Ohio State Highway Patrol
Planning Services Section
Research & Development

Automatic Plate Reader Technology

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Note: For purposes of this paper, all references to Automatic Plate Readers will be specifically about the Remington-Elsag model that was tested by the Ohio State Highway Patrol.

ABSTRACT

In 2004, the Ohio State Highway Patrol (OSHP) conducted a four-month evaluation of Automatic Plate Reader (APR) technology. The equipment used in the evaluation was obtained through Remington-Elsag Law Enforcement Systems. The goal of the evaluation was to determine if APR technology can be used to identify stolen vehicles, stolen license plates, and wanted felons, as well as assist the Division in Homeland Security efforts. Infrared cameras were attached to Ohio Turnpike gates to scan the license plates of vehicles entering the state. Mobile APR cameras were assigned to two marked patrol cars for additional coverage on the Turnpike and on an unmarked investigative car for use during joint anti-theft operations with the Cleveland Police Department. Researchers analyzed alarms produced by APR technology to determine its ability to accurately scan license plate characters and match them to a Hot List database. Staff also compared the rates of stolen and recovered vehicles during similar time periods in 2003 and 2004 to determine the effect of APR technology on OSHP operations. Researchers found that APR technology had a significant impact on stolen vehicle recoveries when used on fixed sites on Turnpike gates and in special enforcement operations in the city of Cleveland. APR technology had limited utility during normal patrol activities using marked cars on high speed, multi-access highways. While the technology has the potential to assist law enforcement agencies in Homeland Security efforts, such as tracking hazardous material carriers entering the states, important issues may need to be addressed through state or federal legislation. During the four-month evaluation, APR technology led to the apprehension of 23 criminal suspects and the recovery of 24 stolen vehicles valued at $221,000.

INTRODUCTION

In 2003, 1.3 million motor vehicles were stolen in the United States, at an estimated value of $8.6 billion. If the vehicle theft industry were organized as a single company, its revenues would rank among the top 60 largest corporations in the nation. Trafficking in stolen vehicles is the second most profitable criminal activity next to drug dealing.[1] According to the Federal Bureau of Investigation's Uniform Crime Report, a motor vehicle was stolen every 25 seconds in the United States in 2003; 37 percent were never recovered. Although Ohio typically ranks below the national average for automobile thefts, each year over 40,000 Ohioans have their vehicles stolen. Akron, Cincinnati, Cleveland, Columbus, Dayton, and Toledo are considered Ohio's high theft cities, accounting for nearly 60 percent of the statewide total. On average, the odds of a stolen vehicle occurring in one of these Ohio cities is 1 in 72 registered vehicles, over twice the national average of one in 153 registered vehicles. The direct loss to Ohio residents for unrecovered stolen vehicles exceeds $100 million annually.

In early 2004, the Ohio State Highway Patrol (OSHP) redirected resources to develop several vehicle theft countermeasures. While an incentive program for officers (Blue Max) had operated successfully since 1972, more needed to be done. OSHP developed a new, more intensive stolen vehicle training curriculum that included not only stolen automobiles and advanced vehicle identification techniques, but also theft of commercial motor vehicles, heavy equipment, motorcycles, and ATVs. In addition, the Division established several partnerships with local, state, and federal authorities to reduce vehicle theft and increase recovery rates in the state. Finally, OSHP began to aggressively pursue new technologies to increase the efficiency and effectiveness of the Division in combating criminal operations. One of these was license plate scanning or Automatic Plate Reader (APR) technology.

APR technology uses small, black and white infrared cameras that have the ability to read reflective license plates. The infrared cameras illuminate and take pictures of the front or rear license plates. The images of the vehicle including the license plate characters and pixel information is read by image processing hardware. The pictures are analyzed with different software algorithms that enhance the image, detect the plate position, extract the plate string, and identify the fonts using special artificial intelligence methods. Information obtained from the license plates is compared to entries in an integrated database consisting of stolen vehicles, stolen license plates, wanted felons, etc. APR technology can be used in all lighting, including nighttime, and during most weather conditions (excluding thick fog and heavy falling rain or snow that may block visibility of the license plate). In order to obtain the best recognition performance, the maximum speed between APR cameras and target vehicles is 30 to 35 mph. Beyond this speed limit, APR technology has a progressive degradation of performance, but still maintains some recognition capability up to 65 mph difference between objects. Although the most common use of APR systems for law enforcement agencies is the identification of stolen vehicles, the technology can potentially be used in Homeland Security initiatives or to identify vehicles involved in child abduction cases.

In mid-2004, OSHP began a four-month evaluation (August 1, 2004 to November 30, 2004) of the Remington-Elsag Automatic Plate Reader (APR). The goal of the evaluation was to determine the effectiveness of APR technology in the identification of stolen vehicles, stolen license

plates, and wanted felons and to assist the Division in developing Homeland Security programs. APR technology is currently being used in a limited capacity by law enforcement across the country, and inquiries from a number of federal, state, and local agencies throughout the course of the project underscore the rising interest in the emergent technology. OSHP partnered with the Ohio Turnpike Commission (OTC), State Controlling Board, and the Federal Bureau of Investigation (FBI) to pilot the technology. A memorandum of understanding between OSHP and the FBI assured that a static, electronic criminal file was sent daily by the National Crime Information Center (NCIC) to the Division for use in the project. The NCIC file consisted of 345,000 license plates, including 8,000 Ohio plates. OSHP added their active vehicle and person warrant files to the NCIC file (approx. 1,700 entries) to increase the number of Ohio license plates and (potentially) increase the number of criminal apprehensions during the evaluation. Collectively, the electronic file of criminal license plates was referred to as the Hot List.

OSHP installed six stationary cameras to use at Ohio Turnpike gates. The cameras were mounted to lanes 2, 3, and 4 of both the east and west gates to scan license plates of vehicles entering the state (see Appendix A-1). In addition, two mobile cameras were attached to marked patrol cars for use on the Turnpike (see Appendix A-2). OSHP attached a third mobile camera to an unmarked investigative car for use during joint anti-theft operations with the Cleveland Police Department. When there was a match between the scanned image and an entry in the Hot List file, the system generated an alarm. Because the system only matches license plate numbers and letters, not states, the operator must visually validate matches. OSHP dispatchers were responsible for validating Turnpike gate alarms and the officers using mobile APR technology were responsible for confirming their Hot List matches.[2] The alarms were stored in a database for 31 days for evaluation purposes. The system automatically deleted license plate scans if no match was made, thus researchers were unaware if there were appreciable differences in system performance between license plate scans that produced an alarm versus those that did not. Further, researchers were unable to determine if the system produced multiple scans of the same vehicle, thereby overstating system performance.[3]

METHODOLOGY

To determine the effectiveness of APR technology, researchers collected toll gate data supplied by the Ohio Turnpike Commission and APR data generated by Remington-Elsag. Cumulative data including toll counts, APR license plate scans (also referred to as transits), and accepted and rejected alarms were collected for the entire length of the project. An in-depth analysis of data collected from Turnpike gates occurred from August 5, 2004 to October 5, 2004, at which time staff determined that enough information had been collected regarding the performance of the fixed cameras. While the coding of rejected plates continued by dispatchers and officers after October 5, visual confirmation by researchers was discontinued. Detailed APR alarm data for mobile cars was collected for the entire length of the project (August 10, 2004 to November 30, 2004). Positive APR alarms (state and license plate match) for both gates and cars was also collected for the entire four-month evaluation.

The in-depth analysis of APR alarms involved Research staff visually confirming and coding license plate images to determine license plate states and reasons why alarms were accepted or rejected by dispatchers and officers. Rejected alarms were coded into pre-defined categories

including: match – wrong state, partial occlusion, partial or incomplete reading, stacked or small letters, string is not a plate, or other – including dirty plates. License plate scans that contained multiple errors were coded according to the seriousness of the error. For instance, license plates that misread characters and also had stacked or small letters were coded as misread letters (partial or incomplete reading), because errors such as these were associated with the performance of the technology. Since OSHP understood that the system was unable to read stacked or small letters before testing the equipment, this was considered a less serious performance problem. When evaluating APR technology, scans of non-license plate characters, misread or incomplete license plate reads, and to some extent partial occlusions, are considered the most serious errors of the APR technology.

Accepted alarms were coded as "positive," meaning the license plate characters and state match a Hot List entry. Accepted alarms were then coded into sub-categories to distinguish those that were valid (meaning they resulted in an arrest or apprehension) versus those that were unknown or invalid. Unknown or invalid "positive" alarms were classified as system demonstrations, vehicle not located, not removed from NCIC list, wrong plate, system down, or other. Appendix B provides a complete description of all alarm codes and Appendix C contains sample license plate images.

Researchers experienced problems collecting detailed data on the performance of APR technology for time of day or weather conditions. The time needed to complete a multi-factorial analysis was beyond the scope of the current evaluation. Anecdotally, the OSHP District 10 commander mentioned problems with the cameras "seeing" license plates in fog or rain. Further, researchers were aware that the system was inactive several times during the evaluation period, which could impact the overall results of the study. Finally, researchers discovered that transits, which were thought to be exclusively APR license plates scans, consisted of other types of non-license plate characters (coded as "string is not a plate"). This includes such items as phone numbers and writing on commercial motor vehicles, letters on mailboxes, yard signs, etc. This has become one of the central issues in determining inefficiencies in the technology. Remington-Elsag staff are completing a diagnostic evaluation of the system to determine the actual number of license plate scans that were conducted during the evaluation period. Pending their results and continued use of the technology, OSHP staff may conduct an independent evaluation of this issue at a later time.

RESULTS

The analysis of data is broken down into three sections: Turnpike gates, unmarked investigative car, and marked patrol cars. Researchers felt that this was necessary because of the different environments and applications, level of use, and outcomes associated with the deployment of the technology. If the APR system's overall recognition ability shows potential, further uses of the technology will be based primarily on its performance in specific situations. Analyses of accepted and rejected alarms as well as various rates were calculated for each application. Researchers also looked at the impact that APR technology had on OSHP operations.

Turnpike Gates

During the four-month evaluation, 2,768,182 vehicles entered the state via the Ohio Turnpike. There were 2,175,257 vehicles that entered the state through the six Turnpike gates with APR technology, meaning 79 percent of vehicles that entered Ohio on the Turnpike were subject to license plate scans. According to Remington-Elsag, APR technology performed 1,875,231 "transits." As previously mentioned, transits were initially considered to be individual license plate scans, but as the evaluation continued they were found to be scans of strings of reflective characters that may or may not be license plates. Further, it is unknown how many transits (potentially) involved the same vehicle, further reducing the overall number of license plate scans. At this point in time, the actual number of license plate scans by APR cameras is unknown. Regardless, we do know that 14 percent of available vehicles were not scanned by APR technology.[4] This is most likely due to factors inhibiting the reflectivity of license plates (i.e., plate covers, dirty plates, weather conditions, etc.) or APR system unavailability. More research is needed to gain a better understanding of what constitutes "transits."

Of the 1,875,231 transits that occurred during the four-month evaluation, 3,286 resulted in an alarm (.2 percent of transits). Of the 3,286 alarms, 108 were considered "positive," meaning the state and license plate characters matched (three percent of alarms). During the four-month evaluation, APR technology recorded 17 valid alarms, meaning an arrest or apprehension occurred in .5 percent of all alarms or 16 percent of "positive" alarms. Figure 1 shows various rates of scanning for APR Turnpike gates. Researchers found only one notable difference in the performance between east and west gates. It appears that the west gate was much more likely to generate an alarm than the east gate (64 percent versus 36 percent). This is most likely due to false alarms generated for commercial vehicles due to stacked or small letters on license plates or the reading of non-license plate characters (i.e., phone numbers) on the back of trucks. According to Turnpike staff, more commercial vehicles enter the state via the west than east gates, and Research found a large number of false alarms generated by commercial vehicles during the evaluation. Otherwise, Research noted few differences between the performances of APR fixed cameras. Figure 1 provides rates for APR alarms at Turnpike gates.

Figure 1
APR Gate Rates

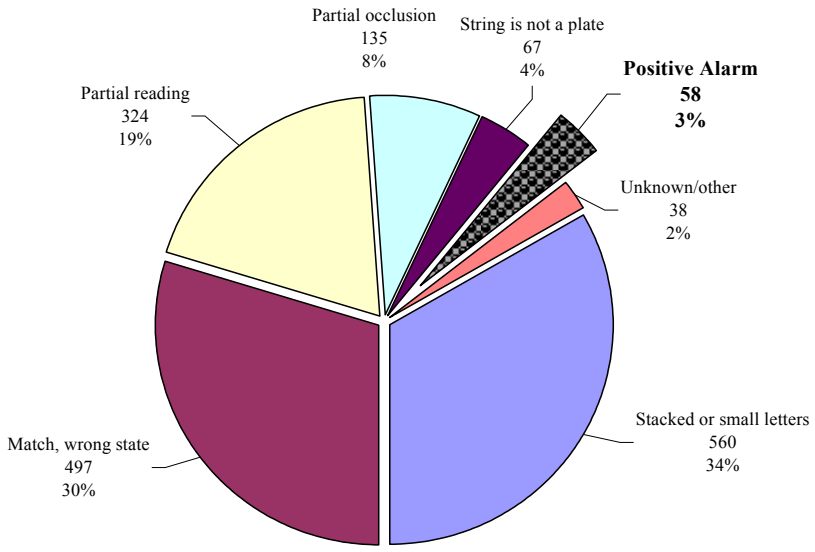
Category	#	Rate per scan	Rate per alarm	Rate per positive alarm
Passive Scans	1,875,231			
Total Alarms	3,286	1 in 571		
Positive Alarms	108	1 in 17,364	1 in 31	
Valid Alarms	17	1 in 110,308	1 in 194	1 in 7

APR Gate Alarms by Category

Detailed APR alarm information was collected for Turnpike gates during a two-month period from August 5, 2004 to October 5, 2004 (n=1,700). Research staff were able to code 1,679 alarms (99 percent of all alarms). The results of coding show thirty-four percent of alarms included stacked or small letters, 30 percent matched – but were the wrong state (license plate characters matched only), and 19 percent were partial scans (one or more characters were not recognized by

the system). There were 67 cases (four percent) in which the APR technology alerted to strings of non-license plate numbers or letters. Fifty-eight or three percent of alarms were "positive" (state and license plate match a Hot List entry). Figure 2 provides details on the 1,679 gate alarms.

Figure 2
APR Gate Alarms



Source: Remington-Elsag, Inc., 2004. Includes all APR generated alarms for Turnpike gates from August 5, 2004 to October 5, 2004. Data was maintained on the online system for 31 days for evaluation purposes only.

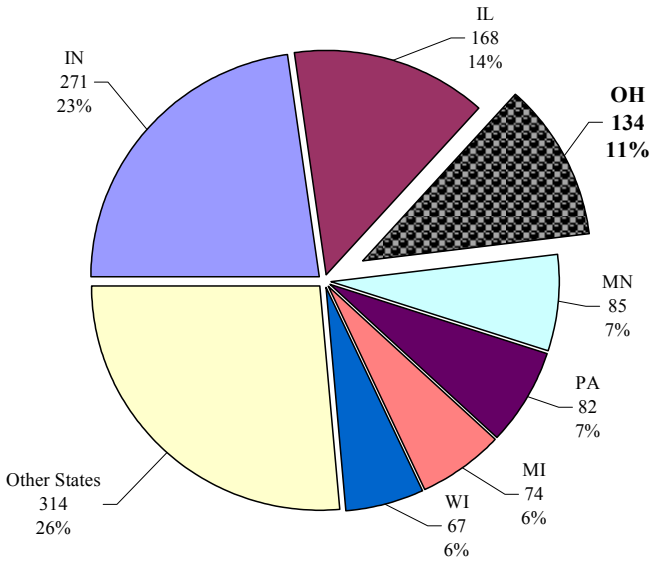
Of the 58 positive gate alarms generated during the two months, 29 percent were no longer valid in NCIC, 21 percent were not located by officers, and 17 percent were valid (resulted in an apprehension or arrest). In nine cases (16 percent) the system had a positive alarm (license plate and state match) but on a wrong vehicle (i.e., tractor-trailer but entry was for a motorcycle). There were seven cases (12 percent) in which the system was down and an alarm came several hours later and three cases involving some other scenario that invalidated the alarm (i.e., front license plate was stolen and driver was operating vehicle with other plate).

APR Gate Alarms by State

In addition to coding each APR generated alarm into pre-defined categories during the 60-day in-depth analysis, researchers visually confirmed license plate states. Because the technology was designed to specifically read Ohio license plates, actual state identification was necessary to understand system performance across states. Research stopped this process after two months, believing the sample was large enough and realizing little else would be gained from continuing the arduous task.

Researchers were able to identify the license plate state for 71 percent of alarms during the evaluation.[5] Of these alarms, the majority of plates were from Indiana, Illinois, Ohio, Minnesota, Pennsylvania, Michigan, and Wisconsin (see Figure 3).

Figure 3
APR Gate Alarms by State



Source: Remington-Elsag, Inc. 2004. Data was maintained in the online system for 31 days for evaluation purposes only. Data does not include 113 cases of non-state license plates including government issued plates, dealership plates, uhauls, or temporary license plates. This includes a large number of Ohio dealership plates (small numbers) that were excluded from the above analysis. OSHP was unable to identify the state in 371 cases (22% of total).

Because the APR technology was customized to recognize Ohio license plates better than other states, the main focus of the system was on Ohio license plate reads. As Figure 4 shows, 72 percent of Ohio license plate alarms were matches, but wrong state (excluding Ohio dealership plates). It is unknown how many Ohio license plates the technology missed, but it is clear that APR technology performed as expected in terms of correctly reading Ohio license plates. Since many of the other state APR alarms were on commercial vehicles, the majority of which includes stacked or small letters, performance was less than optimal, although given the known system capabilities the technology appeared to perform well on non-Ohio license plates.

Figure 4
APR Turnpike Gate Alarms by State

State	Valid	Reason #1	Reason #2
IL	4%	39% stacked or small letters	21% partial reading
IN	3%	44% stacked or small letters	26% partial reading
MI	7%	61% match, wrong state	12% stacked or small letters
MN	1%	68% stacked or small letters	12% match, wrong state
OH*	11%	72% match, wrong state	11% valid
PA	7%	41% match, wrong state	33% stacked or small letters
WI	6%	49% stacked or small letters	28% match, wrong state

*Does not include a large number of Ohio dealership plates that include small characters.

Study results indicate that standardizing license plates across states would greatly enhance the performance of APR technology. Non-uniform license plate characters (stacked or small characters) led to the vast majority of misread license plates. Easier state recognition on the plates would also improve the usefulness of APR technology, as would the elimination of duplicate license numbers on vehicles. Analysis of Indiana plates shows that the state produces identical strings of license plate characters for different types of vehicles (i.e., motorcycles and commercial motor

vehicles). Finally, license plate covers reduce the reflectivity of the letters and numbers. Although researches were unable to determine the actual impact that this had on the camera's ability to scan license plates, it should be noted that there was not a single APR alarm with a license plate cover.

APR Turnpike Gate Impact

To determine the potential impact of APR technology on OSHP Operations, researchers searched the Ohio State Highway Patrol's Records Information Management System (RIMS) for data related to auto thefts, including stolen and recovered vehicles (identified as nature code 410 in RIMS) in both 2003 and 2004 on the Ohio Turnpike. Given several limitations associated with the RIMS system, this was the most direct way to measure the impact of APR fixed camera technology.

From January 1, 2003 to November 30, 2003, officers patrolling the Ohio Turnpike reported 39 auto thefts including stolen and recovered vehicles. From August 1, 2003 to November 30, 2003, the time-frame that mirrors the arrival of APR technology in 2004, OSHP officers recorded 12 stolen vehicle recoveries. Overall, 31 percent of vehicle recoveries on the Ohio Turnpike in 2003 occurred during the four-month time frame.

From January 1, 2004 to November 30, 2004, officers patrolling the Ohio Turnpike recorded 36 auto theft recoveries. This was eight percent lower than the previous year. Conversely, from August 1, 2004 to November 30, 2004, there were 18 documented cases of auto theft recoveries. This represents 50 percent of the total cases of auto theft recoveries for 2004 and a 50 percent increase over the number of vehicle recoveries for the same time period in 2003 (see Figure 5). Of the 18 auto theft recoveries during the four-month evaluation, seven were linked to the APR fixed cameras (39 percent). The resulting number of vehicle recoveries that were not due to the APR system (11) is nearly identical to the 12 recoveries recorded during the same time frame the previous year.[6]

Figure 5
Auto Thefts Including Stolen and Recovered*

Category	2003	2004	% Change
11 Months (Jan – Nov)	39	36	**-7.7%**
4 Months (Aug – Nov)	12	18	**+50.0%**

*Data obtained from the OSHP Records Information Management System (RIMS). Analysis only includes cases in which stolen and recovered vehicles were the primary nature code (410).

Overall, during the four-month evaluation, APR fixed cameras were responsible for 19 criminal apprehensions and the recovery of nine stolen vehicles valued at $167,000. It is important to note that these results do not include the 34 instances of alerts to vehicles (or license plates/wanted persons) that were not removed from NCIC, 27 instances that vehicles were not located, or the eight cases involving stolen license plate recoveries or the apprehension of wanted persons.

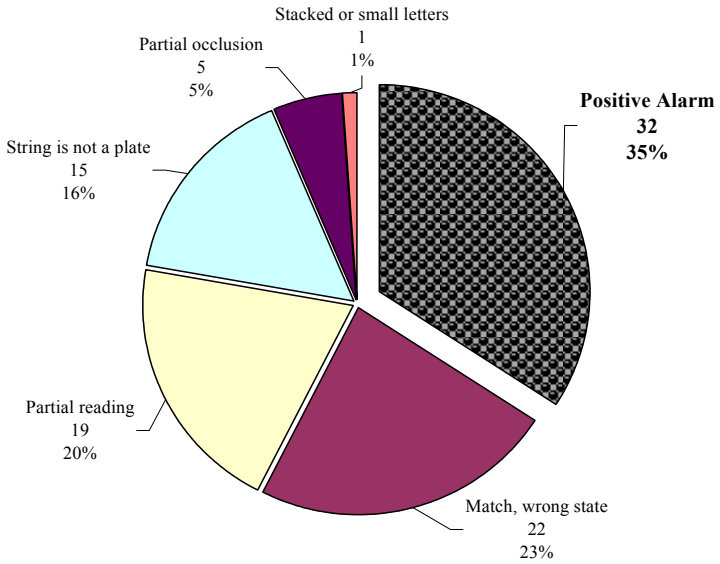
Unmarked Investigative Car

OSHP installed a mobile APR camera in an unmarked investigative car for use in joint anti-theft operations with the Cleveland Police Department. Several advantages to using APR

technology in this manner were identified, including: 1) increasing the likelihood of finding stolen vehicles, license plates, or wanted persons, 2) better evaluating the ability of APR technology in scanning (a large number of) Ohio license plates, and 3) determining the value of APR technology in specialized situations beyond core patrol activities.

Detailed APR alarm information (n=93) was collected from the unmarked investigative car for August 10, 2004 to November 30, 2004 (see Figure 6). During the nearly four-month evaluation, the unmarked investigative car performed 37,339 scans, which included 93 alarms. Of the 93 alarms, 34 percent were "positive," 24 percent were matched – but wrong state, and 20 percent were partial or incomplete reads. There were 15 cases in which APR cameras alerted to non-license plate characters (16 percent), a rate four times higher than for fixed cameras. The unmarked investigative car recorded only one positive alarm involving a license plate with stacked or small letters. This is most likely do to with the fact that the APR investigative car was used in an urban setting, which includes fewer commercial vehicles or out-of-state license plates containing non-standard characters.

Figure 6
APR Unmarked Investigative Car Alarms



Source: Remington-Elsag, Inc., 2004. Includes all APR generated alarms for the OSHP investigative car from August 10, 2004 to November 30, 2004. Data was maintained on the online system for 31 days for evaluation purposes only.

Of the 31 positive APR alarms, 18 were valid and eight were not removed from NCIC (58 percent and 26 percent respectively). Two alarms were matches but wrong vehicles, two involved vehicles that were not located, and one was the result of a system demonstration (six percent, six percent, and three percent respectively). The percent of "valid" alarms for the unmarked investigative car was three times higher than for stationary cameras (56 percent versus 17 percent). Further, the overall rate of valid alarms per scans was 1 in 2,074 for the investigative car versus 1 in 100,989 for the fixed cameras, displaying the overall efficiency (and effectiveness) of APR technology when used in targeted urban settings. Figure 7 provides rates of APR alarms involving the unmarked investigative car.

Figure 7
APR Unmarked Investigative Car Rates

Category	#	Rate per scan	Rate per alarm	Rate per positive alarm
Passive Scans	37,339			
Total Alarms	93	1 in 401		
Positive Alarms	31	1 in 1,204	1 in 3	
Valid Alarms	18	1 in 2,074	1 in 5	1 in 2

Total alarms do not include instances in which the mobile APR technology alerted to the same vehicle multiple times. Because researchers do not know how many passive scans involve the same vehicle, duplicate counts of scans are included.

APR Investigative Car Impact

To determine the potential impact of the APR technology on joint operations with the Cleveland Police Department, researchers reviewed RIMS cases for OSHP Cleveland Operations for 2003 and 2004 (see Figure 8). From January 1, 2003 to November 30, 2003, Cleveland Operations had 30 stolen vehicle recoveries. From August 1, 2003 to November 30, 2003, the time frame associated with the introduction of APR technology in 2004, Cleveland Operations recorded 16 stolen vehicle recoveries. This represents 53 percent of the total vehicle recoveries in 2003. Of the 16 vehicle recoveries that occurred during the four-month time frame, 50 percent were the result of salvage inspections or other non-active patrol duties (recoveries involving informants, tips, title inspections, etc.).

From January 1, 2004 to November 30, 2004, Cleveland Operations had 66 stolen vehicle recoveries. This is an 120 percent increase from last year. From August 1, 2004 to November 30, 2004, Cleveland Operations recorded 29 stolen vehicle recoveries, an 81 percent increase from the same time period last year. Fourteen of the 29 stolen vehicle recoveries during the four-month evaluation were associated with APR technology (48 percent). The 29 stolen vehicle recoveries represent 44 percent of the total for the year (compared to 53 percent in 2003). However, of the 29 vehicle recoveries that occurred during the four-month time frame, only 14 percent were the result of non-patrol activities (compared to 50 percent last year). Eighty-six percent of vehicle recoveries occurred during active enforcement efforts while using the APR technology.

It is important to note that some of the recoveries during the evaluation period attributed to APR technology may have occurred without the system (abandoned vehicles). Further, stolen vehicle recoveries in OSHP Cleveland Operations were significantly higher before the evaluation period. Regardless, the APR technology allows officers to expand their coverage as well as scan nearly all vehicles that they have contact with (not just suspect vehicles). As the data clearly demonstrates, the APR system has led to more proactive enforcement. During the four-month evaluation, the number of stolen vehicle recoveries from active enforcement efforts (not including salvage vehicle inspections, title inspections, informants, tips, etc.) went from 50 percent in 2003 to 86 percent in 2004.

Figure 8
OSHP Cleveland Operations
Auto Thefts Including Stolen and Recovered*

Category	2003	2004	% Change
11 Months (Jan – Nov)	30	66	**+120.0%**
4 Months (Aug – Nov)	16	29	**+81.3%**

*Data obtained from the OSHP Records Information Management System (RIMS). Analysis only includes cases in which stolen and recovered vehicles were the primary nature code (410).

An additional aspect of the impact analysis involved the unmarked patrol car's level of daily activity (see Figure 9). For purposes of the evaluation, level of activity was measured by how many passive APR scans were conducted in a given day. During the four-month evaluation, the unmarked patrol car had 34 days of no activity (0 scans), 50 days of low activity (1-499 scans), 13 days of medium activity (500-999 scans), and 12 days of high activity (1,000 or more scans). Beyond daily activity, researchers were interested in knowing the outcome of APR activity, or how many arrests or apprehensions occurred as a result of APR use (valid alarms). Overall, APR technology attached to the investigative car led to one stolen vehicle or stolen license plate recovery every four days that it was used ("use" is defined as one or more passive scans in a given day), regardless of the level of activity. A closer examination of the data revealed that few recoveries occurred on low activity days (average of 1 recovery every 50 days) compared to medium and high activity days. During days that the APR technology conducted 500-999 scans (medium activity), officers average one vehicle or stolen license plate recovery every three days. On high-activity days (1,000 or more scans), officers averaged one stolen vehicle or stolen license plate per day.

Figure 9
OSHP Unmarked Investigative Car
Days of Use, Scans, and Valid Alarms

Category	Days	Total Scans	Total Alarms	Positive Alarms	Valid Alarms	Valid Alarm Rate
No Activity (0 scans)	34	0	0	0	0	
Low Activity (1-499 scans)	50	11,505	32	4	1	1 in 50 days
Medium Activity (500-999 scans)	13	9,303	22	8	5	1 in 3 days
High Activity (1000 or more scans)	12	16,531	43	19	12	1 per day

APR technology had a positive impact on OSHP operations involving joint anti-theft operations with the Cleveland Police Department. APR technology seems to increase officer efficiency by allowing passive license plate scans of all vehicles instead of (or in addition to) manual, officer-initiated checks of suspect vehicles only. Overall, stolen vehicle recoveries by Cleveland Operations are up 120 percent in 2004 (11 months) and 81 percent during the four-month evaluation period. While there was a noticeable increase in officer activity prior to the introduction of APR technology in OSHP Cleveland Operations in 2004, it appears that APR technology has increased the amount of stolen vehicle recoveries as a result of active patrol duties, which increased from 50 percent in 2003 to 86 percent in 2004. Further, the effectiveness of APR technology was dependent on its level of use. During low activity days, APR technology was responsible for an average of one stolen license plate or stolen vehicle recovery every 50 days. On high activity days, officers using APR technology averaged a stolen vehicle or stolen license plate every day.

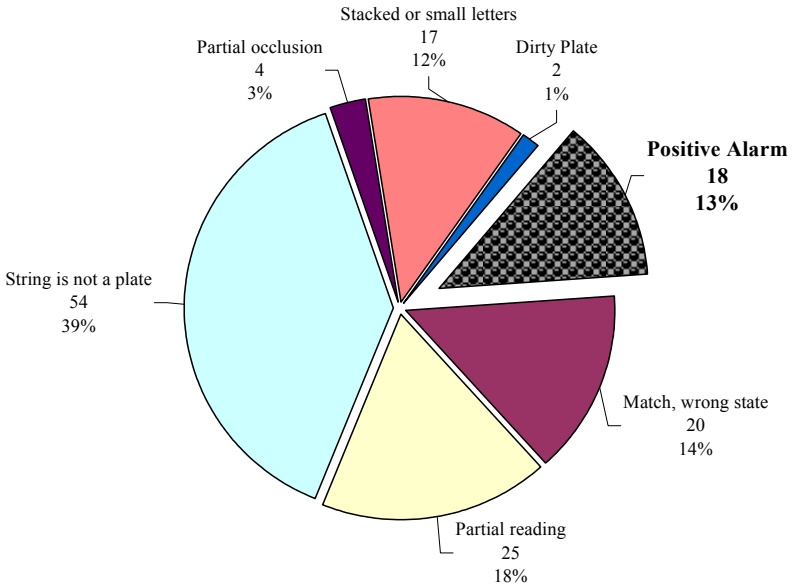
Although some of the recoveries attributed to APR technology may have occurred without the use of the product, overall it appears that the system increased officer productivity during joint anti-theft operations in Cleveland, Ohio.

Marked Patrol Cars

Mobile APR cameras were attached to marked patrol cars for use during routine patrol activities on the Ohio Turnpike. Due to the lack of activity (APR scans) early in the project from the first marked patrol car, OSHP attached a second APR camera to another vehicle in late October to increase use of the APR system. Overall, it appears that the technology had little value for officers during routine patrols on the Ohio Turnpike.

Detailed APR alarm information was collected on marked patrol cars from August 10, 2004 to November 30, 2004 (n=140). During the nearly four-month evaluation, marked patrol cars performed 37,883 scans, which included 140 alarms. Of the 140 alarms, 39 percent were alarms on non-license plate characters, 18 percent were partial reads, 14 percent were matched – but wrong state, and 13 percent were "positive" (see Figure 10). The rate of alerts to non-license plate characters ("string is not a plate") was twice as high than for the unmarked investigative car and ten times higher than the rate for fixed cameras.

Figure 10
APR Marked Patrol Car Alarms



Source: Remington-Elsag, Inc., 2004. Includes all APR generated alarms for the OSHP patrol cars from August 10, 2004 to November 30, 2004. Data was maintained on the online system for 31 days for evaluation purposes only.

Of the 18 "positive" alarms from marked patrol cars, 15 were APR technology demonstrations (83 percent). This significantly raised the level of performance of the technology, but overstated its usefulness. Of the other three "positive" alarms, two involved license plates that were previously recovered and not removed from NCIC files and one was valid. The one valid alarm involved the apprehension of a suspect who had stolen a license plate. It appears that APR technology during routine patrol on high-speed highways has little value for OSHP. As Figure 11

shows, the rate of valid alarms per APR scan for marked patrol cars was one in 37,883; a rate 18 times worse than for the unmarked investigative car (one in 2,074). It appears that APR mobile technology is better suited for use in low speed, high theft urban settings. (See section on Unmarked Investigative Car.)

Figure 11
APR Marked Patrol Car Rates

Category	#	Rate per scan	Rate per alarm	Rate per positive alarm
Passive Scans	37,883			
Total Alarms	140	1 in 271		
Positive Alarms	18	1 in 2,105	1 in 8	
Valid Alarms	1	1 in 37,883	1 in 140	1 in 18

Total alarms do not include instances in which the mobile APR technology alerted to the same vehicle multiple times. Because researchers do not know how many passive scans involve the same vehicle, duplicate counts of scans are included. The large number of APR system demonstrations for marked patrol cars during the evaluation increased the rate of positive alarms.

The high rate of non-license plate character recognition on mobile alarms is cause for concern. The Remington-Elsag system specifications that indicate the cameras read characters of a certain height and length did not always appear to be the fact; non-reflective scans of roadway surfaces and porch pillars during the evaluation indicate the contrary. It is also important to note that entries by law enforcement agencies into the NCIC database include all the characters that appear on a license plate (without regard to their height, width, or location), most notably stacked characters that were often found on commercial motor vehicles, small letters on Ohio dealership plates, and stacked or small letters before, in the middle of, or at the end of normal size characters in some out-of-state license plates (i.e., Indiana, Pennsylvania, and Michigan). Because the APR technology being evaluated is unable to recognize these characters, license plates that contain non-standard letters or numbers can never be positively identified by APR technology. These NCIC entries will always produce false alarms.

CONCLUSION

In 2004, OSHP conducted a four-month evaluation of APR technology. The goal of the study was to determine the effectiveness of the APR technology and its impact on Division operations, as well as its usefulness in Homeland Security operations. Preliminary results from the evaluation of the technology are encouraging. During the four-month evaluation, APR technology led to the apprehension of 23 criminal suspects and the recovery of 24 stolen vehicles valued at $221,000. Due to the different environments and uses of APR technology, the evaluation was divided into three sections: Turnpike gates, unmarked investigative car, and marked patrol cars. As Figure 12 shows, Turnpike gates and the unmarked investigative car accounted for 35 of the 36 valid alarms produced by APR technology.

Figure 12
APR Activity by Category

Category	Total Scans	Total Alarms	Positive Alarms	Valid Alarms	Valid Alarms Per Scan
Turnpike Gates	1,875,231	3,286	108	17	1 in 110,308
Investigative Car	37,339	93	31	18	1 in 2,075
Marked Patrol Cars	37,883	140	18	1	1 in 37,883

- **Turnpike gates** were responsible for 19 criminal apprehensions and the recovery of nine stolen vehicles valued at $167,000.
- **Unmarked investigative car** led to three criminal apprehensions and 15 stolen vehicles recoveries valued at $54,000.
- **Marked patrol cars** yielded one criminal apprehension involving a stolen license plate.

Overall, given the known system capabilities, APR technology was fairly accurate in recognizing license plate characters and matching them to Hot List entries. Performance of APR technology varied significantly based on the environmental setting and level of use. The APR technology met OSHP expectations in 67 percent of Turnpike gate alarms, 59 percent of investigative car alarms, and in only 39 percent of marked patrol car alarms (see Figure 13). It should be noted that the large number of system demonstrations included in the marked patrol car numbers ("positive alarms") overstates its performance. While the rate of incomplete or partial scans was consistent across environments, the percent of non-license plate scans ("string is not a plate") varied considerably. Thirty-nine percent of marked patrol car alarms were due to non-license plate scans, over twice the percent of the unmarked investigative car and nearly ten times the rate for Turnpike gates.

Figure 13
APR Alarms by Category

	APR Meets Expectations					APR Performs Poorly	
Category	Positive Alarms	Match, wrong state	Stacked or small characters	Partial occlusion	Other	Incomplete or partial scan	String is not a plate
Turnpike Gates	3%	30%	34%	8%	2%	19%	4%
Investigative Car	34%	24%	1%	5%	0%	20%	16%
Marked Patrol Cars	13%	14%	12%	3%	1%	18%	39%

Researchers identified four significant areas that need to be addressed before APR technology can fully benefit Homeland Security and criminal patrol operations. First, the large number of license plates that contain stacked or small characters, especially on commercial motor vehicles, limits the pool of stolen or suspect vehicles that are accurately scanned by APR technology. Because all characters on license plates are entered into NCIC files, scanned vehicles with plates that contain stacked or small letters/numbers will not produce valid APR alarms. Therefore, any vehicle with plates that contain these characters (e.g., hazardous material carriers used in biohazard attacks) will not be correctly identified. Second, limits on manpower restrict the ability of agencies to follow-up on all APR alarms. OSHP officers were unable to locate 25 percent of vehicles that generated "positive" APR alarms from Turnpike gates. The disposition of these cases is unknown, and additional personnel and interagency cooperation may increase the number of vehicles that are located by officers. Third, a nationwide effort to update NCIC records in a

timely manner is needed to reduce the number of "false" alarms. Officers spent a considerable amount of time following up on APR alarms for previously recovered vehicles that were not removed from NCIC files. Fourth, data suggests that license plate covers reduce the reflectivity of plates and license plate frames obscure the identification of some states. Overall, at least 14 percent of vehicles were not scanned by APR technology and researchers were unable to recognize the state in 22 percent of license plate images.

APR technology had little impact on normal dispatcher duties. The agency had no major problems in downloading NCIC data, although researchers found that 31 percent of "positive" alarms from Turnpike gates and 26 percent of "positive" investigative car alarms were no longer valid in the NCIC database. The APR technology increased the efficiency and productivity of officers by auto scanning license plates and reducing the need for individual file checks. Officers appeared more comfortable using the technology during slow speed patrols, and found it more difficult during high speed activities. Early implementation of the system required a large commitment of Information Technology (IT) staff. Ongoing maintenance or an aggressive expansion of the system may require additional IT resources. Overall, OSHP experienced few technical difficulties instituting the technology.

APR technology appears to be best suited for use on limited access, high auto theft corridors and for routine patrols at slower speeds. Ohio Turnpike gates offered an ideal opportunity to test APR technology because fixed cameras were able to capture license plate images at slow speeds. Further research is needed to determine the effectiveness of fixed cameras at higher speeds. Overall, APR technology played a major role in the 50 percent increase in stolen vehicle recoveries on the Turnpike from 2003 to 2004. Similarly, the mobile camera attached to the unmarked investigative car helped contribute to the 81 percent increase in stolen vehicle recoveries in OSHP's Cleveland Operations. In particular, during the 12 days considered "high activity" (1,000 or more license plate scans), APR technology averaged a stolen vehicle recovery or apprehension every day. A more widespread but targeted approach to APR deployment would prove successful in the recognition and recovery of stolen vehicles in Ohio.

APPENDIX A
APR Camera Installations

1. Fixed APR cameras attached to Ohio Turnpike gates.

2. Mobile APR camera attached to an Ohio State Highway Patrol vehicle.

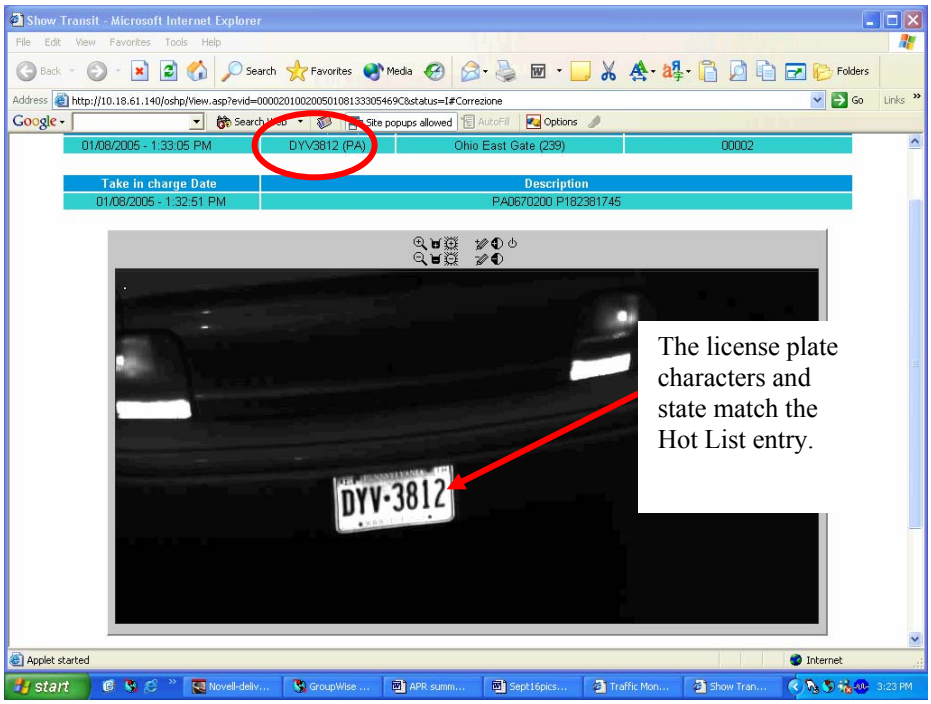
APPENDIX B

APR Alarm Code Definitions

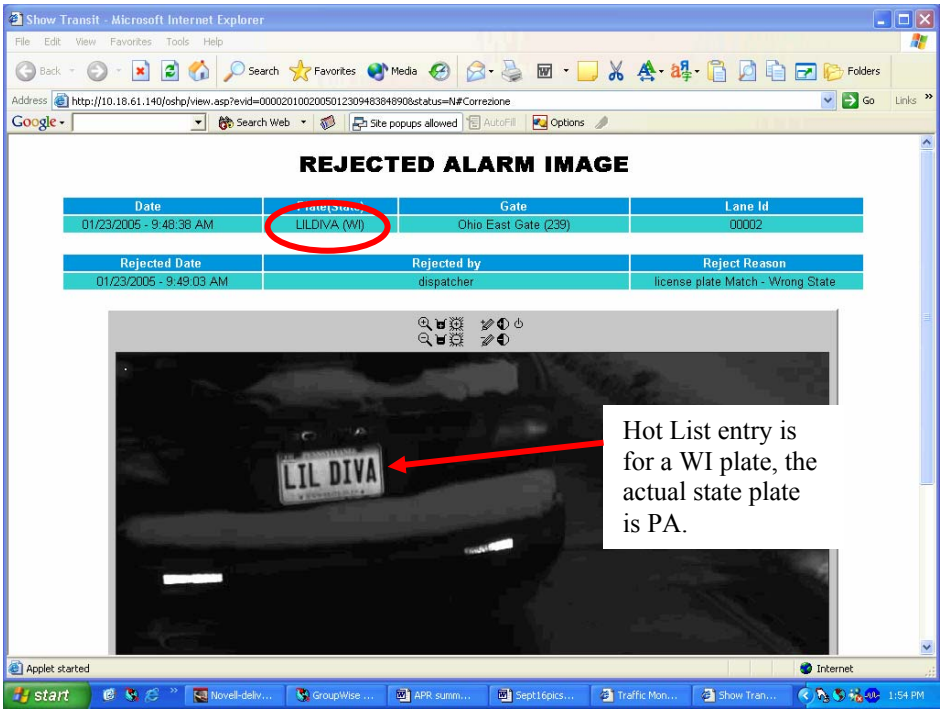
Categories	Definition
Rejected Alarms	
Match – wrong state	License plate characters match a Hot List license plate. The license plate state does not match the entry.
Partial occlusion	An obstruction (i.e. trailer hitch) partially hides one or more license plate characters. The characters that are not hidden from the APR camera view match a Hot List entry.
Partial or incomplete reading	APR technology fails to recognize one or more license plate characters. There is no apparent reason for the failure in camera recognition.
Stacked or small letters	One or more license plate characters are smaller than normal height (common in Ohio dealership plates) or are smaller and stacked either in front of or behind normal size characters (common in commercial motor vehicles). The normal size characters are correctly read and generate an APR alarm.
String is not a plate	APR cameras scan reflective, but non-license plate characters that generate an alert to a Hot List entry. This was often seen in lettering on the back of commercial motor vehicles. Other non-license plate scans included: for sale signs, pickup truck bed liners, house porch posts, etc.
Other	Partially dirty license plates and other rare occurrences in which the APR camera scanned the remaining characters that matched a Hot List entry.
Positive	APR cameras correctly scanned the license plate characters and the license plate state matched the state of the Hot List entry.
Accepted Alarms ("Positive")	
System demonstration	OSHP officers were demonstrating the APR technology to the media or other law enforcement professionals.
Not located	OSHP officers were dispatched to intercept an alert but were unable to locate the suspect vehicle.
Not removed	The law enforcement agency that was responsible for the Hot List entry failed to remove a previously recovered stolen vehicle or license plate from the NCIC database.
Wrong plate	License plate characters and state match the Hot List entry, but was located on the wrong vehicle. Researchers often saw this with commercial motor vehicles from Indiana.
System down	APR technology was unavailable or not functioning.
Other	Includes occurrences such as one license plate was stolen and the owner was still using the identical second license plate on the vehicle.
Valid	APR alarms that resulted in the recovery of a stolen vehicle, a stolen license plate, or the apprehension of a criminal suspect.

APPENDIX C
APR Alarm Images

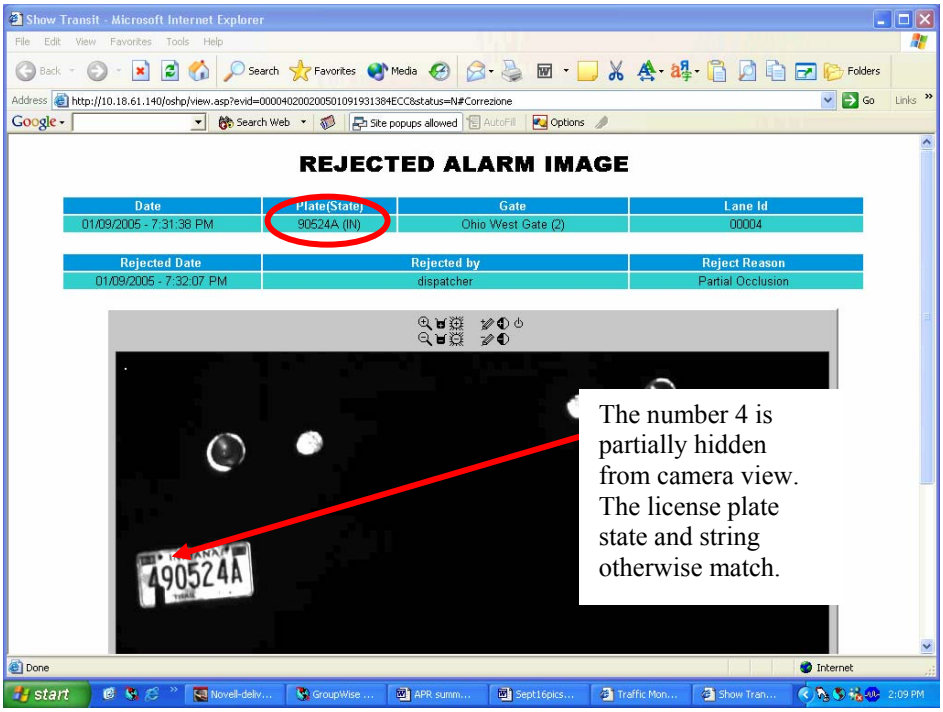
1. Valid alarm



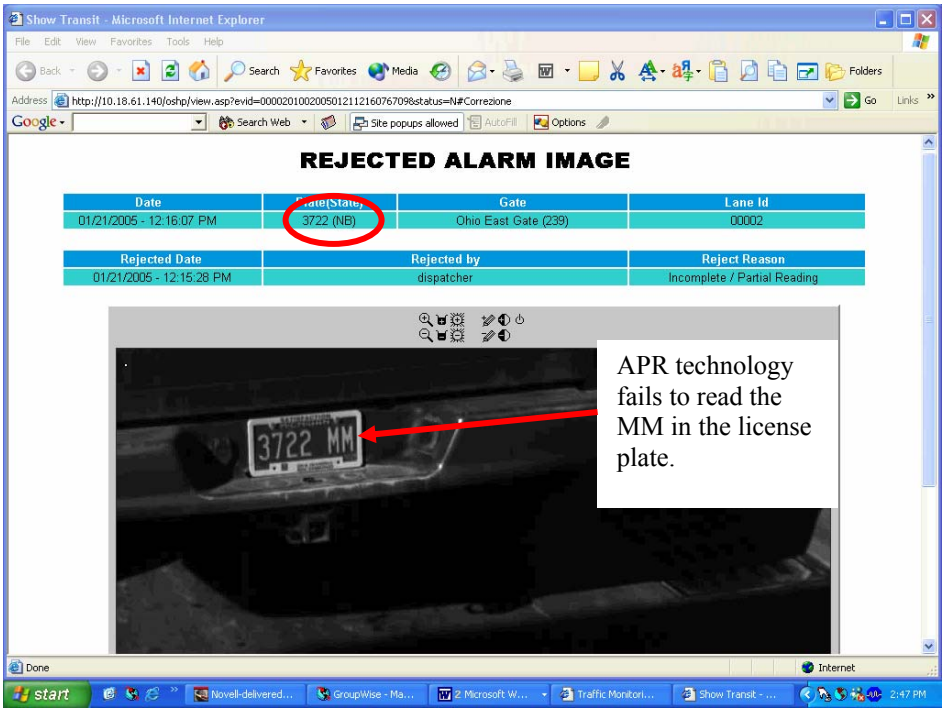
2. Match, wrong state



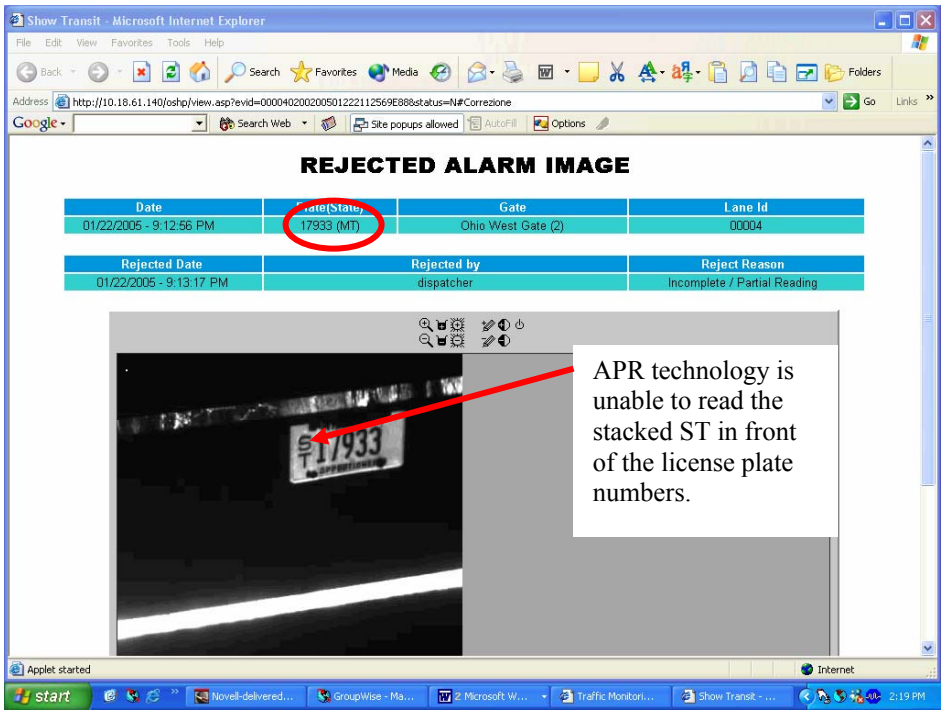
3. Partial occlusion

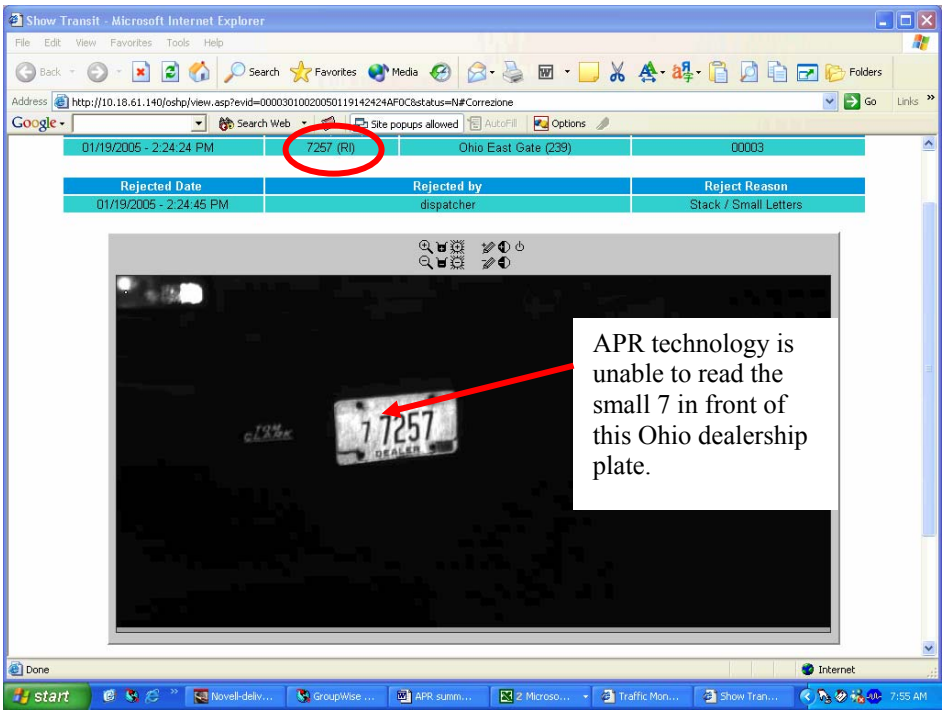


4. Partial or incomplete reading

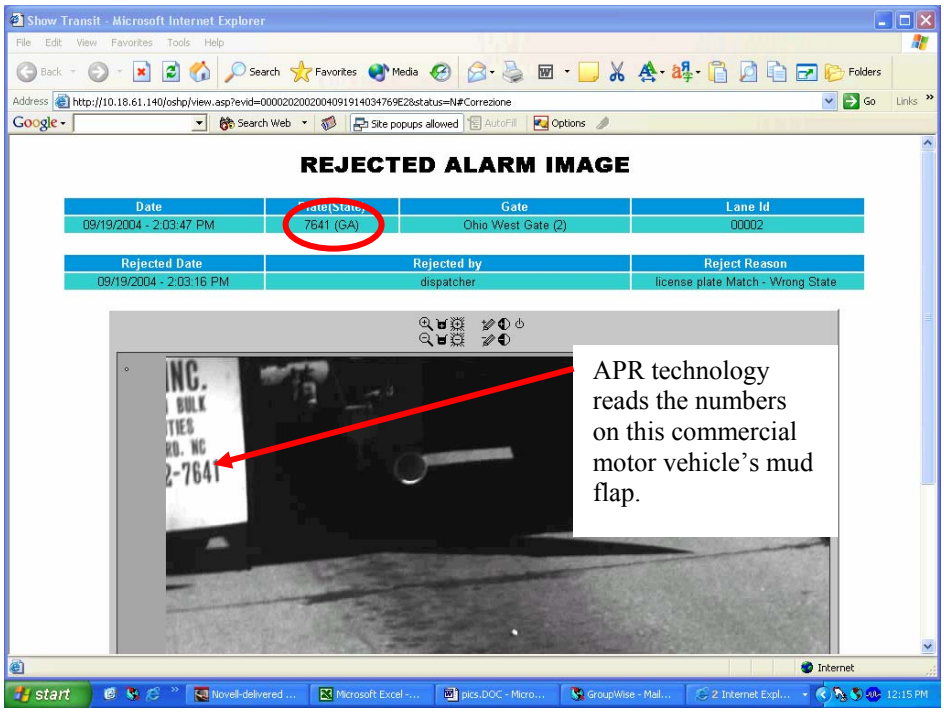


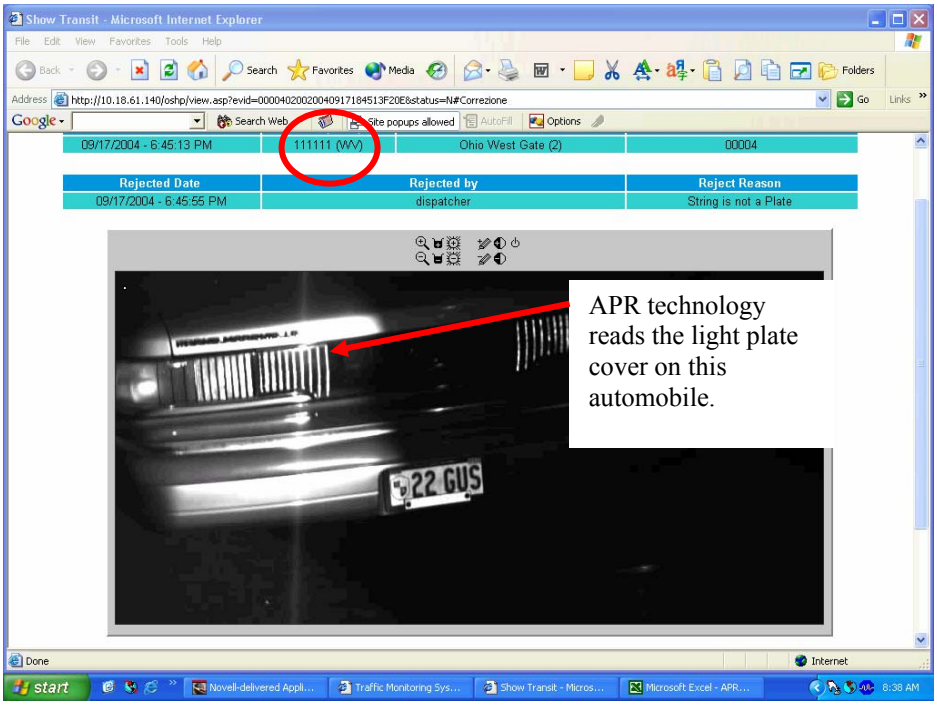
5. Stacked or small letters



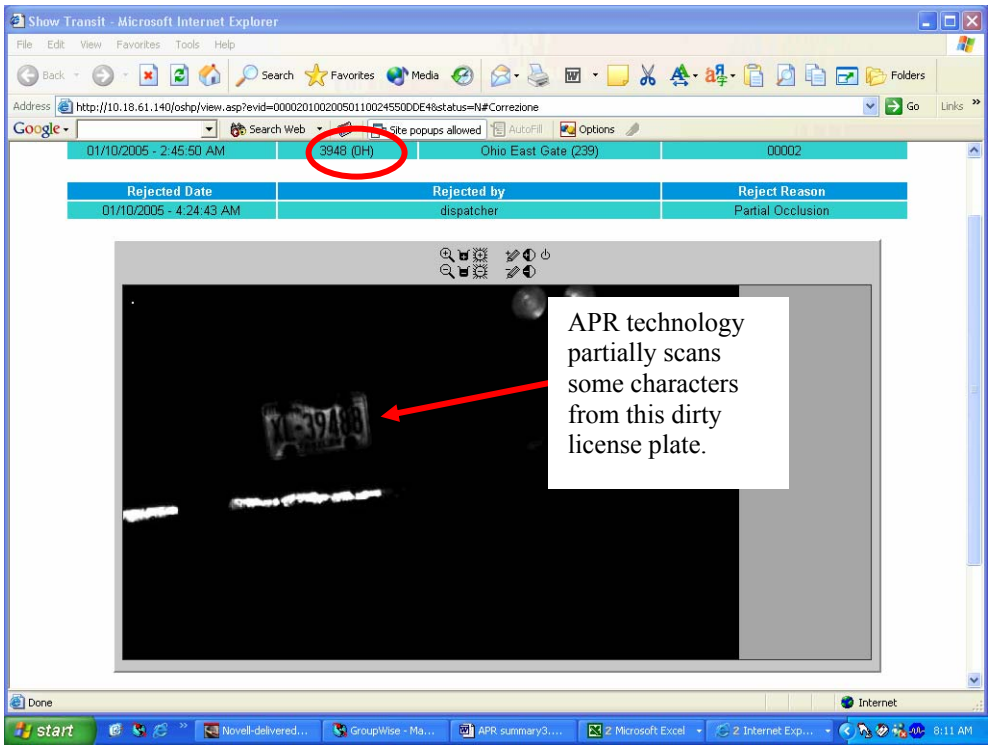


6. String is not a plate





7. Other – dirty plate



[1] Phillips, Lt. Paul (1998). Hot Wheels. Florida Crime Prevention Association.
[2] OSHP officers assigned to mobile units were responsible for downloading Hot List files daily via a wireless interface located at District 10 Headquarters. Information about the previous day's activity contained in the mobile APR system (i.e. details about license plate scans and alarms) was also uploaded to the main server at this time.
[3] Researchers did find that mobile APR technology produced multiple vehicle scans associated with alarms. APR alarms that occurred for the same license plate at nearly the same time of day were excluded from the analysis. Staff were unable to determine the impact that multiple vehicle scans had on the overall number of license plates read. Further, researchers are unsure if APR technology on Turnpike gates produced multiple license plate scans.
[4] Represents the difference between the total number of APR technology scans or "transits" that were conducted at Turnpike gates (1,875,231) and the total number of vehicles that the Ohio Turnpike Commission reported entering the state via lanes 2, 3, or 4 of the East or West Gates (2,175,257) during the evaluation period.
[5] Of the 1,679 APR gate alarms, OSHP identified the license plate state on 1,195 alarms. There were 371 APR alarms of unknown origin (including alarms for non-license plate characters) and 113 APR alarms for non-state identified plates, including uhauls, dealerships, and government issued plates. There were 98 cases of license plates of dealerships during the evaluation, the majority from Ohio. Researchers did not include these in the analysis.
[6] Researchers identified two additional cases of auto theft recoveries attributed to the APR technology during the time frame that were not included in the analysis. Again, because of limitations to the RIMS system, staff felt for consistency purposes that it was better to not include these cases in this discussion, only those with a primary nature code of 410 in RIMS were included.