Technology Approaches to HOV Occupancy Declaration and Verification:
State-of-the-Practice Review

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Technology Approaches to HOV Occupancy Declaration and Verification

1. Introduction

The Dallas/Fort Worth (DFW) region has a network of 75 miles of HOV lanes. In addition, 33 miles of managed lanes are currently under construction. The DFW region commenced operation of the first segment of the managed lane facilities in December 2013. The ability to charge different user fees by vehicle occupancy level and give high-occupancy vehicles (HOV) a discount requires users to inform the agency operating the managed lane of their occupancy level. The use of “declaration lanes” to allow drivers to self-declare their vehicle occupancy by driving in a specified lane is not sustainable in many of DFW’s urban corridors due to limited right-of-way. Thus, the DFW region must explore technology options to allow travelers to communicate their vehicle occupancy level. This document highlights the technologies currently in use around the country and potential emerging technologies for vehicle occupancy verification.

2. Methods for HOV Occupancy Verification in Use

This section discusses the current and future methods for verifying vehicle occupancy.

2.1 Registered User

Most high-occupancy toll (HOT) lanes in the U.S. are conversions of existing HOV lanes and have retained the HOV policy in place prior to the conversion. For example, if the HOV facility allowed vehicles with two or more occupants, then those users retain the same privileges in the converted HOT lane while single occupant vehicles pay a toll through electronic means. Under this typical scenario, higher occupant vehicles continue use of the converted lane without establishing a toll account and displaying a transponder. In recent years several projects have emerged that require all users of the HOT lanes, regardless of occupancy status, to register as a user through an established toll account. This approach provides a mechanism by which declared HOVs can be targeted for spot occupancy enforcement by virtue of their identification through the tolling system as a unique registered account. Two projects that provide examples of this approach are in operation – I-85 in Atlanta and I-95 in Miami – and are described in detail below. The I-635 LBJ TEXpress Lanes in Dallas, which opened its first segment in December 2013, require all users, including discounted HOV2+, to display a transponder to use the facility. HOV2+ qualify for a 50% discount during the peak travel times once they activate the HOV status via a mobile app or in a website (1).

2.1.1 I-85 Express Lanes in Atlanta

The I-85 Express Lanes in Atlanta, GA is a HOT lane where three or more carpoolers use the lane free of charge while single and two-occupant vehicles pay a toll (2). Prior to the HOT lane operation in October 2011 the HOV lane operated under an HOV2+ policy. After conversion, Georgia increased law enforcement officers along the corridor to enforce the vehicle occupancy requirements. Although the human element is vital to effective enforcement, technology innovations were included in the project to help automate enforcement (3, 4).

All carpoolers with 3+ occupants have to self-identify as carpoolers. All motorists must register for a Peach Pass even if they are a 3+ occupant carpooler. The Peach Pass account allows up to 10 vehicles per account. Motorists have several tolling account options, allowing them to register as carpoolers or single occupancy vehicle as default settings. Frequent non-carpooling users of the HOT lanes are able to identify themselves as carpoolers when appropriate by changing the “toll mode” status of their account. Motorists are able to change their mode selection on-line, by phone, by smartphone app, or in person at a customer service center up to 15 minutes prior to entering the facility. The toll mode change may be selected for various durations (i.e. 4 hours, 1 day, weekdays, and indefinitely) (5).

Police officers are able to target vehicles declared as HOV3+ by checking vehicle carpool status and then verifying if a registered carpooler meets the occupancy requirement. Patrol vehicles are fitted with automated
technologies to help police officers identify which vehicles to check their occupancy level (see Figure 1). Automated license plate readers (ALPR) use cameras mounted on the patrol vehicles to automatically identify license plate numbers and compare them with the tolling database to check carpooling status. The unit then notifies the officers which vehicles are registered carpoolers that need to have their occupancy level checked. ALPR autonomously check up to several thousand plates during a normal patrol shift compared to manual checks of several hundred. Added enforcement capabilities with ALPR include identifying stolen vehicles, vehicles associated with Amber alerts, vehicles with expired registrations, etc. The ALPR provides added benefits to the law enforcement community while simultaneously enforcing the HOT lanes.

![Automatic License Plate Reader Laptop and Cameras Installed on Patrol Vehicles](image)

**Figure 1: Automatic License Plate Reader Laptop and Cameras Installed on Patrol Vehicles (2)**

Due to the lack of roadway space for physical barrier separation and limited police enforcement pull-off areas, the enforcement strategies rely on the “invisible barrier” system called, Gantry Controlled Access (GCA), to prevent vehicles from improper access/egress from the HOT lanes that are delineated with double white line pavement markings. By monitoring progressive vehicle locations from station to station, and comparing the physical location of the vehicle to the station locations and known barrier entry/egress zones, the system automatically determines when a vehicle has illegally crossed the electronic barrier.

### 2.1.295 Express in Miami

For the 95 Express project in Miami, a registration process is used that focuses on peak period commute trips (6). Qualified carpoolers are required to register every six months to be a valid carpool. Each participant must live within three miles and work within one mile of their carpool partners or they must meet at a park-n-ride location. Florida Turnpike Operations is responsible for toll collection and issuing violations and South Florida Commuter Services (SFCS), a Florida DOT program, is responsible for carpool registration through their
software, RidePro. The participants display decal that indicates they are using the lane toll-free. Carpools are eligible to use the lanes for commuting purposes only. There is not an age requirement, commuters only need to possess a valid driver’s license and be employed. Currently they do not register school pools or taxis. Public County School buses are eligible to use the lanes if they are transporting students.

All eligible license plates are transmitted by SFCS to Florida Turnpike Operations. The eligible vehicle travels under the gantry and registers as a non-toll paying vehicle. A photograph is taken and forwarded to Turnpike Operations; they look for eligibility as a registered license plate. If registered, the vehicle will not receive a toll violation. Florida Highway Patrol (FHP) monitors the lanes to ensure each vehicle has a 95 Express Decal with 3+ traveling in the vehicle or is a hybrid vehicle. If a vehicle has a less than three commuters in the vehicle, they receive a toll violation. If stopped twice, they are removed from the carpool program for a period of one year. SFCS actively works with employers to promote registration.

Registered carpoolers are responsible for shielding their SunPass transponder. Older transponders need to be placed in a protective bag while newer SunPass transponders need to be covered by a deflective shield. Registered carpools who wish to drive solo would use their transponder by unshielding it.

2.1.3 Pros
- No space constraints (no declaration zone needed)
- Lower capital, equipment, and O&M costs than declaration lanes solution
- Allows law enforcement to target users
- Occupancy status cannot be changed while in the lane at the tolling zone which reduces enforcement disputes
- Enforcement can be at the gantry or at any point along the facility (portable reader required)

2.1.4 Cons
- Mobile readers required for law enforcement
- Could be considered a burden on existing HOVs in a conversion situation

2.2 Transponder-Based – Switchable Transponder

A new generation of transponders has been introduced recently that allows the driver to select a particular mode of operation such as vehicle occupancy or number of axles. In HOT lane facilities the driver declares his occupancy status by interacting with the transponder.

2.2.1 How it Works

Switchable transponders can be divided into two categories based on how they operate: On/Off and Always On transponders. The On/Off transponders provide a mechanism, such as a cradle or sliding tab, that turns on or off the transponder. In the off position the transponder is not read by the AVI reader which is equivalent to removing the transponder from the vehicle. The Always On transponders are more technological advanced in that they provide a mechanism, such as switch or selector button, that allows the driver to select their occupancy status by changing the transponder data that is read by the AVI reader. In most cases this is accomplished via a two or three position switch or a selector button that, when pressed, causes the transponder to change from one denomination to another.

For Dallas there are two ways switchable transponders can be implemented. If it is a priority to allow the current HOV users to continue using the HOT lanes without requiring them to carry a transponder, then an On/Off
transponder solution is more adequate. In this scheme SOV users will require to have an active transponder and HOV user do not need a transponder. SOV users that occasionally use the HOT lanes in HOV mode will need to have a switchable transponder in the off position. However, this scheme will make toll avoidance violation enforcement more challenging because HOV users without a transponder cannot be easily distinguished from SOV violators.

The other option is to require all users to carry a transponder. Under this scheme both, an Always On or On/Off transponders could be used but the Always On transponder has the advantage of providing a more robust toll enforcement solution.

2.2.2 Manufacturers
Every major transponder manufacturer in the U.S. has a switchable transponder offering on the market or under development as shown in Table 1.
Table 1: Current Switchable Transponder Offerings in the U.S.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Type</th>
<th>Availability</th>
<th>Photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sirit</td>
<td>IDentity Self Declaration Tag – Title 21</td>
<td>Always On (3 pos. switch)</td>
<td>On the market</td>
<td></td>
</tr>
<tr>
<td>Sirit</td>
<td>IDentity Self Declaration Tag ISO 18000-6C</td>
<td>On/Off</td>
<td>On the market</td>
<td></td>
</tr>
<tr>
<td>Transcore</td>
<td>eZGo Anywhere HOT/HOV OBU</td>
<td>Always On (up to 15 selector button)</td>
<td>On the market</td>
<td></td>
</tr>
<tr>
<td>Kapsch (Mark IV)</td>
<td>E-ZPass IAG (Planned for I-495 Express Lanes Capital Beltway)</td>
<td>N/A</td>
<td>On the market</td>
<td>N/A</td>
</tr>
<tr>
<td>Kapsch</td>
<td>TS3304 5.9 GHz</td>
<td>Always On (4 selector button)</td>
<td>On the market</td>
<td></td>
</tr>
<tr>
<td>Telematic Wireless</td>
<td>FP-101x Clip Activated</td>
<td>On/Off</td>
<td>On the market</td>
<td></td>
</tr>
</tbody>
</table>

Sources: 7, 8, 9, 10, 11

2.2.3 Where are Switchable Transponders Being Used?
Currently only four HOT lane facilities use the On/Off switchable transponder: I-394 and I-35W Express Lanes in Minnesota, I-15 Express Lanes in Salt Lake City, and SR-167 HOT Lanes in Seattle. None of these are directly applicable to the DFW region because they do not use the protocols compatible in the north Texas region. The recently opened I-495 Express Lanes Capital Beltway in Virginia and the Metro Express Lanes I-10 in Los Angeles use the Always On type switchable transponder. None of these switchable transponders are directly applicable to the DFW region because they do not use protocols compatible in the north Texas region.

2.2.4 Pros
- No space constraints (no declaration zone needed)
- No need to shield or remove transponder
• Occupancy status can be changed on-the-fly without the need of accessing your account
• Does not require development of a web or smartphone application to change occupancy status
• Potentially allows HOV2 vs. HOV3+ differentiation
• Simplicity
• Lower capital, equipment, and O&M costs than declaration lanes solution
• Enforcement can be at the gantry or at any point along the facility (portable reader required)

2.2.5 Cons

• Driver may need to carry two transponders (If protocol is different from NTTA’s)
• New technology (particularly for the Always On transponders)
• NTTA does not support switchable transponder technology (need software changes)
• No sticker tag form factor available

3. Methods for HOV Occupancy Verification in Development

3.1 Nomadic Device – Real-time Ridesharing using Smartphone

An emerging approach to in-vehicle occupancy verification is through the use of technology-assisted ridesharing integrated with the managed lanes tolling system. Although this approach has not been field tested, the concept would rely on verification of occupants through a smartphone-based ridesharing application. The ridesharing application would offer a mechanism for drivers and riders to connect on either a formal or casual (real-time) basis to form a carpool. The ridesharing technology provider would provide access to precise information on the vehicle, driver, rider(s), time of origin and destination, and duration of journey. The participants would allow this information to be transmitted to the tolling provider in order to receive a carpool discount.

Toll enforcement would only be necessary for vehicles declaring high occupancy status in order to obtain a toll discount. Only commuters using the ridesharing application with a registered toll account could opt into the program and benefit from toll incentives. Providing this solution for occupant verification could eliminate the need for law enforcement or other forms of field verification because it provides a back-office solution to occupancy detection.

A pilot program to verify vehicle occupancy for pricing discounts by implementing real-time ridesharing is currently being pursued in Austin, TX by TxDOT, the Capital Area Metropolitan Planning Organization (CAMPO), and the Central Texas Regional Mobility Authority (CTRMA). The pilot is funded with a Value Pricing grant from the U.S. DOT. The purpose of the pilot is to determine whether an in-vehicle method that leverages real-time ridesharing technology can serve as a reliable and low-cost method for verifying occupancy. Carma, a private corporation, has developed the mobile application software to support real-time ridesharing. The field demonstration started on February 25, 2014 and will last until the spring of 2015. Drivers for Carma will receive rebates on toll fees along the CTRMA’s 183A and Manor Expressway/Highway 290 toll roads.

Under the pilot project, tolling and ridesharing will be integrated to provide a toll discount to verified carpools. The system will confirm the vehicle occupancy of participating drivers, using real-time ridesharing technology from Carma – in conjunction with TxTag transponders. The Carma real-time ridesharing technology will also be able to determine if multiple riders rode with the same driver. To verify vehicle occupancy, the Carma Network Operations Center will interface with the CTRMA Operations Center to provide precise information on the vehicle, driver, rider, time of origin and destination, and duration of journey.
The goal is to demonstrate that real-time ridesharing technology, when used in conjunction with existing electronic tolling, is a reliable method of automated occupancy verification for managed lanes, and can be an effective incentive to reduce the total number of SOVs on the corridor.

3.2 Connected Vehicle – Onboard Airbag Sensors

Using connected vehicle technology to transmit vehicle occupancy based on the onboard airbag sensors is another alternative to occupancy verification (12, 13). Many of the in-vehicle technologies that could be used for occupancy detection have been developed as a response to occupant safety concerns. Advanced air bags rely on sensors to cancel deployment when the occupant is in a potentially dangerous position. The U.S. Federal Motor Vehicle Safety Occupant Crash Protection Standard mandates the use of advanced or “smart” air bags in the front seats of new vehicles sold. The standard started to apply to 35% of 2007 model year vehicles and was increased to 100% adoption for 2009 model year vehicles.

Weight sensors have been the most widely employed method for occupant detection in vehicles. These sensors determine the size of an occupant by measuring the forces exerted on the seat by the occupant. Over the last decade, occupant detection systems based on weight sensing technologies have evolved to incorporate increasing numbers of individual sensing elements or arrays of elements, enabling these systems to map the force or pressure distribution of seated occupants and to classify occupants and their location on the seats. These detection systems are generally classified as either cushion-based or frame-based, depending on the placement of the sensors.

Cushion-based systems rely on sensor elements within or adjacent to the seat cushion itself. These sensors detect the force upon the seat cushion to estimate the occupant’s seated weight on the cushion. For systems using an array of multiple sensor elements, a pattern of the load across the seat can be used to help differentiate between adult occupants, children, or a child seat. Occupant position (leaning forward or sitting back) may also be inferred by the fore/aft load distribution across the cushion.

Frame-based systems incorporate resistive strain gauges or load cells which are typically built into the seat floor mounts or onto the seat side rails, and measure the weight of the both the seat and its occupant. Estimates of an occupant’s location can be obtained by analyzing changes in the relative distribution of loads among the frame sensors over a short time interval while the vehicle is in motion.

Most weight sensing systems are capable of determining little more than the position of an occupant’s center of mass relative to the seat. It is therefore relatively easy to trigger a spurious positive occupancy reading by placing heavier objects on the seat. Weight sensors must also be carefully calibrated to control for variations in seat size, weight, or padding thickness. These drawbacks are not generally associated with more sophisticated systems capable of mapping the pressure distribution on seat, however.

The Delphi Passive Occupant Detection System B (PODS-B) is one example of a cushion-based system in production. PODS-B uses a silicone-fluid-filled bladder tied to a pressure sensor for measuring the weight of seat occupants. An additional strain gauge sensor measures the cinching force of the seatbelt. The system, shown in Figure 2, is capable of differentiating between large and small adults as well as children. Delphi supplies an Occupant Detection System that helps a passenger control airbag deployment to several car manufacturers including Jaguar, Ford, and General Motors.

Figure 2: Delphi PODS-B System
A more advanced cushion-based system, developed by International Electronics & Engineering (IEE) in partnership with Siemens VDO Automotive, uses dozens of interconnected sensors. Such a system can not only discern the magnitude and location of the center of a seat occupant’s mass, but the detailed shape of the occupant’s seat pressure pattern as well. Their Occupancy Classification (OC) system consists of an IEE-developed flexible polymer mat which is integrated into the front passenger seat. The mat contains numerous force sensing resistor (FSR) cells and a Siemens electronic control module integrated into the edge of the mat. The layout of the OC sensor mat is shown in Figure 3. In operation, the weight of a seat occupant gives rise to discrete occupancy-pressure pattern, as indicated by the contour pattern overlay on the pad layout in Figure 4. The system then determines the occupancy classification using pressure analysis, morphology analysis, and pattern recognition. The IEE/OC system is currently fitted to cars manufactured by BMW, Chevrolet, DaimlerChrysler, General Motors, Hyundai, Kia, Rolls-Royce, and Suzuki.

Figure 3: IEE/Siemens OC System

Figure 4: IEE/Siemens OC Pressure Distribution

The Advanced Weight Sensing II (AWS) system from Siemens is their latest generation frame-based occupancy detection system. Strain gauge sensors (Figure 5) located in the seat track at the four corners of the seat classify the occupant’s weight and center of gravity in the seat. The system is also able to compensate for that portion of the occupant’s weight that is transferred to the vehicle floor through the occupant’s legs.

The Bosch iBolt system is one example of a highly compact frame-based sensor. Each iBolt strain sensor is little larger than the normal seat securing bolt (Figure 6), and can be easily integrated into the seat structure by replacing existing bolts. There is usually no need to alter existing seat designs or modify the system for different kinds of vehicle seats or for differing seats.

Figure 5: Siemens AWS II Sensor
3.2.1 Challenges for Using Airbag Sensors

The main technical issue for “piggyback” systems is the interface to the automatic airbag sensor (AAS). A “plug-and-play” interface is essentially required, whereby the automatic vehicle occupancy verification (AVOV) add-on connects to a standardized interface. The interface must be capable of providing relevant parameters from the AAS to the AVOV add-on; furthermore, these parameters must provide unambiguous classification of seat occupancy. A parameter such as airbag arming status (no/low/high deployment) is insufficient since the “off” state could indicate either no occupant or a rear-facing infant seat, for example. Rather, the necessary parameters need to indicate the internal state of the AAS occupancy classifier. The testing procedures specified in the Federal Motor Vehicle Safety Standard (FMVSS) require AAS to determine correct airbag deployment for five types of seat occupants (50th percentile adult male and 50th percentile adult female, rear-facing or conversion child safety seat, and 3- and 6-year-old children). Since the standard is specified in terms of AAS performance, it leaves manufacturers free to implement a variety of classification schemes for their AAS implementations, none of which are required to be “public.” Vehicle and parts manufacturers are also free to utilize any technology or methodology for occupancy classification so long as the production system meets FMVSS performance testing requirements.

Many of the safety subsystems put into vehicles are from suppliers. These subsystems rely on critical data to perform their function. Depending on the vehicle subsystem, this data may or may not be shared with other vehicle systems. Furthermore, there is concern in the industry about how sharing this data will affect the performance of a safety subsystem and the liability implications of making this data available. Thus, the availability of data, such as sensor data from an airbag system, may not be readily available to public transportation agencies for traffic management and enforcement applications. This is an emerging area, and there is uncertainty and risk for public agencies to rely on this information being available in the near future.

3.3 In-Vehicle Occupancy Detection

3.2.2 Monocular (2D)

Researchers at Eaton Corporation and the University of Michigan have been investigating the suitability of monocular (single camera) images for an occupancy classification system. Their prototype system uses a monochrome complementary metal oxide semiconductor (CMOS) camera and near-infrared (NIR) illumination located in the roof liner of the vehicle along the centerline and near the edge of the windshield. Subsequent efforts use a modified method that combines foreground/subject identification with the classification step. This method is claimed to yield faster and reliable identification and classification of vehicle occupants; as shown in Figure 7, the identification of occupants is usually quite precise. A trial of the improved system achieved 91 percent detection accuracy at speeds of up to 80 times faster than the prior effort.

A monocular vision–based interior protection system from Delphi Automotive includes a single monochrome camera and an NIR illuminator mounted near the rear-view mirror. The active LED and the associated NIR pass filter create a relatively constrained illumination environment that is less sensitive to occupant color and ambient lights. Tests of the prototype system reveal a 97 percent average correct classification rate.
3.2.3 Time-of-Flight (3D) Systems

Three-dimensional (3D) optical time-of-flight (TOF) imaging methods are a type of range measurement. These methods employ active illumination sources (mostly lasers) that emit either short pulses or continuous wave modulated beams, and evaluate the delay or phase shift of the beam reflected from a distant object. The time-of-flight sensor is different from other optical sensors in various ways and is more suitable for an occupancy classification system. First, the sensor can work both day and night, regardless of ambient lighting conditions. Second, unlike vision-based systems, TOF-based 3D sensors work reliably on textured and non-textured surfaces. Finally, the depth sensor is implemented on a CMOS chip, and this provides a small, inexpensive, and relatively high-resolution depth sensor for an occupancy classification system.

3.2.4 NCTCOG HOV Tag Proof-of-Concept Test

A new in-vehicle technology for vehicle occupancy detection emerged recently. The NCTCOG conducted its own high level testing of the device to verify the manufacturer’s accuracy claim of 90%. This product is in the proof-of-concept stage and was tested accordingly. Testing of this device indicates an accuracy of at least 90% for correctly detecting passengers’ position in the first row seats and the middle seat of the second row. Detection of all the seats in the second row may be possible in a future version of the device by modifying the hardware. The device tested is a self-contained, compact, in-vehicle device that determines the occupancy of the vehicle and then transmits that information using existing toll collection technology and infrastructure. The device is not dependent on any driver or occupant interaction. TTI tested the device to confirm the manufacturer’s claim of 90% accuracy. The test consisted of 48 runs, each lasting at least 10 minutes, using the following configurations:
Table 2: Data Collection Breakdown

<table>
<thead>
<tr>
<th>Facility</th>
<th>Passenger Configuration</th>
<th>Day</th>
<th>Night</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>US75</td>
<td>D</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>D+FP</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>D+FP+BP</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>D+BP</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>I-30W</td>
<td>D</td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>D+FP</td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>D+FP+BP</td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>D+BP</td>
<td>4</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>32</strong></td>
<td><strong>16</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>

Notes:
D: Driver
FP: Front Passenger
BP: Back Passenger

Out of the total 48 test runs, three had errors. The three errors can be grouped as follows:

- Error 1: added front passenger: actual was D; measured was D+FP
- Error 2: missed front passenger: actual was D+FP+BP; measured was D+BP
- Error 3: missed back passenger: actual was D+BP; measured was D

3.3 Roadside Occupancy Detection

Video systems have been deployed in the past for vehicle occupancy verification. While video continues to serve a useful role in HOV facility monitoring, it has not proven adequate for the task of vehicle occupancy verification. The collective experience from several studies and implementation projects has concluded that video methods are not as reliable as live visual inspection.

The use of video in HOV lane surveillance and enforcement was tested in Los Angeles and Orange County, California, in 1990. Multiple cameras were used to obtain three or four different views into vehicle cabins, and displayed on split-screen monitors. The study concluded that video cameras operating alone cannot identify the number of vehicle occupants with enough certainty to support citations for HOV lane restrictions. Roughly one-fifth of vehicles identified as violators using recorded video were actual vehicles in compliance with the occupancy restriction. The high false positive rate was primarily due to the inability of the camera system to distinguish small children or sleeping adults in the rear of the vehicles and additionally hampered by poor lighting conditions, glare, and tinted windows.

In 1995, the Dallas Area Rapid Transit and the Texas Department of Transportation (TxDOT) tested the use of real-time video and license plate reading for HOV lane enforcement on the I-30 HOV lanes in Dallas, Texas. The high-occupancy vehicle enforcement and review (HOVER) system employed three-way views of vehicle cabins and license plate recognition (LPR) to record occupancy and vehicle identification. Enforcement agents reviewed the archived images to identify HOV violators. An effectiveness study of the HOVER system revealed that the video and LPR implementation failed to achieve the necessary image quality and accuracy for effective enforcement screening.
Another application of video enforcement, the I-15 Congestion Pricing Project in San Diego, California, initially used gantry-mounted video cameras to provide a record of single-occupancy vehicle (SOV) violators on the carpool-only lanes of the Express Lanes facility. Operators were required to review the videotape and provide a count of SOVs using the Express Lanes. Problems with the video system, however, led to its elimination in 1998. Researchers from San Diego State University reported in a 2001 report on enforcement effectiveness that operators could not reliably distinguish SOV violators on video and found it difficult to discern the number of vehicle occupants, especially for back-seated passengers.

### 3.3.1 San Diego Experience

An infrared camera and image processing unit was tested for effectiveness as an automated enforcement system as part of a comprehensive evaluation for the San Diego Association of Governments (SANDAG) on I-15; with a report released in 2011. The device was billed as being capable of detecting the number of vehicle occupants up to a range of 50 meters for cars traveling up to 80 mph. The basic concept of the system relies on the ability to project two wavelengths of low intensity infrared light at passing vehicles. Two digital images are taken as the beams intercept each vehicle; eliminating non-facial traits of the image and logging each image with a timestamp and occupancy count. Final vehicle images were then saved to a central hard drive with green spheres masking human faces as a preventative step to ensure personal privacy.

The automated vehicle occupancy verification (AVOV) system was tested through controlled and uncontrolled field testing procedures. The uncontrolled testing was done as regular field testing, where the unit was observed with live, actual traffic. However, ground verification of vehicle occupancy is difficult to gather as a confirmation of the results from the infrared camera. Controlled testing was done on the AVOV unit with test vehicles that had a pre-determined number of occupants. The controlled variables in this set-up included testing for different size vehicles, various body types (e.g. adult, child), a few seating positions (e.g. middle, back seat), and altered travel speeds. Dummies (non-humans) were also tested in the controlled observations, and if the system had detected their presence as actual occupants, then those occurrences were deemed to be failures.

Out of a total of 1405 independent events conducted under the controlled experiment, 1127 events had failed to correctly identify the passengers who were sitting in the vehicle (excluding events that had a dummy occupant) – resulting in an overall passing rate of roughly 20%. The uncontrolled, field observed images had a successful passing rate of roughly 31%, excluding cases with dummy occupants. The initial review of logged images from the uncontrolled test had shown that the AVOV system could not find any human facial features that were contained within the captured images. In some cases, the image output generated a default green sphere in a space where there was no know vehicle occupant, even in images where the occupant was observed to be elsewhere. However, the summary of the evaluation results had reported a more optimistic view of the technological system capability. The report suggested that it can be feasible to achieve better image quality for facial processing as future technology progresses. Also, the evaluation suggested that a better camera mounting position may have yielded more positive results.

### 3.4 Satellite-Based Technology

This technology has been used mostly for truck tolling in Europe. Recently, several manufacturers have introduced OBU devices in the USA that combine satellite-based technology with an accelerometer and algorithms to enhance the accuracy of the GPS position so is capable of discriminating between adjacent lanes. The data is transmitted wirelessly to the back office. Similar to switchable transponders, the OBU device could have the means to allow the driver to declare his occupancy. The main advantage of this technology is that infrastructure requirements are minimal. On the other hand, recurring cellular communication charges may be too costly.
4. Enforcement

In HOT facilities violations can be grouped into three major categories: toll avoidance, occupancy violation, and illegal entry/exit violation. Each type of violation needs its own enforcement approach to minimize or deter the chances of occurrence.

- Toll avoidance: toll cannot be collected because of the vehicle not having the proper means of being identified (e.g. transponder or license plate) by the toll collection system. This document will not discuss this type of violation since there is proven VES technology that addresses this type of violation.

- Occupancy violations: consists of not carrying the required number of occupants. To date visual enforcement provides the most reliable means for occupancy verification. As described earlier in this document automated occupancy detection technology has not proven to be reliable to date. However, technological advancements in hardware and software are improving the accuracy rate.

- Illegal entry/exit violations: consists of drivers weaving in and out of the facility to avoid the toll collection points. This type of violation occurs in HOT facilities without a barrier to separate them from the general purpose lanes. This can be addressed by police enforcement or creating an electronic barrier to deter improper double white solid line crossing using tolling entry/exit logic and placing intermediate gantries with VES and AVI equipment.

4.1 Current Enforcement Operations

There are more than twenty HOT/Express Lanes currently in operation in the U.S. Each one with different needs, challenges, and constraints. A nationwide scan identified the following enforcement approaches. Most of these facilities utilize a combination of these approaches:

Decal/Hang-Tag: Use of decal or hang-tag for easier visual identification, by enforcement police, of a vehicle claiming to be HOV.

Enforcement Pocket: A pocket or adjacent area along the facility, usually next to the tolling zone, allows police to inspect vehicle occupancy or illegal double white solid line crossings.

Enforcement Booth: Similar to Enforcement Pocket but the visual inspection is conducted from a booth adjacent to the HOT/Express Lane.

Self-Reporting: Drivers can report HOV violators online or by telephone.

Enforcement Patrols: Police vehicles patrol the facility to identify illegal double white solid line crossings and occupancy violators.

Surveillance Cameras: Enforcement cameras, accessible by law enforcement in their vehicles, enable police to see vehicles before and after they pass under the gantry, and to watch for illegal movement in and out of the HOT/Express Lanes. These cameras are different from the VES cameras.

Enforcement Beacons: There are several variations of this approach. Enforcement beacons on the gantry alerts enforcement police monitoring the lanes when a vehicle without a transponder passes underneath. Another approach is where the enforcement beacon shows the transponder status of each vehicle that travels under the gantry and based on that the police officer can inspect the occupancy status declared by the driver.
**Virtual Barrier:** A virtual barrier is created by placing intermediate gantries with VES and AVI equipment and using tolling entry/exit logic to detect illegal entries and exits (i.e. double white solid line crossing).

**Mobile Technology** - There are various mobile technologies in use:

- Enforcement transponder: Special transponder in police vehicles used when following SOV through toll zone. Audible tone on enforcement transponder if valid transponder is read in vehicle being followed.
- Mobile Reader Mounted on police vehicle: Reads transponder in adjacent vehicle. Includes information on last valid reads.
- License Plate Readers: police has license plate readers mounted on their vehicles and connection to up-to-minute toll account data through their on-board computers.
- Hand held enforcement devices: verify if a vehicle has a transponder and its status.

**Other:** Other approaches include future In-vehicle technologies and automated occupancy detection and public education campaigns.

**Table 3: Enforcement Approaches Currently Utilized in HOT/Express Lanes in U.S.**

<table>
<thead>
<tr>
<th>Approach</th>
<th>Enforcement Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decal/Hang-Tag</td>
<td>Occupancy</td>
<td>● 95 Express, Miami</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● US-290 QuickRide, Houston</td>
</tr>
<tr>
<td>Enforcement Pocket</td>
<td>Occupancy and Illegal Entry/Exit</td>
<td>● I-25 HOV Tolled Express Lanes, Denver</td>
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<tr>
<td></td>
<td></td>
<td>● I-680 Express Lanes, San Francisco</td>
</tr>
<tr>
<td>Enforcement Booth</td>
<td>Occupancy</td>
<td>● Katy Managed Lanes I-10, Houston</td>
</tr>
<tr>
<td>Self-Reporting</td>
<td>Occupancy and Illegal Entry/Exit</td>
<td>● SR-167 HOT Lanes, Seattle</td>
</tr>
<tr>
<td>Enforcement Patrols</td>
<td>Occupancy and Illegal Entry/Exit</td>
<td>● Everywhere</td>
</tr>
<tr>
<td>Surveillance Cameras</td>
<td>Illegal Entry/Exit</td>
<td>● 95 Express, Miami</td>
</tr>
<tr>
<td>Enforcement Beacons</td>
<td>Occupancy and toll avoidance</td>
<td>● 95 Express, Miami</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● I-394 &amp; I-35W MnPASS Express Lanes</td>
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<tr>
<td></td>
<td></td>
<td>● SR-167 HOT Lanes, Seattle</td>
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<td></td>
<td></td>
<td>● I-15 Express Lanes Salt Lake City</td>
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<tr>
<td>Virtual Barrier</td>
<td>Illegal Entry/Exit</td>
<td>● I-85 Express Lanes, Atlanta</td>
</tr>
<tr>
<td>Mobile Technology</td>
<td>Occupancy and Illegal Entry/Exit</td>
<td>● I-394 &amp; I-35W MnPASS Express Lanes</td>
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<tr>
<td></td>
<td></td>
<td>● I-85 Express Lanes, Atlanta</td>
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<tr>
<td></td>
<td></td>
<td>● I-680 Express Lanes, San Francisco</td>
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</tbody>
</table>
4.2 Geometric Design in the Corridor

The enforcement area needed for enforcement personnel to pull over occupancy violators is an important aspect of the geometric design of the corridor. Sufficient cross sectional width is needed for the safety of the enforcement personnel and users of the lane. Sufficient longitudinal distance is needed where a vehicle must decelerate from free-flow speeds down to a full stop. Figure 8 presents design guidelines for enforcement areas from the Managed lanes Handbook published by TTI.

![Figure 8: Space Guidelines for Directional and Bi-Directional Enforcement Areas](image-url)
5. **Bibliography**


10. Kapsch Trafficom. Transponder Units TS3304/00 and /01. [Specs] 2011. 1000005441-02_EN-US.

