EVALUATION OF WIDE-AREA DETECTION SYSTEMS

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SUMMARY

This study evaluates the state-of-the-art technology of wide-area detection systems (WADS). WADS is a fast developing technology and its continuous evaluation and review is essential for the intelligent transportation systems (ITS) programs and research. The study investigates the capabilities, accuracy, costs, limitations, and potentials of WADS in comparison to competing traffic detection technologies. It also investigates WADS rural applications.

INTRODUCTION

Drivers' expect limited to no delays on rural highways. However, during construction periods or inclement weather conditions substantial delays may occur. It is important to investigate various types of traffic and environmental sensors that can detect needed information. Information is power. Relaying relevant information to the system users is effective for better planning on the individual level, and also contributes to better traffic management from the perspective of traffic operators.

WIDE AREA DETECTOR SYSTEM TECHNOLOGY

WADS are a major development to Closed Circuit Television (CCTV). CCTV has been used on highways and tunnels primarily for incident detection for decades. They have been used on the Antwerp Ring Motorway in Belgium since 1965. In 1994 there were 209 cameras operating on this facility with only two to three operators monitoring the cameras. Thus only partial monitoring was possible (1). WADS utilize image processing technology to convert video camera pictorial data to a digitized form. Then it analyzes, and manages the data to emulate the functions of the human eye and other types of traffic detectors.

Wide area detection encompasses the camera field of view (FOV), as opposed to point detection, which detects vehicles in a relatively small size area. WADS may monitor traffic and track vehicles in several lanes for a distance about 100 meters (depending on camera optics and position); such field of view may have numerous virtual detectors. Point detectors (such as inductive loops, radar, ultrasonic, and microwave) typically detect traffic in short range and narrow band. More than one detector is usually needed to monitor traffic per lane. Inductive Loop Detectors (ILD) must be installed in each lane and in tandem in order to perform traffic count and speed per lane.

The Basic Technology

Video Image Processing (VIP) is the basic technology of WADS. It is based on digitizing every pixel in the field of view. Pyramid processing is essential for cost effective and speedy processing. It reduces the original image to a coarser and smaller one. Thus less data is stored and processed (2).

VIP generally falls into three main technology systems: The tripwire (or trip-line) system, the tracking base system, and the spatial analysis system. In practice most systems operate in a hybrid fashion.

Tripwire system: This system detects the immediate change within a group of pixels within a virtual detector. Thus it can perform occupancy, volume counts, density, speed, and other parameter calculation through various locations and sizes of virtual detectors. The drawbacks to this approach are that the underlying incident detection algorithms remain the same as for conventional detectors. Also, the accuracy of detectors is heavily dependent on the camera field of view (3, 4)

Tracking base system: This system provides more information and it is more accurate than trip line based detectors' (4). It tracks individual vehicles moving through the camera screen. It also gives relevance to the flow of vehicles and objects in real time and provides a microscopic description of vehicle movements. This can reveal new data on events such as sudden lane changes, vehicles traveling in the wrong direction, and stationary vehicles. However, the increased sophistication requires more computing power, requires vehicles to be discernible, and can be more restrictive in camera positioning (3).

Spatial Analysis: This system concentrates on analyzing the two-dimensional (x-y coordinates) information that video images provide. The underlying strategy is to describe how the visible road space is being utilized at a particular instant. Disturbances in traffic flow can then be determined by analyzing how these disturbances vary over time. Use of road space is usually divided into three categories: no traffic present, moving traffic present, and stationary traffic. These are essentially qualitative decisions (3).

Major Features

WADS are a flexible and versatile developing technology that may be catered to various needs, and applications. It is capable of obtaining lane occupancy, volume counts, speed data (average, variance, etc.), density, headway, vehicle classification (via vehicle length), queue length, and vehicle delay. It also may be used to monitor wrong way vehicle detection, lane change, and provide a real-time video screen for incident monitoring.

Logical commands (such as: and, or, greater than, etc.,) may also be used for incident detection from the various cameras outputs. Incident detection may be obtained from commands such as vehicles presence for 'n' or more seconds, vehicle speeds less than 'n', and/or queue length exceeded 'n'. Logical command traffic parameter results may be used for selecting messages for Variable Message Signs (VMS) and other Advanced Traffic Management System (ATMS) options

Operation Aspects and Limitations

The camera's field of view is the most important element for data and traffic parameters accurate representation. The FOV is a function of the video camera range (optics), the position and orientation of camera, especially its height above the roadway. The ranges vary from one instrument to another for present technologies. However, the maximum range is 100 to 200 meters of roadway length. The width of the field of view could be up to 6 tracking strips (lanes, shoulders, ramp entrance or exits, or other areas of interest). However, it is important to note that the larger the FOV, the larger the percentage of error (for most traffic parameters), and the larger the percentage of false alarms for incident detection.

Virtual detectors are set on the video image that is displayed on the monitor. A virtual detector may vary in size and shape. It can be few centimeters wide to tens of meters wide. It may cover one lane or several lanes. Virtual detectors may intersect or overlap. The number, location, and dimensions of detectors must be carefully chosen for each project location and the type of traffic parameters needed.

The selections of location, size, shape, number and uses of virtual detectors are also of prime concern. Many virtual detectors may be easily set on the monitor, but there is no need for superfluous data. Data processing and storage can be costly. Verification of data through true manual counts is highly recommended.

Eight to ten video cameras may be processed though a video tracking unit (VTU). A personal computer, Pentium or higher, are usually required to interface to the VTU for data processing, analysis, and storing of traffic parameters. It also can provide a VCR tape recording mechanism for storing of selected events.

Cameras' locations and verification of their field of vision with ground true coordinate is the first basic task in obtaining meaningful and accurate results. Attention must be given to the cameras' mounting structure in term of stability under various environmental conditions. Corrections of sway and re-aligning the incoming video images with previous images and identified landmarks are also possible. However, reducing the frequency and magnitude of sway is essential.

Variation of objects and background lighting, particularly at night and during lighting storms, require special filtering attention. Image processing technology utilizes a blank background containing only identified objects including vehicles, motorcycles, bicycles and pedestrians. Shadows and undesirable artifacts are filtered out. Thus proper filtering techniques enhance WADS accuracy of information. Furthermore, WADS may not function adequately under severe visibility conditions near the video cameras such as rain, snow, sandstorms, fog, and smog.

COMPARISONS OF VARIOUS TRAFFIC SENSORS TECHNOLOGIES

There are numerous traffic detector technologies. Inductive loop detectors (ILD) are the most used technology for intersection and for highway traffic count stations. Loop detectors operate on the principle of inductance; they are installed in a variety of sizes and shapes. Inductive loops may be placed on the road surface, but are usually placed 10 to 20 inches in pavement to exhibit a longer life span. ILD are capable of measuring flow, occupancy, vehicle speed (in pairs), among other traffic parameters that may be measured or calculated (5).

The capabilities of the WADS technology are diverse, flexible, and evolving. However, such capabilities must be evaluated for the specific settings in regard to accuracy, cost and usefulness of application at various traffic and environmental conditions. Table 1 provides comparison of WADS vs. ILD for benefit evaluation on freeway (6).

The accuracy of the various detector technologies varies for the different traffic parameters. Also the accuracy varies among the several commercial brands of the same technology. Furthermore, the accuracy for the same traffic parameter, for the same technology and commercial brand also vary for various installation practices (e.g., height and orientation of camera) and various environmental conditions (visibility condition, changing visibility, shadows, etc.,). Also, the virtual detector and other data programming methods (e.g., data filtering and processing techniques) can significantly affect the accuracy of data for the various parameters.

Vehicle count accuracy was reported for five detector technologies in a test on I-4 in Florida (7). The count results were compared to the ground truth counts. ILD was the most accurate with 0.2% error, followed by RTMS microwave radar with 1.9% (this technology had varied positive and negative errors at low and high traffic rates). The Autoscope 2003 had 2.1% error, the SDU-300 ultrasonic error was 4.0%, and finally the SPVD magnetometer had 6.8% error from the ground truth. Other traffic parameters such as lane change, queue length, and vehicle classification had low to significant errors for various WADS types and studies (8). Queue length and average speeds (individual vehicle speed varied considerably) were relatively accurate for WADS detectors in several studies. Queue lengths were reported within one car error for 95% of the cases in several test studies. The average absolute velocity error for freeways was within 3 mph for several studies (8).

Table 1: Comparison of Wide Area Detector Systems (WADS) vs. Inductive Loop Detectors (ILD) for Benefits Evaluation on Freeways

Function	WADS	ILD
Year round installation, maintenance	Yes, except for underground conduit and wiring	No
Lane closure required	No, may be shoulders	Yes
Usable during reconstruction	Yes	No
Susceptible to deterioration	No	Yes
Visual detection monitoring	Yes	No
Reliable speed measure	Yes	Yes, with speed trap pairs
Stopped vehicle detection over wide area	Yes	Not practical
Wrong way vehicle detection	Yes	Yes, with second loop
Vehicle classification	Yes, 3 classes	Yes, with speed trap pair
Spatial occupancy, density measurement	Yes	No
Queue length measurement	Yes	No
Delay, extend, combine detector outputs	Yes	No
Provide MOE's, stops, delays, etc.	Yes	No
Incident detectors	Yes	Yes, if processed at central location
Visual surveillance capability	Yes	No
On-line video processing capability	Yes	-

Source: Reference 6

Comparison of cost of WADS to ILD and other competing traffic detector technologies must be viewed with caution. WADS have the most comprehensive and flexible capabilities. It combines the capabilities of performing traffic parameter data and surveillance. The equipment and installation cost for one unit (camera or loop detector and their accessories) of WADS are several times more costly that ILD (5, 6). However, one unit of WADS (video camera and processing accessories) can monitor a traffic area, which needs several ILD units. In addition, when the users delay due to installation and maintenance is considered, WADS benefit-cost ratio ranged from 1.25 to 18.4 for various traffic scenarios (6, 9). Benefit-cost analysis must be performed for each project due to the high variability associated with the numerous parameters. The desired application and complexity of the project are also primary factors for economic feasibility analysis.

Generally when one lane (such as a ramp entrance), or only specific traffic parameters are desired, most likely WADS technology will not be suitable at this stage of development. WADS technology is desirable for multiple lanes and multiple tasks, especially for surveillance and incident detection and management.

EVALUATION OF WADS PROJECTS

WADS video image processing has been use for numerous project applications for about ten years. Most of the applications have been for intersections. However, WADS usage for freeway applications has increased substantial in recent years. The most comprehensive WADS project in USA in recent years is the Detection Technology for Intelligent Vehicle-Highway Systems (IVHS) Project, which was sponsored by the Federal Highway Administration (10). The following is a brief description of the each test site:

The Minnesota Test Sites

The freeway test site was located on I-394 (US Rte 12) at the Penn Avenue crossing in Minneapolis. The freeway has two unrestricted lanes in each direction, as well as two reversible high-occupancy vehicle (HOV) lanes. The HOV lanes are located between the normal eastbound and westbound lanes. The eastbound lanes and the HOV lane closest to the eastbound lane were used as the test site. The bridge crossing at Penn Avenue has a variable message sign facing the westbound traffic.

Speed-measuring inductive loop detector pairs were installed in the three monitored lanes to obtain vehicle count and speed data which were compared to radar, infrared, ultrasonic, acoustic, and video image processors (VIP). Video cameras were installed to observe downstream traffic moving away from the cameras.

Another test site was a surface street located on Olson highway (TH-55) between Lyndale Avenue and North Oak Lake Avenue, just east of the I-94 overpass. The westbound traffic was monitored. Westbound Olson Highway has three through-traffic lanes and a left and right turn bays.

The Florida Test Site

The highway test site was located on I-4 and the SR 436 interchange in Altamonte Springs, north of Orlando. The site was selected because it accommodates both freeway and surface-street data acquisition. It has an excellent alignment for the overpass with respect to the interstate for mounting the detectors.

The freeway contains three lanes in both east and west directions at this location, with the innermost lanes reserved for car pools during peak traffic hours. The SR 436 bridge provided a mounting structure for the detectors overlooking the freeway. The three lanes of I-4 westbound traffic into Orlando were monitored from a vantage point, where data from upstream (approaching) vehicles were acquired. The camera was mounted directly over the middle of the monitored freeway lanes. Double-loop inductive detectors were installed in all three westbound lanes to measure traffic count and speed.

The westbound SR436 surface-street test location has three through lanes and two left-turn lanes that lead to an entrance ramp for I-4 West to Orlando.

The Arizona Test Sites

The freeway test site was located at a stretch of I-10 called the Papago freeway near the Thirteenth Street, just east of the tunnel in Phoenix. There are three westbound lanes and one high-occupancy vehicle lane within this segment. A variable message sign hangs over the rightmost lane. Loop detectors and overhead detectors were used similar to the other two test sites.

The surface-street test site was selected in Tucson. It was along Oracle Road at the intersection with Auto Mall Drive and across the street from the largest shopping mall in Tucson. The traffic is well funneled into the three north-south lanes by a traffic signal on the north side of the intersection. The site locations were chosen carefully to meet various criteria. Table 2 presents the test conditions that were satisfied at the test sites.

The tests were conducted between January 1993 and September 1994. Inductive loop detectors were used on all lanes at every site. They were used mostly in pairs to measure speed. The other detectors' technologies used for the project are presented in Table 3. Table 4 presents the advantages and disadvantages for various technologies based on the test site evaluation (10).

In Japan, WADS have been used for ATMS in the cities of Tokyo, Osaka, and Kobe. The systems measured speed and volume with an accuracy exceeding 90 percent. Evaluation of the systems revealed more accurate results for cameras installed at 6.5meter height, than cameras at lower installation heights, which exhibited problems in differentiating obscured vehicles in the lane furthest away from the camera. Also, it was noted that engineers with no knowledge of VIP were able to operate the system in a relatively short time (3).

Some of the problems encountered by researchers for WADS installation in London were adjacent artifacts that cast strong shadows. They led to false detection of stationary traffic, and rapid variations in contrast due to functioning of the auto-iris causing image content to change at a faster rate than the system rate thus distorting the result (3).

Table 2: Test Conditions Satisfied at Test Locations

TEST CONDITION	MINNESOTA		FLORIDA		ARIZONA	
	Freeway	Surface Street	Freeway	Surface Street	Freeway	Surface Street
Time of Day Daylight	x	x	x	x	x	x
Dawn	x	x	x	x	x	x
Dust	x	x	x	x	x	x
Night	x	x	x	x	x	x
Vehicles Passenger cars	x	x	x	x	x	x
Trucks	x	x	x	x	x	x
Semi-trailer	x	x	x	x	x	x
Buses	x	x	x	x	x	x
Emergency vehicles	x	x	x	x	x	x
Motorcycles	x	x	x	x	x	x
Bicycles		x		x		x
Road equipment	x	x	x	x	x	x
Traffic Patterns Multiple lanes	x	x	x	x	x	x
Normal traffic	x	x	x	x	x	x
Turning vehicles		x		x		x
Congestion	x	x	x	x	x	x
Long queues	x	x	x	x	x	x
Stopped vehicles	x	x	x	x	x	x
Adjacent-lane-vehicles	x	x	x	x	x	x
Lane Straddlers	x	x	x	x	x	x
Weather Clear	x	x	x	x	x	x
Overcast	x	x	x	x	x	x
Fog			x	x		
Abrupt lighting changes (luminaries, lightning			x	x	x	x
Cold temperature extremes	x	x				
Hot temperature extremes			x	x	x	x
Heavy snow	x	x				
Heavy rain			x	x	x	x
Smog					x	
Haze			x	x		
Artifacts Shadows	x	x	x	x	x	x
Sun glare	x	x	x	x	x	x
Electromagnetic interference	x	x	x	x	x	x
Wind sway and vibration	x	x	x	x	x	x

Source: Reference 10

Table 3: Detectors Used in the Minnesota, Florida, and Arizona sites

Technology	Manufacturer	Model	Output Data
Ultrasonic Doppler	Sumitomo	SDU-200 (RDU-101)	Count, speed
Ultrasonic Presence	Sumitomo	SDU-300	Count, presence
Ultrasonic Presence	Microwave sensors	TC-30C	Count, presence
Microwave Detector Motion Medium Beamwidth	Microwave sensors	TC-20	Count
Microwave Detector Doppler Medium Beamwidth	Microwave sensors	TC-26	Count, speed binning
Microwave Detector Doppler Narrow Beamwidth	Whelen	TDN-30	Count, speed
Microwave Detector Doppler Wide Beamwidth	Whelen	TDW-10	Count, speed
Microwave Radar Presence Narrow Beamwidth	Electronic Integrated Systems	RTMS-X1	Count, presence, speed, occupancy
Active IR Laser Radar	Schwartz Electro-Optics	780D1000 (Autosense I)	Count, presence, speed
Passive IR Presence	Eltec	842	Count. Presence
Passive IR Pulse Output	Eltec	833	count
Imaging IR	Grumman	Traffic Sensor	Presence, speed
Video Image Processor	Econolite	Autoscope 2003	f
Video Image Processor	Computer Recognition systems	Traffic Analysis System	f
Video Image Processor	Traficon	CCATS-VIP 2	f
Video Image Processor	Sumitomo	IDET-100	f
Video Image Processor	EVA	2000	f
Passive Acoustic Array	AT&T	SmartSonic TSS-1	Count
Magnetometer	Midian Electronics	Self-Powered Vehicle Detector	Count, presence
Microloop	3M	701	Count, presence
Tube-Type Vehicle Counter	Timemark	Delta 1	Count

"f" : count, presence, occupancy, speed, classification based on length. Some provide headway, density, and alarm function

Source: Reference 10

Table 4: Advantages and Disadvantages of Various Detection Technologies

Technology	Advantages	Disadvantages
Ultrasonic	• compact size, ease of installation	• Performance may be degraded by variation in temperature and air turbulence
Microwave Doppler	• Good performance in inclement weather • Direct measure of speed	• Cannot detect stopped or very slow-moving vehicles • Requires narrow-beam antenna to confine footprint to single land in forward-looking mode
Microwave True Presence	• Good performance in inclement weather • Detects stopped vehicles • Can operate in side-looking mode to service multiple lanes	• Requires narrow-beam antenna to confine footprint to single lane in forward-looking mode
Passive Infrared	• Greater viewing distance in fog than with visible -wavelength	• Performance potentially degraded by heavy rain or snow
Active Infrared	• Greater viewing distance in fog than with visible-wavelength sensors • Direct measurement of speed	• Performance degraded by obscurants in the atmosphere and weather
Visible VIP	• Provide visible imagery with potential for incident management • Single camera and processor can service multiple lanes • Rich array of traffic data available	• Large vehicles can mask trailing smaller vehicles • Shadows, reflections from wet pavement, and day / night transitions can result in missed or false detentions
Infrared VIP	• Possibility of using same algorithms for day and night operation and avoiding day /night algorithm transition problems • Rich array of traffic data available	• May require cooled IR detector focal plane for high sensitivity; implies somewhat more power and less reliability
Acoustic	• Potential for identifying specific vehicle types by their acoustic signature	• Signal processing of energy received by the array is required to remove extraneous background sounds and to identify vehicles
Magnetometer	• Can detect small vehicles, including bicycles • Useful where loops cannot be installed	• Difficulty in discriminating longitudinal separation between closely spaced vehicles
Inductive Loop Detectors	• Standardization of loop amplifier electronics • Excellent counting accuracy • Mature, well understood technology	• Reliability and useful life a strong function of installation procedures • Traffic interrupted for repairs and installation • Decreases life of pavement • Susceptible to damage by heavy vehicles, road repairs, and utilities

Source: Reference 10

The Antwerp, Belgium WADS system was integrated easily into the existing CCTV in 1991. The system operates at 77 % detection rate with a 4% false alarm rate (0.02 false alarms per camera per day). Finally an early evaluation of WADS technology in Nice, France, deemed necessary the removal of nearby tree branches which caused false alarms during windy conditions. Polarized filters were helpful in reducing reflection. Also, protection of transmission cables from electromagnetic disturbances generated by a nearby railroad was also necessary to eliminate interference with the transmitted data (1, 3).

CONCLUSION AND RECOMMENDATIONS

The evaluation of WADS, and its comparison to various traffic sensors helps focus on the potential uses of WADS technology for rural applications. Even though it is evident that the highest potential for WADS is congested urban and suburban highway networks, rural applications are also feasible in certain cases. Highway maintenance may be the best suited for WADS rural applications. WADS video cameras may be used on movable cranes, and data may be transferred via wireless communication to a traffic operation center. Data threshold alarms may be used in analyzing the data. Then data can be appropriately conveyed to the highway users and relevant agencies.

ACKNOWLEDGEMENT

The Pennsylvania Department of Transportation through Urban Engineers, Inc., Philadelphia, PA, provided partial funding for this project. This paper was prepared by the authors. The contents of this paper do not necessarily reflect the official views or policies of the Commonwealth of Pennsylvania. This paper does not consitute a standard, specification, or regulation.

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