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16. Abstract

Enforcement of vehicle-occupancy requirements for high-occupancy vehicle (HOV) and high-occupancy toll (HOT) lanes is critical to protecting eligible vehicles' travel-time savings, trip reliability, and safety. Vehicle occupancy verification is a principal impediment to more efficient HOV/HOT lane enforcement because it requires visual inspection of passengers in individual vehicles. Several semi- and fully automated techniques for determining the number of persons in a moving vehicle have undergone limited field testing; however, no automated solution has yet been developed for permanent field implementation with sufficient reliability. The purpose of the white paper is to review and synthesize concepts, methods, and technologies for automated vehicle occupancy verification; identify potential roadside and in-vehicle technologies that may be considered for further research and development; and identify a path for implementing automated occupancy verification systems. This paper provides a reference point using publicly available information, a snapshot at the time of its preparation, with recognition that technologies could be in the private research and development process with potential to address the issues raised here.

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Automated Vehicle Occupancy Verification Technologies

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CHAPTER 1
INTRODUCTION

- *What are the issues and concerns with vehicle occupancy enforcement for high-occupancy vehicle (HOV) and high-occupancy toll (HOT) lanes?*
- *How is occupancy enforcement performed now?*
- *What are the shortcomings of the current methods?*
- *What are the criteria for effective occupancy verification?*
- *What is the purpose of this white paper?*

Background

HOV lanes have been in operation for almost four decades. Today, there are more than 2400 lane-miles of HOV projects, including arterial street applications, throughout North America, with many more overseas. HOV lanes have proven successful in increasing person throughput in congested urban freeway corridors. However, HOV lanes require effective enforcement policies and programs to operate successfully. Enforcement of vehicle-occupancy requirements is critical to protecting eligible vehicles' travel-time savings and safety. Visible and effective enforcement promotes fairness and maintains the integrity of the facility to help gain acceptance among users and non-users.

Vehicle occupancy verification is a principal impediment to more efficient HOV lane enforcement. A myriad of technologies have been developed and refined in recent decades to improve the integrity of enhanced transportation systems. However, the target of many of these technologies has usually been the vehicle, not the occupants. Several semi- and fully automated techniques for determining the number of persons in a moving vehicle have undergone limited field testing, including operator-monitored video cameras and infrared composite imaging. However, no automated solution has yet been developed for permanent field implementation, and no system has been found foolproof enough to satisfy traffic courts in upholding citations issued. As a result, HOV facility operators have traditionally relied on field enforcement to manage occupancy violations.

Increasingly there is interest in expanding HOV operation to HOT lane operation. The growing use of pricing as a means to readily manage demand is facilitated by the development of electronic toll collection (ETC) technology as an increasingly practical and inexpensive tool. Pricing helps maximize the use of available pavement and still prioritize operation for HOV use. The introduction of pricing into the HOV operation is seen by many as an opportunity to further manage the facility by spreading peak hour demand and allowing other users into the lanes as capacity allows.

As more and more HOT lanes emerge that cater to a wider array of users through pricing, enforcement is made more complicated. Among the greatest challenges in implementing a HOT lane is determining who is an HOV that receives free or reduced pricing for travel on the facility. For priced lanes, persistent violation problems can breed disrespect for enforcement and result in a significant loss of revenue. In the extreme, some sponsoring agencies are considering eliminating rideshare incentives on their managed lanes because of the difficulty associated with monitoring and enforcing these users. The consequences of unchecked violators resulting from enforcement challenges impact not only mobility but revenue as well. The growing number of HOT lane projects—both new and adaptations of existing HOV lanes—will require effective enforcement to protect toll revenues. Table 1-1 summarizes the various active and planned managed lanes projects showing HOV, HOT, and express toll lane (ETL) projects, which illustrates that the HOV component continues to be an important element of planned facilities.

Table 1-1. Managed Lanes Facilities Inventory.[1, 2]

Facility Type	Operational	Planned
HOV	Over 100 (22 states)	33 (11 states)
HOT	7 (5 states)	17 (6 states)
ETL	0	12 (4 states)

With over 100 HOV lanes in operation and 50 HOV and HOT lanes projected for the near future, there is a developing market for a more efficient, automated system for occupancy verification and enforcement. Technologies for automating the enforcement function of verifying occupancy urgently need to be explored.

Purpose of This White Paper

The objectives and purpose of the white paper encompass the following:

- Review and synthesize concepts, methods, and technologies for automated vehicle occupancy verification. This research includes not only operational technologies but also future implementations of concepts under development.
- Identify potential concepts and technologies that may be considered for further research and development.
- Develop criteria for improved occupancy verification, with a focus on functional requirements for robust systems and techniques.
- Develop guidance toward implementing automated occupancy verification systems and addressing concerns of personal privacy, legal/jurisprudence efforts, and cost.

This paper provides a reference point using publicly available information, a snapshot at the time of its preparation, with recognition that technologies could be in the private research and development process with potential to address the issues raised here.

Traditional HOV/HOT Enforcement Practices

Before delving into the potential concepts and technologies for automating HOV enforcement, it is important to first examine the state of the practice in HOV and HOT enforcement. Many HOV facilities in the United States have operated successfully with low violation rates using an effective combination of law enforcement resources, physical enforcement areas on the facility, and supporting fine structure and adjudication authority. However, as transportation funding concerns grow, the cost of a manpower-intensive operation to enforce HOV requirements comes into question.

Vehicle occupancy verification currently depends exclusively on manual methods. The primary method employed is direct visual observation of the interiors of vehicles by enforcement personnel. Operational techniques for verifying and enforcing minimum vehicle occupancy requirements on HOV and HOT facilities include stationary patrols and roving patrols. Team patrols use various combinations of stationary and roving patrols working in unison to monitor an HOV facility and to apprehend violators. Potential combinations may include multiple stationary patrols, multiple roving patrols, or a combination of stationary and roving patrols. The team approach is generally utilized on HOV/HOT projects when it is impossible, or considered unsafe, for a single officer to detect and apprehend a violator. In this case, one officer detects the HOV violation and subsequently informs another officer stationed downstream for the purpose of apprehension.

Geometric Design Methods to Aid Visual Inspection

The choice of enforcement technique is dictated largely by the geometric constraints of the HOV/HOT facility. The term "enforcement area" is used to refer to a number of potential design treatments that provide space for police personnel to monitor an HOV facility, pursue a violator, and apprehend a violator and issue a citation. Space adjacent to an HOV lane is required for these functions, which primarily equates to a continuous or intermittent wide shoulder area of at least 4.3 m (14 ft). The two types of enforcement areas are low-speed areas at entrance and exit ramps, and high speed areas along the HOV mainline. Low-speed areas provide the best opportunity for accurate visual verification of occupants.

The enforcement area design becomes even more critical for HOT operations where compliance of both HOV occupancy and lower-occupant vehicle (LOV) toll payment must be enforced. In the context of HOT lanes, the term "operating concept" refers to the process by which vehicles on the HOT facility are differentiated into toll and HOV users. Two types of operating concepts have been used on HOT facilities:

- **HOV-ineligibles tagged.** Vehicles not meeting the eligibility/occupancy requirements for the managed lane facility (those paying to use the facility) are the only vehicles required to have a toll transponder. At a stationary enforcement zone or through roving patrols the vehicle occupancy is first checked, and for vehicles not meeting occupancy requirements the toll payment must also be verified. Automated violation enforcement systems (VESs) have thus far not been implemented under this scenario since not all vehicles are required to have transponders. This is the most common strategy among early HOT lane projects that involved conversion of HOV to HOT, primarily because it retains the privileges of the HOV (i.e., does not require them to secure a transponder).

- **Universal tag.** Under this operating concept, all vehicles in the HOT lane are required to have a toll transponder, including HOVs, and VESs using photographic methods are used to enforce toll payment. Users in vehicles that meet the eligibility/occupancy requirements for the managed lane facility (those that get a free or discounted trip) are required to access a special lane to receive a reduced (or zero) toll for the trip. The special lane could be an in-line pullout on the main lanes or a pullout lane on a ramp or in a connecting park-and-ride facility. At this discount/credit lane the vehicle occupancy is visually verified. This scenario follows the model used on toll facilities with ETC.

For a barrier-separated facility using a "universal tag" operating concept, HOV traffic may be segregated into a special lane at the tolling area to bypass the ETC readers. Officers in this case need only observe traffic in the special lane for occupancy violations, with toll violations in the non-HOV lane being handled by automatic photo or video enforcement. For barrier-separated facilities using an "HOV-ineligibles tagged" operating concept, the presence of toll and HOV traffic on HOT lanes requires enforcement officers to differentiate not only between HOV and non-HOV vehicles, but also between legitimate (toll-paying) and illegitimate low-occupancy vehicles. In this case, it is advantageous to locate some observation and/or enforcement areas slightly downstream of tolling areas on the facility so that officers can observe transponder status (as shown by a roadside indicator beacon or similar technology aid) as well as vehicle occupancy in the tolling zone.

Technology-Assisted Techniques

Technological countermeasures have been employed for toll evasion on HOT lanes and other forms of priced managed lane facilities. These technologies are designed to assist manual occupancy verification efforts by confirming payment status of lower-occupancy vehicles:

- **Indicator beacon.** One approach to transponder verification uses an automatic vehicle identification (AVI)–activated overhead beacon mounted on the toll reader gantry to indicate when a toll transponder passes under the reader. Under this approach, enforcement personnel must be within the line of sight of the tolling zone in order to see both the overhead beacon and the triggering vehicle. Also, many ETC systems do not process billing transactions in real time, so this approach cannot determine if a transponder is linked to a valid toll account; it merely indicates that a readable transponder is present in the vehicle.
- **Handheld and mobile systems**. Compact and portable transponder verification systems are available in handheld configurations, which are suitable in situations where a suspected violator has been pulled over by an enforcement officer. Mobile transponder verification systems mounted on law-enforcement vehicles can enable officers to remotely verify transponders from their police cruisers while driving alongside or behind vehicles in the HOT lanes.

Supporting Regulatory Measures

Legislation governing the citation and fine structure for HOV violations incorporates several characteristics, each of which influences the potential effectiveness of enforcement and violator behavior:

- **Controlling legislation.** Laws for HOV violations can be enacted on the state or local level. Alternatively, existing state or local laws can be used to enforce HOV regulations. However, laws explicitly addressing HOV violations at the state level have a greater chance of being uniformly applied.
- **Type of violation.** On buffer-separated or non-separated HOV facilities, enforcement personnel must concern themselves with an additional type of HOV violation. Motorists who violate the buffer or double lines indicating prohibited access to the HOV lane pose a serious safety hazard to traffic in the HOV and general-purpose lanes.
- **Fine amounts.** Fines constitute the chief deterrent against HOV violators. Fine assessments for HOV violations vary widely among the various states, and the general experience with fines for non-compliance with HOV facility operating requirements is that higher fines equate to lower violations.
- **License penalties.** Next to the potential cost of a ticket, the possible imposition of demerits on a driving record provides the greatest deterrent to potential HOV violators. Demerits or "points" provide an additional weapon with which to combat persistent, repeat violators since the higher insurance premiums and the possible loss of driving privileges resulting from multiple point assessments can impose substantial costs and inconvenience.

Violations on most HOT facilities are handled under existing laws regulating HOV lane usage, rather than being classified as toll evasion. It is important in implementing a HOT conversion that existing fines be reviewed and, if necessary, updated. The concept of HOT lanes—selling "unused" capacity in the HOV lanes—means that the potential negative impact of uncontrolled violators on HOT revenue, person-movement capacity, and public approval can be large. Penalties for violations must be adequate to discourage the willful violator such that reliance on dedicated enforcement officers can be minimized. Currently, aggregate penalties on HOT/HOV projects in the United States vary from $45 to $351 for a first offense.

Policy and Administrative Approaches to Carpool Enforcement

Agencies are exploring a variety of creative administrative methods to verify compliance and reduce enforcement costs for HOT facilities, seeking to work around constraints of funding or retrofitted facilities that limit the ability to invest in the physical infrastructure for enforcement areas. Below is a sampling of several ideas, which do not have any verifiable field application to date:

- **Carpool definition**—defining two-person carpools as two persons in the front seat to simplify field enforcement. Since back-seat occupants are difficult to see and are frequently children, requiring HOV occupancy with two or more persons (HOV2+) credit with front-seat passengers alone could enhance enforcement operations.

- **Peak period emphasis**—designating carpool exemptions for peak periods only. This presumes that the types of carpools prevalent during peak periods are commuters, whereas at other times they are non-commuters on non-work trips and would be carpooling regardless of an incentive.
- **Back-office ride tracking and trip credit**—carpool ride-matching and ride-tracking programs that can verify—pre- or post-trip—commuter matches for carpooling (e.g., through self-declaration via Internet or cell phone), comparing the use of toll tags by the registered carpoolers during the commute period. The theory is that verification is made through a back-office process without requiring the field conditions to support visual verification. The toll credit can be made accordingly and/or other incentives provided (coupons, discounts, airline miles, etc.).
- **Differential tolling**—tolls that are based on the number of vehicle occupants. With the growth in the number of managed lanes and toll facilities, a differential pricing scheme based on vehicle occupants could allay some of the principal environmental justice concerns associated with toll facilities, as well as encourage higher average occupants per vehicle on these facilities. An ancillary benefit to differential tolling is the potential for more accurate reporting of mobility measures. Current verification methods for occupants rely on manual methods, but an automated system could improve the efficiency of this approach.

Costs and Manpower Requirements under Traditional Methods

The cost of manual occupancy verification and enforcement is large, especially for HOT facilities (Table 1-2). In 2001, the San Diego Association of Governments (SANDAG) spent $60,000, or $3700 per lane mile, to enforce the two-lane, 8-mile I-15 project. This sum is dwarfed by the sums spent in 2005 for enforcement of the 10-mile, four-lane SR-91 facility in Orange County—$360,000, or $9000 per lane mile. A similar sum was expended for the 11-mile I-394 project in Minneapolis—$200,000, or $8900 per lane mile.

Table 1-2. Annual Costs for HOT Enforcement.

HOT Facility	I-15	I-394	SR-91
Centerline length	13 km (8 miles)	18 km (11 miles)	16 km (10 miles)
Number of lanes	2	2	4
Budget year	2001	2005	2005
Annual enforcement costs	$60,000	$200,000	$360,000
Costs per lane per km (per lane/mile)	$2300 ($3700)	$5500 ($8900)	$5600 ($9000)
Source of enforcement funds	Toll revenues	Toll revenues	Toll revenues

Note that much of the disparity in cost arises from the number of man-hours devoted to enforcement. Costs for I-15 are based on one officer providing three four-hour shifts per week, while I-394 enforcement costs reflect 12 four-hour shifts per week. The SR-91 Express Lanes funds 14 eight-hour shifts per week, with two officers present during morning and evening peak periods.

Comparable costs for well-funded HOV enforcement programs are typically much lower although enforcement budgets for HOV facilities can, in rare cases, be just as large as those for HOT facilities. The 2004 budget of $390,000 for enforcing the I-95/I-395 and I-66/I-267 HOV lanes in northern Virginia equates to $1700 per lane per km ($2800 per lane/mile) for the 113 km (70 miles) along these facilities. The 2003–2004 enforcement budget for the 28.8 km (18 mile) Nassau County section of the Long Island Expressway HOV lanes was $308,000, or $5300 per lane per km ($8600 per lane/mile).

Using a conservative figure of $150,000 per project, approximately $16 million is needed annually to adequately fund HOV enforcement on U.S. HOV and HOT projects. The largest expense in enforcing HOV compliance is law enforcement manpower for occupancy verification. This figure does not reflect planned projects.

Shortcomings of Traditional Methods

Reliability

Current practices in occupancy verification and enforcement suffer from substantial problems. It is essentially impossible to verify the correct number of occupants in vehicles with very high accuracy using visual inspection. Many factors such as high speeds, window tint, and poor lighting conditions caused by bad weather or dawn/dusk conditions significantly impair an officer's ability to "eyeball" vehicle occupants. Rear-occupant detection is especially problematic—the few reports on accuracy of rear-occupant counts indicate that half the time, the officer fails to see rear occupants, especially when they are children.

Safety

The need for officers to position themselves at the roadside next to moving traffic creates a potentially dangerous enforcement environment. In order to reduce the exposure of officers to injury, expensive barriers must be built to protect officers while observing and apprehending violators.

Cost

The high cost of visual occupancy verification manifests itself in two ways: infrastructure and operations. On the infrastructure side, visual enforcement requires enough space for an officer to stand and observe the interior of the vehicle cabin and sufficient room to apprehend a violator. Providing that space within the right-of-way can be expensive, particularly in retrofit situations. Physically separating HOVs from toll-paying vehicles has proven to be advantageous from an operations perspective, but it requires a separate lane where HOVs can self-declare their eligibility for a free or discounted toll. The additional lane for HOVs also requires space for the observer to verify vehicle passengers.

With regard to operations costs, the physical presence of law enforcement officers to count people in vehicles can be an expensive endeavor with limited reliability, even if enforcement is random and targeted. HOT lanes have demonstrated that enforcement can be enhanced and HOV violation rates reduced using revenue generated from the project; nevertheless, transportation funds are scarce, and a reliable, automated method to improve HOV enforcement while reducing costs can free that funding for other critical project needs.

Criteria for Improved Occupancy Verification

The HOV lane experience has provided transportation professionals with a wealth of information on the ways to effectively plan, design, and operate HOV systems. As HOV facilities evolve to offer greater opportunities for freeway mobility and as technology developments support new operational strategies, improvement in enforcement methods for flexibility and reduced cost will help maintain the viability of this freeway approach. The lessons of the HOV experience demonstrate that any new technology for enhancing enforcement should meet basic criteria:

- be effective,
- be efficient,
- be safe,
- be physically feasible,
- reduce violations,
- do not adversely impact operations,
- be cost-effective,
- have ease of implementation,
- address privacy concerns, and
- be legally defensible.

The remaining chapters of this paper describe the potential technologies and concepts for automated enforcement, and define a possible roadmap for advancing the concepts to meet agency needs and address legal and privacy issues.

CHAPTER 2
STATE OF THE PRACTICE IN AVOV TECHNOLOGIES

- *What constitutes an automated vehicle occupancy verification (AVOV) system?*
- *What research and development—both domestic and international—has taken place to support AVOV systems?*

Description of AVOV Systems

In general terms, the operation of an automated system for AVOV follows a three-step process:

- **Step 1—Image or data acquisition.** In this step, information or data are gathered from one or more sensors. At this point the data from the sensors are largely in a raw state. If any processing of the sensor information occurs in this step, it is usually limited to verifying that usable information has been received. In the case where sensors output continuous signals, for example, some type of control logic may monitor signal levels to determine if the sensors are functioning properly.
- **Step 2—Data processing/feature extraction.** The purpose of this step is to "clean up" the sensor data and render it into a form that can be optimally processed in the subsequent classification step. Most commonly, the information from multiple sensors is "reduced" by discarding extraneous data and/or summarizing it into a set of key features. In the context of image processing, as an example, this step would include the segmentation of the image into foreground and background, or the creation of a composite image from multiple raw images. Other examples include the creation of a "pattern map" based on the output of a distributed set of multiple pressure sensors.
- **Step 3—Classification.** Once the key features have been identified and extracted from the sensor data, they are used in the classification step to choose the appropriate decision alternative, e.g., whether or not an occupant is present in the vehicle. In practice, this involves comparing the key features from the sensor data to a set of pre-defined criteria to find the closest match; each decision alternative will correspond to certain ranges in the respective criteria. Analogously, Step 2 of the process essentially creates a particular shape of "peg" or "block," which is fitted in Step 3 into the appropriate "hole."

For this white paper, two main approaches to automated vehicle occupancy are considered. The first approach, roadside systems, relies on surveillance equipment suitably positioned to obtain pictures or other images of the interiors of passing vehicles. This approach represents an extension of current traffic-monitoring techniques, with many of the same inherent benefits and drawbacks. In particular, the difficulty of reliably capturing details from the interiors of fast moving vehicles requires a high level of performance from the imaging system, which can only be obtained by very expensive devices. Chapter 3 provides a more detailed discussion of roadside systems.

The second approach, in-vehicle systems, seeks to leverage the capabilities of next-generation adaptive airbag systems for the purpose of occupant counting. This approach has received considerable attention since its proposal in the recent report, *Automated Vehicle Occupancy Monitoring Systems for HOV/HOT Facilities.*[3] As outlined in the report, these advanced airbag systems will have the ability to distinguish between an empty seat in a vehicle and one occupied by various sized adults, infants, and children. This information could then be used by a "piggyback" system or application to verify the number of vehicle occupants. In-vehicle systems are discussed more fully in Chapter 4.

Unlike roadside systems, in-vehicle systems would not require expensive, high-precision sensing devices. Furthermore, the sensing systems would be incorporated as standard safety equipment in future passenger vehicles. In-vehicle systems would, on the other hand, require a communications capability between vehicles and roadside infrastructure. Two key obstacles, however, confront any development toward occupancy verification based on in-vehicle systems. In-vehicle systems are predicated on the assumption that occupancy information can be easily retrieved from the advanced airbag systems and subsequently transmitted to roadside communications devices. This assumption may ultimately prove to be invalid if privacy objections or the reluctance of automotive manufacturers to accommodate occupancy verification technologies proves to be insurmountable. The second obstacle facing in-vehicle systems relates to their timetable for deployment. Advanced airbag systems are not expected to become a nearly universal presence in North American vehicle fleets for at least 10 to 15 years or even longer, and it is doubtful that occupancy verification technologies could be easily retrofitted to non–factory-equipped vehicles.

Research and Development Overview

Much of the research related to AVOV draws on several domestic and international initiatives to improve driver perception and safety.

Federal Safety Regulations

Revisions to federal motor vehicle safety standards are a huge impetus toward development of systems that can distinguish the number and position of vehicle occupants. The U.S. Federal Motor Vehicle Safety Occupant Crash Protection Standard (FMVSS 208) mandates the use of advanced or "smart" air bags in the front seats of new vehicles sold. These safety systems must be capable of suppressing airbag deployment if a seat is unoccupied or occupied by a child or rear-facing infant seat; they must also be capable of reducing the force of deployment if a seat contains a medium-sized passenger. The phase-in schedule for the advanced airbag requirement encompasses 65 percent of 2008 model vehicles, with 100 percent phase-in for 2009 model vehicles. Some auto manufacturers are also using side-curtain air bags, which are even more sensitive to out-of-position passengers than the frontal air bags due to the much shorter distance between the side of the vehicle and the passenger. Occupancy detection systems are consequently a critical part of some side air bag systems. This is creating enormous financial incentives for researchers and represents a major investment by manufacturers—one industry analysis in 2001 put the value of occupant-sensing products in 2006 at $US3.6 billion.[4]

Vehicle Infrastructure Integration

Significant research has been devoted to the study and application of communications technologies that would support wireless data integration of vehicles with the national transportation infrastructure. These vehicle infrastructure integration (VII) technologies support a wide array of VII concepts and applications that can enhance commerce, mobility, and, most importantly, safety. The current vision of VII technologies within the United States is embodied in the U.S. Department of Transportation (USDOT) VII System. The VII System will be a nationwide data network that wirelessly links vehicles with the transportation infrastructure and with value-added services. The VII System will support applications related to safety, mobility, and commerce, and will support applications sponsored by both public and private sectors. Such a system may ultimately facilitate the operation of in-vehicle occupancy detection systems by communicating occupancy verification information.

International Safety Programs

International efforts largely mirror U.S. efforts, with the Advanced Passive Safety Network[5] and the Proposed Reduction of Car Crash Injuries Through Improved Smart Restraint Development Technologies (PRISM) project[6] focusing on advanced occupant protection systems. The Accident Information and Driver Emergency Rescue (AIDER) project[7] investigated video monitoring of occupants and vehicle communications for the purpose of enhancing rescue operations in accident situations. The Foresight Vehicle program is developing advanced driver assistance systems (ADAS),[8] while the Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) report, *Automated Vehicle Occupancy Monitoring Systems for HOV / HOT Facilities,*[3] provides a comprehensive case for adoption of advanced in-vehicle systems for use in occupancy verification.

Facility-Related Projects

SANDAG is studying the feasibility of applying state-of-the-art VESs to improve accuracy in verifying vehicle passenger counts and enforcing single-occupancy vehicle (SOV) toll provisions of the future I-15 Managed Lanes.[9] Some aspects of the VES study are being developed concurrently with, and will be integrated into, the FasTrak™ ETC system for the I-15 Managed Lanes. Other more advanced approaches would require proof-of-concept testing, which may be conducted on the existing barrier-separated reversible HOT lanes subsequent to the deployment of the I-15 Managed Lanes toll system in 2008.

CHAPTER 3
ROADSIDE SYSTEMS

- *What is a "roadside system" for AVOV?*
- *What are the various technologies that support a roadside system for verifying occupancy?*
- *What are the key challenges and functional requirements for a roadside system?*
- *What are the technology trends and future outlook for roadside systems?*

Sensing Technologies

Roadside technologies for vehicle occupancy detection have been developed and tested over nearly two decades. Despite this long developmental history, roadside systems have yet to achieve viable levels of accuracy and reliability required for HOV lane enforcement. This section presents general descriptions of the various sensing technologies for roadside detection and their characteristics. Table 3-1 summarizes the benefits and drawbacks to the various technologies that have been investigated for use in occupancy detection. Additional details on the technologies can be found in the synthesis report supporting this white paper.[10]

Table 3-1. Comparison of Technologies for Roadside Vehicle Occupancy Detection.

Technology	Benefits	Drawbacks
Video	Commercially available systems	Poor resolution Inferior to visual inspection Unusable in low lighting
Microwave	Usable under all lighting conditions	Slow imaging speed Poor resolution Cannot penetrate metallic window tint Very expensive
Ultrawideband radar	Commercially available systems	Slow imaging speed Poor resolution Inadequate range Cannot penetrate metallic window tint
Single-band infrared	Usable under all lighting conditions	Not developed past custom prototype Cannot distinguish human skin from other objects of similar temperature Expensive
Multi-band infrared	Can distinguish unique infrared (IR) signature of human skin Usable under all lighting conditions Can potentially operate autonomously	Not developed past custom prototypes Very expensive

Video Systems

Video systems have been deployed in the past for observing the number of vehicle occupants. While video continues to serve a useful role in HOV facility monitoring, it has not proven adequate for the task of vehicle occupancy enforcement. The collective experience from studies and implementation projects in California and Texas has concluded that video methods are not as reliable as live visual inspection. Results from a video surveillance and enforcement study in Orange County, California, in 1990 concluded that reviewers of video images could not identify the number of vehicle occupants with enough certainty to support citations for HOV lane restrictions.[11] Over one-fifth (21 percent) of vehicles identified by videotape reviewers as violators actually had the proper number of occupants. Similar results were reported for a 1995 test of real-time video and license plate reading (LPR) for HOV lane enforcement on the I-30 HOV lanes in Dallas, Texas.[12]

In 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 SOV violators on the carpool-only lanes of the Express Lanes facility. Problems with the video system, however, led to its elimination in 1998. In their 2001 report on enforcement effectiveness, San Diego State University researchers reported that the operators could not reliably distinguish SOV violators on the videotapes and found it difficult to discern the number of vehicle occupants, especially for those in back seats.[13]

Passive Microwave Systems

Passive microwave systems generate imagery from the natural radiation emitted and reflected by the environment within the microwave spectrum. This spectrum occurs at wavelengths longer than those in the infrared region but shorter than those for radio waves. Passive microwave systems are able to detect emissions through plastic and other thin, non-conductive material. Some disadvantages of passive microwave systems are their very large size and high cost. The imaging speed of passive systems is relatively slow because the imager needs time to accumulate sufficient amounts of microwave energy for a good "exposure." The long wavelengths used by this method mean that image resolution will be relatively coarse. Passive microwave systems are therefore limited in application to the scanning of slow-moving vehicles with unenclosed cargo trailers.

One example of this application is Joanna, a passive microwave system that monitors stowaways attempting to cross the Channel Tunnel by concealing themselves in the cargo bed of commercial trucks.[14] Joanna's several 35 GHz microwave detectors, scanning in series, are able to see through non-metallic coverings on unenclosed truck cargo beds. The system has achieved considerable success since it entered operation, detecting several hundred stowaways per month.

Ultrawideband (UWB) Radar Systems

The very short pulse length of UWB (typically 1 nanosecond) makes it possible to build radar with better spatial resolution and very short-range capability relative to conventional radar. UWB pulses generate a wide range of frequencies that are directionally beamed into an area. The pattern of absorption and reflection across this frequency range by materials within the scanning area is sensed by the instrument; this pattern depends on the types of materials being probed and their distances from the instrument. The ultrawideband device then constructs a representation of the scanned area based on the strengths of the various reflected frequencies and their correspondence to known substances.

The chief weakness of UWB systems is their inability to penetrate any metallic barriers. This severely compromises their use in vehicle occupancy detection settings, where passengers must be sighted though windows surrounded by sheet metal. The presence of metallic window tints, which are already a popular window tinting option, also blocks UWB emissions. UWB devices are also not appropriate for use in high-speed image acquisition because they require one-third to one-half second to complete the imaging process. Changes to Federal Communications Commission (FCC) rules in 2002 also severely reduced the allowable power levels for UWB devices. UWB devices must therefore be placed extremely close to a barrier in order to penetrate beyond it. Most applications of UWB systems are seen in military, police, or search-and-rescue operations where the need to locate stationary concealed individuals is great. Companies offering UWB products include Camero,[15] Cambridge Consultants,[16] and Time Domain Corporation.[17]

Infrared Systems

The main potential benefit offered by infrared systems is the ability to operate in darkness as well as daylight. Infrared systems operating in certain wavelengths can utilize camera illumination that is outside the visible light range and that consequently would minimize driver distraction. The primary developmental thrust for roadside infrared occupancy detection systems has focused on near-infrared (NIR) systems, which detect the reflection of shorter infrared wavelengths from objects illuminated by an NIR source. The NIR band is more suitable for occupancy verification purposes because it is not as readily blocked by vehicle glass or window tint.

Single-Band Infrared Systems

Research into single-band NIR systems, though limited, has had promising initial results. Georgia Tech Research Institute (GTRI) developed a roadside infrared vehicle-monitoring system for the Georgia Department of Transportation (GDOT) in 1998.[18] Designed for counting the number of occupants in vehicles passing by at highway speeds, the prototype consisted of a computer-assisted infrared imaging system, utilizing a single near-infrared camera illuminated by an infrared light source. A field test of the prototype demonstrated its ability to capture images of vehicles at speeds up to 80 mph. A qualitative assessment of system accuracy involved a real-time comparison with visual observation. Researchers claim that the system was superior to visual inspection at identifying rear passenger occupants. GDOT ultimately declined further development, and to date, no further work has been undertaken.

Multi-band Infrared Systems

Multi-band infrared systems exploit the infrared reflection characteristics of human skin. By imaging two infrared bands using dual infrared cameras and generating a differential image (the difference in brightness between corresponding pixels of the two images), these systems can isolate the signature of human skin from that of other materials in the vehicle cabin. Such systems are also noteworthy in that they are capable of autonomous occupancy classification.

In 1998, the Minnesota Department of Transportation and researchers from Honeywell and the University of Minnesota developed a machine vision system for vehicle occupancy detection, utilizing a pair of synchronized near-infrared cameras to capture dual-band near-infrared images.[19] Researchers conducted a field test of the system in February 2000.[20] Vehicles containing one or two front-seat occupants were driven at 50 mph under both daylight and nighttime conditions. The prototype captured images through the windshield, and the resulting automated occupancy counts were compared to those obtained by visual inspection. Researchers reported 100 percent correct identification of the number of occupants by the system for a randomly selected subset of 100 images. No further development has occurred since the limited field test.

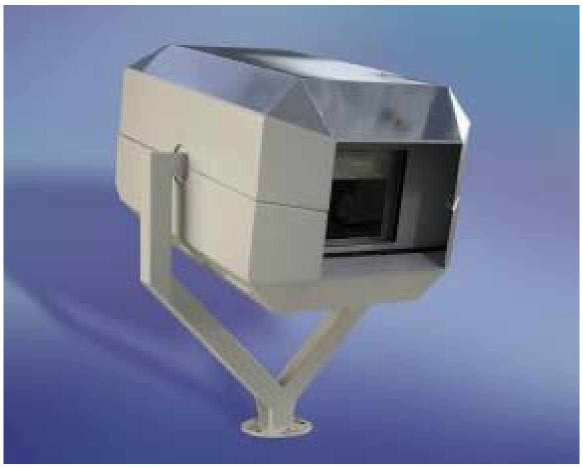

Figure 3-1. Cyclops Vehicle Occupancy System.[21]

In 2003, the U.K. Department of the Environment, Transport, and the Regions funded a three-year research project to develop an automated vehicle occupancy camera detection system begun in Leeds, United Kingdom. The resulting Cyclops system (Figure 3-1) uses visible and NIR wavelengths to count vehicle occupants through the front windshield of oncoming vehicles at highway speeds. Like the Minnesota effort, Cyclops exploits the NIR absorption properties of human skin; a combination of the visible and NIR images yields a skin signature that contrasts with its surroundings. Tests of the Cyclops system on the United Kingdom's first HOV lane (on A467 in Leeds) were conducted in 2005; results indicated a 95 percent success rate in detecting real people and rejecting decoy information such as hands or dummies.[22] The cost of a Cyclops installation providing single-lane coverage is estimated to be $165,000.

Key Challenges and Functional Requirements for Roadside Systems

All roadside occupant detection systems must overcome significant obstacles that have thus far limited their effectiveness. Purely considering sensing technologies, the main challenges can be categorized as follows:

- **Cabin penetration.** Can the technology see through tinted vehicle windows?
- **Environmental conditions.** Can the technology operate in all weather conditions and night-time operation?
- **Good image resolution.** Can the technology resolve details such as heads and limbs?
- **Fast image acquisition.** Can the technology operate at highway speeds?
- **Observational restrictions.**

Note that for the last criterion, all technologies for roadside detection must be located to optimize the view into the vehicle cabin. Additionally, roadside systems can only detect unobstructed occupants, which may be difficult in the case of rear-facing infant seats, smaller rear-seat occupants, or occupants "curled up" sleeping in the back seat. In fact, the two most significant development efforts into automated occupancy detection systems have only focused on through-the-windshield monitoring, which is only effective for detecting front-seat occupants.

The performance of each technology with respect to the first four criteria is summarized in Table 3-2.

Table 3-2. Performance Comparison for Roadside Occupancy Detection Technologies.

Desirable Property	Visible Light (Passive)	Near Infrared	Thermal Infrared	UWB Radar	Microwave
Not blocked by tinted vehicle windows	☒	☑	☒	☒	☒
Capable of all-weather and night-time operation	☒	☑	☑	☑	☑
Capable of resolving vehicle cabin details	☑	☑	☒	☒	☒
Fast enough to capture vehicles moving at freeway speeds	☑	☑	☑	☒	☒

From Table 3-2, it is apparent that the infrared range holds promise for a roadside occupancy detection system. Most importantly, typical vehicle window tints do not significantly block transmission of near-infrared wavelengths (0.7–2.4 μm), as may be seen in Figure 3-2. Note that while the wavelengths of visible light (0.4–0.7 μm) and thermal infrared (3.0–5.0 μm) are significantly attenuated by 35 percent tint, near-infrared transmittance is still relatively high. Other technologies such as radar and microwave systems are also not appropriate since a vehicle's metal chassis creates too much interference to effectively image anything inside the vehicle.

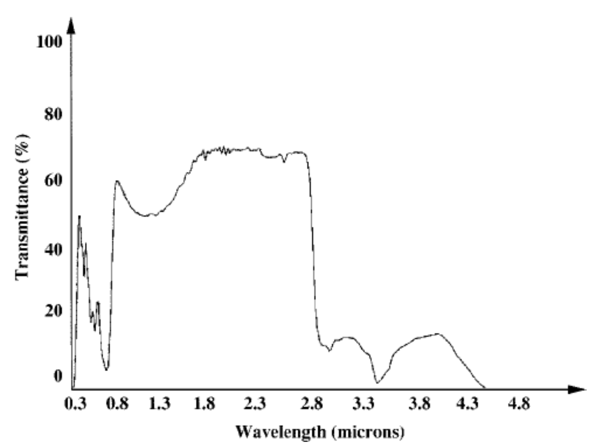

Figure 3-2. Transmittance of Typical 35 Percent Tinted Vehicle Window.

To satisfy the requirement of 24-hour operation, nearly all roadside systems must employ active illumination. The exception to this rule occurs with thermal and microwave sensors, which measure the direct radiated heat of the subject. Visible light systems are thus precluded since the supplemental illumination required for photo and video systems would pose a hazard to drivers.

Infrared sensors, especially those sensitive to near-infrared wavelengths, have nearly ideal properties for seeing into vehicle interiors. Infrared sensing is largely unaffected by weather conditions such as rain, fog, or haze. For use in darkness, infrared systems can employ supplementary infrared illumination, which is invisible to drivers. Most notably, the reflection characteristics of human skin change significantly in the near-infrared region, being highly reflective at shorter wavelengths and almost completely absorbent at longer wavelengths.

Specifically, a major portion of the reflected-infrared range, the so-called near-infrared range (0.7–2.4 μm), is suited for detection of vehicle occupants. The principal image-processing problem in roadside occupancy detection has traditionally been reliable segmentation of occupants from other objects in the vehicle cabin. Near-infrared fusion techniques have been demonstrated to isolate the "signature" of human skin, making this an ideal method for detecting the faces of vehicle occupants. If the near-infrared range is split into upper and lower bands at 0.7–1.4 μm and 1.4–2.4 μm, respectively, then vehicle occupants will produce consistent signatures in the respective images.

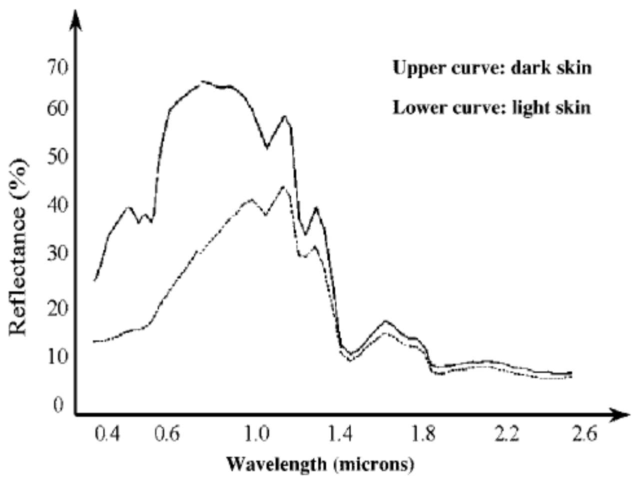

Figure 3-3. Reflectance of Human Skin.

In the upper band image, human skin will appear consistently dark irrespective of its physical characteristics and the illumination conditions. In the lower band image, skin will appear comparatively lighter. This is because human skin appears to have very high reflectance for wavelengths shorter than 1.4 μm but very low reflectance for wavelengths longer than 1.4 μm, as shown in Figure 3-3. The fusion technique combines upper and lower near-infrared band images to create a composite image. The pronounced difference in skin reflectance between the two infrared bands results in a unique feature that is readily distinguished from the rest of the vehicle cabin.

Technology Trends and Outlook

While multi-band infrared systems appear to be the technology of choice for roadside detection due to their performance advantages, the chief barrier to their implementation appears to be their high cost. Infrared sensing cameras have until recently been prohibitively expensive, requiring integrated mechanical systems for cooling and image scanning. For example, a camera capable of covering the entire near-infrared spectrum (0.7–2.4 μm) cost $75,000 in 1999; a multi-band infrared system would require two of these. More recently, even though the Cyclops system from Vehicle Occupancy Ltd. uses more limited cameras (covering only 0.7–1.4 μm), its estimated package price is $165,000.

Advances in semiconductor manufacturing are now yielding faster and cheaper sensor arrays that either require no cooling or can be cooled by solid state methods (thermoelectric). Greater image acquisition speed is being achieved by larger, two-dimensional sensing arrays, as opposed to older, "line-by-line" scanning sensors. Image-processing circuits are now being integrated into the sensor circuitry for higher resolution and reduced image "noise." Such trends are continually reducing the cost of high-resolution infrared imaging systems and offer great promise in terms of future sensor speed and mechanical reliability.

Continual progress in the computational speed and power of microprocessors is enabling increasingly advanced image-processing techniques to be applied to the problem of vehicle occupant classification. For occupancy detection, classification refers to the methods for "recognizing" the presence of occupants in a vehicle. A robust classifier uses sophisticated pattern recognition algorithms to distinguish vehicle occupants. Such classifiers are developed by "training" them with large numbers of sample images. The classifier then "learns" the best way to correctly differentiate between a predefined set of alternatives. While a treatment of the various classification algorithms is beyond the scope of this paper, it should be noted that advanced computing techniques such as fuzzy neural networks and support vector machines are now being employed to reduce the "learning curve" (number of training images required) and improve classification accuracy.

Although the potential for roadside occupancy detection systems has never been greater, no system has yet entered commercial production.

CHAPTER 4
IN-VEHICLE SYSTEMS

- *What is an "in-vehicle system" for AVOV?*
- *What are the various technologies under development?*
- *What are the key challenges and functional requirements for an in-vehicle system?*
- *What are the research needs for advancing in-vehicle AVOV systems?*
- *What are the technology trends and future outlook for in-vehicle systems?*

Sensing Technologies

The range of technologies applicable to in-vehicle occupancy detection systems is potentially much wider than that of roadside systems. Most importantly, in-vehicle systems are not limited to remote sensing techniques alone. Direct contact or close-proximity sensing technologies, such as weight sensors, electric field sensors, and biometric sensors, can also be employed. Moreover, multiple technologies can be combined for greater accuracy and reliability.

As previously noted in Chapter 2, in-vehicle occupant sensing is currently enjoying a wealth of research interest. Recent research developments and decisions by major automotive parts suppliers suggest certain trends that can be used to assess the relative viability of the various technology options. The general factors considered in this assessment include the following:

- technical development,
- commercial interest,
- integration potential (for full cabin coverage),
- implied system performance, and
- suitability for vehicle occupancy verification purposes.

The results of this assessment are summarized in Table 4-1 and Table 4-2. Table 4-1 includes the sensing technologies deemed most viable in the near term, while Table 4-2 summarizes those technologies that are relatively less promising or nonviable. A discussion of the most promising sensing technologies follows.

Table 4-1. High-Interest Sensing Technologies (Near-Term Viable) for In-Vehicle Occupancy Detection Systems.

Sensing Technology	**Advantages**	**Disadvantages**
Weight sensors	▪ Newer frame-based systems integrate easily ▪ Immune to nearly all ambient conditions ▪ Low parts cost ▪ In production ▪ Large development interest—nearly every manufacturer and parts supplier	▪ Simpler systems can be fooled by weights on the seat, require careful calibration, and are somewhat inaccurate ▪ Frame-based sensors can only be used on front seats ▪ Cushion-based sensors must be built into seats
Electric field sensors	▪ Detects a signature biometric characteristic ▪ Cannot be blocked by non-conductive objects ▪ Immune to nearly all ambient conditions ▪ Can be used for front and rear seats ▪ Low parts cost ▪ In production ▪ Moderate development interest—systems have been investigated by NEC/Honda/Elesys, International Electronics & Engineering (IEE), Allied Signal, Siemens, and TRW	▪ Must be integrated into seat surfaces or located directly overhead ▪ Limited sensing range ▪ Can be blocked by conductive materials such as foil
Monocular vision	▪ Small form factor ▪ Low parts cost ▪ Low illumination requirements ▪ Pre-production development status ▪ Moderate development interest—systems have been investigated by Eaton Corporation, Siemens, Delphi, and Magna Vectrics	▪ Must be located within line of sight of vehicle occupants ▪ Occupant classification is restricted to using only texture and area-based methods
Three-dimensional time-of-flight sensors	▪ Deals well with complex scenes ▪ Immune to nearly all ambient conditions ▪ Compact form factor ▪ Low parts cost ▪ Pre-production development status ▪ Large development interest—systems have been researched by Fraunhofer/Siemens, IEE, Canesta, and DaimlerChrysler/Conti Temic	▪ Must be located within line of sight of vehicle occupants ▪ Moderate to high illumination requirements

Table 4-2. Low-Interest Sensing Technologies for In-Vehicle Occupancy Detection Systems.

Sensing Technology	**Advantages**	**Disadvantages**
Ultrasonic	▪ Immune to ambient lighting conditions ▪ Low parts cost ▪ In production	▪ Requires careful integration and accurate setup/calibration ▪ Affected by temperature ▪ Multiple seat systems may be unfeasible due to mutual interference ▪ Can be blocked by newspaper ▪ Low interest—only one production system from ATI and Autoliv
Thermal infrared	▪ Detects a signature biometric characteristic ▪ Immune to all ambient lighting conditions	▪ Image can be distorted by hot drinks ▪ Can be blocked by objects ▪ Less effective in high cabin temperatures ▪ Not developed past proof of concept ▪ Low interest—research only
Omnidirectional imaging	▪ Potential to detect all occupants in cabin ▪ Moderate interest—systems have been researched by DaimlerChrysler and Siemens Automotive	▪ Large size ▪ High parts cost ▪ Computationally intensive ▪ Prototype development status
Stereo imaging	▪ High-quality imaging ▪ Near-production development status ▪ Moderate interest—systems have been researched by Advanced Computer Vision (ACV), Siemens, and TRW	▪ Requires feature such as edges or texture for greatest accuracy ▪ Limited to front-seat occupants ▪ More sensitive to ambient lighting changes ▪ Computationally expensive ▪ Line-of-sight operation
Structured lighting	▪ Immune to nearly all ambient conditions ▪ Computationally cheap and fast	▪ Possible eye risk from laser light-emitting diode (LED) exposure ▪ Coarse depth imaging—poor interpretation of complex scenes ▪ Requires careful setup and calibration ▪ Line-of-sight operation ▪ Prototype development status ▪ Obsolete technology
Volumetric modeling	▪ Accurate biometric measurements	▪ Computationally very expensive ▪ Limited sensing range ▪ More sensitive to ambient lighting changes ▪ Requires multiple cameras for a single seat ▪ Proof of concept only ▪ Low interest—research only
Smart card and biometric	▪ Integrates with existing AVI readers ▪ Near-production development status	▪ Requires active user input ▪ Susceptible to countermeasures

All of the most promising sensing technologies share the virtue of being particularly appropriate for occupancy-monitoring purposes. Each may be used in principle to monitor any seat in a vehicle although multiple sensing devices would be required, and the precision of each system is sufficiently accurate to ensure reasonable immunity to subversion tactics. As such, the following detailed discussion of sensor technologies has been limited to those listed in Table 4-1. For space considerations, it is hoped that Table 4-2 furnishes a sufficient review of the remaining technologies. Additional details on the "low-interest" technologies can be found in the synthesis report supporting this white paper.

Weight Sensors

Weight sensors have been the most widely employed method for occupant detection in vehicles. These sensors are used to determine the size of an occupant by measuring the forces exerted on the seat by the occupant. Over the last 10 years, 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.

Most weight-sensing systems are capable of determining little more than the position of an occupant's center of mass relative to the seat.[23] 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 the seat, however. Such an advanced cushion-based system, developed by IEE in partnership with Siemens VDO Automotive, uses dozens of interconnected sensors (Figure 4-1). This 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, as shown in Figure 4-2.[24] The IEE Occupant Classification (OC) system is currently fitted to cars manufactured by BMW, Chevrolet, DaimlerChrysler, General Motors, Hyundai, Kia, Rolls-Royce, and Suzuki.

The Bosch iBolt system (Figure 4-3) is one example of a highly compact frame-based sensor.[25] Each iBolt strain sensor is little larger than the normal seat-securing bolt 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.

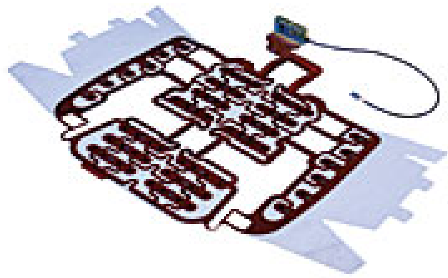

Figure 4-1. IEE/Siemens OC System.

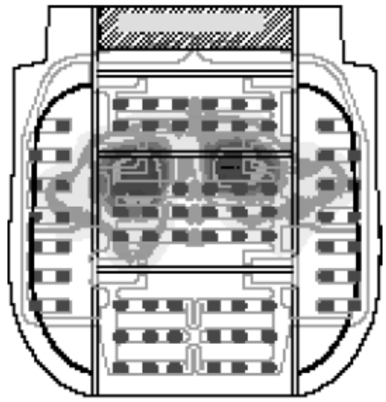

Figure 4-2. IEE/Siemens OC Pressure Distribution.

Figure 4-3. Bosch iBolt.

Capacitive and Electric Field Sensors

This technology determines occupant presence and position by reading changes in an oscillating low-level electromagnetic field generated by the system. The field is generated between two fixed electrodes that effectively act as signal antennas; i.e., one electrode behaves as a transmitter, and the other forms a receiver. The strength of the field detected by the receiver electrode will decrease if a dielectric (insulating) material is placed near or between the electrodes.[26] Sensors utilizing this principle are alternately known as capacitive or capacitive-coupling sensors since the capacitance of the two-electrode system varies in direct proportion to the insulating properties of the "gap" between the electrodes.

Electric field sensing technologies exploit the fact that the human body, composed primarily of water, has a dielectric constant approximately 80 times that of air. The electric field between the electrodes will therefore change markedly depending on whether a human body is present within the field. The magnitude of the change is proportional to how much of the electric field is blocked; therefore, this technology can be used to determine the distance of a body from the detector or to estimate a body's size. Multiple sets of electrodes may be used to triangulate the position of a vehicle occupant as well.

This technology is highly discriminatory since many inanimate objects (hats, newspapers, etc.) have much lower dielectric constants than that of water. However, highly conductive materials such as metals can defeat the system by creating a short circuit between the electrodes and "blinding" the sensor. The sensing range of this technology is also limited to at most 0.6 m, so the sensors must be located very close to an occupant's body or head.

A current production example of an electric field sensing system is the Occupant Position Detection System (OPDS) from Elesys.[27] Elesys is a cooperative venture between Honda and NEC, and was formed to commercialize parallel electric field sensing research efforts by Honda Research & Development Corporation[28] and NEC.[29] The OPDS uses a series of flexible, conductive cloth capacitive sensors embedded in the seatback. Six sensors are affixed laterally across the seatback, while another vertically oriented sensor is located at the seat side support where the side airbag is installed. The lateral sensor array is used to measure the height of the seat occupant, while the side sensor is used to detect the head of a small occupant or child.

The OPDS control unit and transmitter are installed in the seat frame. Figure 4-4 illustrates the arrangement of the OPDS components. The system can reliably determine the size and position of the seat occupant and is not affected by seat position, wear, water, or seat ventilation. The OPDS offers effective protection for children in the event of side airbag deployment and fully complies with the National Highway Traffic Safety Administration (NHTSA) FMVSS 214 mandate for "Side Impact Protection: Dynamic Performance." The OPDS system is currently available on Honda and Acura vehicles.

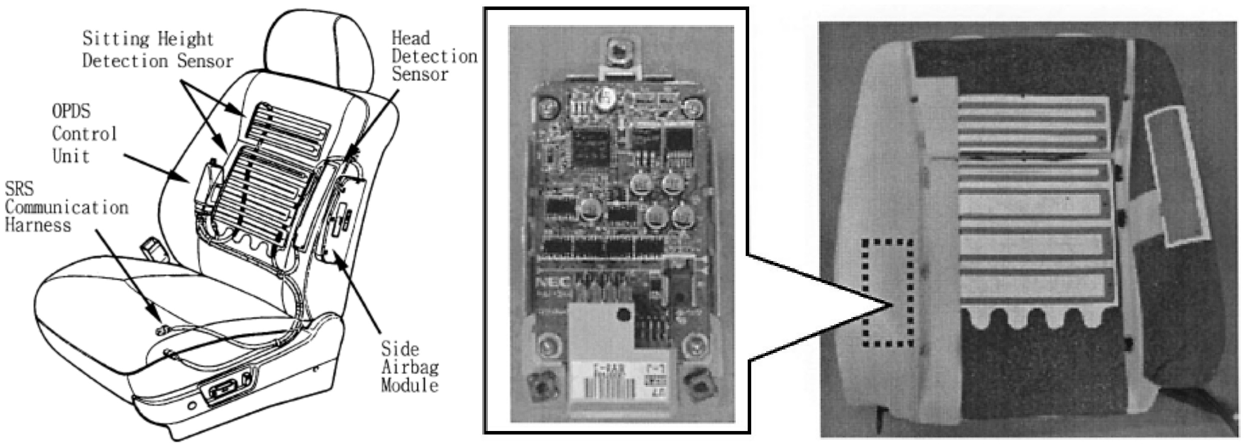

Figure 4-4. Elesys Occupant Position Detection System.

Monocular (Two-Dimensional) Imaging

Optical and NIR sensing methods are arguably the most active area of in-vehicle occupant-sensing research. Virtually all major automotive manufacturers and parts suppliers have systems under development, and their research is well represented in the literature. The rapid development of complementary metal oxide semiconductor (CMOS) photodetector arrays has dramatically improved the potential feasibility of optical systems. The latest generation of CMOS cameras for automotive applications offers small size, high performance, and rugged operation at relatively low cost.

Researchers at Eaton Corporation and the University of Michigan have been investigating the suitability of monocular (single camera) images for an occupancy classification system.[30] Their prototype system uses a monochrome CMOS camera and 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.[31, 32] 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 (Figure 4-5). Tests of the prototype system reveal a 97 percent average correct classification rate.[33] The system is expected to enter production around 2008.[34]

Figure 4-5. Raw Image (Left) and Extracted Image (Right) of Passenger.

Three-Dimensional Time-of-Flight Imaging

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 occupant 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 occupant classification system.

Progress in CMOS microelectronics is now enabling the production of very compact, integrated TOF sensors suitable for integration into the vehicle cabin. A system from Siemens VDO Automotive is nearing production[35]; it consists of a short integration time (SIT) camera and a pulsed NIR illuminator located near the rear-view mirror. The system can determine the location, shape, and size of the passenger occupant.

The Siemens SIT camera, developed by the Fraunhofer Institute for Microelectronic Circuits and Systems, represents one approach to TOF measurement. A sensitive photodiode imaging array with a high-speed synchronous electronic shutter is synchronized to an NIR laser diode illumination source. The NIR source generates extremely short-duration pulses (on the order of nanoseconds) that illuminate the entire imager field of view. The amount of the received light at the image sensor depends on synchronous timing of the laser diode, the reflectance of the objects in the scene, the travel time of the pulse, and the shutter switch timing. The reflectance of the target object also exerts an influence on the measurement. For these reasons at least three exposures are required. The first measurement uses a long opening of the shutter without NIR illumination to determine the level of background illumination. The second measurement is taken under active NIR illumination with the shutter duration longer than the length of the light pulse in order to measure the total illumination from direct and early-reflected sources. Finally, a measurement is taken with the shutter synchronized to open only during an illumination pulse, thereby measuring the direct illumination intensity only. The two actively illuminated measurements can be subtracted to obtain the reflectance of the targeted object. For pulses lasting just several nanoseconds, a higher-power laser diode can be employed that still meets laser class 1 eye safety regulations. Note that short shutter times minimize the effect of background illumination as well.

A TOF imager developed by IEE uses a slightly different approach for obtaining range information, in that the scene is broadly illuminated by a modulated NIR LED light beam instead of pulsed NIR. This modulated beam is reflected by an object and detected by the CMOS imager. Due to the travel time of the light to and from the target, the phase of the reflected beam is retarded compared to the phase of the modulation signal in the transmitter. This phase delay can be measured and directly converted into the distance between the target and the camera. Figure 4-6 graphically illustrates the distance map created from a seated adult passenger; the nearest points appear blue in the map. The system is capable of performing both occupant classification and occupant head position, depending on the intended application.[36, 37] The most recent test results for system performance indicate nearly 100 percent accuracy in classifying occupants[38] and an ability to track head movement at 25 frames per second.

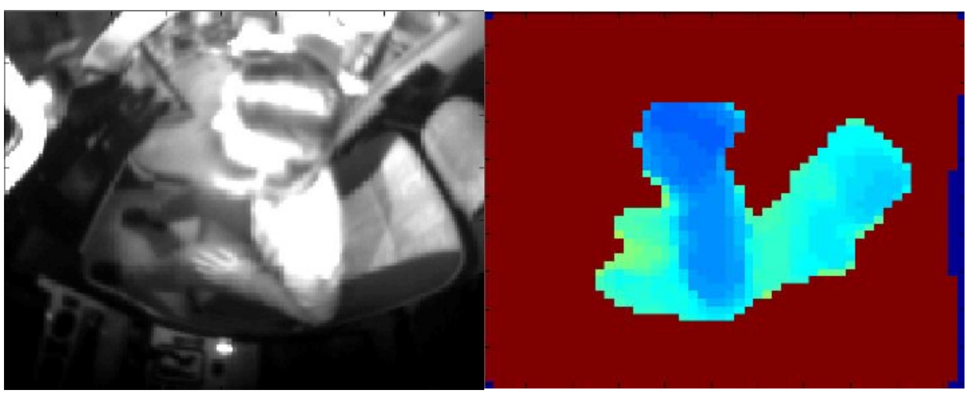

Figure 4-6. Adult Passenger (Left) and Distance Map (Right).

Researchers at Canesta have also developed a TOF imager that determines distances from the phase delays between original and reflected NIR signals.[39] The imager incorporates a bandpass filter and noise reduction algorithms to minimize artifacts caused by ambient light. In limited testing the system correctly classified over 98 percent of vehicle occupants.

DaimlerChrysler and Conti Temic are also developing a TOF imaging system that functions similarly to the IEE system.[40]

Telematics for In-Vehicle Occupancy Verification

Any in-vehicle system will require some means of communicating occupancy information to a roadside reader. There also needs to be a way to retrieve occupancy information from the advanced airbag system (AAS). By far the biggest unanswered technical question for in-vehicle occupancy detection systems is whether the information used by the airbag system to classify occupants can be easily retrieved for enforcement purposes. Such retrieval capability would at the very least require access to certain AAS data parameters through a data or test port; in particular, data pertaining to the class of occupants (child, adult, etc.) are needed.

Unless extraordinary measures are taken, most likely at the state legislative level, to mandate disclosure and access to the required data, a "piggyback" AVOV application based on the capabilities of advanced airbag systems will not be possible in the near term. This conclusion stems from both public and non-public reasons:

- The transmission of AAS occupancy information to external monitoring equipment is viewed as a severe threat to privacy; this view is shared across a broad coalition of government, industry, and advocacy groups. Equipment manufacturers and the government agencies overseeing motor vehicle safety standards are highly sensitive to public transmission of AAS data; they are concerned that public acceptance of the technology would be severely undermined if this capability existed.
- Automotive manufacturers are further opposed to allowing "piggyback" access to AAS data on liability grounds. The long-term performance of proposed advanced airbag systems has yet to be determined. While manufacturers will be able to implement systems that comply with federal safety standards, it is not precisely known to what degree the performance of AAS will degrade over time. This presents a big difficulty for any "piggyback" AVOV system since it provides a means to directly monitor the accuracy of the AAS. Manufacturers are extremely reluctant to allow third-party access to AAS parameters for liability reasons since a demonstrated degradation of AAS performance would necessarily expose manufacturers to the possibility of large-scale safety recalls.
- As occupancy monitoring is not considered a safety issue, it is very unlikely that AVOV applications could simply be mandated by regulatory action. Instead, legislative action at the state or federal level would be required.

Over the longer term, VII technologies such as dedicated short-range communications (DSRC) will eventually provide a high-speed data link between vehicles and roadside infrastructure. The VII vision is a nationwide system that integrates vehicles, and users within those vehicles, with the transportation infrastructure. Public and private entities involved in providing VII services are also connected to and interact with the VII network.

Successful deployment of the VII System not only requires significant development and deployment of a new nationwide network, but collaboration of federal, state, and local government and a wide range of business interests within the vehicle community as well. The USDOT is currently collaborating with a large and diverse group of interested parties toward conducting a VII System proof-of-concept demonstration scheduled for the Detroit area in 2007. Safety, mobility, and commerce applications will be demonstrated and evaluated, and the results will be included as part of a 2008 funding decision for VII nationwide deployment.

The national VII System is comprised of three main components, as illustrated in Figure 4-7:

- **Onboard equipment (OBE)**—a processing and communications platform, resident on VII-equipped vehicles, that provides an interface with the driver, an interface with vehicle systems, position sensing using the global positioning system (GPS), and radio communications using a portion of the spectrum (DSRC) specifically authorized by the FCC for VII purposes.
- **Roadside equipment (RSE)**—equipment positioned along highways, at traffic intersections, and at other locations, which includes DSRC communications functions, optional connection to a local safety system (including the traffic signal controller), and a connection to the VII network.
- **VII network**—the national network that connects to all RSEs and to computers that host VII applications.

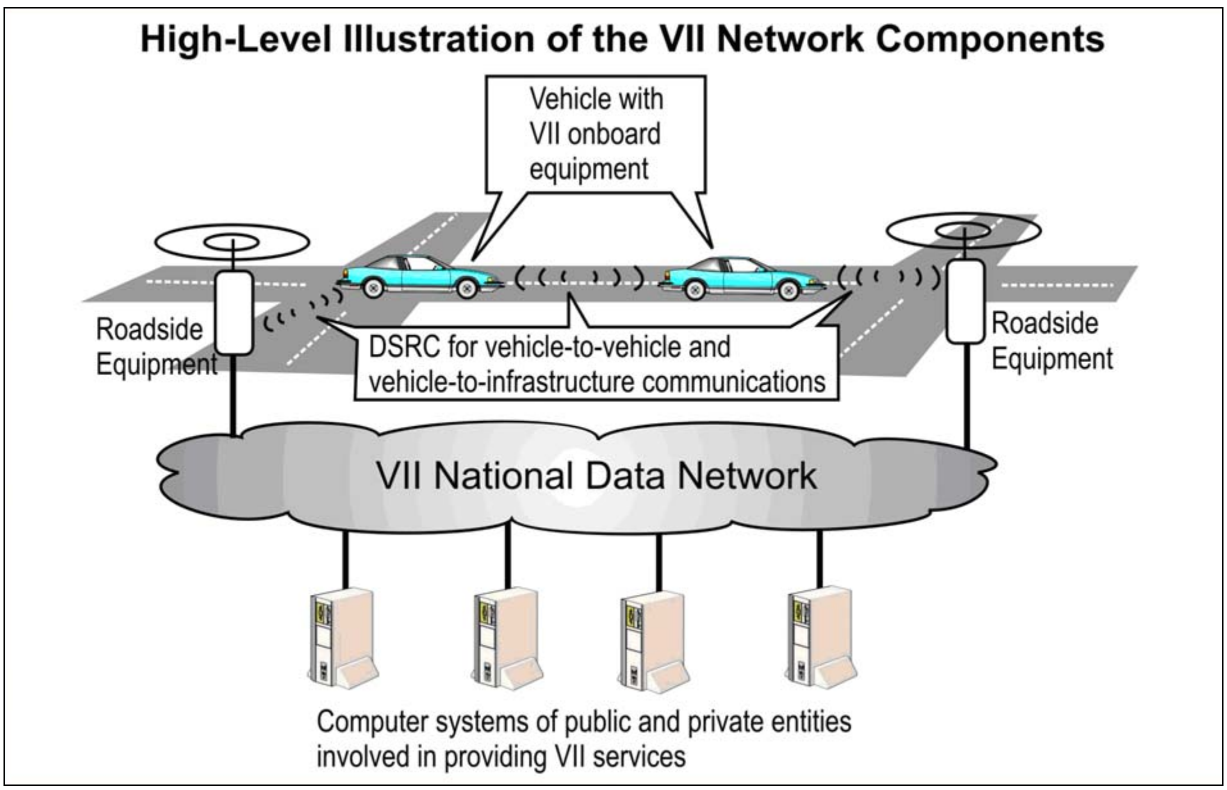

Figure 4-7. Vehicle Infrastructure Integration System Concept.

VII System network users include a variety of organizations that support vehicle operations. These will include state and local departments of transportation (DOTs), vehicle original equipment manufacturers (OEMs), vehicle fleet owners, and response agencies as well as planning organizations interested in monitoring traffic and roadway conditions. It is expected that vendors could use in-vehicle messages to advertise nearby services.

The VII System would appear to be a nearly ideal system for transmittal of vehicle passenger data to traffic management systems because it is designed to collect data from onboard sensors and communicate it to organizations that process and use the data for safety, mobility, and commercial uses.

Technical and Policy-Related Obstacles

The main technical issue for "piggyback" systems is the interface to the AAS. A "plug-and-play" interface is essentially required, whereby the 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 FMVSS require AAS to determine correct airbag deployment for five types of seat occupants (50th percentile adult male and 5th 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 schema 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.

For a "plug-and-play" AVOV system to be feasible, manufacturers would need to modify the existing AAS to include this capability. This would necessitate the development of a standardized parameter set that could be seen by an end-user application (AVOV), and additional circuitry to drive the communications interface. Given the critical safety role of AAS, aftermarket "hacks" should be avoided since they do not include design input from the OEM and may therefore adversely affect AAS operation or long-term reliability.

Fundamental policy issues exist that will, at best, be serious obstacles and, at worst, prevent VII for use for this purpose. First, a fundamental tenant of VII development is that it will not be used for enforcement. It is expected that the traveling public will completely reject the implementation and deployment of VII if it is used by enforcement agencies to identify and act against errant drivers. For one example, current VII planning will prevent its use to notify enforcement agencies of an accident or air bag deployment, in order to protect the privacy of drivers who do not wish to report their involvement in an accident. Secondly, maintaining personal privacy is a paramount requirement of VII development. A number of measures are being taken to maintain anonymity of vehicles and drivers and to prevent specific vehicles from being tracked.

This said, for commercial applications, and possibly for some public applications, drivers may subscribe to VII services for which they share relevant private information, such as credit card data. Extensive security protocols are envisioned for VII to support exchange of such sensitive data. Under this scenario, the driver must "opt in" and actively agree to share information. While policy, enforcement, and legal issues must be addressed, it would be technically feasible to develop an HOV "subscriber" application such that in exchange for occupancy information, drivers would be permitted to utilize HOV/HOT facilities and accrue the benefits provided to carpoolers.

Key Challenges for In-Vehicle Systems

The near-term implementation of in-vehicle occupancy detection systems faces several obstacles.

Accuracy and Reliability

Most systems under development are being designed to satisfy motor vehicle safety requirements of 100 percent accuracy for static testing of different-sized occupants in the front seats. This is a high standard of accuracy which no systems have yet been shown to have achieved. Furthermore, the long-term performance of proposed advanced airbag systems has yet to be determined.

Rear-Occupant Detection Capability

All current occupancy detection systems are being developed exclusively for front passengers. While the classification of rear occupants may eventually occur, it is not a near-term federal requirement and will depend on whether rear side-curtain airbag systems become commonplace.

Most of the technologies that are likely to be employed for rear occupants will primarily be concerned with occupant position (to mitigate potential injury to an out-of-position occupant's head, for example). Promising technologies for this application include electric field sensors, which are relatively inexpensive and can be incorporated into vehicle seatbacks. These sensors could not be easily added as an aftermarket item, however, because they would at minimum require the disassembly of the rear seat. Monocular vision sensors and TOF sensors could also provide rear-seat coverage but only if additional sensors were added in the rear headliner of a vehicle.

Communications Integration

While no substantial technical issues preclude "piggyback" systems for in-vehicle occupancy monitoring, privacy and liability concerns effectively rule these systems out. The transmission of occupancy information to roadside infrastructure effectively depends on the development of an "opt-in" commercial application within the framework of the VII network. However, the essential business model for VII commercial services is as yet undefined, and the implementation of consensual occupancy verification applications within the DSRC framework will depend on effective advocacy by stakeholders.

Retrofit Feasibility and Costs

It is doubtful that any of the in-vehicle systems being developed can be easily or cost-effectively retrofitted into older vehicles. All in-vehicle systems are designed to be integrated into the airbag control module, and require custom programming to communicate and operate with existing restraint systems.

Market Penetration

Assuming the above communications questions could be adequately addressed, it will still be many years before the majority of vehicles on the road come equipped with in-vehicle systems. It is doubtful that older vehicles could economically be retrofitted for this capability, unless OEM systems can be readily adapted for very low per-vehicle costs. It is therefore likely that in-vehicle–based systems can only be used as a supplementary enforcement tool over the near term.

Technology Trends and Outlook

Potentially the most cost-effective approach to in-vehicle occupancy detection involves leveraging the capabilities of advanced airbag systems. Current federal regulations will require 100 percent of new vehicles to have advanced airbag systems by 2009. These systems must be capable of reliably detecting and classifying front-seat occupants. It is likely that cushion-based weight sensors, in conjunction with NIR optical sensors or electric field sensors, will predominate in such systems. Some examples of systems in or near production include the following:

- Siemens and IEE are developing a system utilizing seat pressure sensors and a 3D TOF monocular camera. Similar systems are also being developed by TRW and ACV, Daimler Chrysler and Conti TEMIC, Robert Bosch, and Delphi Automotive.
- Elesys (jointly owned by Honda and NEC) has a system that uses pressure sensors in the seat cushion and electric field sensors in seatbacks.

In addition, as rear side-cushion airbags become more prevalent, occupant position sensors are increasingly likely to be incorporated into rear seatbacks. Electric field sensors seem the most likely candidate for this application, with small form factor optical sensors being the next suitable alternative. It is therefore conceivable that over the next decade, most vehicles will include systems that can detect both front and rear passengers.

CHAPTER 5
LEGAL AND PRIVACY CONSIDERATIONS

- *What are the legal and privacy concerns associated with AVOV?*
- *What are similar applications of automated enforcement, and how have they been addressed from a privacy perspective?*
- *What are ways that privacy concerns can be addressed for AVOV?*

Overview

Putting aside the issue of technical capability, statutory and policy authority to deploy automated vehicle occupancy verification technologies may be obstructed in many states. Although no state or community has expressly received or been denied the authority to use AVOV, precedent for automated vehicular enforcement technologies has been set in some locations. For HOV facilities, occupancy violations are typically designated "moving violations" and in many states result in assessment of points on the driving record. On the other hand, enforcement for toll evasion is not considered a moving violation in the same sense as a traditional HOV violation, but rather an infraction regarded as "theft of service" that impacts the financial viability of the facility. In viewing the statutory framework, legal concerns, and privacy considerations, there are distinct differences between automated enforcement of moving violations versus automated enforcement of infractions like toll evasion.

As of the date of this report, the primary form of automated enforcement technology currently employed in the United States is photographic imagery recorded by automated violation detection systems. For moving violations, these systems almost exclusively take the form of *red light* enforcement at intersections and *speed* enforcement (either fixed or mobile). Principal objections to automated enforcement have involved privacy and due process concerns.

As an automated enforcement tool, an AVOV system under the traditional HOV enforcement regime would likely face the same legal and privacy challenges as automated enforcement cameras and similar devices. Therefore, this chapter gives a description of current legislation related to automated enforcement practices as well as an illustration of the arguments against their use. These arguments raise questions about the legality of automated enforcement systems and the perceived invasion of privacy some drivers may associate with such systems.

Statutory Framework

As of October 2006, 21 states and the District of Columbia have passed legislation regarding the operation of automated enforcement cameras for the purpose of detecting speed and/or red light violations.[41] These laws generally include provisions allowing enforcement agencies to cite the registered vehicle owners by mail. Some states, such as Arkansas and Utah, require that an officer be present at the time that the citation is issued. State legislatures in New Jersey, West Virginia, and Wisconsin have banned the use of automated photo enforcement for any purpose. These and other differences in automated enforcement laws are summarized below in Table 5-1. Violators issued citations by existing enforcement systems are generally not penalized with a moving violation, thereby placing much less importance on the ability of the enforcement system to recognize the driver.

Table 5-1. Summary of Automated Enforcement Laws by State.

	Category	Number of States
States with no automated enforcement	No specific state statute	21
	Photo radar prohibited entirely	3
	Photo radar only under conditions*	3
	Automated enforcement prohibited (except toll facilities)	1
	Subtotal	28
States with automated enforcement	No specific state statute	9
	Statewide automated enforcement	10
	Jurisdictions or municipalities within a state having automated enforcement	4
	Subtotal	23
Total		**51**

*Conditions include requiring that photo radar only be employed in school zones or railroad crossings, or when an officer is present.
Note: Totals include the District of Columbia.
Source: Insurance Institute for Highway Safety and Florida Department of Transportation

There are currently two approaches that have been implemented by state governments with regard to the implementation and operation of automated enforcement systems.[42]

One approach places the responsibility of the recorded violation on the driver of the vehicle. Therefore, cameras must be positioned so that a frontal view of the vehicle and driver are recorded. The photograph of the driver must also be of sufficient quality so as to clearly determine the identity of the driver. Of the 18 states that have adopted legislation permitting the use of automated enforcement cameras, Arizona, California, Colorado, and Illinois require that photographic evidence of the driver be obtained. The San Francisco red light running program photographs the driver and matches the image to a driver's license photograph. A citation in this case, which carries the same penalty as if it had been issued by an officer, can only be issued if both photos show the same individual.[43]

Another approach is to hold the registered owner of the vehicle responsible for violations recorded by enforcement cameras, thereby only requiring enforcement cameras to capture photographic evidence of the vehicle's license plate. It is much less important for an automated enforcement system to identify the driver when the penalty associated with the violation is not the same as a traditional moving violation; therefore, citations issued in this manner typically carry a standard maximum fine and do not assess points on the driver's record or count as a moving violation. However, the difference in penalties between a violation caught on camera and one witnessed by a police officer is the source of some opposition, as will be discussed later.

Toll evasion is typically punishable as an infraction, not as a moving violation. Although there are inconsistencies in the use of the term "moving violation," most use the term only to refer to a violation that assesses points on the driver's record. The important distinction to make between toll evasion versus red light or speed violation is that toll evasion penalties do not assess points on the driver's record (Florida is the only state where a statute mentions the assessment of points for toll violation). Red light runners and speeders pose a risk to public safety, whereas toll evaders only pose a risk to the financial security of the toll facility. But does this explain why photographic evidence used to track down toll evaders is less controversial than red light/speed cameras?

There is less controversy due to the simple fact that the penalty associated with toll violation is the same whether it is issued by an officer or caught on camera. Tickets issued by red light/speed cameras carry a significantly lower penalty than when issued by an officer, and are therefore often viewed as revenue generators rather than devices to ensure public safety. On the other hand, toll violations involve some level of choice in both use and compliance with the requirements of the facility.

Legal Issues

The constitutionality of automated enforcement has been challenged many times, but in all cases, the government has been upheld.[44]

Opponents of automated enforcement programs often claim that the use of camera technology constitutes an invasion of privacy and is an affront to rights guaranteed by the U.S. Constitution. However, every court that has reviewed automated enforcement practices has upheld the legality of using camera technology to photograph and cite traffic violators. Numerous state courts, as well as the U.S. Ninth Circuit Court of Appeals, have rejected various challenges to the constitutionality of automated enforcement programs.

Opponents of automated enforcement strategies often argue that owners are presumed guilty when issued a citation. However, the counter-argument suggests citations issued by photo enforcement systems merely serve as a summons and therefore do not attach a presumption of guilt.[45] Current laws typically state that photographic evidence captured by automated enforcement systems is sufficient to issue a citation to the registered owner of the vehicle. In this way, the photograph serves as prima facie evidence that the owner was operating the vehicle at the time of the offense. However, such evidence may be rebutted by the presentation of any competent evidence that the charged person was not the driver of the vehicle at the time the violation occurred. The registered owner may present a defense in person or, in some states, can simply submit an affidavit stating under oath that he or she was not the driver at the time of the offense. Other states require that the owner identify the driver to rebut the citation.

Although the decriminalization of traffic violations captured on camera allows jurisdictions to issue citations by mail, it has also been the source of opposition. Critics often argue that automated enforcement is in conflict with the equal protection clause of the Fourteenth Amendment because punishments differ between a ticket issued by an automated system and an officer who witnesses the violation.[46] The traditional penalty for speeding or red light running is a criminal misdemeanor whereby points are assessed on the violator's driving record. The penalty for these same violations recorded by an automated system carries only a fine.

The increasing decriminalization of traffic tickets may also cause public favor of automated enforcement programs to drop because of the increased perception that such programs are intended to serve as revenue generators and not deterrents. However, the typical penalty for driving in an under-occupied vehicle in an HOV lane is usually just a fine, so a citation issued as a result of being detected by an AVOV system would be the same as if the citation had been issued by an officer. Therefore, this same argument may not be a source of opposition for AVOV technology.

Privacy Concerns

The U.S. Supreme Court has clearly ruled that there is a lesser expectation of privacy while operating a motor vehicle than in other venues. However, many people have a perception of privacy while in their vehicles and feel they are giving up this privacy if they drive in an area employing automated enforcement strategies. Many opponents believe that the use of automated enforcement programs is analogous to "Big Brother" tracking the actions of drivers. Therefore, it is not unreasonable to assume that an automated system for the purpose of verifying vehicle occupancy will face various privacy concerns.

Privacy concerns (or perceptions thereof) may be mitigated by employing enforcement techniques that the public will view as the least invasive. For example, an AVOV system employing a seat-sensor device, which is incapable of identifying passengers, may face less opposition than a system involving onboard photography or any other kind of device identifying individuals within a vehicle. However, a system that is not able to identify the driver will likely place limitations on the severity of the penalty that can be assessed against the registered owner of the vehicle.

Besides the identification of vehicle passengers, other privacy concerns have arisen in response to the concept of AVOV systems. Table 5-2 illustrates the types of privacy concerns that may be raised with both camera and toll transponder enforcement. Some members of the public have expressed concern that insurance companies will have access to the information obtained by AVOV systems, with differential impacts upon insurance rates. For example, a driver whose photo shows a less-than-ideal driving behavior (such as talking on a cell phone or eating in the car) may be cause for the insurance company to increase the driver's premiums. As another example, commuters who may travel long distances on corridors employing AVOV technology will likely have information collected at multiple locations. In this way, the system may serve as a means to track vehicles, and this information could be used to determine the driver's travel patterns, which insurance companies could use to determine premiums. Finally, an AVOV system that is somehow coupled with the vehicle's seatbelt sensors will be able to ascertain information on seatbelt use.

Table 5-2. Summary of Privacy Threats (Adapted from 47).

Risk	Cameras	Toll Transponders
Insurance company raises rates	☑	☑
Insurance company drops coverage	☑	☒
Location data sold to marketing company	☒	☑
Increased risk of criminal charges	☑	☑
Increased risk of tickets and fines	☑	☑
Data used in divorce proceedings	☑	☑
Parental surveillance of teens	☒	☑
Government surveillance and data mining	☑	☑

Resolving Concerns

Privacy for automated enforcement is not significantly different from other areas where privacy guidelines have been formulated. The principles below apply[47]:

- **Collection limitation**—Do not collect more data than needed for the primary purpose.

- **Data quality**—Be clear on what level of accuracy to expect from tools.
- **Purpose specification**—State what the data are used for.
- **Use limitation**—Do not use data for new purposes without consent.
- **Security safeguards**—Keep data safe and secure, and only keep what is needed.
- **Openness**—Tell people when data are collected and what they will be used for.
- **Individual participation**—Let people correct faulty data.
- **Accountability**—Be proactive in supporting these principles.

Based on the information presented in this chapter, there are three primary privacy issues associated with an AVOV system for HOV enforcement. Those issues are presented below, accompanied by approaches for potentially resolving privacy concerns.

Photographic Record of Occupants

The overriding issue of concern to the public is the capture of images representing the inside of the vehicle and how that might be used for other purposes. In-vehicle data captured through AAS that do not produce photographic images may be more palatable to the public because they cannot specifically identify individual features and behavior. Whichever system develops over time, either roadside or in-vehicle, the principles outlined above will need to guide the use and storage of automated enforcement data.

VII Barriers

A fundamental tenant of VII development is that it will not be used for enforcement due to privacy concerns. Current VII planning will prevent its use to notify enforcement agencies of an accident or air bag deployment, in order to protect the privacy of drivers who do not wish to report their involvement in an accident. A number of measures are being taken by manufacturers to maintain anonymity of vehicles and drivers and to prevent specific vehicles from being tracked.

This hurdle can be addressed by a driver "opt-in" approach where the motorist actively agrees to share information. Nevertheless, there will be a need for HOV stakeholder engagement in the VII process to move forward with an in-vehicle application that addresses VII and manufacturer concerns.

Legal Definition of HOV Infraction

HOV infractions are typically defined as moving violations although they do not have the same impact on safety as do most moving violations. Alternatively, the nature of toll evasion infractions, which seem to be less controversial with the public when enforced by automated methods, constitutes a "theft of service" and carries different penalties for violation. HOV occupancy requirement violations could be considered a theft of "level of service" since they threaten the operational qualities of the facility.

The statutory, legal, and enforcement framework under which HOV lanes developed over time logically pointed to defining an occupancy violation as a moving violation since there was not a premise for a "theft-of-service" approach and no prevailing adjudication method to handle violations as such. However, as more HOVs are adapted to HOT operation, and as new HOT lanes are developed, the opportunity exists to modify the way occupancy violations are legally defined. This supports the premise of "choice" and the prospect to waive privacy rights if a choice is made to use the HOV/HOT lane and receive the associated benefits.

The Role of Public Education

Public education and awareness are crucial to the success of automated enforcement programs. Favorable public opinion can be the difference between a successful and unsuccessful program. Successful red light and speed camera programs are often attributable to thorough public awareness and education campaigns. An outreach campaign for an AVOV system should incorporate the following elements that address the basic principles of data privacy:

- clear description of the operation of the AVOV equipment in non-technical terms,
- clear statement of the program objectives,
- description of the advantages of automated enforcement,
- explanation of other measures being taken to combat violators, and
- description of the use of the AVOV data and program revenues.

Public outreach efforts should begin before implementation of automated enforcement and continue even after the system is fully operational. An ongoing public awareness campaign is needed to assure the public that the enforcement program is proceeding in the most effective and fair manner. A practical field demonstration of a system, potentially using automated technologies as an aid to law enforcement officers, could provide public comfort and support stakeholder arguments for in-vehicle implementation.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

- *Where do we go from here?*

Considered purely on a technical level, there are no insurmountable obstacles to the development of automatic vehicle occupancy verification systems, both for the in-vehicle approach and the roadside approach.

With respect to roadside systems, a solution to the longstanding problem of cabin penetration has been demonstrably solved by researchers on the Minnesota Guidestar project. Differential infrared imaging can be used to isolate the human skin signature from other details in the vehicle cabin. This technique is usable under all lighting conditions and is able to penetrate all forms of vehicle window tint. The chief obstacle to this approach is the high cost of the necessary imaging cameras. While advances in semiconductor manufacturing are gradually making these cameras more affordable, the cost for a pair of cameras capable of imaging for this application is still $150,000.[48]

Similarly, federally mandated occupancy classification accuracy requirements for advanced airbag systems (100 percent accuracy in static testing) are driving the development of systems that will be more than sufficient for occupancy verification applications. Here again, cost plays an important consideration since virtually no vehicles will be able to be economically retrofitted. A system of vehicle occupancy verification based on in-vehicle sensing will therefore not be viable until the vast majority of vehicles incorporate advanced airbag systems. Assuming median age and median lifetimes of 9.2 years and 16.9 years, respectively, for passenger automobiles, it could take anywhere from 2017 to as late as 2025 until 50 percent penetration is achieved.[49] More probably, market penetration in the metropolitan areas served by managed lanes facilities will occur more quickly since the auto emission testing programs in most of these areas will likely accelerate the replacement of older vehicles.

Over the longer term, the eventual deployment of the VII System promises to render AVOV to a subscriber-based software application running on the VII network. For a VII-based AVOV application to occur, however, a strong case must be made to the appropriate standards committees for the inclusion of such a capability, and the development of a viable VII business model should be encouraged. Currently, VII equipment is expected to be standard equipment beginning with the 2020 model year. Table 6-1 describes the estimated timeline for deployment of advanced airbag systems and VII infrastructure. As shown in the table, near full deployment of VII infrastructure is not expected until 2035.[50] It is also apparent that a VII-based AVOV system, which depends on the near universal prevalence of suitably equipped vehicles and VII infrastructure, cannot be reasonably implemented for at least another 25 years.

Table 6-1. Advanced Airbag Systems and Vehicle Infrastructure Integration Deployment Timeline.

Year (Targeted)	Year (Conservative Estimate)	Event
2009	2009	Advanced airbag systems for front passengers become standard in all new passenger vehicles.
2010	2010	Side-curtain airbags for all passengers become standard in all new passenger vehicles.
2012	2014	VII infrastructure is deployed to a sufficient level for automotive companies to start outfitting vehicles with DSRC transceivers.
2015	2025	AAS-equipped vehicles account for 50 percent of all passenger vehicles on the road.
2018	2025	Sufficient VII infrastructure is deployed so that drivers of new vehicles do not experience uncomfortable gaps in VII services based on the location of their travel.
2020	2025	DSRC transceivers become standard in all new passenger vehicles.
2035	2050	Close to full roadside deployment of DSRC occurs across the United States. Full roadside deployment includes the entire interstate system, all paved state highways, and all paved local roads that have traffic signals in the vicinity.
2028	2035	DSRC-equipped vehicles account for 50 percent of all passenger vehicles on the road.

The following phased action plan is based on this study:

1. **Near term (2–5 years).** If automatic vehicle occupancy detection is desired within a near-term timeframe, the only viable option is the development of roadside systems. It may be that the high cost of the necessary components for such systems can be justified given the growing market of HOT lane projects, which offer a financial argument for HOV compliance. Until reliability is improved, roadside systems could be used as an enforcement tool to assist officers in identifying potential violators, without many of the legal issues associated with automated enforcement. At the same time, HOV/HOT lane stakeholders should play an active role in the development of VII standards for subscriber AVOV applications.
2. **Intermediate term (5–15 years).** Once roadside AVOV systems are successfully demonstrated, legislation is needed to permit their operation on HOV/HOT facilities. Progress should also continue in developing in-vehicle applications for occupancy verification and the public acceptance issues associated with them.
3. **Long term (20–30 years).** The long-term scenario for AVOV is roll-out of VII-based in-vehicle systems for occupancy verification, provided the social impediments are resolved. Public resistance will be the most difficult challenge.

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