

Automated Video Incident Detection Systems

Requested by

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Quick verification of incidents on major freeways is critical to provide rapid incident response and avoid congestion, with studies showing that for every seven minutes of delay in verification there is one additional mile of queue in the system. Currently Caltrans transportation management centers (TMCs) use closed-circuit television (CCTV) cameras to verify incidents. However, no automated methodology is in place for detecting incidents. Operators currently use these cameras to verify incidents only after they have been reported through other channels. This passive process leads to delays in incident verification.

Caltrans is interested in technologies that will allow CCTV cameras to automatically detect abrupt changes in traffic conditions on the freeway in real time and alert TMC operators visually by depicting the traffic condition on the TMC monitors automatically. With this approach, operators can instantly detect and verify incidents in real time without undue delay.

Before implementing these technologies, Caltrans needs information about the deployment of such systems in other states and countries. This Preliminary Investigation presents the results of a literature search identifying existing research and other documentation about how other states and countries are using automated video incident detection systems. Caltrans was particularly interested in:

- Minimum requirements for implementation of these systems, including optimal placement.
- Types of cameras and systems used by other states.
- Preferences for using commercial software versus writing original code for camera operation.
- Camera system requirements, specifically, whether the video must be recorded for detection to work.
- Ability and requirements of camera system operation at night.

Summary of Findings

Consultation with DOTs and Vendors

We successfully contacted six departments of transportation and two vendors concerning automated video incident detection (we also attempted unsuccessfully to reach the District of Columbia, Florida, and Hawaii). Of the state DOTs contacted, only Massachusetts told us they are currently using automated video incident detection (although New Mexico is conducting limited testing and Virginia will deploy systems in an upcoming project). Note that Citilog indicated that Maryland and New York are using Citilog systems in their tunnels. CTC will provide the relevant contact information for Maryland and New York customers once it is provided by Citilog. Citilog also indicated it is working on installations in a California tunnel.

Massachusetts is willing to share technical documentation for its detection system and documentation related to its evaluation of other detection systems but because of security concerns they will only share the information directly with Caltrans. Contact Tony Wade (see **Contacts**) for more information.

Citilog and Traficon provided (or will provide in the near future):

- General product information, video clips and images.
- System minimum requirements, technical documentation, case studies, performance data and test reports.
- Contact lists for state and European transportation agencies using their products.

Related Research

We gathered information in three topic areas:

- Installation and Efficacy.
- Incident Detection System and Algorithm Development.
- Research in Progress.

Following is a summary of findings by topic area.

Installation and Efficacy

Studies show mixed results about the accuracy of automated video incident detection systems.

- The results of one study presented at a 2008 conference shows 85 percent accuracy for these systems.
- A 2007 California study illustrates the significant number of false alarms generated by such systems, and a 2006 journal article reports on poor performance because of low maturity of the technology, complex algorithms due to the provision of extensive functionality, and suboptimal camera location and height for image processing.
- A 2005 conference paper about a Caltrans study found an automatic incident detection system on the San-Mateo bridge to be efficient in detecting accidents and incidents, and not significantly affected by adverse weather conditions. A 2005 report by the Virginia Transportation Research Council similarly found a system to be effective.
- A 2004 study by the University of Utah Traffic Lab compares several vendors, finding Traficon to be the most accurate at 96 percent. Systems performed well under day and dusk conditions and during inclement weather conditions.

- A 2000 USDOT scan found that it was not widely used by states at that time because of false alarms.

Camera Location and Height

- The same University of Utah Traffic Lab study suggests that the ideal camera location is on the mast arm of the signal pole, and that cameras should be mounted as high as possible—40 to 50 feet and 20 feet at minimum.
- A 2012 report by the University of North Texas concludes that the “height of the camera should be sufficient so that the camera captures a high angle view such that the vertical occlusion is minimized,” and includes illustrations of poor and reasonable camera angles. A height of 40 to 60 feet is ideal.
- A 2008 journal article similarly notes that “cameras should be placed as high as possible and in the middle of the detection zone,” and if this is not possible, they should be placed near the fastest lane to avoid occlusion.

Incident Detection System and Algorithm Development

Several studies discuss the challenges of developing automated incident detection systems, including algorithms that minimize false alarms.

- A 2012 TRB Annual Meeting paper shows that use of automated incident detection in nationwide traffic management centers is limited because of the high rates of false alarms and calibration complexity.
- A 2008 conference paper similarly shows that these systems have not been widely deployed in England because of “false alert rates which have added unnecessarily to the workload of control room operators,” and looks for solutions to overcome these problems.
- A 2010 Institute of Electrical and Electronics Engineers (IEEE) conference paper shows that good performance can be obtained for video-based incident detection of wrong-way drivers, still standing vehicles and traffic jams.
- A 2008 IEEE paper reviews the challenges of false alarms because of glare, snow, rain and shadows.
- Other studies evaluate various algorithms for automated incident detection.

Research in Progress

- We found one project in progress at the University of Maryland that is evaluating the use of high-definition video for traffic monitoring and analysis. This study includes “the development of real-time ‘event’ detection algorithms specially tailored to our unique combination of HD image capture, wireless transport, and real-time processing.”

Gaps in Findings

Based on the available literature, it is unclear how widely used automatic incident detection systems are among states or how effective these systems are, including at night and in inclement weather. We found little information in the literature on post-implementation evaluations or comparisons of off-the-shelf software (although we were able to find some information about optimum camera placement and height).

We were able to find only one state DOT (Massachusetts) that indicates it uses automated video incident detection and were unsuccessful in attempts to reach the DOTs in the District of Columbia, Florida, and Hawaii. What information we did find on system minimum requirements comes (or is forthcoming) from vendors and from Massachusetts DOT, which will provide information upon direct request from Caltrans.

Next Steps

CTC is currently awaiting several documents from Citilog and Traficon, including contact information for their transportation agency customers, and will forward them to Caltrans upon receipt. Caltrans might consider:

- Following up in a few months with Virginia DOT, which is currently conducting a project to implement automated video incident detection.
- Making further contacts based on information provided by Citilog and Traficon. We expect these contacts will be able to provide further information about minimum system requirements and accuracy.
- Contacting the District of Columbia, Florida, and Hawaii concerning their possible use of automated video incident detection.

Contacts

Departments of Transportation

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Note: The results of discussions with the DOT representatives above were provided separately to Caltrans staff.

Automated Video Incident Detection Vendors

Citilog

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Trafficon

Steve Brown
Chief Technical Officer, CT West Inc. (Trafficon affiliate).
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Consultation with Vendors

Citilog

Contact: Bruce Winner, Business Development - North America , (407) 595-2339 (mobile), bwinner@citilog.com.

Citilog video incident detection products have been used on more than 700 projects worldwide, including in Florida, Massachusetts, New York, and Maryland tunnels (note that this claim is not supported by information from New York and Maryland interviewees, possibly because authorities other than DOTs control tunnels in these states). Citilog also says it is working on installations in a California tunnel. Citilog software is typically installed in transportation management centers, and analytics are performed real time to recognize stopped vehicles and those that are traveling in the wrong direction. Its software can tap into existing TMC camera systems, and can be used with any brand of camera, whether fixed or pan-and-zoom – it works by analyzing the video stream. Analysis doesn't require recording, although that is an option. Performance varies depending on camera placement and how far cameras are apart (so that the best performance is achieved in tunnels with overhead camera installations 300 to 400 feet apart with overlapping views and so 100 percent coverage). In general, the higher the cameras are placed the better – on regular roadways, 45 feet high and to the side of the road is typical. Accuracy rates can be well above 95 percent for stopped vehicles on regular roadways, although false alarms are an issue, especially at night (although systems can track headlights and taillights at night). Accuracy for debris detection is generally around 80 percent. Again in tunnels accuracy is higher – Citilog recently achieved 99.9 percent accuracy with 0 percent false alarms for a tunnel in France (cameras were placed 200 feet apart and Citilog assisted tunnel designers in camera positioning).

Citilog agreed to provide:

- General product information, video clips and images (see below).
- System minimum requirements, technical documentation, case studies, performance data, and test reports (see below; other documents are forthcoming pending approval).
- Contact information for state and European transportation agencies using its products (forthcoming pending approval).

Citilog provided the following documents, which were sent separately to Caltrans due to size:

- MediaTunnel Technical Description: Provides an overview of one of Citilog's software packages.
- MediaTunnel MediaRoad Technical Description Recommendations: This document gives an overview of the technical details of image processing, types of alarms, performance data, and traffic data collection.
- MediaRoad VisioPad – Camera layout Recommendation: This document reviews the technical details of camera position and layout, some basic video rules to follow, FOV, and images of good and poor FOVs.
- Citilog sept10 – Architecture.ppt: This PowerPoint presentation provides an overview of a number of different configurations that systems can have based on type of video signal and communications systems available.
- Transport Roads & Maritime Services Report from Australia on Citilog's MediaTunnel: This report gives details on product performance.

Citilog provided the following video clips of Citilog in action on open roadways and in tunnels, which were provided separately to Caltrans due to size and file type:

- C90_CITIOLOG_27072011_063258_StopB.avi
- Nantes1.avi

Images of Citilog in action include:

- Snow Ramp 1 – Car on entry ramp in slick conditions.
- Snow Ramp 2 – Car starts to lose control.
- Snow Ramp 3 – Car is stuck in snow and alarm noted to TMC.
- Snow Ramp 4 – Possible help coming via another motorist.
- Snow Ramp 5 – No luck, tries to dig out by himself.
- Stopped Car Tunnel 1 – Car stops in tunnel.
- Stopped Car Tunnel 2 – Stopped car alarm sent to TMC and driver gets out of car.
- Stopped Car Tunnel 3 – Just in time as another car rear-ends stopped car.
- Stopped Car Tunnel 4 – Driver watches collision.
- Stopped Car Tunnel 5 – Other car continues on.
- Entrance 1 – Car on entry ramp loses control.
- Entrance 2 – Crosses lanes into lane of moving car.
- Entrance 3 – Collision between two cars.
- Entrance 4 – Car flips onto side.
- Entrance 5 – Both cars continue to move down highway.
- Entrance 6 – Cars stopped and alarm sent to TMC.

Traficon

Contact: Steve Brown, Chief Technical Officer, CT West Inc. (Traficon affiliate), (951) 691-1385, (719) 210-4682 (mobile), steveb@ct-west.com.

Traficon agreed to provide:

- General product information (provided separately to Caltrans).
- System minimum requirements, technical documentation, case studies, performance data, and test reports (forthcoming).
- Contact lists for state and European transportation agencies using its products (forthcoming).

The interviewee noted that Traficon offers a thermal camera for nighttime operation (and said that Caltrans District 11 has already purchased some of these cameras). CTC will forward remaining information once it is provided by Traficon.

Related Research

Installation and Efficacy

“Improving Road and Tunnel Safety Via Incident Management: Implementing a Video Image Processing System,” Jo Versavel, Ilse Roelants, *Proceedings of the ITA-AITES Second International Symposium*, 2006.

<http://www.ita-aites.org/fileadmin/filemounts/general/pdf/ItaAssociation/Committees/COSUF/Roelants.pdf>

This report gives a general overview of the:

- Basic functions of incident management, including traffic monitoring, incident detection and verification, driver information and incident clearing.
- Automatic incident detection.
- The crucial factors for effective incident management: fast detection and verification.
- Other video image processing functions, including queue monitoring, road works monitoring, inverse direction, fallen objects, pedestrians, fire and smoke, and stopping vehicles or left objects.
- Important considerations, such as detection rate, false detections, false detection cost and reliability.

It concludes that it is “now possible to have fully automatic video based incident detection covering both the main road and the hard shoulder.”

“Efficacy of Video Incident Detection System for Advanced Traffic Management Under Non-Adherence of Lane Discipline,” K. Ravinder, S. Velmurugan, S. Gangopadhyay, Central Road Research Institute, *Proceedings of the 15th World Congress on Intelligent Transport Systems and ITS America’s 2008 Annual Meeting*, 2008.

<http://intranet.imet.gr/portals/0/usefuldocuments/documents/03267.pdf>

Citation at <http://trid.trb.org/view.aspx?id=901922>

From the abstract: This paper reports on a study of the effectiveness of a video incident detection system (VIDS) used for advanced traffic management in India. The authors note that India is characterized by traffic conditions where there is non-adherence to lane discipline. In this study, video image processing using Citilog software was applied on one urban section for traffic incident detection and measurement of traffic parameters like traffic flow. The main function of the media video processing system is the automatic incident detection and the recording of video sequences showing the different phases of an accident from its causes to its consequences. In addition, the system is able to provide the operator with various types of traffic easements and the system diagnostic indicators, including alarms upon detection of a vehicle stopped on traffic lane in fluid traffic conditions, a vehicle stopped on traffic lane in congested traffic conditions, general slow down on traffic lanes, a slow-moving vehicle, a fast-moving vehicle, or a vehicle traveling against the flow of traffic. The authors discuss the equipment needed, the set-up and installation parameters, and the reliability of the VIDS (including the frequency of false alarms). They found an accuracy level of up to 85% in the field tests. The authors support the use of Intelligent Transportation Systems (ITS) as an option for innovative and cost effective solutions for achieving maximum capacity out of the existing highway facilities, thereby enhance traffic safety. They conclude that VIDS can be successfully implemented under Indian traffic conditions where there is non-adherence of lane discipline for advanced traffic management system.

“Image Recognition and Incident Detection—A Progress Report,” *Proceedings of the 15th World Congress on Intelligent Transport Systems and ITS America’s 2008 Annual Meeting*, 2008.

Citation at <http://trid.trb.org/view/2008/C/902801>

From the abstract: This paper introduces the work that Transport for London (TfL) has been doing in the field of image processing and video analytics. TfL has been evaluating the technology and the market to determine the suitability of using such systems in a dense urban environment such as London. The authors discuss digital video compatibility, “Smart Camera” deployment, and the development of a test library for systems evaluation. They describe the deployment of a small scale congestion detection system linked to the London Traffic Control Centre (LTCC), extending their monitoring capability. Testing was carried out on the following criteria: congestion, stopped vehicles, banned turns, vehicle counting, subway monitoring, and bus detection. The findings of this pilot deployment results in the recommendation to take two products forward for further testing/evaluation in the next stage for the purpose of traffic counting. Concentrating solely on two devices should also allow further optimizing of detection capability to deliver improved results. Both of these smart cameras performed best for traffic counting; in one case, the complexity of the detection configurations shows considerable potential for numerous applications.

“Accelerated Incident Detection and Verification: A Benefit to Cost Analysis of Traffic Cameras,” *Journal of Intelligent Transportation Systems*, Vol. 11, Issue 4, 2007: 191-203.

Citation at <http://trid.trb.org/view/2007/C/840587>

From the abstract: Traffic incidents are a major contributor to congestion on US freeways, resulting in millions of dollars in property damage and significant deaths and injuries each year. Because a single incident can cause traffic delays, equally devastating secondary incidents can result. Thus, the faster an incident is detected, verified, and cleared, the less significant the impact. Traffic cameras and other technologies are widely used for this purpose. This work examined the effectiveness of traffic cameras at five metropolitan freeway sites in South Carolina using the traffic simulation software PARAMICS to simulate various incident scenarios and traffic camera operations through application programming interfaces. The authors used these interfaces to produce random spatial and temporal occurrence of incidents, including the incident start times, durations and locations. A benefit-cost analysis based on the simulation results suggested traffic cameras returned \$12 for every dollar spent under the prevailing conditions at the study sites. A sensitivity study, varying different benefit- and cost-related parameters, such as deployment costs, number of incidents, and discount rate, revealed benefit-cost values that were always above one.

Innovative Transportation Products and Services: Final Report, California Center for Innovative Transportation, CCIT Research Report #UCB-ITS-CWP-2007-1, 2007.

<http://www.its.berkeley.edu/publications/UCB/2007/CWP/UCB-ITS-CWP-2007-1.pdf>

This report is a compilation of three reports, including “Evaluation of an Incident Detection Camera Network in the San Francisco Bay Area.” In this project, cameras from two systems (Citilog and Econolite) were used to detect vehicles on Bay Area freeways; data was collected for two months. Both Citilog and Econolite cameras are mounted on the top of a tower on northbound I-880. Each system had a high number of alarms that were either false or due to nonincidents such as congestion, rain and water reflection. While Citilog detected far more incident alarms (54) than Econolite (17), Citilog also detected more false alarms (9) compared with Econolite (4). For Citilog, one out of every seven incident alarms was a false alarm, and for Econolite, approximately one out of every five was a false alarm.

“Video Incident Detection Tests in Freeway Tunnels,” P. Prevedouros, X. Ji, K. Papandreou, P. Kopelias, V. Vegiri, *Transportation Research Record 1959*, 2006: 130-139.

Citation at <http://144.171.11.39/view.aspx?id=776527>

http://media.wix.com/ugd/4af4c9_e40fcdd544a6311f40c86d58efa6e231.pdf?dn=10.3.15.pdf

From the abstract: European regulations for the management of roadway tunnels became much more stringent after the 1999 Mount Blanc inferno. Several video image processing (VIP) devices for traffic surveillance have automated incident detection (AID) capabilities. Autoscope, Citilog, and Traficon were invited to make installations for testing their VIPs with eight preexisting cameras in Attica Tollway tunnels. The suppliers of the competing devices were responsible for setting and calibrating the devices for best results. No literature was found in which VIPs developed in 2000 or later were evaluated for incident detection. A 3,013-incident database was used to derive the detection rate and false-alarm rate for each device for the whole database, separately for each closed-circuit television camera, and by type of incident. Changes in detection performance after each manufacturer’s intervention were evaluated. T-tests were conducted on the significance of effects of low, medium, and high volume in weekday and weekend traffic, and natural or artificial lighting. A separate analysis was conducted for incidents that were artificially generated by Attica Tollway engineers and staff at off-peak times. The results show promise, but the evaluated performance was poor because of three reasons: low maturity of the technology, complex algorithms due to the provision of extensive functionality, and suboptimal camera location and height for image processing, but VIP devices must adapt to tunnel limitations.

“Under Observation: This Automated Incident Detection System is on the Pulse,” Tim Giles, *Traffic Technology International*, August/September 2006: 114-115.

<http://security.nice.com/ArticlesInterviews/Documents/Under%20Observation%20-%20North%20Texas%20Tollway%20Authority.pdf>

Citation at <http://trid.trb.org/view.aspx?id=793073>

From the abstract: This article describes the North Texas Transportation Authority’s (NTTA) sophisticated video surveillance system, which keeps track of the region’s 1.2 million customers and 54 miles of tollway. The system combines high-performance digital video recording and advanced video analytics to automate event detection as much as possible. The NTTA command center, as augmented by this system, responds to approximately 200 traffic accidents weekly, all but 1 percent of them detected using video surveillance. The system also works in conjunction with NTTA’s dynamic message signs (DMS), which display traffic-related information such as commuting times and warnings as to accidents ahead on the roadway. This surveillance project, because of its success, will be expanded in 2007 to include 400 cameras to cover new areas of the NTTA toll system.

“Highway Data Collection & Incident Management: Implementing a Video Image Processing System,” Jo Versavel, *Proceedings of the 12th World Congress on Intelligent Transport Systems*, 2005.

Citation at <http://trid.trb.org/view/2005/C/771639>

From the abstract: This paper discusses the wide range of capabilities and some of the limitations of video image processing for highway incident detection as Traficon has experienced it over the past 20 years. Two main items are focused: nowadays video detection has proven to be a very reliable incident management tool. This ITS technology is the fastest system to detect incidents. Next to incident management, this paper will also focus on traffic data collection via Video Image Processing (VIP). A definition is given of traffic data quality and some new insights will demonstrate that video detection, when it is used correctly, offers great potential for highway data acquisition. A detailed case study of the highway incident detection and traffic data collection project in Atlanta will serve as an illustration.

“Video-Based Automatic Incident Detection on San-Mateo Bridge in the San Francisco Bay Area,” Thomas Wells, Eric Toffin, *Proceedings of the 12th World Congress on Intelligent Transport Systems*, Paper #1213, 2005.

<http://www.citilog.fr/pdfs/ITS%20world%20congress%202005%20paper%201213%20Citilog%20-%20MTC%20-%20nov05.pdf>

Caltrans tested an active video surveillance system by Citilog that assists traffic operators in identifying and quickly responding to road incidents:

The system uses algorithms capable of learning traffic patterns and for that reason does not require any set-up or calibration. Thus this system is usable on any field of view as opposed to a pre-determined field of view as for conventional video detection systems. The image processing algorithm analyses movement within the frame and automatically spots any stopped trajectory in the image. (page 3)

Results (page 10) show that:

- The system proves to be efficient in detecting accidents or incidents on traffic lanes, but also vehicles pulled-over on the shoulder.
- The low frequency of unwanted alarms is key to an efficient deployment of the system.
- The system is relatively insensitive to traffic conditions. It shows the same efficiency to detect isolated stopped vehicles in fluid, stop and go or congested traffic.
- The system is insensitive to time of day and weather conditions. In several cases the system has detected stopped vehicles at night at great distances. It is not significantly affected by adverse weather conditions such as rain, clouds or shadows.

Phase III Autotrack: Integrated CCTV/VIVDS Prototype Field Test: System Refinement and Development of Shoulder Detection, Virginia Transportation Research Council, September 2005.

http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-cr2.pdf

The purpose of this project was to develop and test a prototype system that adds the automatic detection of shoulder incidents to Virginia DOT’s current system of CCTV systems, which required manual operators. Researchers found that this integrated system (called CCTV/VIVDS or Phase III Autotrack) is feasible and beneficial, and can be used to effectively identify shoulder events (stopped or slow moving vehicles) under clear weather conditions as well as rainy conditions, if provisions are made to clear away drops from the camera lens.

Page 6 includes a diagram of the system design. Field tests show a 100 percent detection rate for stopped vehicles and almost no false alarms except in a thunderstorm. The system was also effective at detecting slow moving vehicles in good weather (page 12).

Evaluation of UDOT’s Video Detection Systems: System’s Performance in Various Test Conditions, P. Martin, G. Dharmavaram, A. Stevanovic, University of Utah Traffic Lab, December 2004.

<http://www.mountain-plains.org/pubs/pdf/MPC04-166.pdf>

This study evaluated four video detection systems—Traficon, Autoscope, Iteris and Peek—at eight locations in Utah. Traficon performed well in all the test conditions with 96.4 percent correct detection, followed by Autoscope (92.0 percent) and Iteris (85.2 percent). Peek generated the lowest percentage of correct detection with 75.8 percent under all test conditions. Systems performed well under day and dusk conditions, with 87.2 percent correct detection for both conditions. The night condition recorded a correct detection of 73.4 percent, with 19.9 percent false calls. Video detection in inclement weather generated 81.3 percent correct detection and 14.1 percent false calls. Missed detection under all conditions ranged from 4.6 percent to 6.8 percent. Overall, video detection generated 83 percent correct calls and 17 percent discrepant calls.

The report includes principles for setting up such systems, including (page 5):

- The ideal camera location is on the mast arm of the signal pole.
- Cameras should be mounted as high as possible, ideally 40 to 50 feet. UDOT recommends a minimum camera placement of 20 ft., because dirt, spray and mist could collect on the camera lens at lower heights.

Incident Management Successful Practices: A Cross-Cutting Study, USDOT Intelligent Transportation Systems, April 2000.

http://ntl.bts.gov/lib/jpodocs/repts_te/11484.pdf

A scan of states concludes that automated incident detection is not widely used because of false alarm rates and system data requirements (page 16).

Camera Positioning

Low Cost Wireless Network Camera Sensors for Traffic Monitoring, University of North Texas, July 2012.

<http://d3koy9tzykv199.cloudfront.net/static/0-6432-1.pdf>

This project tested an autonomous traffic monitoring system for Texas DOT, Abacus from Iteris. Table 16 on page 153-157 gives an overview of products, and page 158 contains baseline requirements. Page 159 shows correct camera perspective:

The height of the camera should be sufficient so that the camera captures a high angle view such that the vertical occlusion is minimized. Moreover, the horizontal distance from the camera to the road surface, Δx , should be reasonable so that horizontal occlusion is also minimized. In Figure 48, both poor and reasonable camera perspectives from different viewing angles are illustrated.

After testing in various weather conditions and at night, researchers conclude (page 190):

- Precise calibration and operator-controlled camera movement are competitive goals. Camera calibration is computationally expensive. Also, even if “self-calibrating,” the software will not operate properly without some input from the operator. (Perhaps this function is in place to ascertain whether the result is reasonable.) If the camera is moved by a human operator, the calibration process must be repeated.
- Specialized expertise is required for development. The development of a [video analytics (VA)] system for traffic monitoring requires knowledge of image processing, computer vision, projective geometry pattern recognition and artificial intelligence.
- If bandwidth is not an issue, placing VA processing at the [Traffic Management Center (TMC)] is as effective as placing it in the field. The input to the VA system is video. The quality of the video is important. If good quality video is available at the TMC (and it generally is), then the system operation is equal to a road-side installation. Furthermore, the costs of housing, weather hardening and field maintenance is less.
- Camera placement (perspective) is crucial. Near or over the roadway at a height of 40 to 60 feet is ideal. The farther the camera is from the road, the greater becomes the problem of occlusion. Vehicle counts become less accurate. The height of the camera affects the perceived size of the vehicles and ultimately makes calibration more difficult.
- It would be cost-effective for TxDOT to develop and deploy its own freeway oriented VA system. Admittedly, this conclusion is dependent on the number of installations that are anticipated. Not counting maintenance in the years following installation, the breakeven point likely occurs with approximately 12 installations.

“Tunnel Talk: 10 Steps to Success in Implementing AID,” S. Vandebuerie, S. Collins, P. Van Houtteghem, *Traffic Technology International*, 2008 Annual Edition: 130-133.

http://www.traficon.com/mediastorage/FSMLDocument/1727/en/art_tti_tunneltalk_dec07.pdf

Citation at <http://144.171.11.39/view.aspx?id=859623>

From the abstract: This article reviews some of the key concerns to be addressed when implementing an automatic incident detection (AID) system for road tunnels. Understanding the goal of the AID system is key. Mainly, it is there to reduce the time between an incident occurring and response to the incident, given the dangers unique to tunnels that can make a simple incident much more dangerous than it would be in the conventional road environment. Video detection, when used in the correct way for the operating conditions, can provide superlative AID. This means that all parties should work together when a system is designed: the video detection supplier, the system integrator, and the end customer. The size of the AID system will dictate the scope of time required for installation and fine-tuning. A high-quality input source is key in order to generate images that are accurate and easy to use. Issues to consider are camera placement, field of view, and redundancy. Installation and cabling are critical to having a highly functional system. Finally, the staff who will be using the system need training to take full advantage of its capabilities and to ensure that it is operating at peak efficiency and usefulness. After-warranty maintenance is another concern that should be addressed in the initial planning.

From page 3 of the article:

Camera position: In general, cameras should be placed as high as possible and in the middle of the detection zone. If this is not possible, placement near the fastest lane is preferred to avoid occlusion (i.e. slow-moving trucks masking other vehicles on adjacent lanes). In tunnels with an average height of around 4.5m, cameras can only be mounted at a limited height. To obtain good quality images, the camera is best placed over the center of the road, with a large inclination.

Freeway Network Traffic Detection and Monitoring Incidents, University of Minnesota Center for Transportation Studies, October 2007.

Citation at: <http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1506>

From the abstract: We propose methods to distinguish between moving cast shadows and moving foreground objects in video sequences. Shadow detection is an important part of any surveillance system as it makes object shape recovery possible, as well as improves accuracy of other statistics collection systems. As most such systems assume video frames without shadows, shadows must be dealt with beforehand. We propose a multi-level shadow identification scheme that is generally applicable without restrictions on the number of light sources, illumination conditions, surface orientations, and object sizes. In the first level, we use a background segmentation technique to identify foreground regions that include moving shadows. In the second step, pixel-based decisions are made by comparing the current frame with the background model to distinguish between shadows and actual foreground. In the third step, this result improved using blob-level reasoning that works on geometric constraints of identified shadow and foreground blobs. Results on various sequences under different illumination conditions show the success of the proposed approach. Second, we propose methods for physical placement of cameras in a site so as to make the most of the number of cameras available.

Chapter 5, page 18, provides a discussion of the positioning of cameras:

The ratio between the amount of information that can be collected by a camera and its cost is very high, which enables their use in almost every surveillance or inspection task. For instance, it is likely that there are hundreds to thousands of cameras in airport or highway settings. These cameras provide a vast amount of information which is not feasible for a group of human operators to simultaneously monitor and evaluate effectively or efficiently. Computer vision algorithms and software have to be developed to help the operators achieve their tasks. The

effectiveness of these algorithms and software is heavily dependent upon a “good” view of the situation. A “good” view in turn is dependent upon the physical placement of the camera as well as the physical characteristics of the camera. Thus, it is advantageous to dedicate computational effort to determining optimal viewpoints and camera configurations.

In order to obtain better views, cameras can be mounted on moving platforms for data collection purposes. A system that would tell the moving platform where to place itself in order to collect the most information will enhance their usefulness. The same algorithms can be used in more restricted settings to identify positions and camera parameters for placement on pre-existing structures.

Our work is focused on the problem of task-specific camera placement, where we attempt to determine how to place cameras relative to vehicle/pedestrian trajectories, in particular highway data collection, in order to provide the maximal amount of information regarding these activities (motion recognition, measurements, etc.) with the minimal number of cameras. This work is an extension of Robert Bodor’s work on optimal camera placement for automated surveillance tasks.

From page 36:

Results about the camera placement experiments coincide with the “intuitive” camera placement we would use to observe vehicles at highways or other traffic sites. Thus these results are promising in a way that our approach seems to provide us with good camera placements.

Incident Detection System and Algorithm Development

“Towards Training-Free Automatic Freeway Incident Detection: A Simple, Single-Parameter Algorithm,” M. Castro-Neto, L. Han, Y. Jeong, M. Jeong, *TRB 91st Annual Meeting Compendium of Papers DVD*, Paper #12-1695, 2012.

Citation at: <http://trid.trb.org/view/2012/C/1129389>

From the abstract: Freeway automatic incident detection (AID) has been extensively investigated over the last four decades. Various algorithms, covering a broad range of types in terms of complexity, data requirements, and efficiency have been published in the literature. However, a recent nationwide survey concluded that the implementation of AID algorithms in traffic management centers is still very limited. The main reasons for this discrepancy are high rates of false alarm and calibration complexity. The main objective of this research was to develop a simple, transferable algorithm that may dispense training on a pre-existing dataset. The dynamic thresholds of the proposed algorithm are based on historical data of traffic, thus accounting for typical variations of traffic throughout the day. Therefore, this approach is able to recognize recurrent congestion, thus reducing the incidence of false alarms. In addition, the proposed method requires no human-intervention, which certainly encourages its implementation. The presented model was evaluated in a newly developed incident database, which contained forty incidents. The model performed better than existing algorithms found in the literature.

“A Review of Computer Vision Techniques for the Analysis of Urban Traffic,” *IEEE Transactions on Intelligent Transportation Systems*, Vol. 12, Issue 3, 2011: 920-939.

Citation at <http://trid.trb.org/view/2011/C/1123114>

From the abstract: Automatic video analysis from urban surveillance cameras is a fast-emerging field based on computer vision techniques. We present here a comprehensive review of the state-of-the-art computer vision for traffic video with a critical analysis and an outlook to future research directions. This field is of increasing relevance for intelligent transport systems (ITSs). The decreasing hardware cost and, therefore, the increasing deployment of cameras have opened a wide application field for video analytics. Several monitoring objectives such as congestion, traffic rule violation, and vehicle interaction can be

targeted using cameras that were typically originally installed for human operators. Systems for the detection and classification of vehicles on highways have successfully been using classical visual surveillance techniques such as background estimation and motion tracking for some time. The urban domain is more challenging with respect to traffic density, lower camera angles that lead to a high degree of occlusion, and the variety of road users. Methods from object categorization and 3-D modeling have inspired more advanced techniques to tackle these challenges. There is no commonly used data set or benchmark challenge, which makes the direct comparison of the proposed algorithms difficult. In addition, evaluation under challenging weather conditions (e.g., rain, fog, and darkness) would be desirable but is rarely performed. Future work should be directed toward robust combined detectors and classifiers for all road users, with a focus on realistic conditions during evaluation.

“Video Based Highway Monitoring,” N. Verstraete, *Proceedings of the 17th ITS World Congress*, Paper #01324706, 2010.

Citation at <http://trid.trb.org/view/2010/C/1127409>

From the abstract: In this paper, the author discusses a general system using video detection modules for traffic monitoring and incident detection on highways, together with some of the underlying detection principles. Video detection is not limited to a single spot on the road, but it can analyse the traffic situation over a large area, and thus better and faster detect any anomalies in the traffic situation. When useful it is also possible to send over images of abnormal traffic to the operator and this only when needed, thus relieving the traffic operator from watching several monitors on a permanent base. Video detection is an excellent way to provide the correct traffic information for a reactive as well as a pro-active traffic management.

“Multimodal Highway Monitoring for Robust Incident Detection,” *Proceedings of the 13th International IEEE Conference*, 2010: 837-842.

http://userver.ftw.at/~pucher/papers/2010_pucher_multimodal-highway-monitoring-for-robust-incident-detection_itsc2010.pdf

From the abstract: We present detection and tracking methods for highway monitoring based on video and audio sensors, and the combination of these two modalities. We evaluate the performance of the different systems on realistic data sets that have been recorded on Austrian highways. It is shown that we can achieve a very good performance for video-based incident detection of wrong-way drivers, still standing vehicles, and traffic jams. Algorithms for simultaneous vehicle and driving direction detection using microphone arrays were evaluated and also showed a good performance on these tasks. Robust tracking in case of difficult weather conditions is achieved through multimodal sensor fusion of video and audio sensors.

Video Traffic Analysis for Abnormal Event Detection, Northwestern University Center for the Commercialization of Innovative Transportation Technology, 2010.

http://www.transportation.northwestern.edu/docs/research/Katsaggelos_videtrafficanalysis.pdf

From page 1:

We propose the use of video imaging sensors for the detection and classification of abnormal events to be used primarily for mitigation of traffic congestion. Successful detection of such events will allow for new road guidelines; for rapid deployment of various transportation and safety agencies; and for interactive displays that alert drivers to, for example, slow down or speed up, move to a different lane, or, alter their driving behavior, so as to reduce the probability of traffic congestion or the occurrence of more abnormal events. Deciding on additional road guidelines or proper display information can be accomplished either via computer simulations or experimentation with field implementations. We extended in-house developed algorithms to detect and track vehicles in video sequences and analyze their trajectories. Through analysis we will classify their trajectories independently but also considering vehicle interactions, into

abnormal and normal events. A main objective of the analysis is to determine how each type of abnormal event affects subsequent traffic, and serves as a predictor of congestion build up. Towards this task we will identify each type of abnormal event by implementing a supervised classifier, and built models to describe them and their effect (over time).

In this report, the authors explain their results according to the following project phases:

- Phase 1(a): Collected video data from various sources.
- Phase 1(b): Implemented a vehicle tracking algorithm.
- Phase 2: Trajectory analysis and classification into abnormal and normal categories.

“Automatic Freeway Incident Detection Based on Fundamental Diagrams of Traffic Flow,”

Transportation Research Record 2099, 2009: 65-75.

Citation at <http://trid.trb.org/view/2009/C/882242>

From the abstract: Algorithms for automatic incident detection (AID) detect traffic incidents on the basis of traffic flow measurements. There are two important steps in an AID algorithm: traffic flow feature generation and incident decision making. In the past decade, the research on freeway AID algorithms has been focused on using artificial intelligence to optimize the decision making of AID algorithms. In this paper, the primary focus is on finding a new set of variables for the feature generation. The new variables, uncongested and congested regime shifts (URS and CRS), are generated by conducting coordinate transformation on loop-detected flow and occupancy measurements. A novel AID algorithm, the fundamental diagrams-based automatic incident detection (FD AID) algorithm, is then developed by implementing the incident-related traffic flow knowledge using those variables. Preliminary results show superior performance of the FD algorithm compared with legacy algorithms.

“Development of an Automatic Traffic Conflict Detection System Based on Image Tracking Technology,”

Transportation Research Record 2129, 2009: 45-54.

Citation at <http://trid.trb.org/view/2009/C/881346>

From the abstract: Increasing reliance on surveillance has emphasized the need for better vehicle detection, such as with wide-area detectors. Traffic information from vehicle trajectories can be especially useful because it measures spatial information rather than single-point information. Additional information from vehicle trajectories could lead to improved incident detection, both by identifying stopped vehicles within the camera’s field of view and by tracking detailed vehicle movement trajectories. In this research, a vehicle image processing system was developed by using a vehicle tracking algorithm, and a traffic conflict technology was applied to the tracking system. To overcome the limitations of the existing traffic conflict technology, this study developed a traffic conflict technology that considers the severity of different types of conflict. To apply this method, video images were collected from intersections at Jungja and Naejung in Sungnam City, South Korea. The image processing approach adopted in this research was based on the use of a single camera installed at the corner of a street to detect vehicles approaching an intersection from all directions, and they were analyzed with the traffic information extracted from the image tracking system. To verify the tracking system, three categories were tested: traffic volume and speed accuracy, vehicle trajectory tracking, and traffic conflict.

“Traffic Monitoring Using Video-Based Vehicle Tracking,”

J. van Huis, J. Baan, A. van Loon,
Proceedings of the 16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services, 2009.

Citation at <http://trid.trb.org/view/2009/C/908579>

From the abstract: Traffic management measures aim for improvement of passive and active safety and reduction of congestion and emissions. Therefore knowledge on road vehicle behavior and traffic flows is required. In this paper we present a system that monitors road traffic using cameras alongside the road. The system is able to classify and track vehicles over 100 meters using a single camera with high accuracy on different types of roads in different types of weather. By combining multiple cameras individual vehicles are tracked over more than one kilometer. From the trajectories information about

individual vehicles, vehicle interactions and traffic flow is extracted. This data can then be used for traffic management research questions. The ambition for the future is to optimize the system for real-time usage in cooperative driving application, incident detection, real-time traffic information, active safety applications and infra-to-vehicle communication.

“Video-Based Automatic Incident Detection for Smart Roads: The Outdoor Environmental Challenges Regarding False Alarms,” *IEEE Transactions on Intelligent Transportation Systems*, Vol. 9, Issue 2, M. Shehata, J. Cai, W. Badawy, T. Burr, M. Pervez, R. Johannesson, A. Radmanesh, June 2008: 349-360.

Citation at <http://trid.trb.org/view/2008/C/863064>

From the abstract: This paper discusses by way of a literature review various means of video-based automatic incident detection (AID) as applied to Intelligent Transportation Systems (ITS). While video-based AID is a useful approach, environmental contingencies such as glare, snow, rain, and shadows can affect such a system’s efficacy in detection accuracy. Hue saturation value (HSV) is one approach to color space for video information to detect shadows. Another such method discussed is the normalization of color space. Both methods are found to require contingent thresholds that are affected by environmental conditions. It was found that there are no snow detection methods in the literature for AID and so their efficacy could not be evaluated. Rain detection was only found for applications in midair rain rather than rain-on-road. Midair rain can be detected via temporal averaging algorithms. Glare detection, it was found, is a well-researched topic with edge detection between regions being an effective means of analysis. The most promising areas of research are presented.

“Improving Incident Detection for Regional Control Centre Operator Support,” David Thomas, Martin Brock, Edwin Carter, Frances Metcalfe, Liz Orme, *Proceedings of the 15th World Congress on Intelligent Transport Systems and ITS America’s 2008 Annual Meeting*, 2008.

Citation at <http://trid.trb.org/view/2008/C/902815>

From the abstract: This paper presents a new approach to Automated Incident Detection (AID) Systems for traffic management based on processing Closed-Circuit Television (CCTV) images. The authors note that these systems have not been widely deployed in England, primarily because of the false alert rates which have added unnecessarily to the workload of control room operators. The authors propose three components to improve the quality of the AID systems: probabilistic methods can be used to achieve improved incident detection by combining a number of data sources, including CCTV images and inductive loops; historic data on likely congestion and incident locations are incorporated when assessing alerts for their relevance to operators; and the resulting alerts are presented to control room operators in a minimally intrusive fashion. The authors describe an initial implementation based on this approach that is currently being developed for evaluation in the Highways Agency’s West Midlands Regional Control Centre. Preliminary results confirm that while installing a commercial CCTV AID system on existing Pan-Tilt-Zoom (PTZ) cameras can result in a high false alert rate, careful system design can deliver benefits that overcome the problems.

“Improved Design for Vision-Based Incident Detection in Transportation Systems Using Real-Time View Transformations,” *Journal of Transportation Engineering*, Vol. 132, Issue 11, November 2006: 837-844.

Citation at <http://trid.trb.org/view/2006/C/794230>

From the abstract: This work examines the feasibility of providing transformed visual input to existing machine-vision based systems, in order to gain increased efficiency and cost effectiveness of integrated transportation systems. Two transformations are developed, homography-based transformation and panoramic image reprojection. Homography-based transformation operates on video of the road scene, provided by classical cameras, and seeks to transform any view to a top-down view. This transforms the three-dimensional problem of image analysis for, e.g., road event detection to a two-dimensional one. Panoramic image reprojection employs panoramic cameras to reduce required hardware, and the complexity and cost incurred in obtaining the desired road view. The image reprojection technique allows

the reconstruction of undistorted, perspective correct views from panoramic images in real time. Tests at sites in Spain, the United Kingdom, and Greece are performed on-line and off-line in combination with operating machine-vision based incident detection systems. Test results indicate that the two methods simplify the input provided to machine vision, and reduce the workload and amount of hardware in implementing complex machine-vision based systems for incident detection. Both modules can be integrated into incident detection systems to improve their overall efficiency and ease of application.

“Full-Scene Image Detection for Mixed Traffic Flow,” S. Liguang, S. Qixin, C. Jinxin, *Research into Practice: 22nd ARRB Conference Proceedings*, 2006.

Citation at <http://trid.trb.org/view/2006/C/795642>

From the abstract: The purpose of this paper is to present the research on background model and shadow detection of video and image detection. Video/Image Detection is modern and effective for the detection of traffic flow because it can be easily installed and integrates both surveillance and detection. The Mixed Traffic flow exists in so many developing countries that emphasize the importance of relevant information collection methods. The Extended Running Average algorithm for obtaining and updating representation of the background scene is proposed and compared with a background model based on Kernel Density Estimation and Three-parameter Background Model in efficiency. A shadow model is proposed, considering the significant impact of the moving object’s shadow to detection efficiency. After analyzing samples which were captured from real traffic scenes, in several color spaces such as RGB and HSV, the utility of proposed method is demonstrated through experiments on several scenes. Through the analysis of the characteristics of mixed traffic flow and available methods on Video/Image Detection, a full-scene image detection framework based on Background subtraction is proposed.

“Video-Based Automated Identification of Freeway Shoulder Events,” Yi Qi, Yin Tang, Brian L. Smith, *Transportation Research Record 1972*, 2006: 46-53.

Citation at <http://trid.trb.org/view/2006/C/776338>

Summary (page 46): <http://www.mtkn.org/products/trd/2007/TRD09-2007.pdf>

From the abstract: The purpose of this research effort was to build on an existing prototype of an integrated CCTV–VIVDS system to provide automatic shoulder event identification functionality. This paper presents the design of the integrated system, provides details on the tools and effort required to support integration of the information technology elements, and describes the results of field testing of the system.

“Comparison and Analysis Tool for Automatic Incident Detection,” Roger Browne, Simon Foo, Shawn Huynh, Baher Abdulhai, Fred Hall, *Transportation Research Record 1925*, 2005: 58-65.

Citation at <http://trid.trb.org/view/2005/C/775962>

From the abstract: A new test bed for automatic incident detection (AID) systems uses real-time traffic video and data feeds from the Ontario, Canada, Ministry of Transportation COMPASS advanced traffic management system. This new test bed, called the AID comparison and analysis tool (AID CAAT), consists largely of a data warehouse storing a significant amount of traffic video, the corresponding traffic data, and an accurate log of incident start and end times. Also presented is a proof-of-concept field evaluation whereby the AID CAAT is used to calibrate and then analyze the performance of three AID algorithms: California Algorithm 8, the McMaster algorithm, and the genetic adaptive incident detection algorithm. In the calibration and testing process, nuisance rate and false normal rate are introduced as two new performance measures to supplement the three traditional measures (detection rate, false alarm rate, and mean time to detection). Further, the pilot evaluation shows the considerable advantages of AID CAAT in its ability to investigate the impact of freeway geometry, traffic flow rate, and traffic sensor spacing on the performance of the three AID algorithms. This work represents the first stage in a series of further tests to develop a set of AID algorithm deployment guidelines.

“Enhancement of Automatic Incident Detection Algorithms for Singapore’s Central Expressway,”

C. Mak, H. Fan, *Transportation Research Record* 1923, 2005: 144-152.

Citation at <http://trid.trb.org/view/2005/C/775160>

From the abstract: Timely detection of accidents, vehicle breakdowns, and events that obstruct normal traffic flow is critical to successful implementation of an incident management system in combating traffic congestion along expressways. The purpose of this study is to enhance the performance of existing expressway automatic incident detection algorithms in detecting lane-blocking incidents. In this study, a video-based vehicle detector system was used along the Central Expressway (CTE) in Singapore to collect 160 incidents. Two main tasks were carried out with the CTE incident database to investigate factors that influence incident detection performance and to investigate the use of these findings to enhance existing CTE-calibrated incident detection algorithms. Results indicated that the inclusion of preincident traffic flow or occupancy conditions and the use of traffic speed together with occupancy in an algorithm would yield enhanced detection performance. Of the algorithms studied, the dual variable algorithm, which uses traffic speed and occupancy, can consistently give the best detection performance. From an efficiency perspective, there were no significant changes in time lag in the detection of an incident. A comparative evaluation suggested that the occupancy-based algorithms were generally more effective than the flow-based algorithms in detecting incidents.

Research in Progress

A Proof-of-Concept and Demonstration of a High Definition, Digital Video Surveillance and Wireless Transmission System for Traffic Monitoring and Analysis, University of Maryland Center for Integrated Transportation Systems Management, start date: March 2009.

Citation at <http://rip.trb.org/browse/dproject.asp?n=21269>

From the description: In this applied research project, the authors plan to conduct a proof-of-concept and demonstration of a high definition (HD), digital video surveillance and wireless transmission system for traffic monitoring and analysis, enabled by rapidly deployable, RF directional wireless links. This system will also provide improved capabilities to emergency responders. The demonstration will consist of HD cameras networked through a 4-node directional wireless network on the University of Maryland campus, and will include the development of real-time “event” detection algorithms specially tailored to our unique combination of HD image capture, wireless transport, and real-time processing. This project will lead to a greater understanding of video technology and image analysis requirements for HD traffic analysis with rapidly deployable advanced wireless systems. It will further allow analysis of gaps between current practice and capability vis-à-vis our HD, high capacity, and deployable wireless image transport system.