Caltrans pilot of Conduent Vehicle Passenger Detection System
Overview

Conceptually, an HOV/HOT lane increases the number of people that use the facility by increasing the number of occupants per vehicle on the roadway. It may also decrease the number of vehicles using the roadway and decrease the overall congestion.

As agencies adopt HOV and HOT lanes, determining compliance with the required occupancy count is a challenge. These systems currently rely on self-declaration by drivers as to whether their vehicle has enough people to be in the lane – voluntary compliance. This self-declaration can take the form of a switchable toll tag setting or, in the case of some systems, simply the act of entering the lane by the driver. In the case of an HOV facility, the act of entering the lane is how a driver indicates that they are qualified for high occupancy. In some facilities there are also exceptions made to the HOV rule for vehicles that qualify as Low Emission Vehicles (LEVs). LEVs or hybrids often qualify for the HOV exemption even though these vehicles may only have the driver in the vehicle (without any passengers).

Not everyone who indicates that they are HOV/HOT qualified will actually have the requisite number of vehicle occupants. Many HOV/HOT roadways have high violation rates, particularly during high volume periods of the day.

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 and determine if the vehicle is HOV/HOT qualified.

Given that vehicles are going past at 40–80 miles per hour under high traffic volumes, enforcement by roadside officers using visual observation is very challenging. Varying lighting and weather conditions present further challenges to roadside observation. To assist officers in the enforcement of HOV/HOT lanes, Conduent introduced the Conduent Vehicle Passenger Detection System® (VPDS). It can establish whether a vehicle is HOV/HOT qualified through the use of cameras, illuminators, and advanced computer vision algorithms.

During pilot trials with live traffic, VPDS has delivered accuracy levels of approximately 95 percent in determining whether a vehicle is a single occupant vehicle (SOV) or a high-occupancy vehicle with two or more occupants (HOV2+). Conduent and Caltrans conducted a trial of Conduent VPDS during a January–March period. This report summarizes the results and lessons learned from that trial.
Description of the Caltrans-Conduent pilot of Vehicle Passenger Detection System

To conduct the trial Caltrans and Conduent selected a location at Interstate 5 and Barranca Parkway in Orange County, California (see Figure 1). This location is a High Occupancy Vehicle facility that has single HOV2+ lanes in the northbound and southbound directions. The roadway also has several general purpose (GP) lanes with only roadway striping between the HOV lane and the GP lanes. The location provided access to electrical power and offered a very wide median that allowed the team to install the equipment with minimal interference with traffic.

The team made a determination to install VPDS equipment on the northbound lane of Interstate 5 with a view to the inside lane. Conduent VPDS was mounted on the driver side of the road in the median, behind the K-rail. The location of Conduent VPDS is indicated by the red dot in Figure 1. The front camera and front illuminator were mounted on a pole which Conduent erected and which was aimed at the front windshield of the oncoming traffic in the HOV lane. Figure 2 depicts the front camera which was approximately 10–12 feet above the road surface. Figure 3 depicts the side camera and side illuminator mounted at approximately 3.5 feet above the road on a structure that Conduent had put in place. The two cameras were separated by approximately 60 feet.

The system used a laser to detect the presence of a vehicle in the lane. The laser was mounted on the rear seat (or side) camera structure and aimed at the lane nearest the equipment. The laser was configured so as to not activate on vehicles in other lanes, but to detect only those vehicles in the near lane. When the laser detected a vehicle in the lane adjacent to the equipment, both the front camera/illuminator and the rear camera/illuminator were actuated and the front seat image and rear seat images were captured.

Conduent collected a series of images in mid-January to train the system. The training dataset consisted of images captured then evaluated by manual image reviewers. The “Manual Image Review” is performed by humans sitting at computer screens reviewing images one by one labeling the vehicle images as containing occupied or empty seats and then a computer vision training algorithm is run to train the system. Through this process, the manual image reviewers label each image as occupied, not occupied or results cannot be determined.

Using this technique, the Conduent algorithm “learns” what constitutes an occupied vehicle seat and what does not. This combined process, which uses computer vision and machine learning, establishes a model which will then be used by the system to automatically evaluate the vehicle images that are captured and ultimately declare whether the vehicle is a single occupant vehicle (SOV) or a high occupancy vehicle with two or more vehicle occupants (HOV2+). Conduent manually reviewed and labeled 10,000 front seat images and 10,000 rear seat images.
The learning process was completed based upon training images, which are a subset of these manually reviewed images. The learning process would be part of an install and setup process for a production system. While the training images are used to create the model, test images are used to check the model’s accuracy and performance. The test image set did not include any images from the training image set, as the intent was to establish an independent set of images to check the automated model against.

Images were gathered throughout the trial and the trained model was used to automatically determine the occupancy state of each vehicle. The images and the automatic declarations were used to assess the performance of Conduent VPDS, as well as measure the performance of human roadside observers (HROs) and determine a violation rate for the facility.

**Description of the key research questions and analysis approach**

Based upon the model which was created, Conduent and Caltrans were then in a position to answer the following questions:

• How accurate would the performance of the automated VPDS model be?
• How accurate would roadside observers be as measured against ground truth?
• Directionally, what was the violation rate for the period under evaluation?

Conduent and Caltrans focused their analysis on a three-day period. During January 27, 28 and 29, Caltrans stationed HROs on the roadside at Interstate 5 and Barranca Parkway.

This technique of counting passengers in vehicles as they pass the location is often employed by agencies to determine throughput on a particular section of roadway. In this case, there were two HROs stationed at various positions near the lane to be counted. The two HROs moved between three positions: one position was on the Barranca Parkway overpass, one position was in the Gore Area adjacent to the roadside, and the third position was next to the roadside in the median near the location of Conduent VPDS. The HRO locations are depicted by the blue dots in Figure 1.

The HROs performed observations and established counts for the periods depicted in Table 1. HROs used clicker counters attached to a clipboard and a tally sheet to placee vehicles into one of seven categories: four special categories and three passenger vehicle occupancy count categories.

<table>
<thead>
<tr>
<th>Day</th>
<th>Morning</th>
<th>Afternoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuesday</td>
<td>January 27 6–9 a.m.</td>
<td>January 27 3–6 p.m.</td>
</tr>
<tr>
<td>Wednesday</td>
<td>January 28 6–9 a.m.</td>
<td>January 28 3–6 p.m.</td>
</tr>
<tr>
<td>Thursday</td>
<td>January 29 6–9 a.m.</td>
<td>January 29 3–6 p.m.</td>
</tr>
</tbody>
</table>
The categories the HRO used were:

- Vehicles with just the driver (one occupant)
- Vehicles with two occupants
- Vehicles with three or more occupants
- Bus
- Motorcycle
- Vanpool

LEVs are identified by a decal as depicted in Figure 4. Conduent VPDS did not attempt to identify the LEVs as part of the experiment.

HROs used tally sheets to establish the count for each category described above across 15-minute intervals. That is, for each category, the HRO would determine the number of vehicles in the category for each 15-minute segment.

They produced a summary for each day that identified counts for each category. The HROs maintained counts by 15-minute segment for the period from 6:00 a.m. to 9:00 a.m. on each of the three days, and also maintained counts by 15-minute segment from 3:00 p.m. to 6:00 p.m. on each of the three days. Complete results for the HROs can be obtained from the authors. Table 2 depicts a sample of the HRO output. A sample from a typical tally sheet is depicted in Table 3.

In the sample depicted here, there were zero Single Occupant Vehicles in the period from 7:00 a.m. to 7:15 a.m. on January 27. Also as depicted in the extracted sample, there were 148 HOV-2 vehicles between 7:00 a.m. and 7:15 a.m. on January 27, and only one HOV-3+ vehicle during this period.

Of the Special Vehicles, during the period of 7:00 a.m. to 7:15 a.m. on January 27, there was one bus, zero van pools, three motorcycles and 16 LEVs.

Table 2: Extracted sample from tally sheet.

<table>
<thead>
<tr>
<th>Time period</th>
<th>January 27</th>
<th>Occupants</th>
<th>Special vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0700-0715</td>
<td>0</td>
<td>148 1 3 1 0 3 16</td>
</tr>
</tbody>
</table>

Figure 4: California DMV low emission vehicle decal. Source: Caltrans.
The tally sheet in Table 3 depicts the daily results for one HRO on January 27. Complete results can be obtained from the authors.

Note that since the Conduent VPDS system did not identify low-emission vehicles, while the HROs did identify LEVs, the following assumption was made in the data analysis: LEVs are single-occupant vehicles, thus we add the LEV counts to the single-occupant counts for each respective time segment to establish the estimated total single-occupant count for the HROs for that time segment.

As will be shown in the results section, even with this assumption, data indicates that the HROs undercount single-occupant vehicles.

Conduent then created similar counts using the Automated Output based on the VPDS for the same period: January 27, 28, 29 from 6:00 a.m. to 9:00 a.m., and from 3:00 p.m. to 6:00 p.m. on each day.

The Conduent results were assembled to establish counts by category using SOV and HOV2+ as the two key categories. This analysis was constructed to establish a comparison of three measuring methods:

1. Human roadside observers, established by hand counts as described above.
2. Conduent VPDS Automated Output, the automatic results produced by the Conduent VPDS model
3. Ground truth was established by conducting a manual image review of the images collected by the Conduent Vehicle Passenger Detection System. Trained reviewers viewed all the images for the evaluation period and a signed a score of SOV or HOV2+.
Some comments on establishing ground truth:

A. Conduent selected this approach as the best available method to establish ground truth for the system. The use of a manual image review approach to step through the images and confirm the occupancy in an uncontrolled traffic environment with high vehicle volume was the most suitable approach to establishing the baseline to measure the Human roadside observers and the Conduent VPDS against.

B. An alternative approach to establishing ground truth in the manner described above would be to know precisely how many occupants are in each given vehicle as they drive past the Conduent VPDS installation.

- In this manner, the researcher could know exactly how many people are in each vehicle because they would pre-select the occupancy counts and then dispatch them to send the vehicles past Conduent VPDS. Note that formal designed experiment methods would be used for most efficient systematic testing.

- Conduent has conducted this test in the preliminary testing phase and was generally able to identify whether vehicles were HOV/HOT qualified under controlled test conditions. This form of ground truth verified accurate results, and could be the subject of separate study if there is interest and funding to pursue.

- There are three challenges to conducting a test where the ground truth is known because the researcher selected vehicles in a controlled approach:

1. The volumes will be lower. The number of vehicles in a controlled test will be significantly lower if every vehicle must have its occupancy confirmed by humans under controlled conditions (that is, when the vehicle is stopped).

   The purpose of this test was to assess the performance of Conduent VPDS in a live traffic, high volume environment and determine how Conduent VPDS performed versus HROs in live conditions, and also measure the Violation Rate.

2. The costs will be higher. Conduent was able to assess more than 12,000 vehicles over the three-day period, since experiment participants were drawn from live traffic on the freeway. Paying for people to drive by under controlled conditions can be done, but cost more.

3. The time to conduct the trial would be longer. This depends upon how much money and resource the team would wish to expend to measure the efficacy of the system.
C. Given the constraints of time, money and scope, Conduent decided to use manual image review by people seated at PCs stepping through the images to establish ground truth. This provided the following benefits:

• The system was able to be tested in a high-volume, live traffic setting.

• The cost of the research effort was reduced and the study could be conducted in a shorter time frame – again, if there is interest and funding to support a controlled study that will more accurately determine ground truth, this should be considered.

• We believe the results did not create a bias for or against Conduent VPDS versus the HROs due to the following observations:
  – The human roadside observers would face many of the same issues that the Manual Image Reviewers faced – for instance, people laying down on the seats or floor.
  – The analysis was accurate when comparing the performance of Conduent VPDS versus HROs, as well as in the establishment of the approximate Violation Rate.

Analysis for each period then took the following form for each 15-minute interval. Final results were reported for each three hour period (6:00–9:00 a.m. or 3:00–6:00 p.m.) as for many 15-minute intervals, the sample size was too small to be statistically significant. The focus of the analysis was on Single Occupant Vehicles, as these vehicles represent the potential violator pool.

<table>
<thead>
<tr>
<th>Table 4: Accuracy metric definitions</th>
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</thead>
<tbody>
<tr>
<td><strong>Human roadside observers</strong></td>
</tr>
<tr>
<td>X – SOV count as established by HROs</td>
</tr>
</tbody>
</table>

| **Conduent VPDS automated output** | Y – SOV count as established by VPDS | Z | Y / Z – Percent of time VPDS is correct versus ground truth |
|--------------------------------------|

| **Ground truth as established by manual image reviewers** | Z – SOV count as established by Manual |
Ground truth images

When creating the ground truth score, Manual Image Reviewers have significant advantages over roadside observers. The Manual Image Reviewer is able to evaluate images as they are frozen in time and displayed on their work station screen.

The Manual Image Reviewer has the benefit of adjusting the zoom, improving the lighting, and can also pause and take a break as needed, while the roadside observer must score in real time without a break.

Conduent VPDS captures images preserving the results for the Manual Image Reviewer. Also, the VPDS algorithm can score the results in real-time or as part of batch processing. When evaluating images, the Manual Image Reviewer views images as depicted in Figure 5. Note that the images are clear and high-quality. In this image, the front passenger seat is occupied and the rear seat is not occupied.

However, since the technology uses line-of-sight imaging, any occupants not in the line of sight would not be detected by the system. This could include children or adults laying on the floor of the vehicle or across the back seat of the vehicle. Note that HROs and enforcement officers would have similar difficulty. The sample images in Figure 5 have been redacted to preserve privacy for the purposes of this report.

The same technique used to establish ground truth can also be applied in an operating setting. Once Conduent VPDS identifies a set of candidate violator vehicles, these same vehicle images can then be reviewed by Manual Image Reviewers, and appropriate correspondence can be sent to the vehicle owner in the form of a warning letter, a toll adjustment letter, or a violation citation if state law permits. Currently, California law requires that an enforcement officer must witness the violation in order to issue a citation.

Table 5: SOV rate for three methods used in the study.

<table>
<thead>
<tr>
<th></th>
<th>Vehicle count</th>
<th>Manual image review SOV rate</th>
<th>Conduent VPDS SOV rate</th>
<th>Roadside observers SOV rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6–9 a.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tue</td>
<td>27-Jan</td>
<td>1,831</td>
<td>26.5%</td>
<td>25.9%</td>
</tr>
<tr>
<td>Wed</td>
<td>28-Jan</td>
<td>1,834</td>
<td>26.1%</td>
<td>23.9%</td>
</tr>
<tr>
<td>Thurs</td>
<td>29-Jan</td>
<td>1,658</td>
<td>30.6%</td>
<td>29.2%</td>
</tr>
<tr>
<td><strong>Evening</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3–6 p.m.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tue</td>
<td>27-Jan</td>
<td>2,102</td>
<td>7.6%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Wed</td>
<td>28-Jan</td>
<td>2,271</td>
<td>6.7%</td>
<td>7.0%</td>
</tr>
<tr>
<td>Thurs</td>
<td>29-Jan</td>
<td>2,377</td>
<td>9.0%</td>
<td>9.6%</td>
</tr>
</tbody>
</table>
The approach of adding the Manual Image Review step in an operating or violation enforcement setting can improve the accuracy from 94 percent to >99 percent, since the manual image reviewers can be instructed to discard those images where the violation may be questioned. In particular, the false alarm rate can be significantly reduced due to the Manual Image Reviewers tossing out questionable candidate violators. This accuracy improvement is based on manual reviewer performance on license plate image analysis which, from a manual review point of view, is a similar task.

The high-quality images that the Conduent VPDS roadside cameras produce enable the algorithm to achieve high levels of accuracy. They also support manual image review for the establishment of ground truth and could be used to assist enforcement.

Data results
At this point, the research team established SOV counts for each time interval of interest as determined by HROs, as determined by Conduent VPDS, and as established by ground truth. As stated above, the HRO SOV count is the sum of the count for the category labeled “1” on the tally sheet with the LEV count.

The results summarized in Table 5 illustrate three key findings

1. In the morning, the SOV rate is approximately 26 percent to 30 percent, while in the afternoon, the SOV rate is approximately 6 percent to 9 percent. Note that the traffic volume is higher for the afternoon segment than the morning segment.

2. The Conduent VPDS SOV Rate very closely approximates the manual image review or ground truth results.

3. HROs were much less likely to identify SOVs, and the SOV rate for HROs is much lower than the Ground Truth SOV rate. Note that this remains even after adding in all LEVs to the HRO SOV count.
Table 6: Results summary

<table>
<thead>
<tr>
<th></th>
<th>Average vehicle count</th>
<th>VPDS SOV rate accuracy</th>
<th>Roadside observers SOV rate accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mornings 5–9 a.m.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 27, 28, 29</td>
<td>1,774</td>
<td>95.0%</td>
<td>35.7%</td>
</tr>
<tr>
<td>Tuesday, Wednesday, Thursday</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mornings 3–6 p.m.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January 27, 28, 29</td>
<td>2,250</td>
<td>95.3%</td>
<td>35.6%</td>
</tr>
<tr>
<td>Tuesday, Wednesday, Thursday</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 depicts the data in a different fashion. As represented in Table 6, the system scored an average of 1,774 vehicles during the morning sessions and an average of 2,250 vehicles during the afternoon periods. The SOV rate from the Conduent VPDS system matched the SOV rate from the manual image review to a 95 percent level, while the SOV rate from the HROs only matched the SOV rate from the manual image review at a 35 percent level.

Further analysis depicted in Table 7 shows the effects of false positives and False Negatives on the system performance. As represented here, there were 12,073 vehicles considered during the period of analysis.

From Table 7, of the 12,073 vehicles under study, 9,802 were declared to be HOV2+ by Conduent VPDS and were confirmed to be HOV2+ by manual image review (true negatives). These vehicles are the non-violator vehicles which were correctly scored as non-violators and represent 81.2 percent of all vehicles. Of the 12,073 vehicles, 1,781 vehicles were declared to be SOV by Conduent VPDS and were confirmed to be SOV by manual image review (true positives). These are “violator” vehicles which were correctly scored as “violators”, and they represent 14.75 percent of all vehicles considered.

From Table 7, of the 12,073 vehicles under study, there were 320 vehicles which were declared to be HOV2+, but were actually an SOV as determined by manual image review (false negatives). This portion of the universe is 2.65 percent and represents missed violators. Therefore, missed violator error is 2.65 percent – that is, Conduent VPDS missed 2.65 percent of the total population that were actual violators. Another related performance metric is the Violator detection rate (VDR) which is calculated as follows:

\[ \text{Violator detection rate} = \frac{\text{true positives}}{\text{true positives} + \text{false negatives}} \]

\[ = \frac{1,781}{1,781 + 320} = 0.85 \text{ (or 85%)} \]

VDR indicates the fraction of the whole population of actual violators that are detected by the system. It is also the probability that any one violator is detected by the system. In the machine learning literature this would be called “Recall“.
The total violation rate is the sum of 14.75 percent (properly declared violators) + 2.65 percent (missed violators) which yields 17.4 percent. When the Low Emission Vehicles, as determined by the HROs, are considered, they represent 5.75 percent of the universe, indicating that the adjusted violation rate is 17.4 percent to 5.75 percent or 11.65 percent, assuming that the HROs’ LEV count is correct (which is the best data we have).

From Table 7, of the 12,073 vehicles under study, 170 were declared by Conduent VPDS to be SOV, but were later determined by manual image review to be HOV2+. These would be designated as false positives. Conduent proposes using a statistic called declared violator accuracy, which is calculated as follows:

\[
\text{Declared violator accuracy (DVA)} = \frac{\text{true positives}}{\text{true positives} + \text{false positives}}
\]

\[
= \frac{1,781}{1,781 + 170} = 0.91 \text{ (or 91 percent)}
\]

In the machine-learning literature, this term is called “Precision”. What DVA measures is the probability that a roadside patrol officer is sent to chase a violator, and then discovers the SOV is actually an SOV. The intent is that the system, when configured for roadside enforcement, should lessen false positives and increase DVA. In this fashion, every time an officer pursues and pulls over a declared violator, the vehicle will be an actual violator. In this study, the DVA was 91.29 percent, but this statistic could be increased by simply adjusting the parameters – a configuration change in the system. In the Conduent analysis depicted in Figure 6, DVA could be increased to 99 percent and still identify 50 percent of the total number of violators. Note that roadside enforcement officers simply cannot chase down even 10 percent of all violators (let alone 50 percent) for the high traffic volumes under study. Note that there is a natural trade-off between DVA and VDR as depicted in Figure 6. The system can be configured to operate anywhere along the curve in Figure 6.

If the intent is to perform enforcement on the roadside, the intent should be to increase declared violator accuracy to 99 percent so that officers are not chasing vehicles that are non-violators. In that case, the system can be calibrated to operate where the red dot is located in Figure 6. If, instead, the intent is to send potential violators to a back office for review, then the focus should be on reducing eliminating missed violator errors and increasing the VDR – Back Office Reviewers can easily review and discard false positives. In that case, the system can be calibrated to operate where the yellow dot is located in Figure 6.

The cost of a false positive for a Back Office Reviewer is small, whereas for a roadside officer chasing a non-violator is costly in terms of time wasted. Note that the imagery can be forwarded (in real time) to the roadside officer, along with the violator indication, so that the officer can review the imagery before deciding to chase down the vehicle. Thus, a level of “manual review” is performed to reduce the system level false alarms and wasted time.
From Table 7, of the 12,073 vehicles under study, 1781 were true positives (correctly identified SOVs), 9802 were true negatives (correctly identified HOV2+s), 170 were false positives (HOV2+s incorrectly identified as SOVs), and 320 were false negatives (SOVs incorrectly identified as HOV2+s). Note that in this application false positives are likely more costly than false negatives. False positives could lead to sending out incorrect violation notices if proper manual review workflows are not in place. False negatives lead to possibly not affecting driver behavior in a way that encourages carpooling and reduces congestion. False negatives could lead to lost revenue, particularly for HOT lane facilities.

Total accuracy = (True Ps + True Ns) / (True Ps + True Ns + False Ps + False Ns)
= (1781 + 9802) / (1781 + 9802 + 170 + 320) = 0.96 (or 96 percent)

The total accuracy metric describes the accuracy of the system when deciding whether a vehicle is an SOV or and HOV2+. The total accuracy performance for Conduent VPDS is 96 percent. This is the total accuracy performance level when the system is calibrated to operate at the green dot in Figure 6. It is close to the maximum total accuracy operating point for the system, given the volume and richness of the training data described above.

Table 8 illustrates that there were, on average, 78 violators per hour. During peak periods, the rate was higher. Realistically, the agency and the highway patrol could not deploy enough officers to enforce this number of violations. If an officer can enforce 4 violations per hour (each taking 15 minutes, optimistically), this would mean the vast majority of violators will not be cited.
For this reason, it may make sense to pursue a strategy where candidate violators and the accompanying images are transmitted to the back office for further review and processing. This processing does not need to be performed in real time, but the images and violations can be conducted over the entire day and distributed among a team designated to review violations. At 78 violations per hour, there is a violation every 45 seconds, indicating the need to slow down the process to allow human review to catch up to the speed of traffic and violations. The challenge for the HRO is that they must observe all vehicles that pass by – one every 5.4 seconds – and pick out the violator.

The task is challenging and requires intense focus for an extended period. Note that the operating point on the curve depicted in Figure 6 can be different for roadside officers and for back office review, even for the same dataset. Thus, the DVA can be made very high for roadside officers to reduce false alarms, while the VDR can be made very high for back office processing on the same dataset. Note that for two-lane or more HOV or HOT lanes, it is even more challenging for roadside officers. However, Conduent is testing the VPDS system in multi-lane facilities with good initial results. See the authors for details.

**Data considerations**

There may be some concern that using the same sensing instrument for automated scoring (namely the front seat and rear seat cameras) as is used to establish the Ground Truth could create a bias against HROs.

As illustrated in Figure 7, HROs, automated scoring and ground truth all follow the same trends across the time period observed for Single Occupant Vehicles, but the HROs simply recorded fewer SOVs. The fact that HROs followed the same trend line as the Automated Output and the Ground Truth would indicate that HROs saw the same increases and declines in SOVs, as well as overall traffic volume, but at a reduced rate for the SOVs – likely due to the fact that the HROs were not able to observe and record the SOVs as quickly as the cameras. Note that HROs were performing more tasks than the Conduent VPDS system. They were tallying seven categories, including identifying LEVs. A better comparison would be for the HROs to just use the same two categories that Conduent VPDS identified: SOVs and HOV2+. However, due to the difficulty of the task (high-speed, high-volume traffic) over an extended period of time, it is likely that the automated system would still outperform the HROs. Further, HROs are limited to daytime and good weather, while the automated system can perform 24/7/365.

In the chart in Figure 7, the top row indicates the count made by the Conduent VPDS camera equipment, while the rows below that illustrate the counts made by HROs in the Gore area from the overpass, and from a roadside-level position. In each case, the HRO records the same number of vehicles for the given time slot, but from Figure 8, the HRO records only roughly one-third the number of SOVs – consequently they are improperly categorizing SOVs as HOVs.
Summary and recommendations
The Caltrans pilot of the Conduent VPDS achieved the key objectives and demonstrated the following findings:

1. Conduent VPDS performed at an accuracy rate of 95+ percent when declaring a vehicle either an SOV or an HOV2+. This makes the system an effective decision support tool for managed lanes enforcement.

2. HROs demonstrated a lower SOV accuracy rate of approximately 36 percent during the pilot. This does not indicate a lack of proficiency on the part of the observers or a deficiency in their training or tools. Rather, this illustrates the challenge of trying to identify occupancy status in vehicles driving by at 60–80 mph under a variety of lighting and weather conditions. In the trial, there were 12,073 vehicles scored over an 18-hour period. The human observers have to identify the vehicle, recognize their status and record the result as the vehicles drive past. Consider trying to view 12,073 vehicles over 18 hours. This is 671 vehicles per hour, or 11 vehicles per minute, or a vehicle every 5.5 seconds. During peak periods the rate is higher. This is the average flow rate for three hours and it doesn’t pause to allow for a break of any kind. Humans simply cannot keep up. The Conduent system can capture images at the rate of one every 0.3 seconds, and then immediately scores them.

This is a task that may be more cost-effectively and efficiently performed by an automated system such as Conduent VPDS.

Figure 7: Roadside observer counts. Source: Caltrans.

Image capture and roadside observers have the same count trends
3. The violation rate was determined to be 11.65 percent. This represents a significant impact to the traffic flow in the lanes and a significant amount of potential violation collections. If the average fine is $300, this study showed that there were 1,406 violations over the three-day period, or $420,000 in uncollected violation revenue. Conduent VPDS performed at an accuracy rate of 95+ percent, which represents an opportunity to improve throughput and improve enforcement. Not all violators will be caught, but the system can provide a significant improvement in the ability to enforce.

4. While 95+ percent represents the accuracy rate for the automated output, Conduent expects that the vehicles which are declared candidate violators by automated output would then be reviewed by Manual Image Reviewers who would evaluate the images and determine what, if any, error occurs. By adding this manual image review step to the process, the accuracy of correctly identified violators can likely be increased to >99 percent based on similar processes for manual review license plate images. At this accuracy level, issuance of correspondence advising vehicle owners that a violation occurred can be pursued by the agency, and the agency can do so with confidence in the results and confidence that very few false alarm violations will be issued.

The pilot demonstrated the effectiveness of Conduent VPDS and indicated potential approaches to deployment. Conduent VPDS can be an additional tool to improve throughput on the roadway and enhance enforcement. For more information, please contact transportation@conduent.com.