Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 06-CR2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Phase III AUTOTRACK: Integrated CCTV/VIVDS Prototype Field Test: System Refinement and Development of Shoulder Detection		5. Report Date September 2005
		6. Performing Organization Code
7. Author(s) Brian L. Smith, Yi Qi, and Yin Tang		8. Performing Organization Report No. VTRC 06-CR2
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 74017
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	FHWA 400 North 8th Street, Room 750 Richmond, VA 23239	13. Type of Report and Period Covered Final Report: August 2004-August 2005
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Virginia Department of Transportation (VDOT) has invested in extensive closed circuit television (CCTV) systems to monitor freeways in urban areas. Generally, these devices are installed as part of freeway management systems (Smart Traffic Centers, STCs). While CCTVs have proven to be very effective in supporting incident management, they simply provide images that must be interpreted by trained operators. Recent studies completed by the University of Virginia (UVA) and the Virginia Transportation Research Council (VTRC) concluded, however, that it is feasible to integrate CCTV with video image vehicle detection systems (VIVDS), which are currently on the market, to provide the ability to measure traffic conditions. Given this positive result, it is advantageous to pursue other data collection applications of an integrated CCTV/VIVDS.

The purpose of this project was to develop and field test a prototype CCTV/VIVDS integrated system (referred to as Phase III Autotrack) that adds the functionality of shoulder detection to the existing traffic data collection capabilities of the previous prototype (Phase II Autotrack). Shoulder detection allows STC operators to improve the safety and efficiency of the freeway system by rapidly responding to vehicles stopped or stalled on shoulders.

Based on the results of this research, the following conclusions may be drawn concerning the feasibility of the new safety/security functionality of integrated CCTV/VIVDS systems:

- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under clear weather conditions.
- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under rainy conditions, if provisions are made to clear away drops from the camera lens.

The Autotrack research program has proven that CCTV/VIVDS integration is feasible and beneficial. Benefits include the following:

- Reduction in the number of devices installed in the field (and requiring maintenance) to support transportation management.
- Reduction of the workload on operators in STCs by automating security scanning.
- Increase in the safety and security of the traveling public by allowing for more comprehensive monitoring of shoulders.
- Stimulation of CCTV/VIVDS commercial product development.

17 Key Words Transportation management systems, Intelligent transportation systems	18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 20	22. Price

FINAL CONTRACT REPORT

PHASE III AUTOTRACK:
INTEGRATED CCTV/VIVDS PROTOTYPE FIELD TEST:
SYSTEM REFINEMENT AND DEVELOPMENT OF SHOULDER DETECTION

Brian L. Smith, Ph.D.
Associate Professor

Yi Qi, Ph.D.
Research Associate

Yin Tang
Graduate Research Assistant

Department of Civil Engineering
University of Virginia

Project Managers
Catherine C. McGhee, Virginia Transportation Research Council
Michael A. Perfater, Virginia Transportation Research Council

Contract Research Sponsored by
the Virginia Transportation Research Council

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

September 2005
VTRC 06-CR2

NOTICE

ABSTRACT

The Virginia Department of Transportation (VDOT) has invested in extensive closed circuit television (CCTV) systems to monitor freeways in urban areas. Generally, these devices are installed as part of freeway management systems (Smart Traffic Centers, STCs). While CCTVs have proven to be very effective in supporting incident management, they simply provide images that must be interpreted by trained operators. Recent studies completed by the University of Virginia (UVA) and the Virginia Transportation Research Council (VTRC) concluded, however, that it is feasible to integrate CCTV with video image vehicle detection systems (VIVDS), which are currently on the market, to provide the ability to measure traffic conditions. Given this positive result, it is advantageous to pursue other data collection applications of an integrated CCTV/VIVDS.

The purpose of this project was to develop and field test a prototype CCTV/VIVDS integrated system (referred to as Phase III Autotrack) that adds the functionality of shoulder detection to the existing traffic data collection capabilities of the previous prototype (Phase II Autotrack). Shoulder detection allows STC operators to improve the safety and efficiency of the freeway system by rapidly responding to vehicles stopped or stalled on shoulders.

Based on the results of this research, the following conclusions may be drawn concerning the feasibility of the new safety/security functionality of integrated CCTV/VIVDS systems:

- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under clear weather conditions.
- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under rainy conditions, if provisions are made to clear away drops from the camera lens.

In its entirety, the Autotrack research program has proven that CCTV/VIVDS integration is feasible and beneficial. Benefits include the following:

- Reduction in the number of devices installed in the field (and requiring maintenance) to support transportation management.
- Reduction of the workload on operators in STCs by automating security scanning.
- Increase in the safety and security of the traveling public by allowing for more comprehensive monitoring of shoulders.
- Stimulation of CCTV/VIVDS commercial product development.

FINAL CONTRACT REPORT

PHASE III AUTOTRACK:
INTEGRATED CCTV/VIVDS PROTOTYPE FIELD TEST:
SYSTEM REFINEMENT AND DEVELOPMENT OF SHOULDER DETECTION

Brian L. Smith, Ph.D.
Associate Professor

Yi Qi, Ph.D.
Research Associate

Yin Tang
Graduate Research Assistant

Department of Civil Engineering
University of Virginia

INTRODUCTION

In recent years, in response to growing congestion, safety, and security challenges, transportation agencies have aggressively deployed information technology to improve surface transportation operations. These deployments, ranging from advanced computer-controlled traffic signal systems, to automatic, wireless toll collection systems, to sophisticated traffic monitoring systems, have generally been classified as "intelligent transportation systems" (ITS). As with other applications of information technology in transportation, ITS has been utilized in cases where more traditional approaches (such as adding capacity and using static signing) have proven to be insufficient to meet the growing challenges.

One element of ITS that has proven very popular is the use of CCTV systems to assist in traffic monitoring. The state of the practice is for operators to use moveable (i.e., operator controllable in pan/tilt/zoom) CCTV cameras to visually assess conditions. Given the popularity of these cameras, agencies have rapidly deployed more, particularly in urban areas. VDOT has deployed over 300 cameras statewide, primarily in urban areas and heavily traveled freeway corridors. Unfortunately, as CCTV systems expand, they require a significant personnel investment to allow sufficient capability to manually monitor the imagery. This has led to the desire to develop additional information technology to automate scanning of digital video to identify anomalies in traffic and/or measure certain traffic parameters (volume of traffic, average speed, density, etc.). Such technology exists in off-the-shelf products, generally referred to as VIVDS; however, its effective application requires that the camera be immovable, thus hampering one of the key advantages of CCTV.

Based on this problem, UVA's Center for Transportation Studies and VTRC developed a prototype system that integrates CCTV and VIVDS, allowing for traffic data collection from moveable CCTV cameras. This system, referred to as Autotrack, is fully described in previously published VTRC reports (Smith, Namkoong, and Tanikella, 2004; Smith and Pack, 2002). While working with VDOT field personnel on the prototype system, it became clear that an application of growing importance for CCTV is safety/security. Operators scan video imagery to identify slow or stationary objects outside of travel lanes for the following reasons:

- Travelers stalled or stopped on shoulders pose a safety risk. It is important to alert motorists to their presence using arrow boards or other appropriate devices.
- Travelers stalled or stopped on shoulders reduce effective system capacity. It has been proven that vehicles on the shoulder results in rubbernecking and, as a result, reduction in effective capacity. This is particularly important during high demand peak periods.
- Vehicles or objects on a shoulder may represent a security risk. As transportation agencies seek to improve the security of the transportation network, it is important to identify potential terrorist devices (for example, car bombs) that may be positioned in dangerous locations (such as beneath major bridges/overpasses).

Thus, it is desirable to design and evaluate an extension to the prototype Autotrack system that provides automated identification of objects of interest on freeway shoulders. This report presents the findings of the project designed to meet this need. In particular, it describes the design and development of the new safety/security functionality of the integrated CCTV/VIVDS prototype (referred to as Phase III Autotrack) and the results of an evaluation of the system at VDOT's Hampton Roads Smart Traffic Center (HRSTC).

PURPOSE AND SCOPE

The purpose of this project was to develop and field test a prototype CCTV/VIVDS integrated system (referred to as Phase III Autotrack) that adds the functionality of shoulder detection to the existing traffic data collection capabilities of the previous prototype (Phase II Autotrack). Based on the experience in the prototype development and testing, the project allows for VDOT to assess the feasibility of using moveable CCTV cameras for data collection and shoulder detection functions. The scope of the project is limited to freeway applications, using CCTV from the Hampton Roads Smart Traffic Center.

METHODS

In order to meet the objectives of this research, the following tasks were completed.

1. *Literature Review*. A review of the literature was conducted to provide a foundation for the research. Literature related to the previously conducted Phase I and Phase II Autotrack studies for VTRC was examined in order to better integrate the new functionality into the existing prototype system (Smith, Namkoong, and Tanikella, 2004; Smith and Pack, 2002). A review of the state of the practice in VIVDS was also conducted.

2. *Design Phase III Autotrack.* Based on an analysis of the Phase II Autotrack prototype, as well as site visits to HRSTC and discussions with HRSTC staff, requirements for the new safety/security functionality necessary to create Phase III Autotrack were generated. A system design was then developed, which considered the identified requirements and the existing functionality provided by the components of the system (namely CCTV and VIVDS).

3. *Development of Phase III Autotrack.* Once the Phase III Autotrack system was designed, the research team focused on developing algorithms that the system would utilize to identify shoulder events. Two algorithms, referred to as the stop-only algorithm and the slow-moving algorithm, were developed for this purpose.

    - Stop-only algorithm: detects a vehicle or other large object that has stopped on shoulders of the freeway.
    - Slow-moving algorithm: detects a vehicle or other large object that is moving slowly on shoulders of the freeway.

4. *Phase III Autotrack Field Deployment and Evaluation.* In order to fully evaluate the prototype system under field conditions, the Phase III Autotrack system was integrated with an existing CCTV camera in the HRSTC. Camera #47 is located on I-264 at Lynnhaven-Laskin. At this location, Camera #47 monitors the westbound four travel lanes and the shoulder.

    To evaluate the system, HRSTC's Freeway Incident Response Team (FIRT) vehicles slowed down and stopped on the shoulder at the test site at random times, over a one and a half month period. Since the stop times were documented, the team could determine whether the Phase III Autotrack system identified the event. This was used to create two performance measures, detection rate and false alarm rate, to consider in the evaluation.

RESULTS

Task 1: Literature Review: VIVDS State of the Practice

Literature concerning CCTV, VIVDS, and integrated CCTV/VIVDS systems was reviewed for this project. The literature related to CCTV, VIVDS, and integrated CCTV/VIVDS is well described in previous articles (Smith and Pack, 2002; Smith, Namkoong, and Tenikella, 2004). Therefore, it will not be repeated here. To provide a brief foundation for this report, an overview of the state of the practice in VIVDS is presented below.

Overview

The increased interest in the use of image analysis methods, both in research and product development, has led to the creation if VIVDS. In fact, researchers at Texas A&M University have shown that VIVDS are more efficient than other surveillance methods, including inductive loops, radar, and active acoustic sensors, for freeway incident detection (Middleton, et al., 2000).

VIVDS can be categorized into two classes according to the techniques used for detection: virtual loop-based (trip wire), and vehicle tracking-based configurations.

Virtual Loop-Based VIVDS

This method defines a number of zones as "virtual loops" in the field of view. When a vehicle crosses one of these zones, its presence is identified due to the change in the imagery's pixel color/intensity. Thus, this method collects exactly the same type of data as traditional point sensors. This is advantageous for field application in that this class of VIVDS can be easily integrated into traditional traffic control systems in place of other point sensors.

There are a number of commercial products on the market in this class. These include Autoscope from Econolite, Vantage from Iteris, VideoTrak from Peek Traffic, and VIP from Traficon. Many transportation agencies are currently using these, and other, virtual loop-based VIVDS in freeway and, particularly, traffic signal control applications. However, these products are currently only intended for use with fixed, immovable cameras.

Vehicle Tracking-Based VIVDS

Vehicle tracking-based VIVDS use image-processing algorithms to "follow" vehicles in a succession of image frames to compute trajectory and automatically identify stopped vehicles in imagery. An advantage of vehicle tracking techniques is their ability to efficiently filter out shadows, lights, and most weather condition changes (Bouzar and Toffin, 2004).

The development of vehicle-tracking based VIVDS has attracted considerable interest in the research community (Agarwal et al., 2004; Rajagopalan and Chellappa, 2000; Schoepflin and Dailey, 2004). However, relatively few vehicle tracking-based VIVDS products are currently on the market. One such product, VisioPaD from Citilog, has been deployed by a number of transportation agencies. However, its focus is on incident detection; it does not provide the capability of collecting traffic performance measures such as volume, speed, and occupancy.

The research team chose to integrate an off-the-shelf virtual loop-based VIVDS with existing moveable CCTV cameras to develop the original prototype Autotrack I system (and subsequent versions II and III). This choice allowed for 1) the incorporation of a VIVDS product with more usage and acceptance by transportation professionals, and 2) a VIVDS platform that provides the flexibility to both collect traffic performance measures and detect abnormal events.

Task 2: Design Phase III Autotrack

The research team met with management and technical staff at HRSTC to establish requirements for the safety and security functionality of the Autotrack prototype. The requirements are described below:

- Automatically detect when a vehicle or other large object has stopped, or is moving slowly, on shoulders of the freeway.

- Detect vehicles or objects within three minutes of their presence.
- Alert STC operators to the identification of a shoulder event.
- Minimize false alarms (i.e., when the system notifies an operator of an event, even though it hasn't actually occurred).

Based on these requirements, the research team developed design modifications to the Autotrack prototype, resulting in the design for Phase III Autotrack.

Phase III Autotrack's new safety/security functionality was integrated with the existing Phase II Autotrack prototype as shown in Figure 1. Phase II Autotrack included six main modules: 1) Autotrack Initialization, 2) Preset Repositioning, 3) Pan-Tilt Repositioning, 4) Zoom Repositioning, 5) Vehicle Detection, and 6) Position Monitoring (Smith, Namkoong, and Tanikella, 2004). The new functionality of shoulder event identification is an expansion of the 5th module of Vehicle Detection and runs simultaneously with the traffic data collection function.

Task 3: Development of Phase III Autotrack

The design, presented in Figure 1, accorded the research team the flexibility to consider multiple algorithms to process data collected by VIVDS speed and stopped presence detectors, in order to identify shoulder events. At the test site, five speed detectors and five stopped presence detectors were defined, in both the shoulder and the adjacent travel lane. The detector layout and the defined detection zones are illustrated in Figure 2. Note that the white markings on the shoulder were added by the research team for ease of calibration; they are not required for the deployment of such a system. The next subsections of this task describe the algorithms developed for stop-only vehicle detection and slow-moving vehicle detection.

Stop-Only Vehicle Detection Algorithm

As the name implies, the stop-only vehicle detection algorithm is intended to identify objects that are completely stationary on the shoulder. For this algorithm, a 30-second threshold was set for all presence detectors. In this case, an alarm will sound after any of the presence detectors has identified a stopped object for more than 30 seconds.

Slow-Moving Vehicle Detection Algorithm

In preliminary testing of the stop-only algorithms, it became clear that, in many cases, vehicles travel slowly through the shoulder as they prepare to stop. This type of event was deemed worthy of detection. Originally, the slow-moving vehicle detection algorithm was designed to determine if: 1) the speed detectors on the shoulder were registering moving vehicles, and 2) the speed data collected from the speed detectors were less than 30 mph. However, in preliminary testing, it was found that this algorithm generated a large amount of false alarms. By closely examining the recorded CCTV video, the research team identified that the shadows caused by vehicles passing on travel lanes were being identified as slow moving shoulder vehicles. This phenomenon is illustrated in Figure 3.

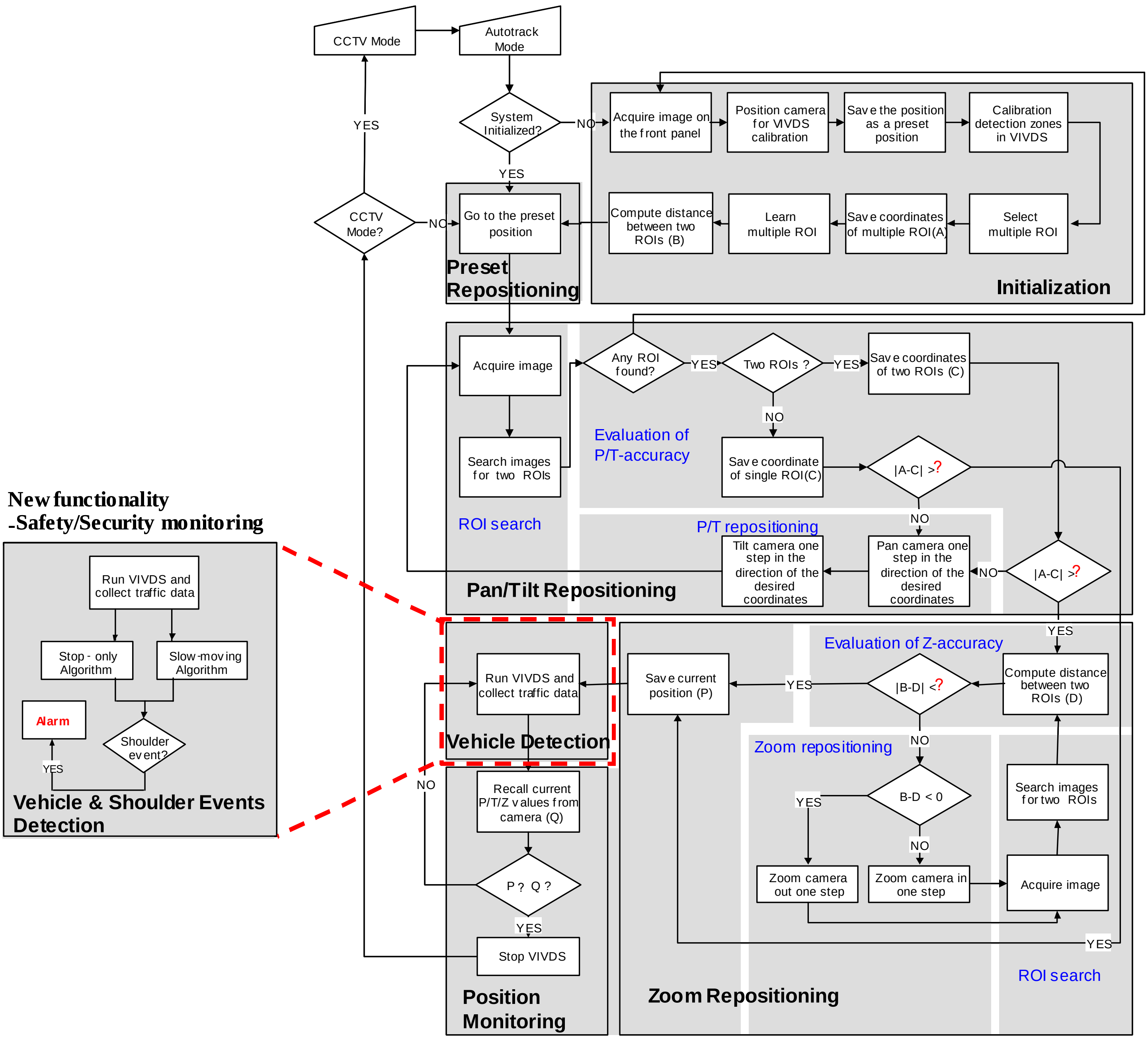


Figure 1: Phase III Autotrack Design

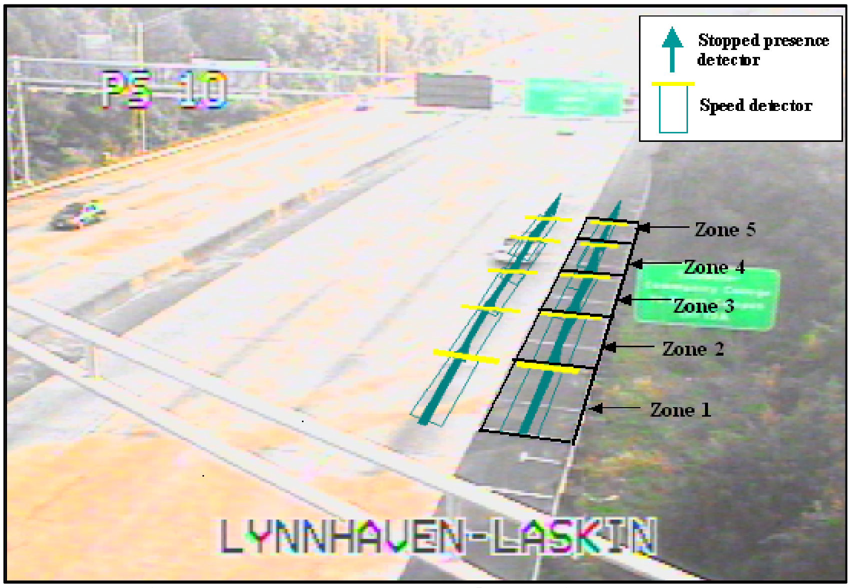


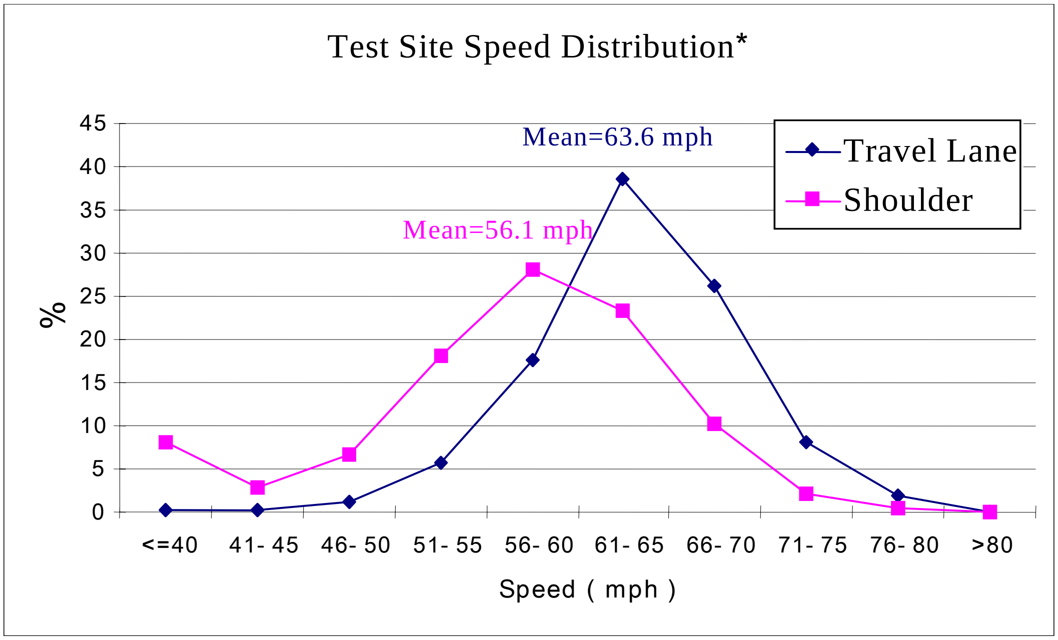
Figure 2. Detector Layout and Detection Zones

Figure 3. False Alarm Cause - Shadow Effect of Passing Vehicles

In order to reduce the false alarm rate caused by the shadows of passing vehicles, data were used from VIVDS speed detectors on both the shoulder and the immediately adjacent travel lane. According to the data collected from these detectors, it could be determined if a detector on the shoulder was “triggered” by the shadow of passing vehicles on adjacent travel lanes as follows:

1. At least one of the speed detectors on the adjacent travel lane would be triggered within one second before or after the shoulder speed detector was triggered.

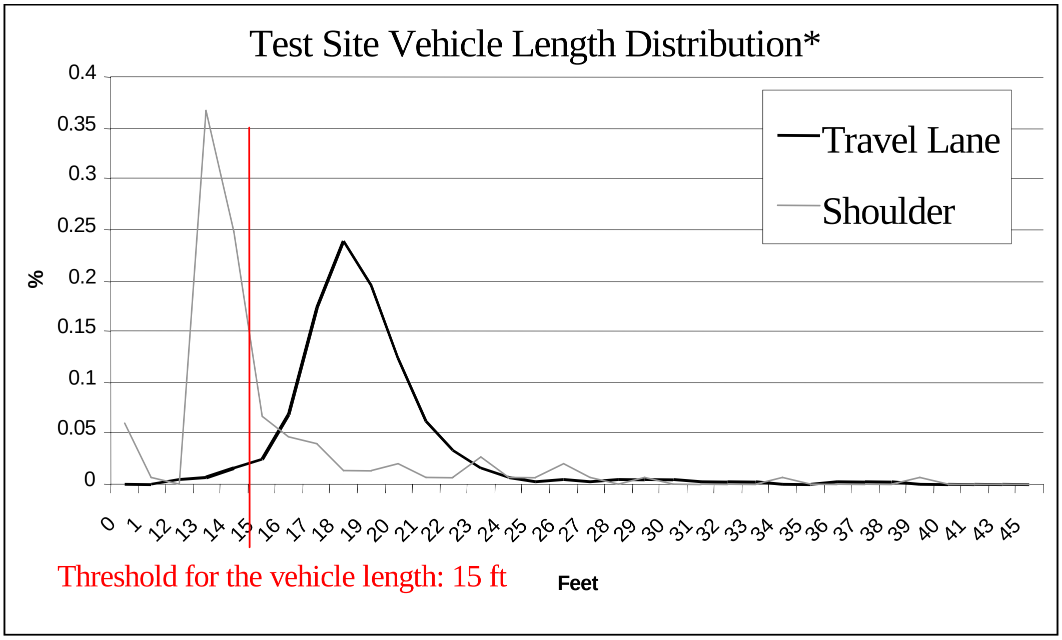
2. The difference of the speeds of the passing vehicle and its shadow is typically less than 25 mph. Figure 4 shows the speed distributions of passing vehicles in the travel lane and their shadows on the shoulder for a 4-hour period. By assuming that these speeds are normally distributed, it can be concluded that there is nearly a 100% probability that the difference of the speeds of an individual passing vehicle and its shadow is less than 25 mph.



*Test time period: 5:45AM-9: 45AM, Jan 31st, 2005 (Incident free)

Figure 4. Test Site Speed Distribution

3. In most cases, the vehicle length data collected from the mis-triggered shoulder detector were less than 15 feet, while the actual vehicle lengths are usually greater than 15 feet. The distribution of the vehicle lengths, collected from both the shoulder detectors and the travel lane detectors over a 3-hour period, is shown in Figure 5. The plot shows that about 80% of vehicle lengths collected from the shoulder detectors are shorter than 15 feet and that 95% of vehicle lengths collected from the travel lane detectors are longer than 15 feet. This is due to the fact that the shoulder detectors are triggered by the shadows of passing vehicles, which are shorter than the length of real vehicles. This vehicle length phenomenon will be site specific – based on sun angle, other light obstructions, etc. Therefore, it is recommended that the length threshold be specified on a site-by-site basis.



*Test time period: 11:05 AM-14: 25 AM, Dec 9th, 2005 (Incident free)

Figure 5. Test Site Vehicle Length Distribution

Based on these findings, the following screening tests were included in the algorithm to reduce the false alarms caused by the shadow effect of passing vehicles.

Test 1. Test if there is a vehicle passing the adjacent travel lane within one second before or after the shoulder speed detector was triggered. If true, do not indicate a slow-moving shoulder event.

Test 2. Test if the maximum speed on the travel lane is 25 mph greater than the maximum speed on the shoulder within one second before or after the shoulder speed detector was triggered. If true, indicate a slow-moving shoulder event.

Test 3. Set 15 feet as a threshold to test if real vehicles or the shadows of passing vehicles triggered the detectors. If the vehicle length data of the triggered shoulder detector are less than 15 feet, conclude that the shoulder detector was triggered by the shadow of passing vehicles.

Finally, to eliminate other false alarms caused by minor instantaneous disturbances, such as the vibration of the CCTV camera due to environmental conditions, a 5-second persistency test was added. This persistency test requires that at least 2 potential alarms were generated and that more than five shoulder detectors out of 10 were turned on within five seconds.

The final slow-moving vehicle detection algorithm is presented in Figure 6.

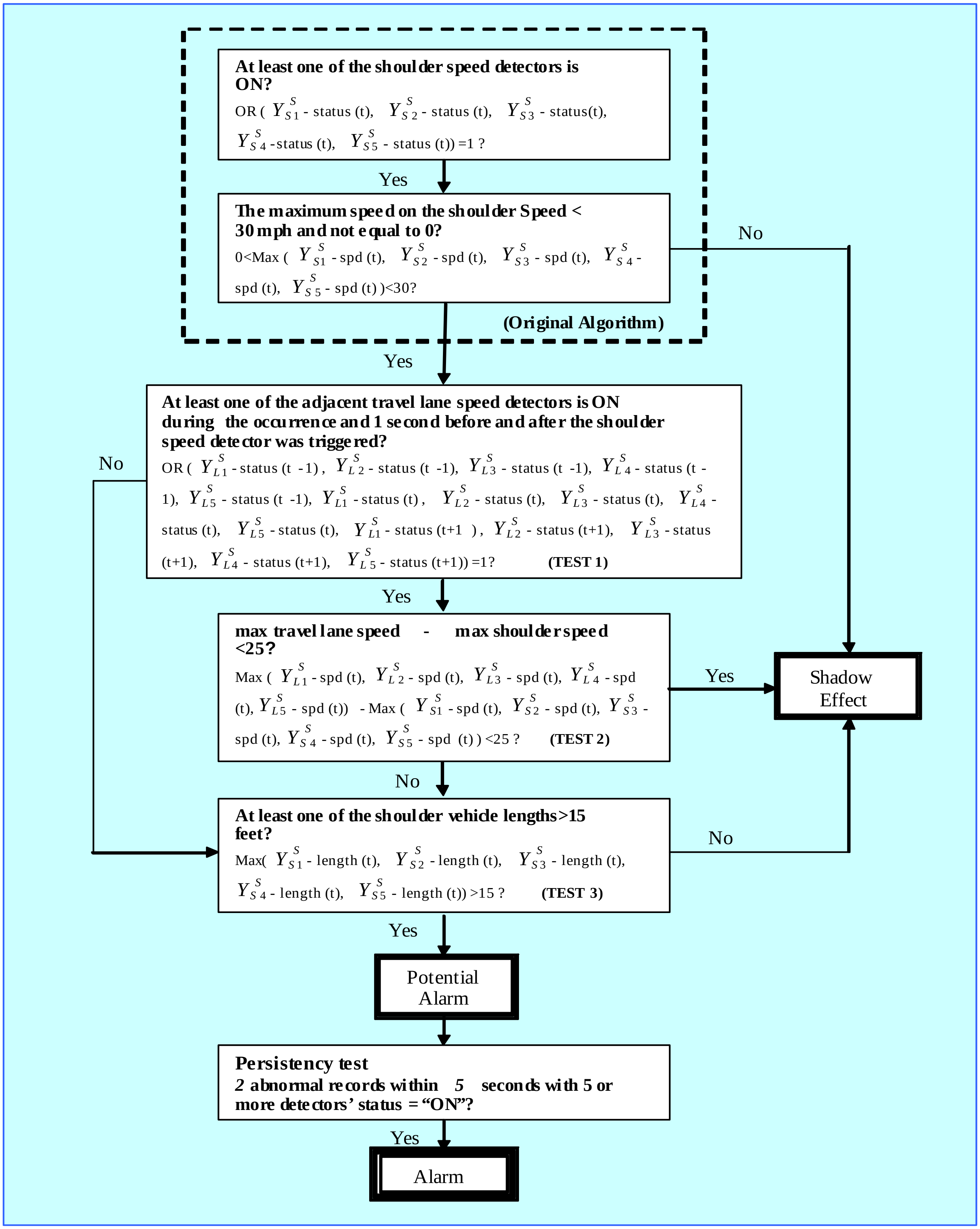


Figure 6. Final Slow-Moving Vehicle Detection Algorithm

Task 4: Phase III Autotrack Field Deployment and Evaluation

Hampton Roads STC provided the test site and one CCTV camera for this research. As described in the methodology section, camera #47, which monitors westbound I-264 at Lynnhaven-Laskin, was used in the field test.

The safety/security functionality of Autotrack was tested from May 2, 2005, through June 17, 2005. The HRSTC staff coordinated stops by their FIRT vehicles at the test site several times every day. The duration of the field test allowed for the research team to observe how the system functioned under different weather conditions (the actual conditions are described in Tables 1 and 2). To verify each alarm generated by the system, the research team recorded the video of the study site during the field test period.

Performance Measures

In order to assess the quality of the added functionality, the research team chose to analyze performance measures widely used to test incident detection algorithms - detection rate (DR) and false alarm rate (FAR). These two criteria are commonly defined as follows:

$$\text{Detection Rate} = \frac{\text{Total Number of Incidents Detected}}{\text{Total Number of Real Incidents}}$$

$$\text{False Alarm Rate} = \frac{\text{Number of False Alarms}}{\text{Total Number of Algorithm Decisions}}$$

However, the above definition of the FAR is problematic. This is because the calculation of FAR depends on the total number of decisions made by the algorithm. In cases where the decision time interval of the algorithm is small, the total number of decisions will be very large. Thus, the FAR may be quite low, even if the frequency of false alarms is intolerable to the operators in the Traffic Monitoring Center. For example, in this study, the decision time interval for the stop-only vehicle detection algorithm is one second. If the algorithm generates five false alarms per hour, per location, the FAR will be 5/3600=0.14%. While this seems very small, the "actual" FAR will be unacceptable for the traffic operators. Therefore, the FAR in this study was modified and defined as the percentage of false alarms as compared to total alarms, which can be expressed by the following equation:

$$\text{False Alarm Rate} = \frac{\text{Number of False Alarms}}{\text{Total Number of Alarms}}$$

Field Test Results

The test results for the stop-only vehicle detection algorithm and the slow-moving vehicle detection algorithm are summarized in Table 1 and Table 2.

Table 1. Field Test Results of Stop-Only Algorithm

Date	Detection Rate	False Alarm Rate (FA/TA*)	No. of Incidents	No. of Alarms	Test duration (hrs)	Weather Condition
3-May	100%	2/15	13	15	8.4	Clear
4-May	100%	0/5	5	5	6.4	Clear
5-May	100%	0/3	3	3	8.6	Clear
6-May	100%	5/11	6	11	9.5	Rain, Total Precipitation = 1.51 inch
10-May	100%	0/9	9	9	10.5	Clear (noisy video image)
11-May	100%	0/7	7	7	9.2	Clear
16-May	100%	0/3	3	3	8.5	Clear with mist in the early morning, windy
17-May	100%	0/9	9	9	10.5	Clear
20-May	100%	0/10	10	10	5.3	Rain, Total Precipitation = 0.09 inch, windy
21-May	100%	0/6	6	6	5.3	Clear
23-May	100%	9/11	2	11	10.5	T-storm, Total Precipitation = 0.38 inch
2-Jun	100%	0/2	2	2	10.5	Rain , Total Precipitation = 1.06 inch
Total	100%**	17.6%**	75	91	103.2	

*FA is the number of false alarms; TA is the number of total alarms
** Weighted Average

Table 2. Field Test Results of Slow-Moving Algorithm

Date	Detection Rate	False Alarm rate (FA/TA*)	No. of Incidents	No. of Alarms	Test duration (hrs)	Weather Condition
3-May	100%	2/8	6	8	8.4	Clear
4-May	80%	1/6	5	6	6.4	Clear
5-May	100%	0/3	3	3	8.6	Clear
6-May	75%	110/113	4	113	9.5	Rain , Total Precipitation = 1.51 inch
10-May	100%	4/12	8	12	10.5	Clear (noisy video images)
11-May	83.3%	0/5	6	5	9.2	Clear
16-May	100%	3/6	3	6	8.5	Clear with mist in the early morning, windy
17-May	100%	0/6	6	6	10.5	Clear
20-May	100%	4/8	4	8	5.3	Rain, Total Precipitation = 0.09 inch, windy
21-May	100%	0/3	3	3	5.3	Clear
23-May	81.8%	2/11	11	11	10.5	T-storm, Total Precipitation = 0.38 inch
2-Jun	100%	7/9	2	9	10.5	Rain , Total Precipitation = 1.06 inch
Total	91.8%**	72.7%**	61	190	103.2	

*FA is the number of false alarms; TA is the number of total alarms
** Weighted Average

Note that stopped vehicle and slow moving vehicle events are counted separately. In some instances, one vehicle will trigger both a stop-only event and slow-moving event if the vehicle moves slowly in the detection zone before it finally stops. Otherwise, the event will be counted as either a stop-only event or a slow-moving event, depending on the movement and the location of the vehicle.

Considering these results, it can be concluded that the Phase III Autotrack prototype can effectively detect shoulder events with a low false alarm rate in good weather conditions.

However, it is clear that weather causes significant problems with the new functionality. A detailed discussion of the test results is provided below.

- *Detection rate.* The detection rate of the stop-only vehicle detection algorithm is 100% and the detection rate of slow-moving vehicle detection algorithm is 91.8% under all weather conditions. In clear weather conditions, slow-moving vehicles on the shoulder can be detected by the algorithm with a detection rate of 95%. On rainy days, the detection rate of the slow-moving vehicle detection algorithm is reduced to 85.7%.

- *False alarm rate.* While the overall false alarm rates are 17.6% for the stop-only vehicle detection algorithm and 72.7% for the slow-moving vehicle detection algorithm, these values are somewhat misleading. In fact, both algorithms have acceptable performance under good weather conditions. It can be observed that, during the eight test days with clear weather conditions, there were only 2 false alarms from the stop-only vehicle detection algorithm and 10 false alarms from the slow-moving vehicle detection algorithm. Most of the false alarms were caused by the shadow effect of passing clouds. Furthermore, the false alarm rates on three of the rainy days (May 20^{th}, May 23^{rd} and June 2^{nd}) are still tolerable. However, May 6^{th} is an exceptional day, during which the false alarm rate of the slow-moving vehicle detection algorithm is extremely high (110/113=97%). By closely examining the video collected on May 6^{th}, it is clear that the large number of raindrops affixed to the dome housing of the camera is distorting the image presented to the Autotrack system (see Figure 7).

May 6^{th}, 2005 June 2^{nd}, 2005

Figure 7. Rainy Day– Difference Between With/Without Rain Drops on CCTV Camera

CONCLUSIONS

Based on the results of this research, the following conclusions may be drawn concerning the feasibility of the new safety/security functionality of integrated CCTV/VIVDS systems:

- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under clear weather conditions.

- An integrated CCTV/VIVDS system can be used to effectively identify shoulder events (stopped or slow moving vehicles) under rainy conditions, if provisions are made to clear away drops from the camera lens.

- The Autotrack research program has proven that CCTV/VIVDS integration is feasible, allowing moveable CCTV cameras to be used for both traffic condition measurement and safety/security monitoring.

- A cost analysis of the prototype Autotrack system (see the Costs and Benefits Assessment section at the end of this report) reveals that deploying the system on a production basis is not financially feasible. However, commercial products now exist that independently allow safety/security monitoring from moveable CCTV cameras, and that also allow the limited use of presets to reposition moveable CCTV for VIVDS application. Therefore, it is economically preferable to discontinue development of Autotrack in favor of exploring application of the emerging commercial products.

RECOMMENDATIONS

1. *VDOT Smart Traffic Centers should consider the utilization of commercial products for automated safety/security monitoring at select CCTV sites.* The results of this research demonstrated the *feasibility* of shoulder event detection using moveable CCTV cameras. Recently, commercial products have been introduced that claim to provide this functionality (without, however, the ability to measure traffic conditions). On an as-needed basis, VDOT's Smart Traffic Centers should consider installing, and monitoring the performance of, these commercial products.

2. *VDOT Smart Traffic Centers should include traffic monitoring requirements and safety/security monitoring requirements in new CCTV procurements.* Given the feasibility of monitoring traffic and safety/security using moveable CCTV cameras, demonstrated by the Autotrack prototype, and given the fact that commercial products are emerging that approach the full capabilities of Autotrack, VDOT should "push" the industry. To do this, it is recommended that on new CCTV procurements, VDOT include the following requirements:

   - The CCTV system shall measure traffic volumes, vehicle speeds, and lane occupancy over all travel lanes within the field of view. This functionality shall include the ability of VDOT personnel to define detection zones and set system parameters. All data produced by this functionality shall be produced in a well-documented output format.

   - The CCTV system shall allow VDOT personnel to define zones for event detection. When vehicles stop or move below a threshold speed within the zone, the system shall produce an alert output.

   - The traffic measurement and event detection functions shall operate whenever the CCTV is in its base, preset position. When an operator moves the camera, the functions will automatically be temporarily disabled. Once the operator chooses to reposition the camera in the base, preset position, the functions will automatically restart.

- The CCTV system shall include an automatic “timeout” function that will return the camera to its preset position after it has been moved. The timeout value shall be configurable by VDOT.

COSTS AND BENEFITS ASSESSMENT

This research effort, along with previous projects that developed and evaluated the Autotrack prototype, were intended: 1) to showcase the potential uses of VDOT’s CCTV infrastructure beyond manual monitoring, and (2) to investigate technical issues related to the integration off CCTV and VIVDS. The results of this research provide the following benefits to VDOT:

- The prototype Autotrack system has demonstrated that it is feasible for existing CCTV to provide automated traffic monitoring and safety/security functionality, in addition to supporting their primary mission of visual monitoring of roadways for operator interpretation. This provides benefits to:

  — Reduce the number of devices installed in the field (and requiring maintenance) to support transportation management.

  — Reduce the workload on operators in STCs by automating security scanning. This will allow VDOT to keep STC staff levels at reasonable levels, even as the systems grow in geographic scope.

  — Increase safety and security of the traveling public by allowing for more comprehensive monitoring of shoulders.

- Technical advancements developed in creating the Autotrack prototype have been published in VTRC reports and in a number of technical journals. This has supported the overall maturation of the CCTV/VIVDS products available on the market. While there is currently no product on the market that combines the Autotrack prototype’s ability to measure traffic conditions and provide safety/security monitoring simultaneously, products do now exist that independently allow safety/security monitoring from moveable CCTV cameras, and that also allow the limited use of presets to reposition moveable CCTV for VIVDS application. This benefits VDOT by providing commercial, off-the-shelf products to utilize for particular applications, allowing for greater benefit to be realized from the existing CCTV infrastructure.

A cost analysis of the prototype Autotrack system reveals that it is not in VDOT’s best interest to proceed with installing Autotrack in a production environment. The design of Autotrack was intended to support the research mission of the program. Therefore, the cost of deploying a single Autotrack system is not negligible. Table 3 presents a cost estimate for outfitting a single CCTV camera with the prototype system (note, this does not include the cost of integrating this software with STC software). Commercialization of the prototype system would certainly reduce the cost significantly. However, given that there are commercial products rapidly approaching the functionality of Autotrack, it is more prudent for VDOT to monitor these products and use them on an as-needed basis.

Table 3. Cost Estimate for Autotrack Production Deployment

Equipment	Component	Cost
Major components of system	Autoscope	$2,100
	Dell PC (memory >1.0 GB; Video Card> 32MB; Hard drive> 80 GB)	$1,500
	Image acquisition board IMAQ PCI-1049 and NI-IMAG	$1,111
	RS-485 to RS- 232c convert+ accessory	$200
Cables and accessories	USB PDA/SERIAL ADAPTER	$20
	ACR Wire adapt	$10
	Power Supply 110-120V, 60Hz to 24VAC @ 1.1 Amps	$20
	Coax Cable for video feeding (RG-59/U BNC)	$30
	Video cable (RCA)	$10
	Internet cable	$20
Total		**$5,021**

REFERENCES

Agarwal, N., Andrisevic, N., Vuppla, K., Stachowicz, M.S., and Burlev A. *Vehicle Detection and Tracking in Video for Incident Detection.* Minnesota Department of Transportation, Office of Research Services, St. Paul, 2004.

Bouzar, S., and Toffin, E. *Active Video Surveillance of Traffic on PTZ Cameras.* Citilog S.A. Inc., Philadelphia, PA, 2004.

Middleton, D., Parker, R., Urbanik, T., Kuhn, B., Balke, K., and Jasek, D. *Vehicle Detection Workshop*. Texas Transportation Institute, The Texas A&M University System, College Station, 2000.

Pack, M.L. *Automatic Camera Repositioning Techniques for Integrating CCTV Traffic Surveillance Systems With Video Image Vehicle Detection Systems*. Masters Thesis in Engineering. University of Virginia, Charlottesville, 2002.

Rajagopalan, A.N., and Chellappa, R. *Vehicle Detection and Tracking in Video Center for Automation Research.* University of Maryland, College Park, 2000.

Schoepflin, T.N., and Dailey, D.J. A Cross-Correlation Tracking Technique for Extracting Speed from Cameras Under Adverse Conditions. In *Transportation Research Record 1867*, 36-45, Washington, D.C., 2004.

Smith, B.L., and Pack, M.L. *Camera Positioning and Calibration Techniques for Integrating Traffic Surveillance Video Systems with Machine-Vision Vehicle Detection Devices*. VTRC 03-CR9. Virginia Transportation Research Council, Charlottesville, 2002.

Smith, B.L., Namkoong, S.J., and Tanikella, H. *Integrated CCTV/VIVDS Prototype Field Test.* VTRC 05-CR2. Virginia Transportation Research Council, Charlottesville, 2004.

Tanikella, H. *Design and Field Evaluation of a System for Integrating Closed Circuit Television Camera (CCTV) Systems With Video Image Vehicle Detection System (VIVDS).* Masters Thesis in Engineering. University of Virginia, Charlottesville, 2004.