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City of Anaheim/Caltrans/FHWA Advanced Traffic Control System Field Operational Test Evaluation: Task C Video Traffic Detection System

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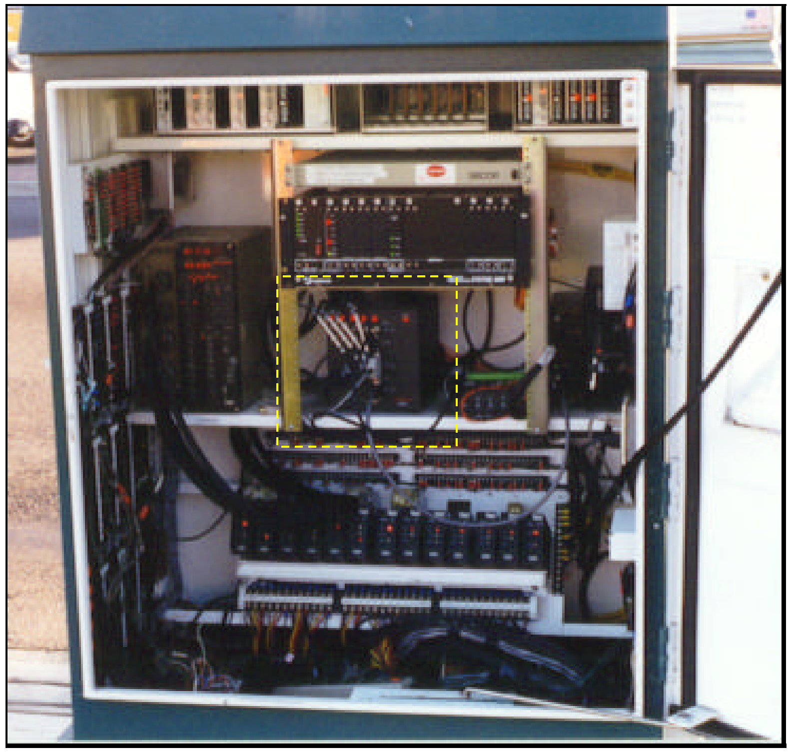

Final Report

City of Anaheim / Caltrans / FHWA

Advanced Traffic Control System Field Operational Test

Evaluation Task C

Video Traffic Detection System

Prepared for California PATH, Caltrans, and US Dept of Transportation FHWA

Agreement No. SA1272-18286LD

by the Transportation Electronics Laboratory, Dept. of Electrical Engineering

California Polytechnic State University, San Luis Obispo, California

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Executive Summary

A technical evaluation was conducted as a subtask of the "City of Anaheim Advanced Traffic Control System Field Operational Test (FOT)", funded by the US DOT / FHWA and the California Department of Transportation. Partners for this FOT are the City of Anaheim, Odetics Inc. of Anaheim, JHK Consulting, and the California Department of Transportation. This report is the result of evaluation Task C "VTDS Evaluation", one of three evaluation tasks covering components of the FOT. The component evaluated under Task C is a video-based vehicle detection system for actuation of traffic signals at intersections. This system, referred to as the Vantage VTDS, was developed and is currently marketed by Odetics Inc. (manufacturer) as a low-cost replacement for inductive loop detectors. It utilizes video cameras mounted on existing luminaires with a view of each of four traffic approaches at an intersection. The product cost for a four-approach intersection is quoted by the manufacturer to be $15,000 for all equipment, not including installation costs.

The FOT provided for the deployment and testing of the VTDS, and the support of a comprehensive independent evaluation. During the course of the FOT, the product line was split from the originally-proposed general-purpose detection system into separate freeway monitoring and intersection signal actuation products. Only the intersection product was evaluated under this FOT. The sample VTDS unit provided by the manufacturer for evaluation was a November 1996 release of the commercial product.

The VTDS detects the presence of vehicles in "virtual detection windows" which are established in the video image during the setup procedure, duplicating the function and location of inductive loop detectors. Setup and calibration of the system in the field requires only a standard TV monitor and serial PC mouse. The user interface for the VTDS was found to be unsophisticated but effective. Two useful features are the storage of up to four detection window setup configurations, and the option for remote setup and calibration via a serial port connection.

The evaluation focused on the detection performance of the system with respect to the intended application – the detection of vehicles on intersection approaches for signal actuation purposes. Test metrics and Measures of Effectiveness (MOEs) were developed for this purpose. Deployment specifications restricted our field tests to three signalized intersections at which detection cameras were set up and operated by the manufacturer. Video-taped field data was acquired from these intersection camera feeds, accessible at the manufacturer's facility. A 12-condition video test suite, which represented a typical range of testable traffic and environmental conditions, was assembled from this data, and from video tapes provided by the manufacturer from installations in Texas and Delaware. Documentation was provided by the manufacturer on system operation and setup. Evaluation personnel received training at the manufacturer's facility on the proper setup and operation of the system, and all tests were performed in compliance with these directions.

As means for classifying all possible types of correct or incorrect detection situations, nine *vehicle detection event classes* and six *phase actuation event classes* were defined. The VTDS test unit was sourced from the video-tape test suite, and data taken by manual observation of the response of the system for each vehicle passing through the virtual detection windows as displayed on a video monitor. Data was reduced to several composite measures of performance, designed to answer practical questions of relevance to potential users of the system. All test procedures and metrics were approved by Anaheim FOT Evaluation Oversight Team (EOT), which consisted of representatives of all FOT partners.

Among the test results: 65% of all vehicles flowing through detection windows at the intersections were detected correctly, just as they would be detected by a properly working inductive loop detector. 80.9% of all vehicles flowing through detection windows were detected adequately for purposes of proper actuation of the signal phases. An average false detection and latched detection rate of 8.3% was observed. A condition-weighted average of 64.9% of all red-green transitions, and 64.0% of all green extensions were actuated correctly. Relative to all metrics, the general accuracy of the system appeared to be good under ideal lighting and light traffic conditions, but degraded at higher levels of service and conditions of transverse lighting, low light, night, and rain. We noted problems in robustly handling low vehicle-to-pavement contrast, scene artifacts such as headlight reflections and transient shadows, and electronic image artifacts such as vertical smear, which is typical of CCD (charge coupled device) video cameras.

A comprehensive review of published literature and product information suggested that there is a lack of evaluation standards and meaningful test data for video-based signal actuation products. This makes direct comparison of the results of the present study with results reported for similar products extremely difficult.

Following their pre-release review of this report, Odetics announced that since the completion of this evaluation, they have observed findings similar to ours in their internal test program, and that both the hardware and software of the VTDS have been subsequently replaced, resulting in significant performance improvements. We have not tested this new system.

Context

This report is the final product of evaluation Task C “VTDS Evaluation”, one of three evaluation tasks covering the City of Anaheim Advanced Traffic Control System Field Operations Test. The technical specifications for this evaluation task are based upon information provided in the proposal to the FHWA IVHS Corridors Program "Advanced Traffic Control System" [1], and upon information provided in FOT partners meetings conducted monthly between September 1994 and April 1995 at the Anaheim Traffic Management Center (TMC). The Field Operational Test (FOT) is cost-share funded by the Federal Highways Administration in cooperation with the California Department of Transportation (Caltrans), the City of Anaheim, and Odetics Inc.

Funding for this evaluation task is provided via California Department of Transportation Task Order No. 004, and the Master Interagency Agreement No. 65V313, as it pertains to the California State University.

This report attempts to conform to guidelines set forth in the publication "Intelligent Vehicle Highway Systems Operational Test Evaluation Guidelines", November 1993 Version, by the U.S. Department of Transportation Federal Highways Administration (FHWA), Office of Traffic Management and IVHS, IVHS Operational Test Division [11]. This reference was prepared by the Mitre Corporation under contract to the FHWA, based upon the requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA) Title VI, Part B, Sections 6053(c) and 6055(d).

Authority

The technical performance of evaluation test Task C, as set forth in this document, was executed by the Cal Poly Transportation Electronics Laboratory, directed by Professor C. Arthur MacCarley, under the auspices of the PATH Evaluation Team, California PATH / U.C. Berkeley, and the California Polytechnic State University Foundation.

All FOT partners were an integral part of the process to develop goals, objectives, modes of evaluation, test methods, and the overall evaluation workplan. Certain data were provided by the system vendor, Odetics Inc., as identified in this document. The Evaluation Test Plan was originally developed by the PATH Evaluation Team and subsequently reviewed, modified through five revisions, and ultimately approved by all FOT Evaluation Oversight Team (EOT) members, consisting of the City of Anaheim, JHK Consulting, Odetics Inc., Caltrans and the DOT/FHWA. Accordingly, the final Task C evaluation workplan with amendments, reduced test suite, and test methods employed are the joint responsibility of the Evaluation Oversight Team membership. The Cal Poly Transportation Electronics Laboratory and the PATH Evaluation Team assume all responsibility for the accurate and objective execution of the workplan, and the conclusions based upon these test results, unless otherwise noted.

Disclaimer

The statements and conclusions of this report are those of the authors and the Anaheim FOT partners, and not necessarily those of the State of California or the California Department of Transportation. The evaluation results described in this document are based solely upon tests conducted by the Cal Poly Transportation Electronics Laboratory, with the oversight and approval of the City of Anaheim, Odetics Inc., the California Department of Transportation and California PATH. This report does not constitute a standard, regulation or specification. The mention of commercial products, their sources, or their use in connection with the work reported herein is not to be construed as an actual or implied endorsement of such products. Odetics, Inc. has requested that we note that they do not necessarily agree with the conclusions reached in this report, and that they have replaced the system evaluated herein with a significantly improved product.

Acknowledgements

The author gratefully acknowledges the support of the California PATH / U.C. Berkeley, the California Department of Transportation, and the U.S. Department of Transportation Federal Highways Division. In particular, I wish to acknowledge the guidance and direction of the contract monitor, Robert Tam of PATH / U.C. Berkeley, and Frank Cechini, the DOT/FHWA program manager for field operational tests.

Except where noted, this report was written by Prof. C. Arthur MacCarley, Director of the Cal Poly Transportation Electronics Laboratory. Most of the data reduction was performed by Tod Eidson, Matt Cotton, and Jan Nimick, research assistants in the Cal Poly Transportation Electronics Laboratory. Chad Tindel, research assistant, performed much of the background literature survey included in the Appendix of this report. Significant technical and procedural advise was provided by Profs. James Moore of the University of Southern California, and Profs. Michael McNally and R. Jayakrishnan of the University of California, Irvine. Technical advise was provided by Joseph Palen and Richard Macaluso of the California Department of Transportation New Technology Division, Keith Jasper of Booz Allen Hamilton Inc., and the traffic engineering staff of the City of Anaheim. Oversight of the Anaheim FOT was provided by James Parel, John Lower, and John Thai of the City of Anaheim. Tim Larson, consultant to Odetics and the original developer of the VTDS, served as the Odetics liaison to the FOT during the first two years of the project. He also provided valuable historical information and reviews of proposed test procedures. Rick Crawshaw, the VTDS product manager, and Karl Tipple, technician, both of Odetics Inc., supported the evaluators' field data acquisition in December 1996 at Odetics' facility, which included daily setup during pre-dawn hours.

Evaluation Objectives

The purpose of the Task C evaluation is to assess the performance and effectiveness of a computer vision based video traffic detection apparatus, deployed as part of a Field Operational Test (FOT) conducted in the City of Anaheim. The subject system is manufactured by Odetics, Inc., a manufacturer of automation and telecommunications equipment, located at 1585 S. Manchester Ave., Anaheim, California. The system is referred to by the manufacturer as the Vantage Video Traffic Detection System, or VTDS. It will be referred to henceforth as the VTDS.

The subject system utilizes EIA RS-170 analog video signals provided by up to four visible spectrum monochrome video cameras, deployed at intersections for the purpose of traffic signal actuation and vehicle counting. The cameras and associated communications network were deployed by Odetics, JHK Consultants and subcontractors selected by Odetics with the cooperation of the City of Anaheim Traffic Engineering Office.

During the course of the FOT, the Vantage VTDS was developed, laboratory tested, installed, calibrated and operated off-line by Odetics Corp, in cooperation with the City of Anaheim. By "off-line" it is meant that the system was not used to actually actuate signals at any intersection. A single VTDS unit provided by Odetics was tested in a laboratory environment by the evaluation team, using video-taped scene data obtained from Odetics-installed video cameras located at three intersections proximate to their facility in Anaheim.

The original objectives of the Task C evaluation, as stated in the final revision of the Task C Evaluation Workplan (included in Appendix C), are restated below:

- To assess the absolute performance of the Odetics VTDS with respect to the following detection functions: traffic count (accumulated), instantaneous and time-average vehicle speed, volume (vehicles per unit time per lane), and density measurement (vehicles per lane per unit distance).
- To assess the performance of the Odetics VTDS relative to competing real-time and archival detection options (eg., inductive loops, tube detectors, ultrasonic presence detectors, passive infrared presence detectors).
- To assess the relevance of the VTDS deployment and/or projected deployment to the FHWA's overall objectives for the Field Operational Test Program.
- To assess the selection of the experimental conditions and constraints, ie., the selected intersection, the traffic metrics provided by the system, and any test limitations introduced by this deployment.

These evaluation objectives were subsequently relaxed to reflect the limitations of the final FOT deployment and modifications of the VTDS FOT deliverables occurring in late 1996 following a redefinition of the VTDS product line. The Task C focus was restricted to the first and last objectives listed above, as they related to the subject FOT tasks described in the following section.

During the course of the FOT, all evaluation activities and methods were reviewed and either approved or rejected by the Evaluation Oversight Team (EOT), and meetings of the EOT were held monthly beginning in September 1994 for the purpose of overseeing the activities of the evaluators as well as coordinating the FOT partners' contract activities. At the time of this report, the FOT remains in progress awaiting the completion of the SCOOT component (Task A) and the assessment of institutional issues (Task B).

Subject FOT Tasks

Evaluation Task C pertains to Tasks 6 through 10 stated in the FOT proposal to the FHWA from Caltrans, the City of Anaheim, and Odetics [1]. These FOT deliverables involve the preparation, development, deployment, operation and testing of the Odetics VTDS. For reference, the specific FOT tasks are:

6. Develop VTDS Field Test Plan

    6.1 Perform Site Analysis of Anaheim Intersection

    6.2 Develop Field Test Plan and Support Evaluation Test Plan

    6.3 Prepare Video Camera Subsystem Installation Plans

    6.4 Prepare Communications System Installation Plans

    7. Development

8. Communications Equipment Procurement and Installation

    8.1 Prepare Equipment Specifications and Select Equipment

    8.2 Installation and Integrate Video Camera Subsystem

    8.3 Install and Integrate Communications System

9. Set Up Mobile Lab for Remote Tests

10. Test

FOT Tasks (6) through (8.3), except for Task (7), deal with the video cameras which provide the inputs to the VTDS, and the communications network required to transmit video signals to Odetic's facility and the Anaheim TMC. Task (7) is the development of a software user interface and operations manual for the VTDS. Task (9) involves the modification of an existing mobile test laboratory vehicle to serve as a platform for acquisition of video data to be used for testing and calibration of the VTDS. Task 10 encompasses all performance tests of the VTDS, including support as required for the independent evaluation team. The proposal cites test conditions including various lighting conditions, various forms of atmospheric obscuration, and various traffic conditions.

From September 1994 through December 1997, the evaluators reviewed selected documents made available by Odetics or JHK to all the FOT partners, including the site analysis and the Odetics test plan. Following ultimate finalization and later modification of the Task C evaluation workplan, the evaluators performed specific tests to evaluate the VTDS system performance, using a suite of videotaped traffic scenes recorded from video feeds at the Odetics facility or from Odetics-supplied video tapes from other locations.

Evaluation Task C Time Line

Provided below is a list of approximate dates of significant milestones, deliverables or changes in the FOT related to the VTDS system and its evaluation. This provided only to establish the chronology and sequence of selected key events. This list is neither complete nor reflective of the relative importance of any particular event. Dates are approximate, as recorded in minutes of meetings, document dates, and from interviews with FOT participants.

FOT proposal submitted to FHWA by partners	June 1993
Selection of PATH evaluation team	July 1993
First evaluation team proposal submitted	September 1993
Date of first FOT/EOT meeting	November 1993
Official start of FOT partners' contracts	not available
Official start of evaluation team contracts	March 1994
Evaluation Oversight Team Charter presented by JHK/Anaheim	October 1994
VTDS product demonstration at FOT meeting	November 1994
Final evaluation team proposal submitted	December 1994
First draft of Task C evaluation workplan submitted	March 1995
VTDS Field Test Plan submitted by Odetics	August 1995
FHWA / BAH major project review meeting	November 1995
Partners/EOT approval of Task C evaluation workplan, revision 5.0	December 1995
FHWA approval of Task C evaluation workplan	May 1996
VTDS video camera subsystem and communications system installation plans submitted by Odetics	June 1996
Revision of Test Suite to accommodate restriction to vendor-provided monochrome cameras	July 1996
Evaluation restricted to stopline presence detection	September 1996
VTDS product line split. Evaluation restricted to intersection detection product only. Test suite revised to accommodate.	October 1996
Revision of Test Suite to restrict field tests to Odetics' instrumented intersections	October 1996
Partners/EOT acceptance of final Video Test Suite	October 1996
Transition from Tim Larson to Mike Juha representing Odetics	November 1996
Delivery of sample VTDS system for evaluation	November 1996
Field data collection at Odetics' facility	December 1996
End of Odetics' contract	December 1996
Presentation of preliminary results to EOT/partners	March 1997
Completion of Phase Detection tests requested by Odetics	May 1997
Presentation of final results to EOT/partners	June 1997
Delivery of first draft Task C evaluation report	October 1997
Caltrans/PATH approval of draft 2.0 of Task C evaluation report	December 1997
BAH/FHWA review completed	January 1998
Final Task C report draft submitted	February 1998
End of evaluators' contract (with extensions)	March 1998

System Description

The VTDS is described by the manufacturer as a low-cost system, ultimately intended for deployment over a wide geographic area, to provide combined “surveillance and control for entire cities and counties” [1]. The system supports up to four video cameras per unit, simultaneously processing camera inputs. The system originally proposed was intended to calculate standard traffic metrics such as average traffic speed, volume, and count, as well as provide presence detection for traffic signal actuation at up to four traffic approaches, using existing color or monochrome CCTV surveillance cameras. The system as tested was reduced in function by the manufacturer to traffic signal actuation only, and was restricted to use bundled monochrome video cameras and environmental housings.

The primary function of the system as-tested was the detection of the presence of vehicles in virtual detection windows located each lane of an intersection approach, just ahead of the stop bar. The system is intended to mimic and replace the function of inductive loops that are typically used for this application. Detection is accomplished by computer-vision analysis of the video signal provided by a standard surveillance-type video camera viewing the approach area, from a position on top of the mast arm of a luminaire located on the opposite approach of the intersection. The field of view of the camera is such that all lanes of a particular approach are covered. One VTDS unit can process up to four cameras; therefore, only a single system is need at each four-way intersection. The lane detection signals generated by the VTDS are intended for actuation of the traffic signal control system.

The VTDS has provision for detection of vehicles in an upstream “approach” window in each lane, within the limits of the field of view of the video camera. It also has provisions for tallying cumulative vehicle counts on a per-lane basis. Once deployed and calibrated, the system is designed for continuous operation in signal actuation service.

Complete details on the VTDS system operation, capabilities, and installation may be found in the VTDS Intersection Operators’ Manuals [7,8], VTDS Installation Guide [9], and VTDS System Configuration Report contained in Appendix D,E,F, and G of this report.

Evaluation Work Plan and Video Test Suite

A preliminary test suite was proposed based upon information provided in Odetics documents “Anaheim Advanced Traffic Control System FOT Test Plan (Intersection)” dated 27 August 1996, and “Anaheim Advanced Traffics Control System Field Operational Test VTDS Installation, System Configuration” dated 3 September 1996. The proposed test suite was tailored to the scope of the Anaheim Field Operational Test and the specific requests of the evaluation oversight team. The test suite was not as comprehensive as the Odetics-proposed test suite described in the former two documents in that it did not cover conditions of thick fog, lightning strikes, snow or heavy rain - conditions that we do not reasonably expect to be able to sample in the FOT area. However, it added variations in camera placement, vertical-mode camera vibration, glare, and a range of noise and signal degradation factors typically encountered in above-ground roadway sensor installations.

Each test sequence was originally designed to be 15 minutes in duration, but was later extended to a total of 30 minutes in duration. The first fifteen minutes were used for system autoregistration and background subtraction. Once the system is operating in steady state, the remaining fifteen minutes were used as the actual data collection and performance assessment interval.

According to the Odetics VTDS “Operating Instructions Video Traffic-Detection System” dated 1 December 1994 [7], “the VTDS provides statistics for traffic parameters such as traffic volume, flow rate, speed and headway between vehicles.” These functions are also referred to the Caltrans/Anaheim/Odetics FOT proposal dated 7 June 1993. Accordingly, Task C subtask 10 of the final evaluation workplan submitted October 1995 specifies that accuracy of traffic count, speed, volume and density will be evaluated. However, subsequent documents (above referenced) redefined the intended function of the VTDS, as deployed under this FOT as an “Intersection Detection Product”, intended solely to produce real-time vehicle presence data similar to that provided by inductive loops. The performance metrics proposed by Odetics in Section 6.0 of the August

27,1996 “FOT Test Plan, VTDS (Intersection)” related only to the assessment of presence/phase detection accuracy.

The original test suite was based on the evaluation of selected elements from the following range of test conditions, which are referenced in the subsequent test suite table:

Index of Test Conditions:

1. Environmental
   a. Clear
   b. Fog
   c. Rain
2. Illumination
   a. Overhead, full sun
   b. Steep incidence angle, transverse
   c. Steep incidence angle, into sun
   d. Steep incidence angle, away from sun
   e. Low light (dusk/dawn)
   f. Night
3. Traffic Level of Service (LOS)
   a. LOS A-B
   b. LOS C-D
   c. LOS E-F
4. Number of Lanes
   a. 1
   b. 2
   c. 3
   d. 4
5. Noise/Interference Factors
   a. None
   b. Wind-induced vibration (horizontal, sway)
   c. Ground-induced vibration (vertical, due to heavy vehicle)
   d. Electromagnetic interference (auto ignition)
   e. Compromised power quality (power line noise)
   f. Degraded video signal (ohmic connection or line)
   g. Optical degradation (dust on window)
   h. Optical degradation (water drops on window)
6. Axial camera position
   a. Directly above traffic lane
   b. Roadside, approximately 20 degrees off traffic axis
7. Camera height
   a. high (>8 meters)
   b. medium (5-8 meters)
   c. low (<5 meters)
8. Camera angle (steepness)
   a. Shallow (<10 degrees)
   b. Steep (>10 degrees)

The following test suite was originally proposed, based upon the evaluation workplan:

Test Sequence Number	1. Environ mental	2. Illumi-nation	3. Traffic LOS	4. Number Lanes	5. Interfer-ence	6. Camera axis	7. Camera height	8. Camera angle	Notes
1.	clear	ovrhd sun	A-B	2-4	none	above	7-9 m	steep	1
2.	clear	ovrhd sun	C-D	2-4	none	above	7-9 m	steep	1
3.	clear	ovrhd sun	E-F	2-4	none	above	7-9 m	steep	1
4.	clear	ovrhd sun	A-B	2-4	none	roadside	7-9 m	steep	
5.	clear	ovrhd sun	C-D	2-4	none	roadside	7-9 m	steep	
6.	clear	ovrhd sun	E-F	2-4	none	roadside	7-9 m	steep	
7.	clear	transverse	B-E	2-4	none	above	7-9 m	steep	1
8.	clear	transverse	B-E	2-4	none	roadside	7-9 m	steep	
9.	clear	into sun	B-E	2-4	none	above	7-9 m	steep	1,6
10.	clear	into sun	B-E	2-4	none	roadside	7-9 m	steep	6
11.	clear	low light	B-E	2-4	none	above	7-9 m	steep	1
12.	clear	low light	B-E	2-4	none	roadside	7-9 m	steep	
13.	clear	night	B-E	2-4	none	above	7-9 m	steep	1
14.	clear	night	B-E	2-4	none	roadside	7-9 m	steep	
15.	rain	day	B-E	2-4	none	roadside	7-9 m	steep	
16.	rain	night	B-E	2-4	none	roadside	7-9 m	steep	
17.	fog	day	B-E	2-4	none	roadside	7-9 m	steep	2
18.	fog	night	B-E	2-4	none	roadside	7-9 m	steep	2
19.	clear	ovrhd sun	B-E	2-4	wind vib	roadside	7-9 m	steep	
20.	clear	ovrhd sun	B-E	2-4	grnd vib	roadside	7-9 m	steep	
21.	clear	ovrhd sun	B-E	2-4	local EM	roadside	7-9 m	steep	3
22.	clear	ovrhd sun	B-E	2-4	dust	roadside	7-9 m	steep	4
23.	clear	night	B-E	2-4	dust	roadside	7-9 m	steep	4
24.	rain	day	B-E	2-4	droplets	roadside	7-9 m	steep	5
25.	rain	night	B-E	2-4	droplets	roadside	7-9 m	steep	5
26.	clear	ovrhd sun	B-E	2-4	none	roadside	7-9 m	shallow	
27.	clear	into sun	B-E	2-4	none	roadside	7-9 m	shallow	6
28.	clear	ovrhd sun	B-E	2-4	none	roadside	>9 m	steep	7
29.	clear	ovrhd sun	B-E	2-4	none	roadside	<7 m	shallow	8

Notes:

1. From Harbor and Katella camera feeds.
2. Fog density sufficient to diffuse image or cause headlight backscatter.
3. Auto ignition noise, unshielded, 0.5 meter from system enclosure.
4. Light dust coating on camera enclosure window.
5. Raindrops on camera enclosure window.
6. Sun at approximately 10 degree incidence angle to road surface.
7. Full extension of mobile tower or mount on overcrossing.
8. Camera height set at threshold of vehicle obscuration.

As part of our workplan specifications, we had planned to use some existing video footage for our test suite. We provided Odetics with a sample test scene tape, acquired from our mobile video tower, for their calibration purposes. On September 17,1996 we were directed by the EOT to restrict our evaluation exclusively to presence detection. We were also advised at that time that only Odetics-supplied monochrome video cameras could be used. Odetics subsequently provided one of their video cameras for our use, to replace the Burle color reference camera on our mobile video tower. With some modifications to the camera housing required, we replaced this camera as requested. The restriction to vendor-supplied cameras prevented the use of previously acquired field test data for some conditions in the VTDS video test suite.

Our test plan called for the use of mobile tower-acquired video data for VTDS test suite conditions 10, 11, and 15-18, which we did not expect to be able to acquire from the designated Anaheim intersections. At the October 22,1996 FOT meeting, Odetics' representative explained that recently the VTDS had actually been split into two product lines - an intersection detection product and a freeway measurement product. They considered only the intersection detection product within the scope of the FOT, and it had a number of technical restrictions. The issue of optimal camera placement was raised by Odetics, with the objection that roadside camera placements specified in the approved evaluation workplan would not be adequate for proper operation of the system. The mobile surveillance tower, with a maximum height of 10 meters, is capable of meeting the required height specifications and therefore minimizing the possibility of vehicle occlusion. However, the 10-30 degree off-axis placement was cited as the primary problem, as well as concerns about possible vehicle occlusion. Consequently, we were directed by the EOT to abandon test scenarios in the evaluation workplan which required the use of our mobile video tower. As a result, we were restricted to acquisition of video data taken from the three instrumented intersections in Anaheim. This eliminated the evaluation of the tolerance of the VTDS to camera placements other than those at the three test intersections. These test conditions had originally been of interest since the ability to use existing CCTV cameras was a key part of the original FOT proposal. This also eliminated the test condition for camera elevation below 7 meters (shallow camera angle).

At the November 11, 1996 EOT meeting, our final evaluation workplan was approved by the EOT. All test suite data would be acquired from existing video camera installations operated by Odetics at intersections proximate to their facility in Anaheim. Specific days and times of access to the video feeds at Odetics facility were negotiated. Odetics staff would observe all data acquisition and test procedures conducted at their facilities. For some sequences, we would rely on Odetics' staff to start the VTRs at specified times.

The EOT requested that we not evaluate the vehicle count capability provided by the system, since this was not of primary interest in intersection control. It was agreed among the EOT membership that a detection event was defined for evaluation purposes as the entry of an individual vehicle (possibly including trailer) into a defined zone of detection located immediately behind an intersection stop bar. Using the video test suite sequences, we would ascertain the accuracy of VTDS-reported vehicle detections over fifteen-minute test intervals for each of the test conditions. The Test Suite Matrix was reduced from 29 to 18 test scenarios.

Reduced set of conditions for Anaheim test suite:

Test Sequence Number	1. Environ mental	2. Illumi-nation	3. Traffic LOS	4. Number Lanes	5. Interfer-ence	6. Camera axis	7. Camera height	8. Camera angle	Notes
1.	clear	ovrhd sun	A-B	2-4	none	above	8-10 m	steep	1
2.	clear	ovrhd sun	C-D	2-4	none	above	8-10 m	steep	1
3.	clear	ovrhd sun	E-F	2-4	none	above	8-10 m	steep	1
4.	clear	transverse	B-E	2-4	none	above	8-10 m	steep	1
5.	clear	into sun	B-E	2-4	none	above	8-10 m	steep	1,6
6.	clear	low light	B-E	2-4	none	above	8-10 m	steep	1
7.	clear	night	B-E	2-4	none	above	8-10 m	steep	1
8.	rain	day	B-E	2-4	none	above	8-10 m	steep	8
9.	rain	night	B-E	2-4	none	above	8-10 m	steep	8
10.	fog	day	B-E	2-4	none	roadside	8-10 m	steep	2
11.	fog	night	B-E	2-4	none	roadside	8-10 m	steep	2
12.	clear	day	B-E	2-4	wind vib	roadside	8-10 m	steep	7
13.	clear	day	B-E	2-4	grnd vib	roadside	8-10 m	steep	7
14.	clear	day	B-E	2-4	local EM	above	8-10 m	steep	3
15.	clear	day	B-E	2-4	dust	roadside	8-10 m	steep	4
16.	clear	night	B-E	2-4	dust	roadside	8-10 m	steep	4
17.	clear	day	B-E	2-4	droplets	roadside	8-10 m	steep	5
18.	clear	night	B-E	2-4	droplets	roadside	8-10 m	steep	5

Notes:

1. From Harbor & Katella, Clementine & Freedman, or Anaheim & Freedman camera feeds.
2. Fog density sufficient to diffuse image or cause headlight backscatter.
3. Simulated auto ignition noise source, unshielded, 0.5 meter free air path from VTDS system enclosure.
4. Light dust coating on camera enclosure window, consistent with typical residues observed on unattended roadside-mounted surveillance video cameras.
5. Raindrops on camera enclosure window, simulating hooded but non-wiper-equipped surveillance camera during windy rain conditions.
6. Sun at approximately 10 degree incidence angle to road surface.
7. Manually induced vibration in horizontal or vertical plane, approximately one second period, typical magnitude based upon field observations.
8. Weather permitting, at Odetics-connected intersections in Anaheim.

Following the November 1996 EOT meeting, we took delivery of a VTDS evaluation unit at Odetics' Anaheim facility. Odetics staff confirmed that the unit was fully operational, with the most recent firmware available, and was properly calibrated. Figure 1, below, is a single video frame from our documentary video records showing the evaluation unit prior to setup for testing at the Cal Poly Transportation Electronics Laboratory.

Figure 1. Odetics VTDS Evaluation Unit (on top of video tape recorder).

Field Data Collection

Video data was collected at Odetics' Anaheim facility December 17 through 20, 1996 from camera feeds at three intersections proximate to the facility, and from video footage provided by Odetics from other locations at which VTDS systems had been installed. The three test intersections were:

- Harbor Blvd & Katella Blvd
- Clementine Road and Freedman Way
- Anaheim Blvd and Freedman Way. The locations of these intersections in the study area, and the location of Odetics' facility at which the video feeds were accessed, are shown in Figure 2, below. The Anaheim Traffic Management Center (TMC), not shown, is located approximately three miles north of this area.

Figure 2 below indicates the location of the three test intersections (dashed circles) and the Odetics facility (dashed box) in which the video feeds were accessed. The Anaheim Traffic Operations Center, not shown, is located approximately two miles north of this area.

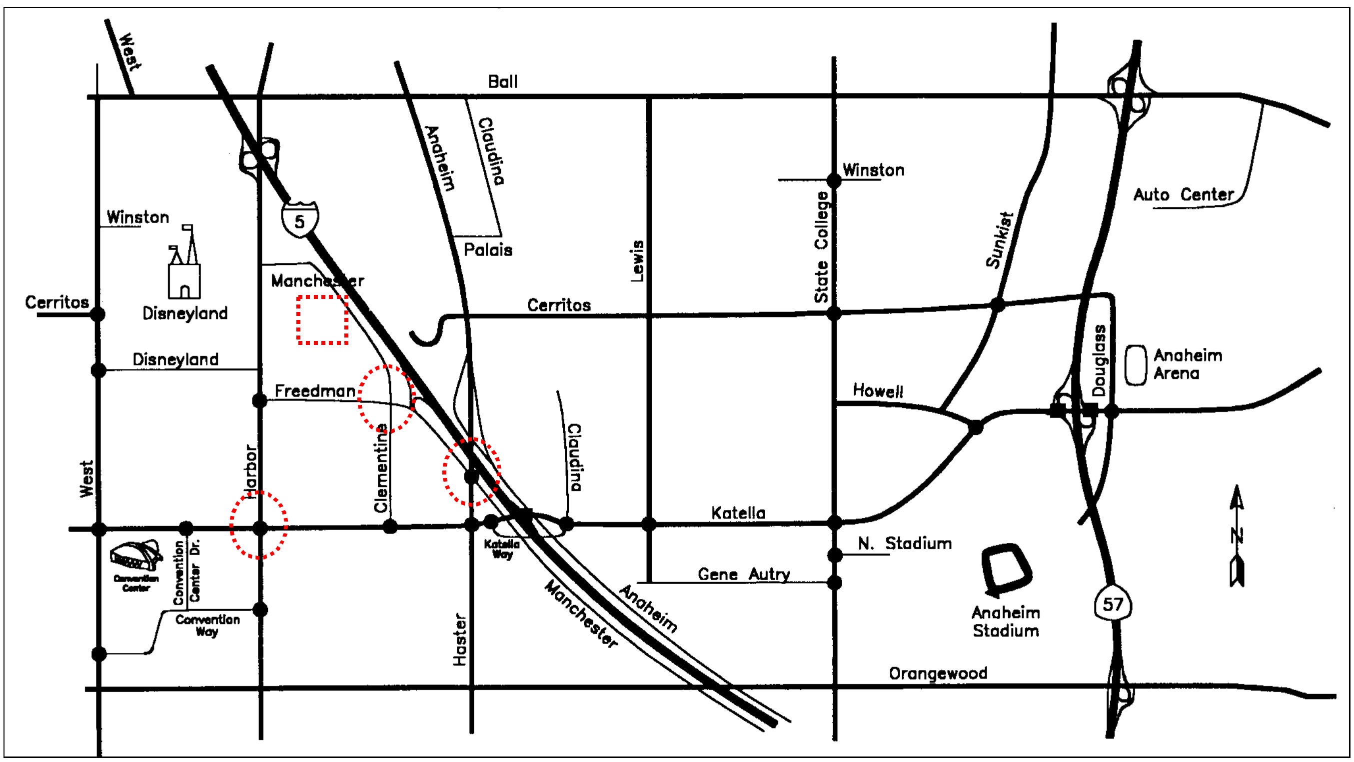
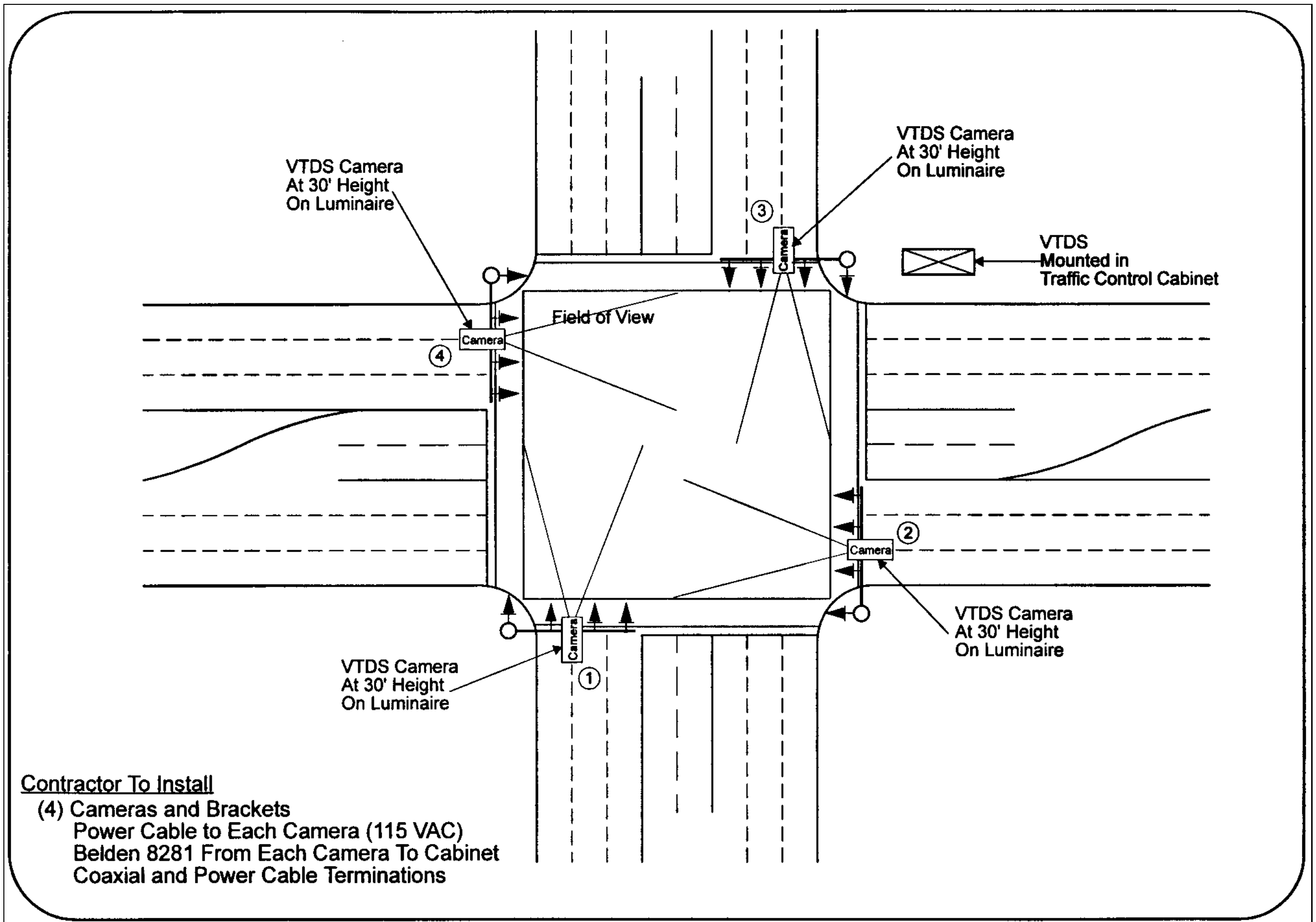


Figure 2. VTDS Test Intersections, City of Anaheim. (Map from FOT Proposal [1].)

Camera placement and field of view are critical requirements for the proper operation of the VTDS. The camera must be placed at least 30 feet above the road surface on the overhanging mast arm of street light luminaires, positioned as shown in Figure 3 below, which is a copy of Figure 1.1-2 in the Odetics "Installation Guide for the Intersection Product, Video Traffic-Detection System" [9].



Typical Intersection Plan

Figure 3. Recommended Camera Deployment, from Odetics VTDS Installation Guide.

A sample correct camera field of view is illustrated in Figure 3.3-1 of the referenced Odetics manual. This is reproduced as Figure 4 below for convenience. All cameras and related equipment at the three test intersection were installed and maintained by Odetics for product development and test purposes. No non-Odetics camera installations or roadside camera placements were used. This assured that all camera installations and fields of view used in the evaluation would meet Odetics' requirements. No video data taken by the Odetics mobile laboratory was provided, presumably since the mobile laboratory could only provide roadside camera placements which were inappropriate for the intersection detection product.

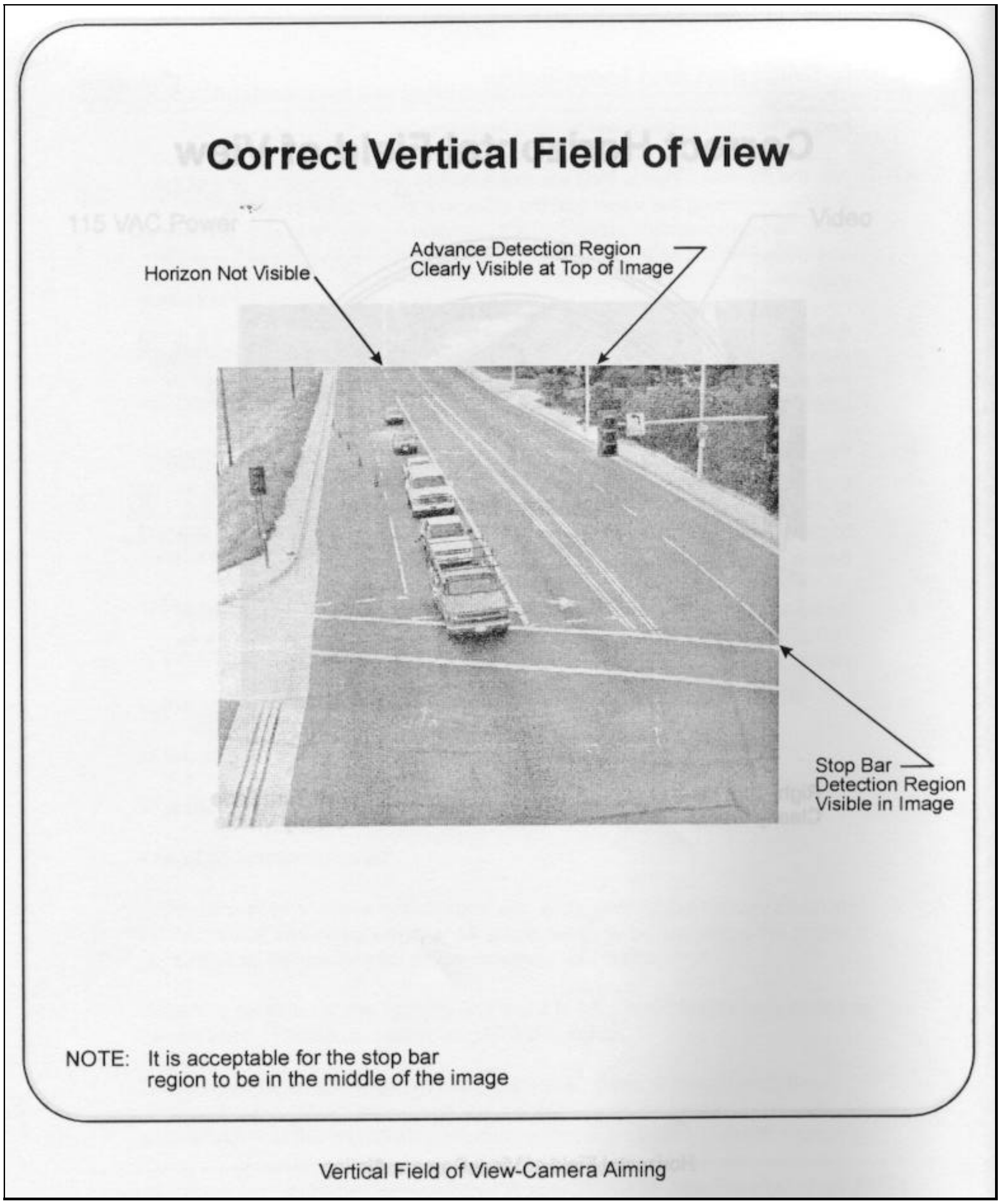


Figure 4. Recommended Field of View, from Odetics VTDS Installation Guide.

Figures 5 and 6 below are ground-level photographs of the Harbor/Katella and Clementine/Freedman test intersections, at which most of the test conditions were recorded. The positions of the VTDS cameras in each photograph are highlighted by dashed circles.

Figure 5. Harbor and Katella Test Intersection.

Figure 6. Clementine and Freedman Test Intersection.

Video signals from the intersection cameras are brought into the Odetics facility via fiber optic and RF links. Test sequences were recorded by the evaluators on S-VHS video tape using two Panasonic AG-series professional VTRs. We used the right audio track for narration or other instrumentation coding, and we recorded SMPTE (Society of Motion Picture and Television Engineers) standard linear time code on the left audio track.

At none of the intersections was a VTDS system "in the loop", that is, being used for actual signal actuation. However, the correct hardware configuration when engaged for this purpose is shown in Figure 7 below, reproduced from Figure 1.2-1 on page 9 of the VTDS Installation Guide [9].

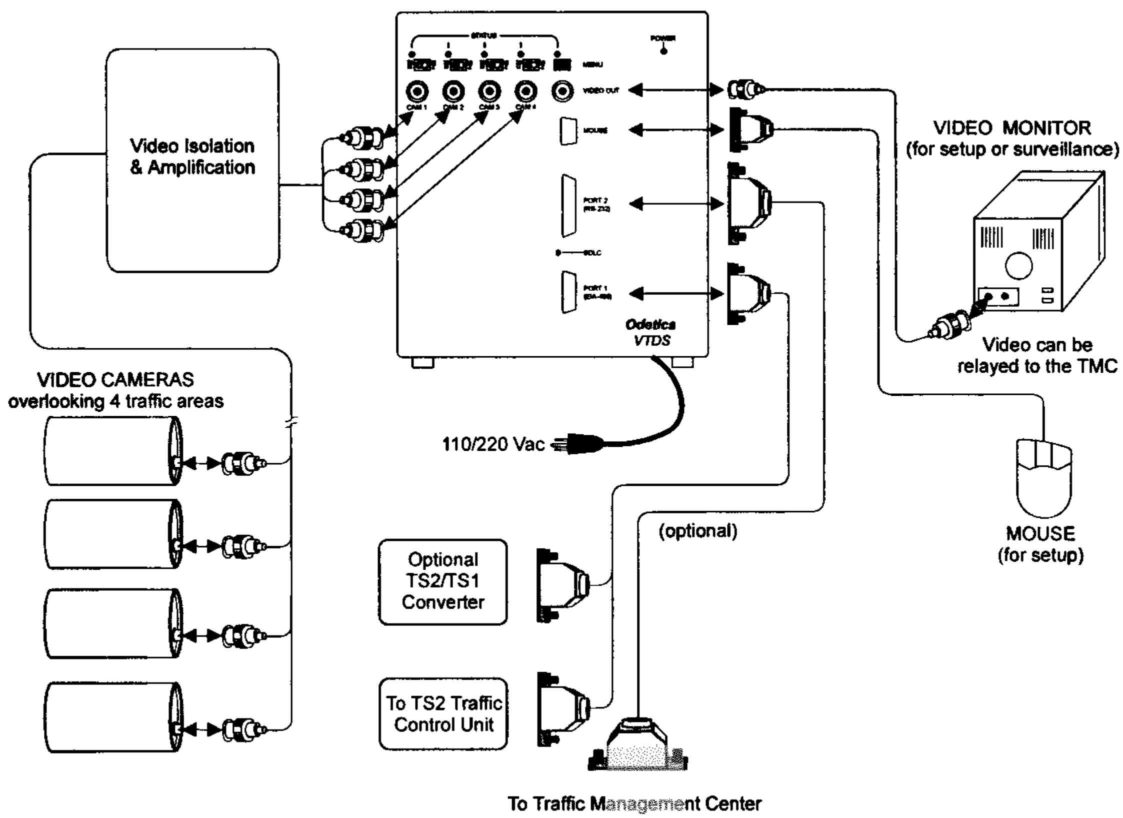


Figure 7. VTDS Hardware Configuration for Signal Control, from VTDS Installation Guide.

For some of the intersection approaches, the video feeds provided at Odetics' facility contained binary data from the output of selected inductive loops at the intersection, encoded in the vertical blanking interval of the video signal using an Odetics experimental device referred to as a "Loop Encoder". This device permits transmission of data from on/off data from selected sources such as inductive loop outputs, along with the video signals. Odetics utilizes this information as part of their product testing and validation. Much of the acquired video tapes were from video feeds passed through the loop encoder at the source (inaccessible to us), with information recorded in the video frame. Although loop data was present in encoded form on some video tapes, since we did not have access to a loop encoder unit to decode this, and since it was outside the scope of the present evaluation, we did not utilize any loop detector data in our evaluation of the VTDS system. The Loop Encoder and the encoded data that it produces are considered by Odetics to be a proprietary. The lead evaluator was required by Odetics to sign a non-disclosure agreement before being permitted to record the necessary video feeds from the test intersections. The terms of the non-disclosure agreement could possibly be interpreted to require that we secure in perpetuity or destroy all loop-encoded video data after it is used for the immediate evaluation. This would include the final VTDS Video Test Suite, approximately one quarter of which contains loop encoded inter-frame information and, for one condition, the burned-in ASCII screen display. While this is not expected to compromise the evaluation accuracy, it raises the question of ownership of and access to the Test Suite generated under FHWA/Caltrans funding. It also may constrain the use of the Test Suite for future evaluation purposes without the permission of Odetics. With the concurrence of the EOT, we did not utilize any of the encoded loop information, although it is permanently encoded in some of the videotaped data that comprises the video Test Suite. The encoded loop data appeared to be selective, not covering all lanes on each approach. However, we noted that if the encoded loop data had been comprehensive and could have been verified with respect to the outputs of the loop sense amplifiers, it may have been possible using the Odetics Loop Encoder to verify the accuracy of the inductive loops, making possible direct comparison with the output of the VTDS. It is apparently used for this purpose in product development at Odetics. The installation and interface of the loop encoder in conjunction with the VTDS in the field cabinet in illustrated in Figure 8 below, from the VTDS FOT Site Analysis and Installation Guide (Appendix D) [10].

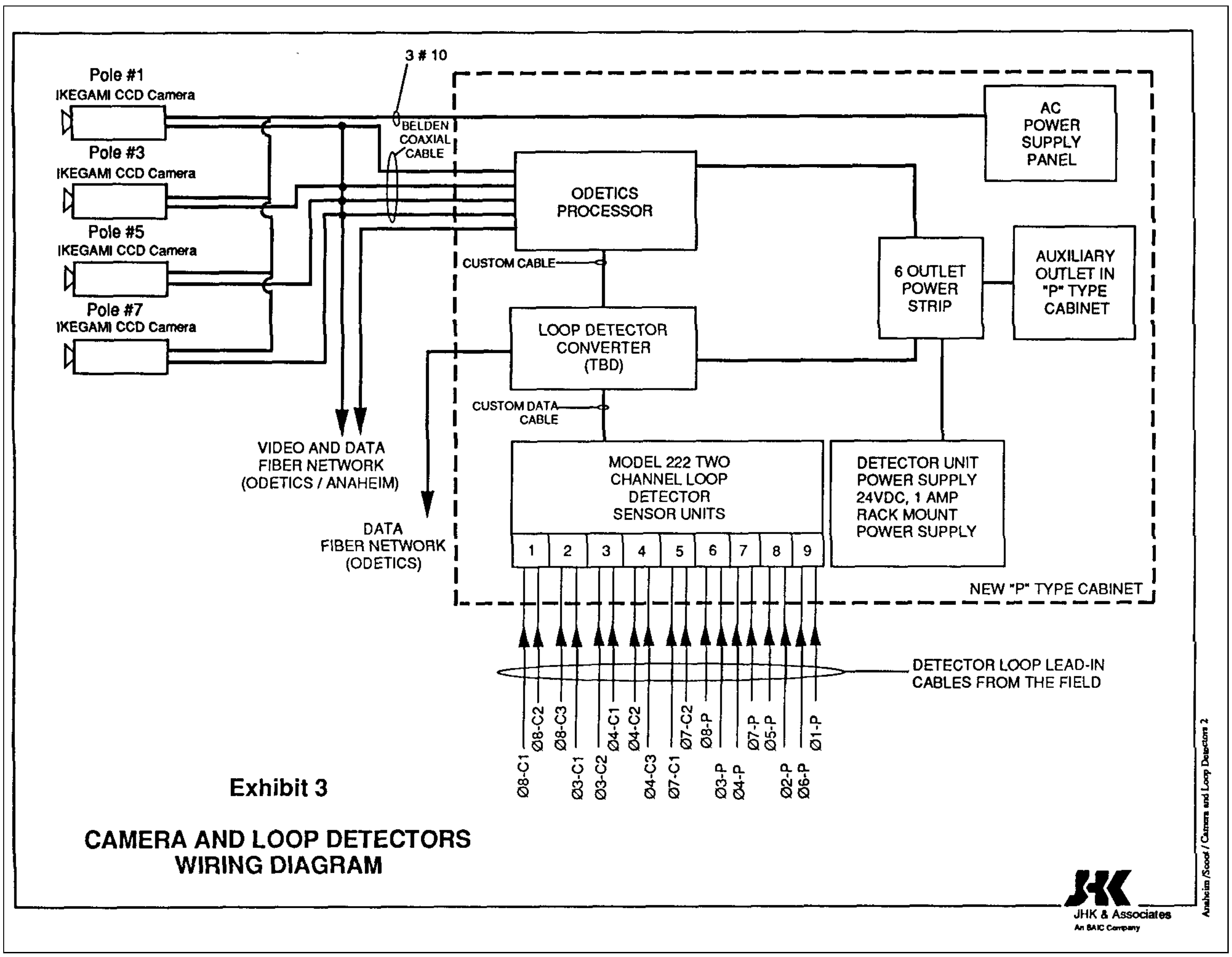


Figure 8. VTDS Interface with Video Cameras and Odetics Loop Encoder in Field Cabinet.

During the four-day period of field data acquisition, we encountered all required illumination conditions, with the exception of steep illumination angle sun glare, and all weather conditions except rain and fog. December 17 1996 encountered high winds due to a Santa Ana condition, a seasonal occurrence in the geographic area of the FOT. During the prior weekend, rain conditions were recorded by Odetics personnel, at our request. All images were acquired from Odetics-installed monochrome video cameras at the three instrumented intersections. One sequence of color video was also acquired at the Freedman and Clementine intersection, using an existing color camera that had been installed by Odetics for experimental purposes.

Sequences were acquired from 6:15 AM to 8:30 PM on December 17 and 18, 1996. Additional dusk and night sequences were acquired December 16, 1996. Traffic conditions ranging from LOS A through E were observed, generally correlated with the location of each intersection and the time of day. We have been unable to acquire fog or glare conditions at these intersections. For the glare condition, we requested the use of an Odetics tape from their installation in Austin Texas, containing a late-day sun-glare condition. It was not possible to obtain a fog condition either from the intersections under test or Odetics' stock video footage library.

Data from field cameras was acquired at the Harbor and Katella and the Freedman and Clementine intersection. For the Harbor and Katella intersection, since multiple video lines were available, it was possible to acquire unencoded raw video as well as video containing loop-encoded information. With only a single video feed from Freedman and Clementine and from Freedman and Anaheim Blvd., only loop-encoded video was available (with one exception on December 18, when the connection was changed at the intersection cabinet). We were assured by the program manager that the presence of the burned-in display of the loop encoder output in the video frame would not effect the performance of the VTDS, since the display characters did not overlap the detection windows in the image. One technician raised concern that the display information might have some effect for night sequences, since it might alter the background average illumination level in the scene.

While at Odetics' facility, we were informed that the two in-field VTDS systems (at Freedman and Clementine and at Harbor and Katella) were running an experimental version of the software, different than the production version provided to us, and that various experiments were in progress using the systems, such that data generated by these may not be consistent with that produced by the evaluation system provided to us. To assure consistency of our evaluation results, we did not use the outputs of in-field systems. All of our reported results were generated by processing the selected videotaped segments through the sample system provided to us for evaluation purposes.

We recorded a total of nineteen two-hour S-VHS tapes, December 16-19, 1996. An additional four "rain tapes" were acquired the previous week by Odetics personnel at our request, using the VTR we left at the facility for this purpose. At Odetics request, copies of all 23 original data tapes used in this evaluation were made and retained by Odetics.

We used a standardized data collection form developed for these tests for logging all video data and test conditions. Copies of the field data forms as well as all raw data are contained in the Appendix H.

Photographic and camcorder video documentation was acquired at each intersection to record intersection configuration information and general traffic conditions. Photographs were taken of the VTDS equipment installation inside the controller cabinets at the Harbor and Katella intersection and the Freedman and Clementine intersection. The cover of this report shows the Harbor and Katella cabinet.

On December 10, 1996 we requested additional specific instructions (beyond that provided in the training session) on the preferred configuration of the "detection windows" used by the system. In response, Odetics provided an updated VTDS Operating Instructions manual (Appendix G). This described the user interface and operation of the VTDS unit, and the preferred setup of the detection windows. During our video data collection at Odetics facility, we observed Odetics staff experimenting with several variations from the specifications, in particular, the use of overlapping double loops at each detection position, but we were verbally assured by the program manager that the Operating Instructions description is correct for the setup of the windows for our evaluation tests. In all tests, the detection window setup conformed to these specifications.

At the Odetics facility we also inspected the mobile surveillance laboratory, as required under FOT Task 9. At the time of our inspection, the vehicle appeared to no longer be in use for this application. Two monitors, one VTR, and a few other unconnected equipment items in a rack mount frame and miscellaneous materials storage were observed. The interior and exterior of the vehicle were photographed for documentary purposes, and are shown respectively in Figures 9 and 10 below. It does not appear from our inspection that this trailer was being employed in the field testing of the VTDS Intersection Product. Since the vehicle can only be parked on the side of a roadway, it could not be used for acquisition of video sequences usable by the VTDS Intersection Product, which requires camera placements in the roadway centers of intersection approaches. It is suitable for and was probably utilized for the development of the earlier version of the VTDS, which was specified as a general purpose data collection and signal actuation detection system.

Figure 9. Mobile Laboratory Exterior.

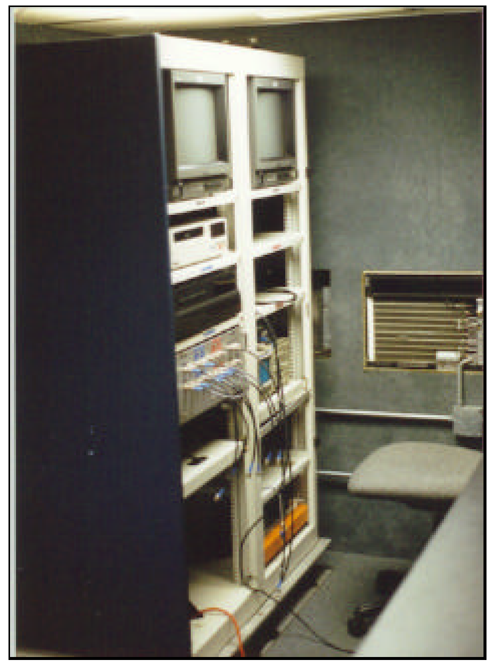


Figure 10. Mobile Laboratory Interior.

The evaluation test plan called for acquisition of all Anaheim intersection video data from field camera feeds accessible in the Anaheim TMC. Following data collection at Odetics on December 19, 1996, we attempted to obtain video data at the TMC. Upon arrival, we found that all remote camera controls and most of the video feeds to the TMC were temporarily inoperable. We returned later to acquire video data in conjunction with the January FOT meeting at the TMC, but determined that none of the available video feeds conformed to the required VTDS camera placement specifications (30 feet elevation, centered over roadway, monochrome cameras). Consequently, it was not possible to use any video feeds from the Anaheim TMC for evaluation of the VTDS. This represented a fundamental change in our approved Task C test plan protocol, which relied upon the expected use of Harbor/Katella and other intersection video feeds at the TMC.

A field work report was distributed to the FOT partners at the December 22, 1996 EOT meeting.

System Test and Data Reduction

System setup and detection zone configuration conformed to the instruction we were given at Odetics facility, which we documented on video tape, and the specifications of the Odetics VTDS Operating Instructions

(Appendix G) [7,8]. Detection windows were placed in each lane of an approach as illustrated in Figure 11 below, copied from page 16 of the Odetics VTDS Operating Instructions [7]. The system is typically configured to detect vehicles present at the stop bar of the approach. These are labeled in Figure 6 as "Count Windows". The option is also provided to place another set of "Approach Windows" well upstream of the approach, to meet the needs of adaptive signal control algorithms such as the SCOOT (Split Cycle and Offset Optimization Technique" or for excess queue length detection.

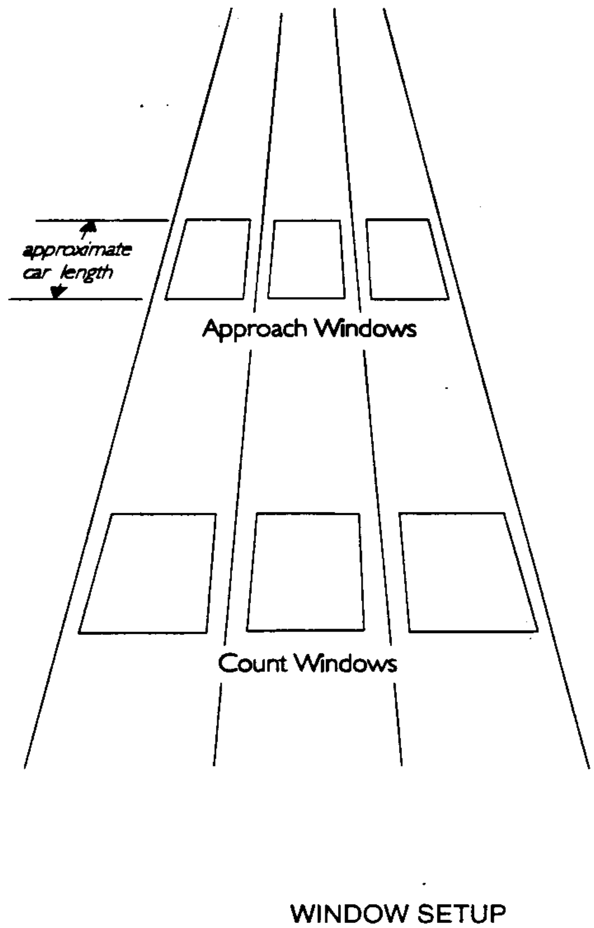


Figure 11. Specifications for Detection Window Setup, from Odetics VTDS Operating Instructions.

An typical detection zone placement for both types of windows is shown on Page 17 of the "Operating Instructions, Intersection Product, Vantage VTDS" [8], duplicated as Figure 12 below.

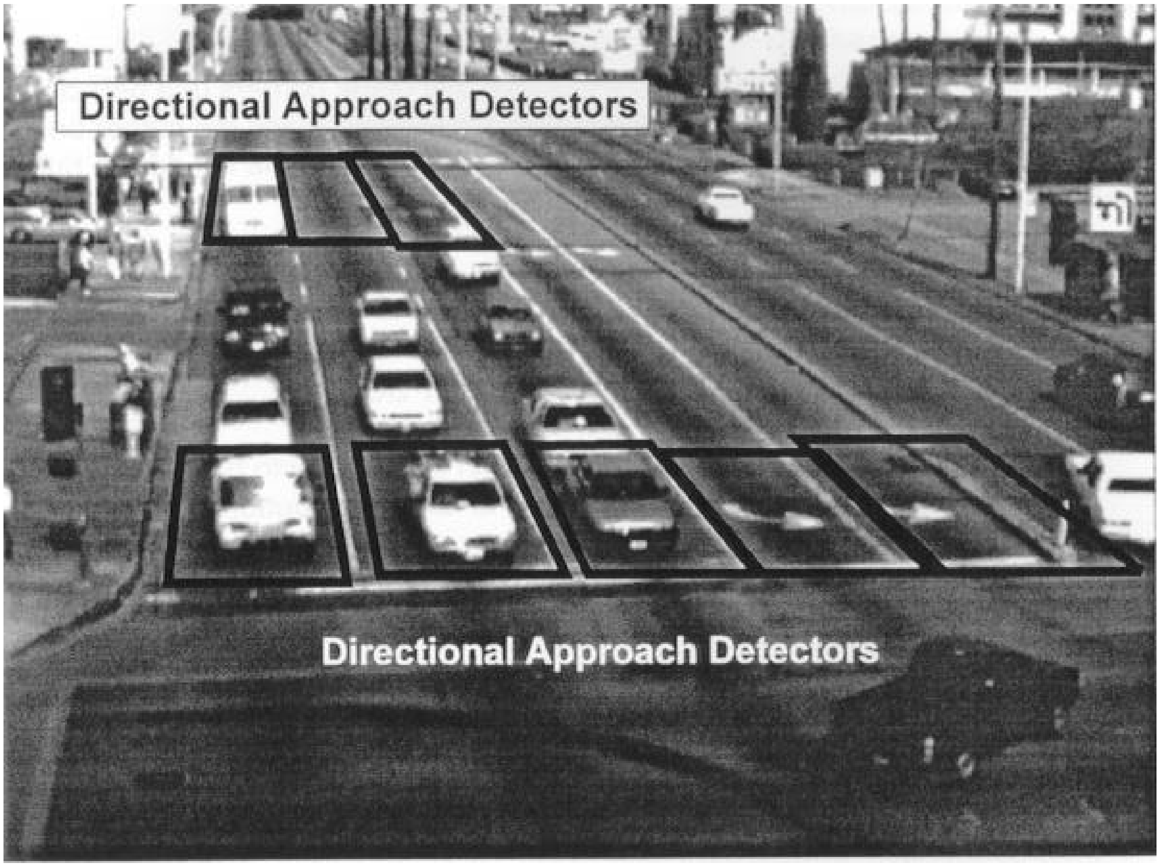


Figure 12. Example of Ideal Setup for Stop Bar and Advance Detection Windows, Reproduced from Operating Instructions for Odetics VTDS.

In the FOT Partner's Proposal [1], the VTDS system evaluated under Task C was intended to serve as a detector for the SCOOT system evaluated under Tasks A and B of this FOT. The complementary nature of these two advanced traffic control technologies made their pairing in the same FOT logical. The link to SCOOT was eliminated in 1995 at the request of the FOT partners. Lacking the need for "Approach Windows" at the test intersections in the study area, we were advised to evaluate only detection at the stop bar windows, which are used for signal actuation. The system provides both binary presence detection and accumulated vehicle counts for each lane from these windows. Although this feature was specified as in the FOT proposal as a deliverable, we did not evaluate vehicle count accuracy at the request of Odetics and with the concurrence of the partners. At the request of Odetics, following the presentation of our preliminary data at the May 1997 EOT meeting, we evaluated an additional metric referred to by Odetics as "Phase Detection" accuracy, defined as the percent correctly actuated signal cycles at an intersection utilizing the VTDS as a replacement for inductive loops. We consulted with Anaheim traffic control personnel to determine the exact actuation control laws in place at Odetics' camera-equipped intersections, and used these control laws to determine the accuracy of actuation of the red and green signal intervals for each phase at the intersections under test.

The final test suite was acquired from Odetics video camera installations located at:

- Harbor Blvd & Katella Blvd, Anaheim
- Clementine Road and Freedman Way, Anaheim
- Anaheim Blvd and Freedman Way, Anaheim
- Odetics-supplied tapes from systems installed in Dover, Delaware and Austin, Texas.

Approximately 50 hours of raw video tape data were reduced to produce the final test suite. The final revision of the reduced Test Suite Matrix (below) was consistent with the field data opportunities encountered. The video test suite was modified due to data availability:

The following test conditions were deleted:

3. Clear, overhead sun, LOS E-F.	(LOS E-F unavailable)
10. Fog, day, LOS B-E.	(Fog unavailable)
11. Fog, night, LOS B-E	(Fog unavailable)
13. Clear, day, ground vibration	(Superceded by TC 12, wind vibration)
15. Clear, day, LOS B-E, dust	(Inaccessibility of camera)
16. Clear, night, LOS B-E, dust	(Inaccessibility of camera)
17. Clear, day, LOS B-E, droplets	(Inaccessibility of camera)
18. Clear, night, LOS B-E, droplets	(Inaccessibility of camera)

The following test conditions were added, per verbal consensus of the FOT partners, but excluded from the overall system assessment::

19. Clear, day, LOS B-E, overhead wires in field of view
20. Clear day, LOS B-E, color camera

With these modifications, the test suite was reduced from 18 conditions to 12 conditions. Of these, only 9 conditions were used for the overall assessment of the system. Conditions 14, 19, and 20 are not included in the overall test suite average figures, since they examine degraded (EM interference or overhead wires in view) or non-standard (color video) deployments of the system, respectively.

Condition 12 (wind vibration), which was planned and approved for a roadside camera position, was derived instead from Odetics-installed intersection camera placement. Condition 13 (ground vibration) was eliminated since, due to the high-wind conditions recorded December 17, it was largely redundant with respect to condition 12. Condition 14 (EM noise) was synthesized in the laboratory using a bench-mounted automotive ignition system as a broadband electromagnetic noise source, to add EM noise to an existing sequence taken from a later section of the Test Condition No. 2 data tape. The effects of non-ideal camera placement, non-vendor-supplied video cameras, fog, dust, and water droplets on the camera lens/window could not be evaluated from the available video data.

Each of the twelve 30-minute video sequences in the Test Suite were reproduced on a Panasonic AG-series S-VHS VTR through a Hotronic time base corrector (TBC), into the VTDS unit. The TBC provides full-frame re-synchronized of the video signal from the VTR, to eliminate any possible timing degradation as a result of the video recording process. The original (first generation) video data tapes were used as the inputs to the VTDS unit, to avoid any possible loss of resolution or increased noise due to generation loss. The video output of the VTDS was observed on a reference monitor and recorded on another S-VHS VTR, and this video taped data was used for the detailed detection analysis. This procedure permitted us to examine the performance of the system in closed detail, using slow-scan and single frame analysis of the detection scenes. This detailed analysis would not have been possible if the real-time VTDS output was used since it is not possible to slow down or stop the input video data stream to the VTDS without effecting it's operation. Manual data reduction methods were used to observe all (correct or incorrect) detection events based upon human observation of video tapes. Two completely redundant analysis sessions were performed for each test segment to assure against error in the visual observations of the graduate research assistants performing this data collection.

Final Test Suite, As Acquired:

Test Sequence Number	1. Environ mental	2. Illumi-nation	3. Traffic LOS	4. Number Lanes	5. Interfer-ence	6. Camera axis	7. Camera height	8. Camera angle	Notes
1.	clear	ovrhd sun	A-B	2-4	none	above	8-10 m	steep	1
2.	clear	ovrhd sun	C-D	2-4	none	above	8-10 m	steep	1
4.	clear	transverse	B-E	2-4	none	above	8-10 m	steep	1
5.	clear	into sun	B-E	2-4	none	above	8-10 m	steep	1,3
6.	clear	low light	B-E	2-4	none	above	8-10 m	steep	1
7.	clear	night	B-E	2-4	none	above	8-10 m	steep	1
8.	rain	day	B-E	2-4	none	above	8-10 m	steep	1
9.	rain	night	B-E	2-4	none	above	8-10 m	steep	1
12.	clear	day	B-E	2-4	wind vib	above	8-10 m	steep	1,4
14.	clear	day	B-E	2-4	local EM	above	8-10 m	steep	1,2,7
19.	clear	day	B-E	2-4	Wires in View	above	8-10 m	steep	1,5,7
20.	clear	day	B-C	2-4	Color Camera	above	8-10 m	steep	1,6,7

Notes:

1. From Harbor & Katella and Clementine & Freedman camera feeds.
2. Simulated auto ignition noise source, unshielded, 0.5 meter free air path from VTDS system enclosure.
3. Sun at approximately 10 degree incidence angle to road surface.
4. Actual wind-induced vibration in horizontal or vertical plane, approximately one second period, typical magnitude based upon field observations.
5. Overhead wires and suspended tri-light signal in field of view.
6. Direct feed from Odetics-installed color video camera at Clementine & Freedman.
7. Not included in overall normalized performance result, since these conditions represent non-standard installations of VTDS.

30-minute data collection intervals were used for each test condition, each consisting of a 15-minute test period preceded by a 15-minute autoregistration period. All test conditions were analyzed with respect to both individual vehicle detection performance and intersection phase actuation performance.

Vehicle Detection Test Procedures

Following several initial analysis runs using the approved final Test Suite, and consultation with Anaheim traffic management personnel, we identified nine possible **vehicle detection event** classes, summarized below and described with examples in the following section. The vehicle event classes were reviewed by the FOT partners at the May EOT meeting using brief video samples of each type of event, and were subsequently used in the final reduction of the field test data.

1. Correct Detection

A vehicle is detected when it enters a detection zone, stays continuously detected while in the zone, and detection ceases when it leaves the zone.

2. Detection with Latch

A vehicle is detected when present in a detection zone, stays continuously detected while in the zone, but detection remains on indefinitely after it leaves the zone.

3. Multiple Detections

A vehicle is detected when present in a zone, but while in the zone detection ceases and repeats at least once, including the possibility of a final latch condition.

4. Failure to Detect

A vehicle is not detected at all when present in a detection zone.

5. Drop After Detection

A vehicle is initially detected after entering a zone, but later dropped (and not redetected) while stationary in the zone.

6. Tailgate

Detection remains on for the second and possibly later vehicles following the leader in a platoon. (Detection correct for presence purposes such as signal actuation, but not for count or queue length determination purposes.)

7. Tailgate with Latch

Tailgate event, but detection remains on indefinitely after last car in platoon leaves.

8. False Detection

Detection reported when no vehicle present or near detection zone. Detection ceases when either the causal image artifact is no longer present or after five seconds.

9. False Detection with Latch

False detection which stays on indefinitely.

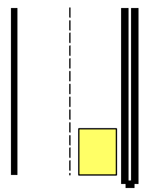
In the detection event class samples that follow, an active detection is indicated by the illumination of the four corners of the detection window in the captured video screen image. This feature is provided by the VTDS unit for operator verification of vehicle detections and for setup of the detection zones.

Event Class 1: Correct Detection

Location: Freedman & Clementine, EB

Date/Time: 17 December '96, 11:00

Site Plan:

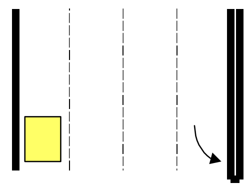


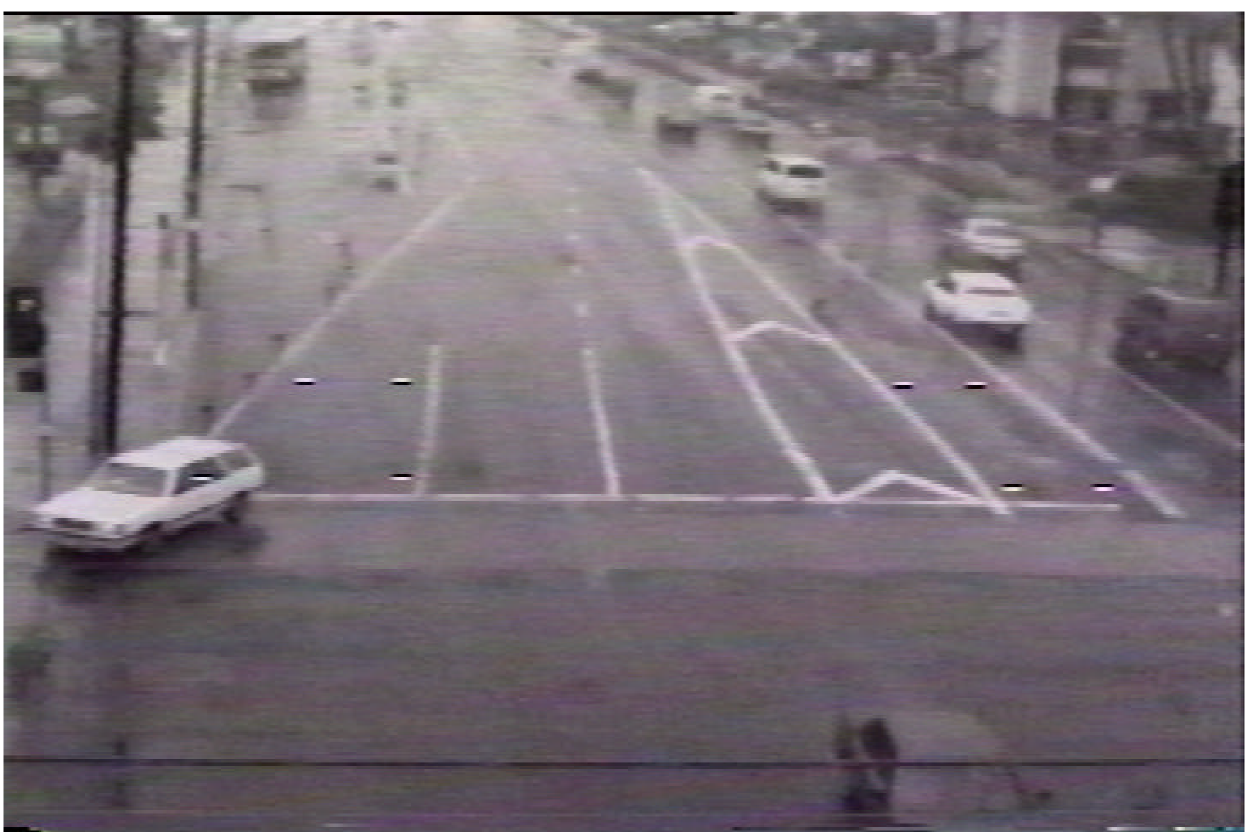
Event Class 2: Detection w/ Latch

Location: Harbor & Katella, NB

Date/Time: 11 December '96, 11:00

Site Plan:



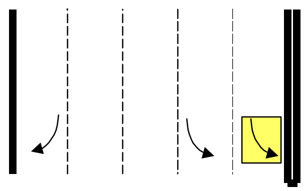


Event Class 3: Multiple Detection

Location: Harbor & Katella, SB

Date/Time: 17 December ‘96, 11:00

Site Plan:

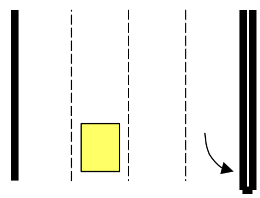


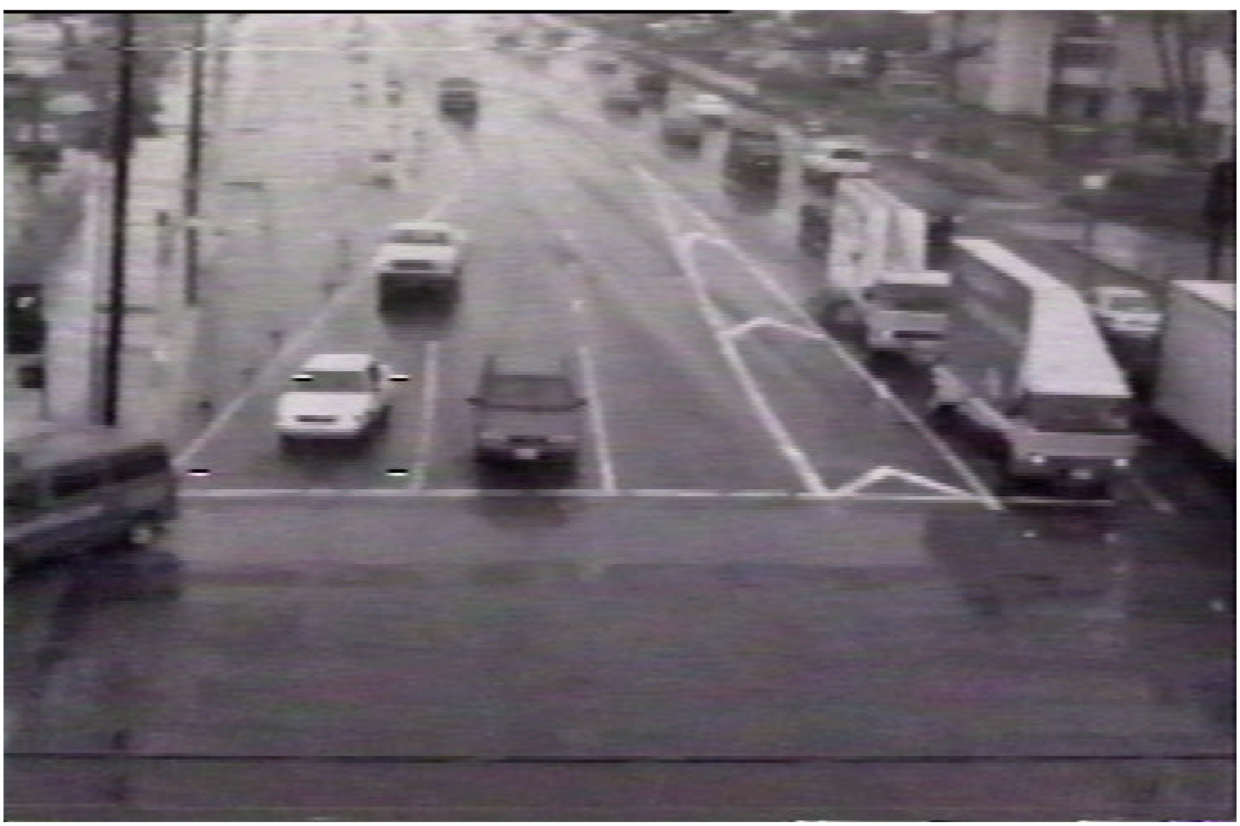
Event Class 4: Failure to Detect

Location: Harbor & Katella, NB

Date/Time: 11 December '96, 11:00

Site Plan:



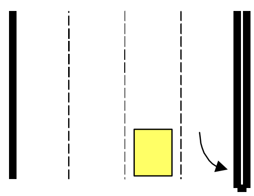


Event Class 5: Dropped After Detection

Location: Harbor & Katella, NB

Date/Time: 11 December '96, 11:00

Site Plan:

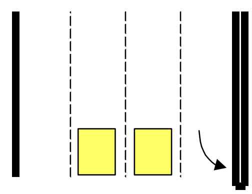


Event Class 6: Tailgate (Failure to Count Subsequent Vehicles)

Location: Harbor & Katella, NB

Date/Time: 17 December '96, 6:00

Site Plan:

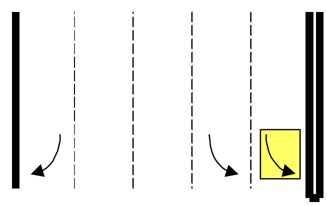


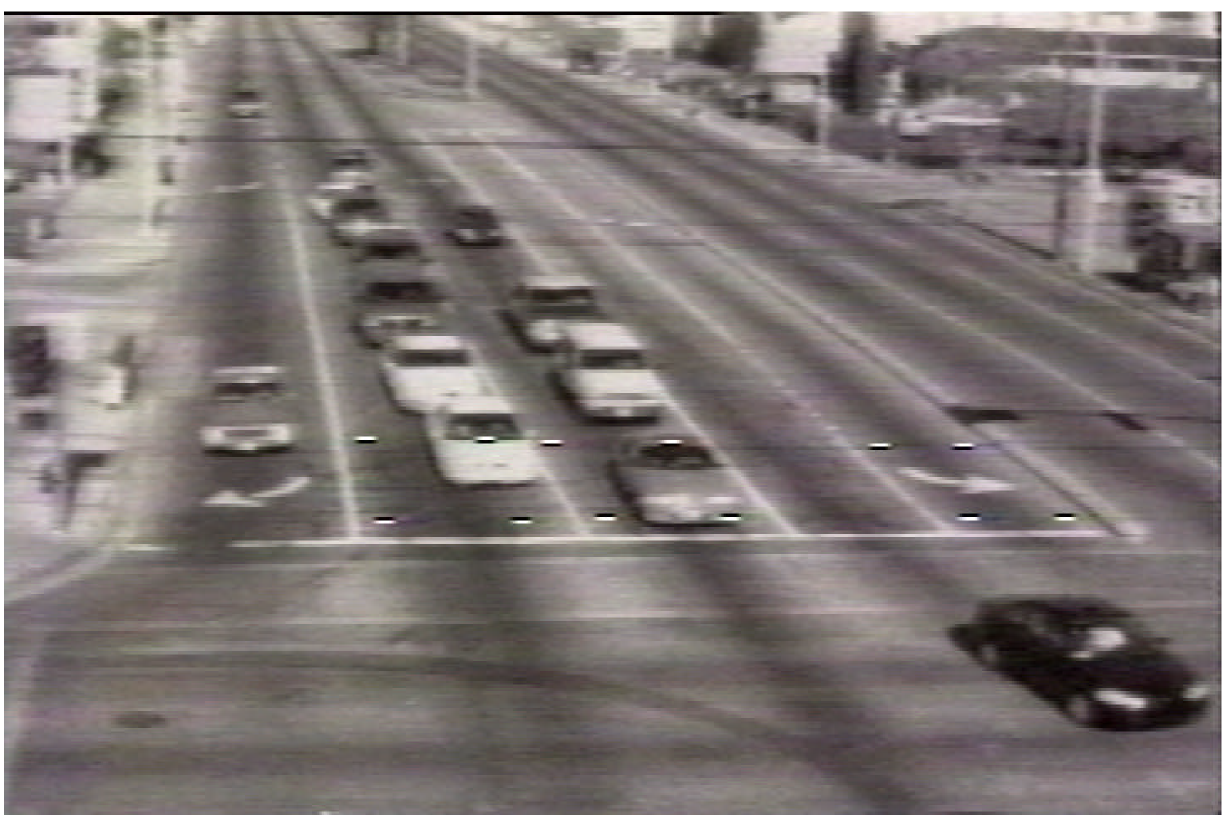
Event Class 7: Tailgate w/ Latch
(Tailgate with Latch after Final Vehicle)

Location: Harbor & Katella, SB

Date/Time: 17 December ‘96, 11:00

Site Plan:



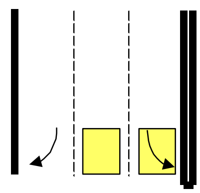


Event Class 8: False Detection

Location: Freedman & Clementine, NB

Date/Time: 17 December ‘96, 11:00

Site Plan:

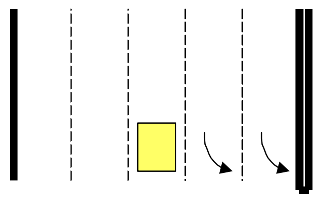


Event Class 9: False Detection w/ Latch

Location: Harbor & Katella, EB

Date/Time: 11 December '96, 17:00

Site Plan:



Vehicle Detection Test Results

The following pages present the results of vehicle detection accuracy tests with respect to the implementable test suite conditions (1,2,4,5,6,7,8,9,12,14,19 and 20). "Total Detections" refers to the sum of the left column, which are all vehicle detections reported, either correctly or incorrectly, by the VTDS. Detection class results shown in ***bold italics*** represent actual vehicles that were either detected (left column) or not detected (right column) by the VTDS. Detection class results in the left column which are not shown in bold italics represent non-existent vehicles detected by the VTDS. A complete breakdown of the data for each test condition follows each summary.

Test Condition 1

Clear, Overhead Sun, LOS A-B

15 Minutes***, 32 Actual Vehicles***

Correct Detection: 26

Detection with Latch: 0

Dropped After Detection: 0

Multiple Detections: 0

False Detection: 5

False Detection with Latch: 0

Failure to Detect: 1

Tailgate: 5

Tailgate with Latch: 0

Total Detections: 31

	Lane 1	Lane 2	All Lanes	All Lanes
Vehicle Detection	Through + Right	Through		% of Actual Vehicles
Correct Detection	10	16	26	81.3%
Detection w/ Latch	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	0	0.0%
Failure to Detect	0	1	1	3.1%
Dropped after Detection	0	0	0	0.0%
Tailgate	0	5	5	15.6%
Tailgate w/ Latch	0	0	0	0.0%
False Detection	0	5	5	15.6%
False Detection w/ Latch	0	0	0	0.0%
Total Detections	10	21	31	96.9%
Actual Vehicles	10	22	32	100.0%

<u>Test Condition 2</u>

Clear, Overhead Sun, LOS C-D

15 Minutes**, *210 Actual Vehicles***

Correct Detection: 173

Detection with Latch: 5

Dropped After Detection: 1

Multiple Detections: 2

False Detection: 20

False Detection with Latch: 0

Failure to Detect: 14

Tailgate: 15

Tailgate with Latch: 2

Total Detections: 201

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Through	Lane 4 Left Turn	Lane 5 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	29	76	55	10	3	173	82.4%
Detection w/ Latch	0	0	0		5	5	2.4%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	2	0	0	2	1.0%
Failure to Detect	4	2	6	0	2	14	6.7%
Dropped after Detection	0	0	0	0	1	1	0.5%
Tailgate	7	4	2	1	1	15	7.1%
Tailgate w/ Latch	0	0	0	0	2	2	1.0%
False Detection	1	1	4	6	8	20	9.5%
False Detection w/ Latch	0	0	0	0	0	0	0.0%
Total Detections	30	77	61	16	17	201	95.7%
Actual Vehicles	40	82	63	11	14	210	100.0%

<u>**Test Condition 4**</u>

Clear, Transverse Sun, LOS B-E

15 Minutes, ***183 Actual Vehicles***

Correct Detection: 137

Detection with Latch: 0

Dropped After Detection: 0

Multiple Detections: 0

False Detection: 6

False Detection with Latch: 0

Failure to Detect: 44

Tailgate: 2

Tailgate with Latch: 0

Total Detections: 143

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	62	65	10	137	74.9%
Detection w/ Latch	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	0	0	0.0%
Failure to Detect	18	24	2	44	24.0%
Dropped after Detection	0	0	0	0	0.0%
Tailgate	1	1	0	2	1.1%
Tailgate w/ Latch	0	0	0	0	0.0%
False Detection	5	1	0	6	3.3%
False Detection w/ Latch	0	0	0	0	0.0%
Total Detections	67	66	10	143	78.1%
Actual Vehicles	81	90	12	183	100.0%

Test Condition 5

Clear, Into Sun, LOS B-E

15 Minutes***, 142 Actual Vehicles***

Correct Detection: 121

Detection with Latch: 0

Dropped After Detection: 4

Multiple Detections: 0

False Detection: 0

False Detection with Latch: 0

Failure to Detect: 3

Tailgate: 14

Tailgate with Latch: 0

Total Detections: 125

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	48	64	9	121	85.2%
Detection w/ Latch	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	0	0	0.0%
Failure to Detect	0	0	3	3	2.1%
Dropped after Detection	1	2	1	4	2.8%
Tailgate	5	8	1	14	9.9%
Tailgate w/ Latch	0	0	0	0	0.0%
False Detection	0	0	0	0	0.0%
False Detection w/ Latch	0	0	0	0	0.0%
Total Detections	49	66	10	125	88.0%
Actual Vehicles	54	74	14	142	100.0%

Test Condition 6

Clear, Low Light, LOS B-E

15 Minutes***, 130 Actual Vehicles***

Correct Detection: 59

Detection with Latch: 0

Dropped After Detection: 8

Multiple Detections: 11

False Detection: 4

False Detection with Latch: 0

Failure to Detect: 42

Tailgate: 21

Tailgate with Latch: 0

Total Detections: 82

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Through	Lane 4 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	13	15	25	6	59	45.4%
Detection w/ Latch	0	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	1	6	2	2	11	8.5%
Failure to Detect	6	18	14	4	42	32.3%
Dropped after Detection	1	4	1	2	8	6.2%
Tailgate	4	7	10	0	21	16.2%
Tailgate w/ Latch	0	0	0	0	0	0.0%
False Detection	1	3	0	0	4	3.1%
False Detection w/ Latch	0	0	0	0	0	0.0%
Total Detections	16	28	28	10	82	63.1%
Actual Vehicles	24	44	50	12	130	100.0%

Test Condition 7

Clear, Night, LOS B-E

15 Minutes***, 254 Actual Vehicles***

Correct Detection: 142

Detection with Latch: 0

Dropped After Detection: 7

Multiple Detections: 34

False Detection: 22

False Detection with Latch: 0

Failure to Detect: 44

Tailgate: 61

Tailgate with Latch: 0

Total Detections: 205

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Through	Lane 4 Left Turn	Lane 5 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	34	44	24	14	26	142	55.9%
Detection w/ Latch	0	0	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	1	29	3	1	0	34	13.4%
Failure to Detect	17	12	3	6	6	44	17.3%
Dropped after Detection	5	1	1	0	0	7	2.8%
Tailgate	13	9	18	11	10	61	24.0%
Tailgate w/ Latch	0	0	0	0	0	0	0.0%
False Detection	3	4	8	6	1	22	8.7%
False Detection w/ Latch	0	0	0	0	0	0	0.0%
Total Detections	43	78	36	21	27	205	80.7%
Actual Vehicles	69	66	46	31	42	254	100.0%

<u>Test Condition 8</u>

Rain, Day, LOS B-E

15 Minutes**, *213 Actual Vehicles***

Correct Detection: 104

Detection with Latch: 24

Dropped After Detection: 10

Multiple Detections: 13

False Detection: 3

False Detection with Latch: 6

Failure to Detect: 49

Tailgate: 25

Tailgate with Latch: 1

Total Detections: 160

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Through	Lane 4 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	28	27	33	16	104	48.8%
Detection w/ Latch	16	3	2	3	24	11.3%
Multiple Detections (Additional detections of correctly detected vehicle)	2	4	3	4	13	6.1%
Failure to Detect	4	19	17	9	49	23.0%
Dropped after Detection	1	2	3	4	10	4.7%
Tailgate	8	7	7	3	25	11.7%
Tailgate w/ Latch	0	0	0	1	1	0.5%
False Detection	0	1	0	2	3	1.4%
False Detection w/ Latch	2	2	0	2	6	2.8%
Total Detections	49	39	41	31	160	75.1%
Actual Vehicles	57	58	62	36	213	100.0%

Test Condition 9

Rain, Night, LOS B-E

15 Minutes**, *446 Actual Vehicles***

Correct Detection: 272

Detection with Latch: 1

Dropped After Detection: 14

Multiple Detections: 10

False Detection: 16

False Detection with Latch: 8

Failure to Detect: 46

Tailgate: 111

Tailgate with Latch: 2

Total Detections: 321

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	All Lanes	All Lanes
Vehicle Detection	Through + Right	Through	Through	Left Turn	Left Turn		% of Actual Vehicles
Correct Detection	77	116	45	21	13	272	61.0%
Detection w/ Latch	0	0	1	0	0	1	0.2%
Multiple Detections (Additional detections of correctly detected vehicle)	2	0	6	0	2	10	2.2%
Failure to Detect	12	17	10	2	5	46	10.3%
Dropped after Detection	1	4	3	0	6	14	3.1%
Tailgate	26	4	42	21	18	111	24.9%
Tailgate w/ Latch	0	0	2	0	0	2	0.4%
False Detection	1	8	2	4	1	16	3.6%
False Detection w/ Latch	0	0	8	0	0	8	1.8%
Total Detections	81	128	65	25	22	321	72.0%
Actual Vehicles	116	141	103	44	42	446	100.0%

Test Condition 12

Clear, Overhead Sun, LOS B-E, Wind Vibration

15 Minutes**, *211 Actual Vehicles***

Correct Detection: 129

Detection with Latch: 0

Dropped After Detection: 8

Multiple Detections: 5

False Detection: 15

False Detection with Latch: 0

Failure to Detect: 55

Tailgate: 19

Tailgate with Latch: 0

Total Detections: 157

	Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	All Lanes	All Lanes
Vehicle Detection	Through + Right	Through	Through	Left Turn	Left Turn		% of Actual Vehicles
Correct Detection	42	37	35	13	2	129	61.1%
Detection w/ Latch	0	0	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	3	2	0	0	0	5	2.4%
Failure to Detect	6	9	25	6	9	55	26.1%
Dropped after Detection	0	2	3	2	1	8	3.8%
Tailgate	14	4	0	0	1	19	9.0%
Tailgate w/ Latch	0	0	0	0	0	0	0.0%
False Detection	1	3	2	5	4	15	7.1%
False Detection w/ Latch	0	0	0	0	0	0	0.0%
Total Detections	46	44	40	20	7	157	74.4%
Actual Vehicles	62	52	63	21	13	211	100.0%

Test Condition 14

Clear, Overhead Sun, LOS B-E, EM Noise

15 Minutes**, *205 Actual Vehicles***

Correct Detection: 171

Detection with Latch: 1

Dropped After Detection: 0

Multiple Detections: 5

False Detection: 11

False Detection with Latch: 2

Failure to Detect: 6

Tailgate: 27

Tailgate with Latch: 0

Total Detections: 190

Vehicle Detection	Lane 1 Through + Right	Lane 2 Through	Lane 3 Through	Lane 4 Left Turn	Lane 5 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	26	75	59	7	4	171	83.4%
Detection w/ Latch	0	0	0	0	1	1	0.5%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	0	0	5	5	2.4%
Failure to Detect	2	0	1	1	2	6	2.9%
Dropped after Detection	0	0	0	0	0	0	0.0%
Tailgate	12	7	5	1	2	27	13.2%
Tailgate w/ Latch	0	0	0	0	0	0	0.0%
False Detection	1	1	2	4	3	11	5.4%
False Detection w/ Latch	0	0	0	0	2	2	1.0%
Total Detections	27	76	61	11	15	190	92.7%
Actual Vehicles	40	82	65	9	9	205	100.0%

Test Condition 19

Clear, Overhead Sun, LOS B-E, Overhead Wires in View

15 Minutes***, 51 Actual Vehicles***

Correct Detection: 22

Detection with Latch: 0

Dropped After Detection: 2

Multiple Detections: 2

False Detection: 3

False Detection with Latch: 1

Failure to Detect: 5

Tailgate: 15

Tailgate with Latch: 7

Total Detections: 30

Vehicle Detection	Lane 1 Right Turn	Lane 2 Through	Lane 3 Left Turn	All Lanes	All Lanes % of Actual Vehicles
Correct Detection	9	6	7	22	43.1%
Detection w/ Latch	0	0	0	0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)	0	0	2	2	3.9%
Failure to Detect	1	0	4	5	9.8%
Dropped after Detection	0	1	1	2	3.9%
Tailgate	4	5	6	15	29.4%
Tailgate w/ Latch	0	3	4	7	13.7%
False Detection	3	0	0	3	5.9%
False Detection w/ Latch	0	1	0	1	2.0%
Total Detections	12	8	10	30	58.8%
Actual Vehicles	14	15	22	51	100.0%

<u>Test Condition 20</u>

Clear, Overhead Sun, LOS A-B, Color Camera

15 Minutes**, *26 Actual Vehicles***

Correct Detection: 22

Detection with Latch: 0

Dropped After Detection: 0

Multiple Detections: 0

False Detection: 500

False Detection with Latch: 0

Failure to Detect: 4

Tailgate: 0

Tailgate with Latch: 0

Total Detections: 522

	Lane 1	Lane 2	Lane 3	All Lanes	All Lanes
Vehicle Detection	Through + Right	Through	Left Turn		% of Actual Vehicles
Correct Detection	7	8	7	22	84.6%
Detection w/ Latch				0	0.0%
Multiple Detections (Additional detections of correctly detected vehicle)				0	0.0%
Failure to Detect		3	1	4	15.4%
Dropped after Detection				0	0.0%
Tailgate				0	0.0%
Tailgate w/ Latch				0	0.0%
False Detection	5	161	334	500	1923.1%
False Detection w/ Latch				0	0.0%
Total Detections	12	169	341	522	2007.7%
Actual Vehicles	7	11	8	26	100.0%

Phase Actuation Test Procedures

Six **phase detection event** classes were identified. Phase detection event classes are recorded once for each main phase applicable to the selected approach at the intersection under test. For a simple intersection, this would be the red and green phases.

For the selected intersection approach, we treat individually the set (possibly several lanes in set) of through lanes and, if present, the set of protected left turn lanes. All lanes in each approach (through set or left set) are logically OR'ed together for this analysis. This means that a detection event is recorded whenever a vehicle is detected at any window in the set. Thus, detection of a vehicle in any lane of the approach set constitutes a valid detection event for that approach.

We subdivide the six phase detection events into three types for each of the two main signal intervals possible on each applicable approach (through or left turn). Each phase detection event is defined below and illustrated with a sample digitized video frame from the Test Suite.

Red Interval (Effecting Actuation of Red/Green Transition)

1. Correct actuation (Correct).

During red interval, detection within one second of arrival of first vehicle, and detection held constant by logical OR of all lanes until observed R/G transition.

2. Failure to actuate correctly (Fail).

During red interval, first vehicle not detected within one second of arrival or, after initial detection, logical OR of detection zones for all waiting vehicles FALSE at any time prior to observed R/G transition.

3. False actuation (False).

During red interval, when no vehicles are present in any detection zone, detection occurs, either continuous or intermittent.

Note that both (2) and (3) **(Fail and False)** can occur during the same interval.

Green Interval (Effecting Actuation of Green/Red Transition)

4. Correct green extension.

During green interval, every vehicle or platoon* is detected and no false detections occur.

5. Potential failure to extend green.

During green interval, one or more vehicle(s) or platoon(s)* was not detected.

6. Potentially false green extension.

During green interval, detection occurred when no vehicle or vehicles was/were present.

* A platoon is defined for this purpose as a set of vehicles separated by less than one second, even if the vehicles are in different lanes within the approach set.

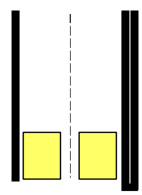
Note that both (2) and (3) **(Fail and False)** can occur during the same interval.

Phase Detection Class 1:
Red Interval (Call for R/G Transition)
Correct Actuation

Location: Freedman & Clementine, EB

Date/Time: 17 December '96, 11:00

Site Plan:

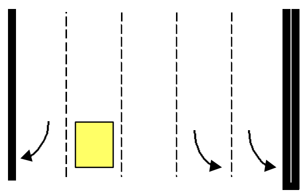


Phase Detection Class 2:
Red Interval (Call for R/G Transition)
Incorrect Actuation:
Failure to Actuate Correctly

Location: Harbor & Katella, SB

Date/Time: 17 December '96, 11:00

Site Plan:

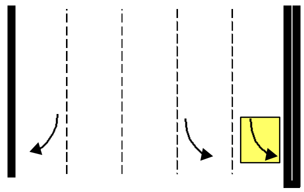


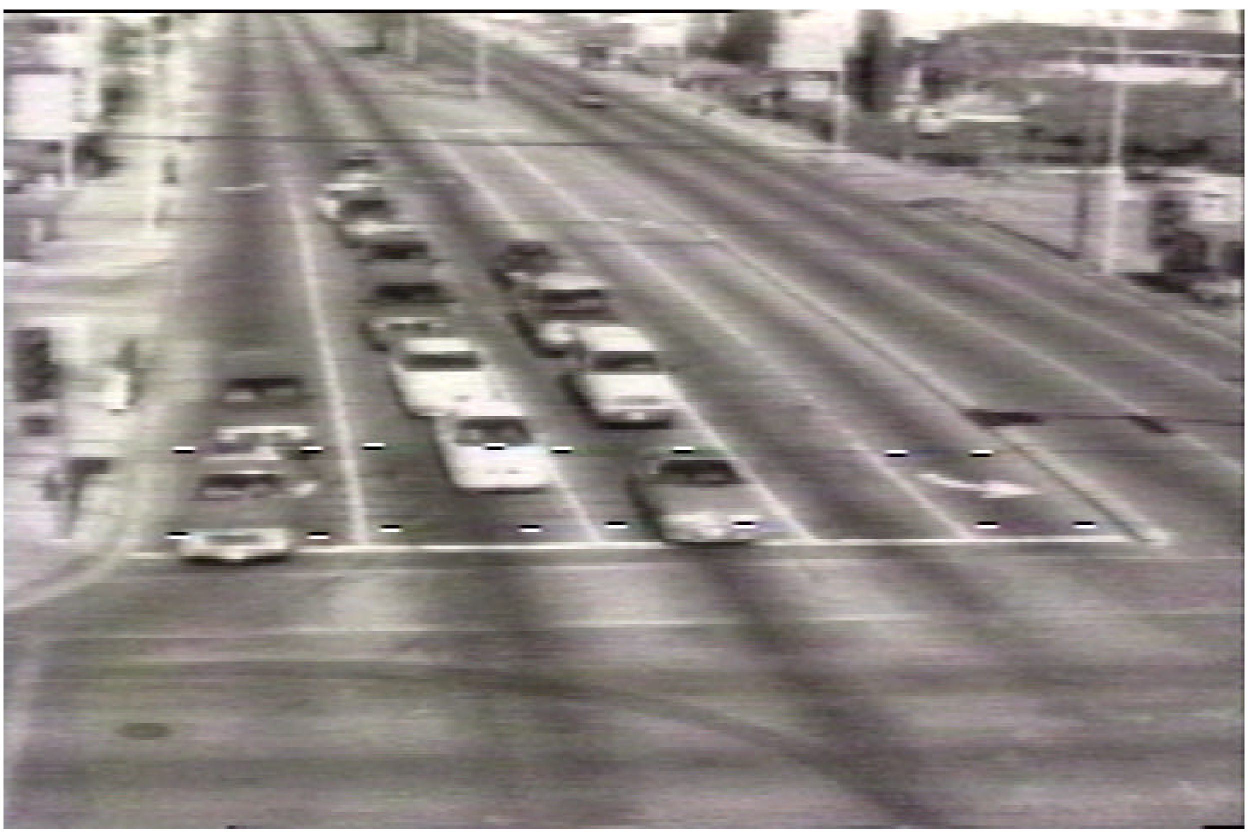
Phase Detection Class 3:
Red Interval (Call for R/G Transition)
Incorrect Actuation:
Potential False Actuation

Location: Harbor & Katella, SB

Date/Time: 17 December ‘96, 11:00

Site Plan:



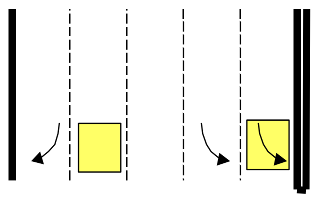


Phase Detection Class 4:
Green Interval (Green Extension)
Correct Extension

Location: Harbor & Katella , SB

Date/Time: 17 December '96, 11:00

Site Plan:

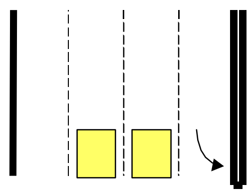


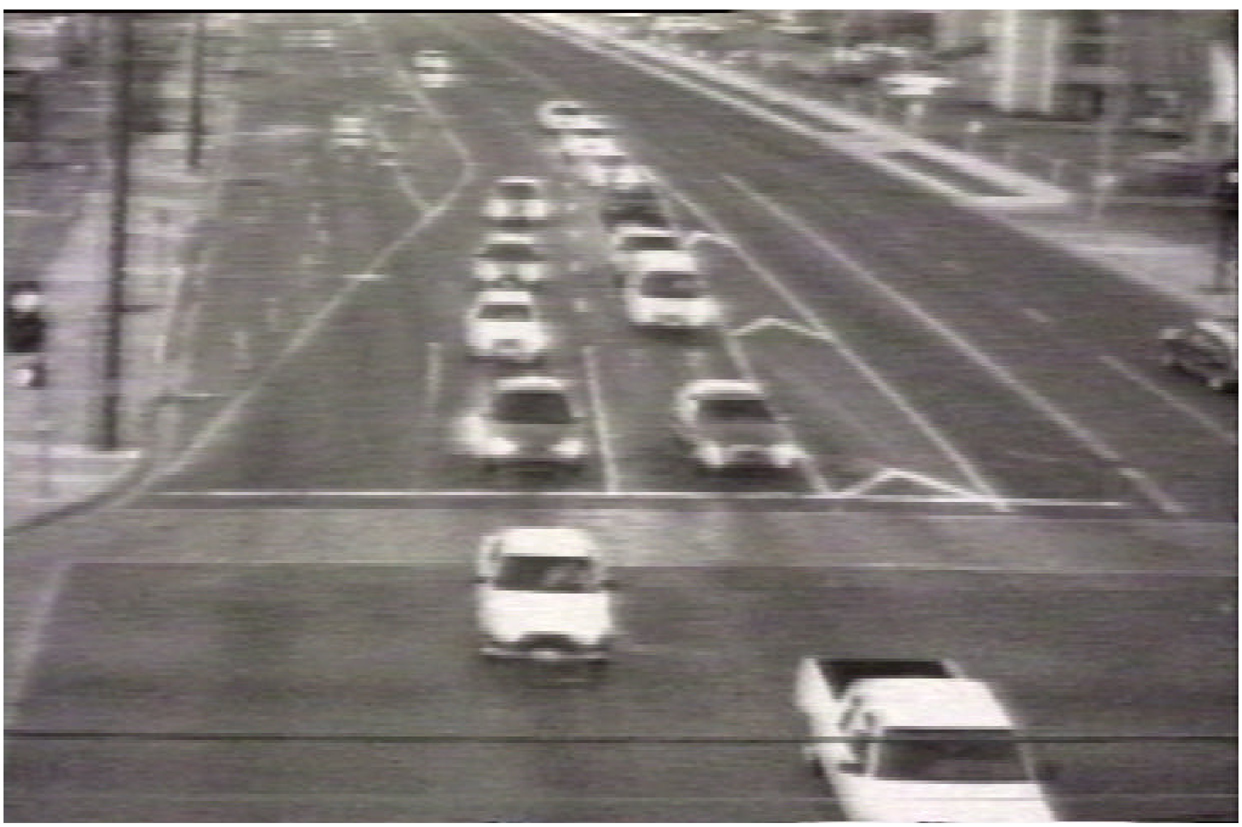
Phase Detection Class 5:
Green Interval (Green Extension)
Incorrect Extension:
Potential Failure to Extend

Location: Harbor & Katella, NB

Date/Time: 17 December '96, 6:00

Site Plan:



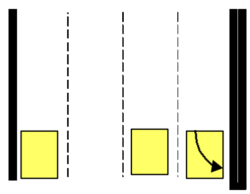


Phase Detection Class 6:
Green Interval (Green Extension)
Incorrect Extension:
Potentially False Green Extension

Location: Harbor & Katella, NB

Date/Time: 11 December ‘96, 11:00

Site Plan:



Phase Actuation Test Results

Test Condition 1
Clear, overhead sun, LOS A-B

15 Minutes, 20 Complete Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	20	0	0	0
Green	19	1	0	0

Left Turn Phase (None at this intersection)

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:15:33	1			1								
0:16:16	1			1								
0:16:59	1			1								
0:17:43	1			1								
0:18:25	1			1								
0:19:00	1			1								
0:19:53	1			1								
0:20:40	1			1								
0:21:26	1			1								
0:22:12	1			1								
0:22:54	1			1								
0:23:39	1			1								
0:24:24	1			1								
0:25:09	1			1								
0:25:52	1				1							
0:26:36	1			1								
0:27:21	1			1								
0:28:04	1			1								
0:28:47	1			1								
0:29:29	1			1								
TOTAL	20	0	0	19	1	0	0	0	0	0	0	0
Total Correct	39											
Total Fail	1											
Total False	0											
% Correct	97.5%											
% Fail	2.5%											
% False	0.0%											

Test Condition 2
Clear, overhead sun, LOS C-D

15 Minutes, 7 Through Cycles, 6 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	7	0	0	0
Green	4	3	0	0
Left Turn Phase				
Red	2	0	3	1
Green	4	0	2	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:45:17	1				1				1	1		
0:47:42	1				1				1	1		
0:50:04	1			1				1	1	1		
0:52:23	1				1		1			1		
0:54:46	1			1			1					1
0:56:58	1			1					1			1
0:59:25	1			1								
TOTAL	7	0	0	4	3	0	2	1	4	4	0	2
Tot Correct	17											
Tot Fail	4											
Tot False	6											
% Correct	63.0%											
% Fail	14.8%											
% False	22.2%											

Test Condition 4
Clear, transverse light, LOS B-E

15 Minutes, 12 Through Cycles, 8 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	9	3	0	0
Green	9	3	0	0
Left Turn Phase				
Red	5	3	0	0
Green	5	3	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:15:00	1				1			1			1	
1:16:35		1			1		1			1		
1:18:22		1		1				1			1	
1:18:53	1			1				1			1	
1:20:46	1			1			1			1		
1:21:43	1			1			1			1		
1:23:00	1			1			1			1		
1:24:34	1			1			1			1		
1:25:39	1			1								
1:26:48		1			1							
1:28:20	1			1								
1:29:14	1			1								
TOTAL	9	3	0	9	3	0	5	3	0	5	3	0
Tot Correct	28											
Tot Fail	12											
Tot False	0											
% Correct	70.0%											
% Fail	30.0%											
% False	0.0%											

Test Condition 5
Clear, into sun, LOS B-E

15 Minutes, 11.5 Through Cycles, 9 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	11	1	0	0
Green	10	1	0	0
Left Turn Phase				
Red	7	2	0	0
Green	5	4	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:15:13	1						1			1		
0:16:34	1			1			1				1	
0:18:42	1			1				1			1	
0:20:04	1			1			1			1		
0:21:27	1			1			1			1		
0:22:17		1			1		1			1		
0:23:35	1			1			1			1		
0:24:35	1			1				1			1	
0:25:59	1			1			1				1	
0:27:41	1			1								
0:28:32	1			1								
0:29:14	1			1								
TOTAL	11	1	0	10	1	0	7	2	0	5	4	0
Tot Correct	33											
Tot Fail	8											
Tot False	0											
% Correct	80.5%											
% Fail	19.5%											
% False	0.0%											

Test Condition 6
Clear, low light, LOS B-E

15 Minutes, 7 Through Cycles, 7 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	4	2	1	0
Green	1	5	0	1
Left Turn Phase				
Red	3	4	0	0
Green	4	3	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:45:58	1				1			1			1	
1:48:09	1				1	1	1			1		
1:50:31			1	1			1			1		
1:52:56	1				1		1			1		
1:55:09	1				1			1		1		
1:57:11		1			1			1			1	
1:59:38		1			1			1			1	
TOTAL	4	2	1	1	6	1	3	4	0	4	3	0
Tot Correct	12											
Tot Fail	15											
Tot False	2											
% Correct	41.4%											
% Fail	51.7%											
% False	6.9%											

Test Condition 7
Clear, night, LOS B-E

15 Minutes, 6 Through Cycles, 6 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	3	1	2	0
Green	2	1	1	2
Left Turn Phase				
Red	5	1	0	0
Green	6	0	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:17:13	1				1	1	1			1		
0:19:34			1		1	1	1			1		
0:22:02		1			1		1			1		
0:24:24	1			1			1			1		
0:26:23			1			1		1		1		
0:28:44	1			1			1			1		
TOTAL	3	1	2	2	3	3	5	1	0	6	0	0
Tot Correct	16											
Tot Fail	5											
Tot False	5											
% Correct	61.5%											
% Fail	19.2%											
% False	19.2%											

Test Condition 8
Rain, day, LOS B-E

15 Minutes, 6 Through Cycles, 6 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	3	0	1	2
Green	0	0	4	2
Left Turn Phase				
Red	0	1	0	5
Green	0	1	0	5

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:45:00	1					1		1	1		1	1
0:47:10		1	1			1		1	1		1	1
0:49:49	1					1		1	1		1	
0:52:15	1				1	1		1	1		1	1
0:54:58		1	1		1	1		1			1	1
0:57:35			1			1		1	1		1	1
TOTAL	3	2	3	0	2	6	0	6	5	0	6	5
Tot Correct	3											
Tot Fail	16											
Tot False	19											
% Correct	7.9%											
% Fail	42.1%											
% False	50.0%											

Test Condition 9
Rain, night, LOS B-E

15 Minutes, 5 Through Cycles, 5 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	1	3	0	1
Green	1	3	1	0
Left Turn Phase				
Red	1	3	1	0
Green	5	0	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:17:04		1				1		1		1		
1:20:02		1	1		1			1		1		
1:22:57		1			1		1			1		
1:25:57	1			1					1	1		
1:28:56		1			1			1		1		
TOTAL	1	4	1	1	3	1	1	3	1	5	0	0
Tot Correct	8											
Tot Fail	10											
Tot False	3											
% Correct	38.1%											
% Fail	47.6%											
% False	14.3%											

Test Condition 12
Clear, overhead sun, LOS B-E, wind vibration

15 Minutes, 5 Through Cycles, 6 Left Turn Cycles

	Correct	**Fail**	**False**	**Fail and False**
Through Phase				
Red	2	2	1	0
Green	1	4	0	0
Left Turn Phase				
Red	0	3	1	2
Green	1	4	0	1

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:46:34		1			1			1			1	
1:48:56		1			1			1			1	1
1:53:44			1		1			1	1		1	
1:56:03	1			1					1	1		
1:58:20	1				1			1	1		1	
								1			1	
TOTAL	2	2	1	1	4	0	0	5	3	1	5	1
Tot Correct	4											
Tot Fail	16											
Tot False	5											
% Correct	16.0%											
% Fail	64.0%											
% False	20.0%											

Test Condition 14
Clear, overhead sun, LOS B-E, EM Noise

15 Minutes, 7 Through Cycles, 7 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	7	0	0	0
Green	7	0	0	0
Left Turn Phase				
Red	2	1	2	2
Green	3	1	2	1

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:45:37	1			1				1			1	
1:48:02	1			1					1	1		
1:50:23	1			1					1	1		
1:52:42	1			1			1			1		
1:55:06	1			1			1					1
1:57:18	1			1				1	1			1
1:59:47	1			1				1	1		1	1
TOTAL	7	0	0	7	0	0	2	3	4	3	2	3
Tot Correct	19											
Tot Fail	5											
Tot False	7											
% Correct	61.3%											
% Fail	16.1%											
% False	22.6%											

Test Condition 19
Clear, overhead sun, LOS B-E,
overhead wires in view

15 Minutes, 6 Through Cycles, 7 Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	0	2	3	1
Green	3	0	3	0
Left Turn Phase				
Red	2	3	1	1
Green	5	2	0	0

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
0:46:04			1			1	1			1		
0:47:42		1	1			1		1			1	
0:49:16			1			1		1	1	1		
0:52:30			1	1				1		1		
0:53:47		1		1				1		1		
0:58:33		1		1			1				1	
									1	1		
TOTAL	0	3	4	3	0	3	2	4	2	5	2	0
Tot Correct	10											
Tot Fail	9											
Tot False	9											
% Correct	35.7%											
% Fail	32.1%											
% False	32.1%											

Test Condition 20
Clear, overhead sun, LOS A-B, color video camera

15 Minutes, 11 Complete Cycles

	Correct	**Fail**	**False**	**Fail and False**
Through Phase				
Red	1	0	7	3
Green	2	1	6	2

Left Turn Phase (none at this intersection)

TIME	**Thru**	R-G		G-R			**Left**	R-G		G-R		
	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE	Correct	Fail	FALSE
1:17:50		1	1			1						
1:18:31		1	1		1	1						
1:19:13			1			1						
1:22:20			1			1						
1:22:54			1		1	1						
1:26:01			1			1						
1:26:43			1	1								
1:27:40		1	1		1							
1:29:09			1			1						
1:29:37			1			1						
1:29:55	1			1								
TOTAL	1	3	10	2	3	8	0	0	0	0	0	0
Tot Correct	3											
Tot Fail	6											
Tot False	18											
% Correct	11.1%											
% Fail	22.2%											
% False	66.7%											

Overall Performance Test Results

We attempt here to reduce the data from all test conditions into composite metrics indicative of the overall system performance. Normalized overall scores are generated for each detection event class using weightings of each test condition based upon expected environmental and traffic conditions occurring in Anaheim, California over the course of a typical year. The weighting factors are applied to each of the test conditions, such that common conditions of medium traffic, overhead sun light and regular night illumination predominated, while less common conditions such as transitional lighting, rain, and wind were minimized. This score represents our best attempt to fairly portray the large quantity of individual test data in some single composite form. Since the weighting factors applied cannot be entirely objective in their derivation, this overall score should be considered only one view of the data, subject to multiple interpretations.

We begin by recognizing that, over the course of a typical year, some of the conditions in the test suite occur much more often than others. Our objective is to assess and fairly weight a range of conditions, representative of both time-dependent changes and the diversity of traffic conditions, intersection configurations, and camera placements possible within the study area. For example, normal daylight and night conditions predominate, transitional and glare lighting occurs a smaller percentage of the time, while rain and wind conditions are rare. Also, light-to-moderate traffic conditions dominate, especially at night, while heavy traffic occurs only for limited daily periods. Since EM noise, color camera use, and wires in the field of view represent non-ideal deployments, we do not consider these conditions in the overall system assessment. Therefore, the composite result is based upon only 9 of the 12 test suite data sets.

We set forth below a possible set of factors, applied to each test condition, intended to fairly weight the contribution of each to a composite performance metric for each detection event class.

Table 1. Derivation of Weighting Factors for Composite Metrics

			Available Test Data												Total
Illumination	**Hrs/Day**	**% Avg Day**	**TC1**	**TC2**	**TC4**	**TC5**	**TC6**	**TC7**	**TC8**	**TC9**	**TC12**	**TC14**	**TC19**	**TC20**	
Day, overhead/diffuse	7	29.17%	X	X					X		X	X	X	X	
Night	9	37.50%						X		X					
Transverse	4	16.67%			X										
Dawn/Dusk	3	12.50%					X								
Glare	1	4.17%				X									
Traffic															
Light (LOS A-B)	8	33.33%	X												
Moderate (LOS C-D)	2	8.33%		X											
Heavy (LOS E-F)	2	8.33%													
Varied (LOS B-E)	12	50.00%			X	X	X	X	X	X	X	X	X	X	
Environment	**Days/Yr**	**% Avg Year**													
Calm (clear or overcast)	310	84.93%	X	X	X	X	X	X				X	X	X	
Rain (possibly with wind)	30	8.22%							X	X					
Wind (without rain)	20	5.48%									X				
Other (no TC data)	5	1.37%													
Specifications															
Ideal			X	X	X	X	X	X	X	X	X				
Non-ideal												X	X	X	
Composite %			8.26%	2.06%	7.08%	1.77%	5.31%	15.92%	1.20%	1.54%	0.80%	0.00%	0.00%	0.00%	43.94%

These factors are observed estimates only, since the time of transition between dawn/day, day/dusk, dusk/night, etc., are not rigorously established. Also, the annual percentage of time that windy conditions above a certain threshold prevailed, or rain was falling (on an hourly basis) could not be readily determined from published weather data, which is reported in terms of days in which threshold were exceeded or volume (ie., rainfall) rather than net hours in which the condition was observed. However, we did not consider the exactness of this hourly distribution to be critical to the validity of the resultant conclusion. For comparative purposes, we define an *average test day* based upon the distribution in Table 1 and summarized in Table 2 below.

Table 2. Summary of Time-dependent Weighting Factors for Composite Performance Metrics

Test Cond No. (i)	Condition Description	Yearly Avg Hrs / Day	Normalized Weighting Factor (a)
1	overhead sun, light traffic	4	0.1879
2	overhead sun, moderate traffic	4	0.0470
4	transverse sun, varied traffic	4	0.1611
5	sun glare, varied traffic	1	0.0403
6	dawn/dusk, varied traffic	2	0.1208
7	night, varied traffic	8	0.3624
8	rain, mid-day, varied traffic	0.25	0.0273
9	rain, night, varied traffic	0.25	0.0351
12	wind, mid-day, varied traffic	0.50	0.0182
14	EM noise, mid-day, varied traffic	N/A	0
19	wires in view, mid-day, varied traffic	N/A	0
20	color camera, mid-day, varied traffic	N/A	0

The *yearly average hours per day* column represents the average number of hours per day, over a typical year, during which the test condition is assumed to be valid. The *normalized weighting factor* divides the average number of hours per day for each condition by 24 hours. All possible daily conditions are not represented in our data set, due to the restrictions of the experimental site, and seasonal and traffic limitations. However, we extrapolate from the data available to reasonably approximate typical conditions at the three test intersections in Anaheim.

The resultant formula representative of overall performance based upon the above weighting factors is given by:

$$\mathit{Composite\,Score} = \sum_i a_i c_i$$

$$= 0.1879c_1 + 0.0470c_2 + 0.1611c_4 + 0.403c_5 + 0.1208c_6 + 0.3624c_7 + 0.0273c_8 + 0.0351c_9 + 0.0182c_{12}$$

where c_i are the percentage data for the detection metric of interest during the i^{th} test condition.

Overall Vehicle Detection Results

We present below a reduction of the *Vehicle Detection* data utilizing the above weighting factors to arrive at composite performance metrics appropriate to answer several typical questions about the overall system performance. First, we present the weighted average results for each Detection Event Class, using the above weighting factors for each test condition.

Vehicle Detection Overall Score

Normalized to Number of Actual Vehicles

9 Conditions Weighted, 135 Minutes, 1821 Actual Vehicles

Correct Detection: 65.0%
Detection w/Latch: 0.42%
Multiple Detections: 6.2%
Dropped After Detection: 2.2%
False Detection: 7.7%
False Detection w/Latch: 0.1%

Failure to Detect: 16.5%
Tailgate: 15.9%
Tailgate w/Latch: 0.1%

Now we postulate and attempt to answer several possible questions based upon this composite data:

1. *As a percentage of all vehicles flowing through detection windows at an intersection, how many are correctly individually detected, just as they would be detected by a properly working loop detector?*

To answer this question, we consider here the ability of the system under test to report the presence of a vehicle when actually present in a detection window, and to not report a vehicle present when no vehicle is actually present in the detection zone. The gap between subsequent vehicles in a platoon must be correctly detected, so that the system would correctly *count* vehicles passing through a detection window. For this metric, c_i for each of the i test conditions is just the percentage of vehicles passing through each detection window that were logged in the “Correct Detection” vehicle detection event class. Note, however, that although this metric assesses the percentage of vehicles that would be correctly added to a count, it is not a metric of the accuracy of the counting ability of the system, since the count can be incorrect in both an additive and subtractive sense, i.e., false detections and multiple detections can contribute to higher-that-actual count results.

Answer: 65.0%.

2. *As a percentage of all vehicles flowing through detection windows at a signalized intersection, how many are detected adequately for purposes of proper actuation of the signal phases?*

For proper actuation of signal phases, it is only necessary for the system to correctly identify the presence or proximity of vehicles relative to the detection zone. The system is not penalized for inability to distinguish between a sequence of closely spaced vehicles. Therefore c_i for each condition is the total of the “Correct Detection” and the “Tailgate” detection event classes.

Answer: 80.9%.

3. *As a percentage of the total number of actual vehicles flowing through detection windows at a signalized intersection, how often are vehicles “missed” such that proper actuation of the red/green signal phase transition might not occur?*

At the test intersections in Anaheim, the signal controllers do not latch the presence signal from a vehicle detected during the red interval. This assures against wasting a green phase when a vehicle may have already turned right during the red, or left the approach for some reason such as running the light. Therefore, a “miss” can occur if a vehicle is either not detected, or is initially detected and then dropped while waiting in the detection window. Not included in this total are vehicles not individually detected in platoons in platoons (Tailgate event class) or following latched detections (Detection with Latch, False Detection with Latch, or

Tailgate with Latch classes) since these do not represent vehicles waiting during a red interval. C_i for each condition is the total of the “Failure to Detect” and the “Dropped After Detection” event classes.

Answer: 18.7%

4. *As a percentage of the total number of actual vehicles flowing through detection windows at a signalized intersection, how many vehicles are “missed” in such a way that proper green extension might not occur?*

In this case, we consider only vehicles not presence detected while in motion through a detection window. The system is not penalized for tailgates or latches since we are only concerned with the ability of the system to report to report the presence of any vehicles flowing through the detection window at the intersection. C_i for each condition comes only from the “Failure to Detect” event class.

Answer: 16.5%

5. *As a percentage of the total number of actual vehicles flowing through detection windows at a signalized intersection, how many detections are incorrectly reported such that the green interval could possibly be incorrectly extended?*

We consider here events in which no vehicle was ever present in the zone to warrant a detection reported by the system. Thus C_i includes the “False Detection” event class, and the three latch condition classes, but does not include the “Multiple Detection” event class, since this occurs only when an actual vehicle is stopped in a detection window, and is intermittently detected/not detected.

Answer: 8.3%

6. *As a percentage of the total number of actual vehicles flowing through detection windows at a signalized intersection, how many detections are incorrectly reported such that actuation of the red/green phase transition might incorrectly occur?*

We consider events in which no vehicle is present in the zone to warrant a detection reported by the system. Therefore, the criteria are the same as for the previous false green extension case. C_i includes the “False Detection” event class, and the three latch condition classes, but does not include the “Multiple Detection” or “Tailgate” event classes. Multiple detection is excluded since this occurs only when an actual vehicle is stopped in a detection window, and is intermittently detected/not detected.   Tailgates are excluded because they are valid presence detections as discussed above. However, latches can leave a window in an actuated state when no vehicle is present. If the period of latch extends into the red interval, the presence of a non-existent vehicle may be reported.

Answer: 8.3%

7. *What is the tendency of the system to overcount vehicles, as a percentage of the total number of actual vehicles flowing through detection windows?*

This figure represents the extent to which a vehicle count provided by the system could be above the correct number. It is not mitigated by the concomitant tendency of the vehicle to undercount due to failures to detect vehicles. The case includes those event classes in which the vehicle count would be incorrectly incremented. Thus C_i includes the “False Detection”, “False Detection with Latch”, and “Multiple Detection” event classes only.

Answer: 14.0%

8. *What is the tendency of the system to undercount vehicles, as a percentage of the total number of actual vehicles flowing through detection windows?*

This figure represents the extent to which a vehicle count provided by the system could be below the correct number. It is not mitigated by the concomitant tendency of the vehicle to overcount due to false or multiple detections. The case includes those event classes in which the vehicle count would be not be incremented when it should have been. c_i includes the "Failure to Detect", "Tailgate" and "Tailgate with Latch" event classes only.

Answer: 32.5%

Overall Phase Actuation Results

We consider here a reduction of the *Phase Actuation Accuracy* data utilizing the above weighting factors to arrive at detection performance metrics appropriate to answer the four key questions associated with proper signal phase actuation listed below. We present the results of combining the data on a percentage basis, using the above weighting factors, for each Detection Event Class across the admitted nine test conditions:

Since Phase Actuation Accuracy is a property of the overall intersection and traffic, not solely the a function of the detection device, the data is reported as the number of elapsed signal phases that were correctly or incorrectly actuated using the detection system as the sensor. In reducing these totals to percentages, we divide by the total number of elapsed signal phases during the period of the test. Recall that we subdivide the six phase detection events into three types for each of the two main signal intervals possible on each applicable approach (through or left turn):

Red Interval (Effecting Actuation of Red/Green Transition):

1. Correct actuation (Correct).
2. Failure to actuate correctly (Fail).
3. False actuation (False).
4. Both Failure to actuate and false actuation during same interval.

Green Interval (Effecting Actuation of Green/Red Transition):

1. Correct green extension.
2. Potential failure to extend green.
3. Potentially false green extension.
4. Both potential failure to extend and potential false extension during same interval.

Note that all detectors on a given approach are considered to be logically OR'ed together for purposes of this assessment. This permits a red/green transition to be reported as correctly actuated, even if only a single vehicle out of several is detected waiting at the stop bar. However, it also increases the possibility of an incorrect red/green transition or an incorrect green extension if any of the detection windows on the given approach are falsely triggered during the respective phases. A "Correct Actuation" is reported for the interval only if no errors (Failure to Actuate or False Actuation) occurred at any time during the interval. If either a "Fail" or "False" (one or the other, not both) occurred at any time during the interval, this is reported in the respective category. A "Fail" and a "False" can occur during the same interval, since a false vehicle detection and a failure to detect a vehicle can occur during the duration of either a red or green single interval. If both a "Fail" and a "False" occurred during the same interval, this is reported in the "Fail and False" category. The sum of the "Fail", "False" and "Fail and False" categories represents the total percentage of all elapsed cycles in which error in detection could *potentially* lead to an incorrect control actuation. It was not possible to assess whether an incorrect control action did indeed follow, since at none of the three test intersections was the VTDS actually driving the signal controller.

Normalized Overall Score
Phase Actuation

9 Conditions Weighted,
80 Total Through Cycles, 53 Total Left Turn Cycles

	Correct	Fail	False	Fail and False
Through Phase				
Red	67.1%	16.7%	14.2%	1.6%
Green	51.2%	25.6%	8.5%	14.7%
Left Turn Phase*				
Red	62.6%	28.8%	4.1%	4.5%
Green	76.8%	18.1%	1.9%	3.2%

* For the Left Turn Phase calculations, the normalized weighting factors were corrected to compensate for the lack of a left turn phase during TC1. This was accomplished by removing TC1 from the overall test basis and re-normalizing all factors based upon the remaining test conditions.

The overall concerns of traffic engineering personnel we interviewed in Anaheim and other municipalities can be reduced to the general question "Do the signal controls at the intersection actuate properly when using the video detection system to replace inductive loops?" Without actually putting the video detection system in the control loop as the primary sensor, it is not possible to answer the question based upon an actual controller response. However, we attempt to *predict* the answer to this question using the composite phase actuation results above. As a weighted average percentage of all elapsed cycles during the test periods, how many cycles would have been assured to be actuated correctly because the detector functioned in a way equivalent to a deployment of correctly operating loop detectors. Conversely, how many cycles could possibly be incorrect due to incorrect detection at one or more times during a signal interval.

Again, note that this approach considers the logical OR of all detection window signals. We calculate the "Correct" cases by averaging entries in the "Correct" column, which effectively applies equal weights to control actions on either through and left turn phases. Missed detections during either a red or green interval are tolerated if detection is triggered by another vehicle at any detection window on the given approach within +/- 1 second. False detections during either a red or green interval are tolerated if actuation is triggered by an actual vehicle at any other detector on the approach within +/- 1 second. Note again that *it is possible, in each case, that the cycle may sill be actuated correctly, even if vehicle detection was not correct in all cases over the interval.*

Overall phase actuation accuracy questions may be answered in terms of four basic actuation concerns effecting traffic regulated by the signal control at the intersection:

Situation	% Cycles with Completely Correct Actuation	% Cycles Actuated, either correctly or due to false detection.	% Cycles with Possible Incorrect Actuation
Data Basis:	% Correct	% Correct + % False + % Fail & False	% False +% Fail & False
1. Vehicle(s) waiting at red for green; proper actuation of green.	64.9%	77.1%	-----
2. No vehicle(s) waiting at red; possible unjustified actuation of green.	-----	-----	24.4%
3. Vehicle(s) flowing on green; proper extension of green.	64.0%	78.2%	-----
4. No vehicle(s) flowing on green; possible unjustified green extension.	-----	-----	14.2%

User Interface

According to information provided by Odetics, the Vantage VTDS utilizes a dedicated Texas Instruments 320C-series DSP microprocessor. It dos not appear to be running a general-purpose operating system. The user interface display incorporates block characters overlaid on the video scene as displayed on a conventional EIA-RS170 (CCTV) monitor. A standard serial-port mouse is use for the positioning of an underscore-type cursor. All selections are made from menus tabs via mouse clicks. No conventional keyboard is used. A hardware reset button is provided for initialization and/or restart from fault. A power-on reset mechanism is incorporated so that the system powers up to a working state.

Although somewhat crude by standards of competing systems running windowed operating systems for their user interfaces, we found the VTDS interface to be adequate for all system setup tasks, and in our view, elegant in its simplicity. The lack of an overly-featured user interface is consistent with the advertised efforts of the manufacturer to keep per-unit costs for the system low. Since the system does not require either a computer-type (e.g., VGA) monitor or keyboard, the equipment required for site setup and recalibration following camera realignment is minimized. This adds convenience for field personnel, especially, for example if minor adjustment is needed following camera lens cleaning or if a camera becomes misaligned due to high winds.

Cursor tracking of the mouse movements was without perceptible lag. The screen-displayed menu text consists of black-outlined white block characters. This representation assures that the characters are viewable against either a light or dark video scene background. The characters are quite large with respect to the screen size, primarily to accommodate the resolution of standard EIA-RS170 video display (525 interlaced vertical x 200-400 horizontal lines) which is much poorer than the resolution that PC users have come to expect from computer monitors (VGA=640x480).

We found menu selection of parameters to be logical and easily mastered with minimal instruction. Three-letter abbreviations are used for menu tabs to keep each as narrow as possible on the low-resolution display. Some of the abbreviations were not necessarily intuitive, although all were easily learned. Setup speed is slower than could be attained using a keyboard, but for a system that only uses a mouse for all user input (except reset), the user interface seemed to be well-executed and entirely useable for the task. The selection of each corner of a detection zone requires clicking on a menu plank and then selecting the placement location on the video overlay.

During data collection at Odetics facility, the use of remote communication over the video camera links for setup and configuration of the VTDS was observed, although we could not test this feature with the VTDS unit in our laboratory. This feature could be of considerable convenience in actual deployment, avoiding the need to physically visit the intersection control cabinet to make adjustments.

Another useful feature was the load (LOD) command which gave the system the ability to store and restore setup configurations at a later time.   We used this feature during our testing procedures, but did not specifically evaluate it or any other command features.

The system permits the setup of two detection zone (or window) classes – *detection* or *count*, and provides for two placement optimizations: *approach* and stop bar *detection.* All tests were performed using detection windows located behind the stop bars, located and shaped as we were instructed during training at Odetics and discussed in the provided manuals. Count windows, which are detection windows that also display a cumulative vehicle count next to the window, were not used or tested for accuracy, at the request of Odetics.

Two manuals were provided with the VTDS system:

Operating Instructions Intersection Product, Vantage Video Traffic Detection System VTDS. Manual No. 4836027, Rev. A.   Odetics Copyright 1996. (29 pages) [8]

Installation Guide for the Intersection Product, Video Traffic-Detection System VTDS (Preliminary Print). Manual No. 4836026 Rev. A. 6/96. (55 pages) [9]

Both appear to be PC word-processed, black-and-white photocopied documents, with velo report bindings. Hardware and camera setup and installation is covered adequately in both documents. Detection window setup is dealt with tersely in the operating instructions (page 16), although the sample scene photo on page 17 and Figure 1.1-1 on page 6 of the Installation Guide were helpful and illustrative with regard to the size, shape and proper placement of the windows.

The intersection plan diagrams provided in the installation guide were very descriptive with respect to camera placement requirements. Hardware installation instructions also seemed comprehensive. Power requirements, video cable routing, environmental considerations, and lightning protection procedures are covered.

Copies of both manuals are included in the Appendix of this report.

Product Cost

According to the partners' proposal to the FHWA and the vendor's published promotional information, the Odetics Vantage VTDS is described as a "low-cost system", "for deployment over a wide geographic area", to provide combined "surveillance and control for entire cities and counties". Only one system unit per intersection is required, since the VTDS supports up to four video cameras per unit, covering up to four intersection approaches.

According to Odetic's sales information provided to the City of Anaheim, the cost of each system unit is USD $15,000, and they estimate that a typical contractor would mark up this cost by 15% to cover the cost of installation. Odetics Web-based information indicates the cost per intersection to be $20,000. It is unclear if this includes this cost includes installation, but this would seem to be the case based upon the quote given to the City of Anaheim. Due to the newness of the product, no documented life-cycle costs were available to the best of our knowledge. Although reliable "total" cost information is impossible to obtain for competing products, the quoted per-intersection cost of the VTDS system appears to be average or below average compared with advertised or informally quoted costs for equivalent or similarly capable products.   We make this statement as an informal observation, and not based upon any comprehensive cost comparison.   Direct cost comparisons would be difficult to assess until a complete installation for one or more intersections is package quoted by an installation contractor. System configuration vary widely among similar products, e.g., some complete systems including video cameras, some processing units only, some with and some without video surveillance communications capability, and all with widely varying features. We also note that the VTDS unit we tested is a specialized product, designed only for intersection detection, whereas several competing products (see below) are general-purpose processors with broader monitoring capabilities.

Comparable Commercial and Near-Commercial Products

The use of video-based computer vision for traffic data collection purposes has been commercially viable since approximately 1989[1]. Over twenty-five commercial and near-commercial products are known to be either currently or previously on market or in the late product development stages. A comprehensive summary of the systems available as of 1995/6 is provided in [6].

The deployment of computer vision-based products for the control of signalized intersections is a fairly recent development, with commercial products only available since approximately 1995. It is possible that many such systems are in the development stages, and are not yet publicly offered. The commercially-available systems other than the Odetics VTDS that were are aware of are listed below (in alphabetical order). Selected vendor literature for each system is included in the Appendix. Where available in published form, test results (unverified) for each system are also included in the Appendix. Of the systems listed below, we informally observed that the Econolite system appears to be the market leader in the USA, followed by Devlonics/Trafficon which advertises a large installed base in Europe, and Peek / Video Trak which just recently entered the market.

Computer Recognition Systems (CRS) "Transfo VIVDS". Sheffield, U.K. Available in the USA from Transfomation Systems, Inc. 2537 South Gessner, Suite 212, Houston, Texas.

Devlonics/Trafficon "CCATS Video Image Processor VIP3 Vehicle Presense Detector". Manufactured by Trafficon n.v. Bissegemsestraat 45 B-8501 Heule (Kortrijk) Belgium. Available in the USA from Control Technologies, 2776 S. Financial Ct. Sanford, FL 32773. Phone (407) 330 2800.

The Trafficon CCATS VIP3 is a specialized version of the Trafficon product line of general-purpose traffic monitoring and detection systems. It has apparently undergone extensive testing in Europe (City of Stockholm comparative results included in Appendix). It is compatible with both CCIR (European) and EIA (USA/Japan) video cameras, and is non-camera-specific, allowing existing CCTV deployments to possibly be used (assuming camera placements are adequate). The system also provides real-time compressed video, traffic count, and optional measurement metrics upon request. Interface is via a (non-included) detachable host PC running provided interface software.

A recent entry into the intersection actuation market, with prior products deployed experimentally for traffic monitoring and HOV enforcement. Current test under way in Houston, Texas. Test results and detailed product information not yet available.

Ecolux Corp. (Prototype system) Available from Synchronex, 1199 North 5th St. San Jose, CA 95112 Phone (408) 275 8392 .

Contract recently awarded to deploy and test protytpe system by this manufacture in Redwood City, CA. Unknown if product accommodates intersection control. No published information yet available.

Econolite/ISS "Autoscope 2004". Available from Econolite Control Products, Inc., 3360 E. LaPalma Ave, Anaheim, CA 92806 USA. Phone (714) 630-3700

Econolite offers several Autoscope series products for different purposes. The Autoscope 2004 is specifically marketed for intersection detection, as a replacement of inductive loop detectors. The system is based upon a proprietary undisclosed hardware platform. It's user interface is provided via a separate detachable (not included) host PC which runs their optional "ScopeServer for Windows" software, which provides a full-featured windowed user interface. Variations of the product are available with additional software features: 2004ID includes incident detection capability, 2004LE for direct loop emulation and/or count station emulation. The system is claimed to have the capability to also measure volume, speed, occupancy, headways, queue lengths, and vehicle classification.

Eliop Trafico "EVA". Available from Eliop Trafico, S.A. San Nazario, 1 28002 Madrid, Spain.

The EVA is a dual-purpose product, intended for both freeway data collection and intersection actuation. Video compatibility is PAL (Phase Alternating Line) European standard, but NTSC compatibility is apparently available on request. Deployment in the USA has been limited.

[1] The original US patent related to traffic detection via computer vision was issued to the University of Minnesota in 1988.

Peek "Video Trak-900". Available from Peek Traffic Transit Corporation, 3000 Commonwealth Blvd., Tallahassee, FL 32303 USA. Phone (904) 562 2253.

The Peek Video Trak-900 was designed and is currently deployed for traffic measurement purposes (count, speed, volume) but is currently being advertised and tested for intersection detection also, in conjunction with Peek's intersection signal control products. The system is based on a 3U VME bus architecture, and utilizes a proprietary Sarnoff Pyramid processor. It is intended to serve as a general-purpose video traffic detection platform, and claimed to provide adequate flexibility for a wide range of traffic detection and monitoring tasks. Limited Caltrans test results on this system in a traffic counting/monitoring application are included in the Appendix.

Related Studies and Evaluations

Although numerous studies have been performed on video-based detection systems for traffic flow monitoring and measurement, few are known to exist for intersection detection systems due to the relative newness of this application of video technology. A number of limited performance evaluations have been or are currently being conducted by potential customer municipalities and agencies. Consultants have been active in this area, with several private (unpublished) system assessments known to have occurred since 1995. We have requested data from all system vendors previously listed related to the performance evaluation of their systems. Most responded with advertised specifications. Only one (Trafficon) provided the results of independent study, but the study (Stockholm) was limited in scope. We have followed relevant literature closely in an attempt to maintain current awareness of developments in this area and the results of any published evaluations.

Based upon the information provided to us or found in our literature searches to date, we are not aware of any work in which the detection accuracy and/or correctness of intersection phase actuation has been comprehensively and rigorously evaluated. Indeed, a lack of standards for system testing in this new class of products is recognized, with most information in circulation based upon sales claims and subjective or limited observations by potential customers. Metrics such as system reliability, quality of user interface, and non-comprehensive observations of detection accuracy have been reported by the following agencies:

Minnesota Department of Transportation / SRF Consulting: Autoscope, 1996.

Texas Department of Transportation, Autoscope and Peek, 1997.

California Department of Transportation, Peek, 1996.

City of Austin, Texas: Odetics VTDS, 1996.

City of Houston and Texas DOT, Texas: CRS Traflo, 1997.

Michigan Department of Transportation: Autoscope and Odetics VTDS, 1996.

City of Irvine: Autoscope, 1995.

City of Stockholm, Sweden: Autoscope, Peek and Trafficon, 1997.

Details from those studies above for which data or results could be publicly obtained are included in the Appendix.

Conclusions and Discussion

The requirements for an intersection vehicle detection sensor, video or otherwise, are extremely demanding. Vehicle drivers rely upon the proper function of this system under all possible traffic conditions, at all times of the day, under all possible weather conditions. The system must also be adaptable for all possible camera placement configurations and all possible approach layouts. This degree of robustness and adaptability is especially important when considering deployment over a large network of intersections, since the cost of using different detection sensors at different intersections may defeat the economic advantages of the alternative sensor.

It is appropriate to contrast these requirements with those of more typical video-computer-vision-based systems designed to measure traffic flow metrics such as count, average speed, volume, average headway, or queue length. For this latter class of systems, camera placements can be much better specified in practice, without the a priori constraints of every possible intersection in a network. The ramifications of incorrect detection are typically only statistical errors, which tend to anneal over time and traffic volume. Compare this with the possibility of vehicle waiting indefinitely at a red light, the result of a failure to detect for an intersection detector.

For the VTDS under ideal or near ideal traffic, camera configuration, and illumination conditions, the ability of the system to detect a vehicle for purposes of signal actuation appeared to be good. This is supported by data from Test Conditions 1 and 2 using Overall Vehicle Detection Question 2 as the primary criteria. This indicates that for signal actuation purposes (includes correct detection and tailgate event classes) the system detected vehicles adequately 97.2% (TC1) and 89.5% (TC2) of the time. Even under ideal conditions, however, the system tended to falsely detect often. False detections under these two test conditions, as addressed in Overall Vehicle Detection Questions 5 or 6, occurred for 15.6% (TC1) and 12.9% (TC2) relative to the actual number of vehicles. The ramifications of false detections can be the unjustified actuation of a minor phase or the extension of a green interval when unnecessary. Whether this is a potential problem at a particular signalized intersection is dependent on the configuration and traffic flow patterns.

Over all test conditions, the system performance as a vehicle detector, as evidenced by both the basic detection tests and the effect-based phase actuation tests, is in our opinion not adequate for reliable general signal actuation. Average presence detection (Overall Detection Question 2) accuracy over the full-spec subset of the test conditions was 80.9%, while false detection (Overall Detection Questions 5 or 6) occurred 8.3% relative to the total number of actual vehicles.

Although the system we tested was designed to provide individual vehicle counts for each detection window, we did not directly test this feature at the request of Odetics. We therefore comment upon the count accuracy of the system for reference purposes only, aware that the system will not be deployed for this purpose. The cumulative vehicle count for each test condition is reported as "Total Detections", which is the sum of the results from the detection event classes in the left column of each of the Vehicle Detection data summaries. If this number is divided by the "Actual Vehicles" sum from each data summary, the result is the vehicle count accuracy of the system for the given test condition.

Care must be observed in assessing the count performance of any system, since the tendency of a system to falsely detect (overcount) is cancelled by the tendency of a system to fail to detect (undercount). This is a mean-vs-distribution statistical problem, eg., it is not possible to distinguish a random process with zero mean but a large variance from a deterministic process if only the sample mean (total count in this case) is reported. We address this by segregating two count accuracy metrics: Overcounting is assessed under Detection System Question 7 with an average value of 14.0% above the true number of vehicles. Undercounting is assessed under Detection System Question 8 with an average value of 32.5% below the true number of vehicles reported over all test questions. It may therefore be observed overall that the system tended to undercount somewhat more than it overcounted, and cumulative vehicle counts produced by the system might tend to be lower rather than higher than actual.

The system performance degraded with respect to all event classes and Overall Detection Questions under conditions of transverse lighting, low light, and non-rain night. Under daylight conditions, performance degradation was observed during rain. Night results did not appear degraded compared with day under rain conditions, but other factors such as variations in traffic conditions could account for this exception to the more general trend.

The effects of wind vibration on the camera primarily manifested as increased failures to detect, while false detections under these conditions did not vary significantly from the overall average. We noted that the mounting positions of the cameras on street lamp luminaires were highly susceptible to vibration in the lateral plane of motion, since the luminaire provides very little resistance to torsion forces on the mast.

Several specialized conditions were tested at the request of Anaheim traffic engineering personnel or the FOT partners, although none of these were included in the overall performance assessment. These conditions involved cables in the camera's field of view, electromagnetic interference, and the use of a color rather than monochrome video camera as the signal source.

The system's detection effectiveness degraded significantly when telephone or power lines were present in the camera's field of view. But surprisingly, the tendency of the system to false detect under these conditions did not vary significantly from the average over all conditions.

The presence of an unshielded automotive ignition system in close proximity to the VTDS system unit or input video cable did not appear to have any significant effect on the system performance. This system is considered well-designed for the street-side environment in this respect.

The system appeared to be intolerant of an NTSC input signal from an Odetics-installed color camera at one of the test intersections. The most significant degradation appeared in the form of increased false detections.

The system handles four, but only four, intersection approaches, which makes it optimum for most typical four-approach intersections. For intersections that require five or more camera views to cover all required sensor positions, two VTDS units would be required.

As discussed previously, the user interface is somewhat crude compared to competing product offerings. But this user interface is necessitated by one of the key advantages of the system: its setup requires only a TV-type (EIA-RS170) monitor and a standard serial PC mouse. No keyboard, terminal or PC is required. The tradeoff is probably a question of individual preference to a potential user. Most other products of equivalent function require the field connection of a notebook PC running setup software.

Phase Actuation tests add the influence of factors unrelated to the function of the VTDS. This or any other video-based detection system is just a sensor, intended to replace the function of another sensor, inductive loops, as an input to a traffic signal controller. Although outside the scope of our workplan, we conducted the Phase Actuation tests at the specific request of the system vendor, who expressed the strong opinion that absolute detection performance tests, which treat the video detection system the same as inductive loops, might not fairly represent the capabilities of the product. We feel that the Phase Actuation tests are valid as a means for extrapolating how a typical intersection control might respond using the VTDS as its vehicle sensor. However, if different traffic conditions prevailed during the tests, the reported Phase Actuation results could have been significantly different. Note, for example, that perfect results would be reported for any interval in which there was no traffic, and that in general, the less traffic per cycle, the greater the chance that all detection events occurring during that cycles will be correct. We therefore feel that, due to the strong dependency upon external factors unrelated to the basic function of the detection system, Phase Actuation test results are interesting but should not be used as a primary metric of evaluation for detection systems of this kind.

The performance of video-based intersection vehicle detection systems in general appear to be limited in three areas:

View-related limitations of the intersection detection environment.

These include inescapable problems of vehicle occlusion due to cross-traffic, sunlight glare off pavement, headlight reflections off pavement at night and especially when wet, poor vehicle contrast against background, power lines or other objects in the camera field of view, and less-than-optimum camera placement due to limited available camera mounting positions.

Limitations of the imaging device.

Limited dynamic range of CCD cameras restrict the useful contrast in the image at the extremes of illumination (night or bright day). This is a critical consideration in highway surveillance or computer vision applications, especially at night when bright headlights saturate contrast with a dark background, locally saturating the CCD array. Vertical or horizontal smear introduce bright full-field-width vertical or horizontal in the video image, which cannot be removed by image preprocessing. The camera resolution limits the usable information content in the image. Camera-induced image artifacts can have a profound effect on the detection accuracy of the machine vision algorithms which process these images [2,3,4,5].

Robustness of the computer vision algorithm(s) employed for detection.

A number of different methods of various degrees of sophistication have been employed for detection of the presence of vehicle in a designated zone in the video image plane. All employ some mechanism for background accumulation, from which individual frames are subtracted on a pixel-by-pixel basis to differentiate vehicles from the roadway surface or other stationary objects. Many employ as their primary detection method (either entirely or partially) the net or average change in intensity of pixels in the designated detection windows. Some exploit the direction of propagation of the optical flow in the window to differentiate a true vehicle entering the window on the designated approach from a cross-traffic occluding vehicle or pedestrian. The most sophisticated methods acquire and track each vehicle as an object in the field of view, and are therefore not constrained to specific detection windows. Some utilize active image stabilization, utilizing pattern matching with the accumulated background or reference features in the field of view. A few utilize chromatic (color) information in the image as an aid to differentiating vehicles from shadows or other image artifacts that could be incorrectly be detected as vehicles. No algorithmic approach is ideal, although more sophisticated approaches are known to produce more accurate and robust results.

All three factors appeared to be at work in the present system evaluation.

There is nothing that can be done about the environmental limitations of the intersection. Structures for mounting cameras and the presence of wires or other objects in the field of view generally cannot be moved or replaced solely for the purpose of improved video detection. Indeed, the diversity of possible intersection configurations poses fundamental limitations for all video-based signal actuation systems. These may, in some situations, be insurmountable regardless of how well a given system can process the image for detection purposes. The system must be able to deal with non-optimum camera placements, partial occlusion situations, wires in the field of view, etc. It is unlikely that any system will be able to overcome all such physical limitations in all cases.

With respect to the imaging device (video camera), it is expected that the vendor, Odetics, specified and installed optimum cameras for the input requirements of the VTDS. Cost, however, was surely a factor, so that high performance cameras that might, for example, be immune to vertical smear may not have been practical. Odetics informed us that they utilized Ikegami monochrome video cameras at all test intersections. The OEM model numbers were not determined. It was explained that these cameras are ordered with infrared-cut (IR) filters installed, based on their belief that suppression of headlight-generated IR in the image will reduce detrimental image artifacts. Daytime performance of the camera appeared to be excellent. However, we observed vertical smear, flare and bloom, from headlights at night and during day rain conditions. It appeared that these image artifacts contributed to some of the false detections observed in the night and night/rain sequences.

We did not inquire, nor was any information provided by Odetics regarding the theory of operation, algorithms, or operational mechanism of the VTDS. We make no attempt herein to suggest or speculate upon any of these functions. However, from working with the system extensively, we have observed phenomena that suggest the possibility of algorithmic performance limitations in three areas:

Poor ability to distinguish vehicles in low-contrast cases. Dark vehicles are often not "seen" by the system, and this trend increases as illumination levels decrease.

Lack of directional discrimination. The direction of object entry into the detection zone seemed to make little difference to the detection reported. We observed this from the fact that cross-traffic occluding vehicles tended to trigger detections as easily as actual vehicles on the designated approach.

Threshold hysterisis. We observed that the system had an unusually high tendency to "latch" a detection, often in situations which could not be explained by high residual contrast in the detection window following a valid detection. This suggests a possible deficiency in the background extraction or adaptation method, such that the departure of a vehicle from the detection zone is not always recognized.

It is possible that these postulated algorithmic limitations are related to or constrained by system hardware limitations. Since one of the advertised features of the system is low cost, cost/performance tradeoffs may be involved to some degree.

Following the presentation of our final test results to the EOT and FOT partners on June 17, 1997, Odetics indicated that a new software release was under development that could potentially improve the system performance. In correspondence dated April 2, 1998, Odetics stated that they had observed findings similar to ours in their internal test program, and announced that both the hardware and software of the VTDS system had been subsequently replaced. Insurmountable processor, memory and A/D conversion limitations of the existing hardware were cited. Odetics stated that improved software running on the new system would provide significantly improved performance compared to the product evaluated herein. We have not tested this new system.

Based upon the background study and literature search we conducted on video-based detection products for signal actuation (summarized in the Appendix), there appears to be a critical lack of evaluation standards in this area such that system-to-system comparisons between different tests are extremely difficult. Simple statements of any single metric such as cumulative count accuracy, percent correct detections, percent overcount, percent undercount, or percent false detections alone can be very misleading to the potential user. Reports of indirect metrics such as "phase detection" alone can obscure the actual accuracy of the detection system beneath the circumstances of the traffic patterns and signal controller programming encountered at the intersection(s) during the test.

Not withstanding the restrictions and limited scope of this study, the evaluation results reported herein are believed to be both comprehensive and rigorous, among the first tests at this level conducted on a video-based signal actuation product. We feel that it is important that the reader note this if any attempt is made to compare results from this test with other bodies of data reported for this or other products of this type. The evaluators and sponsoring agencies neither endorse nor denigrate the product tested. Although this evaluation was restricted to only the Odetics VTDS, we are aware of no other independent test results that would demonstrate conclusively either better or worse performance by competing products.

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