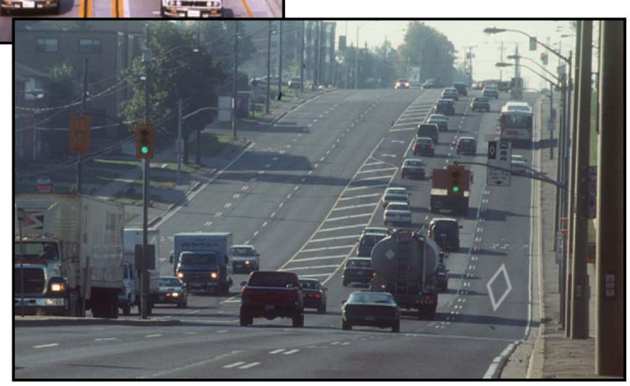
ENTERPRISE

Ontario

Automated Vehicle Occupancy Monitoring Systems for HOV / HOT Facilities

FINAL REPORT



MRC

Consultants in Transportation

McCormick Rankin Corporation

December 2004

December 16th, 2004

RE: **Final Report**
Automated Vehicle Occupancy Monitoring Systems
For HOV/HOT Facilities

Dear Sir / Madam:

We are pleased to provide you with a copy of our report titled *Automated Vehicle Occupancy Monitoring Systems for HOV/HOT Facilities*. This study has been undertaken by McCormick Rankin Corporation of Mississauga, Ontario, Canada on behalf of the pooled-fund ENTERPRISE ITS research program, and managed by staff of the Ministry of Transportation of Ontario.

This report provides a basis on which electronic / automated processes for monitoring HOV / HOT lanes can be developed. It outlines a number of viable concepts to be considered for development, demonstration, and/or field evaluation. The results were compiled through a comprehensive review of current practice and previous research, and consultation with members of the transportation industry including law enforcement, auto manufacturers and transportation planners. The study demonstrates the feasibility and potential benefits of automating the occupancy detection task, and highlights the social concerns and commercial issues that need to be addressed

Should you have any questions or require further information after reading this document, please feel free to contact the undersigned.

Yours very truly
McCormick Rankin Corporation

Steve Schijns, P. Eng.

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Automated
Vehicle Occupancy Monitoring Systems
for
HOV / HOT Facilities

Final Report

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December 2004

Preface

This study has been undertaken by McCormick Rankin Corporation of Mississauga, Ontario, Canada on behalf of the pooled-fund ENTERPRISE ITS research program. Project management has been by staff of the Ministry of Transportation of Ontario.

As a pooled-fund study, this study is subject to the views and requirements of many different jurisdictions. Some ENTERPRISE members, for example, are very sensitive to the use of the term "enforcement" in the automated occupancy monitoring context, reflecting previous and current issues and experiences in their home states. Nevertheless, it is recognized that the primary function of the automated occupancy monitoring system is to assist in the enforcement of proper HOV facility operations. The term "enforcement" is therefore used without prejudice throughout the body of the report, but is consciously excluded from the study title and Executive Summary.

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EXECUTIVE SUMMARY

Police and High Occupancy Vehicle (HOV) facility operators have long called for an effective system of counting vehicle occupants on the road, to allow more cost-efficient, targeted and reliable HOV lane management. This research study builds on previous work to lay out a new way of addressing this problem.

Research to date has focused on the use of photographic-based systems to record vehicle occupancy from outside the moving vehicle. Such systems have shown some promise, but suffer from inherent flaws in dealing with tinted windows, different vehicle types and passenger seating arrangements, varying weather and light conditions, and high-volume high-speed operation, and as a consequence appear unlikely to be able to be relied upon as a fully automated HOV monitoring system.

This study focuses on recent advances that indicate the potential for the development of an *in-vehicle* system for automatically counting the number of vehicle occupants and making that information available to an external recording system. This could form the basis of an automated, comprehensive HOV facility monitoring program.

A variety of in-vehicle systems to count and record vehicle occupancy are available “off the shelf” and a technically feasible pilot project could be implemented in the near term. Front passenger seat occupancy is currently being monitored for air bag safety reasons (such systems are mandatory in 100% of new vehicles sold in the U.S. from the 2006 model year onwards) and “smart” windshield-mounted transponders with roadside readers are also in use for electronic toll highways.

An effective Occupancy Monitoring System (OMS) would allow the tracking and citation of 100% of HOV facility violators (including freeway *and* arterial HOV lanes, plus carpool lots and other HOV facilities). It would be invaluable in identifying HOVs in a High Occupancy Toll (HOT) lane, and would allow HOT lane operation in a non-barrier-separated environment.

Wideranging consultation with HOV practitioners and proponents revealed some enthusiasm for the prospect of a reliable automated HOV monitoring system, but highlighted some areas of major concern, particularly:

- Public / political perceptions regarding personal privacy
- The difficulties associated with making the necessary legal / legislative changes
- Practical issues of auto industry rollout
- Cost and economics

The Business Case for an automated OMS compares the cost of rolling out the system (in-vehicle components, roadside equipment, and back office / administrative costs) against the benefits (reduced policing cost, more effective facility monitoring capabilities, and substantially increased fine revenues). Definitive figures cannot be attached to the costs and benefits at this stage. Indications are that the capital cost of a full-scale rollout on all North American HOV facilities would be substantially greater than the annual investment currently made in police work and lane monitoring, although the potential for a quantum increase in fine revenue from HOV lane violators may even the equation somewhat.

As violations (and fine revenues) decrease over time with an effective OMS, the value of the system would accrue mainly from being able to maintain the operational integrity of the lane and engender public support for HOV network expansion. This may be particularly valuable to the arterial HOV area, which suffers today from lack of public support due primarily to apparent inability to manage and control usage.

Over and above the HOV and HOT lane applications, an automated OMS offers the potential to contribute "added value" in numerous areas of urban transportation:

- Managed Lanes, Value Pricing, and Congestion Pricing
- Interoperability with "Standard" tolling
- Safety / Seat Belt Use
- General HOV Monitoring (off HOV lanes)
- Data Collection
- Vehicle emissions
- Vehicle Identification
- Vehicle / Operating Diagnostics
- Vehicle Safety Systems
- Emergency Systems
- Passenger security systems
- Transit Service
- Preferential Parking
- Carpool Incentives
- Insurance
- Marketing
- Use of HOV Facilities by Non-HOVs

To progress the OMS opportunity, further work needs to be done in the Technical, Social-Political, and Commercial spheres. It is important to tackle the problems in the latter two areas, since the technical aspects of the problem are well advanced but further work in that area will be fruitless unless the critical issues of roll-out, public perception, political / legal support, cost, and auto industry commercial requirements are resolved. It is imperative that further work involves both government and the auto industry. Broadly speaking, actions are required in all three areas:

Technical Action Plan

- develop a real, practical, working prototype of an in-vehicle OMS
- apply a pilot project in a HOT lane environment as well as in a non-separated HOV lane

Social-Political Action Plan

- carry out market research to understand public / user perspectives
- develop appropriate legislation to support the use of an automated OMS
- expand on the Business Case and address financing issues

Commercial Action Plan

- consult with the auto industry to develop an implementation strategy

1. INTRODUCTION

This study of Automated Carpool Detection Systems for High Occupancy Vehicle Lane Monitoring has been undertaken for the ENTERPRISE Program, a pooled-fund program of various U.S., Canadian, and European transportation authorities targeting innovative and practical research in the area of Intelligent Transportation Systems (ITS). It has been carried out by McCormick Rankin Corporation, a Canadian firm with expertise in both HOV systems and ITS applications.

1.1 The Problem

High Occupancy Vehicle (HOV) Lanes are intended to offer a fast, reliable, and safe trip for shared-ride vehicles (carpools, vanpools, buses), thereby attracting travelers to those modes in preference to driving alone. HOV lanes are most effective during peak travel periods in urban areas, when general purpose lanes typically become congested and unreliable. The functionality of an HOV lane relies on it being used exclusively by the designated type / class of vehicles; if appreciable numbers of ineligible vehicles use it as well, not only will the performance of the lane suffer and affect all users, but the public perception of the value of the lane (by both users and non-users) is likely to suffer and lead to even more misuse. This may eventually lead to near-elimination of the HOV priority function and loss of public support for other HOV lanes and Transportation Demand Management (TDM) initiatives.

A typical buffer-separated freeway HOV lane, with police observation in use to monitor the lane for violators (Long Island Expressway, New York)

HOV lane compliance relies, like most transportation systems, on adherence to posted rules and regulations (communicated by signage, pavement marking, and education / driver testing). This is supplemented by police monitoring and enforcement activity in the field. HOV lane enforcement is only one of many police activities on the road, and given limited police resources it tends to be a lower priority when compared to accident investigation, traffic management, dangerous driving, safety infractions, etc.

Barrier-separated HOV lanes with limited access/egress (e.g. Houston, TX) can be monitored by visual inspection at a single terminal point.

HOV lanes come in many forms, and are in operation on both arterials and freeways. They are also used in tolled highways and lanes ("HOT Lanes"), whereby eligible HOVs are offered a lower toll than other vehicles. From an enforcement perspective, HOV lanes that are separated from other lanes by a physical barrier (concrete or pylons) are easier to enforce and tends to have lower violation rates than a non-separated lane. Some lanes are separated by a painted buffer, while others are distinguishable from general lanes by signage only. HOV lanes may operated during peak periods only, or on a 24 hour per day basis. HOT facilities must be barrier-separated and have enforcement staff physically inspect HOVs in order to distinguish them from other toll lane users. On arterial roads, HOV lanes must often also accommodate vehicles turning into or out of the general traffic lanes. Taken together, these conditions yield a transportation strategy that is very difficult to enforce on a day-to-day basis.

A well-used highway HOV lane with a committed enforcement program (regular police presence, supplemented by periodic “blitzes”) may have violation rates (proportion of ineligible vehicles in the HOV lane) as low as 1% - 5%. A typical objective for a freeway HOV lane is to maintain violation rates below 10%. At higher levels of violation, public support begins to suffer. If the HOV lane is poorly utilized by eligible vehicles, or if the eligibility rate is set at a more restrictive 3+ rather than the typical 2+, or if the hours of operation or vehicle eligibility rules vary throughout the day, the violation rate tends to creep upwards and to require targeted police enforcement activity.


An arterial HOV lane has to allow turning vehicles to use it as well. (Dufferin Street, Toronto)

Arterial roads pose a much more challenging environment for HOV lane compliance. Typical arterial HOV facilities in Toronto[1], Mississauga, Ottawa[2], Sydney[3] and Brisbane[4] demonstrate violation rates of between 50% and 80% of HOV lane users. These are clearly unacceptable levels, and they hamper the public support and willingness to move forward with important HOV initiatives in those areas.

These symptoms stem in large part from the practical difficulty of manual enforcement. A police officer in the field must drive in the lane or beside it, or sit stationary in a safe place while scanning all HOV lane vehicles, determining the number of vehicle occupants, intercepting ineligible vehicles, writing out a citation and returning to the observation area. This is a tedious, labor-intensive practice that

1.

[1] Peak period violation rates of between 44% and 79% for six arterial HOV 3+ facilities reported in *Review of HOV Lane Operation and Policy*, report to Metropolitan Planning and Transportation Committee, Sept. 19, 1995

[2] Peak hour violation rates of between 51% and 62% for Portage Bridge HOV 3+ lane, reported in *Portage Bridge HOV Lane Operation: Draft Working Paper*, K.Mucsi, City of Ottawa, Dec. 30, 2002

[3] Peak period violation rates of between 39% and 74% for four arterial HOV 2+ corridors, reported in *Sydney Transit Lane Surveys*, New South Wales Roads and Traffic Authority, August 1998

[4] Peak period violation rates of between 69% and 80% for three HOV 3+ facilities, 1998 data reported in *Brisbane HOV Arterial Roads Study*, PPK and McCormick Rankin Cagney, January 2001

typically yields no more than a half-dozen citations per hour, while violations may number in the hundreds.

Furthermore, the officer must deal with environmental conditions of snow, darkness, sunlight reflections, and rain, and with vehicles traveling at high speeds that may have darkened / tinted glass, reclining passengers, and/or child seats with or without children. Often legitimate HOVs are stopped by police because they cannot see readily confirm the number of occupants from "instant" observation.[5]

The problem is thus one of a high risk of inappropriate use of HOV lanes and the consequential negative impact on lane function, level of effort dedicated to enforcement, HOV incentive, public perception / support, and general respect for rules of the road.

As a result, police and facility operators have long called for an effective means of carrying out automated or remote enforcement, to allow more cost-efficient, targeted and reliable HOV enforcement practice.

While several attempts have been made to develop such an automated system for detecting vehicle occupancy, they have either been found infeasible or not brought to the level adequate for day-to-day use. This research study builds on previous work to lay out a new way of addressing this problem.

1.2 Purpose and Objectives of Study

This study seeks to lay the groundwork for developing an electronic / automated process or technique to observe vehicle occupancy in support of HOV lane monitoring for compliance.

This requires two elements:

- Automated system to detect the number of people in a vehicle while using a HOV / HOT facility
- Automated system to communicate that information to enforcement authority

Once in the hands of the enforcement authority, the occupancy information may be used in support of manual (field) police action – stopping and citing the violator while using the lane – or to trigger a ticket-by-mail automated fine / penalty system. How the occupancy information is used by the enforcement authority is beyond the scope of this study, but awareness of the different ways it might be used is a factor in the development and assessment of alternatives.

The study is undertaken in five stages:

- Reviewing and synthesizing past research in this area.
- Consulting with police, auto industry, and transportation planners to identify issues, baseline requirements, areas of current research, technical aspects, and partnership opportunities.

1.

[5] In New Jersey, a 1996 field study revealed that 36% of vehicles stopped for an HOV lane violation in fact had enough occupants. This level of inaccuracy wastes valuable police time, creates ill-will, and disrupts traffic unnecessarily.

- Undertaking research, consultation and review to advance the understanding of the problem and identify potential solutions
- Develop a set of potentially viable concepts, with a supporting business case, to be considered for development, demonstration and/or field evaluation.
- Outline an Action Plan for further work.

2. SYNTHESIS OF CURRENT PRACTICE

The purpose of the synthesis is to document the state of current practices in HOV occupancy monitoring, to summarize the state of research results by others in this field, and to investigate current / new technology of relevance to the monitoring and enforcement task.

This information has been compiled primarily from project experience and from internet and literature searches.

2.1 Enforcement Practices

HOV occupancy monitoring today is carried out exclusively by manual methods.

Various operational strategies have been developed for enforcement of different kinds of HOV facilities. The strategy adopted depends upon the nature of the facility and its operation including factors such as:

- arterial vs freeway
- painted line vs buffer vs barrier separation from general purpose lanes (GPLs)
- location of HOV lane (median lane vs shoulder lane etc)
- length of HOV lane
- existence or otherwise of exclusive HOV off-ramps
- existence or otherwise of enforcement bays
- existence or otherwise of wide shoulders
- existence or otherwise of other observation vantage points
- operating conditions on the HOV facility and on adjoining GPLs
- resources available to the enforcement agency

HOV lane enforcement usually requires police officers to monitor the HOV facility from a stationary or a moving vehicle within or beside the HOV lane. These officers observe the occupancy of passing vehicles within the HOV lane and apprehend the offending vehicles to issue violation tickets. Many on-freeway HOV facilities have enforcement areas designed and built into them to facilitate enforcement in a safe and efficient manner.

Curbside arterial HOV lanes can be enforced by officers observing approaching vehicles and directing suspected violators into a cross-street. This can be undertaken with any number of officers present.

Patrols by motorcycle or patrol car can be used in many HOV lane situations. While it is not an efficient method of observing a high proportion of traffic in an HOV lane and apprehending a high proportion of violating vehicles, it does enable officers to observe and enforce many other laws at the same time (e.g. speeding, following too closely etc).

Where exclusive HOV off-ramps exist, enforcement can be undertaken at the location where the ramp terminates on the surface street network.

Operating strategy alternatives that have been developed for median HOV lanes on freeways include:

1. Single-officer strategies:
   a. Stand outside car in observation pocket, observe violator, signal to pull over to median shoulder.
   b. Stand outside car in observation pocket, observe violator, chase and pull over.
   c. Cruise adjacent GPL and observe HOV use; cross buffer and chase violator.
2. Paired-officer strategies:
   a. Stand outside car in observation pocket, observe violator, signal to pull over to median shoulder. If violator does not pull over, radio to officer standing in downstream observation pocket to signal to pull over. If violator still does not pull over, second officer gives chase.
   b. Upstream officer acts strictly as a spotter. Upon observing a violator, officer radios to officer standing in downstream observation pocket to pull over suspect. If violator still does not pull over, second officer gives chase.
   c. Each officer operates semi-independently per 1a or 1b or 1c above.

It has been found that daily police activity is not necessary to keep HOV lane violations to an acceptable level; a program of varied frequency and level of effort has been found to be just as effective.

The act of enforcement can itself cause problems with traffic flow due to "rubbernecking" by passing motorists, but it has been found that the simple presence of police in the field (even without actively pursuing HOV lane violators) can be an effective deterrent to violators.

On occasion, police have tried to speed the enforcement process by mailing citations to the registered owner of the offending vehicle, thereby eliminating the need to stop and physically fill out a citation at the roadside. This practice has faced legal challenges, however, and is not widespread; most jurisdictions require the officer to be able to appear in court and provide the evidence that he/she personally witnessed the offence..

Enforcement on arterial HOV lanes is usually more difficult to carry out than on a freeway because arterial lanes are usually not buffer separated, making it easy for general traffic to pull in and out of the HOV lane to avoid enforcement areas. Often arterial HOV lanes are required to be entered or crossed by general traffic for legitimate purposes, such as to access property or to make turns at intersections. This makes the manual enforcement task difficult, if not impossible.

HOV monitoring is often seen as a minor policing issue whereby limited police resources are assigned to higher priority activities (particularly during peak periods) of traffic management, incident investigation, and safety-related issues. Police have found, however, that

> The most frequently cited operational issue facing HOV lanes, in a survey of 32 U.S. Transportation professionals:
> "How to adequately enforce the HOV lanes, particularly non-barrier-separated HOV lanes" *(Urban Transportation Monitor, July 9, 2004)*

motorists who violate HOV lane rules are often at high risk for other highway offences.

The Institute of Transportation Engineers (5) notes that, "*to date, there are no established automated HOV lane enforcement programs.* ***The primary reason for the lack of established programs is the inherent difficulty in determining vehicle occupancy"***.

2.2 Previous Research on Automated HOV Occupancy Detection

Documented research on HOV occupancy monitoring and enforcement has, to date, focused on photography from outside the vehicle. A number of Jurisdictions have studied and tested methods for using video and other photographic technology for HOV lane surveillance and enforcement. These include:

- Caltrans (1990): Video
- TxDot/DART (1995-1999): Video
- Georgia DoT (1997): Digital Infrared
- MnDoT (1998): Infrared/Video
- Leeds, UK (2002): Video

Brief descriptions of the tests and their results follow. Material in *italics* is drawn verbatim from Reference 5.

2.2.1 California Department of Transportation

The use of video in HOV lane surveillance and enforcement was tested by Caltrans in 1990 (Billheimer, Kaylor and Shade 1990). The study was conducted to test and demonstrate the use of video equipment in determining the vehicle occupancy, documenting violator identity, and assisting in the enforcement of HOV lanes.....

The study concluded the following about the use of video in HOV lane enforcement:

- *Video cameras operating alone cannot identify the number of vehicle occupants with enough certainty to support citations for HOV lane restrictions. The video tests had a false alarm rate of 21 percent (21 percent of vehicles identified by video tape reviewers as violators actually had the required number of occupants). Small children or sleeping adults in the rear seat were not captured by the video camera; poor light conditions, glare, and tinted windows compounded the problem of viewing passengers in the interior of the vehicle.*
- *The use of video as a real-time enforcement aid appears to be limited to those locations lacking enforcement areas for officer observation. At these locations, a video camera could be safely positioned to assist a downstream officer in determination of vehicle occupancy. The study noted, however, that an officer stationed beside an HOV lane in an enforcement area was in a much better position to observe violations than an officer at a remote video monitor.*

- *Videotape provides a freeway and HOV lane monitoring tool that is potentially more consistent and accurate than existing techniques for documenting vehicle occupancy.*

There does not appear to have been any further work on this or related projects in California since that time. Conventional on-road enforcement efforts, combined with good design and strong utilization, have maintained HOV lane violation rates well within acceptable levels on most facilities.

2.2.2 Dallas, Texas

The Dallas Area Rapid Transit (DART) and the TxDOT tested the use of real-time video and license plate reading for HOV lane enforcement on (1-30), HOV lane in Dallas, Texas (Turner 1998)

A one-day demonstration test and subsequent video analyses in 1995 determined that current pattern recognition algorithms would not be sufficient to automatically determine vehicle occupancy. Results of the demonstration test did reveal that high-quality video combined with automatic license plate readers could be useful in improving the HOV enforcement process.

The Texas Transportation Institute (TTI) project team worked with Transformation Systems (Transfo) and Computer Recognition Systems (CRS) to design and install a video-based high-occupancy enforcement and review (HOVER) system on the 1-30 HOV lane. The system could ultimately be used to assist DART enforcement personnel in determining compliance with vehicle occupancy restrictions. The enforcement system performs the following basic functions:

- *collect and transmit video images of vehicle license plates and vehicle compartments for all HOV lane users to a remote computer workstation,*
- *perform automatic license plate character recognition on the license plate video image,*
- *synchronize the captured video images of vehicle occupants with license plate numbers, and*
- *search a license plate database containing vehicles that have been observed with two or more occupants (“whitelist”) and display the vehicle license plate number and vehicle compartment images of potential violators on an enforcement workstation.*

Transfo and CRS installed and integrated an HOV lane enforcement and review system (HOVER) on the HOV lane in Dallas. Testing of the enforcement system began in November 1997 and concluded in April 1998. The results of the operational test indicated that the HOVER system, in its current state, could support a program that mails HOV information to suspected violators (similar to the HERO program used in several states).

The study’s limited budget prevented several improvements that could improve the capabilities of the HOVER system. With several enhancements to the system (e.g., improved license plate recognition and “whitelist” license plate database), the HOVER system could be used to perform enforcement screening.

> *Significant enhancements to the system (e.g., high-quality video cameras, additional camera views, improved video signal transmission, improved license plate capture and recognition) could enable its use for HOV mailed citation programs, although enabling legislation does not currently exist in Texas. The research team recommended implementation of these enhancements and further testing.*
>
> *The existing HOVER system met the original performance specifications in terms of its features and functions. Several changes and/or enhancements to the system could significantly improve its usability and its potential for use in HOV lane enforcement.*

Further details of this project are documented in Reference 7. The performance of the system in darkness remains unclear. It is noted that while the system is reported to have the potential to be used for automatic enforcement, there are many enhancements that were noted as being necessary to enable this potential to be further evaluated. No further testing has been undertaken since 1997-98 tests.

2.2.3 Atlanta, Georgia

The Georgia Tech Research Institute has developed a prototype vehicle occupancy system that may help Georgia DOT to determine the number of persons in a moving vehicle (Gimmestad, n.d.; ITS International July/August 1997, 75). Although the prototype system was developed for freeway and HOV lane monitoring purposes, the accurate detection of vehicle occupancy is a key component of automated HOV enforcement systems. The prototype system uses digital infrared cameras and infrared strobe lighting to capture views of vehicle interiors, and it is capable of collecting vehicle images at the rate of two per second. A non-intrusive vehicle detection unit is used to trigger vehicle image capture, as well as collect vehicle volume and classification data.

Georgia Tech researchers have advised that no further work has been undertaken on this project since the proof of concept prototype was developed.

2.2.4 Minneapolis, Minnesota

In 1998, the Minnesota Department of Transportation carried out a study with the Department of Computer Science from the University of Minnesota to examine the prospect of using mid-infrared and near-infrared cameras to determine vehicle occupancy. The mid-infrared setup could not produce clear images at highway speeds. The near-infrared scheme worked much better, but the team could not develop the system to the level of accuracy and reliability needed for real-world automated occupancy detection. It was noted that side images were clearer than images taken through the front windshield, due to the different spectral composition of the two types of glass.

Ultimately, the study concluded that, *"…there is potential for developing an automatic vehicle occupant counting system using the near-infrared bandwidth. However, near-infrared cameras can only produce images when looking through glass not metal or heavy clothes."* It notes that *"…there may be a limit to the level of accuracy that can be obtained with this technology if an automatic vehicle occupant* *counting system would be required to count children in car seats or persons who are lying down in an automobile"*[6]

Clearly, there would also be issues with this technology accurately counting passengers in panel vans and similar types of vehicles.

Discussions with Kevin Schwartz of Minnesota Department of Transportation indicate that the Department has not undertaken further work on the project since the report above was published. The findings suggest that the technology may be useful for HOV monitoring for data collection purposes however that it would probably not be suitable for automated enforcement.

2.2.5 Leeds, UK

A three year research project to develop an automated occupancy camera detection system for use in the enforcement of HOV lanes began in Leeds, U.K. in 2003. Funded by the U.K. Department of the Environment, Transport and the Regions, the project research partners are:

- Photonics Consultancy (lead partner);
- University of Sussex;
- Laser Optical Engineering Limited;
- Golden River Traffic Limited; and
- Leeds City Council.

The system is still at the developmental stage. It was proposed to use infrared cameras and state-of- the-art high-speed image processing methods to count and recognize occupants inside moving vehicles from the roadside.

Initial testing showed that the near-infrared part of the spectrum was not suited to the task, due to the absorptive qualities of most car windows at those wavelengths. Subsequent study focused on automating the task of searching for faces in pictures taken of front or side windows of a moving car. Some success was noted in that area of work.

Meanwhile, infra-red cameras were also tested, despite their very high cost. A 1.5 micron gap in the absorption of the heat-resistant layers on car windows was found, through which infra-red cameras could "see". Under bright sunlight the infra-red approach could yield images in which human skin could readily be distinguished, but practical obstacles remain in creating an infra-red system that would work under cloudy or dusk lighting conditions. Laser diodes would provide the infra-red response but would add substantially to the cost.

Field testing brought the visual and infra-red systems together; a combination of the two images yields a an image of a face as a "darker blob" which contrasts with its surroundings and can be recognized immediately by the specially-developed

1.

[6] Automatic Passenger Counting in the HOV Lane, I. Pavlidis et al, University of Minnesota for Minnesota Department of Transportation, Minneapolis, MN, June 1999

processing software. A working prototype of the system is intended to be demonstrated on the A647 HOV lane in Leeds in September 2004.[7]

2.2.6 Conclusion from Existing Research

Despite several research attempts and pilot projects, the automated vehicle occupancy monitoring problem appears not much closer to being solved than when it was first studied more than a decade ago. None of the research efforts to date have developed a system that is completely reliable and accurate enough to allow ticket by mail (i.e. approaching 100%).

One development program is underway in the U.K., and the prospect is being held out that advances in computing technology, video recognition systems, and automated systems will soon (or eventually) reach the point when high-speed video from an externally-mounted camera (likely in combination with an infrared recognition system) will become a feasible means of determining vehicle occupancy.

Any such system would need to be practical, functional in varying weather and light conditions and be capable of identifying occupancy of the full range of HOV eligible vehicles (panel vans, cars with tinted glass, vehicles carrying small children etc.) No tests appear to have been carried out in more complex settings such as HOV 3+ facilities, or on urban arterial applications. Furthermore, all systems tested to date rely on single site-specific applications and have not addressed the functional requirements of an extensive network of freeway and arterial HOV lanes; a violator might simply avoid the one static camera location and use the remainder of the HOV lane (the vast majority of which are not barrier-separated from adjacent lanes).

It may therefore be concluded that the need for a system of automated vehicle occupancy monitoring remains, and that systems that attempt to monitor occupancy from outside the vehicle appear inherently incapable of achieving the effectiveness and reliability that is needed for automated HOV enforcement.

It may be noted however that in-vehicle systems and other areas of HOV monitoring research remain (apparently) unexplored and exhibit considerable promise.

2.3 Currently Available Technology Related to Monitoring and Enforcement

This section focuses on in-vehicle systems for occupancy detection, combined with various methods of processing and transmitting that information to agents responsible for monitoring and enforcing HOV facilities. Note that *both* elements are necessary for a functional HOV lane monitoring system.

The range of options for such methods is extensive, and the concepts discussed here are not necessarily exhaustive. The following provides a basis for discussion and consideration of future directions that are available for investigation.

1.

[7] project information from Dr. J. Brocklehurst, Photonics Consultancy (Aug 2004) and from www.laseroptical.co.uk

2.3.1 In-Vehicle Systems for Occupancy Detection

While occupancy detection systems for HOV applications have focused on using visual identification from outside the vehicle, rapid development of in-vehicle devices has generated technologies that can detect the number and location of occupants within the vehicle itself.

The main impetus for in-vehicle occupancy recognition systems appears to be air bag safety. It has been found that vehicle occupants (particularly passengers) who are seated too close to an air bag, or who are in child seats installed inappropriately, are at risk of injury from airbag deployment. As a consequence, the U.S. Federal Motor Vehicle Safety Occupant Crash Protection Standard (FMVSS 208) requires the use of "smart" air bags in the front seats of new vehicles sold in the U.S. as follows:

- 20% of 2004 model vehicles
- 65% of 2005 model vehicles
- 100% of 2006 model vehicles and thereafter.

"Smart" air bags rely on sensors to cancel deployment when the occupant is in a potentially dangerous position. FMVSS 208 does not apply to rear seats. Although the Standard applies only to vehicles sold in the U.S., that is the largest single auto marketplace in the world and most global manufacturers respond to the U.S. direction. Similar requirements may emerge in Europe and elsewhere.

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 area of automotive technology represents a major investment by the industry – one industry analysis in 2001 put the value of occupant-sensing products to 2006 at $US3.6 billion[8]. This far exceeds the level of effort being put into HOV lane monitoring and enforcement, and suggests that there may be considerable value in designing an HOV lane function that piggybacks on the in-vehicle occupancy detection initiative that is already well underway.

To comply with FMVSS 208, the technology used to detect vehicle occupants is not specified, as long as it meets criteria in terms of reliability, cost-effectiveness, size / weight, etc. Technologies for in-vehicle occupant sensing that have been investigated (not just for airbag operation) and/or developed to implementation include:

- Mechanical systems
- Various forms of photography
- LED imaging
- Infrared sensors
- Thermal imaging
- Weight sensors
- Capacitive and electric field sensors
- Ultrasonic range sensing

1.

[8] Automotive Systems Demand Report, Strategy Analytics Ltd., 2001

- "Medical" applications sensors (e.g. heart beat, breathing monitors etc)
- Finger Printing and biometric recognition
- Smart cards and readers

A brief outline of each in-vehicle system follows.

2.3.1.1 Mechanical Systems

The most basic device to monitor occupancy is the seatbelt, which already has sensors in it to monitor whether or not it is in use. A supplementary system can monitor seat belt pay out, whereby the seat belt would have to be extended a certain distance before registering an occupant, or seat belt movement over a period of time could be measured to confirm use.

In many jurisdictions, seatbelt use is mandatory. However, seatbelt use still relies on individual action and 100% compliance in general use has never been achieved. Even though the technical means of enforcing it are available (e.g. linking vehicle ignition with seatbelt closure), enforcement tends to rely on periodic blitzes supported by promotional marketing and education. There is some political sensitivity to the minority view that mandatory seatbelt use is an infringement on personal rights, but police, health, safety, and insurance industries are unanimous in its support. Australia is considering the implementation of in-vehicle devices to ensure that all occupants are belted before the vehicle can be operated[9].

If seatbelt closure were to be the sole measure of vehicle occupancy and not combined with some other occupancy sensor system, there would be a risk that a driver could simply leave a passenger belt buckled without any occupant in the seat.

HOV lane monitoring could be combined with seat belt monitoring in jurisdictions where seat belt use is mandatory – ie if at least two seat belts are not in use while in the HOV lane, the vehicle would be intercepted by police; if there is only one occupant, then the HOV misuse penalty applies, while if there are two or more occupants but the seat belt(s) are not in use, then the seat belt penalty applies.

2.3.1.2 Photography / Video

Photography from inside the vehicle is emerging as a technology that would have potential uses for security and emergency response systems. Such systems are already included in concept cars that have been displayed by manufacturers. They normally take the form of a very small lens housing in the rear-view mirror or overhead console, linked with an in-vehicle processor. For more sophisticated applications such as airbag deployment guidance, stereo cameras may be used[10,11] in conjunction with three-dimensional image processing to determine location, shape, and size of seated objects. The objective is to improve on weight-sensing systems in terms of occupant

1.

[9] Recommendations of Parliament's Standing Committee on Transport and Regional Services, as noted in "Car Immobiliser Bid to Curb Drink-Driving", Chris Jones, The Courier-Mail, Brisbane, June 22, 2004

[10] e.g. *Vision-based Occupant Sensing and Recognition for Intelligent Airbag Systems*, Y. Owechko et al, HRL Laboratories, 2003, submitted for possible publication in the IEEE Transactions on Intelligent Transportation Systems

[11] "The Future of Occupant Sensing", in *Automotive Engineering International*, p. 57, January 2003

location precision so that as much information as possible is available to the airbag deployment system and it can be adjusted accordingly.

Cameras have been used in research efforts to monitor driver alertness / drowsiness; such a system could readily be extrapolated to determine seat occupancy elsewhere in the vehicle.

Camera-based security systems have also been developed to compare a driver's face with an on-board database of legitimate users.[12] A further use of this technology is to record imagery for auto theft prosecution, or to transmit imagery to guide medical and accident response teams in the event of crash.

A number of reviews refer to the Volvo Safety Concept Car (SCC)[13] that has been shown at recent auto shows. One review of the SCC at www.autoweb.com.au stated that:

> *Joint studies by the Ford Research Laboratory and Volvo Cars have shown that it is possible to increase the amount of important information that is sent from the car to the alarm centre in the event of an accident. This information includes pictures taken by cameras located inside the car.*
>
> *The system also automatically notes how many people are in the car at the time of an accident, where they were sitting, how many of them were using the safety belt and the type of accident in which the car was involved. The system will even, to a certain extent, be able to provide feedback on the actual collision force to which the occupants were subjected…*

The cost, complexity, computing requirements, and practical / design issues have all been highlighted as concerns, but efforts are being made to resolve them so as to have a video-based system suitable for mass market application.

***It may be noted that use of video in the simple occupant counting function has less stringent technical requirements than if it is being used for occupant position sensing for "smart" airbag deployment*.**

2.3.1.3 LED Imaging

A system has been developed using a series of LED infrared transmitters and photodetector arrays to "bounce" LED light beams off a vehicle seat and produce a contour image.[14] The difference in the image when the seat is occupied is registered by an image analysis program and the determination is made of seat occupancy. A compact roof-mounted device is used. Different image patterns such as a child seat can be registered, although it may be difficult to determine whether a rear-facing child seat is actually occupied. This system does not appear to have progressed beyond the prototype stage, but the methodology seems fundamentally sound.

1.

[12] TRW system, as reported in "Candid Camera Security" in *The Australian*, p. 16., April 13, 2000

[13] Information on the Volvo SCC is available at the Volvo Concept Lab web site http://www.conceptlabvolvo.com/us/scc/

[14] *Occupant Detection Systems*, G. Wetzel et al, Telefunken Microelectronic GmbH, Technical Paper 971047, SAE International Congress and Exposition, Detroit, MI, February 1997

2.3.1.4 Thermal / Infrared Imaging

Thermal imaging for the purposes of monitoring the number and location of people and vehicles is already employed in a number of transportation applications such as:

- Transport terminals and waiting areas;
- Vehicle monitoring
- Pedestrian and bicycle paths
- Public space usage

Thermal imagery works by "seeing" the heat emitted by people passing under an infrared radiation sensor. One supplier of thermal imaging equipment, Infrared Integrated Systems (IRISYS)[15] claims that its system works equally well indoors or outdoors and in all weather and in complete darkness. Irisys suggests that future applications for its product include systems to ensure the safe deployment of internal airbags (depending upon on the presence and location of passengers within the vehicle). Also it suggests systems for sensing imminent collisions with pedestrian and triggering the deployment of external airbags.

In-vehicle infrared imaging can be set up as a high-resolution "passive" system which senses body heat and compares that "footprint" with a standard database, or as an "active" system which uses an array of laser beams to scan the passenger compartment and develop a 3-D image of it. Infrared systems tend to be distorted by clothing (gloves, hats), hot objects (cup of coffee), or red-colored material (upholstery), and can be complex and/or costly, so they may not be the first choice for the occupancy monitoring application.

One advantage of thermal imaging over photography would be that it is likely to be more acceptable from the viewpoints of privacy and civil liberties as the vehicle occupants and their precise actions within the car could not be easily identified.

It may be worth noting that direct thermal monitoring (i.e. through heat sensors embedded in seats) has been shown to be an ineffective means of determining seat occupancy[16], particularly when the ambient temperature within the vehicle approaches that of the human body.

2.3.1.5 Weight Sensors

It is a fairly simple matter to employ weight sensors to detect the number of seated passengers in a vehicle. It is the most common technique currently used to guide airbag deployment.

One approach (used, for example, in the Ford-Jaguar-Lincoln-Mercury group) is a bladder filled with silicone fluid tied to a pressure sensor under the seat cushion[17]. Data from the sensor is processed by an in-car unit which governs air bag

1. ___

[15] www.irisys.co.uk

[16] *Direct Thermal Detection for Front Passenger Seat Airbag Suppression*, D. Lambert, Society of Automotive Engineers, 1998.

[17] "Delphi Occupant Detection for Advanced Airbags", Kevin Jost, Automotive Engineering International Online, Oct. 18, 2000

deployment. Another technique is to attach strain sensors to the seat mounting system and measure the change in weight of an occupied seat.

One problem with weight sensing systems in the HOV application is the ability to "fool" the sensor by placing an appropriately-weighted parcel on the seat. This strategy would therefore work best in combination with some other occupancy sensing system rather than as a standalone technique.

Another example of weight sensing technology is the "flexible tactile sensor" developed by Japanese researchers[18], consisting of a thin pressure-sensitive membrane which can be installed within a car seat. It not only measures the presence of a weight on the seat, but can distinguish between a seated person and a child seat, and is reasonably reliable at distinguishing a child from an adult. This is intended to be used in air bag safety systems, so that air bag deployment reflects the size and location of the seat occupant. This type of system would also be able to distinguish between a seated human and a similarly-weighted package, box, or animal.

Another approach is to use magnetostrictive sensors (using principles of magnetic induction) as strain sensors[19], attached either to the seat mounting system or to wires within the seat itself.

It may be noted that, for HOV monitoring purposes, such weight sensors need not be applied to the drivers' seat, since that seat will always have an occupant. They would, however, need to be extended to cover the rear seat(s), since even in a 2+ HOV facility the passenger could be sitting in either the front or rear of the vehicle.

2.3.1.6 Ultrasonic / Radar Sensors

Ultrasonic waves can be used to detect occupants within a confined space.[20] Like infrared systems, this is not a precise technology for airbag use, but could presumably be accurate enough for HOV monitoring purposes. Radar and microwave systems operating under the same principles have been developed[21] but suffer from high cost and difficulty in distinguishing between a person and an inanimate object in the seat.

2.3.1.7 Capacitive Sensor

The human body has a distinctive and constant electrical "footprint", measured by field capacitance. A device may be placed above each seat in a vehicle to generate a low-level electric field which is altered by the presence of a person's head. This change in capacitance can be triangulated to determine the location of the head. It is not affected by hats or clothing. Unfortunately, the system must be located near the head, as its effectiveness diminishes beyond about 0.6m away; this could pose problems registering short passengers or children. Although a capacitive sensor

1.

[18] *An Occupant Sensing System for Automobiles Using a Flexible Tactile Force Sensor*, N. Kuboki et al, Furukawa Review No. 20, Furukawa Electric Company, 2001

[19] *The Use of Magnetostrictive Sensors for Vehicle Safety Applications*, T. Gioutsos, H, Kwun, Society of Automotive Engineers, 1997

[20] Bosch system, as reported in *European Automotive Design*, October 2000

[21] www.cambridgeconsultants.com/am_autoradar.shtml

system has been developed[22] and has applicability in numerous situations (medical, military, air bags, etc.) it has not yet been demonstrated in the particular context of detecting multiple vehicle occupants.

2.3.1.8 Heartbeat / Breathing Monitors

The Volvo Concept Car referred to above employs a heartbeat sensor to determine if animals or people have been locked in the car. It is also used to detect intruders within the vehicle. It may be possible to adapt this technology to determine the number of occupants in a vehicle.

> *...The heartbeat sensor registers the sound of a beating heart – both human and animal. The sensor is activated if for instance a sleeping child has been left in the child seat and the driver locks the door. A signal is transmitted to the remote control unit, which alerts the driver via a combination of audible signals and vibration pulses.*
>
> *The heartbeat sensor is also activated if anyone enters the car and hides inside. In such a case, the driver is not alerted automatically; instead, he or she must manually request this information within a distance of 100 metres from the car.*

Another possibility is to integrate breathing monitors (similar to those commonly used in medical or exercise monitoring applications) into seat belts. A prototype has been developed in Austria.[23] This would, of course, rely on the seat belt being used and would not detect an unbelted person; the associated issues were discussed in Section 2.3.1.1. It may be possible to embed the breathing monitor into the seatback instead, to eliminate the reliance on seatbelt use.

2.3.1.9 Fingerprinting and Biometric Recognition

Research is proceeding in a number of areas on fingerprint and other biometric recognition. A typical application would see the driver press a recognition pad and having a fingerprint compared with vehicle-specific database of allowed users. Positive matching would be required in order to start the vehicle.[24]

The Volvo Safety Concept Car mentioned above reportedly uses the driver's fingerprint on the remote control as a means of recognizing the driver, unlocking the vehicle and automatically adjusting the interior settings of the vehicle. It may be possible to adapt such technology (e.g. to recognize a minimum number of different people) to recognize all occupants of a vehicle as a means of determining the vehicle occupancy. Alternative biometrics (other than finger printing) may also be able to be used in this way – research is underway, for example, to develop a system using biometrics to determine bone density / brittleness of vehicle occupants so that more sensitive people (e.g. seniors) are not faced with seat belt / air bag impacts that are designed for healthy young people.

1.

[22] PASS system by Advanced Safety Concepts, Inc., in www.headtrak.com

[23] VOS company (now part of HENN GmbH, Dornbirn, Austria) as reported in ICARO Best Practices Part 1 – National Car-pool Policies in Europe, p. 66, April 1999

[24] Siemens system, as reported in "Candid Camera Security" in *The Australian*, p. 16., April 13, 2000

This technology could also be used to address the argument sometimes made that "legitimate" carpools in HOV lanes, particularly during peak periods, should consist of adults only, since a parent driving a child to school or an activity does not represent a reduction in vehicle use whereas two adults sharing a ride to work presumably involves leaving a car at home. Biometric recognition would be able to determine the ages and driver status of occupants from the in-vehicle database.

2.3.1.10 Smart Cards and Readers

Smart card technology is being used in a wide range of applications and may be capable of being used as a means of identifying the number of vehicle occupants. For the purposes of HOV occupancy monitoring this could conceivably involve items such as personal identity cards, driver's licenses, transit passes, toll highway transponders, cellular telephones and the like.

It is likely that the cards could be read from within the vehicle. Reading multiple smart cards from the roadside at highway speeds would present greater challenges.

2.3.2 Summary of In-Vehicle Systems for Occupancy Detection

From the information presented in the previous Section, it is clear that in-vehicle occupancy detection has become an established aspect of automotive safety, and that research, development, and implementation continues apace in what has been characterized as a multi-billion dollar new industry.

In-vehicle systems to detect auto occupancy have been developed in the forms of:

- Weight sensors
- Seat belt sensors
- Video, photography, infrared, ultraviolet, and LED light systems
- Thermal imaging
- Capacitive and electric field sensors
- Ultrasonic range sensing
- "Medical" applications sensors (e.g. heart beat, breathing monitors etc)
- Finger Printing and biometric recognition
- Smart cards and readers

For the purposes of the current study, it is not necessary to do a detailed comparative analysis of each implemented, proposed or emerging technique or system to measure seat occupancy in a vehicle. Furthermore, the market is dynamic and no single system has been settled on as a "standard" for the automotive industry. Enough evidence has been put forward, however, that it can be stated with some confidence that **the technology and in-vehicle systems exist to detect the number and location of occupants in a moving vehicle**.

It is also clear that the large-scale implementation of such systems is being driven by "smart" or "safe" air bag requirements, particularly the U.S. FHA's Federal Motor Vehicle Safety Occupant Crash Protection Standard (FMVSS 208), that requires all new vehicles sold in the U.S. to have such systems for the front passenger seat by the 2006 model year. HOV monitoring functionality may be able to "ride the coat-tails" of this safety initiative, and integration of the two functions should be kept in mind as the HOV monitoring strategy progresses.

Several of the more advanced systems being proposed or developed for air bag safety or other purposes reach well beyond the functional requirements of the HOV monitoring program, by measuring occupant location, movement, weight, personal identifying features, etc.

For HOV monitoring purposes, the more basic systems such as weight sensors or seatbelt monitors would appear to be adequate, with due consideration given to countering potential "cheating" strategies that might be employed.

2.3.3 Information Transmission Systems (Telematics) for HOV Monitoring

Once the number of vehicle occupants has been identified using some form of electronic monitoring as described in Section 2.3.1, the corresponding requirement is to transmit that information from the car to the HOV lane monitoring system / service.

Transmission systems that might be used in the HOV monitoring function include:

- Transponder / receiver systems
- Satellite-based systems
- Wireless ground-based systems

A brief overview of current systems follows.

2.3.3.1 Transponder / Receiver Systems

The most basic means of transmitting vehicle information to the roadside is by use of a windshield-mounted transponder which communicates with a reader mounted on a gantry over the traveled lane. This system can be used at speed, and is in widespread use for electronic collection of highway tolls.

The Highway 407 toll system[25], for example, uses a system of UHF antennas mounted on the gantry to track an approaching vehicle and classify it by type (car or truck) and identify whether it has a windshield-mounted transponder. The UHF radio frequency is a 500kbaud 915 MHz link. At an appropriate distance the tolling system emits a brief (10 millisecond) transmission which reads the transponder's identification (account) number and writes the time and place of system entry to the transponder's simple 256 bit memory. At an exit gantry, the transponder information is read and a distance-based toll is automatically calculated and either sent by mail or withdrawn from a pre-authorized account. If there is no response from the auto (i.e. it does not have a transponder), the vehicle's license plate is automatically photographed, linked with a database of registered vehicles, and the toll invoice sent to the registered owner.

The same approach could apply in monitoring an HOV lane, except with vehicle occupancy information embedded in the transponder's data packet. Transponders can

1.

[25] "Highway 407 Sets Standard for ETC", T. McDaniel and D. Galange, Traffic Technology International '96

be “dumb” and simply have vehicle identification embedded in them, or they can host varying degrees of “smart” features.

The use of windshield-mounted transponders and overhead antennae is not mandatory in the OMS application; it is equally possible to use in-pavement antennae / detector loops with downward-directed transponders mounted on the lower part of the vehicle. This may be a less costly, less intrusive (and hence less easily seen and avoided by the motorist) and more flexible communications strategy.

2.3.3.2 Satellite-based systems

The use of satellite-based Global Positioning Systems (GPS) to track vehicle movement is well-established technology in widespread use, particularly among commercial fleet owners. There are more than 20 GPS satellites in orbit, constantly transmitting their location using two microwave frequencies. When a receiver reads at least four satellite transmissions simultaneously, it can calculate its current location in three dimensions to within approximately 10-20 meter accuracy. Differential GPS (DGPS) can be used to obtain accuracy within 1 meter, but requires an additional receiver fixed at a known location nearby. Observations made by the stationary receiver are used to correct positions recorded by the mobile units.

Because the system works on “line of sight”, GPS is also known to have difficulties in working in areas of dense foliage, tall buildings or tunnels.

GPS receivers are passive; they simply register where they are and do not transmit any data. A vehicle-mounted receiver would therefore have to be linked with some other system to define its location relative to HOV facilities (i.e. in an HOV lane or not) and to transmit vehicle identification and occupancy data.

GPS might be applicable to barrier-separated or buffer-separated freeway HOV lanes where the “fuzziness” of the locational information is not critical. It would appear that GPS is less suited to non-separated or arterial HOV lanes, where reliable, accurate positioning relative to nearby general purpose lanes is a prerequisite.

2.3.3.3 Wireless Ground-Based Systems

The ubiquitous cellular telephone can be used to transmit and receive information from a moving vehicle. HOV lanes, being located within or near urban areas, may be assumed to fall within complete cellular phone coverage zones. Several such applications are already in place, a selection of which are outlined below.

General Motors’ Onstar service is an example of how wireless communications work in a highway application. Onstar uses a network of cellular telephone providers (originally analog, but now migrating to digital) covering most of North America to link a GM vehicle with a GM-operated call center. Onstar is linked to sensors within the vehicle and can be triggered either by the motorist or automatically. For example, if airbags are deployed, a message is automatically sent to the Onstar call center, where the operator will phone the vehicle and, if there is no response, dispatch emergency vehicles to the site. The Onstar operator can also use the system to perform simple diagnostics and other measures (e.g. opening a locked door, honking the horn) over the phone. Other vehicle manufacturers have similar systems.

As sensor and diagnostic technology evolves, combined with increased on-board computing power, wireless systems are expected to continue to grow in sophistication and functionality. For example, proposals have been put forth[26] for a national Automatic Life Saving System that would automatically communicate crash recorder data via wireless telecommunications to improve emergency transport and treatment of crash victims. The paper notes that software called "Urgency" has been developed to aid computer-assisted dispatch of rescue resources. The software automatically and instantly converts crash recorder data into a crash severity rating that calculates the probability of the presence of serious injuries in any given crash. The cost of the on-board system is "estimated at between $200 to $300."

The paper suggests that future versions of "Urgency" will include other sensor data such as pre-crash speed and braking deceleration, crash pulse, air bag time and level of deployment, seat belt forces, door openings, presence or absence of fire, **and number, size and seating positions of occupants**. Further it suggests that medical records also can be sent instantly to the Emergency department containing blood type, drug reactions, and current medication etc. so that this information is in place before the patient arrives.

One example of an existing product that might be able to be used in the occupancy monitoring task is WaveCell's telematics toolkit. This is a multiple-input in-vehicle device that transmits data over multiple wireless networks to a master server. A set of "if-then" rules is defined (in advance) for the operation of the in-vehicle device, and actions are controlled by the server. For example, a compartment on an armoured vehicle can only be opened when the system records that the vehicle is at a defined location and/or a defined time (or any other specified situation). In the HOV case, seatbelt sensors or other devices could monitor the number of people in the vehicle, the WaveCell device would transmit that information (e.g. "two or more sensors active = yes; one sensor = no") along with the vehicle's location to a server, where the information would be processed and the results transmitted to the police officer in the field or to the traffic counting centre. The WaveCell system, meanwhile, would also be transmitting vehicle diagnostics and emergency data at the same time.

In California, on-board diagnostics (OBD) have been a required feature of new vehicles since 1988. OBD technology monitors vehicle emissions and currently simply triggers a dashboard warning light if standards are not met; OBD3 will broadcast fault codes to roadside sensors so the authorities will also know if there is a problem (i.e. violation) with the car's emissions control. It is also understood that some vehicle manufacturers are thinking of applying it in other ways, for example as a pre-diagnostic tool upon entering a service center's lot - e.g. as you drive in for servicing, a sensor could pick up the Vehicle Identification Number and any fault codes the car is emitting in relation to its electronic systems. This would enable more rapid diagnostics and servicing.

1.

[26] *Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Service Providers,* H.R. Champion, et al, International Symposium on Transportation Recorders, 3-5 May, 1999 Arlington, Virginia.

It is possible to use cellular phones themselves to track vehicular movement in a general sense through aggregated tracking and triangulation of longitude, latitude, velocity and direction. This information is not precise enough, however, to distinguish between vehicles traveling in two adjacent lanes (i.e. an HOV lane and a general traffic lane) and does not appear likely to be useful in the near term for the HOV monitoring application. It is conceivable, however, that advances in telephone technology may ultimately permit vehicle location to be determined precisely enough to be of use in HOV monitoring.

In any of these systems, if identifying features (e.g. license plate) were included in the transmission from the vehicle, a fully-automated HOV lane monitoring system might arise - instead of identifying violators to police in the field, eligibility might simply be correlated with vehicle sensors in the field. If the ineligible vehicle was located in an HOV lane an automatic citation could be mailed to the vehicle owner. The approaching vehicle could even trigger a time-stamped photograph of the violation by a roadside camera (similar to a red light running installation), to be attached to the citation.

2.4 Summary of Existing Conditions

HOV facility monitoring and enforcement is carried out manually at present. There are currently no established automated HOV lane enforcement programs. The primary reason is the inherent difficulty in remotely or automatically determining vehicle occupancy.

Research has been undertaken in the past on a number of automated systems for monitoring vehicle occupancy. Some of these systems were conceived with an enforcement function in mind. In the past, HOV monitoring system research and testing has focused on systems that utilize roadside photography (of various types) from outside the vehicle to sense the number of vehicle occupants. None of the research to date has identified a system that is accurate and effective enough to be used as a primary HOV lane monitoring tool, due largely to the inherent difficulty in "seeing" through a vehicle to the occupants inside it.

However, research and development in in-vehicle occupancy sensing (primarily driven by air bag safety requirements) has highlighted technology that appears to have the potential to be adapted for use in an HOV monitoring and enforcement function. There is a wide variety of occupancy sensing techniques either in use or under development.

In addition, there are several systems available and in use for communicating diagnostic information (such as vehicle occupancy) between a vehicle and the roadside.

There is no "off the shelf" automated HOV lane monitoring solution readily available and in use at the moment, however. The HOV monitoring function needs to be brought in to the automotive industry's in-vehicle occupancy monitoring effort as a technical parameter, and systems developed to translate that information into a functional, reliable, and effective enforcement tool.

This review of technology has not directly addressed concerns about personal privacy, legal issues, consumer acceptance, large-scale implementation, and product roll-out that are likely to arise with any HOV monitoring system. The opportunity for integration, synergy and bundling with other future automotive systems that may be developed needs to carefully explored and considered. The industry, market, institutional and social constraints and implications that would be associated with each will also need to be explored. These issues are discussed in the Consultation section (Section 3) and addressed further in Section 4.

It is concluded from a review of the material outlined above that:

1. Automated HOV occupancy monitoring and enforcement would be beneficial if a reliable and accurate method can be developed;
2. While photography (including infra-red, near-infrared, video and digital photography) from outside the vehicle has been the primary focus of past research in this area and has been shown to have some potential and some scope for further improvement, this approach to occupancy monitoring appears unlikely to result in a solution that will be effective for real-time enforcement purposes in all relevant vehicle types, in all daylight and weather conditions, and in both freeway and arterial applications;
3. The automotive industry has developed several in-vehicle techniques to monitor vehicle occupancy; these appear to be able to be adapted and/or enhanced to allow HOV occupancy monitoring as a secondary function;
4. Advances in technology appear to make it feasible for a combination of in-car sensing and car-to-roadside information transfer to be able to deliver an effective automated HOV occupancy monitoring system; and
5. Issues such as privacy, consumer acceptance, and market penetration may be more critical to implementing automated occupancy detection systems than the technology itself; these issues will need to be addressed.

3. CONSULTATION

This Section contains details of stakeholder identification and consultation process for the project. It also summarizes input received form the various stakeholders and documents preliminary functional requirements for an Automated Carpool Occupancy Monitoring system.

Synergistic opportunities that have become apparent through the course of this project are also identified here.

The nature of this study is such that there is the need to gather a variety of perspectives from stakeholders, and to bring the documentation up to date in terms of what the auto industry is doing, is planning to do, and is capable of doing in this area. This information helps form the basis for concept analysis and the development of a business case for automated monitoring. The consultation was undertaken by e-mail, letter, and telephone in late 2003 and early 2004.

The following items are addressed in this Section:

- Stakeholder identification;
- Consultation process;
- Stakeholder input; and
- Summary of key issues.

3.1 Stakeholder Identification

There are three categories of stakeholder relevant to contact for this project:

- Planning / Policy / Transportation Providers
    - (generally public sector) selected from among HOV facility operators (MTO, BC MoTH, MTQ, Toronto, Vancouver, National Capital Commission, York Region, Mississauga, Gatineau, etc in Canada; MnDoT, WSDoT, Caltrans, TxDoT, and other U.S.A. states and local jurisdictions; various Australian and European authorities), Transportation Demand Management agencies (Black Creek Region TMA etc.), and Traffic Management Centre operators (MTO, Texas, Georgia, Minnesota, etc.).
- Manufacturing / Design / Vehicle Systems / ITS
    - (generally private sector), including the R&D arms of auto manufacturers, vehicle system and equipment suppliers (private firms developing and providing passenger safety and recognition systems to vehicle manufacturers), telematics suppliers / operators (private firms providing transponder / reader systems to highway authorities), and standards / trade organizations (AIAM-C, ITS America, etc.).
- Users, including enforcement agencies.
    - (state highway patrols, OPP, RCMP, municipal police authorities) and experts in the fields of legislation, privacy, human factors, and marketing.

Table 1 lists the specific stakeholders targeted in the consultation phase of this study.

Table 1: Potential Stakeholder Groups

Stakeholder	Jurisdiction	Contact / Interview
Roadway Agencies – responsible for planning and operating HOV lanes		
Canadian Provinces		
Ministry of Transportation	Ontario, Canada	Phil Masters (Advanced Traffic Mgmt Systems); Brian Gaston (Operations); Kayyoum Ali (ATMS)
407ETR	Highway 407, Ontario, Canada	
Ministry of Transportation and Highways	British Columbia, Canada	Jessie Bains District Operations Engineer Lower Mainland District Office
Transport Department	Quebec, Canada	
U.S. States		
Department of Transportation	Minnesota, USA	Paul Czech Principal Transportation Planner
Department of Transportation	Washington State, USA	Eldon Jacobson Advanced Technology Engineer
Department of Transportation	California, USA	Antonette Clark Chief, HOV Systems
Department of Transportation	New York, USA	Ed Mark Sr. Transp. Analyst
Highway Department	Massachusetts, USA	Luisa Paiewonsky Director of Transportation Planning
Department of Transportation	Texas, USA	Carlos Lopez Director, Traffic Operations Division
Australian States		
Roads and Traffic Authority	New South Wales, Australia	Robert Picone Leader, Bus Priority and Access Traffic Management Branch
Department of Main Roads	Queensland, Australia	Dennis Walsh
Municipalities		
Santa Clara County	Santa Clara, California, USA	John Elson
City of Toronto	Toronto, Ontario, Canada	John Niedra Director, Transportation Infrastructure Mgmt
City of Vancouver	Vancouver, British Columbia, Canada	Elizabeth Ballard Traffic Management Engineering Services
City of Burnaby	Burnaby, British Columbia, Canada	Peeter Liivamagi Assistant Director Traffic Engineering Systems
York Region	York Region (within Northern Greater Toronto Area), Ontario, Canada	Kees Schipper Commissioner, Transportation and Works
City of Mississauga	Mississauga (within Western Greater Toronto Area), Ontario, Canada	Tom Mulligan Director, Transportation and Engineering Planning, Transportation and Works Dept.

Agence Métropolitaine de Transport	Montreal, Quebec, Canada	James Byrns
Société de Transport De L'Outaouais	Gatineau, Quebec, Canada (within Ottawa / Gatineau urban area)	Salah Barj Chef, Stratégies et développement
Enforcement Agencies – responsible for enforcing HOV lane compliance		
Ontario Provincial Police (OPP)	Ontario, Canada	Inspector Alex Kehoe Regional Director, Operations
Royal Canadian Mounted Police (RCMP)	Canada (responsible for policing in the province of British Columbia)	Staff/Sgt Jim McVeigh
Minnesota State Patrol	Minnesota, USA	Capt Tom Fraser
Washington State Patrol	Washington State, USA	Capt Braniff, Field Operations Bureau
California Highway Patrol	California, USA	Doug Milligan Operational Research and Enforcement Policy Unit, Research and Planning Section
Texas Highway Patrol	Texas, USA	Texas Dept of Public Safety
Georgia Dept. of Motor Vehicle Safety	Georgia, USA	Captain Dan Jones
York Regional Police	York Region (Greater Toronto Area), Ontario, Canada	1 District Traffic Unit
Vancouver Police Department	Vancouver, British Columbia, Canada	Sgt Kinder Sandhu
Auto Manufacturers – representing in-car safety and technology systems		
Canadian Vehicle Manufacturers Association (CVMA)[27]	Canada	Ovi Cola Vincenzo Technical Consultant
Association of International Auto Manufacturers of Canada (AIAM-C)[28]	Canada	Mark Namtais President
DaimlerChrysler Canada	Canada	John Mann Director of Engineering
Ford	Canada	
General Motors	Canada	Stew Low
Volvo	Canada	Hugues Bissonnette Products Planning Manager
Others		
Wavecell	Ottawa, ON	
Johns Hopkins University APL	Mass. USA	
Transportation Research Board – HOV Committee		Dave Schumacher
Federal Highway Administration		Jon Obenberger

1.

[27] representing DaimlerChrysler, Ford, G.M., International Truck & Engine, Volvo Cars
[28] representing BMW, Denso, Fiat, Honda, Hyundai, Isuzu, Kia, Lamborghini, Mazda, Mercedes, Mitsubishi, Nissan, Peugot, Porsche, Saab, Subaru, Suzuki, Toyota, Volkswagen

ITS America		Paul Najarian Director, Technology Integration and Telecommunications
ITS Canada		Colin Rayman General Manager
Black Creek Regional Transportation Management Association	Black Creek Region of Greater Toronto Area, Ontario, Canada	Janet Lo Executive Director

3.2 Consultation Process

3.2.1 Letter of Introduction

Stakeholder consultation was initiated by a letter of introduction from McCormick Rankin and completed by telephone interview carried out by a senior consultant.

Stakeholders were sent letters on McCormick Rankin Corporation letterhead introducing the project (copy in Appendix B). The letter provides a brief background to the project including:

- explanation of the project purpose;
- explanation of Enterprise's role and how further information on Enterprise can be sourced;
- description of the need for an automated HOV enforcement system;
- a summary of some of the issues and opportunities that have arisen in this field to date;
- a disclaimer from commitment to future directions or policy by Enterprise or its member organizations;
- advice that we would seek the agency's input to the project through a telephone interview;
- invitation to nominate a contact person for their agency; and
- contact details for the study team

3.2.2 Information sought from Stakeholders

Specific information to be sought from each stakeholder is summarized in Table 2 below. These areas can be broadly grouped into four categories:

- Areas of current research
- Baseline requirements
- Technical aspects
- Legal/legislative/privacy implications

Table 2: Information Sought from Stakeholders

Issue to be Addressed	Stakeholders Group					
	Road Authorities	Municipalities	Enforcement Agencies	Vehicle Manufacturers	Transportation Management Associations	Experts in Legislation, Privacy, Human Factors, and Marketing
Areas of Current Research	✓	✓		✓		
Cost (both on board vehicle and system-wide)	✓	✓	✓	✓	✓	✓
Universality of application/mandatory vs voluntary	✓	✓	✓	✓	✓	✓
Privacy concerns	✓	✓	✓	✓	✓	✓
Accuracy/reliability	✓	✓	✓	✓	✓	✓
Effectiveness	✓	✓	✓	✓		
Technological problems/issues	✓	✓	✓	✓		
Commercial issues (e.g. proprietary systems vs. open systems)	✓	✓	✓	✓		✓
Time frame for implementation	✓	✓	✓	✓	✓	
Legal or legislative obstacles	✓	✓	✓	✓	✓	✓
Ticket by mail	✓	✓	✓		✓	✓
Are there other ways to accomplish the same ends	✓	✓	✓	✓		
Potential other applications/benefits /synergies	✓	✓	✓	✓	✓	✓
Partnership opportunities	✓	✓	✓	✓		

3.2.3 Telephone Interviews

Contact with the stakeholders took the form of several questions, initially by telephone using a free conversation format. That is, it was not presented as a formal "questionnaire". For the purposes of ensuring completeness and consistency, the study team member interviewer did, however, refer to a copy of a pro forma checklist covering all of the issues that were relevant to this part of the study. The interviewer:

a. explained who we are, who we are working for, what we are doing, and how we arrived at the contact information

b. briefly described the concept of a system that monitors vehicle occupancy and transmits that information to police who are charged with enforcing freeway and arterial HOV lane usage

c. noted some of the other potential applications of such a system (High Occupancy Toll lanes, traffic counting, seatbelt enforcement, carpool priority parking, carpooling incentive programs, and so on)

d. enquired as to what issues or concerns might arise or need to be addressed

The interviewer let the respondent identify issues initially, then triggered some discussion regarding their views on the relative significance of possible issues such as:

- cost (both on board vehicle and system wide) (who pays – HOV operators, manufacturers, users?)
- universality of application / mandatory vs voluntary
- privacy concerns
- accuracy / reliability
- effectiveness
- technological problems / issues
- commercial issues (e.g. proprietary systems vs. open systems)
- time frame and strategy for implementation (e.g. near-term objectives vs. time needed for fleet turnover, widespread vs. targeted application)
- legal or legislative obstacles
- ticket by mail
- are there other ways to accomplish the same ends
- potential other applications / benefits / synergies

The discussions were framed strictly in the vein of technical research for system feasibility, emphasizing that we are not retained by any government to implement any such system, and that this is simply background academic research that may trigger further exploration of the technology and possibilities by the industry.

Following the telephone interview the study team followed up with individual stakeholders by e-mail or mail if and as necessary.

3.3 Stakeholder Input

Individual stakeholder comments that have been received are included in Appendix C, under the headings:

1. Cost
2. Privacy Issues
3. Technological Problems / Issues
4. Accuracy and Reliability
5. Mandatory vs Voluntary Application
6. Timeframe for Implementation

7. Legal or legislative obstacles
8. Ticket by Mail
9. Potential other Applications / Benefits / Synergies
10. Partnership Opportunities
11. Commercial Issues
12. Alternative Solutions
13. Other Issues Suggested / Raised

The comments received in telephone interviews reflect the agencies' experience with HOV enforcement issues and relevant officers' / employees' opinions. It should be recognized that the comments themselves have been made by individual officers / employees interviewed and therefore should not be construed to reflect official future direction or policy of the agencies represented.

These comments do, however, form an excellent basis for assessment of current issues and future potential for the concepts discussed.

We are indebted to those who took the time to participate in this study. Some agencies declined to participate, while a few did not return repeated calls. It was found that the auto manufacturers were generally uninterested in discussing the subject, for reasons of commercial confidentiality, low priority, and/or unwillingness to be seen to support a project that could ultimately add cost to a new vehicle and influence new car sales. While this is an understandable perspective, it points to the need for any subsequent work in this area to find a more effective mechanism to involve the auto industry.

3.4 Summary of Stakeholder Comments

The following is a summary of the individual comments from stakeholders that were received and were detailed in Appendix C. Common themes have been identified, as have conflicting notions.

3.4.1 Cost

The cost associated with implementing an automated HOV enforcement system was seen as being a very important issue by many of the stakeholders. 13 of the stakeholders interviewed made specific comments about costs. Many of the balance indicated that they did not have a feel for the kind of costs that would be involved.

It is fair to say that the relatively abstract nature of the concept being discussed would make it difficult for stakeholders to understand and form a detailed view on cost issues. **This is, therefore, an area that should be further explored in later phases of research.**

Of the 13 groups that made specific comments on costs:

- Eight expressed a view that the cost should **not** be passed directly onto the motorist (some qualified this by saying that this would only be acceptable if there was some tangible benefit to the user – e.g. if the equipment necessary provided exclusive access to an HOT facility)

- Four stated that cost benefit/cost effectiveness of a system would need to be proven early in the process for their governments to have any interest in pursuing the concept.
- Two noted that their agencies do not derive revenue from the HOV enforcement activities that they undertake, and their agencies' approach to enforcement would probably be different if it did. It was also noted that public perception / acceptance of enforcement activities may be more positive if revenue were to be earmarked rather than being pooled into general coffers.

3.4.2 Privacy Issues

The privacy aspects of implementing an automated HOV monitoring system were viewed as very significant by many of the stakeholders. 16 groups made specific comments about privacy. Five groups commented that privacy was the **single biggest issue** that would need to be overcome to enable a system to be implemented, or stated that they thought that sensitivity to privacy in their jurisdiction would prevent an automated HOV system from **ever** being implemented.

Suggested methods of addressing/managing privacy appropriately included:

- linking the system to some form of exclusive benefit bestowed by accepting the implications of having the monitoring equipment in the vehicle. Access to these benefits could perhaps be conditional upon the motorist entering into a user agreement through which privacy issues are clearly defined and the user consents to the monitoring regime proposed. This is the approach that has been adopted, apparently successfully, for toll facilities and border crossing systems particularly in California.
- Permit option of prepayment or automatic direct debit for fees and fines so that detailed invoices (noting times, dates, number of passengers etc) are not mailed to vehicle owner. This is unlikely to provide an acceptable result in isolation as it is likely that most people would want the right to challenge any enforcement regime (particularly an automated one).
- Await a time of increased public acceptance of surveillance and monitoring before implementing an automated HOV monitoring system. One school of thought proposes that surveillance and monitoring (or the potential for surveillance and monitoring) is rapidly increasing in many aspects of modern life. Examples are:
    - Surveillance cameras in public places
    - Introduction and acceptance of photo radar and red light running cameras in some jurisdictions
    - Telephone and cell phone records
    - Credit card and other financial records
    - Increased passport and border controls
    - Event data recorders in vehicles

- Data sharing between government departments and across jurisdictional boundaries

  It is considered by some that the public's sensitivity to automated monitoring will decrease over time as more such systems become commonplace. Consequently, privacy concerns that are raised in 2004 may diminish in significance in coming years or decades. On the other hand, the ever-encroaching monitoring of what was once private activity may generate stronger public resistance as time goes on.

- Implement a significant public education campaign to make clear the benefits to society and to justify the arguments for an automated HOV monitoring & enforcement system.

  This may not be a solution in itself however it would be desirable as a part of a package of measures to implement HOV initiatives including any new enforcement regime.

A number of respondents suggested that an in-vehicle device that had a monitoring for enforcement purposes function (regardless of other functions that the device may have) would probably always be unacceptable to the public.

3.4.3 Technological Problems / Issues

Seven respondent groups made specific comments about technological problems or issues. Of these, five groups stated that they did not believe that technology would be a barrier to the development of an automated HOV monitoring and enforcement system; many noted that social and political and/or cost hurdles would be more significant than those posed by technology. It was noted that in-car monitoring, diagnostic, and communications systems are already being implemented at a rapid pace, and that occupancy monitoring may be included as a minor add-on or supplementary application.

Other issues related to technology that were raised by respondents included:

- A rollout of an in-car system would take a long time and how to get from where we are today to where we want to be is one of the most significant challenges.
- Concern that there should not be any public health impacts of the sensing technology used.
- Technology cannot be expected to provide a solution on its own. In addition to technology, a full package of public education and marketing is needed to influence culture and driving habits this should be combined with good design to enable enforcement to take place.
- Government would need to take on a coordinating role to achieve a consistent platform across different facilities and jurisdictions.

3.4.4 Accuracy and Reliability

Ten groups made specific comments on the need for accuracy and reliability in an automated HOV monitoring and enforcement system. While several noted that technology associated with an automated system would need to be highly accurate and reliable in order to permit automated enforcement including ticket by mail, it was also pointed out that a lower standard of accuracy could be tolerated if the system were to be simply used to flag vehicles for further scrutiny by enforcement officers. **Accurate positive identification of offending vehicles would be a critical requirement** of any automated enforcement system if public faith and hence acceptance is to be achieved.

It was noted that an automated enforcement system would need to overcome problems like violators trying to fool the system (for instance by placing dummy passengers in the car) in order to enter the HOV lane.

Precision and accuracy will be of particular concern if an automated system is to cater for arterial HOV lanes where there are often many legitimate reasons for non-HOVs to enter certain sections of the HOV lane.

It was noted that accuracy and reliability in regions that experience severe weather conditions (for example snow and ice) would present greater challenges than for other regions where severe conditions are not experienced.

3.4.5 Mandatory vs Voluntary Application

Seven groups made specific comments on this issue. Those commenting predominately noted that:

- Government regulation would be necessary to see monitoring equipment installed in all cars even if this were introduced with new cars only.
- Government regulation and co-ordination would be desirable to ensure consistent standards and so that interoperability could be achieved across individual facilities, regions, states/provinces and countries. Ideally, any vehicle should be potentially eligible to use any HOV facility in any jurisdiction.

It is significant that none of the respondents indicated that these issues should be left to market forces to resolve if an automated enforcement system were to be pursued.

In areas with a small HOV network, the overall percentage of the vehicle fleet using HOV facilities would not be high, and the time required before the majority of the vehicle fleet could be fitted with monitoring equipment from new would be very long. Consequently there may not be a great benefit in fitting all cars.

It is noted that the stakeholder agencies contacted for this project are those with a background and current interest in HOV operation. There are many areas in North America where there are no HOV programs in use and therefore little interest in automated HOV monitoring.

3.4.6 Time Frame for Implementation

Nine groups commented on the potential time frame for implementation of an automated HOV enforcement system. Five stated that the timeframe would be “long term”, a number further qualified this by stating that the concept may never be publicly and politically acceptable. **It should be noted that respondents generally noted the need for a better way of monitoring and enforcing HOV facilities in their jurisdictions is immediate.**

The most frequent reason given for the long time frame (other than issues associated with public/political acceptability) is the length of time necessary to roll out equipment into the full new vehicle fleet. This was estimated by some to be of the order of ten years.

Only the respondent from the Texas Department of Transportation noted that the time for implementation could be short term - if it can be linked to HOT lane usage. This is an area likely to be more acceptable to the public. The suggestion is that:

A possible means of introducing an automated HOV enforcement system would be to introduce it for motorists that want to use a particular facility (e.g. for a free ride in HOT lanes for an HOV). These vehicles would need to be fitted with monitoring equipment and the owners would need to accept the conditions of use and entry. Widespread usage may follow more easily once this scenario became established and accepted.

3.4.7 Legal or Legislative Obstacles

Comments on Legal and Legislative obstacles to automated HOV monitoring and enforcement were made by 13 respondents. All noted that new legislation or legislative changes would be necessary to allow automatic enforcement. Comments on the likelihood of such legislative changes being successfully implemented in the near future were mostly negative.

In most cases it was considered that there would not be legal problem with monitoring the number of people in a vehicle (notwithstanding the privacy concerns noted elsewhere in this document) as this is currently carried out (manually) for travel data collection purposes in most jurisdictions. However the enforcement aspects are expected to need to be addressed.

It was noted that safety-related automated enforcement measures such as photo radar and red-light cameras had been politically unacceptable in a number of jurisdictions. Consequently these programs had not been able to be introduced or had been introduced and later withdrawn. It was noted by some respondents that if automated enforcement programs with clear links to safety had been unacceptable politically, that a program whose focus is on travel demand management would be even less likely to find acceptance.

A further problem noted in some jurisdictions is the current principle that, to be successfully prosecuted, traffic violations of all kinds need to be to observed and a ticket written by a law enforcement officer. This officer must then be available to provide evidence in court. This is clearly inconsistent with a proposal to automate the enforcement process and is likely to present a significant challenge in relevant jurisdictions.

It was noted that there may also be implications for the court systems. In some jurisdictions court systems are already heavily loaded with traffic offence cases. The concern was expressed that if an automated enforcement generated many new cases further loading the court system, many of the violations could pass without being dealt with, consequently the entire system (including HOV enforcement) could further lose its effectiveness. This issue would need to be dealt with prior to introducing a new automated HOV monitoring program.

3.4.8 Ticket by Mail

A ticket by mail program for HOV Enforcement would necessitate new or revised legislation in all of the jurisdictions contacted for this project. This need is seen as problematic by the representatives of some of the agencies contacted because automated traffic enforcement systems such as photo radar and red light cameras have not been met with public or political acceptance in the recent past. The laws of some jurisdictions are currently framed such that all tickets must be written by a law enforcement officer and are thus completely inconsistent with automatic enforcement and ticket by mail.

Within other jurisdictions it is considered that the ticket by mail aspect of an automated enforcement system would not present a significant barrier to implementation.

Ticket by mail presents the issue of citing a vehicle owner rather than the vehicle driver. Most jurisdictions that have implemented photo radar or red light cameras address this issue by placing the onus of proving another driver was responsible for committing a violation on the vehicle owner. A number of respondents considered that this arrangement would be appropriate for automated HOV enforcement too.

Reliability and promptness were other prerequisites of an effective ticket by mail program.

3.4.9 Potential other Applications / Benefits / Synergies

Stakeholders suggested a wide range of potential associated applications. There were also some suggestions for interim or alternative HOV enforcement arrangements.

Suggestions that might be relevant to the full implementation of an automated HOV monitoring and enforcement system would include:

- Managed lanes systems whereby toll access could be managed not only by HOV/non-HOV status but where toll price could be varied by the number of occupants in the vehicle.
- Tolling Systems
- HOT lanes
- Car pool incentive programs
- Preferential parking schemes
- Parking management systems
- Seat belt monitoring
- Traffic counting
- Network performance monitoring (vehicles as data probes)
- Data collection for vehicle emission studies
- Electronic license plates
- Digital drivers licenses
- Stolen/unregistered vehicle monitoring and enforcement
- Border crossing and anti terrorism applications

- Enforcement of following too closely
- Speed enforcement/speed control
- Red light running enforcement
- Clean vehicle priorities (in conjunction with HOV use)
- Roadside assistance systems
- Transit and HOV priority at traffic signals

3.4.10 Partnership Opportunities

Eight respondents commented on partnership opportunities. All eight suggested that partnership opportunities exist. Most indicated that appropriate partnership opportunities were desirable however one noted that private contractors undertaking law enforcement sent the wrong message to the public and could be interpreted as a profit making/revenue raising activity.

HOT facilities, which are typically privately managed, were suggested as one area that would be particularly applicable for partnership opportunities in relation to an automated monitoring and enforcement system. It was also suggested that partnerships with the private sector would be essential to enable the development and implementation of an automated monitoring and enforcement system.

3.4.11 Commercial Issues

Three interviewees commented on commercial issues. The comments received here reflected the need for any automated monitoring and enforcement system to be interoperable with other facilities and jurisdictions.

The need to ensure an appropriate quality product that that will deliver the required functionality, and the need to respect probity issues were raised as being key requirements.

3.4.12 Alternative Solutions

Potential HOV enforcement solutions other than automated electronic in-car monitoring and enforcement that were suggested include:

- Manual enforcement by police (ie status quo)
- “Honor” system with only occasional random manual checks but including very high fines for violation as a large disincentive to ever being caught.
- Use of manual enforcement as just one component within a package of measures including marketing, education, and engineering.

3.4.13 Other Issues Suggested / Raised

Additional issues and suggestions that respondents raised include:

- There is an immediate need for a better, more cost effective, way of enforcing HOV (and HOT) lanes and facilities.
- HOV enforcement is often not a high priority with law enforcement agencies due to limited resources and the need to focus on safety-related enforcement activities. However, HOV violators tend to violate other traffic rules as well, so HOV enforcement is targeted to some extent on high-risk motorists.

- Funding of HOV enforcement is often not a high priority with transportation authorities because it is expensive and competes for scarce budgetary resources that could be allocated to other infrastructure and TDM programs.
- In most jurisdictions, revenue collected from HOV enforcement does not return to HOV (or other TDM) programs not does it return to law enforcement programs.
- Visible police presence on the ground for the purposes of HOV enforcement has other benefits in relation to the public perception and in relation to the detection of other types of traffic violations and crimes.
- A number of respondents suggested that rather than trying to monitor all vehicles in an attempt to provide 100% enforcement coverage, another approach may be to carry out random enforcement but to significantly raise penalties for non-compliance such that there is a massive disincentive to ever being caught in violation.
- HOV non-compliance (and fine revenue recovery) should ultimately be tied to driver's license and/or motor vehicle registration renewals.
- The deterrent value of enforcement is related to:
    - The chances of being caught
    - The swiftness of the penalty
    - The severity of the penalty

3.5 Implications of Stakeholder Comments

The consultation completed thus far has revealed the following key issues:

- From the viewpoint of the state, provincial and municipal transportation agency representatives consulted the most significant challenges involved in implementing an automated HOV monitoring and enforcement system relate to public and political acceptance of the concept. This in turn relates to perceived privacy and civil liberty issues. It appears to be clear that in many jurisdictions where safety-focused automated enforcement systems such as photo radar and red light cameras have been rejected, TDM-focused automated monitoring enforcement would not find public and political acceptance in the near term.
- Comments from respondents in jurisdictions where photo radar and/or red light cameras are operating and have found public acceptance also indicate that widespread automated enforcement focused on TDM would probably not be acceptable publicly or politically right now.
- It was generally accepted by the transportation agency respondents that the technology necessary to implement an automated HOV monitoring and enforcement system, if not already available, soon would be. Technology therefore was not considered to present a challenge to the concept by this group of stakeholders, particularly when considering the medium and long terms.
- The cost of implementing a technology based automated HOV monitoring and enforcement system was seen a being a significant issue that would compete

with resources for other programs. It is likely that a system would only be supportable if the additional cost of in-car components was nil or marginal. The cost of roadside monitoring equipment (depending upon its quantum) is more likely to be acceptable to transportation agencies if it provides additional functionality (such as traffic data collection) and if revenue gained from enforcement activities is returned to fund the program.

- Ticket by mail, while seen a problematic in some jurisdictions, would have the greatest chance of acceptance if:
    - the system were to provide unambiguous positive proof of offending vehicle identification
    - the violation notices are delivered promptly to vehicle owners
    - the challenge/appeal processes are seen as fair and reasonable, and are not open to abuse (for example avoidance of penalty simply through frivolous challenge)
    - the court system is capable of dealing with the volume of citations
- The desirability of interoperability across different facilities and jurisdictions is widely recognized. It is considered that this will necessitate significant government and industry coordination and cooperation if a consistent rollout across the continent is to be achieved. A considerable, although currently undefined, timeframe may be necessary to achieve this.
- Voluntary participation in a monitoring and enforcement program associated with toll or HOT facilities (possibly privately managed facilities) may provide the most feasible near-term opportunity to trial and/or introduce a system in advance of more widespread implementation. Voluntary participation including explicit acceptance of terms of use would enable a means of overcoming privacy and civil libertarian issues, at least in the context of a pilot project. The success of such a pilot scheme(s) may be useful in ultimately winning wider public acceptance for a more widespread rollout of a system. Conversely poor publicity could introduce significant setbacks.

Suggestions for synergistic opportunities that might be relevant to the full implementation of an automated HOV monitoring and enforcement system have included:

- Applicability in tolling / pricing / lane management environments
- Applicability in non-HOV lane incentive programs such as parking
- Monitoring seat belt use
- Use in data collection / traffic monitoring / network monitoring
- Applicability in other enforcement areas (stolen vehicles, speed monitoring, red light running, border crossing, anti-terrorism, electronic license plates, etc.)
- Motorist support and assistance systems
- Clean vehicle priorities (in conjunction with HOV use)
- Transit and HOV priority at traffic signals

4. OCCUPANCY MONITORING SYSTEM FUNCTIONAL REQUIREMENTS

4.1 Functional Requirements

The technical objectives of the vehicle occupancy monitoring system are:

- Accuracy
- Reliability
- Economy
- Utility and
- Good Design

Table 3 below lists mandatory and desirable functions for each of these objectives.

Table 3 Draft Functional Requirements

Attribute	Mandatory Functions	Desirable (Secondary) Functions
Accuracy	Count to see that the number of vehicle occupants equals or exceeds the threshold figure for the facility it is using.	Count all vehicles and all occupants in those vehicles
		Recognize the current threshold figure for each HOV facility (i.e. 2+ or 3+, time of operation)
	Precisely count all seated occupants in vehicles including small children, children in child seats, etc	Precisely count all occupants in the vehicle including any hiding (eg in luggage compartments etc)
	Precisely recognize non-compliant vehicles and positively identify vehicle registration	
	No false readings (animals, dummies, etc.)	
Reliability	Low rate of "down time"	Tamper-proof
Economy	Capital cost per vehicle less than say ($100?).	Minimal instrument / equipment requirements for new HOV lane infrastructure
	Minimal cost to the individual user	Similar cost to retrofit operating vehicle as for a new vehicle
Utility	Monitoring frequency high enough to discourage evaders	Continuous monitoring rather than point recognition
Privacy	Recognize vehicle, not occupants (per privacy protection)	
Design	Monitor and transmit occupancy data at speeds ranging from 0 to 150 km/h	
	Monitor and transmit occupancy data in all kinds of weather, light, roadway, and traffic conditions	
	Unobtrusive to users	Invisible to users
	Automated – requires no action on the part of vehicle occupants	Feedback to driver (e.g. dashboard light confirming registered number of occupants)
	Minimal additions / changes to vehicle equipment	Can be easily retrofit to existing vehicles

4.2 Alternative Occupancy Monitoring Systems (OMS)

The development of an automated HOV occupancy monitoring system begins with the premise explored in the previous Sections – that the means exist to identify the number of occupants of any particular vehicle and for that information to be available in electronic form, either for transmittal from the vehicle or for an external reader to interrogate.

For that information to be useful in an HOV lane context, it has to be either

a) available for all potential vehicular users of an HOV lane; or

b) available for all "registered" users of an HOV lane, as a subset of all vehicles.

If only a few vehicles are fitted with the device and the HOV lane is used by vehicles with and without the monitoring system, then police presence in the field is still necessary to distinguish between valid and invalid HOV lane users.

No matter what, it is recognized that the rollout of such a system cannot realistically be mandated or retrofit to all registered vehicles in North America in a short period. It may be that automated occupancy counting devices do populate the marketplace over the course of a decade or more (for example, all new vehicles sold in North America beginning in the 2006 model year will be required to at least sense if the front passenger seat is occupied, and fleet turnover would bring that technology into widespread, if not ubiquitous, use by 2012 – 2015). There will, however, always be a proportion of older vehicles in use that do not have an in-vehicle monitoring system.

Furthermore, 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 not be worthwhile applying it to every vehicle in North America; HOV lanes form a tiny proportion of the road network and HOV lane users an equally small proportion of overall road traffic. HOV lane violators are themselves a small subset of HOV lane users. It will make no sense for every new vehicle sold in a rural part of the country to have a mandatory occupancy sensing device for HOV lane monitoring purposes when there is no prospect of any HOV lanes being provided in that region. The monitoring system add-on (either mandatory or voluntary) would therefore be limited to vehicles sold within a certain zone defined by the presence of existing or planned HOV facilities.

This leads to the inevitable conclusion that, for HOV lane monitoring use, there is no near-term possibility of *all* North American vehicles being fitted with occupancy monitoring sensors, and therefore either the use of HOV lanes must be limited to monitoring system-fitted vehicles, or the monitoring system is only to be used as a supplementary enforcement tool rather than an exclusive / automated monitoring system.

For an automated HOV lane monitoring and enforcement system, therefore, the HOV lane users must be "pre-screened" so that every vehicle in the lane has an in-vehicle occupancy monitoring system. The simplest means of doing so is to develop legislation and post signs to that effect – "OMS (Occupancy Monitoring System) Vehicles Only" to supplement the eligibility requirements. This would have the negative effects of both introducing yet another traffic rule violation category (requiring enforcement) and dampening the attractiveness and convenience of the HOV lane for casual or occasional users. It also triggers the need to distinguish not only between HOVs and non-HOVs, but also between HOVs with on-board occupancy monitoring systems and those without.

This "pre-screening" is not unheard of, however: Highway 407 near Toronto requires all vehicles of 5t or over to use an electronic transponder (under threat of a heavy fine); and EZ-Pass style toll lanes are not available to motorists without the pass. As long as there is value in the use of the HOV lane, regular users may be assumed to be interested in obtaining the necessary "permissive" equipment to use it. It is in the proponent's interest, of course, to make such equipment inexpensive, widely available, and convenient to install and use.

The HOV lane violation, under these circumstances, becomes "driving in an HOV lane without an Occupancy Monitoring System" – regardless of the number of occupants – and/or "driving in an HOV lane with fewer than the minimum number of occupants". Unless a vehicle provides positive OMS identification *and* the OMS registers the appropriate number of occupants, the system would automatically record and cite the violation of either the OMS or HOV criteria.

Vehicle Using HOV Lane	**< 2 occupants**	**2+ occupants**
In-Vehicle OMS	HOV violation	No violation
No In-Vehicle OMS	OMS violation	OMS violation

In the case of the vehicle with no OMS and only a single occupant, the violation would be of the OMS statute, since there would be no direct evidence of the number of occupants and the HOV violation would therefore not be recorded. Police observation in the field would be necessary if the HOV violation were to also be applied.

The processing system would have to correlate multiple violations in a single corridor (e.g. a violator driving past four or five monitoring sites along a particular freeway) and issue one citation. Corridor segments could be defined to determine where a second violation occurs (e.g. if a violator is recorded in two different freeway segments along the same trip, they would presumably get two separate citations in the mail, just as if they had been stopped by two different police officers in the two locations).

Alternatively, a basic OMS could be used in combination with police presence in the field to enhance conventional visual monitoring and enforcement. If police were able to "read" the number of occupants in an oncoming vehicle they could focus on closely (visually) scrutinizing vehicles that either do not have an OMS or are "read" as having fewer than the minimum number of occupants. At its most basic, an occupancy register could take the form of a small forward-facing light (green for two occupants, blue for three if necessary) or set of lights mounted on the front, side, or windshield of the vehicle. A more advanced system could provide the police with a handheld or in-vehicle readout of occupancy generated as HOV lane users cross an upstream monitoring station.

This basic OMS would improve police efficiency in citing violators, and could be used to pull violators over or in combination with a police-triggered license plate photo system to support a ticket-by-mail scheme that does not require intercepting and citing violators on the roadside.

All of the above relies on site-specific monitoring stations rather than continuous HOV tracking by satellite or radio. This is a weakness, in that HOV lane violation can occur unrecorded at points between the monitoring sites. GPS accuracy would need to be improved and in-vehicle OMS rollout would need to reach the near-100% level before continuous HOV tracking (and more importantly, non-HOV recognition and tracking) can be relied on for automated HOV lane monitoring and enforcement. These conditions are foreseeable but appear likely to be a decade or more in the future.

However, if the monitoring infrastructure at the roadside is kept simple and low-cost, very good coverage should be achievable in the near term. The following general guidelines may be suggested:

- Freeway barrier-separated HOV lanes:
  - one monitoring site between each access / egress zone
- Freeway buffer-separated HOV lanes:
  - one monitoring site between each access / egress zone
- Freeway non-separated HOV lanes:
  - one monitoring site every 1 or 2 kilometres, and at known high violation areas
- High-speed arterial HOV lanes:
  - one monitoring site per long block, located near the start of a queue-jump zone
- Low-speed urban arterial HOV lanes:
  - one monitoring site per short block, or equipment shifted randomly among enclosures to cover every 3 – 4 blocks.

Compared to the current practice of sporadic field police presence, this level of coverage would represent a quantum improvement in HOV lane monitoring and enforceability.

If, for legal purposes, photographic evidence of the HOV lane violation is required for a ticket-by-mail scheme, the system becomes more complex. It is fairly straightforward to automatically take a photo of a vehicle license plate and correlate that with a database of registered vehicles and send the citation to the vehicle owner, who is then responsible for payment – Highway 407 in Toronto does that several hundred thousand times a month. It does require, however, a fixed overhead gantry-mounted camera system, which then becomes both a costly system to install on a widespread basis (particularly in the arterial HOV lane case) and requires high-capacity telecommunications systems (e.g. fibre optic cable) to send the video imagery to the processing centre. It also requires additional computing power and staffing at the processing centre. Most importantly, though, the gantry is an obvious enforcement point which the conscious HOV lane violator will be able to see and avoid. This problem can only really be avoided in a barrier-separated environment where the HOV lane user is “trapped” in the facility, or by implementing cameras with such frequency (e.g. every 1 km along a freeway HOV lane or every block on an arterial) that the violator cannot realistically avoid *all* the monitoring sites.

Can the camera infrastructure be avoided? Yes, but it requires a vehicle identification “tag” on the OMS and legal acceptance of the reliability of that system. This may not be a significant issue, as electronic vehicle ID systems become more widespread. Automated help systems such as GM’s OnStar rely on electronic ID for vehicle diagnostics and service, and it is reasonable to think that within a few years every new vehicle sold will have (or be capable of) a unique electronic ID tag. This is therefore more a legal issue than a technical one – whether the courts will accept electronic evidence only, without camera or police visual corroboration, of the use of an HOV lane by a vehicle lacking an in-vehicle OMS.

One avenue by which the legal issue may be downplayed could be a High Occupancy Toll facility, whereby an electronic tolling system is in place and, in using the facility, the user inherently agrees to their being monitored and their vehicle identified electronically. It would be a short step technologically to add occupancy information to the vehicle “tag”; effectively, the system would automatically toll all HOT lane users, then delete the toll for those vehicles with an OMS that registers the appropriate number of occupants (the toll “rebate” could even be set at different levels for 2- and 3-occupant vehicles under this system). As an incentive to use an OMS, the public could be advised that only OMS-fitted vehicles would be subject to the automated HOV toll rebate.

The question of whether the OMS “pushes” occupancy information to the roadside antenna or the information is “pulled” by the antenna is one of technology; the more economic approach would be to wait for the vehicle tag to be interrogated by the roadside equipment. Two-way communication is unnecessary for strictly HOV monitoring purposes, but it might be useful for the antenna to confirm its reading of occupancy by triggering a “beep” in the vehicle if not enough occupants are recorded. If desired, the system could be designed to give the motorist enough leeway to shift back into the general purpose lanes prior to the next OMS antenna (for example, by only citing as violators those non-compliant vehicles that are registered by two or more consecutive polling stations).

To summarize, the thought process in developing alternative Occupancy Monitoring Systems for HOV lane use is:

- implement in-vehicle occupancy sensing system covering all passenger seats
- process and display that information either visually or electronically (e.g. a windshield-mounted tag/transponder)
- if in electronic form, read that information with appropriately-spaced roadside antennas
- transmit that information to a processing centre, with access by police in the field
- limit HOV lane use to vehicles equipped with OMS

- vehicle in HOV lane with no OMS cited for OMS violation
- vehicle in HOV lane with OMS and fewer than required occupants cited for HOV violation

- OMS enhances conventional police enforcement

or

- Allows police in field to issue tickets by mail

or

- Allows a fully automated ticket by mail enforcement system via
  - License plate photo

    or

  - Citation with no photo per HOV lane user agreement

5. SYNERGISTIC OPPORTUNITIES

The particular question being investigated is whether there is or can be created a practical, feasible means of electronically or remotely observing the number of occupants in a moving vehicle. It is clear that there is a myriad of potential links between such an occupancy monitoring system and other automotive systems and/or potential systems, particularly when considering the nature of new systems that may emerge in the next decade or more. A device or method to monitor vehicle occupancy could conceivably be used for a variety of other purposes. Conversely, the HOV Lane monitoring application might be only a sidebar to a broader application.

While it may not be necessary to integrate these synergistic opportunities into example concepts or draft functional specifications at this point, it is important recognize these and any new emerging opportunities and to incorporate them, where appropriate, in future thinking, planning and action. The following opportunities have been suggested:

1) High Occupancy Toll (HOT) lanes

HOT lanes are in use in a few corridors in the U.S. and are being considered in many new projects. Allowing non-HOVs to pay to use an HOV facility has been seen as a way to optimize person-moving capacity of a highway, and to overcome the perception of underutilization of a potentially valuable public resource. The key task with an HOT facility is to be able to reliably and instantly distinguish between an HOV (which travels free) and a non-HOV (which is assessed a fee).

This is currently done by manual visual inspection at a toll booth upon entry to a barrier-separated HOV facility (I-15 in San Diego, SR 91 in Los Angeles area, and Katy Freeway in Houston). While reasonably reliable, this is a labor-intensive and disruptive process. It is also manifestly unsuitable to a non-barrier-separated HOV lane, where vehicles can move in and out of the lane at almost any location. Being able to monitor vehicle occupancy in an assigned lane would eliminate the manual inspection requirement and allow the HOT concept to be considered as a viable alternative, not only on the 4,000 km of existing HOV lanes in North America, but on the dozens of future highway improvement projects being planned now or in the future.

It may be noted that continuous or frequent monitoring would be vastly preferred over “spot” readings of occupancy in this application, to minimize the risk of non-HOVs weaving in and out of the lane to avoid the known “checkpoints”.

2) Managed Lanes, Value Pricing, and Congestion Pricing

These are all terms dealing with toll lanes on streets and highways (or even area-wide or cordon pricing, such as in central London), featuring price variations by time of day, level of congestion, etc. aimed at balancing between managing the flow of traffic and, in the case of a privately-owned facility, maximizing profitability. As a matter of public policy, flow optimization, or simply marketing, a simple technique for distinguishing HOVs from general traffic could allow HOVs to travel free or at a reduced rate.

3) Interoperability with "Standard" tolling

If the auto occupancy monitoring system were to be compatible / interoperable with existing systems such as the Highway 407 ETR transponder / reader system, there would be synergies for both parties. For a toll facility, it would be an incentive (or perhaps a mandated provision) for more motorists to use transponders, thereby reducing management cost and encouraging toll road use, and for the highway agency and others it would provide another opportunity to use more vehicles as "probes" throughout the road network as a means of monitoring and managing traffic flow.

To carpools using private toll roads, it would offer the opportunity for the government to offer rebates, credits, or other incentives to counter or reduce the cost of travel. Since it has been demonstrated in research that monetary incentives are as powerful, if not more so, than travel time savings by way of HOV lanes, and since the government has no other means of providing HOV priority on privately-owned toll highways (so they can not be brought into a regional HOV lane network), financial benefits to toll road carpoolers could be a significant element in a broad HOV strategy. Toll rebates could be varied and targeted (e.g. full rebate for a 3+ vehicle, half-price for a two-occupant carpool, other discounts for frequent carpooling, rebate only during peak periods, etc.). The rebate might be set at a level that has a long-term cost to the public less than that of constructing an HOV lane that would provide an equivalent incentive to carpool.

4) Safety / Seat Belt Use

One promising technique for monitoring vehicle occupancy is by use of seatbelt-mounted sensors. Such a system would clearly be relevant to the ongoing effort to promote and regulate seatbelt use in vehicles as a safety and health issue. In fact, one scenario might be the fitting of *all* vehicles with seatbelt monitors as a standard item simply in response to the legislated use of seatbelts throughout North America. Once the use of seatbelts was automatically monitored, HOV monitoring would then just be a minor side benefit of the broader safety initiative. Given the cost to individuals and the public health system of personal injuries and death resulting from the lack of seatbelt use, it is likely that a very strong business case could be built for a positive return on investment of seatbelt use monitors from that perspective alone.

5) General HOV Monitoring (off HOV lanes)

Temporary, mobile, or permanent recording stations (or GPS tracking) could be used to monitor HOV travel patterns over the entire trip, not just on the highway. This could provide valuable information about origin-destination patterns, the effectiveness of various combinations of HOV incentive (e.g. how far out of the way do carpools travel to use an HOV direct ramp), and the situations where eligible vehicles do not use the HOV priority facilities provided. This could feed into marketing, planning, design, traffic management systems and communications efforts.

Another use of vehicle occupancy information might be to use passenger counts as the basis for assigning signal priority at congested intersections.

6) Data Collection

Various governments put considerable effort into monitoring traffic flow, counting vehicles, and analyzing and applying the resultant data. Despite this work, the difficulties inherent in observing vehicle occupancy mean that little data regarding HOV use is (or can be) collected, and even biennial classification counts can be unreliable with respect to vehicle occupancy. An automated vehicle occupancy monitoring system would provide not only HOV volumes in a particular location but much more extensive and useful data – HOV (lane) entry and exit points; trip length; turning moves; use of general traffic lanes; cordon classification counts; hourly, daily, and seasonal variations; location of carpool formation / termination; etc. This data could be available on a spot basis or as a continuous widespread recording. It could be used to measure delay, congestion, and travel time. Furthermore, if the monitoring system were to be implemented in all vehicles, the biennial cordon counts would be a thing of the past – real-time and historic information would be available any time, anywhere, for both HOVs and others.

7) Vehicle emissions

One objective of HOV use is to reduce vehicle emissions. It might be feasible to provide carpool operators / users with tax credits or relaxed emissions standards if emissions were to be measured per person rather than per vehicle.

8) Vehicle Identification

Technology that might be used to automatically identify vehicles for automated HOV monitoring and enforcement could have wider application as an “electronic license plate”. There may be significant benefits to be derived from electronic tracking of all vehicles.

9) Vehicle / Operating Diagnostics

The technology that allows vehicle occupancy to be monitored remotely could be used for other purposes as well. For example, selected vehicle diagnostic information might also be monitored at the same time – tailpipe emissions, speed, tailgating, etc. – and be capable of being used for enforcement purposes.

10) Vehicle Safety Systems

An example of the synergies between vehicle occupancy monitoring and vehicle safety systems is in the event of a set of airbags going off and triggering an emergency response team. Simultaneous data regarding vehicle occupancy might help in sending the correct level of response (i.e. the response to a passenger van with several occupants might be different than to that of a single-occupant car crash) which in turn might reduce the risk of fatalities and allow better management of emergency resources.

11) Emergency Systems

Some researchers Ref[29] have suggested systems that not only notify of airbag deployment, vehicle location and the number of vehicle occupants but also crash forces (for various types of crashes – not just frontal impacts that would be associated with airbag deployment), injury probabilities and even automatic transmission of medical records to the relevant Emergency Department. Ref [30] examines the feasibility of a system that would integrate such an Emergency Communication System with Traffic Management systems so that traffic incident management can be factored directly into emergency vehicle routing. The paper examines issues associated with using in-vehicle cellular phones as traffic data probes in addition to their role in communication and crash notification.

12) Passenger security systems

One concept emerging in the auto industry is a remote (key tab) indication of whether a person (either an intruder or a small child) is hidden within a locked vehicle. An occupancy sensor for HOV use might also be applicable to this situation, and vice versa. In other words, if the HOV monitoring system were widespread, then this passenger security benefit could also accrue to carpool users. Conversely, if the passenger security system were widespread, it might be able to be used for HOV monitoring as well.

13) Transit

It is conceivable that a system that monitors private vehicle occupancy could also apply to a public transit vehicle. This would provide transit system operators with more useful real-time data for scheduling, fleet management, transfer co-ordination, passenger service, and other purposes. One application might be to use passenger counts as the basis for assigning signal priority at a congested intersection.

14) Preferential Parking

Preferential parking location and fees have been demonstrated to be some of the most effective Demand Management / HOV incentive measures available. Preferential parking spaces for carpools might be in a gated lot or area that is released by the approach of an eligible carpool. This would eliminate the manual observation or spot inspection requirement that is one of the key problems holding back the widespread implementation of preferential parking in private and public lots as an HOV / TDM incentive measure. It could allow

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[29] Champion, H.R., et al *Reducing Highway Deaths and Disabilities with Automatic Wireless Transmission of Serious Injury Probability Ratings from Crash Recorders to Emergency Medical Service Providers.* International Symposium on Transportation Recorders, 3-5 May, 1999 Arlington, Virginia.

[30] M. Bunn and G. Savage, *Feasibility of an Integrated Traffic Managment and Emergency Communication System for Birmingham, Alabama.* University Transportation Center for Alabama, December, 2000.

private employers to more efficiently and economically manage and police their preferential carpool parking schemes.

15) Carpool Incentives

Over and above the notion of rebates for carpools that use toll facilities, a widespread occupancy monitoring system could conceivably be used directly as a TDM measure, for example by providing financial rewards / incentives to people who complete a high proportion of their annual travel with multiple occupants on any roads, or those who carpool during a certain proportion of peak periods or in defined areas.

16) Insurance

In the event of different rates being set for motorists who drive alone compared to those who carpool, documented carpool use would be information of interest to the auto insurance industry. Rates could theoretically vary from trip to trip depending on the vehicle occupancy.

17) Marketing

Knowing which vehicle is an HOV (or not) could allow carpool-oriented marketing, promotion, and education to be targeted to HOV users. This could be by corridor, by frequency of carpooling, by trip pattern, or by carpool use in general. One obvious example is to provide carpoolers with information about a ridematch program, or more commercial uses (auto dealerships, insurance companies, radio stations, etc.) might have a particular interest in that sub-market. The sensitivity of HOV users to private, for-profit use of that information would need to be assessed.

18) Use of HOV Facilities by Non-HOVs

It is not uncommon for a limited number of non-HOVs to be allowed to use HOV facilities. Taxis are one example, and another group that is gaining increasing prominence is Low Emission or Zero Emission Vehicles. An occupancy monitoring system for general vehicles could be applied to any group that has a blanket exemption by fitting those vehicles with a special version.

6. KEY ISSUES / PROBLEMS

6.1 Definition

The technology to allow for in-vehicle monitoring of the number of occupants and to communicate that information to the roadside is in place. Further development is needed on the part of vehicle systems manufacturers and integrators to embed that occupancy-counting functionality in commercial vehicle systems, but the capability of doing so is not at issue.

Based on the research to date and on the consultation with transportation and enforcement agencies, the key problems facing the automated Occupancy Monitoring System, particularly as it applies to automating the HOV lane enforcement task, are:

1. Roll-out of the technological “solution” to the real world; and
2. Public / political support for HOV lanes, HOV lane enforcement, and automation of enforcement

6.2 Problem / Issue Resolution

6.2.1 OMS Roll-out

HOV lanes are used by private individuals driving vehicles and using systems developed by private industry. The HOV lane operator – the government – sets the parameters and rules by which the HOV facilities can be used. Not often does the government directly guide or require industry or the public to create or use a particular product. It is difficult, therefore, for the HOV system operators to create and implement an automated in-vehicle occupancy monitoring system. Some mechanism is needed to translate the “theoretical” OMS through the auto industry into a suitable market application.

At the same time, however, the effectiveness of an automated OMS relies on it being ubiquitous among (if not the entire vehicle population) at least HOV lane users, to the extent that any HOV lane user without an OMS is the subject of a focused enforcement effort. Consideration must be given to how an HOV lane can accommodate a legitimate HOV without an OMS, and how that vehicle can be distinguished from a non-HOV in the lane.

There are four levels of proponency available to HOV lane operators:

1. “do nothing” and wait for the automated OMS function to arise through other auto industry initiatives such as “smart air bags”, then capitalize on that function as a police support in the field;
2. implement a pilot project or projects in a controlled environment (e.g. a barrier-separated HOT lane), then use those results to refine and expand the initiative to other settings;
3. implement automated OMS as a widespread HOV enforcement strategic direction, and work with the auto industry to develop appropriate in-vehicle systems to support the program (available as an option on new vehicles and as an add-on retrofit product for older vehicles); or
4. Mandate the fitout of all new vehicles with an in-vehicle system of occupancy counting (all seats) and communications at the state or federal level, and prepare a

retrofit package for older vehicles. Implement roadside monitoring equipment and define a near-term deadline for conversion of HOV lanes to OMS-only facilities.

Realistically, the “do nothing” approach is inappropriate and widespread consultation indicates little support for the mandatory approach of strategy (4). This leaves some form of “staged” implementation or roll-out; this may follow a slow schedule or be aggressive, but is unlikely to take the form of strategy (3), an immediate widespread commitment among the dozens of jurisdictions responsible for HOV infrastructure and operations. This inevitably points to strategy (2), whereby a high-profile project or projects takes the lead and demonstrates the feasibility, functionality, and cost-effectiveness of the automated OMS approach. Following that lead, OMS would then become embedded in new HOV facilities and retrofit first to HOV facilities with enforcement problems and eventually as a standard practice for most or all HOV projects.

A key benefit of using a HOT lane as a pilot project is that privacy / political concerns should be minimal; the user (HOV or not) is inherently agreeing to a form of contract with the road operator, and accepts the idea of automated vehicle monitoring and ticket-by-mail payment. Furthermore, if the vehicle occupancy detection is unreliable, the worst that can happen is that a carpool does not receive the toll rebate to which they might be entitled; they will not be fined as being illegitimate users of an HOV facility. The controlled environment (HOT lanes are usually barrier-separated) would allow testing of systems to distinguish between two- and three-occupant vehicles, which is a necessary precursor to OMS applicability to broader freeway and arterial HOV lane applications.

A buffer-separated or non-separated / part time HOV lane application could be tested at the same time, to assess the practical issues associated with monitoring station avoidance and distinction between OMS and non-OMS HOVs and non-HOVs.

If such pilot projects were to be “live” – with users facing real fines for violation – the appropriate legislative and judicial measures would need to be in place first. Legislation that currently requires HOV lane citations to be the product of personal viewing by a police officer, for example, would have to be revised.

The other aspect of the roll-out – actually getting an OMS installed in vehicles and implementing the roadside devices, communication systems, and processing centre, will require further research and development, close co-operation with the auto industry and suppliers, and a fully funded pilot program. This will also require an OMS that can be retrofit to HOT lane users’ vehicles in the pilot project area(s) / corridor(s), with cost to the user kept to a nominal level through design and/or subsidy. While the current research points in the direction such a system can go, it has been hampered by having to work outside the auto industry; subsequent effort in this area will need to have the direct involvement of auto manufacturers and systems integrators.

Roll-out of the OMS beyond the pilot project will need to be considered from both commercial and political perspectives. Mass production and “piggybacking” OMSs on related existing / future systems may be able to keep the cost down to a nominal level, but there is acute recognition that auto manufacturers will resist imposing any such costs on buyers of new vehicles as a matter of competitiveness, affordability, and profitability. There may be legislative direction required (similar to the mandated gradual implementation of "smart" air bags over a three-year period) to overcome market pressures, with the possible need for HOV lane operators (e.g. state governments) to subsidize the purchase of the in-vehicle OMS. This government subsidy in turn may be able to be rationalized if the OMS can be shown to reduce enforcement funding requirements by an equivalent amount, or if it can be cross-subsidized by the increased fine revenue from the 100% HOV lane enforcement system.

6.2.2 Public / Political Response

The enforcement of HOV lanes is widely recognized as one of the key contributors to their success. HOV lane users, as well as those responsible for enforcement, have been loud and clear about the need for an effective enforcement regime. The police view any form of OMS as a significant aid in efficiently and effectively carrying out their duties. To the extent that the OMS can be automated and translated to an automated or "hands off" enforcement program, there is strong support from police.

There appears, however, to be grave concern among transportation authorities regarding the public's acceptance of the "automation" aspect of an OMS. The sense of some uncontrolled "big brother" system tracking individuals' use of the road system and the use of OMS as a revenue generator lead to unease with the notion of a system that works without direct police-on-the-road involvement. Some proponents have cited experiences with photo radar and other ticket-by-mail programs in which these concerns have arisen, in several (but not all) cases leading to political controversy and the demise of the program.

There is no question that photo-based in-car occupancy monitoring systems would raise that privacy-related issue more than simpler seat-weight types of systems, and that the HOV OMS would be better off in terms of public acceptance by concentrating on technologies that are clearly incapable of identifying individuals within a vehicle. This is a major strike against OMSs that involve photography, videoimaging, or biometric recognition.

These concerns may also be underlain by the ambivalence many in the public feel about HOV lanes themselves; a significant proportion of freeway users would just as soon the lanes be opened to general traffic in any case, so any system that makes HOV lane use more restrictive will inevitably trigger a negative response from them.

It may also be noted that the public has demonstrated a broad tolerance for ambiguity and selective enforcement of certain traffic rules, particularly those that are not seen as safety-related. Driving faster than the posted speed limit, for example, is widely practiced and only selectively enforced; only when speeds are excessive and verge on "dangerous driving" does the public expect a rapid and direct police response. In that sense, a moderate amount of HOV lane misuse is widely accepted – and even expected – as witness the typical and accepted guideline that violation rates should be kept below 10% of lane users[31].

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[31] e.g. *HOV Guidelines*, Caltrans, 1990

Although it may be desired by some, it is not generally expected that HOV lanes have 0% violation rates. Thus self-enforcement and conventional police enforcement, reinforced by good design, adequate signage, and an effective penalty regime, are taken to be the "norm" of HOV lane enforcement Best Practice (supported by motorists as long as HOV lane violation is kept below a tolerable level). In such cases, it may not be perceived that there is a *need* to develop an automated or 100% effective OMS and enforcement program. The rationale for an OMS then becomes simply one of funding and optimal use of limited police resources – if the HOV lane enforcement issue can take care of itself, the enforcement agency can focus its staff on other, more pressing, problems. It is difficult, then, to get the public and elected officials excited about what appears to be a mundane administrative issue of police resource allocation.

The public concern about the presence and use of an in-vehicle OMS would seem to be able to be managed such that it does not become an Achilles' heel of the program. Logically, the public acceptance of HOV lanes and their use by legitimate HOVs should correlate to acceptance of any means of confirming and enforcing that restriction. An in-vehicle OMS is no different functionally from a police officer at the roadside peering into the vehicle, which would appear to be an acceptable practice to legitimate HOVs.

The concern lies more with the automation of the enforcement process, whereby the police in the field do not monitor HOV violations but some mysterious system sends a fine in the mail to the vehicle's owner as soon as a violation is recorded in any HOV facility at any time. The onus of proof is on the enforcement agency, to demonstrate conclusively that it was indeed that particular vehicle in that time and place, *and* that the OMS within the vehicle correctly registered the appropriate number of occupants. While no system is foolproof, the automated OMS would need to be demonstrated and proven with a high degree of academic and real-world rigor before it would be accepted by the legislature, the judiciary, and the public. If that proof cannot be demonstrated, the OMS would be relegated to being simply a tool to assist police in the field, and the objectives of the automated OMS would not be met. Furthermore, there would be little interest in rolling out the OMS on a wide enough scale and market penetration to even be an effective field aid.

These concerns about privacy and automation may be overtaken by events in any case, as vehicles, highways, transportation systems, and society in general become more and more "wired". The momentum towards this state, even though not a conscious strategic direction, is very strong and shows little sign of slowing, let alone reversing. As safety-related systems become embedded in vehicles – first air bags, then occupancy monitoring to ensure the air bags operate safely, then sensors to reduce tailgating and unsafe lane changes and reduce the risk of triggering the air bag, then systems to communicate the roadside and with other vehicles to actively prevent collisions – the HOV OMS and automated enforcement practice may simply end up "going along for the ride". In other words, all the systems for an automated HOV lane enforcement program may well be in place (and in use) within a decade even if there is no conscious effort to create them, but simply arising as a byproduct of other programs. Such an evolution in automotive safety systems will only go as far as the market will support, and public concerns about privacy and enforcement automation will be factors in determining the level of market interest.

In summary, consultation has revealed that there are significant “gut feeling” concerns about both public / political support for OMS and the automation of the HOV enforcement process, but the OMS functionality can be addressed through public outreach and technical rigor of systems development. Public acceptance / support of the automation of the enforcement process appears currently to be on shakier ground, but system accuracy and “piggybacking” the program on other related auto industry initiatives appear capable of addressing that concern as systems are rolled out over time.

7. COST ELEMENTS

7.1 In-Vehicle Costs

The Occupancy Monitoring System requires three items of in-vehicle equipment:

- Occupancy recognition device (assume, for current purposes, a bladder-type seat-weight sensor) applied to the front passenger seat and all other passenger seats in the vehicle (note – driver seat does not need to be monitored)
- A gauge in each seat to translate the information from the sensor to an electronic signal denoting the presence of an occupant
- A windshield-mounted transponder which collects the seat gauge results (by wire or via an in-vehicle wireless link) and has that information tied to a vehicle identification number available for interrogation by a roadside antenna

The occupancy recognition system is tied to the monitoring gauge, and is being used in most new vehicles already for the front passenger seat. By the 2006 model year and for every year thereafter, all new vehicles sold in the U.S. will feature this system. Extension of this system to rear seats will also be available by then in certain vehicles equipped with rear / side air bags. The basic price of a three-seat OMS in a new vehicle remains a commercial matter with the vehicle manufacturers and is not readily available. The cost of a retrofit system is likely to be higher, both due to labor requirements and the fact that earlier vehicles have not been equipped to accommodate seat-based monitoring systems. An alternative technology (e.g. seatbelt-mounted breathing monitor) may be more appropriate in the retrofit case. Again, the cost per vehicle is unknown.

Consultation with a leading transponder manufacturer regarding the cost of in-vehicle transponders made the point that current windshield-mounted transponders which pass on static pre-configured information stored in the transponder's chip are valued at $US25. More advanced transponders, capable of transmitting the dynamic information inherent in an OMS, are being developed and rolled out in response to the availability of the newly licensed 5.9 GHz range[32]. This transponder will be fitted with a dynamic processor that could communicate with its vehicle via a link to the vehicle's serial bus. These next generator transponders are costed at in the order of $US100. This cost is likely to fall as volume production quantities are achieved; however there will be costs associated with integrating the transponder into the vehicle that will also offset the falling cost of the tag as production ramps up. Since such transponders will be introduced for reasons other than HOV monitoring, it is reasonable to assign only a fraction of that cost to the HOV function. However, the full cost would be attributable to the HOV program if such a transponder needs to be retrofit to an older vehicle in order for that vehicle to be used in an HOV facility.

It appears reasonable to assign, therefore, an order-of-magnitude in-vehicle OMS cost of something in the range of $US200 - $300 per vehicle for a retrofit, and perhaps two-thirds that for a system embedded in a new vehicle. Research is needed into the

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[32] it has been reported (D. Schnacke, IBTTA Spring 2004 Technical Workshop, in TOLLROADSnews, 16 June 2004) that 5.9 GHz transponders are likely to be standard equipment on new vehicles sold in North America from approximately 2008 onwards, and will be prevalent in the general fleet by the middle of the next decade.

acceptability of that sort of price point to the potential HOV market, as well as into ways to reduce the cost to the motorist.

7.2 Roadside Costs

Median-mounted or pole-mounted antenna arrays would be needed at regular intervals along an HOV facility, or single antennae at a specific site such as a parking lot or barrier-separated HOV lane. Current cost for a single-antenna roadside reader is $US20,000; an additional antenna (for example, in a median-mounted situation where the HOV lane in the opposite direction is also read) is $US5,000 more. The physics of communications at the 5.9GHz frequency preclude the sharing of a processor for antennae other than those at a single site, since antenna lead in distance limitations are in the range of less than 25m.

In addition, the cost of the supporting cabinets, enforcement cameras / poles / gantries, communication linkages, and power supply provisions in a wire line scenario likely to easily run to $US135,000 per km. The total cost for field equipment, with a two-way reader station at 1 km intervals, would amount to $US160,000 per km ($US100,000 per mile). A 16 km (10 mile) two-way freeway HOV facility would therefore require in the order of $US1M in field equipment.

Another minor cost would be new/modified roadside signage.

7.3 Other System Costs

At its most basic, the OMS will need back office and field software systems to interface with the data presented by the roadside readers. This will require custom software development and a host computer (presumably in a location such as a police office or a traffic management centre that already has all the other necessary support staff and systems in place). This would support police work in the field.

To move to a fully automated system of processing, distributing, and collecting ticket-by-mail fines would require additional computing power, mailing systems, checking and administrative staff, customer service staff and facilities, and marketing / publicity resources. This would be required whether for a single HOV facility or a full-scale regional network, and will be an ongoing annual cost of operations.

There will be one-time costs associated with the research and development of the OMS and bringing it to market, and planning / consulting costs for the implementation of the system in each HOV corridor and region. While the net result of the automated OMS is intended to be a reduction in policing requirements, there will (inevitably) continue to be some police effort expended in court, defending against or prosecuting legal challenges.

It is not possible at this point to put dollar figures against the total cost; the amount will vary according to the circumstances of each HOV region and reflect the level of sophistication / degree of automation of the OMS selected.

8. BUSINESS CASE

The Business Case for implementing an automated carpool monitoring system rests on a comparison of the value it creates versus the value of doing the same tasks by another means – or not doing the work at all. The capital costs of such a system, to the extent they can be known at this point, have been outlined in the previous Section. This Section discusses the cost structure that is currently in place to operate HOV lanes.

A key function of the automated carpool monitoring system is to replace or augment work now carried out manually. This includes:

- HOV facility enforcement
- The vehicle occupancy component of traffic counting programs

A second function would be to improve the efficiency of existing systems – for example to generate several times the number of citations in an hour than manual observation could.

The automated system would also have the potential to be used in ways that are currently not done – for example to track travel patterns of carpools as an input to traffic model calibration, to manage preferential parking for carpoolers at public car parks, or to act as probes to yield real-time travel speed information.

In all the above cases, there can be a tremendous range in the level of effort applied and a similar range in the circumstances encountered. In this section, some basic cost elements for conventional work are laid out, as a basis for subsequent comparisons between automated and manual systems.

8.1 Cost of Conventional Enforcement

8.1.1 Enforcement Methods and Funding

The cost of HOV facility enforcement can be found in two areas:

- the capital cost of enforcement-related infrastructure (wide shoulders, observation bays, etc.), and
- the ongoing operational cost (police salaries, vehicles, court costs, administration, etc.).

There is also some revenue (fines) involved although that often does not accrue directly to the budget of the agency responsible for monitoring the facility. Finally, there is an opportunity cost – if police or the courts, for example, can be freed up from HOV observation to apply their efforts elsewhere, then benefits may result in those areas of police work.

There may also be secondary costs that could be affected by carpool observation – additional marketing that takes place to counter public impressions of poorly-performing or much-violated HOV lanes; time and effort to operate a HERO-type program or respond to public complaints regarding enforcement; delays to HOVs due to lane violators; etc.

As discussed in Section 2, conventional HOV enforcement, as is currently practiced in jurisdictions with HOV facilities, relies on police officers to:

1. directly (visually) observe the number of occupants in vehicle traveling in the HOV lane;
2. apprehend the suspected violating vehicle to confirm number of occupants;
3. issue a ticket to the driver of a vehicle confirmed to be violating HOV lane rules.

The methods used to carry out these basic steps vary depending upon the resources available to the enforcement agency and the design and operating conditions on the freeway or arterial road upon which the HOV lane is located.

As a consequence, the costs, efficiency and effectiveness of conventional enforcement vary considerably. A further factor that affects the cost regime of HOV enforcement is the institutional arrangements under which it is undertaken in each jurisdiction.

Some of the arrangements that were identified during the consultation undertaken in the earlier phase of this project included:

- Regular HOV enforcement undertaken by enforcement agency from a dedicated allocation in its operating budget
- Regular HOV enforcement undertaken by enforcement agency from within its normal operating budget (i.e. as part of general traffic enforcement and with no specific allocation for HOV)
- HOV enforcement undertaken by enforcement agency from within its normal operating budget only when significant complaints have been received from public and/or highway authority. (i.e. no regular enforcement undertaken)
- HOV enforcement undertaken by enforcement agency only when specifically paid for by Highway Authority (i.e. no regular enforcement undertaken).

In addition to the above issues it was noted that in some jurisdictions targeted HOV enforcement is only carried out by the enforcement agency by officers on “special duties” outside of their normal duty shift times. This means that the officers are paid overtime rates which increases the real cost of enforcement. Other agencies promote the enforcement of HOV lanes via “paid duty”, whereby officers do voluntary overtime, but at regular rates.

It was also noted that in many cases targeted HOV enforcement is undertaken vigorously in the period after a new HOV lane opens and the intensity is reduced after this initial “settling in” period. The “extra” initial monitoring may come out of an allocation within the project capital budget rather than from day-to-day police operational budget.

8.1.2 Annual HOV Lane Enforcement Costs and Revenues

Although it is often difficult to extract HOV-specific enforcement costs from general police budgets, some indication of the order of magnitude involved may be drawn from the following case studies and project reports:

New Jersey

In New Jersey, I-80 was a 16 km (10 mile) long freeway with a median HOV 2+ lane operating in the peak direction during weekday peak periods.

Enforcement costs (labor and mileage) for 1994 were $264,000[33], which paid for 6 months of enforcement during all operating hours, and 3 months of 3-day-per-week enforcement by 3 or 4 patrol cars. Enforcement costs dropped to $188,000 per year in 1995, covering 6 months of 3-day-per-week enforcement and 6 months at 4 days per week, with 3 patrol cars. Costs for subsequent years were estimated to continue in that range. Results were that violation rates were maintained in the 5% - 10% range (except they were noticeably higher during the three-day-per-week regime). The 1995 figure translates to $11,750/km/year, or $6,000/lane-km/year

It may also be noted that between 23% and 54% of vehicles stopped each month by police were actually valid carpools (3,300 valid carpools stopped, or 37%, out of 9,000 total stops in the first 14 months of HOV lane operation). This highlights the inaccuracy of current practice, with its consequences in terms of poor public relations and inefficient use of police resources.

Houston, Texas

The Houston system of reversible barrier-separated single HOV lanes (four corridors, 59 km total length) was reported in the late 1980s to be policed by two officers, with costs amounting to $US60,000 per year[34]. In the Houston configuration, enforcement can be carried out efficiently from stationary positions at the ends of the barriered segments of HOV lane.

California

On the US 101 and SR 237 HOV facilities in the San Francisco area (74 lane-km of non-separated part-time median lanes), annual enforcement cost in the late 1980s ran to $US215,000[35], or $2,900 per year per lane-km. This covered between 1 and 7 officers in the field.

The California Department of Transportation undertook a detailed study in 1989 regarding HOV lane violation and enforcement strategies. The "*HOV Violation Study*" (Systan Inc, January 1990), recommended an annual enforcement budget of $US400,000 for 87 km of two-way mainline HOV projects in the Los Angeles area. This would be the equivalent of approximately $4500/lane-km/year in 2004 dollars.

Honolulu, Hawai'i

The enforcement budget (1989) for the 3.7 km long Moanalua Freeway HOV lane project (median buffer-separated lanes) amounted to $35,000[36], which paid for parts of the workload of three officers. This was the equivalent of $US4,700 per lane-km per year.

Pacific Motorway, Brisbane, Australia

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[33] "*Enforcement of the I-80 HOV Lanes in Morris County, New Jersey*", I. Perlman, A. Kotchi (2001):
[34] High Occupancy Vehicle Facilities: A Planning, Operation and Design Manual, C. Fuhs, Parsons Brinckerhoff Quade and Douglas, Inc., December 1990, as reported in "Enforcement Issues Associated With HOV Facilities, C. Fuhs, 1991 National Conference on HOV Facilities, Seattle, WA, April 29 – May 1, 1991
[35] ibid
[36] ibid

"*Transit Lane Enforcement Strategy for the Pacific Motorway*" McCormick Rankin Cagney for Queensland Department of Main Roads and Queensland Police Service, 2 March 2001 recommended an enforcement effort that corresponded to budget for the 6km long HOV lanes the equivalent (2004 dollars) of:

- $US12,000/lane-km/year in years 1 and 2 for operation, and
- $US7,100/lane-km/year in subsequent years, subject to monitoring.

All of the above costs refer only to police activity in the field. Any HOV project will trigger additional court activity, for dealing with challenges and processing. There will also be administrative work involved in following up on unpaid fines etc.

HOV facilities on freeways vary widely in their design, operation, and use, so it is difficult to generalize. It is apparent, though, that an enforcement budget of at least $US3,000 - $US6,000 per lane km per year is within the range of practical experience. For a system of 50 lane-km of buffer-separated freeway HOV lanes, therefore, the enforcement agency would be expected to be dedicating $US150,000 - $US300,000 per year to HOV lane-related work. There will be additional costs embedded in related "back office" and legal / court functions.

Over the 4,000 lane-km of U.S. freeway HOV lanes currently in operation, this measure of enforcement cost would translate to some $12M - $24M per year.

There is little published experience from which to draw related to enforcement of arterial HOV lanes. They tend to be enforced more by periodic "blitzes" rather than by regular recurring assignment of officers to the project more typical of a freeway HOV facility.

The potential revenue from HOV lane enforcement also varies according to the situation, but a hypothetical case can illustrate the potential – a 10 km long freeway HOV lane, if monitored by police, could generate one citation every 20 minutes (reflecting the time it takes to observe, stop, and cite a violator rather than the actual violation rate). Over a 2½ hour peak period, that is 7 or 8 citations. Over two daily peaks and 260 weekdays per year, over 3,500 citations could be issued. At a typical fine for HOV lane violation of $100[37], that represents revenue potential of $US350,000. For a system totaling 50 lane-km (per the cost discussion above), close to $900,000 in fine revenue could be generated, against the enforcement cost of less than $300,000 per year. Thus, if the officers can be spared from other duties, HOV lane enforcement has a potentially lucrative return on investment. A key mitigating factor, however, is the fact that fine revenue normally goes into general government revenues and does not specifically return to the enforcement agency or to the HOV program.

Police in the field do not expect to stop and cite every HOV lane violator. A 5% violation rate on a 1,500 veh/h HOV facility translates to 75 violators per hour, and we have already noted that a typical citation cycle is 20 minutes – i.e. 3 per hour. Even in a well-enforced facility the vast majority of violators escape citation (even though a

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[37] the fine for HOV lane violation in several major jurisdictions (e.g. California, Virginia) is substantially higher than $US100.

recurring violator such as a daily commuter would expect to be "caught" on an approximately monthly basis under the above enforcement regime). If the occupancy monitoring task were to automated such that every violator were to be observed and fined (and the violation rate remained at current levels), the fine revenue would increase dramatically. However, the objective of the HOV monitoring system is to reduce violation rates – and hence fine revenue - to a minimal level over time.

8.2 Cost of Operational Monitoring

Tracking the use of HOV facilities is an essential part of operating an HOV system. At its most basic, this entails the manual observation of vehicles using the facility during peak periods during one day or over several days. Each vehicle must be observed and classified by type and occupancy. That data may be supplemented by travel speed runs, bus ridership counts, attitude surveys, and origin-destination tracking, etc. Once the field data is assembled, it must be compiled, analyzed, summarized, and put into useful formats for technical or public use. This is typically done annually for all the HOV lanes within a particular jurisdiction.

As pointed out in *State of the Practice in HOV System Performance Monitoring* (D. Henderson, Transportation Research Record 1856, Transportation Research Board, 2003), few if any jurisdictions have or apply the resources to monitor their HOV facilities to the full extent and quality (accuracy, frequency, scope) desired. Nevertheless, many make a significant investment in HOV lane monitoring (per D. Henderson correspondence):

Area	**Freeway HOV Lanes**		**Annual Monitoring Cost ($US)**
	Corridors	**Total Length** (lane miles)	
San Francisco	9	275	$500,000
Boston	2		$50 - $75,000
Denver	2	18	$10,000*
Long Island	1	60	$75,000
Houston	6	94	$60,000
Los Angeles	14	750	$450,000
Vancouver, WA	1	6	$88,000
Dallas	4	60 – 70	$200,000
Minneapolis	2		$10,000
San Diego	1		$100,000
Seattle		200	Avg. $250,000
		Total	**$1,693,000**

* Volume, travel time only

Data collection and analysis thus ranges from $US10,000 to $US450,000 per year, with a median figure of $US88,000 and an average over the eleven regions of approximately $US154,000 per year.

All these costs are specifically for HOV data collection (e.g. vehicle occupancy monitoring, data analysis, and reporting) over and above the collection of basic traffic volume counts which are normally made available from the regional highway and traffic monitoring system.

If the HOV monitoring costs are assumed to be split approximately 2/3 to the field work and 1/3 to the analysis and reporting work, a large urban area with several HOV lanes would have a typical field work budget in the order of $100,000 per year. This would be supplemented on occasion with special “one-off” studies to respond to particular issues. Over the thirty or more North American urban centers with freeway HOV lanes currently in operation (some with single facilities; others with extensive networks), the annual HOV monitoring field work budget might amount to a total of $2.5 - $3 M per year.

As Henderson notes in TRR 1856, “Several area representatives noted a desire for the development of automated occupancy data collection technology to enhance their data collection programs”. An effective automated carpool monitoring system that provides volume, occupancy, travel time (and hence reliability), and origin-destination pattern information on a continuous regular basis would largely be able to eliminate the need for the field component (i.e. two-thirds) of regular annual manual monitoring programs. The analysis and reporting component of the work would remain (say one-third of the current cost).

8.3 Business Case Summary

From a pure dollars-and-cents perspective, the comparison to be made is between the cost of fitting an automated occupancy monitoring system to vehicles and HOV facilities across North America against the benefits – reduced policing cost, reduced monitoring cost, and increased fine revenue. Not all of the pieces of the puzzle are in place, and further research is required to more carefully define in-vehicle implementation and system operation costs.

Unable to be costed at this point is the value assigned to the influence of an effective monitoring system on public support of the HOV program, and the resulting improvement in proponents’ abilities to expand freeway, and particularly arterial, HOV lanes and related facilities / programs, and then how that direction impacts on Transportation Demand Management in general and benefits fuel consumption, vehicle emissions, congestion, and transit operations over time.

What we do know are the order-of-magnitude figures (in $US) for:

Annual cost of HOV lane enforcement in North America	$12M - $24M
Annual cost of HOV lane monitoring in North America	$2M - $3M
Annual potential fine revenue[38]	
▪ at current violation rates (5% - 10%)	$1.9B - $3.7B
▪ at future violation rates with automated OMS (say 1%)	$375M
Capital cost to retrofit all HOV lanes with monitoring antennae[39]	$400M

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[38] Assume 4000 lane-km of HOV lane; 1,200 veh/lane/h; 3 h/day effective operation; 260 weekdays/year; $US100 fine/violation; average facility length 10km

Capital cost to fit vehicles with OMS in North American HOV markets[40] $2.2B

As discussed above, capital and operating cost of startup, back office, and administrative elements of an automated OMS are region-specific and cannot be pinned down at this stage, while the secondary benefits stemming from improved HOV lane enforceability remain unquantifiable.

All of the above figures, with the exception of in-vehicle OMS retrofit and the one-time cost of implementing an OMS, would grow roughly in proportion to the overall length of HOV lanes in North America. An effective OMS may permit HOV lane growth to accelerate, but overall HOV network growth will reach a "plateau" as implementation becomes constrained by physical and operational feasibility. It must be noted that this is a dynamic and ever-evolving area within the automotive industry; technological advances (e.g. shifting to GPS from roadside readers) may yield some capital cost savings in the future.

While there is not enough reliable and comprehensive data available to present a definitive business case for an automated OMS, the figures above suggest that, as long as capital costs for the in-vehicle components can be kept down (by "piggybacking" on other functions, by limiting OMS introduction to new vehicles, by only monitoring the front passenger seat, etc.) there may be an attractive business case for OMS introduction in the near- to medium-term. The key "positive" financial element stems from the quantum leap in fine revenue available when HOV lanes can have 100% monitoring coverage; not only would an effective OMS slash violation rates to minimal levels, the 100% cost recovery from the remaining violators may well be able to compensate for the investment in the automated system over time.

Interestingly, the highest period of up-front capital cost would coincide with the highest period of fine revenue; as capital cost requirements diminish over time, the violation rate (and hence fine revenue) would also be dropping.

While an automated OMS would be able to substantially reduce the level of effort and funding currently allocated to direct field enforcement and monitoring, the current investment in that aspect of HOV lane operation (less than $30M per year across North America) is not high enough to warrant, on its own, the substantial investment required in a large-scale advanced OMS. Even in a small-scale pilot project or controlled environment, the direct savings generated are likely to be small compared to the OMS installation and operating cost. Only if fine revenue for violations were recoverable and assigned against the OMS cost would there be a business case to be made.

The role of an automated OMS in achieving the synergistic benefits across the transportation system as described in Section 5 cannot be quantified at this point, but those opportunities should be recognized.

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[39] $160,000 per km x (1,500km of two-way HOV lanes + 1,000 km of single-lane HOV facilities)

[40] $250 per vehicle x 10% of all vehicles in U.S. and Canadian centres with freeway HOV lanes (total population 100.6M in 1996 + 8% growth to 2004 x 0.8 vehicles/person)

Of course, all HOV practitioners endorse the notion of an effective monitoring and enforcement regime, and the notion of a violator-free facility is inherently attractive. The value of an effective automated OMS in resolving critical HOV program issues is not quantifiable.

9. SUMMARY AND ACTION PLAN

9.1 Summary of Findings

This investigation into the automation of vehicle occupancy monitoring systems (OMS) has revealed:

- Research to date has not developed an effective means of remotely and automatically monitoring the number of occupants in a vehicle using an HOV lane, for the purposes of managing HOV lane operation in a variety of real-world situations
- Systems based on external photography of a vehicle appear to be inherently flawed or limited in their ability to be applied to a wide range of real-world real-time HOV lane monitoring situations, nor do they appear to be capable of the accuracy and reliability required to be used in a fully automated HOV facility enforcement program.
- Recent advances and future direction in in-vehicle electronic systems indicate the potential for the development of an in-vehicle system for automatically counting the number of vehicle occupants and making that information available to an external recording system. This could form the basis of a fully automated and comprehensive HOV facility monitoring and enforcement program.
- Systems to count and record vehicle occupancy are available “off the shelf” and a technically feasible pilot project could be implemented in the near term. Front passenger seat occupancy is currently being monitored for air bag safety reasons (such systems are mandatory in 100% of new vehicles sold in the U.S. from the 2006 model year onwards) and “smart” windshield-mounted transponders are also in use in electronic toll highways.

Wideranging consultation with HOV practitioners and proponents revealed some enthusiasm for the prospect of a reliable automated HOV monitoring system, but highlighted some areas of major concern:

- Personal privacy
- Legal / legislative changes required
- Practical issues of auto industry rollout
- Cost and economics

In light of these concerns, the consultation panel was divided on the feasibility of wide-scale implementation of an automated OMS in the foreseeable future. In real terms, systems can be easily designed to have no personal identifying features (e.g. a seat weight monitor). Many other issues can best be dealt with through the implementation of a pilot project in a barrier-separated High Occupancy Toll lane environment.

The Business Case for an automated OMS compares the cost of rolling out the system (in-vehicle components, roadside equipment, and back office / administrative costs) against the benefits (reduced policing cost, more effective facility monitoring capabilities, and substantially increased fine revenues). Although it is the prospect of recording and citing 100% of HOV lane violators rather than cost savings on enforcement and monitoring that generates the revenue to offset the system implementation and operation cost, it must be considered that a key objective of the OMS is to reduce HOV lane violation – and hence fine revenue – to minimal levels. How motorists will react over time – and whether a significant number of violations continue to occur - with a 100% reliable automated OMS governing HOV lane operations remains to be seen.

As described in Section 5, an automated OMS offers the potential to contribute "added value" in numerous areas of urban transportation:

- HOV lanes
- High Occupancy Toll (HOT) lanes
- Managed Lanes, Value Pricing, and Congestion Pricing
- Interoperability with "Standard" tolling
- Safety / Seat Belt Use
- General HOV Monitoring (off HOV lanes)
- Data Collection
- Vehicle emissions
- Vehicle Identification
- Vehicle / Operating Diagnostics
- Vehicle Safety Systems
- Emergency Systems
- Passenger security systems
- Transit Service
- Preferential Parking
- Carpool Incentives
- Insurance
- Marketing
- Use of HOV Facilities by Non-HOVs

It has not been possible at this stage to quantify the value of OMS in these contexts or to investigate them in detail. Nevertheless, these potential synergies do contribute to the overall Business Case for an automated OMS.

9.2 Outstanding Issues and Future Research and Development Needs

While much progress has been made in this study towards identifying and developing a ready-to-use new system of automated vehicle occupancy monitoring, continued activity is required on several fronts. Areas of further work are grouped under Technical, Social-Political, and Commercial categories; the study has demonstrated that a successful result will depend on substantial progress in all three of these areas. The timing of such activity is obviously dependent on funding, but work is needed sooner rather than later if this three decade-old problem of HOV monitoring is to be solved.

It should be noted that the technical aspects of developing an effective automated OMS are well advanced as a result of previous R&D efforts and ongoing auto industry and ITS programs. The consultation results clearly point out, however, that the main risks lie in the Social-Political and Commercial areas. It is therefore inappropriate to focus solely on the technical aspects of the problem in future work. In fact, unless the social and commercial aspects are resolved, it may be pointless to pursue the technical solution any further – producing an elegant OMS prototype will be a waste of time and money if the conditions for its real-world application cannot be created.

Underlying the following discussion of future actions is the recognition that this issue involves many parties in the public and private spheres, and that there are few existing forums in which work can be done in a joint multi-jurisdictional effort that has both academic rigor and credibility and "real" commercial applicability. A major challenge will be to find or create an appropriate forum through which this issue can be progressed. It is imperative that further work involve both government and the auto industry.

Technical Action Plan

The thrust of further work in the technical area will be to develop a real, practical, working prototype of an occupancy monitoring system, and to apply it to an active HOV facility as a pilot project. The conclusions of this study support the development of an in-vehicle OMS rather than further research into external photo/infrared systems.

This will require a thorough analysis of the various alternative means of measuring vehicle occupancy, a simple yet effective communications methodology, and the development of the necessary roadside equipment to read and transmit the occupancy information.

In the initial stage, the concentration should be on the technology of the solution rather than the practice of enforcement. Concentration on tying the OMS to existing vehicle systems (particularly those related to air bag deployment and seat belt use) appears to be the best "short cut" to widespread use. The enforcement process can be relatively easily automated (for example, by triggering a photo of the violating HOV lane user, tied to a ticket-by-mail scheme) once the basic technology has been demonstrated to be effective, accurate, and reliable.

A barrier-separated HOV facility, or preferably a HOT project, would be the ideal setting for a pilot project, once the technology has been confirmed. A fleet of user vehicles will need to be fitted with the OMS; a mix of public volunteers and government employees may be used, particularly if a HOT lane rebate can be used as a monetary incentive to participate.

A demonstration of how the OMS would work in a non-barrier-separated facility, under varying field conditions, will also be needed. Further work would be useful in identifying violators during the period when not all vehicles are equipped with an OMS.

Although this work can take place in an academic research setting, it would be highly desirable to begin to get major auto manufacturers and suppliers involved in the R&D process.

Social-Political Action Plan

The consultation process clearly identified several issues and obstacles in the social-political arena that will need to be resolved if an effective OMS is to emerge. Gaining an understanding of the "real" public / user view towards an in-vehicle OMS in the HOV lane context will be a first step in helping decision-makers come to grips with the concept. Market research is needed to gain knowledge in this area. Will the motorists resist yet another Big Brother-like intrusion on their "personal space" or will OMS simply be accepted as part of the ubiquitous monitoring of actions in modern society? Are motorists satisfied with the current arrangements for HOV lane enforcement and do they view an automated OMS as unnecessary?

Secondly, the concerns of senior government officials, elected representatives, and the judiciary need to be identified and addressed. The status of current legislation governing the OMS practice needs to be summarized and, where necessary, alternative legislation drafted and tested. Note that OMS technology, until it is in widespread use, gives rise to the creation of a third category of HOV lane violation (to the current "too few occupants" and "ineligible vehicle" categories) – the "use of HOV facility without an in-vehicle OMS" prohibition, which is needed to separate those vehicles with too few occupants from those which simply do not have an OMS. Without the OMS violation category, police monitoring in the field would still be required, thereby defeating the purpose of the automated OMS scheme. This would need to be debated and reflected in the legislation.

As a third issue, closely related to the Technical and Commercial spheres of influence, the Business Case for an OMS (and its automation) needs to be fleshed out, with a firmer understanding of the "real" costs involved and quantification of the benefits not only in the area of HOV facility monitoring but throughout the various synergistic opportunities identified in this study. The relationship of HOV lane-generated fines and various levels of OMS application needs some study, and the value to the proponent of a violator-free HOV facility must be defined.

Various financing issues are to be resolved – will the government subsidize OMS retrofits to HOV lane users? Will the government contribute to the introduction of OMS in new vehicles? Will in-vehicle OMS be mandatory in all new vehicles sold in HOV lane regions? How will OMS costs be passed on to users? Will increased HOV lane fine revenue be fed back to the enforcement task? Will fine levels increase? And so on. How these questions are answered will have considerable bearing on the Business Case for widespread OMS introduction.

Commercial Action Plan

The problem of rolling out an automated OMS into the North American marketplace needs to be thought through, again in consultation with industry. The roles of government and industry in implementing an OMS need clarity and definition – will government legislate OMS implementation or will the auto industry take it on as a simple commercial matter of adding OMS to existing functionality? Should there be a consistent technological approach across the industry, or would an end-results specification provide benefits in terms of how flexibly manufacturers approach the OMS problem? A joint government / auto industry task force would be appropriate.

The other key commercial issue relates to cost of implementation and rollout across the entire HOV marketplace. How to keep capital and operating costs down while creating consumer enthusiasm and takeup will be a major question.

10. REFERENCES

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APPENDIX A
Pro forma Letter of Introduction to Stakeholders

[Date] 2004

[Organization]
[Address]

Attention: [Name]

RE: ENTERPRISE Research: Automated Carpool Occupancy Detection System for High Occupancy Vehicle Lane Operations

Our File: W.O. 5438

Dear Sir,

McCormick Rankin has been commissioned to research possible means of automating carpool occupancy detection for use in High Occupancy Vehicle (HOV) Lane Operations. The purpose of this project is to conduct early research into the potential for vehicle occupancy to be detected remotely, to enhance the effectiveness of HOV lane operations.

This study is being conducted on behalf of ENTERPRISE, a consortium of public agencies dedicated to the advancement of Intelligent Transportation Systems (ITS). ENTERPRISE members include the U.S. Federal Highways Administration, several U.S. states, Ontario and the Netherlands' Transport Ministry. More information can be found at www.enterprise.prog.org .

HOV lanes are being used throughout North America and overseas to maximize the person carrying capacity of highways and to provide for more efficient commuting trips for carpool and bus users. Police and HOV facility operators have long called for an effective means of observing vehicle occupancy to allow more cost-efficient, targeted and reliable HOV enforcement practice.

Some of the issues and opportunities that have arisen to date are:

- Vehicle occupancy monitoring by direct observation in the field is resource intensive for police and faces inherent difficulties in accurately observing vehicle interiors and safely apprehending violators.
- Research to date has focused on photography (of various types) from outside the vehicle to determine occupancy. Such systems are unlikely to be effective in all conditions (freeways, arterials, bad weather, darkness, high speed, etc.) and for all relevant vehicle types.
- Technological advances in automotive systems (e.g. detection systems for safety and security purposes) may be suitable to be adapted or augmented to enable electronic "in car" occupancy detection.
- Communication systems that transfer information between vehicles and external stations are being employed for a variety of purposes such as navigation systems, incident response, electronic tolling, and even vehicle diagnostics. Similar systems may have potential for use in vehicle occupancy monitoring.

This research project has just commenced and while the above observations need to be considered, they do not constitute, at this time, commitments to future direction or policy of any ENTERPRISE member organization.

We are currently seeking stakeholder input to determine key issues and to determine areas where further research work should focus. As the [Organization], is clearly a key stakeholder in this area, we would like to offer you the opportunity to provide valuable input to this process.

A member of our project team will be contacting you by telephone in the near future to discuss [Organization]'s perspective on this topic.

In the meantime, if you have any queries about the administration of the project, or should you wish to nominate a particular person within your organization as a contact point for our project team, please contact:

Mr Paul Matthews
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Thank you in anticipation of your assistance and input with this research. We look forward to working with you on this most interesting project that we believe has the potential to benefit many sectors of the transportation industry.

Yours very truly
McCormick Rankin Corporation

Paul Matthews
Senior Consultant

APPENDIX B
Stakeholder Contact Details

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GM Canada	Stew Low	1908 Colonel Samuel Smith Drive Oshawa, ON L1H 8P7	905 644 6786	
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APPENDIX C
Stakeholder Input

Contact with the stakeholders for the Automated Occupancy Detection System study took the form of several questions, initially by telephone using a free conversation format. That is, it was not presented as a formal "questionnaire". For the purposes of ensuring completeness and consistency, the study team member interviewer did, however, refer to a copy of a pro forma checklist covering all of the issues that were relevant to this part of the study. The interviewer:

1. explained who we are, who we are working for, what we are doing, and how we arrived at the contact information
2. briefly described the concept of a system that monitors vehicle occupancy and transmits that information to police who are charged with enforcing freeway and arterial HOV lane usage
3. noted some of the other potential applications of such a system (High Occupancy Toll lanes, traffic counting, seatbelt enforcement, carpool priority parking, carpooling incentive programs, and so on)
4. enquired as to what issues or concerns might arise or need to be addressed

The interviewer let the respondent identify issues initially, then triggered some discussion regarding their views on the relative significance of possible issues such as:

- cost (both on board vehicle and system wide) (who pays – HOV operators, manufacturers, users?)
- universality of application / mandatory vs voluntary
- privacy concerns
- accuracy / reliability
- effectiveness
- technological problems / issues
- commercial issues (e.g. proprietary systems vs. open systems)
- time frame and strategy for implementation (e.g. near-term objectives vs. time needed for fleet turnover, widespread vs. targeted application)
- legal or legislative obstacles
- ticket by mail
- are there other ways to accomplish the same ends
- potential other applications / benefits / synergies

The discussions were framed strictly in the vein of technical research for system feasibility, emphasizing that we are not retained by any government to implement any such system, and that this is simply background academic research that may trigger further exploration of the technology and possibilities by the industry.

Following the telephone interview the study team followed up with individual stakeholders by e-mail or mail if and as necessary.

Stakeholder Input

Individual stakeholder comments that have been received are collated below by major topic headings.

The topic headings are:

    1. Cost
    2. Privacy Issues
2. Technological Problems / Issues
3. Accuracy and Reliability
4. Mandatory vs Voluntary Application
5. Timeframe for Implementation
6. Legal or legislative obstacles
7. Ticket by Mail
8. Potential other Applications / Benefits / Synergies
9. Partnership Opportunities
10. Commercial Issues
11. Alternative Solutions
12. Other Issues Suggested / Raised

These comments received in telephone interviews reflect the agencies' experience with HOV enforcement issues and relevant officers / employees' opinions. It should be recognized that the comments themselves have been made by individual officers / employees interviewed and therefore should not be construed to reflect official future direction or policy of the agencies represented.

These comments do, however, form an excellent basis for assessment of current issues and future potential for the concepts discussed.

We are indebted to those who took the time to participate in this study. Some agencies declined to participate, while a few did not return repeated calls. It was found that the auto manufacturers were generally uninterested in discussing the subject, for reasons of commercial confidentiality, low priority, and/or unwillingness to be seen to support a project that could ultimately add cost to a new vehicle and influence new car sales. While this is an understandable perspective, it points to the need for any subsequent work in this area to find a more effective mechanism to involve the auto industry.

1. Cost

California Highway Patrol:

- CHP does not derive revenue from citations that it issues.

Ministry of Transportation Ontario:

- Cost/Benefit would be important to government in determining the level of investment (time and money) that it would be prepared to commit.
- Public support problem if equipment costs more for individual motorists

CalTrans:

- Cost allocation would be a big issue.
- Funding contribution through FHA may be possible (FHA funds 88% of construction costs for carpool lanes in California).
- A service fee (e.g. annual fee) for users may be difficult to have accepted.

- The Government may see some value in contributing towards funding in-car equipment depending upon conditions. This may depend upon where revenue raised by fines was channeled.

Washington State Department of Transportation:

- Most important aspect is that any automated system would need to be cost effective.
- DoT does not derive revenue from citations.
- Currently spend $390,000 over two years to do manual data collection on Highway HOV usage so some expenditure on a monitoring system that would eliminate this cost may be able to be justified. However users would not be interested in paying more for equipment that simply provides the government with data.

Massachusetts Highway Department

- Equipment would need to be cost effective.
- Unlikely that the state would want to subsidize in-car equipment although it has subsidized vanpool seats and subsidizes transit use.

Association of International Auto Manufacturers of Canada

- The cost of placing equipment in vehicles will be a significant issue.

Texas Department of Transportation

- The cost of in-car components would need to be borne by the user (ie the car owner) and roadside equipments costs should be met by the Government.

Black Creek Transportation Management Association

- Cost is a serious issue for carpoolers, many are on low wages and carpool because they cannot afford to drive alone.
- A cost of $20 per vehicle would probably not be an issue but say $3000 per vehicle most certainly would be.
- Pricing should not affect the choice or accessibility of carpoolers to HOV facilities.
- It would not be acceptable for the cost of cars to increase just to enable HOV enforcement.
- Government in Ontario would probably not want to enter into cost sharing for in car equipment.

Agence Métropolitain de Transport (Montreal)

- People probably would not accept the cost of equipment being built into new vehicle cost, particularly if it competes with other options.

Société de Transport De L'Outaouais

- Cost would be problematic. There is no perceived value to the individual users. Individuals may be willing to pay for access to a special facility but would be less willing to pay if it is a general control issue.
- Cost/Benefit should be undertaken comparing cost of technological solution with police enforcement. Need to first determine the most cost effective method of control, and then determine who pays.

Roads and Traffic Authority of New South Wales

- Enforcement could potentially be self-funding so cost may not be a real problem.

Department of Main Roads, Queensland

- Cost would be unknown and some time into the future in any event. It would be difficult to recoup money particularly if program was successful in preventing HOV violations. Also would be difficult to impose additional costs on drivers. Probably would need to convince motor industry to change (ie include equipment in new vehicles) in the past for vehicle safety this has been done by the government running comparative analysis of vehicle safety records thus encouraging industry to lift performance of poorer performing models.

Region of York

- The cost of in-car equipment should be rolled into the purchase of the vehicle. It would only be acceptable to the public if there was a perceived benefit to them.

2. Privacy Issues

Ministry of Transportation Ontario:

- Privacy is a big concern. It has the potential to stop an initiative more quickly than anything else. This issue will need to be managed carefully.
- Technical barriers can probably be overcome problem would be public policy related to privacy and cost.
- Biggest issue would be privacy / social acceptance. People will not want something inside their car that monitors them for enforcement purposes. It would be a different matter if it was for their own convenience. (e.g. a toll route transponder).

CalTrans:

- California has “Fast Track” transponder toll system and camera enforcement systems for red light running. Privacy concerns have been addressed for these. Fast Track requires a signed user agreements through which users accept that they may be photographed and certain data could be used by, or shared with, the CHP and the FBI. The red light running program required legislation signed by the Governor.
- The INS high speed border crossing system between California and Mexico requires users to have a transponder. The system has a database of regular driver photographs for each vehicle registered in the program. Data including video footage is able to be shared with the CHP and FBI again due to a prerequisite user agreement.
- The California Motor Vehicle Registry is wary about opening up records to other agencies, mostly due to personal data privacy concerns. Currently the registry system is used for processing “Fast Track” (toll transponder) violations. Photographs must be scrutinized by a person (not by machine) to determine the license plate number and the drivers face must be blacked out before the photograph can be used. This is cumbersome.

Ontario Provincial Police

- Civil libertarian issues will be the biggest obstacle for introduction of an automated HOV monitoring system. This lobby already fights against police access to in-vehicle event data recorders (GM and other brands of cars are being produced with data recorders that record vehicle speed, seat belt usage and other information that is useful in fatal crash investigations). Currently, police need to obtain a court order (or the owner's approval) for access to event data recorder.

Washington State Department of Transportation

- Privacy and civil liberty climate in Washington State and perhaps many states within the USA means that automated enforcement (without a person being involved) will probably "never happen"
- Understand that California has recently passed legislation specifying that the contents of a vehicle's event data recorder is the property of the vehicle owner. Other States will probably follow. This may cause problems for the concept of automated enforcement from within the vehicle.

City of Burnaby

- Concerns about privacy are a serious issue. Not sure if they can be overcome.
- May need a significant public education campaign to spell out the benefits to society and to justify the arguments for an automated HOV monitoring & enforcement system.

Massachusetts Highway Department

- Privacy concerns will make it very difficult to gain public, and hence political, support.
- The privacy climate in Massachusetts is such that general video surveillance has not been possible on municipal roads. The Department did not even consider introducing a "HERO" program as was done in other states because of this climate. The state currently has secondary seatbelt enforcement legislation in place. Primary enforcement was introduced but was revoked because of adverse public opinion.
- The Department is very interested in furthering HOV enforcement practices however the social / political climate in Massachusetts is not conducive to anything that may be seen to intrude on privacy or civil rights.

York Regional Police

- The current situation regarding police deploying surveillance and monitoring technology is dependent upon the person's "reasonable expectation of privacy". For example, a camera can be set up in an open public place where there is an expectation that other people may be watching, however a warrant would be needed in order to set up a camera in a location where a person may have a reasonable expectation that he/she is not being watched. This situation would need to be clarified with respect to electronically monitoring people inside a car.

Texas Department of Transportation

- Privacy issues would be tough. The Texas Legislature only meets every two years and for the last three sessions proposed red light running camera legislation has been overwhelmingly rejected (partly due to privacy issues). That proposal only involved photographing the vehicle bumper and license plate and was justified on the basis of the large number of lives saved each year. Consequently, it is likely that a system that identifies the vehicle and the number of occupants in it for HOV enforcement purposes would probably have less chance of being acceptable.

City of Vancouver

- Would expect that privacy would be a big issue if sensing people inside their cars.

Black Creek Transportation Management Association

- Some people would be concerned about the privacy aspects of an automated HOV enforcement system.

Road and Traffic Authority of New South Wales

- There would be issues associated with privacy.

Regional Municipality of York

- Privacy was raised as a major concern when the 407ETR (an electronically monitored toll route) was first launched. People were concerned about bill arriving with details of where / when they had been traveling. To address these concerns 407ETR offered the option of prepayment of the toll account which would obviate the need for an itemized bill. It is understood that the take up rate of this option was quite low in practice. People are becoming used to cellular telephones and credit cards leaving an "electronic trail" and that they will probably become more desensitized to this issue in the future. In the coming decades it may not be an issue of concern.

Agence Métropolitain de Transport (Montreal)

- Don't think that privacy should be a big problem. Agency already undertakes origin destination surveys based upon license plates and contacts people at their homes. There should be a way to work within legal constraints.

Société de Transport De L'Outaouais

- Automated HOV enforcement system would not be accepted in Quebec at all. There is a legal limitation on the ability to observe individuals so cameras etc. could be problematic if focusing on individuals.

Association of International Auto Manufacturers of Canada

- Privacy will be a big problem. People will not accept a device in all cars simply for the purposes of HOV enforcement. Even if it is part of a broader system (e.g. for seatbelt monitoring, HOT lanes etc) it might not be acceptable to the public. Difficult to see it being implemented in most or all vehicles.

Department of Main Roads, Queensland

- State red light and speed camera legislation was introduced some years before the Federal privacy legislation was enacted. While the state legislation addresses privacy it may have been more onerous had it been drafted after the subsequent federal privacy act. It covers keeping records and passing them onto others (relevant authorities). Public acceptance has been good and is based upon these initiatives being part of an enforcement regime. In relation to any future legislation including possible automated HOV legislation Parliament would make a judgment on the reasonableness of whatever was proposed.

3. Technological Problems / Issues

Ministry of Transportation Ontario:

- Aware that photographic methods of counting occupants have not been overly successful and do not seem to promise a full solution.

- A rollout of an in-car system would take a long time and how to get from where we are today to where we want to be is one of the most significant challenges.

- An affordable interim step may be necessary. Such a step may be a self identifying transponder into which the motorist keys the number of occupants in the vehicle. Only vehicles with a transponder would be permitted in the HOV lane and license plate Automatic Vehicle Identification could be used to cite transponder violations. Random checks of transponder programming could be undertaken by pulling a sample of "eligible" vehicles off the lane onto a low speed parallel enforcement lane where police could either stop vehicles or check the number of occupants at low passing speeds. This direction off the HOV lane onto an enforcement lane could be done by electronic signing although this itself would require manual enforcement oversight. This concept would be similar to Ontario's "GO Train – Proof of Payment system". That is a transponder and the minimum number of occupants would be required at all times to travel in the HOV lane but manual enforcement would be undertaken only occasionally and on a sample basis however the fine for violations should be set at such a high level that it is a significant disincentive to risking being caught. This could be applied to highway HOV lanes (ideally barrier separated) but would not be applicable to more complex arterial HOV lanes.
- Probably no technical barrier to an in-car automated system. Problems would be more with public policy aspects.
- In the past there have been discussions between MTO and 407ETR (toll route) about the use of 407 transponders as data probes to detect incidents in locations that are not covered by loop detectors and compass cameras. Not all cars on the road would need to have transponders fitted for this to be useful.
- Technically it is probably feasible to do this (in-car automated HOV enforcement) with currently available technology.

Association of International Auto Manufacturers of Canada

- 20% of vehicles currently being produced increasing to 100% in 2 to 3 years will have a front passenger side weight sensor to determine if that seat is occupied by an adult or a child for the purposes of airbag deployment. Many vehicles already have front seatbelt sensors to give warnings if belts are not fastened.
- California was discussing introducing OBD3 onboard diagnostics that would transmit diagnostic codes to roadside sensors for the purposes of emission monitoring and enforcement. Need to check with California Air Resources Board to determine current status.
- Technology would not be a barrier to the development of an automated HOV enforcement system – privacy would be a big problem.

City of Vancouver

- Systems such as GMC "On-Star" are very sophisticated in relation to diagnostics, air bag deployment, vehicle location etc so presumably automated HOV enforcement would be technically feasible too.

Black Creek Transportation Management Association

- There may be health concerns in relation to the sensing technology (is it safe to be exposed to)
- Government would need to take on a coordinating role to achieve a consistent platform across different facilities and jurisdictions

Agence Métropolitain de Transport (Montreal)

- Technological issues can be overcome however acceptance may be an issue.

Société de Transport De L'Outaouais

- Technology is not a barrier; any limitations could be overcome.

Department of Main Roads, Queensland

- Technology will not solve the problem but may be used as an aid.
- In addition to technology, a full package of public education and marketing is needed to influence culture and driving habits this should be combined with good design to enable enforcement to take place.

4. Accuracy and Reliability

Ministry of Transportation Ontario:

- If a system was to be used to flag vehicles for further scrutiny by police, the technology does not need to be 100% perfect, however if it is to be used to automatically cite violators it must be defensible in court and needs to be 100% reliable. Conversely the cost of the system would need to be much less if it just flagged possible violators for police to manually check.
- Automated enforcement system would need to overcome problems like violators trying to fool the system (for instance by placing dummy passengers in the car) in order to enter the HOV lane.

CalTrans:

- Main issue is that any automated system needs to be very, very accurate so that it can be used for enforcement without human intervention and so that it does not result in false violations causing complaints and loss of faith in the system.

Ontario Provincial Police:

- Accuracy and reliability of an automated HOV enforcement system would be an issue for the highway authority because police would no longer necessarily be involved in enforcement.

City of Burnaby

- Understands that a high rate of inaccuracies and anomalies contributed the withdrawal of the photo radar program in British Columbia. There were too many incidences of disputed dates, incorrect vehicle identification etc for public acceptance. Public would probably view the use of technology for enforcement of safety issues as acceptable however other purposes (such as HOV enforcement) would probably not be viewed as acceptable. In British Columbia red light cameras are seen as an acceptable, safety-related, use of technology however photo radar was viewed by the public as a revenue raising initiative and not strictly safety-related. HOV enforcement would probably suffer from this too.

Massachusetts Highway Department

- Equipment would need to be accurate and reliable and cost effective, but public support would be the biggest challenge (that may not be able to be overcome).

Association of International Auto Manufacturers of Canada

- Reliability of the system would need to be addressed.

City of Vancouver

- Vancouver has arterial HOV lanes on a grid system, so there are many legitimate reasons for non-HOVs to enter the lanes (property access, right turns etc). For an automated system to be useful in this context it would need to be precise enough to determine the difference between permitted activities and violating vehicles.

Minnesota State Patrol

- Reliability would be an issue, in particular relating to the positive identification of the offending vehicle. A verifying photograph of the vehicle in the HOV lane would be possible and would probably be necessary if an automated system were to be introduced in the long term.

Agence Métropolitain de Transport (Montreal)

- Don't see technology standing in the way of automated enforcement being reliable; the issue is how the data is used for enforcement.

Société de Transport De L'Outaouais

- Technological issues standing in the way of automated enforcement being reliable could be overcome, however weather conditions, particularly in winter, can be a challenge.

5. Mandatory vs Voluntary Application

Ministry of Transportation Ontario:

- Standardization across facilities and jurisdictions would be desirable so that once fitted a vehicle could be used anywhere.

Massachusetts Highway Department

- Interoperability for cars from other regions/states/countries would be an issue. They should ideally all be able to use an HOV lane.

Texas Department of Transportation

- In-car equipment (should it become acceptable) should be standard equipment and regulation would needed to provide for it to be in place.

Black Creek Transportation Management Association

- The Government would need to (and should) plan and regulate any automated system.
- Need consistent standard and interoperability across different jurisdictions, facilities and contractors and different vehicle types. Also need to realize that technology changes rapidly.

Road and Traffic Authority of New South Wales

- The relatively low number of kilometers of HOV lanes in place compared with the total road network means that the percentage of the fleet using HOV lanes would be very low. Therefore there may not be a great benefit associated with fitting all cars.

Agence Métropolitain de Transport (Montreal)

- This will be hard to sell unless the equipment is external to the vehicle.

Société de Transport De L'Outaouais

- Widespread use would require government regulation.

6. Timeframe for Implementation

Ministry of Transportation Ontario:

- Roll out of an in-car system would take a long time and how we get from where we are today to where we want to be is one of the most significant challenges.
- The need for enforcement is immediate; MTO will have HOV lanes open next year however the realization of a fleet-wide automated system is realistically a long time in the future.
- Timeframe for an automated in-car system will be long term. Time to have a full rollout given 8-10 year lifespan of a car may be a problem.

Washington State Department of Transportation

- Washington State will probably not use an automated system for enforcement of any kind in the foreseeable future, if ever.
- Timeframe for automated enforcement would definitely be long term, if ever. The 7 to 10 year life on cars means that it would be a very long time for all of the fleet to be instrumented from new.

Massachusetts Highway Department

- Timing on an acceptability of an automated HOV enforcement system is probably a long way off even if technical hurdles can be overcome.

Texas Department of Transportation

- Time frame for implementation could be in the short term if it can be linked to HOT lane usage where acceptance by public may be more forthcoming.
- A possible means of introducing an automated HOV enforcement system would be to introduce it for motorists that want to use a particular facility (e.g. for a free ride in HOT lanes for an HOV). These vehicles would need to be fitted with and the owners would need to accept the conditions of use and entry. Maybe more widespread usage could follow more easily once this scenario became established and accepted.

Black Creek Transportation Management Association

- Need to introduce in phases and learn how it works before moving to the next phase. It would be a mistake to roll out HOV lanes with automatic enforcement on opening day especially if enforcement is an expensive component.

Road and Traffic Authority of New South Wales

- In Australia there may be a problem with implementation of in-car system because of the relatively high average age of the vehicle fleet and the relatively low turnover. This means that it would be a long time before new vehicles would be rolled out to extensively cover the fleet.

Agence Métropolitain de Transport (Montreal)

- If the technology is available, it would be best done in conjunction with the development of new HOV facilities.

Société de Transport De L'Outaouais

- A minimum of three years assuming that the technology is available. This includes a one-year pilot study (in all weather conditions).

Department of Main Roads, Queensland

- Timeframe for an automated HOV enforcement system would definitely be long term. This is a concept that is ahead of its time for Queensland because the public would not see the need or benefit at this time. Therefore it would not be acceptable politically. It might be different if there was severe gridlock being experienced throughout the network.

7. Legal or Legislative Obstacles

California Highway Patrol

- California's Vehicle code only permits photo enforcement for red light violations. Unless a new law is enacted, automatic devices could not be used for enforcement purposes.

CalTrans

- An automated HOV monitoring system would require new legislation.

Washington State Department of Transportation

- Automatic enforcement would require new legislation that may not be politically popular, further DoT management would need to be convinced that it was worth proposing and there are many more pressing issues than HOV enforcement.

Vancouver Police Department

- It would need to be determined whether violations would be a Provincial offence or a bylaw offence.
- It would need to be determined what the opportunity for review would be and how this could be done if the process was entirely automatic.
- The impact upon the court system which is already heavily loaded would be an important consideration.

York Regional Police

- Currently there are two options open to Police for traffic violations. A Part 1 summons is used for simple traffic offences. It is issued personally "on the spot". A Part 3 summons is used when for more serious violations (where an increased penalty may apply) or where further time is needed for investigation. It must be issued within 6 months. Changes would probably be needed to accommodate an automatic process.

Ministry of Transportation Ontario:

- There would need to be legislation changed to allow an automatic system to operate.

Texas Department of Transportation

- Probably not a legal or legislative problem with automatically counting people in a vehicle (police do this now) but there would be a problem with regard to the enforcement process, ticket by mail and privacy issues with the use of data.

City of Vancouver

- This would need to be a Provincial initiative.

Road and Traffic Authority of New South Wales

- The general direction in New South Wales is moving more towards automatic enforcement (red light running and speeding) and away from manual enforcement by police so automatic HOV enforcement would be consistent with this direction. There would still be legislative issues that would need to be addressed.

Minnesota State Patrol

- Biggest issues would be statutory changes necessary. Minnesota does not have photo radar or red light cameras. All violations must be issued by a person who then needs to be able to provide evidence in court.

Agence Métropolitain de Transport (Montreal)

- There should be ways around any legal or legislative obstacles, for example you may only use photo evidence in the case where a ticket is contested. We delete the files from our old origin/destination surveys. There should be an approach and procedures to use technology while protecting an individual's privacy.

Société de Transport De L'Outaouais

- In Quebec because of the Charter of Rights, individuals may not be monitored in a private space, therefore control of occupants in a vehicle becomes problematic.

Department of Main Roads, Queensland

- Queensland legislation for automatic enforcement (speed cameras and red light cameras) places a high onus of proof on the chain of evidence procedures so that there is no doubt about the quality of evidence. HOV enforcement would be the same and obstacles could be overcome.
- The would be no legal or legislative obstacles with automatically monitoring the number of people in a vehicle as long as their identities were not used for any other purposes and the photographs were not distributed.

8. Ticket by Mail

CalTrans

- An automated HOV monitoring system using ticket by mail would require new legislation.

Texas Department of Transportation

- Ticket by mail would require new legislation (refer to difficulty noted in 2)

Ontario Provincial Police

- A key problem with Ontario's Photo Radar that was introduced in the 1990s and subsequently withdrawn was that there was a long delay (about one month) between the photograph being taken and the vehicle owner receiving the notice in the mail. People commonly complained that they could not remember being on a particular road etc. Any new system should provide the violator with the notice quickly.
- Automated system would need to be certain about the vehicle identification. A problem with photo radar was that paralegals often argued that there was more than one vehicle in a photograph and that it was not certain which one was speeding.
- Need to consider who is responsible for paying the fine. With photo radar the vehicle owner was responsible unless it was able to be proven in court that he/she was not the

driver. In most instances this necessitated the actual driver appearing in court and admitting that they were driving.

Ministry of Transportation of Ontario

- Ticket by mail would be a difficult issue (as it was with photo radar); it is only feasible to cite the registered owner and he/she may not be the actual driver.

Washington State Department of Transportation

- Washington State laws are currently framed such that a ticket must be written by a person so automated ticket by mail is not presently an available option.

Black Creek Transportation Management Association

- A ticket by mail system would pose some issues but these could be worked out as for photo radar and other programs.

City of Burnaby

- The issue of distinguishing between the vehicle owner and driver for the purposes of issuing a fine should not be difficult. The same approach as was used for photo radar should be undertaken. Suggest that if the fine is paid up-front by the owner no demerit points are allocated. However, if the matter is taken to court the penalty can include monetary fine plus demerit points on record affecting insurance premiums etc. The consequences of allowing the matter to be dealt with by a court therefore are becomes uncertain however the consequences are greater. Most people would, therefore, simply pay the initial fine.

Region of York

- Ticket by mail has been used for other programs and should not be overly difficult to implement.

Minnesota State Patrol

- Officers are currently permitted to take down details of violations then write the tickets and mail them later. This is done to ensure that when there is an enforcement presence 100% of violations are captured. This is the nearest thing that they have or are likely to have to an automated ticket by mail system in the foreseeable future.

Agence Métropolitain de Transport (Montreal)

- The public would probably approve; they want to know that the HOV lane is being enforced as long as it is fair.

Société de Transport De L'Outaouais

- There would be issues. It would be difficult to collect and people are less likely to pay if not actually pulled over and handed a ticket. There would be extra cost for collection.

Department of Main Roads, Queensland

- There would be no issues to overcome in relation to ticket by mail aspects of an automated HOV enforcement system in QLD as the State already has ticket by mail for red light running and speed camera programs.

9. Potential other Applications / Benefits / Synergies

Ministry of Transportation Ontario:

- This has applications broader than just for enforcement of HOV lanes. It could be part of managed lane systems. Most managed lane systems are currently free for eligible HOVs and tolls are paid for non-HOVs. A system like this could allow you to balance between overcrowding and underutilization. Prices could be varied depending on the number of occupants of a vehicle (i.e. not just HOV/non-HOV).
- Interim step that uses self-identifying transponder that is user programmed with number of passengers (described in section 3) might be a realistic within a shorter timeframe.
- Potential Synergies include:
    - HOT
    - Tolling
    - Carpool incentive programs
    - Preferential Parking Schemes
    - Seatbelt Monitoring
    - Traffic Counting

CalTrans

- Pressure to raise revenue has driven demand for HOT lanes. Usage of an automated system with HOT lanes may be possible but it is very important to preserve the travel time savings in the HOV lane to ensure incentive to form carpools and for those who pay in the HOT lane.
- All semi trailers in California are fitted with a transponder. It has also been suggested that all cars be fitted with a front license plate transponder. This has not been pursued.
- Potential Synergies include:
    - Replacing loops on freeways for data collection
    - Enable data collection for use in emission models (to study whether carpools are making a difference to air quality in reality and the impacts of Hybrid SOV cars in carpool lane)
    - Electronic license plate/transponder.

Ontario Provincial Police

- Synergies such as seatbelt enforcement would need changes in legislation because the current law states that the police officer must witness the violation. Civil libertarian lobby would probably oppose this and it would probably not gain acceptance.
- A system that simply flagged potential HOV violators for police to apprehend and check would probably be of use because it would make the task of HOV enforcement easier and would give the police a reason to stop vehicles that may lead to other offences being detected.

Washington State Department of Transportation

- There may be the potential for Washington State to use an automated system for data collection (rather than enforcement)

- Washington State has a "HERO" program whereby violators are reported by other motorists and are sent information then warnings by the DoT and the State Patrol. Perhaps an automated system could be used to trigger this (rather than actual enforcement).
- Possible synergies might include:
    - HOT lane applications
    - Seatbelt enforcement (would be problematic)
    - Border crossing/anti terrorism applications may be of interest. A system that notifies enforcement officers of the number of people in a car or a van (including hidden persons) may have benefits with respect to border crossings/people smuggling etc.

City of Burnaby

- Maybe an automated HOV system would have road pricing applications.

York Regional Police

- Other potential applications might include:
    - Seatbelt enforcement
    - Following too closely
    - Speeding (perhaps a transponder could communicate with roadside equipment at speed zone boundaries. A full time "all encompassing" speed enforcement system would have massive safety benefits).

Texas Department of Transportation

- Other uses such as seatbelt monitoring are fraught with privacy and legal issues that also affect HOV enforcement and would not be easily accepted either.

City of Vancouver

- Parking inspector's hand held equipment is linked to vehicle registration and police notification systems (for detection of stolen/unregistered vehicles) an automated HOV enforcement system could be similarly linked. Perhaps vehicle registration could be checked as they drive by.

Black Creek Transportation Management Association

- Larger businesses and institutions (with more than 1000 employees) may be interested in this because some are interested in tracking carpools for preferential parking purposes. Difficulty in enforcing has been cited as a reason for not implementing schemes in the past. Those that do have such programs (e.g. McMaster University) rely on a booth operator to manually check occupancy.
- Synergies might include:
    - Using a similar approach to promote / prioritize "clean" vehicle use such as electric vehicle use of HOV lanes (but shouldn't encourage SOVs just because they are clean – HOV use and clean vehicle use should be tied together)
    - GPS for the purposes of roadside assist etc (one of the biggest problems with carpooling in relation to Guaranteed Ride Home and emergency ride home features is how often the carpool car breaks down).

Region of York

- Other ITS systems will tie into new cars in the next decade (such as vehicle following packages etc) HOV monitoring should probably link into these.
- Transit priority and HOV priority at signal control are other synergies that are apparent.

Agence Métropolitain de Transport (Montreal)

- Data could be used for performance monitoring and to monitor for maintenance issues.

Société de Transport De L'Outaouais

- System could be used in conjunction with preferential HOV parking programs to better manage parking supply. The number of on-street and off-street HOV reserved parking spaces could be dynamically adjusted to reflect changes in demand based upon knowledge of incoming HOV vehicles.

Department of Main Roads, Queensland

- Other synergies could include:
  - other enforcement (speed, red light),
  - data probes,
  - Public Transport linkages (vehicles and transit passes)
  - smart card,
  - digital driver's licenses.

Realistically, however, the domain for this includes tolling, red light and speed enforcement. To extend those linkages any further would be too complicated.

10. Partnership Opportunities

Ministry of Transportation Ontario

- Potential for partnership opportunities are obviously there including public private partnerships. We have seen this with photo radar when it was introduced a quasi-private organization did some of the processing. Most existing HOT and toll roads are managed privately.

CalTrans:

- Partnership opportunities would be difficult if you are just looking at the HOV lane but by including HOT in the scenario this would change. HOT facilities are already private.

Texas Department of Transportation

- Partnerships (such as was done in San Diego with enforcement by private contractors of red light running) would be inappropriate. It would be seen to be self-serving, revenue raising and profit making. It sends the wrong message to the public. Government should be responsible for enforcement.

Black Creek Transportation Management Association

- Partnership opportunities are necessary because government would need to plan and regulate, set standards and end goals but is not well placed to implement it, doesn't have R&D capacity or access to the components necessary. Partnership with private sector will be necessary to deliver an automated system.

Road and Traffic Authority of New South Wales

- Partnership opportunities exist because of the general direction that the State has been taking in relation to enforcement.

Region of York

- Partnership opportunities would be a good idea if you can find them.

Agence Métropolitain de Transport (Montreal)

- Partnership opportunities would exist. Responsibilities such as park and ride security are now contracted out. This type of control and enforcement may be able to be done on similar lines.

Société de Transport De L'Outaouais

- Partnership opportunities are an imperative as public agencies will not pursue this on their own. Public-private partnerships are a possibility.

11. Commercial Issues

Black Creek Transportation Management Association

- Proprietary vs open system is a juggle; need consistent standard and interoperability but do not want a monopoly controlling it.

Agence Métropolitain de Transport (Montreal)

- Automated system should not be a proprietary system. It needs to be interoperable with other agency systems.

Department of Main Roads, Queensland

- In relation to introducing new product it may be best to facilitate as part of a toll road project. From government's point of view it is important to accept the best product from the market place and one that provided the right sort of data. Probity issues would need to be respected. A good system that worked well elsewhere would be considered.

12. Alternative Solutions

Ministry of Transportation of Ontario

- HOV enforcement is difficult but police enforcement is probably the best way to do it.
- As an alternative to automated enforcement consider an "honor" system with random spot checks and very high fines as a disincentive to ever being caught.

Black Creek Transportation Management Association

- HOV enforcement should initially be based upon an "honor system" with random spot checks similar to Ontario's GO Train proof of payment system. That is that all users of the system are not checked each time they use the system. Random spot checks by police should be undertaken and this fact should be well publicized. The penalty for violation should be serious and increasing with repeat offences. For example $500 first offence, $1000 second offence, driver's license suspended for 3rd offence and driver's license cancelled for fourth offence.

- Would prefer to see the above described system adopted first in combination with physical HOV facilities, good signage and real time traveler information first.
- Government needs to communicate well with public and private sector before and during the implementation.

Department of Main Roads, Queensland

- Does not think that there are other ways of doing this, however need to use all of the other elements discussed earlier (marketing, education, manual enforcement and engineering).

13. Other Issues Suggested / Raised

Ontario Provincial Police

- A serious issue in Ontario (and perhaps in other jurisdictions) is that the courts are jammed already. A proportion of alleged violators will opt for a trial (perhaps 40%). If an automated HOV system increases the number of violations being recorded, this will increase the court's caseload and worsen the situation. Currently, many violators avoid penalties because the courts do not have time to deal with them. If this is not addressed, it may become common knowledge / practice for HOV violators to opt for a trial on the basis that few cases actually make it to court to be dealt with. If this were to happen, enforcement of any type will be ineffective because the penalty could easily be avoided.
- During the 1990s, photo radar in Ontario involved a monetary penalty only (i.e. no demerit point on drivers license record) so it was not a big disincentive to speeding. Consequently it is suggested that any future penalty for HOV violation be set high enough to be a significant disincentive.
- Police enforcement presence on the ground has the benefit that the police are able to enforce other laws at the same time (e.g. intoxicated driving, stolen vehicles, stolen property, drugs, firearms, etc). Also it is a visible deterrent to unsafe driving practices. A machine that enforces HOV enforcement will not be able to perform these other roles.

City of Burnaby

- There may be public resistance to police being engaged in HOV enforcement (with or without an automated system) when they could be involved in more high priority duties. The perception may be different if HOV enforcement revenue was channeled back into enforcement rather than being directed to provincial coffers.

Massachusetts Highway Department

- HOV enforcement is a significant issue for the Department because they have to pay police special rates (overtime) to carry it out. Consequently, it is expensive. Revenue from HOV enforcement is directed to the State's general fund so it does not return to HOV projects or HOV enforcement activities.

Ministry of Transportation of Ontario

- The merits of real time traffic guidance management (ie directing individual motorists to use particular routes to minimize congestion and delays across the network) have been debated in the past. One of the problems that is raised is that individual motorists would be unwilling to take a route that they perceive is not in their own best interests (e.g. drive further out of their way) for the "good" of the overall network. Initially only the "top end" of the market would be able to afford instrumentation. These drivers are likely to ignore recommended routes that appear to disadvantage their personal trip making. So there would be little or no benefit from the system's initial implementation and its credibility with the public would fail. The whole concept of HOV monitoring and enforcement may be affected by similar perceptions (ie individual's utility vs efficiency of whole network).

- Whatever solutions are investigated it is important to bear in mind Ontario's climate and weather conditions (viz: exposure to snow and ice, the use of snow plows, road salt etc). A solution that works fine in warmer climates may not be appropriate in Ontario.
- People may not be willing to have a device in their car that monitors them for enforcement purposes. Some are likely to try to disable the device.
- HOV enforcement is difficult but police enforcement is probably the best way to do it.

Black Creek Transportation Management Association:

- In Ontario right now there are higher priority issues than an automated HOV enforcement system. Infrastructure (including HOV infrastructure), better signage, ITS aimed at providing real time traveler information and traffic management to make the network more efficient are all areas that would be better funded ahead of this. The situation may be different in other jurisdictions.
- Collection of fine revenue may be a problematic issue. This should ultimately be linked to renewal of driver's license or vehicle registration.
- A "carrot and stick" approach needs to be applied with penalties applied for HOV violation and incentives (in the form of tax relief, vehicle registration rebates etc) applied to encourage carpooling. Incentives for carpoolers need to include increased speed (through physical HOV facilities) and preferential parking schemes etc.
- Timing for implementation of HOV facilities should be now. There is public outcry about gridlock. Any coordinated initiative to relieve gridlock would be well accepted by the public. Need to employ simple manual methods first. Subject to good delivery, now is the time for HOV implementation.
- A downside to automated enforcement is that police presence is required for other purposes and to monitor other violations and crimes. Diminishing police presence on the road would not necessarily be a good thing.

Royal Canadian Mounted Police

- HOV compliance is a provincial matter (the RCMP is responsible for enforcing in areas that have HOV facilities and do not have provincial police services). RCMP is therefore responsible for some HOV enforcement in British Columbia.
- RCMP focus is on enforcement for safety purposes ahead of compliance issues so HOV enforcement is not usually a high priority. Provincial funding for targeted HOV compliance enforcement in British Columbia has stopped so non-compliance on HOV facilities is the subject of almost daily complaints by motorists.

Minnesota State Patrol

- The current fine for HOV violation in Minnesota is $130. The HOV lane sign is a regulatory sign so the penalty includes one drivers license demerit point (4 demerits and license is suspended). This record also affects insurance premiums. Notwithstanding, this does not seem to be a significant deterrent to HOV lane violations. Because enforcement cannot be 100% coverage there should be a very high fine, say $700, so that there is a significant disincentive to ever being caught.

CalTrans

- HOV violations are a moving violation. Consequently, the fine is $341 which is high by comparison to the fine for the same offence in other jurisdictions. The penalty for violation also includes driver's license demerit points which affect driver's insurance premium costs and Department of Motor Vehicle record.

Texas Department of Transportation

- Would definitely like a better enforcement system than is available currently.

City of Vancouver

- Interested in automated HOV enforcement research because the police do not have enough resources to enforce HOV lanes adequately all of the time.
- Vancouver is unlikely to install more HOV lanes in the future as the focus will probably be on bus only lanes.

Department of Main Roads, Queensland

- In relation to the deterrent value of enforcement this is related to:
    - the chances of being caught,
    - the swiftness of the penalty,
    - the severity of the penalty.