1080 resolution recommended)
• Only works in daytime

<u>Numina</u>
• Bad accuracy rates based on a 2021 pilot

<u>Miovision</u>
• Did not work with GoodVision because of resolution issues</td></tr>
<tr><td><u>Streetlight</u></td><td>• Can rely on fewer count stations
• The numbers were not way off but looked like trends</td><td>• Expensive subscription fee
• Streetlight needs FDOT to have more permanent count stations to be accurate
• The numbers are not very specific, so their use is limited to trends</td></tr>
</table>

Agency	Summary of Program	Product Description	Benefits	Challenges
		Thermal Imaging: TrafiOne – FLIR TrafiSense – FLIR • Pointed at the location where peds usually stand when they want to push the crosswalk button • It detects their presence and sends a signal to the controller	• Thermal images gave fewer false calls than the video camera • Can connect a cellular modem to the thermal camera and have a cloud-based application to access the information • The vendor is responsible for supplying the modem • Can also plug in directly to the camera	• Only used for detection; not accurate for counts • Same FLIR would detect pedestrians or bikes but not cars. It would detect cars if the camera's angle is moved to the lane. • Costs $6,000–8,000 per approach (lower end is AC, upper end includes a solar panel). Solar panels are used for midblock crosswalks because it is cheaper than running power from a nearby utility service. The solar power system has to be designed with enough support battery backup. • Cellular service costs $35–50/month each
		LiDAR	• More demand and activity on a moveable bridge (openings a day) would justify using this technology	• Not justified for intersections • There is a yearly subscription for the service • Much more expensive than other technologies
City of Cambridge	Cambridge is a small city with 135 traffic signals. 35% of Cambridge residents walk to work. The city does not use any pedestrian activation and most signals are activated on pedestrian recall. **Areas of interest:** • Study the effects of COVID-19 • Study the impact of construction of casinos • Turning movement data • Separate crossing and non-crossing pedestrians • Permanent counts for calibration • Traffic data for Synchro or Vissim • Data for planning **Lessons learned:** • Need to budget for ongoing communication **Addressing security concerns:** • Do not record any videos • The quality of the image does not allow reading license plates • Camera is mounted 25 ft high	**Video:** Miovision TrafficLink • They have another package for cities looking for ATSPM • 360° camera • Mounted 25 ft. high • Permanent installation • Installed 13 devices in 2019 • The calibration: access the video feed from the cloud server and start drawing detection zones at the detection zone Gridsmart	**Miovision TrafficLink:** • Gives volume of pedestrians at crosswalk • Documents volumes in 15-minute bins • Documents turning movements • Simple calibration process • 1 camera is enough per intersection • 360° camera provides turning movement data and reduces the number of cams needed per intersection • Can access in a visual format (e.g., what was the peak volume at a certain time and date?) or export as CSV • Different cost packages are available through Miovision • Can stream and save video feeds locally if needed • Access to a very interactive user interface • If the annual subscription is not renewed, data can be extracted from the physical location using a USB • Mounted too high to be vandalized. • In case of a vehicle damaging the pole and camera, the police department can go after the involved person and charge their driver's insurance • Traditional infrared sensors can be more accurate for pedestrians but the camera can count all modes at once • Cameras work well at night because they have infrared vision	• Cost • Pedestrians get confused when signals' technology levels vary. For example, if the majority of signals automatically detect pedestrians, then pedestrians forget to push the button in locations that do not have automatic detection. **Miovision TrafficLink:** • Accuracy was not tested. • We don't do quality control. We are thinking about it. • There might be data caps related to video downloads • Annual fee associated with communication for devices and access to the portal ($1,000/location/year) • Traditional infrared sensors can be more accurate for pedestrians • When connecting to signal timing, multiple stakeholders need to be involved • Significantly undercounts bikes in high-bike-volume locations • Too much data is provided. Every movement at the intersection is split into modes and 15-minute bins. • Miovision does not provide an insurance policy • Continuously paying for repairs as trucks knock it over • Client is responsible for maintenance • Cannot identify e-scooters • Does not work properly with snow (e.g., snow-covered cars or snow-covered roads)
Louisiana Transportation Research Center	LTRC is working on an in-house pedestrian detection and count algorithm. This was inspired by the failure of proprietary sensors to achieve good accuracy in a 2018–2019 pilot. The private vendor could not dig into their algorithm to correct for the high errors, which motivated LTRC to build an in-house algorithm.	**Video:** Numina Miovision Reveel Cognomatics Video Turnstyle Motionloft Migma Iteris Oconowhite	• More practical in areas with high pedestrian density	• State DOT is not willing to invest time and money at this point • Need more federal requirements for measuring to take it further • Political concern • Vandalism • Security concerns • There is no push so far for detection (real-time applications) • Existing infrastructure is low-tech and not suitable for smart devices **Numina:** • Rain damaged the units (environmental issue) • Extreme weather affected reliability (environmental issue) • Low accuracy counts, especially on crowded and shared paths (where traditional equipment cannot be used)

Agency	Summary of Program	Product Description	Benefits	Challenges
TxDOT	Accuracy, price, and setup are considered the most important factors to TxDOT. TTI has or will test some camera products. Shawn Turner indicated that TxDOT will only install tried and proven technologies. Miovision was tested recently, and they plan to test Eco-Counter CITIX in the summer of 2022. Miovision was selected based on a competitive procurement process. TxDOT will continue to rely heavily on IR technology because it is cheap and reliable. This fiscal year, TTI will install 30 permanent counters. The locations will also include inductive loop detectors for bikes. **Areas of interest:** • Store the data in the cloud • Have the output ingested into a statewide count exchange program • Counts differentiated by mode • Study behavioral crossing patterns on large stretches of roads to see if there are enough crossings to warrant a midblock signal • Focus on midblock locations **Addressing security concerns:** • Only store the videos for a brief period for count generation • The quality of the video does not allow facial recognition • Maybe retain video for some months (Shawn Turner)	**Video:** Eco-Counter CITIX Miovision TrafficLink Miovision Scout	• Can be used in challenging settings where infrared does not work, such as crowded locations and shared paths • Same technology can be used for detection and counting but with a more complex algorithm • Improves the quantity and quality of pedestrian exposure data available for safety analyses **Miovision TrafficLink:** • Miovision's algorithm is affordable for a permanent installation • Good accuracy • Accurate even during hours of low light **Eco-Counter CITIX:** • Self-contained (does not require access to signal) • Less expensive than Miovision ($10,000)	• Cost • TxDOT did not get a lot of responses from automated video vendors to their previous solicitations • Large data volume may be required • Questionable ability for counting and detection in darkness and bad weather conditions • The processing of temporary data is expensive • Accuracy definitions may be misleading; detection accuracy is different from count accuracy • Don't have a large budget to do experimentation • Vandals use spray paint to cover the sensors **Miovision TrafficLink:** • Expensive ($15,000) • Need to have access to traffic signal equipment **Miovision Scout:** Challenging to get all 4 approaches in bigger intersections.

Maricopa Association of Governments	MAG initiated contact with 7 vendors for the pilot study in 2021. The first priority was to see if cameras can detect crossing peds and determine their timing in order to communicate with the control cabinet to extend crossing time if needed. The second objective is to evaluate count accuracy.
	
	Addressing security concerns:
	• Edge computing
	• Problem with edge computing is that it makes quality control impossible
		Video:
		
		Boulder AI
		
		Currux
		
		Gridsmart
		
		Iteris
		
		Miovision
		
		Rhythm Engineering
			• Insurance for vandalism is handled by the risk management team
			• Flexibility with video processing to save money
			
			Boulder AI:
			• Capable of running a video from a traditional CCTV camera
			• 1 camera per crosswalk
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Near-miss analyses including approach speed
			
			Currux:
			• Capable of running a video from a traditional CCTV camera
			• 1 camera per crosswalk
			• The AI node can be connected to the internet over a cellular modem
			• 98% accurate counts
			• 97% detection accuracy
			• Output includes:
			  • Turning movement counts at intersections along with colored dots for different classes of modes (vehicle, pedestrian, bike)
			  • Vehicle classifications and speed studies
			  • Wrong way detection and notification
			  • Corridor travel time
			  • ATSPM
			  • Interactions with controller for advance detections
			
			Gridsmart:
			• Online platform for live video visualization and data access
			• 92% detection accuracy
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Vehicle classifications
			  • Interactions with controller for advance detections
			
			Iteris:
			• Camera with video and radar sensor
			• 1 camera per crosswalk
			• Online platform for live video visualization, data access, and review
			• 90% count accuracy
			• 98% detection accuracy
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Vehicle classifications
			  • Corridor travel time
			  • ATSPM with pedestrian delay and conflicts
			  • Interactions with controller for advance detections
			
			Miovision:
			• 360° fish eye camera covers the entire intersection
			• Online platform for live video visualization and data access
			• 99% count accuracy
				• When using technology for signal timing, the use of different vendors can cause issues. Detection is done by one vendor and the signal control is done by another vendor. The agency needs to get both vendors on board.
				• If the mounting pole gets knocked out due to an accident all the systems need to be recalibrated, causing delays in schedules
				• Glare affects counting accuracy
				• Shadows result in double-counting pedestrians
				• Different vendors use a different number of cameras
				• Counting bikes is more challenging
				• Algorithms trained at one intersection might not be successful at another intersection
				• Micro-mobility adds noise and lowers performance
				• Calibration is not a fully automatic process
				• Temporary counts are costlier because they are charged hourly
				• Edge computing does not allow accuracy checks
				• Need multiple high-resolution cameras to analyze near misses
				
				Boulder AI:
				• Overcounts by 79%
				• Counting accuracy is dictated by the lighting condition, shade, apparel of the pedestrian or bicyclist, and party size
				• Does not distinguish between pedestrians and bikes
				• Not recommended by MAG
				
				Currux:
				• Counting accuracy is dictated by the sun lighting position and party size
				• Missed detection increases in early morning and late evening
				
				Gridsmart:
				• Vendor-provided camera
				• Beta version
				• Need 2 cameras per crosswalk
				• Overcounts pedestrians by 36%
				• Not recommended by MAG
				
				Iteris:
				• Counting accuracy is dictated by the lighting condition. More accurate counts were found in full light.
				• The system misses detection in the early morning and in dark/not-fully-lit conditions
				
				Miovision:
				• Counting accuracy is dictated by the lighting condition, apparel of the pedestrian or bicyclist, and party size
				• The system missed at least 1–2 persons when they were crossing the crosswalk in a large group
				• Sometimes bicyclists were counted as pedestrians
				• Missed detection in dark/not-fully-lit conditions
				
				Rhythm Engineering:
				• Need 2 cameras per crosswalk
				• Counting accuracy is dictated by the lighting condition and shadows, mix of pedestrians and bicyclists, and party size
				• Pedestrians were counted as bicyclists because of the shadows
				• Need 4 cameras to get turning movement counts

Agency	Summary of Program	Product Description	Benefits	Challenges

			• 97% detection accuracy
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Vehicle classifications
			  • Corridor travel time
			  • ATSPM
			  • Interactions with controller for advance detections
			
			Rhythm Engineering:
			• 98% count accuracy
			• 98% detection accuracy
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Speed on approaches
			  • Corridor travel time
			  • ATSPM
			  • Automatic signal timing plan generation
			  • Interactions with controller for advance detections	

		Thermal Imaging:
		
		FLIR
			• Online platform for live video visualization and data access
			• FLIR will be releasing a new module to distinguish between pedestrians and bicyclists in the future
			• Detection accuracy of 99%
			• Output includes:
			  • Vehicle counting on roadway segments
			  • Turning movement counts at intersections
			  • Wrong way detection and notification
			  • Corridor travel time
			  • ATSPM
			  • Interactions with controller for advance detections
				• Need 2 thermal cameras to cover 1 crosswalk
				• Not able to distinguish between pedestrian and bicyclists
				• The accuracy of the system may be sensitive to the presence of vehicles on crosswalks
				• Overall, overcounts elements in the crosswalk
				• The system overcounts in higher magnitude in the early morning and daytime, compared to evening
				• Shade affects count accuracy

Nevada DOT	Real-time trajectory to improve signal safety systems. Traffic safety audit. Identify intersections to improve.	**LiDAR:** Nevada LiDAR Matrix, Inc	• The software detects, classifies, and checks movement • Covers the whole intersection • More accurate than video technology • Cameras have challenges in low light conditions but LiDAR doesn't • Suited for real-time traffic control • Works for bikes as well • Facilitates a new effort to collect e-scooter data. We distinguish them from pedestrians by speed because they have the same cloud. • More detection range than cameras	• Must change batteries every few days • AV LiDAR algorithms don't work for roadside LiDARs • We realized that agencies don't need 365/24 data • Startups have a hard time getting projects • Sensor surface dirt can influence performance
Baltimore Metropolitan Council	Looking at before-and-after counts to make a case for leadership. Safety assessment.	**Video**	• Low cost	• Used only in daylight hours • Need to change batteries, so it is labor intensive

Appendix B. Survey Design

The goal of the project's survey was to solicit information from subject matter experts and experienced government agency employees to gain an improved comprehension of agency practices and product capabilities that goes well beyond what can be gleaned from the literature.

An online survey was designed using Qualtrics and sent to 194 experts within related agencies, institutions, and companies. Qualtrics is a survey tool that meets stringent information security requirements not found in most free online survey tools. It also has important quality control features, such as preventing multiple submissions from a single survey participant. Below is the survey outline and questions.

<u>Introduction page including CTR and TxDOT logos and project description</u>

- Q1: Select job description that applies the most to you:
    - DOT, MPO, or city employee
    - Subject matter expert or other

<u>General background about pedestrian data collection in your agency</u>

- Q2: Which agency or organization do you represent? What is your position?
- Q3: Do you collect or use any form of pedestrian information? (Yes, No)
- Q4: Do you collect multimodal traffic information (e.g., bicycles, scooters, micro-mobility)? (Yes, No)
- Q5: Do you have a well-established pedestrian data collection program? (Yes, No)
- Q6: If applicable, how established is your pedestrian data collection program (this may include goals, guidelines, documentation, plans, etc.)?
    - It's new but still needs refining
    - Very well established and up to date
    - Very outdated

If you answered yes to Q5:

- Q7.1: Does the program involve some form of automated data collection (rather than periodic/systematic manual collection efforts)? Please describe what the program involves.
- Q7.2: When was the last time this program was updated with new methods and technologies?
    - Not applicable
    - Less than a year ago
    - 1–4 years ago
    - More than 4 years ago

If you answered no to Q5:

- Q7.3: Is there a plan to develop a pedestrian data collection program in the future?
    - No
    - Yes, we are working on it
    - Yes, but the time line is not clear
- Q8: If applicable, what do you use the collected data for?
- Q9: Please fill out the table below about different data collection technologies.

Technology	Do you use it?	How often?	List the top 3 vendors or products you use	Is your agency satisfied with this technology?
• Passive Infrared • Active Infrared • Pressure/Acoustic Pads • Thermal Imaging • Automated Video • LiDAR • Radar	• Not used • I don't know • Pedestrian and multimodal • Only pedestrian • Only multimodal • Experimental program	• Never • Rarely • Sometimes • Often • Very Often		• Yes • No • TBD

- Q10: Additional methods or other notes:
- Q11: Please fill out the table below about the key characteristics of these technologies for pedestrian data collection.

Technology	Accuracy	Ease of implementation	Durability of hardware	Additional comments
• Infrared • Pressure/Acoustic Pads • Thermal Imaging • Automated Video • LiDAR • Radar	• Excellent • Acceptable • Bad	• Excellent • Acceptable • Bad	• Excellent • Acceptable • Bad	

<u>Questions about emerging technologies you currently use</u>

- Q12: Please answer the following questions related to emerging technologies that you already use.
    - When did you start using the technology?
    - Do you consider your experience successful? (Yes, No, Somewhat)
    - Advantages
    - Disadvantages
- Q13: Please answer the following questions related to emerging technologies that you already use.

- What are the challenges you are experiencing? Please be vendor specific if possible
  - What recommendations and advice would you have for other agencies starting to use this technology?
- Q14: How did you evaluate vendors and make final decisions?
- Q15: What do you use the collected data for? Please provide specific examples if possible.

Questions about emerging technologies you do not use

- Q16: Please answer the following questions about your agency's future considerations of some technologies for pedestrian data collection.
  - Are you considering using it? (Yes, No)
  - Why or why not? What are the main concerns?
- Q17: Please answer the following questions related to emerging technologies that you do not already use.
  - Will this technology enable your agency to collect new types of data? Are you aware of any advantages to using this technology?
  - How will you decide on vendors?

The following questions are about third-party data sources that rely upon smartphones or probe vehicles

- Q18: The following questions are about third-party data sources.

Data source	Do you use it?	Are you considering it?	If you have used it, please tell us how you use it and your experience. If not, are you considering it, and why or why not?
• StreetLight or INRIX products • Strava Metro • Wi-Fi/Bluetooth • Cell tower mobile phone positioning • GPS • Location-based services (LBS)	• Yes • No • I don't know	• Yes • No	

Closing

- Q19: If available, please provide the links to relevant pedestrian data collection documents.
- Q20: This completes the survey. If you are interested in receiving a final copy of the report that describes how new technologies are put into practice, please provide the following information:
  - Name
  - Locality/organization name

    - Email
- Q21: We highly value your input. Please let us know if you would be interested in being interviewed by our team to discuss these issues in further detail. (Yes, Maybe, No)
- Q22: If you have other comments, please provide them below.

Appendix C. Qualtrics Survey

Below are screenshots from Qualtrics, where the survey was implemented.

Texas Department of Transportation

CTR CENTER FOR TRANSPORTATION RESEARCH

The Center for Transportation Research at The University of Texas at Austin invites you to participate in a quick survey to better understand practices around the use of technology for improving traffic operations and pedestrian safety.

Your individual responses will be treated in strict confidence. The results of the study will be published only in summary form so that your identity and privacy are protected. The survey will take about 15 minutes to complete, but we think you'll find it interesting and fun to do.

We would appreciate it if you can complete the survey by **March 30th, 2022**.

Thank you in advance for your participation in this important study sponsored by Texas Department of Transportation (*TxDOT*).

If you have any questions about the study, feel free to contact the study coordinators Angela Haddad (angela.haddad@utexas.edu) or Kenneth Perrine (kperrine@utexas.edu).

0% 100%

Select Job description which applies the most to you:

- DOT, MPO, or City employee
- Subject Matter Expert or Other

If applicable, what do you use the collected data for?

	Data application examples
Pedestrian	
Multi-Modal	

Please fill out the table below about different data collection technologies.

	Do you use it?	How Often?	List the top 3 vendors or product you use	Is your agency satisfied with this technology?
Passive Infrared Sensors	Not used			
Active Infrared Sensors	Not used			
Pressure/ Acoustic Pads	Not used			
Thermal Imaging	Not used			
Automated Video				
LiDAR				
Radar				

Pedestrian and Multi-Modal
Only pedestrian
Only multi-modal
Experimental program
Not used
I don't know

Please fill out the table below about the key characteristics of these technologies for **Pedestrian** data collection.

	Accuracy	Ease of Implementation	Durability of hardware	Additional comments
Infrared Sensors				
Pressure/Acoustic Pads				
Radar				
Thermal Imaging				
Automated Video				
LiDAR				

Additional methods or other notes:

Questions about emerging technologies you currently use

Please answer the following questions related to emerging technologies that you already use.

	When did you start using the technology?	Do you consider your experience successful?	Advantages	Disadvantages
Automated Video				

Please answer the following questions related to emerging technologies that you already use

	What are the challenges you are experiencing? Please be vendor specific if possible	What recommendations and advice you would have for other agencies starting to use this technology?
Automated Video		

How did you evaluate vendors and make final decisions?

What do you use the collected data for? Please provide specific examples if possible.

Questions about emerging technologies you do not use

Please fill this table about you agency's future considerations of some technologies for **Pedestrian** data collection.

	Are you considering using it?		Why or Why Not? What are the main concerns?
	Yes	No	
LiDAR	○	○	
Thermal Imaging	○	○	

Please answer the following questions related to emerging technologies that you do not already use

	Will this technology enable your agency to collect new typed of data? Are you aware of any advantages to using this technology?	How will you decide on vendors?
LiDAR		
Thermal Imaging		

The following questions are about third-party data sources that rely upon smartphones or probe vehicles.

The following question are about third-party data sources?

	Do you use it?	Are you considering it?	If you have used it, please tell us how you use it and your experience. If not, are you considering it, and why or why not?
StreetLight or INRIX products			
Starva Metro			
Wi-Fi/Bluetooth			
Cell Tower Mobile Phone Positioning			
GPS			
Location-based services (LBS)			

Appendix D. Value of Research

D.1. Introduction

Although this project covers a popular topic, addressing the "Vision Zero" objectives of many DOTs at the state and municipal levels, the task of assessing the value of its research is difficult. This is due to the qualitative nature of some applications for automated pedestrian detection and the fact that outcomes depend on the purchase and installation of new equipment by DOTs, whose technology adoption rates cannot be fully predicted.

Comprehensive, multi-month pedestrian count data can be essential to transportation planners working on improving pedestrian safety through a corridor or optimizing pedestrian flow around places such as sports stadiums or shopping centers. To assess the value of this project, the research team analyzed the costs of such a surveying effort using manual (in-person) counters compared to using automated counting technology. Other criteria, such as the following, are possible for separate analyses, some of which are quantitative, while others are more qualitative:

- The value of time saved for users of all modes by optimizing the network in real-time using pedestrian counting technologies
- Avoiding expenses caused by the selection of technology that isn't appropriate for the intended use or of unnecessary services
- Justifying the installation of a pedestrian hybrid beacon or other street safety feature and realizing its benefits
- Assessing safety improvements and resulting cost savings from utilizing pedestrian counting technologies

For the last point, it is especially important to note that since crashes can cost millions of dollars, any safety application that yields a reduction in crash rate generally produces an immediate, sizeable benefit-to-cost ratio.

D.2. Pedestrian Counting Technology Cost Comparison

For this assessment, assume that a DOT would like to measure pedestrian activity in a pedestrian-heavy area, such as a shopping district, comprised of the roadway network pictured in **Figure D.1**.

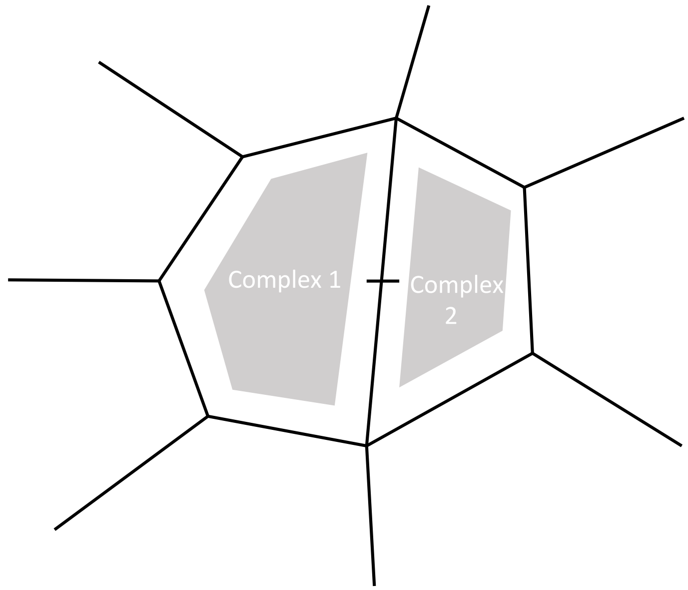

Figure D.1: Example roadway network for value of research analysis

There are eight intersections in this roadway network, and manual pedestrian counting by hired contractors situated at each intersection could cost on average $120 per hour per intersection.

Over the course of one year, assuming a counting time of 16 hours a day (6 am to 10 pm), that adds up to 5,840 hours. The total cost would be $700,800, an enormous expense for a DOT, in addition to the major logistical challenges a manual count would pose. Due to these costs and for logistical reasons, manual pedestrian measurement over such a long time period is clearly not feasible, which further illustrates how the new technologies studied in this project can bring significant value to DOTs by allowing for consistent, continuous, long-term data collection. If, informed by this project, a DOT installed at these intersections video-based pedestrian counting technology, such as the Miovision TrafficLink, it would lead to very significant cost savings. Per intersection, the TrafficLink would cost $11,500 for equipment, plus a $1,000 annual maintenance fee and $4,000 in installation labor costs, totaling $132,000 for all eight intersections (with $8,000 annually thereafter so long as the equipment continues to operate). It is important to note that not only is the video-based technology more capable of continuous data collection than manual counters; for properly calibrated systems, it is likely more consistently accurate.

D.3. Final Benefit-Cost Ratio

This project cost: $65,000.

To calculate the benefit-cost ratio for the hypothetical eight-intersection installation described in this analysis, we take the cost of the project and proposed equipment ($65,000 + $132,000 = $197,000) and compare that to the cost of manual data collection ($700,800). The resulting benefit-cost ratio for a single year is **3.6:1**.

In evaluating this over the course of 20 years with a 5% discount rate, the benefit-cost ratio becomes **101:1**. This roughly models a similar installation performed once per year over 20 years.

This benefit-cost ratio analysis is inherently modest, in that it only analyzes a single site for one year without recognition that many of the project's other uses have significant safety benefits. It is important to note that future benefit-cost analyses can be performed to help DOTs justify upfront pedestrian detection equipment installation costs with specific objectives in mind, including those concerning safety, planning, traffic operations, and capabilities that were formerly infeasible.