Case Study

SANDAG Pilot of Conduent® Vehicle Passenger Detection System

Overview

As more agencies adopt the use of High Occupancy Vehicle (HOV) and High Occupancy Toll (HOT) lanes as a tool for improving system throughput, one of the challenges is that these systems rely on self-declaration by drivers as to whether the vehicle has the requisite number of occupants to use the lane. This self-declaration can take the form of the presence of a toll transponder, a switchable toll tag setting, or in the case of HOV systems, simply the act of entering the lane by the driver is how they declare that they are qualified.

This leads to enforcement challenges in that not everyone who indicates that they are HOV/HOT qualified will actually have the requisite number of occupants. This "honor" system where there is a reliance on individual drivers to accurately declare their HOV/HOT status is generally enforced by officers placed by the side of the road who attempt to look into vehicles to determine the number of passengers in the vehicle.

Given the fact that vehicles are going past at 50-90 miles per hour - often under heavy traffic conditions - and the enforcement officer is relying on human eyesight under a variety of lighting and weather conditions, enforcement can be a challenge. To assist officers in the enforcement of HOV/HOT lanes, Conduent Transportation has introduced the Conduent® Vehicle Passenger Detection System (VPDS) which, by employing cameras, illuminators, and algorithms based upon computer vision techniques, is able to establish whether a vehicle is HOV/HOT qualified.

During pilot trials with live traffic, VPDS has delivered accuracy levels of approximately 95% for HOV2 facilities, when declaring whether a vehicle is a Single Occupant Vehicle (SOV) or whether the vehicle is an HOV. Conduent Transportation and the San Diego Association of Governments (SANDAG) conducted a trial of VPDS during April-June, 2015. This report summarizes the results and lessons learned from the trial.

Figure 1:

Side Camera and Illuminator (I-15 and Miramar Way)

Description of the SANDAG Trial

To conduct the trial SANDAG and Conduent Transportation selected a location on the Interstate 15 Express Lanes at Miramar Way in San Diego, CA. This location is a HOT lane facility that has toll gantries for the purpose of reading the toll transponders. Because of this proximity to toll lane equipment, Conduent Transportation had access to electrical power for the VPDS.

The system was located on the right shoulder of the northbound HOT lanes on I-15 directly adjacent to an existing toll gantry. VPDS was mounted on the passenger side of the road in the shoulder area. The front camera and front illuminator were mounted on a pole which Conduent Transportation erected and which was aimed at the front windshield. The front camera was approximately 10-12 feet above the road surface. The side camera and side illuminator were mounted at approximately 3.5 feet on a structure that Conduent Transportation had put in place on the roadside.

Images were collected on the outermost northbound Express Lane (Lane #3) during the period of April through June, 2015. During the initial phase of the trial, Conduent Transportation confirmed that the system was operating under stable conditions, with a reliable power supply, and that the images gathered were suitable for determination of HOV/HOT status of the vehicles. This test was unique from previous pilots due to a combination of two factors:

1. the system was mounted on a roadside pole and not a gantry, and
2. the system was on the passenger side of the vehicle which created some obstructed viewing of front seat passengers due to the vehicle's passenger side "A" pillar partially blocking the view.

This is a situation that may be encountered in the field, but among the lessons learned is that when mounting on a passenger side location, the front camera should be on a gantry or cantilevered pole to avoid vehicle passenger side "A" pillar obstruction. This is discussed further in the lessons learned portion of the document.

Data Collection and Analysis

There were several thousand images collected as part of the trial, but the analysis focused on two sets of data. The two datasets were:

1. a dataset from a "controlled" test using vehicles and drivers that SANDAG drove in normal public traffic on the roadway, and
2. a dataset from an "uncontrolled" test which used vehicles under normal public traffic on the roadway.

The data collection and analysis procedure was as follows:

1. the VPDS system would collect imagery and store the imagery in removable hard drives at the roadside
2. SANDAG would remotely connect to the VPDS system at the roadside and count vehicle images collected and perform a sample of human manual image review to establish the 'ground truth' of the occupancy state of a sample of vehicle images
3. the removable hard drives would be shipped to Conduent Transportation
4. Conduent Transportation would count the vehicle images, perform automatic occupancy state determination of the vehicles, and perform human manual image review to establish the 'ground truth' of the occupancy state of all of the vehicles in the datasets.

Note that since the roadway is an HOV2+ facility, the VPDS system declared each vehicle's occupancy status as "SOV" or "HOV2+". Accuracy is defined as the number of correct occupancy status declarations divided by the number of eligible vehicles detected. Eligible vehicles are all vehicles detected excluding buses, motorcycles, and van pools.

Conduent Transportation was primarily focused on the accuracy of declaring the vehicle occupancy status of the automated VPDS. Accuracy is established using the output from VPDS once a location-specific model is created and used to score the images the system sees. The model which was used for scoring of the collected images was created based upon data collected on May 29 -31, 2015. These images are, of course, not in the datasets under test in the "controlled" test nor the "uncontrolled" test.

Figure 2:

Front Camera and Illuminator (I-15 and Miramar Way)

The assessment of the system accuracy performance was developed using data and images collected during the month of June 2015. Note that the system had never seen these images before and these images were not used in generating the model described above. The VPDS accuracy level was based upon comparing the automated output from VPDS to analysis performed by human reviewers looking at images that were captured by the system. The human reviewers slowly and methodically review the images and create the ground truth which provides the basis for comparison.

As the primary HOT lane stakeholder on the I-15 Express Lanes, SANDAG was focused on two performance statistics. The first statistic was the capture rate of vehicles – how many vehicles drove through the lane as determined by the Toll Lane Reader versus the number of vehicles VPDS captured and scored for SOV/HOV2+ status. These numbers differ in that the Toll Collection System is a production-hardened system that relies on production versions of laser-based triggers that have been used in many toll installations while the Conduent Transportation prototype system depended upon a combination of laser-based and software-controlled triggers. The second statistic was the accuracy of the system with respect to declaring the occupancy status of the vehicle. While both statistics – capture rate and accuracy – are very important, Conduent Transportation was focused on the measurement of accuracy. Capture rate is a statistic that depends upon the vehicle detection method used, and is a problem that has been solved in toll collection systems and license plate recognition systems. Results for accuracy and capture rate are explored more fully in the Data Results and Summary sections.

The two sets of data used in the analysis are:

1. SANDAG-controlled tests during the month of June whereby SANDAG vehicles and drivers drove on the roadway past the VPDS installation point. These vehicles would drive past the location at a known date, time, and with a known occupancy. SANDAG personnel would then compare the automated results generated by VPDS to the known conditions: date, time, and occupancy. The controlled tests were run over on the following dates: June 10, June 11, June 12, June 17, June 24, and June 25.
2. Conduent Transportation and SANDAG agreed to conduct uncontrolled tests to evaluate the system using the available traffic past the location during the period of June 1-5, 2015. This analysis was conducted over ten separate 15-minute intervals during the week of June 1-5.

Data Results

During the trial, the two sets of data were generated, including imagery and automated VPDS results. The imagery was reviewed my human reviewers in front of a computer screen to verify the data collected in dataset 1 ("controlled" test – SANDAG vehicles and drivers and passengers) and to establish the actual vehicle occupancy status in dataset 2 ("uncontrolled" test – public roadway vehicles).

Column 1 in Table 1 is the date the data was collected. Column 2 indicates the number of controlled passes that SANDAG personnel made past VPDS within normal public traffic using SANDAG vehicles and SANDAG personnel sitting inside the vehicles in various passenger configurations. Column 3 is the total vehicles within two date periods. The first date period was June 10-17, the second date period was June 24-25. During the first date period, an image capture parameter which locks out vehicle triggers after a trigger has been received was set to 0.75 seconds to avoid thermal damage to the VPDS illuminator unit. However, it was noted that this value of "lock-out" was likely causing the system to miss vehicles. Thus, the parameter was changed to 0.30 seconds during the second date period to reduce the number of missed vehicles. Column 4 is the number of vehicles captured by VPDS as counted by SANDAG personnel when they remotely logged into the VPDS system and the data was stored in hard drives at the roadside on VPDS. Column 5 is the number of vehicles captured by VPDS as counted by Conduent Transportation after the hard drive was shipped back. Column 6 is the number of vehicles where VPDS correctly declared the occupancy state of the vehicle. Column 7 is the percentage of correct occupancy declarations out of the number of vehicles captured for the available images.

From the table, two initial observations can be made. The first observation is that the number of vehicles that VPDS did capture was larger for the

Table 1: Controlled Test Results

Date	Vehicle Passes	Total Vehicles	Vehicles Captured by VPDS (SANDAG)	Capture Rate	Vehicles Captured by VPDS (Conduent Transportation)	Number of Correct Occupancy Declarations	% Correct Occupancy Declarations
June 10	18	69	54	78.3%	49	48	98.0%
June 11	18						
June 12	15						
June 17	18						
June 24	18	36	33	91.7%	26	25	96.2%
June 25	18						
4.128 mm	105	105	87	82.3%	75	73	97.3%

SANDAG count (column 4) than for the Conduent Transportation count (column 5). Unfortunately, this was due to corruption of data on the hard drive when removing the hard drive from the system and shipping it from the roadside VPDS back to Conduent Transportation. The SANDAG count was determined by SANDAG personnel remotely logging into VPDS and analyzing the data on the hard drive as it was mounted on the roadside system – no data corruption.

The Conduent Transportation count was determined after the hard disk was removed from the roadside VPDS and shipped back to Conduent Transportation. Unfortunately, when received by Conduent Transportation, the hard disk was corrupted and disk recovery tools were required to recover as many image files as possible. Not all image files were recoverable. Since this failure was identified, better hard disk removal and data handling procedures have been instituted and in all recent VPDS installations beyond the SANDAG installation hard disk data corruption has not been observed.

The second observation is that the number of vehicles captured by VPDS is less than the total number of vehicles in the test, whether the SANDAG count is used (column 4) or the Conduent Transportation count is used (column 5) – VPDS missed some vehicles. As indicated in Table 1, of the 105 vehicle passes during the controlled tests, VPDS captured 87 vehicles (using the more accurate SANDAG count). There are two reasons for this result. The primary reason for missed vehicle data is a software setting on the VPDS installation. For the controlled passes conducted on June 10, 11, 12, and 17, the system was set to only capture one vehicle every 0.75 seconds. This is a lock out feature which can be used to extend the life of the Illuminator Flash. Conduent Transportation had set the reset time to 0.75 seconds to preserve the flash. However, during times of heavy traffic the system will often see more than one vehicle every 0.75 seconds – resulting in a miss. This is not a failure of the occupancy status detection algorithm, but simply a result of a trigger setting. Setting a detection and trigger interval to capture all vehicles is a function that is well understood and can be readily adjusted. During the period where the reset period was set at 0.75 seconds, the system captured 54 out of 69 vehicles (capture rate of 78.2%) – during periods of heavy traffic with little separation between vehicles this is to be expected given the reset period set to 0.75 seconds. To assess the impact of the reset time on the capture rate, on June 19th, Conduent Transportation adjusted the reset time to 0.30 seconds. Of the 36 vehicles in the controlled test on June 24th and 25th, VPDS captured 33 of the 36 vehicles (capture rate of 91.7%) – a significant improvement over the previous period. The remaining 3 vehicles were missed due to lack of computational power. The Conduent Transportation system was using a single processor to assess the vehicle occupancy, when under normal operating conditions a four core multi-threaded processor would be used. At installations and tests of VPDS conducted after the SANDAG testing, the trigger

Table 2: Uncontrolled Test Results

Date	Time	Total Vehicles	Vehicles Captured by VPDS (SANDAG)	Capture Rate	In-Scope Vehicles Captured by VPDS (SANDAG)	In-Scope Vehicles Captured by VPDS (Conduent Transportation®)	Number of Correct Occupancy Declarations	% Correct Occupancy Declarations
6/1/2015	05:15 – 05:30	47	46	97.9%	38	37	34	91.9%
6/1/2015	05:30 – 05:45	73	71	97.3%	60	59	57	96.6%
6/2/2015	07:15 – 07:30	165	158	95.8%	145	139	136	97.8%
6/2/2015	23:00 – 23:15	111	110	99.1%	102	99	94	94.9%
6/2/2015	23:15 – 23:30							
6/2/2015	23:30 – 23:45							
6/2/2015	23:45 – 00:00							
6/3/2015	12:30 – 12:45	134	131	97.8%	123	83	76	91.6%
6/3/2015	16:30 – 16:45	359	301	83.8%	279	265	249	94.0%
6/4/2015	16:30 – 16:45	460	312	67.8%	252	138	122	88.4%
6/5/2015	15:45 – 16:00	445	368	82.7%	342	352	331	94.0%
Overall		1794	1497	83.4%	1341	1172	1099	93.8%

lock out period was set to 0.25 seconds and a four core processor was used (similar to that widely available in laptop computers) and a capture rate of well over 99.5% was observed when matching transactions between VPDS and a tolling system. Note that under roadway testing conditions and lab life testing, the illuminator can easily withstand a lockout period of 0.25 seconds without having any thermal failures of the VPDS illuminator unit and without missing vehicles. The reader should see Conduent Transportation for more details on these latest results.

Again, Conduent Transportation was focused on accuracy of the VPDS algorithm, and not on the capture rate. With the proper detection and trigger in a production setting, and with a four core processor, Conduent Transportation is confident capture rate issues can be overcome. These are the same challenges license plate recognition systems and toll collection systems routinely manage, so VPDS would rely on the same techniques.

Accuracy results of the controlled test are depicted in the rightmost two columns of Table 1. Note that the overall accuracy when declaring "SOV" or "HOV2+" was 97.3% which is similar to previous public roadway tests of VPDS.

Uncontrolled Test

With respect to the uncontrolled tests, Conduent Transportation and SANDAG evaluated system performance for the period of June 1-5 using the traffic present on the I-15 Express Lanes. The analysis was conducted over select 15-minute intervals in order to represent a variety of conditions: daylight and nighttime, heavy traffic and light, etc... SANDAG selected the 15-minute intervals. Table 2, below, summarizes the results.

Columns 1 and 2 in Table 2 are the date and time the data was collected. Note the variety of lighting and traffic volume conditions. Column 3 is the total number of vehicles on the roadway during each 15- minute period as determined by the toll collection system. VPDS was mounted very close to a tolling point, thus the toll system can accurately determine the number of vehicles that went past it. Column 4 is the raw vehicle count as determined by SANDAG. As in the Controlled Test described in Table 1, above, SANDAG personnel remotely logged into the roadside VPDS and used a tool to

examine and count the captured vehicle images that resided on the VPDS hard disk. Column 5 is the capture rate which is the Raw Vehicle Captured divided by the Total Vehicles. Note that as explained above for the Controlled Test Results, capture rate suffered due to: (1) Lock Out period set for the triggering system; and (2) Using only a single core processor. As described above, capture rate can be improved by reducing the trigger lock out time, and, in general, image capture for each car in a high speed highway system has been solved for tolling systems and, in production, VPDS would use the same technology and methods so as to achieve an almost 100% capture rate. Column 6 is the number of "In-Scope" vehicles counted by SANDAG when remotely logging into the roadside VPDS. Note that this vehicle differs from the "Raw" count in that buses, motorcycles, and van pools were excluded from the count due to not being in scope for VPDS. Column 7 is the number of "In-Scope" vehicles counted by Conduent Transportation after the roadside VPDS hard drive was shipped back to Conduent Transportation. As described, above, in the discussion of results on the Controlled Test, hard disk corruption and recovery resulted in loss of data relative to the SANDAG count. In addition, a minor bug in the analysis tool that Conduent Transportation provided SANDAG was discovered which, after fixing, enabled Conduent Transportation to find images that had been misplaced – this resulted in Conduent Transportation counting more vehicles on 6/5 than SANDAG. Columns 8 & 9 describe the accuracy performance of VPDS.

Among the key findings are the following:

1. Capture Rate: again as noted during the Controlled Tests, the Conduent Transportation system did not capture all vehicles that passed by the system installation. The toll collection system data indicates that there were 1,794 eligible vehicles which passed by the toll reader during the evaluation period. VPDS captured 1,497 vehicles for the same period. This yields a capture rate of 83.4% for VPDS installation.

    a. During the evaluation period (June 1-5), the VPDS software had been set to limit the number of vehicles evaluated to one every 0.75 seconds, that is, the system was locked out from capturing another image for 0.75 seconds once a vehicle image was captured. This setting was put in place to extend the life of the Illuminator Flash and resulted in some vehicles being missed. During the Controlled Test period, the 0.75 second lock out setting, led to a Capture rate of 78.2%, consistent with the findings during the Uncontrolled Test. The Capture Rate is particularly bad during the periods of heavy traffic. For the time period of 16:30-16:45 on June 4th, the Capture Rate is 312 out of 460, or 67.8%, as would be expected during periods of heavy traffic where more of the vehicle-to-vehicle time intervals (headway) would be less than 0.75 seconds.

    b. Further the system was operating with a single core processor which contributed to a lower Capture Rate. Some images were not evaluated by the system since the core processor could not keep up with the vehicle passing by resulting in vehicles being dropped from the image analysis buffer.

    c. The lockout time period for the Illuminator and the use of a single core resulted in a lowered Capture Rate. In a production setting, the lock out period would be set to 0.3 seconds or less---this was the setting for the period after June 19th, and the Capture Rate for the Controlled Test improved dramatically. The ability to capture the images is a well understood engineering problem that has been managed in a variety of applications including license plate recognition systems and toll collection systems. Conduent Transportation did not focus on Capture Rate as a key component of the experiment and is confident Capture Rate for the system will be on par with other toll collection components.

2. Accuracy: Conduent Transportation found the accuracy of VPDS to be on a par with previous pilots. Based upon the analysis period from June 1-5, Conduent Transportation achieved accuracy levels of 93.8% once the model was trained for the SANDAG installation. The expectation is that any enforcement or toll adjustment strategy would involve review by humans, who would confirm the results from VPDS and then create correspondence to be sent to the customer. This correspondence may take the form of a toll adjustment or a violation notice (depending upon prevailing state and local regulations), but this important step would enable a toll agency to confirm the results prior to issuing a customer notice.

3. Among the key considerations in evaluating the system performance is that the system as deployed was Pilot level hardware. Conduent Transportation continues to work on the basic technology for VPDS and also has made great strides in making the installation production hardened. In a production deployment, the operating plan would include regular preventative maintenance as well as routine monitoring of the system. This would ensure that performance degradations would not occur or would be quickly corrected.

Summary and Lessons Learned

The SANDAG installation on the I-15 Express Lanes at Miramar Way provided several new opportunities to evaluate and extend the use of VPDS.

The results using the automated algorithm were consistent with previous installations. VPDS produced an accuracy of 97.3% for the controlled testing. Note that this was over a smaller sample size — producing an accuracy of 93.8% for the uncontrolled testing.

Lesson learned for the SANDAG VPDS Pilot:

1. The installation on the passenger side of the road while using a standalone pole was a first for this Pilot. In previous installations the system was installed on the driver side shoulder, and/or with a gantry for the front camera. The installation on a passenger side pole resulted in some obstruction for the front camera. In the future, the intent will be to mount on a gantry whenever a passenger side installation is warranted.

2. Capture rate is an important metric, as well. The science that Conduent Transportation is testing is the accuracy of the VPDS algorithm. The ability to detect and trigger on all vehicles has been deployed with other systems such as license plate recognition or toll collection systems. In a production environment, capture rate is as important as accuracy. Conduent Transportation is confident that capture rate for VPDS can be on par with other similar systems such as license plate recognition for the evaluation of capture. Both statistics - of the system scoring algorithm and capture rate of all vehicles - will be considered in future trials, and Conduent Transportation will work with SANDAG to run the Pilot trial again with both accuracy and capture rate as key metrics, if SANDAG wants to pursue this trial.

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