Preliminary Investigation (PI-0289)

Caltrans Division of Research, Innovation and System Information

Automated Video Traffic Monitoring and Analysis

Requested by
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Executive Summary

Background

California Department of Transportation (Caltrans) operates an extensive network of closed-circuit television (CCTV) cameras on state highways. These cameras allow traffic management center (TMC) operators to monitor traffic conditions and respond to crashes, stalled vehicles, wrong-way drivers and other situations. With recent advances in data storage, processing and communications, transportation agencies have begun to explore how video analytics software could be used to enhance traffic monitoring by analyzing camera feeds in real time and automatically detecting changes in traffic characteristics that could indicate an incident. Automated video analysis could also provide historical data about traffic conditions and trends that could inform the design of traffic management systems on state highways.

Caltrans is seeking information about how other state departments of transportation (DOTs) are using automated video traffic monitoring and analysis systems to detect incidents and to perform other functions, such as counting vehicles, bicycles and pedestrians. Findings from this investigation will be used to inform Caltrans' continued examination, testing and deployment of automated incident detection systems.

Summary of Findings

Survey of Practice

An online survey was distributed to state DOT members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Operations, which includes members of state DOTs in all 50 states and the District of Columbia.

Eleven state DOTs responded to the survey. Seven agencies have implemented, tested or plan to test automated video analytics software:

- Arizona (testing a university research product in fall 2021).
- Arkansas (TrafficVision).
- Delaware (AI-TOMS).
- Michigan (TraffiCalm Systems).
- Minnesota (TrafficVision).
- Oklahoma (Miovision).
- Wisconsin (Bosch Security Systems).

The remaining respondents reported limited or no engagement with automated video analytics or similar systems:

- Colorado DOT is using other technology for similar data collection. The respondent noted that incident detection is best-suited for fixed cameras but the agency is currently using all pan-tilt-zoom (PTZ) cameras.
- Idaho Transportation Department does not currently use video live-feed systems for analytics or traffic monitoring purposes. The agency's only video application uses Miovision Scout units, which range in age from one to seven years, to generate vehicle and turning movement counts and monitor vehicle classification. The respondent noted

that the agency is monitoring automated video traffic monitoring and analysis technology but is not yet in the planning stages or ready to implement.

- The final two respondents—North Dakota and Pennsylvania DOTs—have not implemented, tested or made plans to test automated video analytics software.

Use Cases or Applications

Survey respondents were most likely to use video analytics software to monitor stopped vehicles in a travel lane or on a shoulder, traffic crashes, and debris or objects in the roadway. The Delaware DOT respondent noted that the agency's TMC software also matches vehicles from one camera to another and provides data for occupancy estimates.

Products Used or Tested

Respondents identified the cameras and video analytics software their agencies have used for the use cases noted above. TrafficVision—the most frequently mentioned product—is used in Arkansas and Minnesota and is in the early stages of review in Michigan. Other products states have used or tested include systems from Bosch, TraffiCalm and Miovision; additional systems planned for testing or in development include PowerArena, AI-TOMS and a university-developed research product.

Table ES1 summarizes the systems respondents have implemented or tested, and the purpose or use of each system. Significantly more detail on these systems can be found in the **Detailed Findings** section of the report (refer to the Case Studies and Supporting Documents sections).

Table ES1. Description of Respondents' Products/Systems

State	Product/System and Installation Date	Product/System Description	Purpose/Use
Arizona	University research product Fall 2021	• 10 cameras • Fiber optic communications • PTZ and fixed-view cameras • Video processing on local server	Data on near misses, unsafe driving, debris, incidents and stalled vehicles; also expected to assist with vehicle classification and pedestrian counts
Arkansas	TrafficVision August 2020 to April 2021	• 12 cameras • Cellular link communications • PTZ cameras • Video processing on cloud-based server	Traffic crashes; stopped vehicles in a lane or on the shoulder; jaywalking; and debris or object in roadway
Delaware	AI-TOMS Testing underway	• Fewer than 10 cameras • Cellular link communications • PTZ and fixed-view cameras • Centralized computing using a TMC server	Traffic monitoring
Michigan	TraffiCalm Systems October 2019	• Fewer than 10 cameras • Cell modem communications • PTZ camera (one) and fixed-view cameras • Video processing on board the camera	Wrong-way driver detection

State	Product/System and Installation Date	Product/System Description	Purpose/Use
Minnesota	TrafficVision April 2021 to May 2021	• 16 cameras • Communications via 511 streaming video feed • PTZ and fixed-view cameras • Video processing on cloud-based server	Freeway incident detection
Oklahoma	Miovision 2018	• Unspecified number of cameras • Fiber optic communications • Fixed-view cameras • Video processing on cloud-based server	Traffic counts, turning movement, vehicle classification currently analyzed using recorded video
Wisconsin	Bosch 2020	• One camera • Fiber optic communications • PTZ camera • Video processing on board the camera	Evaluation of stopped and slowed vehicle detection capabilities

Video Analytics Software Integration

Respondents described agency practices to integrate new video analytics software with existing traffic cameras:

- *Arizona DOT* will use Bosch Starlight 7000, Starlight 7000i and Starlight 7100i cameras of various ages in the integration for its fall 2021 pilot.
- *Delaware DOT* is using PTZ and standard CCTV cameras of various ages in the AI-TOMS integration.
- *Michigan DOT's* system integration involved Cohu, Vicon and Moog video alarm cameras that range in age from zero to 10 years. The integration was implemented on the state of Michigan's intelligent transportation system (ITS) network.
- *Minnesota DOT's* TrafficVision camera is connected to the agency's video streams through the Wowza software platform. Although the Cohu cameras involved in the integration are five years old or newer, the camera vendor is not significant since TrafficVision is capturing video through the Wowza-supplied video feeds.

Case Studies

Seven case studies summarize respondents' experiences with using video analytics technology for automated incident detection and traffic counts.

- *Arizona DOT* is working with a university research team to develop and pilot a system that is expected to be installed this fall. The respondent identified ensuring safe operation of both driven, connected and automated vehicles as a goal of the system.
- *Arkansas DOT* recently conducted a demonstration project evaluating the use of the TrafficVision system to identify traffic crashes, stopped vehicles, debris in the roadway and jaywalking. The respondent reported that the demonstration was "reasonably successful" and noted that cost is the main obstacle to a large-scale implementation.

- *Delaware DOT's* response came from a contractor at the agency's TMC who works for Intelligent Automation, Inc. According to the company web site, Intelligent Automation is working with Delaware DOT to develop and test AI-TOMS, an artificial intelligence-based traffic operations and management software tool. Delaware DOT is using the tool for incident detection and other functions, including occupancy estimation and vehicle matching from one camera to another. The company web site notes that AI-TOMS "integrates with sensor data pipeline infrastructure as well as popular existing traffic controllers."
- *Michigan DOT* primarily uses TraffiCalm systems for wrong-way driver detection, with the respondent reporting that the system meets the agency's needs very well. Michigan DOT is exploring other systems as well; a Bosch system is used for one wrong-way detection installation, and the agency plans to test TrafficVision and PowerArena systems. To date, the systems involve fewer than 10 camera feeds statewide. The respondent reported that the agency is currently working on a market analysis and state-of-the-practice document.
- *Minnesota DOT* is currently conducting a 16-camera trial of the TrafficVision system, evaluating the system for incident detection. The system was installed in April and May of this year. While the agency has been impressed by the TrafficVision test, the system does require that cameras return to a preset location and also requires some setup for each camera. The overall cost of the system may prevent a systemwide deployment, but the agency sees the system as "having potential."
- *Oklahoma DOT* installed a Miovision system in 2018 for compiling data on traffic counts and vehicle classifications. Analysis is conducted on recorded video rather than live camera feeds. The respondent also briefly mentioned the recent installation of GRIDSMART detection systems at a few signal locations that have not yet generated analytics. The respondent noted that "[w]e are in the very beginning of any movement into this area" and said the agency is not yet able to fully assess the effectiveness of the systems being explored.
- *Wisconsin DOT* is currently conducting a pilot test of a single Bosch camera system to evaluate the system's detection of stopped and slowed vehicles. The system is not integrated into the agency's traffic video management system, and detailed results are not yet available. Agency staff members are also serving as project champions for an ongoing project within the ENTERPRISE pooled fund study that is investigating the capabilities of commercially available automated incident detection systems.

Recording and Archiving Video

Agency experiences with recording and archiving video are described below:

- *Delaware DOT* records video for a short duration (7 seconds) as incident verifications. Videos are only recorded for a research purpose and are not publicly accessible. There are no protocols in place to extract and provide copies of video clips in response to a public request.
- *Michigan DOT* only records video for training, research and safety purposes. These videos are manually recorded by an operator. Though this type of recording is rare, the videos can be obtained by the public through a Freedom of Information Act request.
- *Minnesota DOT* uses Milestone Systems' open platform IP video management software to record traffic video over a four- to five-day span. Video not pulled before the end of that period is recorded over. The agency doesn't employ precautions regarding privacy

but has documented an office procedure that describes how to provide the video to requestors.

- *Wisconsin DOT's* highway traffic monitoring cameras record on a 72-hour loop; these recordings can be archived for a longer period if an incident is recorded or if requested by law enforcement or the public. Zones can be blocked out on cameras to avoid impeding on the privacy of private property. For recorded live video feeds, nondisclosure can be flagged by the handling agency and the video will not be distributed. Public viewing sources (snapshots, 511 feeds) can also be blocked if requested by the handling agency.

  Anyone can request video footage within the 72-hour recording loop window. Video footage is saved in the archive for 120 days and can be requested for placement in a permanent storage drive. Video is shared with the requestor using cloud storage or via DVD.

<u>Additional Comments</u>

Agencies' additional observations about automated video traffic monitoring systems included:

- *Cloud-based approach.* The Minnesota DOT respondent noted that the cloud-based approach didn't require additional hardware or physical connections. The agency has not yet tested an edge-based system.
- *Effective products.*
  - TrafficVision, TraffiCalm and Bosch wrong-way driving systems have effectively met Michigan DOT's needs.
  - Minnesota and Oklahoma DOTs are still determining product and system effectiveness: Minnesota DOT has conducted only a brief TrafficVision test; Oklahoma DOT is still assessing its Miovision installation.

Related Research and Resources

A literature search of recent publicly available domestic and international resources gathered information and identified a representative sampling of publications and web sites that are organized into the following topic areas:

- National research.
- State research and resources.
- International research.
- Related resources.
- Commercial suppliers.

<u>National Research</u>

Federal Highway Administration (FHWA) publications include a 2019 report seeking to raise awareness of artificial intelligence for transportation systems management and operations. An FHWA fact sheet describes a prototype tool for automated video analysis that was developed in 2015 to help researchers quickly process the unprecedented amount of video data generated through the naturalistic driving study funded by the Strategic Highway Research Program. The tool was developed through FHWA's Exploratory Advanced Research Program.

State Research and Resources

Multiple States

An in-progress project sponsored by the ENTERPRISE pooled fund study is documenting the state of practice for commercially available automated incident detection systems and creating a framework of user needs to inform agencies' procurement documents. The research is focusing on products and tools that detect multiple types of common roadway incidents (such as crashes, stalled vehicles, debris in the road, slow or stopped traffic). Expected to conclude in September 2021, the project builds on a 2014 ENTERPRISE study that documented the results of automated incident detection systems tested in Iowa, Missouri and Ontario, Canada.

California

Two projects completed in 2020 developed prototype systems using machine learning for traffic monitoring of vulnerable road users. A Caltrans project developed an automatic traffic monitoring system focused on detecting and monitoring pedestrians and bicyclists. The system was tested using videos from traffic cameras in Los Angeles. A second study developed a computer vision-based decision support system designed to identify near-crash situations and assess intersection safety for vulnerable users.

Other States

Recent studies in multiple states, including Florida, Missouri, New Jersey, New York, Texas and Washington, have evaluated commercial off-the-shelf and customized systems for automated incident detection, with some systems focused on specific users or use cases, such as wrong-way driving detection. A 2019 Indiana DOT study developed a prototype automated incident detection system designed to integrate with the agency's existing CCTV system. In addition, a 2018 Maryland project surveyed 21 transportation agencies about their current use cases and future plans for video analytics. The report also summarizes a vendor evaluation procedure and testbed that the agency developed.

International Research

Citations from multiple countries, including Australia, Canada, Germany, Japan and New Zealand, reflect continued development and refinement of automated video analysis systems abroad.

Related Resources

Two recent papers focus on refining detection tools for pedestrian safety, with a 2021 TRB paper describing a conflict identification methodology to help engineers and planners understand pedestrian risk at key locations. A 2020 paper takes a similar approach, proposing an improved framework for analyzing video at locations with high-density pedestrian traffic.

Commercial Suppliers

Documentation was obtained for several commercial suppliers of video analytic traffic management components in two categories:

Domestic

- Bosch Security Systems, LLC (Fairport, New York).
- CostarHD, LLC (San Diego, California).
- Derq Inc. (Detroit, Michigan, and Dubai, United Arab Emirates).

- Econolite (Anaheim, California).
- Omnibond Systems, LLC (TrafficVision) (Liberty, South Carolina).
- Pelco Corporations (Fresno, California).
- Street Simplified, LLC (Pasadena, California).
- WTI (Sidewinder/Viper) (Ventura, California).

International

- ai:Go Traffic Management Systems (Auckland, New Zealand).
- Axis Communications (Lund, Sweden).
- GoodVision Ltd. (London, United Kingdom).
- MicroTraffic Inc. (Winnipeg, Manitoba, Canada).
- Miovision Technologies Inc. (Kitchener, Ontario, Canada).

Gaps in Findings

This investigation provides a current snapshot of publicly available resources and state practices regarding video analytics and automated incident detection systems. Because this technology is advancing rapidly, continuing review of the current state of the practice will be required as Caltrans moves forward with its examination of these systems.

In addition, state DOT response to the practitioner survey was limited. None of the agencies that responded to the survey had implemented an automated incident detection system on a statewide level, and several indicated that their systems were too new to fully evaluate. Caltrans could benefit from additional inquiries to nonresponding state transportation agencies.

Next Steps

Moving forward, Caltrans could consider:

- Following up with selected respondents to gather more information about their systems, such as:
    - Arizona DOT, to learn more about the agency's university partner developing the system that will be launched in the fall of 2021.
    - Colorado DOT, to learn more about the other technology used for similar data collection.
    - Idaho Transportation Department, to learn more about the Miovision Scout units in current use and how they might relate to Oklahoma DOT's Miovision installation.
- Monitoring the results of the in-progress ENTERPRISE project that is assessing the state of the practice of automated incident detection systems.
- Following up with survey respondents who are testing systems of interest after they have had more time to develop a fuller picture of the systems' effectiveness.
- Reviewing the findings of the 2018 Maryland DOT survey and feasibility study, which developed a vendor evaluation procedure and a testbed where vendors could demonstrate their capabilities.

- Contacting agencies identified in the literature search as having undertaken a statewide implementation of automated incident detection systems, especially those that are working to integrate these systems with existing CCTV networks, such as:
  - Indiana DOT, which was described in a 2019 report as being in the final stages of integrating such a system.
- Contacting the vendors identified in the literature search for more information about their systems and capabilities.

Detailed Findings

Background

California Department of Transportation (Caltrans) operates an extensive network of closed-circuit television (CCTV) cameras on state highways. These cameras capture real-time conditions at selected locations, allowing traffic management center (TMC) operators to monitor traffic conditions and respond to crashes, stalled vehicles, wrong-way drivers and other situations.

Traffic monitoring is a challenging task, especially on crowded roads. With recent advances in data storage, processing and communications, transportation agencies have begun to explore how video analytics software could be used to enhance traffic monitoring by analyzing camera feeds in real time and automatically detecting changes in traffic characteristics that could indicate an incident. Automated video analysis could also provide historical data about traffic conditions and trends that could inform engineers and planners in designing and implementing traffic management systems on state highways.

Caltrans would like to learn more about how other state departments of transportation (DOTs) are using automated video traffic monitoring and analysis systems to detect incidents and to perform other functions, such as counting vehicles, bicycles and pedestrians. To address Caltrans' interest, an online survey gathered information from state DOTs with experience testing or using these systems. Results of a literature search supplemented the survey findings.

Survey of Practice

An online survey was distributed to state DOT members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Operations. Respondents were asked to provide information about their experiences with using video analytics software to automatically identify traffic incidents in real time and to perform other functions, such as conducting traffic counts.

Survey questions are provided in Appendix A. The full text of survey responses is presented in a supplement to this report.

Summary of Survey Results

Eleven state DOTs responded to the survey. Seven agencies have implemented, tested or plan to test automated video analytics software:

- Arizona (testing a university research product in fall 2021).
- Arkansas (TrafficVision).
- Delaware (AI-TOMS).
- Michigan (TraffiCalm Systems).
- Minnesota (TrafficVision).
- Oklahoma (Miovision).
- Wisconsin (Bosch Security Systems).

The remaining respondents reported limited or no engagement with automated video analytics or similar systems:

- Colorado DOT is using other technology for similar data collection. The respondent noted that incident detection is best suited for fixed cameras but the agency is currently using all pan-tilt-zoom (PTZ) cameras.
- Idaho Transportation Department does not currently use video live-feed systems for analytics or traffic monitoring purposes. The agency's only video application uses Miovision Scout units, which range in age from one to seven years, to generate vehicle and turning movement counts and monitor vehicle classification. The respondent noted that the agency is monitoring automated video traffic monitoring and analysis technology but is not yet in the planning stages or ready to implement.
- The final two respondents—North Dakota and Pennsylvania DOTs—have not implemented, tested or made plans to test automated video analytics software.

Summarized below are findings from the seven survey respondents describing their experiences with automated video analytics systems in these topic areas:

- Use cases or applications.
- Products used or tested.
- Video analytics software integration.
- Case studies.
- Recording and archiving video.
- Additional comments.

Use Cases or Applications

Survey respondents are most likely to use video analytics software to monitor stopped vehicles in a travel lane or on a shoulder, traffic crashes, and debris or objects in the roadway. The Delaware DOT respondent noted that the agency's TMC software also matches vehicles from one camera to another and provides data for occupancy estimates.

Table 1 indicates the types of use cases or applications respondents have implemented, tested or planned to test when monitoring traffic and detecting incidents. (The Oklahoma DOT respondent did not provide information about this type of use case or application.) Table 2 indicates the types of use cases or applications respondents have implemented, tested or planned to test when compiling vehicle classification and volume data.

Table 1. Use Cases or Applications for Monitoring Traffic and Detecting Incidents

State	Traffic Crashes	Stopped Vehicles in Lane or on Shoulder	Near Misses and Potential Conflicts[1]	Traffic Speed	Wrong-Way Drivers
Arizona	X	X	X		
Arkansas	X	X			
Delaware	X	X		X	
Michigan	X	X			X
Minnesota	X	X			X

State	Traffic Crashes	Stopped Vehicles in Lane or on Shoulder	Near Misses and Potential Conflicts[1]	Traffic Speed	Wrong-Way Drivers
Wisconsin		X			
Total	**5**	**6**	**1**	**1**	**2**

1 The full response option presented to respondents: *Near misses/potential conflicts involving vehicle, bicycle or pedestrian movements*.

Table 1. Use Cases or Applications for Monitoring Traffic and Detecting Incidents, Continued

State	Red-Light Violations	Illegal Turning Movements	Jaywalking	Debris or Object in Roadway	Visibility
Arizona		X		X	
Arkansas			X	X	
Delaware					
Michigan				X	
Minnesota				X	X
Wisconsin					
Total	**0**	**1**	**1**	**4**	**1**

Table 2. Use Cases or Applications for Compiling Vehicle Classification and Volume Data

State	Vehicle Counts	Vehicle Classification	Turning Movement Counts	Bicycle and Pedestrian Counts	On-Ramp and Off-Ramp Counts
Arizona		X		X	
Arkansas					
Delaware	X	X	X		X
Michigan					
Minnesota					
Oklahoma	X		X	X	X
Wisconsin	X		X		
Total	**3**	**2**	**3**	**2**	**2**

Products Used or Tested

Respondents identified the cameras and video analytics software their agencies have used for the use cases noted above. TrafficVision—the most frequently mentioned product—is used in Arkansas and Minnesota and is in the early stages of review in Michigan. Table 3 identifies the products used or tested; Table 4 lists the products agencies are testing or plan to test.

Table 3. Products Used or Tested

State	Product Used or Tested
Arkansas	TrafficVision
Michigan	• Bosch wrong-way warning system • TraffiCalm Systems
Minnesota	TrafficVision
Oklahoma	Miovision
Wisconsin	Bosch system integrated with agency camera

Table 4. Products in Test Mode or Planned for Testing

State	Product Tested or Planned for Testing
Arizona	University research product
Delaware	AI-TOMS
Michigan[1]	• TrafficVision • PowerArena

1 The agency is currently reviewing automated incident detection systems provided by these vendors. The agency's experience with these systems is limited.

Video Analytics Software Integration

Agency practices to integrate new video analytics software with existing traffic cameras are summarized below.

- *Arizona DOT* will use Bosch Starlight 7000, Starlight 7000i and Starlight 7100i cameras of various ages in the integration for the fall 2021 pilot.
- *Delaware DOT* is using PTZ and standard CCTV cameras of various ages in the AI-TOMS integration.
- *Michigan DOT's* system integration involved Cohu, Vicon and Moog video alarm cameras that range in age from zero to 10 years. The integration was implemented on the state of Michigan's intelligent transportation system (ITS) network.
- *Minnesota DOT's* TrafficVision camera is connected to the agency's video streams through the Wowza software platform. Although the Cohu cameras involved in the integration are five years old or newer, the camera vendor is not significant since TrafficVision is capturing video through the Wowza-supplied video feeds.
- Rather than describing the agency's system integration, the *Wisconsin DOT* respondent highlighted an ENTERPRISE pooled fund project, championed by Wisconsin DOT staff, that is investigating the capabilities of automated incident detection. In this project, described on page 24, researchers are examining the state of practice for commercially available automated incident detection systems and plan to define common user needs for agency use of these systems. The project is expected to conclude in September 2021.

Case Studies

The case studies below summarize respondents' experiences using video analytics technology for automated incident detection and traffic counts. Case studies are presented for seven state DOTs:

- Arizona.
- Arkansas.
- Delaware.
- Michigan.
- Minnesota.
- Oklahoma.
- Wisconsin.

Additional information about many of the products and systems described in these case studies is included in **Supporting Documents** beginning on page 21 and in **Commercial Suppliers** beginning on page 35.

Arizona Department of Transportation

Arizona DOT is working with a university research team to develop and pilot a system that is expected to be installed this fall. The respondent identified ensuring safe operation of both driven and connected and automated vehicles as a goal of the system.

Product/System Description

Topic	Description
Product/System and Vendor:	Solution developed by university researchers
Installation/Testing Date:	Fall 2021
Costs:	None at this time
Purpose or Use Cases:	• Safe operation of driven vehicles and connected and automated vehicles • Data on near misses, unsafe driving, incidents and stalled vehicles, and debris • Assistance with vehicle classification and pedestrian counts
Number of Camera Feeds:	10; number will be expanded if proven feasible.
Video Processing:	Currently planned for processing on a local server. Once the pilot is complete, the agency will determine the feasibility of expanded processing.
Communications Network:	Fiber optic cable
Video Encoding/Decoding Equipment:	In development
System Integration:	Part of the Cameleon advanced traffic management system

System Operation

Topic	Description
Required Network Data Rates:	In development
Sufficiency of Network Speed:	Expected to be sufficient for standard operations
Performance:	In development
Challenges Defining Detection Zones[1]:	In development

Topic	Description
Camera Types:	• PTZ cameras • Fixed-view cameras
Challenges With PTZ Camera Use[2]:	In development
System Meeting Needs:	In development
Overall Experience:	The system is still in development.

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., “preset creep”).

Arkansas Department of Transportation

Arkansas DOT recently conducted a demonstration project evaluating the use of the TrafficVision system to identify traffic crashes, stopped vehicles, debris in the roadway and jaywalking. The respondent reported that the demonstration was “reasonably successful” and noted that cost is the main obstacle to a large-scale implementation. The project concluded in April of this year.

Product/System Description

Topic	Description
Product/System and Vendor:	TrafficVision
Installation/Testing Date:	August 2020 through April 2021
Costs:	None (no-cost demonstration)
Purpose or Use Cases:	Traffic crashes; stopped vehicles in a lane or on the shoulder; jaywalking; and debris or object in roadway.
Number of Camera Feeds:	12
Video Processing:	Cloud-based server
Communications Network:	Cellular links
Video Encoding/Decoding Equipment:	AXIS cameras using H.264; encoding done on the camera
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	Cellular-based video stream sent to third party, cloud-hosted system. Special demonstration feed was replicated and sent to TrafficVision for each camera.
Sufficiency of Network Speed:	Sufficient
Performance:	No difference in performance under different weather or lighting conditions
Challenges Defining Detection Zones[1]:	None
Camera Types:	PTZ cameras

Topic	Description
Challenges With PTZ Camera Use[2]:	None
System Meets Needs:	Somewhat well
Overall Experience:	The demonstration was deemed "reasonably successful," identifying more stopped vehicles on the shoulder than was observed by the TMC, with many being transient. Many incidents were identified equally well by machine vision and TMC operators. Cost is the primary factor for not implementing.

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., "preset creep").

Delaware Department of Transportation

Delaware DOT's response came from a contractor at the agency's TMC who works for Intelligent Automation, Inc. According to the company web site, Intelligent Automation is working with Delaware DOT to develop and test AI-TOMS, an artificial intelligence-based traffic operations and management software tool. Delaware DOT is using the tool for incident detection and other functions, including occupancy estimation and vehicle matching from one camera to another. The company web site notes that AI-TOMS "integrates with sensor data pipeline infrastructure as well as popular existing traffic controllers."

Product/System Description

Topic	Description
Product/System and Vendor:	AI-TOMS
Installation/Testing Date:	N/R
Costs:	N/R
Purpose or Use Cases:	Traffic monitoring
Number of Camera Feeds:	Fewer than 10
Video Processing:	Centralized computing using a TMC server
Communications Network:	Cellular links
Video Encoding/Decoding Equipment:	N/R
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	N/R
Sufficiency of Network Speed:	Sufficient
Performance:	Weather and lighting conditions affect vehicle detection and tracking performance.
Challenges Defining Detection Zones[1]:	Camera height, offset from roadside, view angle and focal distances affect the detection zone shape and size.

Topic	Description
Camera Types:	• PTZ cameras • Fixed-view cameras
Challenges With PTZ Camera Use[2]:	Drifting of the camera detection zones is observed.
System Meets Needs:	N/R
Overall Experience:	Testing is in progress.

N/R No response

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., "preset creep").

Michigan Department of Transportation

Michigan DOT primarily uses TraffiCalm systems for wrong-way driver detection, with the respondent reporting that the system meets the agency's needs very well. Michigan DOT is exploring other systems as well; a Bosch system is used for one wrong-way detection installation, and the agency plans to test TrafficVision and PowerArena systems. To date, the systems involve fewer than 10 camera feeds statewide. The respondent reported that the agency is currently working on a market analysis and state-of-the-practice document.

Product/System Description

Topic	Description
Product/System and Vendor:	TraffiCalm Systems
Installation/Testing Date:	October 2019
Costs:	$20,000 for materials; $10,000 labor for in-house installation.
Purpose or Use Cases:	Wrong-way driver detection
Number of Camera Feeds:	Fewer than 10 locations statewide
Video Processing:	On board the camera
Communications Network:	Cell modem
Video Encoding/Decoding Equipment:	The only type of video encoding is completed for the short video clips sent out with the wrong-way driver detection system, and encoding is done by the TraffiCalm system. Wrong-way detection system encoding is conducted in the cabinet.
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	The agency's 1GB cell modem doesn't support video analytics. Any analytics happens within the cabinet.
Sufficiency of Network Speed:	Sufficient

Topic	Description
Performance:	Some false detections have been identified during major snowstorms when the snow blows into the devices' detection zone, but this is very rare.
Challenges Defining Detection Zones[1]:	None
Camera Types:	• PTZ camera (one Bosch system in Detroit) • Fixed-view cameras (all other Bosch and TraffiCalm systems)
Challenges With PTZ Camera Use[2]:	None
System Meets Needs:	Very well
Overall Experience:	The respondent noted a "generally good experience" though there were instances early on where animals were tripping the system.

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., "preset creep").

Minnesota Department of Transportation

Minnesota DOT is currently conducting a 16-camera trial of the TrafficVision system, evaluating the system for incident detection. The system was installed in April and May of this year. While the agency has been impressed by the TrafficVision test, the system does require that cameras return to a preset location and also requires some setup for each camera. The overall cost of the system may prevent a systemwide deployment, but the agency sees the system as "having potential."

Product/System Description

Topic	Description
Product/System and Vendor:	TrafficVision
Installation/Testing Date:	April 2021 through May 2021
Costs:	None (no-cost trial)
Purpose or Use Cases:	Freeway incident detection
Number of Camera Feeds:	16
Video Processing:	Cloud-based server
Communications Network:	TrafficVision was able to grab the streaming video the agency makes available to the public on its 511 site.
Video Encoding/Decoding Equipment:	N/R
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	N/R
Sufficiency of Network Speed:	Sufficient
Performance:	More false alarms in low light or poor weather conditions
Challenges Defining Detection Zones[1]:	Cameras on curves are most difficult to calibrate.
Camera Types:	• PTZ cameras • Fixed-view cameras
Challenges With PTZ Camera Use[2]:	TrafficVision seems to be able to handle some preset creep. Given the brevity of the test, it is unknown how much impact this could have over time.
System Meets Needs:	Very well
Overall Experience:	The respondent noted that the agency "[has] been impressed by the test but the system does need the cameras to return to a preset location and does require some setup for each camera." The agency likes the cloud-based operation and the system's ability to take streams from existing 511 video feeds with no changes or integration with an agency system. For a full deployment, the agency may consider providing a higher quality feed to TrafficVision to improve performance. The agency is uncertain about moving beyond the pilot stage due to the high cost of the system but may consider it for some high-crash locations. As the respondent noted, the "[o]verall cost of the system may prevent us from deploying systemwide but we do see the system having potential."

N/R No response

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., "preset creep").

Oklahoma Department of Transportation

Oklahoma DOT installed a Miovision system in 2018 for compiling data on traffic counts and vehicle classifications. Analysis is conducted on recorded video rather than live camera feeds. The respondent also briefly mentioned the recent installation of GRIDSMART detection systems at a few signal locations that have not yet generated analytics. The respondent noted that "[w]e are in the very beginning of any movement into this area" and said the agency is not yet able to fully assess the effectiveness of the systems being explored.

Product/System Description

Topic	Description
Product/System and Vendor:	Miovision
Installation/Testing Date:	2018

Topic	Description
Costs:	N/R
Purpose or Use Cases:	Traffic counts, turning movement, vehicle classification analysis used recorded—not live—video.
Number of Camera Feeds:	N/R
Video Processing:	Cloud-based server
Communications Network:	Fiber optic cable
Video Encoding/Decoding Equipment:	N/R
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	Not applicable. Videos are uploaded for later review; no real-time analysis.
Sufficiency of Network Speed:	N/R
Performance:	N/R
Challenges Defining Detection Zones[1]:	N/R
Camera Types:	Fixed-view cameras
Challenges With PTZ Camera Use[2]:	Not applicable
System Meets Needs:	Somewhat well
Overall Experience:	N/R

N/R No response

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., “preset creep”).

Wisconsin Department of Transportation

Wisconsin DOT is currently conducting a pilot test of a single Bosch camera system to evaluate the system’s detection of stopped and slowed vehicles. The system is not integrated into the agency’s traffic video management system, and detailed results are not yet available. Agency staff members are also serving as project champions for an ongoing project within the ENTERPRISE pooled fund study that is investigating the capabilities of commercially available automated incident detection systems.

Product/System Description

Topic	Description
Product/System and Vendor:	Bosch camera pilot installation; no wide-scale deployment.
Installation/Testing Date:	2020
Costs:	N/R
Purpose or Use Cases:	Evaluate stopped and slowed vehicle detection capabilities

Topic	Description
Number of Camera Feeds:	1
Video Processing:	On board the camera
Communications Network:	Fiber optic cable
Video Encoding/Decoding Equipment:	N/R
System Integration:	None

System Operation

Topic	Description
Required Network Data Rates:	Not applicable
Sufficiency of Network Speed:	Sufficient
Performance:	No difference in performance under different weather or lighting conditions
Challenges Defining Detection Zones[1]:	None
Camera Types:	PTZ camera
Challenges With PTZ Camera Use[2]:	None reported
System Meets Needs:	Somewhat well
Overall Experience:	This small pilot is not integrated into the agency's overall traffic video management system.

N/R No response

1 Respondents were asked to describe any difficulties experienced in defining detection zones that are the appropriate shape and size for various roadway geometries.

2 Respondents using PTZ cameras were asked about any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., "preset creep").

Supporting Documents

AI-TOMS—Artificial Intelligence Traffic Operations and Management System, Intelligent Automation, Inc., 2021.
https://www.i-a-i.com/2020/01/09/ai-toms-artificial-intelligence-traffic-operations-and-management-system/
From the web site: Intelligent Automation, Inc., in collaboration with DelDOT [Delaware DOT] TMC, the University of Delaware, and Jacobs, is developing and testing AI-TOMS, an artificial intelligence-based traffic operations and management software tool. AI-TOMS supplements TMC data ingestion and analysis processes by providing artificial intelligence tools for incident prediction, detection, and mitigation. The AI-TOMS toolkit integrates with sensor data pipeline infrastructure as well as popular existing traffic controllers, making artificial intelligence a plug and play addition to traffic management systems.

Related Resource:

> **Innovative Transportation Management Projects,** Integrated Transportation Management Program, Delaware Department of Transportation, undated.
> https://deldot.gov/Programs/itms/index.shtml?dc=projects
> *From the web page:* DelDOT was recently awarded a federal grant to deploy an artificial intelligence-based integrated transportation management system (AI-ITMS). It is an

excellent example of the Federal Highway Administration's (FHWA's) initiative to raise awareness of artificial intelligence of transportation systems management and operations. The program uses artificial intelligence and machine learning technologies to automate transportation system management and operations to improve safety and efficiency.

The system uses an AI-based transportation operations management system (AI-TOMS) which monitors the traffic on Delaware's roadways and automatically makes decisions to optimize performance. The program aims to work more efficiently than a human operator could by collecting data, analyzing, finding the best solution, and deploying quickly. Some expected outcomes include reduction of incident detection time, automation of operations, enhanced decision making, leveraging connected and automated vehicle (CAV) data for improved management, and increased intelligence over time by building a solutions library. Operation will occur in all three counties in Delaware.

Cameleon ITS, Teledyne FLIR LLC, 2021.
https://www.flir.com/products/cameleon-its/
From the web site: Cameleon ITS is a central software platform for transportation monitoring and management that allows for the control of ITS-specific devices, including cameras, DMS [dynamic message sign] signs, detector stations, gates, signal heads and incident detection. Cameleon ITS includes a complete video management solution native to the application.

GRIDSMART: Traffic Management Made Simple, GRIDSMART Technologies, Inc., 2021.
https://gridsmart.com/
From the web site: The GRIDSMART Solution is the world's most trusted and only field-tested, single-camera system that gathers and interprets important traffic data. GRIDSMART empowers traffic engineers to adjust signal timing and traffic flow strategies, and enables real-time monitoring and visual assessment.

Moog Sensor and Surveillance Systems (Moog S3), Moog Inc., 2021.
https://www.moogs3.com/
From the web site: Moog produces and integrates high-quality, scalable physical-security and RF/Satcom positioning solutions that are designed and manufactured in the USA. High-definition (HD) network camera systems for harsh environments, video tracking systems, pan and tilt positioners, tripods, and poles tailored for security cameras are a few of the surveillance solutions Moog provides to the global marketplace. Moog stands behind every product with exceptional technical support and industry leading warranties.

PowerArena, Motherapp, 2021.
https://motherapp.com/products/powerarena/
From the web site:

> **AI-first computations**
> We make use of cutting edge technology to support an integral stream processing architecture with the ability to process large amounts of real-time data with integrated deep learning algorithms. This allows instant data analysis of your camera streams and other sensors, supported by a variety of handy tools for on-the-spot management.

Cameras, Vicon Motion Systems Ltd, undated.
https://www.vicon.com/hardware/cameras/
This vendor provides "tailored motion capture systems for any application: life sciences, media and entertainment, location-based virtual reality, and engineering."

Wowza Media Systems, Wowza Media Systems, LLC, 2021.
https://www.wowza.com/
Streaming technology provided by this vendor includes a cloud streaming service, streaming server software, a live encoding solution and live streaming expertise.

Recording and Archiving Video

Four respondents described experiences with recording and archiving video:

- *Delaware DOT* records video for a short duration (7 seconds) as incident verifications. Videos are only recorded for research purposes and are not publicly accessible. There are no protocols in place to extract and provide copies of video clips in response to a public request.
- *Michigan DOT* only records video for training, research and safety purposes. These videos are manually recorded by an operator. Though this type of recording is rare, the videos can be obtained by the public through a Freedom of Information Act request.
- *Minnesota DOT* uses Milestone Systems' open platform IP video management software to record traffic video over a four- to five-day span. Video not pulled before the end of that period is recorded over. The agency doesn't employ precautions regarding privacy but has documented an office procedure that describes how to provide the video to requestors.
- *Wisconsin DOT's* highway traffic monitoring cameras record on a 72-hour loop; these recordings can be archived for a longer period of time if an incident is recorded or requested by law enforcement or the public. Zones can be blocked out on cameras to avoid impeding on the privacy of private property. For recorded live video feeds, nondisclosure can be flagged by the handling agency and the video will not be distributed. Public viewing sources (snapshots, 511 feeds) can also be blocked if requested by the handling agency.

  Anyone can request video footage within the 72-hour recording loop window. Requests are submitted via phone or email to a TMC operator who completes an internal request form that is linked to the video ID. Video footage is saved in the archive for 120 days and can be requested for placement in a permanent storage drive. Video is shared with the requestor using cloud storage (the video is uploaded and a link to the video is provided to the requestor by email) or by sending a DVD through regular mail.

Additional Comments

Three respondents offered additional comments about products and systems used for automated video traffic monitoring:

- *Cloud-based approach.* The Minnesota DOT respondent noted that the cloud-based approach didn't require additional hardware or physical connections. The agency has not yet tested an edge-based system.
- *Effective products.* TrafficVision, TraffiCalm and Bosch wrong-way driving systems have effectively met Michigan DOT's needs. Minnesota and Oklahoma DOTs are still determining product and system effectiveness: Minnesota DOT has conducted only a brief TrafficVision test; Oklahoma DOT is still assessing its Miovision installation.

Related Research and Resources

A literature search of recent publicly available domestic and international resources gathered information and identified a representative sampling of publications and web sites that are organized into the following topic areas:

- National research.
- State research and resources.
- International research.
- Related resources.
- Commercial suppliers.

National Research

Raising Awareness of Artificial Intelligence for Transportation Systems Management and Operations, Douglas Gettman, Federal Highway Administration, December 2019.
https://ops.fhwa.dot.gov/publications/fhwahop19052/fhwahop19052.pdf
A discussion of computer vision processing begins on page 29 of the report (page 41 of the PDF), with the author noting that "[t]here are several companies that now provide AI-based computer vision processing for traffic, including Mio[v]ision, Gridsmart, NoTraffic, GoodVision, Waycare and a host of others." Other references to digital video processing appear throughout the publication.

Automated Video Analysis: Analyzing Large Quantities of Transportation Research Data, Exploratory Advanced Research Program Fact Sheet, Federal Highway Administration, August 2015.
https://www.fhwa.dot.gov/publications/research/ear/15070/15070.pdf
From the fact sheet: The second Strategic Highway Research Program (SHRP 2) Safety research area has produced unprecedented data for highway researchers in the form of the naturalistic driving study (NDS). With approximately 2 petabytes of data available to researchers, most of which is video data, new automated tools for data extraction and analysis are required. Developing a prototype tool was the goal of the Exploratory Advanced Research (EAR) Program project, "Machine Learning for Automated Analysis of Large Volumes of Highway Video." The National Robotics Engineering Center, at Carnegie Mellon University (CMU), conducted this research, which was funded by the Federal Highway Administration (FHWA) in 2012.

State Research and Resources

Multiple States

Research in Progress: State of Practice for Automated Incident Detection, ENTERPRISE Pooled Fund Study, start date: October 2020, expected completion date: September 2021.
Project description at https://enterprise.prog.org/wp-content/uploads/ENTERPRISE_Automated_Inc_Detect_Jan2021.pdf
From the introduction: This ENTERPRISE Pooled Fund project is researching the state of practice for commercially available automated incident detection systems. The research is focusing on commercially available products and tools that detect multiple types of common roadway incident types (e.g., crashes, stalled vehicles, debris in the road, slow or stopped traffic) and provide alerts to TMC operators. The objectives are to understand the state of

practice for commercially available automated incident detection systems and to define common user needs for agency use of these systems.

….

The outcome of this task is expected to inform agencies of current system capabilities and provide a framework of user needs that may translate to requirements as agencies procure automated incident detection systems.

Next Generation Traffic Data and Incident Detection From Video, Linda Preisen and Dean Deeter, ENTERPRISE Pooled Fund Study, September 2014.
https://enterprise.prog.org/wp-content/uploads/ENT_VideoAnalytics_Report_Sept2014_FINAL.pdf
From the abstract: The term [v]ideo [a]nalytics refers to the capability of analyzing video feeds to determine events that are not based on a single image. A number of commercially available [v]ideo [a]nalytics systems are available that are capable of processing video streams from fixed and pan-tilt-zoom traffic cameras and then automatically creating alerts for conditions such as traffic incidents, stopped/slow moving vehicles, wrong-way vehicle movements, wildlife, and debris in real-time. Additionally, data collected by these systems can include traffic volume by lane, speed, vehicle classification, and lane occupancy. The Ministry of Transportation of Ontario (MTO) partnered with the ENTERPRISE Transportation Pooled Fund Program to conduct a project to research and document the potential for [v]ideo [a]nalytics as a tool for traffic operations centers (TOCs) and for traffic data collection. This report summarizes the testing results of several systems in the United States (Iowa, Missouri) and in Ontario, Canada, under real-world environments.

California

Automatic Traffic Monitoring and Management for Pedestrian and Cyclist Safety Using Deep Learning and Artificial Intelligence, Mohammad Pourhomayoun, California Department of Transportation, September 2020.
Publication available at https://doi.org/10.31979/mti.2020.1808
From the abstract: In this project, we have designed and developed an effective end-to-end system based on advanced [a]rtificial [i]ntelligence (AI), machine learning, and computer vision to automatically monitor, detect, track, and count pedestrians and bicyclists. The main objective of this project is to improve the safety of pedestrians and bicyclists, by applying self-sensed and AI-powered systems to monitor and control the flow of pedestrians/bicyclists. The developed system includes algorithms for detecting the pedestrians and bicyclists, as well as algorithms for tracking and counting the pedestrians. We evaluated the developed system on real videos captured by actual traffic cameras in the city of Los Angeles. Despite the low quality of some of the videos, the results demonstrated high accuracy and effectiveness of the developed system in automatically detecting and counting pedestrians and bicyclists.

Developing a Computer Vision-Based Decision Support System for Intersection Safety Monitoring and Assessment of Vulnerable Road Users, Arash Jahangiri, Anagha Katthe, Aryan Sohrabi, Xiaobai Liu, Shashank Pulagam, Vahid Balali and Sahar Ghanipoor Machiani, State of California SB1 2017/2018 Trustees of the California State University, March 2020.
https://transweb.sjsu.edu/sites/default/files/1853-Jahangiri-Computer-Support-System-Intersection-Safety_1.pdf
From the abstract: Vision-based trajectory analysis of road users enables identification of near-crash situations and proactive safety monitoring. The two most widely used surrogate safety measures (SSMs), time-to-collision (TTC) and post-encroachment time (PET)—and a recent variant form of TTC, relative time-to-collision (RTTC)—were investigated using real-world video data collected at [10] signalized intersections in the city of San Diego, California. … Video data

analysis was conducted to develop object detection and tracking models for automatic identification of vehicles, bicycles, and pedestrians. Outcomes of machine vision models were employed along with SSMs to build a decision support system for safety assessment of vulnerable road users at signalized intersections. Promising results from the decision support system showed that automated safety evaluations can be performed to proactively identify critical events. It also showed challenges as well as future directions to enhance the performance of the system.

Florida

Testing and Evaluation of Freeway Wrong-Way Driving Detection Systems, Pei-Sung Lin, Cong Chen, Seckin Ozkul and Manvitha Rajalingola, Florida Department of Transportation, November 2018.
https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/fdot-bdv25-977-40-rpt.pdf
From the abstract: [T]here is a continuing need to expand opportunities to reduce crashes by applying new technologies. Sponsored by Florida Department of Transportation (FDOT), this project successfully evaluated video-analytic freeway WWD [wrong-way driving] detection systems currently on the market from three vendors, regarding their capabilities for real-time WWD vehicle detection and Traffic Management Center (TMC) notification. … Six testing locations were selected on [an] I-275 segment between I-4 and I-75 in the Tampa Bay area, and these testing locations were assigned to one of four testing scenarios: (1) testing with normal daily traffic conditions; (2) testing consecutive WWD in both directions; (3) testing under normal light nighttime traffic conditions; and (4) testing under low light nighttime traffic conditions. Real-time WWD incident detection and data collection were conducted through fixed camera video streams at these locations. … The evaluation results and findings from this research project are informative and can be used to support FDOT and other state DOTs in future implementations of WWD detection systems on freeways and limited-access facilities.

Indiana

Development of Automated Incident Detection System Using Existing ATMS CCTV, Stanley Chen, Yaobin Chen, Qiang Yi and Zhengming Ding, Indiana Department of Transportation, October 2019.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3250&context=jtrp
From the abstract: Indiana Department of Transportation (INDOT) has over 300 digital cameras along highways in populated areas in Indiana. These cameras are used to monitor traffic conditions around the clock, all year-round. Currently, the videos from these cameras are observed by human operators. The main objective of this research is to develop an automatic real-time system to monitor traffic conditions using the INDOT CCTV video feeds by a collaborative research team of the Transportation Active Safety Institute (TASI) at Indiana University-Purdue University Indianapolis (IUPUI) and the Traffic Management Center (TMC) of INDOT. In this project, the research team developed the system architecture based on a detailed system requirement analysis. The first prototype of major system components of the system has been implemented. Specifically, the team has successfully accomplished the following:

1. An artificial intelligence (AI) based deep learning algorithm provided in YOLO3 is selected for vehicle detection which generates the best results for daytime videos.
2. The tracking information of moving vehicles is used to derive the locations of roads and lanes.

3. A database is designed as the center place to gather and distribute the information generated from all camera videos. The database provides all information for the traffic incident detection.
4. A web-based [g]raphical [u]ser [i]nterface (GUI) was developed.
5. The automatic traffic incident detection will be implemented after the traffic flow information being derived accurately. The research team is currently in the process of integrating the prototypes of all components of the system together to establish a complete system prototype.

Maryland

"Video Analytics Usage in Transportation Agencies: Nationwide Survey and Maryland Feasibility Study," Zachary Vander Laan, Kaveh Farokhi Sadabadi and Thomas Jacobs, *Transportation Research Record 2672*, pages 34-44, 2018.
Citation at https://trid.trb.org/view/1495496
From the abstract: This paper summarizes the findings from a study conducted by the University of Maryland Center for Advanced Transportation Technology (CATT) regarding the potential to extract meaningful traffic information from existing Maryland Department of Transportation-State Highway Administration (MDOT-SHA) closed-circuit television (CCTV) video feeds via image processing. It describes the survey that was developed and administered by CATT between March 10 and June 8, 2017, focusing on transportation agencies' current use cases and future plans for video analytics. Feedback from 21 agencies (9 of which are using video analytics) indicates a general excitement about the technology, although a persistent theme throughout the responses is that most current solutions are not yet able to provide satisfactory quantitative results (e.g., traffic counts, speeds, turning movements), especially in low light and high glare scenarios. Additionally, the report summarizes the vendor evaluation procedure that was undertaken, which includes identifying suitable video analytics vendors, developing a testbed of representative video clips from MDOT-SHA cameras under various conditions, asking the vendors to demonstrate their product capabilities on the testbed, and analyzing results. With proper camera positioning and calibration, the two vendors who participated achieved results within 5% to 15% of manual counts, and 4% to 7% of probe speeds in the northbound travel direction during a one-hour test clip. However, only one vendor produced results for the more challenging southbound direction, and the estimates were far less accurate (within 25% of manual counts and 20% of probe speeds). Accordingly, it appears that the estimation accuracy is highly sensitive to factors such as camera angle, resolution and visibility.

Missouri

TrafficVision ATMS Integration*, Innovations Showcase Fact Sheet*, Missouri Department of Transportation, April 2016.
https://www.modot.org/sites/default/files/documents/TrafficVisionATMSIntegration.pdf
From the description: Kansas City District has been utilizing Omnibound TrafficVision as an enhancement to the KC Scout Traffic Management Center operations since 2012. TrafficVision provides real-time, video surveillance and automated incident detection utilizing KC Scout's existing CCTV technology, proving invaluable for areas where there are gaps in continuous vehicle detection sensor coverage. Each appliance is capable of monitoring up to 24 configurable cameras. Each connected camera can monitor multiple lanes and opposing directions for stopped vehicles, slowed traffic, wrong-way drivers, etc. TrafficVision is a web-based user interface and was used in KC Scout for three years as a separate tool in incident detection. Using CMAQ funding, KC Scout spearheaded integrating TrafficVision's traffic monitoring technology into our existing Traffic Management System. Now when an incident is

detected, our TMC operators are instantly alerted via pop-up snapshot image through KC Scout's ATMS event receiver. Within one click the operator can create and manage the incident.

New Jersey

Cloud-Based Virtual Traffic Sensor Network With 511 CCTV Traffic Video Streams, Peter J. Jin, Yi Ge, Terry (Tianya) Zhang, Yizhou Wang and Jonathan Martinez, Center for Advanced Infrastructure and Transportation, August 2019.
https://cait.rutgers.edu/wp-content/uploads/2019/01/cait-utc-nc56-final.pdf
From the abstract: This project developed a cloud-computing platform for statewide traffic video data analytics. The platform will use the existing 511 CCTV traffic video streams to generate traffic flow and occupancy data to enrich the existing TRANSCOM data feed primarily containing travel time and event data.

A longitudinal scanline based algorithm is developed to detect vehicle trajectories with minimal computational cost. Special treatment modules including static noise removal, clustering removal, and strand detection methods are developed to address the occlusions and lane-changing problems in the NJ511 CCTV traffic videos. The algorithm is deployed in an Amazon Web Service (AWS) based platform for large-scale processing of the large number of video feeds. The research outcome includes traffic flow data matched with TRANSCOM TransFusion data links. The evaluation results indicate promising accuracy, computational efficiency and low cost of the proposed platform.

New York

Item: 683.10220008—Video Analytic HD IP Camera Assembly—Dome Type, Special Specifications, New York State Department of Transportation, April 2020.
https://www.dot.ny.gov/spec-repository-us/683.10220008.pdf
From the description: This specification shall consist of furnishing and installing HD IP [c]amera [a]ssemblies at the locations shown in the plans and as directed by the [e]ngineer. These [c]amera assemblies shall contain all of the accessories, cables, components, software/licenses and support documents described in the material specification and shall be configured as indicated on the contract documents.

The HD IP [c]amera [a]ssemblies shall have full HD 1080p30 image resolution with an integral 30x optical zoom lens. The camera operation shall include true day-night with variable speed pan and tilt technology with a minimum sensitivity of 0.025 lux @ 30 IRE. The HD IP [c]amera [a]ssemblies shall provide three or more independent output video streams configurable for H.264, H.265 and MJPEG outputs. The HD IP camera shall have video analytic capability that shall be demonstrated and tested prior to acceptance by the regional TMC.

"Analysis of Road User Behavior and Safety During New York City's Summer Streets Program," Mohamed Hussein, Bianca Popescu, Tarek Sayed and Lee Kim, *Transportation Research Record 2586*, pages 120-130, January 2016.
Citation at https://journals.sagepub.com/doi/abs/10.3141/2586-14
From the abstract: Automated computer vision video analysis techniques were used to analyze video data during the operation of New York City's Summer Streets Program at a major signalized intersection. The main objectives of this study were to diagnose pedestrian and cyclist safety issues during the shared space operation and to demonstrate the feasibility of the automatic extraction of road user data (e.g., pedestrian, runner, rollerblader or cyclist) required for microscopic behavior analysis. Road users' speeds and pedestrian gait parameters (step frequency and step length) were automatically extracted and analyzed.

Texas

Video Data Analytics for Safer and More Efficient Mobility, Natalia Ruiz Juri, U.S. Department of Transportation University Transportation Centers, October 2020.
https://ctr.utexas.edu/wp-content/uploads/151.pdf
From the abstract: In this project, the authors refined an approach to using data collected by the City of Austin's traffic monitoring cameras to automatically identify pedestrian activities on roadways. Their approach automatically analyzes the content of video data gathered by existing traffic cameras using a semi-automated processing pipeline powered by state-of-art computing hardware and algorithms. The method also extracts a background image at analyzed locations, which is used to visualize locations where pedestrians are present and display their trajectories. The authors illustrate the use of a scalable tool for the automated analysis of data collected from monocular traffic cameras that can allow agencies to leverage existing infrastructure in the analysis and mitigation of pedestrian safety concerns with two use cases.

Deep Learning Methods to Leverage Traffic Monitoring Cameras for Pedestrian Data Applications, Weijia Xu, Natalia Ruiz-Juri, Ruizhu Huang, Jennifer Duthie, Joel Meyer and John Clary, U.S. Department of Transportation University Transportation Centers, May 2019.
https://ctr.utexas.edu/wp-content/uploads/150.pdf
From the abstract: Transportation agencies often own extensive networks of monocular traffic cameras, which are typically used for traffic monitoring by officials and experts. While the information captured by these cameras can also be of great value in transportation planning and operations, such applications are less common due to the lack of scalable methods and tools for data processing and analysis. This paper exemplifies how the value of existing traffic camera networks can be augmented using the latest computing techniques. The authors use traffic cameras owned by the City of Austin to study pedestrian road use and identify potential safety concerns. The approach automatically analyzes the content of video data from existing traffic cameras using a semi-automated processing pipeline powered by the state-of-art computing hardware and algorithms. The method also extracts a background image at analyzed locations, which is used to visualize locations where pedestrians are present, and display their trajectories. The authors also propose quantitative metrics of pedestrian activity which may be used to prioritize the deployment of pedestrian safety solutions, or evaluate their performance.

Washington

"Video-Based Network-Wide Surrogate Safety Analysis to Support a Proactive Network Screening Using Connected Cameras: Case Study in the City of Bellevue (WA) United States," Lana Samara, Paul St-Aubin, Franz Loewenherz, Noah Budnick and Luis Miranda-Moreno, *TRB 100th Annual Meeting*, Paper #21-03654, January 2021.
Citation at https://trid.trb.org/view/1759595
From the abstract: Surrogate road safety approaches, as part of road improvement programs, have gained traction in recent years. Thanks to emerging technologies such as computer-vision and cloud-computing, surrogate methods allow for proactive scanning and detection of safety issues and address them before collisions and injuries occur. The objective of this paper is to propose an automated and continuous monitoring approach for road network screening using connected video cameras and a cloud-based computing analytics platform for large-scale video processing. Using the wide network of traffic cameras from cities, the proposed approach aims to leverage video footage to extract critical data road network screening (ranking and selection of dangerous locations). Using the City of Bellevue as an application environment, different safety metrics are automatically generated in the platform such as traffic exposure metrics, frequency of speeding events, and conflict rates. Using Bellevue's camera network, the proposed approach is demonstrated using a sample of 40 cameras and intersections. The results and platform provide a proactive tool that can constantly look for dangerous locations

and risk contributing factors. This paper provides the details of the proposed approach and the results of its implementation. Directions for future work are also discussed.

Related Resource:

> **Video Analytics Towards Vision Zero: Traffic Video Analytics,** Case Study Report, City of Bellevue, Washington, December 2019.
> https://bellevuewa.gov/sites/default/files/media/pdf_document/2020/Video%20Analytics%20Towards%20Vision%20Zero-Traffic%20Video%20Analytics-12262019.pdf
> *From the executive summary*: Traffic safety and traffic congestion represent one of the biggest problems in modern cities, and improving these is a major promise of smart cities of the future. Microsoft collaborated with the City of Bellevue to use video camera feeds for traffic video analytics. The partnership's vision was to use the widely deployed traffic camera feeds for traffic analytics on road users as opposed to traditional mechanical or manual approaches. A primary objective of the partnership was to evaluate if video analytics can produce accurate outputs on live video feeds to produce actionable insights to inform Vision Zero strategies. Bellevue is committed to implementing a Vision Zero Action Plan, with the goal of zero traffic deaths and serious injuries by 2030.
>
> The Microsoft team developed a video analytics platform that analyzed videos to produce directional counts of traffic users (vehicles, bicycles, etc.). The results were aggregated into a video analytics dashboard that was deployed at the City of Bellevue's Traffic Management Center from Jul[y] 2017 to Nov[ember] 2018, and produced live alerts on abnormal traffic volumes. The dashboard also helped Bellevue transportation planners understand traffic patterns over long periods of time. For example, it provided the perspective on vehicle and bicycle patterns, prior to and after construction of a dedicated bicycle lane on 108th Avenue. Finally, the video analytics system's insights on directional volumes and unusual traffic patterns provided an additional tool for real-time traffic operations in the Bellevue Traffic Management Center.

International Research

Australia

"Edge-Computing Video Analytics for Real-Time Traffic Monitoring in a Smart City," Johan Barthélemy, Nicolas Verstaevel, Hugh Forehead and Pascal Perez, *Sensors*, Vol. 19, No. 9, page 2048, May 2019.
https://www.mdpi.com/1424-8220/19/9/2048/htm
In this paper, the authors present a pilot project, using a smart visual sensor, in the Australian city of Liverpool, New South Wales. The purpose was to design and evaluate an edge-computing device using computer vision and deep neural networks for real-time tracking of multi-modal transportation. The sensor was evaluated using the town's CCTV live feeds. The authors introduce the interoperable Agnosticity framework designed to collect, store and access data from multiple sensors; and provide results from two real-world experiments.

"Automated Safety Evaluation of Intersections Using Advanced Video Recognition Technology," M. Haque, S. Washington, A. Arun, J. Bunker, T. Sayed and A.K. Debnath, *Proceedings of the 2018 Australasian Road Safety Conference,* October 2018.
Citation at https://trid.trb.org/view/1603342
From the abstract: The present study aims to assess the utility of advanced video recognition technology in assessing road safety at intersections. In particular, this study assessed [the] safety performance of three complex intersections in Brisbane by using safety surrogates automatically measured by an advanced video recognition technology. Traffic movement data on typical weekdays at the chosen intersections were video recorded. Conflict analysis was then performed by analyzing traffic interactions among vehicles, pedestrians and cyclists. In particular, Time-To-Collision (TTC) and Post Encroachment Time (PET) were used to identify frequency, severity and locations of the conflicts at each intersection. Subsequently, suitable countermeasures were identified to reduce these conflicts and improve safety at these intersections.

Canada

"Road Users' Behavior and Safety Analysis of Pedestrian–Bike Shared Space: Case Study of Robson Street in Vancouver," Mohamed Essa, Mohamed Hussein and Tarek Sayed, *Canadian Journal of Civil Engineering*, Vol. 45, No. 12, pages 1053-1064, December 2018.
Citation at https://cdnsciencepub.com/doi/abs/10.1139/cjce-2017-0683
From the abstract: This paper investigates the behavior and safety of road users at the pedestrian–bike shared space of Robson Street in Vancouver. The analysis was conducted using video data, collected during the summer of 2016. Automated video analysis techniques were used to detect different road users and extract their trajectories from video scenes. The extracted trajectories were used to evaluate the speed distributions of different categories of road users, and analyze the interactions (conflicts) between pedestrians and bikes to assess their safety. As well, the paper investigates the effect of introducing a bike dismount sign at both ends of the shared space on both the percentage of cyclists' compliance with the sign and the frequency of pedestrian–bike interactions. Finally, the relationship between the speed of both pedestrians and bikes and the density of the shared space was investigated to develop speed–density relationships in this shared space environment.

"Demonstrating the Viability of Automated Video Analysis for Mid-Block Traffic Data Collection: A Study in the City of Edmonton," Mohamed H. Zaki, Tarek Sayed and Shewkar E. Ibrahim, *TRB 96th Annual Meeting Compendium of Papers*, Paper #17-02117, 2017.
Citation at https://trid.trb.org/view/1437889
From the abstract: Streamlining traffic data collection is a main goal for cities seeking to improve safety and mobility on their roads. Traffic data collection can benefit greatly from the recent advances in automated video analysis. With the ability of accurate measurements and tracking vehicle coordinates, applications to collect reliable traffic flow are practically possible using computer vision. The aim of this paper is threefold. First, to improve the detection and tracking technology through fusion of computer vision approaches. This task is performed by complementary region based detection to the already established featured based tracking. As a result, a better estimation of the road-users position, size and travel information is now possible. Second, to demonstrate the technology in a new application to implement a vision based virtual traffic measurement system. With particular focus on vehicle classification, and the measurement of basic traffic parameters such as counting, speed, headway and gap time measurements. Third, to test and validate the new development on midblock road segments video data collected by the City of Edmonton Office of Traffic Safety (OTS). In demonstrating the application of video analysis for traffic data collection, this paper seeks to underline the

potential benefits which transportation agencies can derive from progressively adopting new technologies in performing everyday tasks.

"Large-Scale Automated Proactive Road Safety Analysis Using Video Data," Paul St-Aubin, Nicolas Saunier and Luis Miranda-Moreno, *Transportation Research Part C: Emerging Technologies*, Vol. 58, Part B, pages 363-379, September 2015.
Citation at https://www.sciencedirect.com/science/article/abs/pii/S0968090X15001485
From the abstract: This paper presents, in detail, a practical framework for implementation of an automated, high-resolution, video-based traffic-analysis system, particularly geared towards researchers for behavioural studies and road safety analysis, or practitioners for traffic flow model validation. This system collects large amounts of microscopic traffic flow data from ordinary traffic using CCTV and consumer-grade video cameras and provides the tools for conducting basic traffic flow analyses as well as more advanced, pro-active safety and behaviour studies. This paper demonstrates the process step-by-step, illustrated with examples, and applies the methodology to a case study of a large and detailed study of roundabouts (nearly 80,000 motor vehicles tracked up to 30 times per second driving through a roundabout).

In addition to providing a rich set of behavioural data about Time-to-Collision and gap times at nearly 40 roundabout weaving zones, some data validation is performed using the standard Measure of Tracking Accuracy with results in the 85[%]–95% range.

Germany

"Calculation of Error Rates for Detection of Critical Situations in Road Traffic," Andreas Leich, Andreas Kendziorra, Hagen Saul and Ragna Hoffmann, *TRB 95th Annual Meeting Compendium of Papers*, Paper #16-5861, 2016.
Citation at https://trid.trb.org/view/1394189
From the abstract: This article is a contribution to the development of methods for road safety analysis. A calculation scheme is derived for error rates of critical situations detected automatically using a roadside stationary detector. A situation is classified as critical, if the time to collision is below some threshold. Calculated error rates are provided on different experiments with camera based vehicle detectors. The experiments demonstrate the best case of measurement accuracy that can be achieved using state of the art automated video surveillance technology. In the experiments, the false positive rate is five and four times higher than the true positive rate. This finding leads to the conclusion that studies known from literature stating there is correlation between the number of near crashes and real crashes should be faced with skepticism as long as no reliable information on error rates is provided.

Japan

"SenseTime Shortlisted to Bring AI Into Japan's Expressway," Ma Si, *Chinadaily.com.cn*, March 2020.
https://global.chinadaily.com.cn/a/202003/27/WS5e7d6a27a31012821728278c.html
From the article: NEXCO Central Japan is a leading expressway company in Japan. Recent installation of CCTV cameras on its expressways aims to better manage and improve response times to different traffic situations.

Leveraging on its technology in deep learning and autonomous driving, SenseTime Japan, the company's Japanese unit, developed a traffic video analysis algorithm that is able to identify and track various types of vehicles over several lanes with high accuracy.

SenseTime said in a statement that such solutions also helped recognize the movements of the expressway workers and road debris, as well as detect traffic congestion and traffic incidents such as wrong-way driving, stranded vehicles, etc.

The algorithm has high robustness of object tracking under occlusions and the AI-empowered solution is not only cost-effective but also durable, reliable and widely adaptable to different environments. Importantly, there is no need to replace existing cameras or alter the camera angles, the company added.

"How Fujitsu is Using AI to Make Japan's Roads and Rivers Safer," Fujitsu Blog Editor, Fujitsu Blog, November 2019.
https://blog.global.fujitsu.com/fgb/2019-11-20/how-fujitsu-is-using-ai-to-make-japans-roads-and-rivers-safer/
From the blog post: The AI Detection System utilizes deep learning technology to train the AI using an extensive variety of images of vehicles as learning data, allowing it to automatically detect various different vehicles (such as passenger cars, trucks and buses) without being influenced by external environmental factors like weather or what time of day it is. Because the system works by switching between 20 standard camera units and one AI system, there's no need to set the processing range for each camera or to configure the angles of the range of scenes captured by the cameras. This makes detection possible without adjusting existing daily camera monitoring processes.

In addition, a variety of incidents such as stopped vehicles and traffic congestion [is] automatically detected and quickly notified to road monitoring operators, allowing them to take rapid initial measures to address traffic incidents. For example, if the position of a vehicle remains unchanged for a certain period, the AI recognizes that it's stopped. If there are more cars on the road than the preset threshold, it recognizes it as traffic congestion. By relaying this information to road monitoring operators using map displays and alert notifications, they can respond more quickly to the incident. In addition, footage of the events before and after detected incidents is stored in archives that can be used for determining causes, and formulating plans for future events.

Going forward, this technology will be capable of detecting abnormal driving, such as cars moving slower than other cars around them, cars moving against traffic, and cars ignoring traffic barriers placed on the road.

New Zealand

"Traffic Flow Estimation Based on Deep Learning for Emergency Traffic Management Using CCTV Images," Nilani Algiriyage, Emma E.H. Doyle, Raj Prasanna, Kristin Stock and David Johnston, *Proceedings of the 17th Information Systems for Crisis Response and Management* (*ISCRAM) Conference*, May 2020.
https://www.researchgate.net/profile/Nilani-Algiriyage/publication/342534949_Traffic_Flow_Estimation_based_on_Deep_Learning_for_Emergency_Traffic_Management_using_CCTV_Images/links/5efa60e145851550507df1d4/Traffic-Flow-Estimation-based-on-Deep-Learning-for-Emergency-Traffic-Management-using-CCTV-Images.pdf
From the abstract: This paper focuses on selecting an appropriate object detection model for identifying and counting vehicles from closed-circuit television (CCTV) images and then estimating traffic flow as the first step in a broader project. Therefore, a case is selected at one of the busiest roads in Christchurch, New Zealand. Two experiments were conducted in this research[:] 1) to evaluate the accuracy and speed of three famous object detection models[,]

namely[,] faster R-CNN, mask R-CNN and YOLOv3 for the data set, 2) to estimate the traffic flow by counting the number of vehicles in each of the four classes such as car, bus, truck and motorcycle. A simple Region of Interest (ROI) heuristic algorithm is used to classify vehicle movement direction such as "left-lane" and "right-lane." This paper presents the early results and discusses the next steps.

"Surveillance-Based Collision-Time Analysis of Road-Crossing Pedestrians," Zahra Moayed, Hsiang-Jen Chien, Derek Zhang and Reinhard Klette, *2019 IEEE Intelligent Transportation Systems Conference*, pages 2361-2366, October 2019.
Citation at https://ieeexplore.ieee.org/document/8917448
From the abstract: In recent years, traffic safety is the main focus of transport agencies in New Zealand. Due to expansions of cities, the extent of infrastructure-based recordings such as CCTVS grows rapidly. Computer vision can play a critical role in using the data and converting it into useful information. In this paper, we apply the latest deep learning technology to detect and classify traffic users including pedestrians and vehicles. The objects are tracked using a Kalman filter, considering the class with the highest probability in the defined estimation error. We calculate a transformation matrix to map recorded video into a top-down view and measure the speed. Associations between pedestrians and a closest approaching vehicle are considered to predict possible crash points. The elapsed time until pedestrians and vehicles reach a crash point is regarded as the risk time in this context. Obtained results can be used in various traffic safety analysis and decisions.

Related Resources

"Automated Video Processing for Pedestrian-Vehicle Conflict Analysis," Spencer Maddox, Colin Usher and Kari Watkins, *TRB 100th Annual Meeting,* Paper #21-01654, 2021.
Citation at https://trid.trb.org/View/1759908
From the abstract: Pedestrian fatalities have risen in the United States over the past decade. On an individual corridor, however, it is difficult to determine whether crashes and fatalities are statistically significant or random occurrences. When considering mitigation efforts, transportation planners and engineers therefore need to accurately categorize pedestrian exposure and risk. Traditionally, risk and exposure were calculated by performing manual counts. Advancements in automated video processing, where objects are tracked from a recorded video, can categorize conflicts automatically. Using outputs from a developed tracking system, this paper defines a successful methodology to identify conflicts and calculate the post-encroachment time. This methodology can be applied to both intersection and non-intersection locations. Results from four sample sites support previous research that mid-block crossings occur more often when crosswalks are not nearby and the relationship between pedestrians and conflicts are not necessarily linear. Using this conflict identification methodology and automated video processing provides transportation planners and engineers with a better understanding of pedestrian risk at key locations.

"A Novel Framework for Automated Monitoring and Analysis of High Density Pedestrian Flow," Muhammad Baqui, Manar D. Samad and Rainald Löhner, *Journal of Intelligent Transportation Systems*, Vol. 24, Issue 6, pages 585-597, November 2020.
Citation at https://trid.trb.org/view/1748366
From the abstract: Pedestrian traffic is an important subject of surveillance to ensure public safety and traffic management, which may benefit from intelligent and continuous analysis of pedestrian videos. State-of-the-art methods for intelligent pedestrian surveillance have a number of limitations in automating and deriving useful information of high-density pedestrian traffic (HDPT) using closed circuit television (CCTV) images. This work introduces an automatic and improved HDPT surveillance system by integrating and optimizing multiple

computational steps to predict pedestrian distribution from input video frames. A fast and efficient particle image velocimetry (PIV) technique is proposed to yield pedestrian velocities. A machine learning regressor model, boosted Ferns, is used to improve pedestrian count and density estimation: an essential metric for HDPT analysis. A camera perspective model is proposed to improve the speed and position estimates of HDPT by projecting 2D image pixels to 3D world-coordinate dat[a]. All these functional improvements in HDPT velocity and displacement estimations are used as inputs to a sophisticated pedestrian flow evolution model, PEDFLOW[,] to predict HDPT distribution at a future time point, which is crucial information for pedestrian traffic management. The predicted and simulated HDPT properties (density, velocity) obtained using the proposed framework show low errors when compared to the ground truth data. The proposed framework is computationally efficient, suitable for multiple camera feeds with HDPT videos, and capable of rapidly analyzing and predicting flows of thousands of pedestrians. The paper shows one of the first steps towards fully integrated CCTV-based automated HDPT management system[s].

Commercial Suppliers

Cited below are resources associated with domestic and international commercial suppliers of video analytic traffic management components:

Domestic

- Bosch Security Systems, LLC (Fairport, New York).
- CostarHD, LLC (San Diego, California).
- Derq Inc. (Detroit, Michigan, and Dubai, United Arab Emirates).
- Econolite (Anaheim, California).
- Omnibond Systems, LLC (TrafficVision) (Liberty, South Carolina).
- Pelco Corporations (Fresno, California).
- Street Simplified, LLC (Pasadena, California).
- WTI (Sidewinder/Viper) (Ventura, California).

International

- ai:Go Traffic Management Systems (Auckland, New Zealand).
- Axis Communications (Lund, Sweden).
- GoodVision Ltd. (London, United Kingdom).
- MicroTraffic Inc. (Winnipeg, Manitoba, Canada).
- Miovision Technologies Inc. (Kitchener, Ontario, Canada).

Domestic

Bosch Security Systems, LLC

Intelligent Transportation Systems (ITS), Bosch Security Systems, LLC, 2021.
https://www.boschsecurity.com/us/en/industries/intelligent-transportation-systems-its/
This vendor offers video analytics for traffic management including automatic incident detection, camera analytics and metadata to collect and aggregate data, and machine learning for customized solutions.

Automatic Incident Detection for Bridges and Tunnels: Improving Mobility and Safety With Analytics-Driven Video Solutions, Bosch Security Systems B.V., 2020.
https://media.boschsecurity.com/fs/media/pb/images/industries_2/transportation/app-note_automatic_incident_detection.pdf
From the fact sheet: Bosch Intelligent IP cameras deliver automatic incident detection enabling TMC operators to quickly react to events such as congestion, a stopped vehicle, or a wrong way driver. Automated incident alerts give operators an improved situational awareness to reduce disruption times, which is especially valuable for emergency response vehicles. At the same time, the cameras continuously record statistics to enable data-driven decision-making on safety improvements. Bosch IP cameras can also trigger third-party systems such as dynamic message signs, flashing beacons, and dedicated short-range communication (DSRC) for smart vehicles to ensure drivers are alerted to safety issues, congestion, or delays, enabling them to take action earlier.

CostarHD, LLC

Intelligent Traffic Solutions Available With ITS Video Analytics, CostarHD, LLC, 2021.
https://cohuhd.com/
From the web site: CostarHD designs and manufactures rugged HD CCTV video surveillance camera systems for critical infrastructure and transportation. Our video cameras monitor the most critical, sensitive environments such as border security and transportation, specifically traffic (ITS), maritime ports, airports, and railways.

Derq Inc.

Powering the Future of Roads for the Safe and Efficient Movement of Road Users and Autonomous Vehicles, Derq Inc., 2021.
http://en.derq.com/
From the web site:

> We provide cities and fleets with an award-winning and patented smart infrastructure [p]latform powered by AI that helps them tackle the most challenging road safety and traffic management problems.
>
> Derq's [p]latform ingests and fuses data from IoT [internet of things] traffic cameras and sensors then runs real-time edge analytics to enable infrastructure perception and V2X/5G applications as well as actionable safety and traffic insights.
>
> *Real-time advanced analytics*
> Proprietary and patented computer vision, machine learning and sensor fusion techniques. Enables highly accurate road user detection, classification and multi-sensor tracking with cutting-edge intent prediction capabilities.

Econolite

Centracs CCTV, Econolite, 2018.
https://www.econolite.com/products/software/centracs-cctv-module/
From the web site: Visually monitoring intersections and roadways is a strategic [a]dvanced [t]raffic [m]anagement [s]ystem [m]odule capability in today's [t]raffic [m]anagement [c]enters. Features such as camera presets, video tours, access prioritization, snapshots, and multicast video, combined with options to supply video feeds to agencies such as police, fire and media, make Centracs Advanced CCTV more than just a simple CCTV solution.

This option of the Centracs ATMS is an enterprise-class IP video surveillance solution, providing seamless management of digital video across IP networks. Video can be transmitted over existing wired and wireless IP networks, ranging from DSL (VDSL) and fiber. Analog cameras are supported through the use of IP video encoders. These various transmission options enable the user to control cameras placed in extremely remote locations, as well as those close by. Video quality and number of streams is a function of the quality and capacity of the communications network.

Omnibond Systems, LLC (TrafficVision)

Traffic Intelligence From Video: Patented Algorithms for Real Time Detection, Omnibond Systems, LLC, 2021.
http://www.trafficvision.com/
From the web site: TrafficVision software turns any traffic monitoring camera into an intelligent sensor. Specifically built for [i]ntelligent [t]ransportation [s]ystems (ITS), TrafficVision monitors digitally encoded video streams of traffic cameras on highways to immediately detect incidents and continuously collect real-time traffic data.

Using existing camera infrastructure, TrafficVision helps traffic managers make proactive decisions based on immediate incident alerts that are visually verifiable, providing more information about what is happening on highways, bridges and tunnels.

TrafficVision helps organizations get more use out of their ITS investment, leveraging both existing and new video assets. By providing the information needed to reduce the impact of incidents and recurring congestion on highways, TrafficVision helps traffic managers provide safer and more efficient travel for the public.

Pelco Corporations

Traffic Monitoring: Enterprise Security Systems and Surveillance Cameras for Traffic, Pelco Corporations, undated.
https://www.pelco.com/solutions/industries/traffic-monitoring/
Pelco provides video management system and intelligent analytics to monitor and manage traffic. VideoXpert integrates with third-party systems and provides incident management tools. Edge analytics are integrated into cameras and capture a variety of information. Panomersive cameras provide more coverage with fewer cameras.

Street Simplified, LLC

Safety Analytics, Street Simplified, LLC, undated.
https://www.streetsimplified.com/safety-analytics
From the web site:

Proactive safety analytics:

- We collect temporary, high resolution video.
- Process it with artificial intelligence on the cloud.
- And work with national safety experts to give you answers.

The data we collect and analyze:

- Near misses.
- Red light running.
- Speeding.

- Crossing off crosswalks.
- Crossing on opposing greens.
- Intersection blocking.

WTI (Sidewinder/Viper)

Welcome to Wireless Technology, Wireless Technology, Inc., 2021.
http://www.gotowti.com/index.asp
From the web site: WTI (Wireless Technology, Inc.) has over a 30 year history of providing innovative solutions, exceptional customer service and is respected worldwide as a [v]ideo [s]urveillance [s]ystems innovator and quality manufacturer. The company's products are installed in numerous locations worldwide.

Sidewinder/Viper: High Definition (HD), Wireless Technology, Inc., 2021.
http://www.gotowti.com/sidewinder/sidewinder_high.asp
From the web site: WTI's HD Sidewinder/Viper series allows your viewers to see high resolution broadcast video with a notably sharper, crisper and clearer picture, regardless of what type of television (HD or standard) they watch.

International

ai:Go Traffic Management Systems

"Traffic Analysis for the 21st Century," ai:Go Traffic Management Systems, 2021.
https://www.ai-go.nz/
From the web site: Utilizing state of the art machine learning technology with proprietary vehicle-tracking software, ai:Go analyzed traffic camera feeds to provide real-time, 24/7 traffic counts, vehicle classification and intersection analysis.

Axis Communications

The Road to Smarter Traffic Management, Axis Communications AB, 2021.
https://www.axis.com/en-us/solutions/solutions-by-industry/traffic
From the web site:

> *Managing traffic intelligently*
> Improve road safety and traffic flow with video-based traffic management solutions from Axis. Together with our partners, we help you visualize our entire road network—providing real-time insight that simplifies decision making and helps you get more from your existing infrastructure. With our intelligent traffic cameras and sensors as part of your advanced traffic management system (ATMS), you can better respond to situations as they occur, plan roadwork maintenance, and optimize long-term mobility.

AI in Video Analytics: Considerations for Analytics Based on Machine Learning and Deep Learning, Axis Communications AB, March 2021.
https://www.axis.com/files/whitepaper/wp_AI_in_video_analytics_en_2103.pdf
From the summary: Algorithm development and increasing processing power of cameras have made it possible to run advanced AI-based video analytics directly on the camera (edge based) instead of having to perform the computations on a server (server based). This enables better real-time functionality because the applications have immediate access to uncompressed video material. With dedicated hardware accelerators, such as MLPU (machine learning processing

unit) and DLPU (deep learning processing unit), in the cameras, edge-based analytics can be more power-efficiently implemented than with a CPU or GPU (graphics processing unit).

Before an AI-based video analytics application is installed, the manufacturer's recommendations based on known preconditions and limitations must be carefully studied and followed. Every surveillance installation is unique, and the application's performance should be evaluated at each site. If the quality is found to be lower than expected, investigations should be made on a holistic level, and not focus only on the analytics application itself. The performance of video analytics is dependent on many factors related to camera hardware, camera configuration, video quality, scene dynamics and illumination. In many cases, knowing the impact of these factors and optimizing them accordingly makes it possible to increase video analytics performance in the installation.

GoodVision Ltd.

Become the Fastest Traffic Data Supplier, GoodVision Ltd., 2021.
https://goodvisionlive.com/solutions/traffic-data-collection/
From the web site: With GoodVision you will obtain traffic data from your surveys in the most convenient way ever. You provide traffic videos and our software captures all the traffic activity in a blink. Counting traffic volumes and reporting it to your customers has never been easier. Let us help you save your precious time now!

- Perform traffic surveys within few hours.
- Compatible with your existing camera equipment.
- Share results to your customers on a click of a button.

GoodVision Video Insights: A Complex Platform for Every Traffic Data Analytical Task, GoodVision Ltd., 2021.
https://goodvisionlive.com/goodvision-video-insights/
From the web site: Join the community of our 3000+ satisfied users on 6 continents:

- Traffic data collection from video.
- Deep traffic data analyses.
- Video storage.
- Traffic project collaboration.

MicroTraffic Inc.

MicroTraffic Road Safety Video Analytics, MicroTraffic Inc., 2021.
https://www.microtraffic.com/about/
MicroTraffic offers core computer vision technology to analyze risk and incidents using existing CCTV or permanent cameras, or can assist with temporary camera installations.

Miovision Technologies Inc.

Video Detection: A Fresh Perspective on Detection, Miovision Technologies Inc., 2021.
https://miovision.com/solutions/video-detection/
From the web site: With easy-to-use tools and the world's best traffic AI, Miovision provides the next generation of video detection:

- *Reliable in all conditions*: Our detection actually "sees" the intersection, meaning if you can see a car in fog or rain, it can too.

- *Single 4k camera, easy installation*: One SmartView 360 camera is all you need to get a complete view of your intersection.
- *True video detection*: Miovision offers more reliable detection that unlocks brand-new analysis at the intersection.
- *Easily prove the impact of your detection solution*: TrafficLink provides far more than just detection, it generates analytics to help you quantify the impact.

Contacts

CTC contacted the people below to gather information for this investigation.

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Appendix A: Survey Questions

The following survey was distributed to members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Transportation System Operations.

Caltrans Survey on Automated Video Traffic Monitoring and Analysis

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Note: The response to the question below determined how a respondent was directed through the survey.

(Required) Has your agency implemented, tested or planned to test the use of **video analytics software** to provide real-time traffic incident detection or to perform other functions, such as providing vehicle classification and volume data?

- Yes (Directed the respondent to **Use of Automated Video Traffic Monitoring and Analysis.**)
- No (Directed the respondent to **Wrap-Up.**)

Use of Automated Video Traffic Monitoring and Analysis

1. Please describe how your agency is using video analytics software to provide real-time traffic monitoring or perform other functions. What **use cases or applications** has your agency implemented, tested, or planned to test? Select all that apply.

   <u>Monitoring Traffic and Detecting Incidents</u>
   - Traffic crashes
   - Stopped vehicles in a lane or on the shoulder
   - Near misses/potential conflicts involving vehicle, bicycle or pedestrian movements
   - Traffic speed
   - Wrong-way drivers
   - Red-light violations
   - Illegal turning movements
   - Jaywalking
   - Debris or object in roadway
   - Visibility

   <u>Compiling Vehicle Classification and Volume Data</u>
   - Vehicle counts
   - Vehicle classification
   - Turning movement counts
   - Bicycle/pedestrian counts
   - On-ramp/off-ramp counts

   <u>Other Applications</u>
   - Signal pre-emption for emergency vehicles
   - Other (Please describe.)
2. Which **cameras and/or video analytics software** have you used for any of the use cases listed above? Please list the devices/systems (vendors and product names) that you:
   Have used or tested:
   Are planning to test:

3. Has your agency integrated or considered integrating new video analytics software with your agency's existing traffic cameras?
    - Yes (Please respond to **Question 4**.)
    - No (Please click "**Next**" to move to the next set of questions.)
4. Please describe the **existing camera network** involved in the integration.
    Camera type(s) (vendor/model):
    Current age(s) of cameras:
    Other details of existing camera network:

Video Analytics System Description

In the questions below, please describe your agency's experience with implementing, testing or planning to test video analytics software for automated traffic monitoring or other applications. *If your agency has tested multiple products, please describe the product that you have **implemented most widely** or that has **most effectively met your needs**.*

1. System details:
    Product/system and vendor name:
    Date(s) installed or tested:
    Cost (indicate up-front costs and any recurring/subscription fees):
2. For what purposes or use cases is your agency using this product? Are you considering expanding your implementation to other use cases?
3. In this installation or test, how many camera feeds is the system processing?
4. Where does the video processing occur?
    - On board the camera
    - On another local device (edge computing)
    - On a server at a traffic management center (TMC) (centralized computing)
    - On a cloud-based server
    - Other (Please describe.)
5. What type of communications network is used to transmit data and/or video from field locations to the TMC?
    - Fiber optic cable
    - Copper phone lines
    - Wireless network
    - Cellular links
    - Other (Please describe.)
6. What type of video encoding and decoding equipment do you use?
7. Where on the network is the encoding/decoding equipment located?
8. Is your video monitoring system integrated with your freeway management system software?
    - No
    - Yes (Please describe.)

System Performance

1. What network data rates are required by the video analytics system?
2. Is your network speed sufficient?
    - Yes
    - No. There are latency issues. (Please describe.)

3. Have you noticed any difference in performance under different weather or lighting conditions?
    - No
    - Yes (Please describe.)
4. Have you had any difficulty defining detection zones that are the appropriate shape and size for various roadway geometries?
    - No
    - Yes (Please describe.)
5. Which camera types do you use? Select all that apply.
    - Pan-tilt-zoom (PTZ) cameras
    - Fixed-view cameras
    - Other (Please describe.)
6. If you use PTZ cameras, have you had any issues with defined detection zones not aligning with lanes when the camera is returned to the preset view (i.e., preset creep)?
    - Not applicable
    - No
    - Yes (Please describe.)
7. How well has this system met your needs?
    - 1 — Not at all well
    - 2 — Slightly well
    - 3 — Somewhat well
    - 4 — Very well
    - 5 — Extremely well
8. Please describe your overall experience with implementing or testing this system (successes, challenges, solutions, lessons learned).

Other Products/Systems

If you have tested or installed additional products or systems for automated video traffic monitoring and analysis, please use this space to describe your experience with those systems.

Recording and Archiving Video

1. Do you record and archive video from traffic cameras, red-light cameras or similar systems?
    - No
    - Yes (Please describe.)
2. If you record and archive video, do you take any precautions regarding privacy issues?
    - Not applicable
    - No
    - Yes (Please describe.)
3. Do you have any protocols or procedures in place to extract and provide copies of video clips upon public request under the Freedom of Information Act and corresponding state laws?
    - No
    - Yes (Please describe.)

Successes, Challenges and Lessons Learned

For the questions below, please consider your experience with **all products and systems** for automated video traffic monitoring that you have implemented, tested or plan to test.

1. In your experience, are there any products or approaches that work best with either edge-based or cloud-based video processing? Please describe the pros and cons you have encountered.
2. Are there any products or systems that are particularly effective for multiple use cases (for example, both traffic monitoring and signal preemption)?
3. Which product(s) or approaches have most effectively met your agency's needs?
4. If available, please provide links to documentation related to your agency's use of automated video traffic monitoring systems, including research reports or white papers. Please send any files not publicly available online to andrea.thomas@ctcandassociates.com.

Wrap-Up

Please use this space to provide any comments or additional information about your previous responses.