I-15 Managed Lanes

Task 2.2.2
Enforcement Concepts and Technologies Report

March 3, 2006
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1.0 INTRODUCTION

The purpose of this *Enforcement Concepts and Technologies* report is to identify technologies and methods that could be used in the development of advanced vehicle occupancy detection for the Managed Lanes (ML) project on Interstate 15 (I-15) in the City and County of San Diego, California. The term managed lanes can be applied to any freeway facility that increases freeway throughput and adds flexibility to the facility’s operations by combining various operational and design considerations. Managed lane operations may be adjusted at any time to better match goals for the most efficient operation of the facility. Similarly, road user charging allow users to travel on a designated roadway for a fee. On the I-15 ML, both concepts are being combined and single-occupant vehicle (SOV) users will be charged a fee that is collected electronically at highway speeds in a multi-lane free-flow environment.

The current plan for I-15 is that tolls will be collected by obtaining usage data at multiple tolling points located on the ML roadway through the use of existing transponder and reader radio communications, whereby windshield mounted transponders are interrogated by a reader that is positioned on a gantry overhead each lane. Toll transactional data is then forwarded to the central toll collection system for processing. In the case of the existing I-15 reversible express lanes, high occupancy vehicles (HOVs) may travel for free and are not required to mount a transponder in the vehicle. HOVs are currently defined as those vehicles with two or more occupants.

The I-15 ML project will expand an existing two-lane reversible express lanes facility, with single entry and exit points at each end of an eight mile segment, to four bi-directional lanes over 20 miles in length and containing multiple intermediate access locations. These new features will make toll payment and in particular, HOV enforcement, more complex, increasing the importance of a reliable violation enforcement system (VES).

This report addresses the question of occupancy enforcement concepts and technologies. In a subsequent report, *Enforcement Strategy Analysis*, feasible occupancy enforcement technologies identified in this report will be further analyzed and combined with specific policies and procedures and the planned toll enforcement system to provide comprehensive alternative enforcement strategies for implementation on the I-15 ML Project. These strategies will be analyzed and, following a limited field test deployment, a recommended alternative may be selected for inclusion on the I-15 ML Project.

The balance of this report is divided into the following sections:

**Section 2: ENFORCEMENT TECHNOLOGY AND ISSUES ON THE I-15 ML:** A discussion of the current enforcement situation, planned changes with the ML project that will affect ML violation enforcement and high level requirements for a ML enforcement system.

**Section 3: AVAILABLE TECHNOLOGIES AND METHODS:** Identifies current and emerging methods and technologies that could be used in ML violation enforcement.
Section 4: TECHNOLOGY OPTIONS ANALYSIS: Briefly reviews technology options and places each option in a strategy package, with the goal of identifying emerging strategies for review in the next report, *Enforcement Strategy Analysis*.

Section 5: FINDINGS AND RECOMMENDATIONS: Provides findings and recommendations, including next steps.

2.0 ENFORCEMENT CONCEPTS AND ISSUES ON THE I-15 ML

2.1 Current Enforcement Situation

The current enforcement program for FasTrak™ on the I-15 reversible lanes relies on a combination of routine and special enforcement by the California Highway Patrol (CHP). Current policy requires that a single occupancy vehicle (SOV) traveling in the I-15 reversible lanes must render a per-trip payment using a valid transponder. HOV users are not required to use a transponder or pay a toll. A gantry mounted indicator light above the two tolling points indicates when a valid transponder has been read. Routine enforcement is performed by the CHP through the use of head counts to verify occupancy. This enforcement takes place in a single enforcement zone which is also the sole tolling point (toll zone) on the facility. The enforcement zone/toll zone is located approximately two miles to the north of the southern terminus of the Lanes, between the Miramar Way and Miramar Road over-crossings.

In the case of special enforcement, if an enforcement officer sees that no indicator light has flashed and the vehicle at the tolling point appears to be single-occupied, the vehicle can be stopped for violation checking and enforcement. Alternatively, if the enforcement officer sees that a SOV vehicle is traveling in the reversible lanes without a transponder mounted, the officer can pull the vehicle over for a possible citation. The system has a wider enforcement shoulder on the inside of the concrete barrier that separates the reversible lanes from the general purpose I-15 lanes, to allow an enforcement vehicle to park adjacent to either reversible express lane, making enforcement vehicles visible, safer and providing easy enforcement access. Additionally, in 2005 SANDAG issued portable cell phones with DirectConnect to the Customer Service Center (CSC) that allow the officer to radio in a motorist’s transponder information to determine when the last valid payment was received. This has added technical capacity for helping an officer discern when a motorist has violated.

Periodic violation rate surveys and manual vehicle occupancy counts on I-15 have reported that initial manual enforcement presence resulted in a decrease in violation rates from approximately 15 percent to as low as five percent, although that number has fluctuated since the FasTrak program began in 1998 and have recently been closer to 15 percent of the total average daily traffic on the reversible lanes. This evidence seems to support the theory that while heavy enforcement presence may produce positive results in terms of lowered overall violation rates; those results are difficult to sustain in the absence of the enforcement officer or a more automated violation detection and enforcement system.
2.2 Planned Changes with the Managed Lanes Project

Table 1 presents the salient enforcement features and methods of the current I-15 reversible lanes FasTrak™ enforcement program and how they compare to the planned ML project. The purpose of the comparison is to identify how planned changes to the current system may affect the need and applicability of technology considered for the new ML Project:

<table>
<thead>
<tr>
<th>Item</th>
<th>Current 1-15 Reversible Lanes</th>
<th>Expanded I-15 ML Project</th>
</tr>
</thead>
<tbody>
<tr>
<td># Lanes</td>
<td>2 reversible</td>
<td>4 bi-directional w/ moveable median barrier</td>
</tr>
<tr>
<td>System Length</td>
<td>8 miles</td>
<td>20 miles</td>
</tr>
<tr>
<td>Enforcement Shoulder</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Enforcement Envelopes</td>
<td>No-have shoulders</td>
<td>On direct access ramps (DARs) only</td>
</tr>
<tr>
<td>Access/ Egress Points</td>
<td>Two-at terminus points</td>
<td>20 – Three DARs, three for BRTs and 14 slip lanes</td>
</tr>
<tr>
<td>HOVs required to carry Transponders</td>
<td>Not required</td>
<td>Possible-Being considered in this technology review</td>
</tr>
<tr>
<td>Overhead Indicator For Valid Transponder</td>
<td>Yes</td>
<td>Possible-Being considered in this technology review</td>
</tr>
<tr>
<td>V-Tolling in Place</td>
<td>No</td>
<td>Possible- Being considered in this technology review</td>
</tr>
<tr>
<td>Automated HOV Enforcement</td>
<td>No</td>
<td>Possible use of a number of automated technologies to assist in enforcement being considered in this technology review</td>
</tr>
<tr>
<td>Violation Citation</td>
<td>Manual on-site</td>
<td>Possible automation being considered in this technology review</td>
</tr>
<tr>
<td>Violator Fine</td>
<td>Yes-$341-moving violation, first offense</td>
<td>Possible changes to legislation and fines</td>
</tr>
<tr>
<td>Channelization of HOV</td>
<td>No-reversible lanes</td>
<td>No-due to Moveable median barriers</td>
</tr>
</tbody>
</table>

Table 1 shows that the planned features that must be addressed in this technology review are the added complexity of the Managed Lanes, including two additional lanes, longer length, bi-directionality and more access/egress points. All of these factors will serve to make the use of manual enforcement less effective and more costly than it is on the I-15 reversible lanes today. Some examples of these impacts are:

- The move from two to four lanes and the reduction in shoulder space means that an enforcement vehicle may not easily be adjacent to a vehicle at all times and may not be able to visually identify a violator as easily as with the I-15 reversible lanes today.
• The multiple access/egress points expand the number of points at which tolling takes place, expanding the complexity of enforcement and the cost of any equipment solutions.

• Multiple access and egress locations also mean that a vehicle may quickly enter and exit the system, making manual enforcement between individual access/egress points more difficult.

• The new tolling locations do not have sufficient shoulder space to park an enforcement vehicle and observe the validity of a transponder read.

• HOV lanes cannot be physically separated from the SOV lanes at the toll points, relying on any implemented enforcement technology to compensate for the lack of physical separation.

• A small portion of the 20 mile ML project will not have physical barrier separation from the general purpose lanes, relying instead on a double-yellow striped buffer separation. In the areas where buffered lanes exist, the need for violation enforcement will likely be more critical.

2.3 I-15 ML Managed Lanes Technology Needs and High Level Requirements

The basic high-level technical requirements for this system identified thus far are:

1. Reduce and then maintain the HOV violation rate to less than five percent.

2. Reduce/eliminate the need for visual checks of the occupancy of the vehicle.

3. Reduce/eliminate the need for a visual check of the presence of a transponder mounted in the vehicle.

4. Cover the entire length of the 20 mile roadway, with possibility of expansion to additional roadways.

5. Be feasible from the standpoint of technical and legislative limitations, e.g., compatible with existing State of California Title 21 specifications for automatic vehicle identification (AVI), or have sound requirements that merit the possible modification of that standard (whether through legislation or administrative law).

6. Perform successfully in a four lane environment with concurrent flow and a moveable barrier.

7. Avoid the need for physically separated HOV and SOV lanes at the tolling points.

8. Integrate to portions of the current reversible lanes tolling system as a part of the phased implementation of the project (pilot field test deployment).

9. Integrate system with the planned Managed Lanes toll system, including video tolling equipment (full implementation phase).

10. Provide a violation enforcement system that is acceptable to the public and can be easily explained and communicated.

11. Rely on technology that is proven in the managed lane/toll environment.
12. Rely on technology that is cost effective relative to the revenues it captures.
13. Rely on technology that can easily be maintained by SANDAG or a contracted vendor.
14. Rely on technology and methods that can be upheld in the legal/court process.

3.0 AVAILABLE TECHNOLOGIES AND METHODS

3.1 Section Overview

This section presents currently available and emerging toll and vehicle occupancy enforcement technologies and methods and their general applicability for use on the I-15 ML project. Each technology or method is reviewed and its pros and cons are presented. The analysis starts with the more manual methods of enforcement and moves toward those methods that rely increasingly on technology and automation. Technologies that are unproven or high risk are identified as such. The following enforcement technologies or methods are examined:

1. Manual Enforcement (3.2)
2. Enforcement Gantry Light (3.3)
3. HOV Transponder Use (3.4)
4. License Plate Enforcement (3.5)
5. Mobile Enforcement Transponder on Board Unit (3.6)
6. Mobile Enforcement Reader on Board Unit (3.7)
7. Handheld Transponder Reader (3.8)
8. Infrared Image Occupancy Detection (3.9)
9. Smart card Validating on Board Unit (3.10)
10. Occupancy Sensors (3.11)

3.2 Manual Enforcement

With completely manual vehicle occupancy enforcement, an enforcement officer traveling in a vehicle must make random stops of vehicles based upon a visual check of the presence of a transponder mounted on the windshield and the occupancy of the vehicle. The officer can be assisted either by stationary observers or another enforcement vehicle, assigned to spot for the presence of a transponder or the absence of passengers.

With a completely manual enforcement system, if an SOV is stopped by an officer and the driver presents a transponder, the officer has no way of confirming that the transponder is valid, unless the transponder number is radioed or phoned into a customer service center or to another up-to-date holder of a list of valid or invalid transponders. Additionally, the officer cannot verify if a valid transponder was actually read at the last tolling point as opposed to a customer shielding the transponder to avoid payment. Finally, the occupancy of the vehicle is often difficult to observe.
from another vehicle, given the possibility that small children or sleeping passengers may not be seen without a stop.

Most of the technologies identified in this report can be used in combination with manual enforcement. The use of an overhead mounted indicator light, such as is currently employed on the I-15 reversible lanes toll system, can significantly reduce the pool of potential violators for the CHP to check by identifying a valid transponder read in an SOV. Other technologies that can improve the efficiency of manual enforcement include the use of the mobile transponder readers and enforcement transponders, both located in enforcement vehicles. These technologies and others further described below, allow the enforcement officer to narrow the pool of potential violators by confirming whether valid transponder reads have taken place at the last tolling point. They do not necessarily address the occupancy issue; i.e., SOV occupancy must be confirmed with a vehicle stop. Nor do they address the fact that a violation citation can only be issued manually after a vehicle stop.

**Positives of Manual Enforcement**

- Low cost to implement. There is no capital investment required. Costs include patrol officer labor, usually with some portion of the labor being set at overtime rates, and vehicle fuel and maintenance costs (often in the form of a mileage reimbursement rate).
- Presence of the enforcement vehicle alone is a deterrent to motorists to violate.
- Presence of the enforcement vehicle has other deterrent benefits such as reduction of speeding.
- Enforcement can be easily targeted and modified to meet problems and traffic conditions.

**Negatives of Manual Enforcement**

- Recurring labor costs are relatively high (approx. $60/hour) and must be rebudgeted annually. Therefore, enforcement program is subject to annual budgetary constraints and priorities.
- Use of law enforcement for violation enforcement is subject to the availability of police, based on other law enforcement priorities.
- There can be more than one law enforcement agency involved in enforcement, further complicating coordination.
- Customers can shield their transponders if they believe no enforcement vehicles are present.
- Customers can also shield their transponders and still present them when stopped by the enforcement vehicle. The officer would then have to confirm via police radio or phone that in fact a valid read had taken place.
- Depending upon the final configuration of the I-15 ML, the lack of enforcement shoulders could impact the ability to use enforcement vehicles and pull over vehicles safely.
• The current manual enforcement system is based upon HOVs not having tags mounted. The potential future transition to “sticker tags” as a cost savings would be difficult if not impossible with this system in that the tags would not be easily removed/remounted for HOV use.

3.3 Enforcement Gantry Indicator Light

The use of an indicator light to confirm a valid transponder read (and therefore payment) is a common practice in managed lanes and in toll applications in general. To be effective for HOV enforcement, the system-assisted light must be used in combination with manual enforcement.

In the case of managed lanes the indicator should be mounted above each lane on the upstream side of the gantry to allow an enforcement vehicle tailing an SOV to easily view whether the indicator light has been activated. Currently, standard green traffic lights are used to display the valid transponder read status on the I-15 reversible express lanes, although the lights can just as easily be a matrix of light emitting diodes (LEDs) (an example is the recently completed MnPASS 394 HOT Lane project). The indicator light is connected to the toll system lane controller so it is activated each time a valid transponder is read in the same lane, which then triggers a green light to flash, indicating a valid payment. MnPASS has reported that they believe that presence of the indicator light itself serves as some deterrent to violators even if no enforcement vehicles are in sight. Also, MnPASS found that some customers who observe an SOV passing through the toll lanes without the light being activated will make calls to MnPASS to report a violator even though there is no special signage set up or a dedicated phone line.1 This indicates that it might be a somewhat effective deterrent to have a special phone line advertised on signage along the I-15 ML that customers could call to report violators.

Positives of Gantry Mounted Indicator Light

• Inexpensive up-front investment in LED light for each lane with a connection to the lane controller.

• Presence of the light most likely has some deterrence effect on potential violators.

• Enforcement vehicles can narrow the pool of potential violators by tailing vehicles and verifying if a valid transponder was read in an observed SOV.

• Potential for use with signage and a phone number for customers to report violators.

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1 Teleconference with Nick Thompson, MnPASS Project Manager, 12/07/05.
Negatives of Gantry Mounted Indicator Light

- Relies on follow-up manual enforcement system to be fully effective.
- Requires that enforcement vehicle or someone monitoring vehicle occupancy be stationed near the tolling point to view the light.

3.4 HOV Transponder Use

At present HOV operators are instructed not to mount a transponder in their vehicle when using the I-15 reversible FasTrak™ lanes. This allows a class of customers to be traveling on the lanes without transponders, thus increasing the opportunity for HOV violations. HOVs could be required to use a transponder with a special HOV transponder class flagged. Alternatively an HOV switch on the transponder could be developed which would be activated by the customer when driving as an HOV. A third option is to require the HOV user to mount a standard transponder at all times and to call in advance and identify the time periods when he or she would be driving as an HOV. In this case the customer’s account would be credited by the back-end of the system for trips made in the pre-registered HOV time periods. In all three cases this would mean that no vehicles should be traveling in the lanes without a transponder and that any vehicle traveling without a valid SOV or HOV transponder would be considered a violator.

For the HOV transponder system to be effective, other enforcement methods would also have to be employed. Occupancy still must be confirmed by visual inspection to ensure that there is no abuse of the use of the HOV transponder. In addition, the gantry indicator light would also be effective, potentially with a second set of LEDs installed overhead to distinguish the valid HOV transponder from an SOV transponder. This would allow CHP to limit abuse of HOV status by stopping SOVs using HOV transponders. Violators without any transponder mounted would still need to be pursued, although enforcement would potentially be made easier because fewer vehicles should be traveling without a transponder and anyone traveling without a transponder can be presumed to be a violator. The use of video cameras at tolling points could also be an effective tool, in that the absence of a transponder could trigger a license plate image being taken and sent to the central data system for automated violation or video toll processing.

Positives of HOV Transponder Use

- Makes anyone traveling without a transponder a violator, easing enforcement target selection.
- Has relatively low upfront cost of an additional LED per lane and depending upon the approach adopted: additional transponders, the cost of developing the switch and distributing the new tags, or the cost of developing the HOV call-in program.
- Allows for automated violation processing and citations if combined with video cameras/license plate capture at tolling points. This would reduce the CHP enforcement burden.
Negatives of HOV Transponder Use

- Would require HOV users to plan ahead to either obtain an HOV transponder and mount it when traveling as an HOV, activate the HOV switch or call-in to activate HOV status and therefore places burden on customer.

- Would cause some legitimate HOV users to not use the HOT lanes, particularly those from outside of the I-15 ML area and occasional users.

- Under all scenarios increases the transponder population, thereby increasing transponder issuance, maintenance and administration costs.

- Relies on some level of manual enforcement to be effective.

3.5 License Plate Enforcement

An HOV enforcement system could be developed around the use of license plates. There are a number of possible uses of license plate monitoring with a range of automation options, outlined below:

3.5.1 License Plate HOV Registration Database

These scenarios revolve around the use of a pre-registered database for HOV users. Two basic scenarios are as follows:

a. Technology Assisted License Plate Check by Enforcement Officer: HOV users pre-register their license plates with SANDAG (or another designated governmental agency) in order to travel on the I-15 ML without a transponder. If a vehicle is visually identified by an enforcement officer as not having a transponder mounted (or if the vehicle travels through a toll point and the overhead indicator does not flash), the next step would be for the officer to verify that the vehicle was registered as an HOV. This verification could occur via a form of license plate check that is currently performed by police (with a new link to this additional database), or, it could be by means of the officer entering the license plate number into a separate unit (touch screen or voice activated) which has an up-to-date database downloaded regularly. If the license plate is not associated with a registered HOV, the vehicle can be stopped for a citation. An alternative use of this option would be if the enforcement officer sees that no overhead indicator was activated at the tolling point by a vehicle and the vehicle appears to be single-occupied and the officer then determines via license plate check that the vehicle is HOV registered. In this case the violator could be stopped, given a citation and the vehicle could also lose its HOV privileges.

Positives of Technology Assisted License Plate Check by Enforcement Officer

- Assists manual enforcement in reducing the pool of vehicles to be stopped and pre-screening potential violators.
• Registration requirement potentially reduces HOV violations in that some potential violators may be hesitant to violate if they are aware of the license plate look-up.

• Low capital investment is required, consisting primarily of software and potentially the provision of a mobile data terminal (MDT) for enforcement vehicles.

• No potential issues with future transponder technology.

Negatives of Technology Assisted License Plate Check by Enforcement Officer

• Still requires manual enforcement for occupancy verification.

• Would require HOV users to plan ahead and register their vehicle, and therefore places burden on customer.

• Would cause some legitimate HOV users to not use the ML, particularly occasional users and those from outside of the I-15 ML area who are not aware of the HOV registration. (This issue possibly could be addressed by having a statewide HOV registration program.)

• Requires agreement of some form with CHP to use the HOV database. Requires coordination with law enforcement agency to install or integrate the MDT to the HOV database.

• Additional on-going expense of cellular wireless communications between the vehicle/MDT and central system/HOV database (this could potentially be avoided if MDT receives updated data between shifts and stores the mirrored data inside of the MDT).

• May require new legislation to allow for this form of enforcement.

b. Automated License Plate Check: HOV users pre-register their license plates with SANDAG (or another designated governmental agency) in order to travel on the I-15 ML without a transponder. In this case, video enforcement cameras located at toll points would capture images of all vehicles without a valid transponder read at that tolling point. These cameras could be the same equipment used in a video tolling or toll enforcement application. A check could be made against a database of registered HOV units, either at the lane level or at a central location. If the vehicle is a registered HOV, the vehicle is assumed to be a valid HOV and the image is not retained. If no HOV registered plate is found then the vehicle would be assumed to be either an SOV with a transponder problem or a violator. This information could be acted upon in either or both of two ways: information could be set up to be conveyed to enforcement vehicles downstream via a wireless connection, or an automatic violation or V-toll notice could be sent to the registered owner of the vehicle.

If the database is connected to a mobile unit in the enforcement vehicle via a wireless connection then the enforcement vehicle could also check abuse of HOV status, as was
discussed above in option 3.5.1a. In this case the SOV using HOV status could lose the HOV privilege, in addition to being issued a citation.

The video technology for this system is proven and in operation with multiple video system vendors offering products: Numerous vendors make either visible light or infrared camera systems that would potentially meet the requirements: Among them are PULNiX, PIPs, Perceptics, CRS, SAIC and INEX. A summary table with information on these vendors and vendor product sheets are included in Appendix A. A discussion of the use of the CYCLOPS infrared camera for this type of application is also included in section 3.9.

Further issues to be resolved for this application, depending upon further development of requirements include:

• Use of infrared versus visible light technology
• Use of high resolution cameras
• Type of lighting required in association with cameras
• Integration with the planned video tolling requirements.
• Potential for and benefit of database look-up in the video camera controller
• Need for rear only or front and rear cameras.

**Positives of Automated License Plate Check**

• Significantly reduces the need for manual enforcement if all non-registered HOV with accounts receive a V-Toll and all others receive a citation.
• Allows for automated violation and citation processing (this would substantially increase the initial costs).
• Could assist manual enforcement in reducing the pool of vehicles to be stopped and pre-screening potential violators.
• Registration requirement potentially reduces HOV violations in that some potential violators may be hesitant to violate if they are aware of the license plate look-up.
• Video equipment could also be used for V-tolling for those customers traveling in the lanes without a transponder and no pre-registration of HOV and for those customers whose transponders fail to be read. This means only pre-registered HOV users would not pay a toll.
• No potential issues with future transponder technology.

**Negatives of Automated License Plate Check**

• Requires an initial upfront investment in camera systems at all tolling points.
Enforcement Concepts and Technologies

- Requires set-up of image review system, even with license plate reading (LPR) software, some manual review and intervention will be required.
- Would require HOV users to plan ahead and register their vehicle, and therefore places burden on customer.
- Would cause some legitimate HOV users to not use the ML, particularly those from outside of the I-15 ML area or occasional users, who are not aware of the HOV registration. (This issue possibly could be addressed by having a statewide HOV registration program.)
- Potentially requires agreement of some form with CHP to use the HOV database for enforcement.
- May require new legislation to allow for this form of enforcement.
- Not all images will be readable so some violators will not receive notice.
- Still requires manual enforcement for verification of occupancy.

3.5.2 Voice Activated License Plate Look-Up for Toll Paid

This system also relies on license plate look-up but in this case the look-up is for a cross-reference to the transponder associated with the license plate of the vehicle being monitored. This option was recommended for further consideration in the I-15 ML Pricing Planning Study.2

In this case the enforcement officer would speak the license plate number of the vehicle being monitored into a voice activated on-board unit (OBU) in his vehicle. This unit would have a wireless connection to the central toll processing database where license plate and transponders are cross-referenced. The enforcement officer would query the system as to the time of last transponder read and the voice recognition software in his OBU would then communicate the results to the officer. If there is no recent valid transponder read and the vehicle appears to be single occupied, the enforcement officer could stop the vehicle for a possible citation. It should be noted that this option was recommended because the mobile transponder reader units discussed below in Section 3.6, were not in use at this time (2002). As

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of this writing, no T-21 mobile units are commercially available; however, this could change if T-21 vendors are willing to develop a prototype.

**Positives of Voice Activated Plate Look-up for Toll Paid**

- Assists manual enforcement in reducing the pool of vehicles to be stopped and in pre-screening potential violators.
- Doesn’t require any pre-registration of HOV users.
- Low initial capital investment—requiring only the installation of the mobile units and related software and interface to the central processing system.

**Negatives of Voice Activated Plate Look-up for Toll Paid**

- Relies on wireless communication link with central processor for real time lane information that could potentially be gathered with a portable reader.
- Potentially requires agreement of some form with CHP to use the on-board unit.
- Still requires manual enforcement for verification of occupancy.

### 3.5.3 License Plate Image (LPR) Spotter Enforcement

On California Route 91 Express Lanes in Orange County, California, the toll plaza is lane separated for HOV\(^3\) and SOV, requiring that HOVs travel through a designated lane. Vehicles traveling through the HOV lane receive a 50 percent discount off of the undiscounted toll. The system uses infrared cameras to capture a rear license plate image for violation enforcement. SR 91 has one tolling location.

SR 91 plans to develop a semi-automated system for HOV enforcement where a spotter located in a booth near the HOV lane checks for vehicle occupancy. If the spotter sees less than three people in the vehicle, he/she presses a button on a unit in the booth which transmits a real time wireless message containing an image of the license plate and surrounding area, an image of the vehicle and transaction data. The message would be sent to a display unit that is mounted in an enforcement vehicle. The violator could then be stopped for violation enforcement.

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\(^3\) HOV on SR91 is defined as three or more passengers.
Positives of LPR Assisted Spotter Enforcement

- Targets vehicles that are known violators due to the use of spotters and the designated HOV lane.
- Has an image of the vehicle for further support of the violation process, particularly in court.

Negatives of LPR Spotter Enforcement

- For SR 91, this option offers relatively low cost incremental investment, as the video enforcement system is already in place. However, on I-15 ML the cost would be significant.
- Would be very labor intensive for I-15 ML project due to multiple tolling points, requiring multiple spotters.
- For system to be effective would require that enforcement vehicles be properly positioned to receive the image and intercept violators. Due to the planned 20 mile length of the I-15 ML, this would require multiple enforcement vehicles, thereby increasing labor costs.
- I-15 ML will not have segregated toll lanes for HOV, nor does it provide additional space for spotter “booths” near each toll point. This would require that spotters review images from a back-office location and thus the central system would need to communicate real-time remote commands (sent by spotters) along with the image data via a wireless communication link.

3.5.4 License Plate Video and Vehicle Occupancy Image

A demonstration test was performed with Dallas Area Rapid Transit (DART) and Texas DOT with Computer Recognition Systems (CRS) in 1998. The test involved the use of CRS video cameras to image both vehicle occupancy and the license plate of the same vehicle. The test involved performing optical character recognition (OCR) on the license plate images, creating a record that included both the license plate number and the number of occupants. The images were then observed on an enforcement work station and were compared to a license plate database of observed vehicles (“white list”) of HOVs. Vehicles owners could be mailed information that they are potential violators. The study found that the system required
several enhancements but that with the improvements the system could be used for mailing HOV citations, pending the passing of enabling legislation.\(^4\)

The camera systems described in 3.5.1 above, including CRS, may be appropriate for use in this system. Also see Section 3.9, Infrared Image Occupancy Identification. The alternative could be updated to use an infrared camera for occupancy detection, although all of the negatives outlined immediately below still appear to apply.

**Positives of License Plate Video and Occupancy Image Use**
- Could potentially meld vehicle occupancy imaging with license plate recognition system described in 3.5.1 for real time enforcement.
- Potentially reduces need for manual enforcement.

**Negatives of License Plate Video and Occupancy Image Use**
- Not proven in any practical highway application, thereby increasing risk.
- Potential for high initial capital costs, including separate video cameras for license plate and vehicle occupancy and software system set-up.
- Potential privacy issues with capture of occupancy image.
- May require new legislation to allow for this form of enforcement. These changes would include the use of the occupancy images as well as for the violation/v-tolling notice.
- Ability of image capture for back-seat occupancy is an issue.
- Issue of capturing images of children or sleeping passenger remains problematic.
- Issue of how to constantly update “white list”. Appears to require a high-level of manual intervention.
- Issue of cars from outside of the immediate region and not regular users. How are they treated if they are not in the white list database?

3.6 Mobile Enforcement Transponder On Board Unit

The mobile transponder unit is a standard transponder that is specially encoded to be used in enforcement vehicles that are shadowing a vehicle at a tolling point. The technology is employed by Minnesota DOT on its MNPASS I-394 HOT Lane project. The system integrator on I-394 is Raytheon and the transponder is a Telematics FP-100A. Attachment B includes a product sheet on this transponder, which has read/write capabilities. However, it should be noted this device is not currently compatible with California’s Title 21 specification which governs transponder technology in the state of California.

When a transponder is read on the leading vehicle and is then rewritten, the shadowing vehicle’s enforcement transponder also receives an audible tone indicating a valid read. The shadowing vehicle must be within three seconds of the leading vehicle (configurable parameter). The technology for the message being sent to an enforcement transponder is located in the reader, not the transponder.

On the MnPASS system approximately 60 law enforcement vehicles have the transponder mounted. These vehicles are not necessarily involved in regular or dedicated HOV enforcement but they can use the unit to check on toll violators if they are near a toll location.

MnPASS reports that this method is not used much in comparison to the other key HOV enforcement methods of manual enforcement and the mobile reader but it is a low-cost option as the transponders cost only about $25 each.5

With the T-21 transponder used on the I-15 ML, it is possible that the transponder read status signal that is currently conveyed from the reader to the transponder in the customer vehicle could also be conveyed to the shadowing enforcement vehicle. The Tag Type field could be potentially used to identify an enforcement transponder. The Title 21 specifications state… “A 4-bit field currently established to uniquely differentiate California’s transponders from transponders that originate from agencies external to the state. In the future the unassigned bits could be used to recommend a unique North American agency numbering scheme, or to further describe the operational behavior of the transponder.”

**Positives of Mobile Transponder On-Board Unit**
- Assists manual enforcement in reducing the pool of vehicles to be stopped and in pre-screening potential violators.

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5 Teleconference with Nick Thompson, MnPASS Project Manager, 12/07/05.
Enforcement Concepts and Technologies

- No significant initial capital costs as transponders are low cost ($25) and off the shelf.
- Requires no operation by the enforcement officer.
- Low risk of problems and failures.

**Negatives of Mobile Transponder On-Board Unit**
- Still requires manual enforcement and manual verification of occupancy.
- Enforcement vehicle must be immediately behind the lead vehicle and must be at the toll point for transponder to be used.
- Will require some development effort in providing the hardware and software to support the use of enforcement transponder within California T21 environment.
- Will likely require legislative changes.

**3.7 Mobile Enforcement Reader On-Board Unit**

The mobile enforcement reader is installed in an enforcement vehicle and allows an enforcement officer to check an adjacent vehicle for (1) the presence of a valid transponder and (2) the time of the last transponder read. This type of equipment is installed and in operation in three dedicated Minnesota State Police patrol vehicles on MnPASS I-394. The device (MER 915) used is produced by the MnPASS system integrator, Raytheon. MnPASS reports that the unit has operated well in the first seven months of operation of the MnPASS lanes and is responsible for about 50% of all enforcement stops. The other 50% is based on visual enforcement.

The full reader system currently installed includes a single antenna, mounted on the roof of the vehicle, a controller unit in the trunk of the enforcement vehicle and a reader display unit mounted next to the driver. The operator must only touch the display screen one time to initiate a read. A different audible sound will indicate a valid versus invalid transponder read. The reader also can display a “No Transponder” message in the absence of a valid transponder. See Attachment C for a product sheet with details on the MER 915 reader.

MnPASS reports that with the single antenna placed on the left side of the enforcement vehicle, only the transponder in a vehicle in the adjacent left lane can be read. MnPASS has plans to add a second antenna on the three enforcement vehicles so that a transponder in the adjacent right lane can also be read. An exceptions file is downloaded daily to the unit via a personal data assistant (PDA) that contains lost and stolen transponder data.

MnPASS reports that a single system (one antenna, display unit and controller) costs approximately $25,000. Follow-up conversations with the vendor indicate that this technology could be developed for the I-15 ML application.
It should be noted that to obtain the last read information with a T21 tag on the I-15 ML, a standard for write capability (i.e., the ability to determine the last read) on the transponder most likely must be developed and implemented. Current documentation available on the Title 21 transponder does not describe the write specifications of the transponder though it allows for transponders to have the write capability. Alternatively, the last read information or some history thereof can be obtained from the back-office where such information is stored. Some sort of cellular technology will have to be employed to obtain such information.

**Positives of Mobile Enforcement Reader On-Board Unit**

- Assists manual enforcement in reducing the pool of vehicles to be stopped and in pre-screening potential violators.
- Enforcement vehicle does not have to be next to tolling location to determine when the last valid transponder read occurred.
- Proven in operation on I-394.
- Relatively low initial capital costs of $25,000 per system, provided that dedicated patrol car units can be assigned to the I-15 ML manual enforcement function.

**Negative of Mobile Enforcement Reader On-Board Unit**

- Still requires some level of manual enforcement to confirm occupancy.
- Potentially requires agreement of some form with CHP to use the units for enforcement.
- Requires that specific enforcement vehicles are assigned to enforcement duty to avoid a full retrofit of CHP vehicles.
- Does not appear to be possible for outfitting to CHP motorcycle patrol unit, although this option could be explored further. Motorcycles have been shown to offer improved flexibility and productivity when patrolling the ML (based on data from existing I-15 reversible lanes).
- Most likely will require development and implementation of defined standard for T-21 transponder write capability.
- May require legislative changes.

### 3.8 Handheld Transponder Reader

Telematics manufactures a handheld transponder reader unit that verifies that a transponder is properly functioning. An example of this unit manufactured by Telematics (FP-100HA TDMA ASTM v6) is shown in Attachment D. The unit is used at MnPASS to check transponders at the Customer Service Center. MnPASS reports that it would be useful to have law enforcement officers who do not have the mobile reader installed in their vehicle to have this transponder reader. This would allow the enforcement officer who makes an enforcement stop, for example when the vehicle has passed through the tolling point and the overhead indicator does not flash, to check if the transponder is properly functioning.
While it is HNTB understanding that no Title 21-compliant product manufacturer currently produces this type of reader for T-21 transponders, it is feasible that this item could be a requirement for inclusion in an RFP if it were found to be a useful item in the HOT lanes enforcement strategy. It should be noted that SIRIT previously manufactured a handheld unit that read T21 transponders, however, at this time SIRIT no longer supports this unit. The SIRIT handheld unit was able to read transponders placed within six inches of the unit.

**Positives of Handheld Transponder Reader**
- Eliminates possible claims of malfunctioning transponders by violators who are stopped.
- Initial capital costs are low.
- Easy to operate during vehicle stop.
- Would work well in conjunction with the enforcement gantry light.

**Negatives of Handheld Transponder Reader**
- Does not reduce the requirement for manual enforcement as it can only be used after an enforcement stop is made.
- Potentially requires agreement of some form with CHP to use the units for enforcement.
- May permit use by motorcycle patrol unit where a mobile enforcement reader on-board unit (3.7) may not.

### 3.9 Infrared Image Occupancy Detection

Image occupancy detection was experimented with in 1998 in combination with license plate recognition (see section 3.5.3). A more recent application of this technology is the CYCLOPS system, developed by Vehicle Occupancy Ltd. The prototype system, is based on the use of a combination of infrared and visible light imaging, was demonstrated first in Leeds, England on the A647 in 2003 and 2004. The system is currently being installed for further testing in the Edinburgh area of Scotland on the Forth Road Bridge by the Forth Estuary Transport Authority. The purpose of the test is to determine if the system could be used in the future, to allow the Authority to charge different fees based on occupancy. It should be noted that the Forth Road Bridge application will be in manual toll lanes. Occupancy will be determined by CYCLOPS and the correct toll then assigned and displayed for both the toll agent and the driver. An IBTTA presentation on the CYCLOPS system and its Forth Bridge application, made by the Authority and Vehicle Occupancy LTD in July 2005, is included as Attachment E and a company brochure is included as Attachment F.

It should be noted that MnPASS has considered testing of the system and Raytheon has expressed interest in performing a test of the system. The issues for MnPASS in proceeding with the test are
that their current system is effective and low cost and there are concerns regarding privacy issues that would have to be surmounted with the community.  

The basic operation of the CYCLOPS system is as follows:

- Dual cameras are mounted in a single housing to take images in both the visible and infrared light spectrum. Infrared and visible light illumination is used.
- The images are melded into a single composite that identifies vehicle occupancy and can distinguish between dummies and live occupants.
- Manufacturer claims 95% accuracy in field trials.
- Manufacturer claims automatic facial detection and people counting. The system can also perform LPR. The license plate/occupancy record can be transmitted to a violation database for automatic violation processing.

**Positives of Infrared Image Occupancy Detection**

- If vendor claims are true the system would virtually eliminate manual enforcement.
- Initial costs could be mitigated or shared if the video equipment could also be used for V-tolling purposes.
- Although initial capital cost would be high, there is potential for violation revenue generation and virtual elimination of violators over time, thus increasing system performance of the ML. Potentially offers strong case for ROI and improved operational reliability (reduced travel delay) for ML.

**Negatives of Infrared Image Occupancy Detection**

- System is not yet proven in any live toll system environment.
- Initial capital costs are likely to be high as equipment will be required at all tolling points and the system will require initial software development and integration for both front and back ends.
- Level of human intervention required in automated violation processing remains a question.
- The issue of rear occupancy detection remains open. May require additional cameras or a change in the current definition of HOV status.

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6 Teleconference with Nick Thompson, MnPASS Project Manager, 12/07/05.
• Issue of child occupancy and sleeping passengers remain—could result in false violation notices being sent.
• High potential for privacy issues exists.
• Would require new legislation to allow this form of enforcement.
• System accuracy and image quality that can be upheld in court is not proven.

3.10 Smart Card Validating on Board Unit (OBU)

The use of smart cards in automobiles has been under investigation and test for a number of years and is also rapidly becoming state of the art in transit fare collection applications. There are cases of smart cards being employed in vehicles where the occupant can either use a contact or contactless smart card for payment of tolls or parking fees. In some cases, the card is in the driver’s hand and the driver can place the card in or near a reader in order to deduct the proper fare. An example of this is the ORANGES project in Orlando on the Orlando-Orange County Expressway (OOCEA), where an EFKON smart card was used for payment in manual toll lanes in a one-year test. In Singapore, smart cards are used as an electronic purse and are mounted in vehicles for highway speed toll collection and are used as well for parking fee payment.

Transit applications are in place in Washington Metro (WMATA) where WMATA has expanded its smart card program to rail, buses and parking. Similar systems are being implemented in Boston, Los Angeles, the Bay Area and San Diego. In San Diego a new transit fare collection system supplied by the Cubic Corporation is being implemented. The system includes the Compass Card, an ISO 14443(A) (Mifare) standard smart card. The possibility exists for the development of a T-21 transponder that could accept the Compass Card for occupancy identification and ultimately toll payment; however, hurdles identified below must be overcome.

In all the implementations described above, the smart card is acting as an electronic purse in that the data from the card is transmitted to the reader at the instance the card is placed in or near the reader and the fare or fee is deducted off the value of the card.

EFKON of Austria has recently announced the production of a smart card on-board unit (OBU) that can be used in HOV applications. According to EFKON, the unit is Infrared (IR) based and can accept two contact-less smart cards that are inserted into a pocket on an OBU “for read and storage of the data prior to entering the HOT/HOV zone”. The EFKON system uses Continuous Air Interface for Long and Medium Communication (ISO TC 204 CALM). An EFKON press release from April of 2005 is included as Appendix G.

According to EFKON, HOV occupancy enforcement with the smart card transponder could be accomplished using an Intelligent Mobile Enforcement Unit. The unit can be used in manual point and shoot mode or it can be fixed to an enforcement vehicle. The IR interrogator has a read distance of 40 meters. The unit can read the OBU for the number of occupants (i.e., the number
of smart cards in the OBU) and confirm that the correct toll was paid based on occupancy. Note that occupancy still must be confirmed by a visual inspection by the enforcement officer.

Another example of an OBU with smart card capability is the MD598, produced by Q-Free ASA of Norway. The OBU accepts a contact smart card. This system uses an RF transponder that communicates at 5.8GHz, which is not an approved United States FCC communications standard for this application. Product sheets for the MD598 are included as Appendix H.

The issue for the use of smart cards for occupancy detection in a ML/HOV situation is complicated by the following factors:

1. Occupancy identification via the smart card requires input not just from the driver using his smart card but potentially from other vehicle occupants as well, which poses practicality and fraud issues. For example, if an OBU does accept additional smart cards for occupants, how does the system handle those occupants who do not have the smart cards? A smart card driver’s license or similarly secure medium has been suggested but that does not work for children and those under 16, visitors or foreigners and the elderly, and that application is not going to be in place on a wide scale in the short to medium term.

2. Occupancy cannot be determined from the use of a smart card alone. Biometrics are difficult and potentially unsafe in this application (for example, fingerprint technology is difficult in that it involves requiring someone to tap the OBU while driving through multiple toll zones). As a result, some form of manual follow-up enforcement, for example in combination with the mobile enforcement unit described above, is still required to prevent abuse.

3. As discussed above, current smart card transponder systems available are not T-21 compatible and technologies using the European 5.8 and 5.9GHz standards are not currently used in the US. Both have standards and FCC issues that could potentially slow or prevent their implementation.

4. Since a T-21 transponder must be used on the I-15 due to interoperability requirements, it would mean that if an IR or a non-915 MHz RF technology were used, it would have to be installed as a parallel system with commensurate additional capital and operating costs.

5. Questions regarding potential interference between competing RF frequencies on I-15 ML toll system communications would also need to be settled if a frequency other than 915MHz were used.
Positives of Smart Card Technology

- Would allow migration to a single regional transportation type card, at least for use with HOVs (and perhaps ultimately all California tolls and San Diego transit systems); however, a regional card would need to address potential integration issues, including intellectual property, and what agency would be responsible for the production, distribution and maintenance of the card base.

- Assists manual enforcement in reducing the pool of vehicles to be stopped and in pre-screening potential violators. Anyone traveling without an SOV transponder or having two smart cards in the OBU would automatically become a violator.

- Allows for automated violation processing and citations if combined with video cameras/license plate capture at tolling points. This would reduce the CHP enforcement burden.

Negatives of Smart Card Technology

- Could require a large initial capital investment in a parallel transponder/reader system and card program distribution if a non-T-21 system were used.

- Does not eliminate the need for manual enforcement.

- Issues remain as to identification of additional occupants beyond driver and occasional users if intended for use as fully-automated violation detection system.

- System is not proven in any current HOV implementation. Use of the Compass card would require an additional integration with the T-21 Transponder.

- Issues exist with the timing of use of 5.8 and 5.9 GHz implementation in the US and potential RF interference if non T-21 system were used.

- Would require agreement with CHP for use.

- May require changes to legislation.

3.11 In-Vehicle Integrated Occupancy Sensors

Other integrated in-vehicle sensing devices in addition to the smart card, discussed in Section 3.10 above, could be used for the purposes of verifying vehicle occupancy, although plans for practical use of these options in near-term (pre-2010) deployment may be unrealistic. For the purposes of identifying a viable enforcement strategy and technologies for the I-15 ML, the following next generation VII applications were considered for their ability to provide a near-term solution for verifying vehicle occupancy:
• Mechanical systems such as seat belt monitoring.
• In-vehicle photography of occupants by an internal camera mounted within the vehicle.
• LED Imaging of vehicle occupancy by a roof mounted imager.
• Thermal/Infrared imaging based on heat monitoring to determine vehicle occupancy.
• Weight sensors to detect presence of passengers in the seats.
• In-vehicle ultrasonic/radar sensors to detect occupancy.
• Capacitive sensor, which uses a human electrical “footprint” to detect number of occupants.
• Heartbeat/breathing monitors which detect the number of heartbeats or require breathing monitors for seatbelt activation.
• Fingerprinting and biometric recognition where occupants would have to identify occupancy by touching a recognition pad or other device.

Any of these systems could potentially detect the number of vehicle compartment occupants and convey that information to enforcement vehicles or to the toll system, for example, via the transponder mounted in the car. The 2004 Ontario study explored in greater detail each of these systems which provides additional reference to their benefits and costs.  

One issue for HOV application is that none of these systems, even those that are technically feasible today, will be fully deployed in vehicles in the near to medium term. The Ontario study points out that all new vehicles in the US are required to have some form of smart air bag system by 2006 for the front two seats. There is no standard however, for what form of system this should take and this does not address cars manufactured in prior years. This means that if an HOV enforcement system were designed to piggyback on the smart airbag technology, any system installed on the I-15 ML would have to also address pre-2006 vehicles that do not have these systems.

The Ontario study also points out that “…The economics of the situation are such that, if the in-vehicle component of the occupancy monitoring system has more than a nominal cost to it, it will

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8 Ibid, p 18.
not be worth applying it to every vehicle in North America.” 9 In other words, HOV alone, with its small percentage of users and a smaller percentage of violators, cannot justify a requirement for large scale implementation of any of these systems.

Based on the above, while the development of in-vehicle occupancy monitors should continue to be followed, they are not considered feasible for the time frame of the I-15 ML implementation and it is recommended that they be dropped from further consideration at the present time. The smart card-validating OBY described previously (in 3.10) could potentially offer a bridge technology to one of these options by demonstrating viability of in-vehicle occupancy verification systems.

4.0 TECHNOLOGY OPTIONS ANALYSIS

For purposes of proposing preliminary groupings for further analysis in the next phase of the study (Strategy Report), three differing levels of enforcement strategy packages are recommended for further consideration. It is possible to combine technologies from the different packages. The groupings are intended to assist in the sorting of options. These are:

**Package 1: Low Level Technology Assisted Manual Enforcement:** Technologies and methods that could be combined in this strategy are:

- Manual Enforcement (3.2)
- Enforcement Gantry Light (3.3)
- Mobile Transponder (3.6)
- Mobile Enforcement Reader (3.7)
- Handheld Transponder Reader (3.8)

This strategy package would rely primarily on manual enforcement but would use a combination of all or some of the above technology alternatives to make the manual enforcement process more effective and efficient.

All of the Package 1 options are not only relatively low cost to implement but also would likely not require significant policy changes or legislation (recognizing that the current T-21 limitations must be addressed) to enact and should not have any major institutional roadblocks. The

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questions to be examined in the strategy report are: (1) the effectiveness of the various methods given the Managed Lanes physical configuration; (2) the limitations of the T-21 transponder technology; (3) which combination of alternatives would be most effective to implement, and (4) what policies would be possible to implement that would maximize enforcement effectiveness. Some or all of these options could still be employed in combination with technologies from Packages 2 and 3. Importantly, they could also be implemented in a relatively short-time frame independently of any the concepts that may require additional piloting and development.

**Package 2: Medium Level Technology Assisted Violation Enforcement**

Technologies that could be used independently or combined to varying degrees in this group include:

- HOV Transponder Use (3.4)
- HOV Registration - Technology Assisted License Plate Review (3.5.1a)
- Voice Activated Look-up of License Plate for Toll Paid (3.5.2)
- License Plate (LPR) Spotter Enforcement (3.5.3)
- License Plate HOV Registration Database with Automated License Plate Check (3.5.1b)
- Smart card-validating OBU (3.10)

HOV transponder use (3.4) has the advantage of requiring that all vehicles have some type of transponder, reducing some types of manual enforcement. This option could be combined with all of the options from package 1, or with some other options from package 2, such as evolution of HOV transponder use to that of a smart card-validating (dual smart card-accepting) OBU (3.10).

In any case, requiring HOV operators to carry transponders can be compatible with use of a license-plate/occupancy detection imaging system, to automate the detection and processing of violations. It should be noted that institutional issues of moving to HOV transponders, including smart card-accepting OBUs, has the potential to initially reduce HOV use. If the HOV transponder requirement is to be instituted, either an aggressive public marketing campaign, or a statewide deployment, or both, would be preferred; however, acceptability to the public may still be an issue.

As discussed in the previous section, the voice activated look up for toll paid does not appear to have any advantage over the use of the mobile enforcement reader (3.7) or a functionally similar unit, in being able to determine whether or not the vehicle has paid the toll when passing through the last tolling point and the mobile reader would be much less expensive to implement; however this assumes that a standard specification for determining last read on the T-21 transponder could be developed or another method of determining last read could be developed.

HOV registration with technology assisted license plate review (3.5.1a) would allow enforcement officers to check if a vehicle is pre-registered by license plate as an HOV and would therefore allow better targeting of the violators being stopped. This would make the enforcement process
more efficient but has the major institutional obstacle of requiring HOVs to pre-register, thereby most likely reducing the pool of HOV users. As with HOV transponder use, if such registration were done on a statewide basis the system would be more feasible; however, acceptability to the public may still be an issue. As with HOV transponder use, this option allows combination with package 1 options and potentially package 3.

The HOV registration with automated license plate look-up (3.5.1.b) would be able to take advantage of the planned automated toll violation enforcement and processing system in much the same manner as the HOV transponder option. Like the HOV transponder, it would also have the benefit of reducing manual enforcement requirements and would have to address the issue of potentially reducing the pool of HOV users. It could also be used in combination with package 1 and package 3.

The smart card validating OBU (3.10) presents the same advantages as the HOV transponder and the HOV pre-registration alternatives in that it could work with an automated toll violation enforcement and processing system and would reduce manual enforcement requirements and could be combined with other packages. As with these other two options it has the potential to reduce HOV usage. While there is currently no T-21 compatible smart card OBU developed, it offers the possibility of interoperability with the regional fare collection program’s Compass Card for occupancy and potentially, fare collection. Since at the present time the smart card OBU alternative cannot rely on any method to independently verify the actual number of occupants in the vehicle, this cannot be considered a fully automated technology for occupancy detection; however, the potential for such development exists. Risk factors associated with the development of the T-21 smart card OBU must be considered in the upcoming Enforcement Strategy Analysis.

The use of the LPR with a spotter (3.5.3), as is planned on SR91, would most likely not be a cost-effective tool on the I-15 ML, in an environment where multiple access/egress points will exist, rendering that solution significantly more labor intensive while still requiring a capital investment in violation enforcement cameras. The technology used for LPR and the transmission of vehicle data to enforcement vehicles may, however, be of further interest to the I-15 ML project.

Package 3: Automated HOV Violation Enforcement: The following remaining technologies have the potential to offer a more automated enforcement option, either substantially reducing or eliminating the need for any additional manual enforcement:

- License Plate Video and Vehicle Occupancy Image (3.5.4)
- Infrared Occupancy Detection (3.9)

Infrared occupancy detection systems such as CYCLOPS (3.9), offer automated occupancy detection. This is the only system of those studied that has actually made claims of accuracy/reliability at or above 95 percent and CYLOPS is designed to determine vehicle occupancy in a single camera housing. It should be noted that CYLOPS is also the only system
studied that is currently designed to automatically detect and confirm occupancy without relying on any manual verification. There remain several questions, such as whether an application of this system can accurately determine rear seat occupancy (for instance, would additional cameras be required and what is the proper configuration for placing cameras in order to capture rear seat and child occupancy). Additionally, there are major institutional obstacles to the implementation of such a system as well. These include the legislation that would be required to allow for the automated violation notices based on interior images and privacy issues that may engender public resistance. These issues must be further considered in the strategy review.

The development of the CYCLOPS-type infrared based system in combination with a video toll camera system appears to offer a superior approach to the type of system described in Section 3.54. This system was tested in 1998 and used traditional toll license plate reading video equipment for both LPR. For purposes of this study, the CYCLOPS type system can be viewed as a more developed successor to that technology.

Finally, the infrared imaging system is not in full operation on any toll facility so there remains a high risk in terms of cost and performance that must be considered in the upcoming Enforcement Strategy Analysis.

5.0 FINDINGS AND RECOMMENDATIONS

Given the current state of available HOV/ML enforcement technologies, no proven system currently in use can completely eliminate manual enforcement of the occupancy rule, particularly in the near to medium term. An encouraging application that could potentially eliminate the need for manual enforcement is the CYCLOPS infrared occupancy imaging system, which is about to be tested on the Forth Road Bridge in Edinburgh, Scotland. In addition to the fact that the system is not yet proven in a toll environment, it must be noted that other major obstacles that must be overcome prior to a full-system implementation include potentially high cost, the issue of rear seat and child occupancy detection and legal issues regarding privacy. A second option, pre-registration of HOV users, would also allow for an automated V-tolling/HOV enforcement system but would also have large potential institutional obstacles that need to be further investigated.

There are also a number of technologies which when used (some in combination) may accomplish the following: (1) supplant manual enforcement; (2) minimize the manual intervention required, and/or (3) assist in making the manual enforcement a cost effective deterrent. These technologies range from the simple and inexpensive, such as an overhead LED indicating a valid transponder read, an enforcement transponder or mobile reader, to the more complex license plate recognition systems, five variations of which have been considered in this report.

At least one technology offers the possibility of in-vehicle occupancy self-validation, through the provision of smart card-accepting OBUs that would be required of any user of the ML wishing to travel under the HOV privilege. In contrast, other longer view occupancy sensor systems, such as
seat belt monitors, biometric detectors, weight sensors and in-vehicle occupancy cameras, while in most cases technologically feasible, are not expected to be in wide-scale use in vehicles within the implementation timeframe for the I-15 ML. Therefore, for purposes of this report as it relates to that project, implementation of those alternatives is not considered feasible at the present time.

The purpose of this report is to identify the technologies and concepts, which when taken as a standalone approach, or in combination with one or more other solutions, could form the basis for an effective occupancy enforcement strategy for the I-15 ML. Strategy types have been grouped into three potential packages in the previous section to assist in the development of strategies in the Enforcement Strategy Analysis. The review of these strategies will include analysis of how each alternative will function and integrate with the planned baseline toll enforcement video camera system. Therefore, recommendations as to next steps include:

- In consultation with SANDAG review strategy packages and their underlying technologies with the goal of determining which combination meet the high level requirements identified in Section 2.3 and are best-suited for further review in the Enforcement Strategy Analysis (Task 2.2.3).

- Begin to further refine packages into strategy alternatives for inclusion in the Strategy Analysis report.

- Monitor developments with the CYCLOPS system test in Edinburgh, Scotland, and assemble more detail as to system costs and actual performance for that system and for the other automated HOV/ML enforcement technologies described previously (in Package 3).

- Further develop information on whether transaction history for the queried tag can be obtained for use with mobile enforcement readers, and more generally to investigate what requirements of Title 21 law are potential impediments to deploying any of the technology solutions described in this report; and where such impediment is found, what the appropriate actions to amend Title 21 to permit use of such technology should be.