Reason

Policy Study 390
February 2011

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by Robert W. Poole, Jr.

Reason Foundation

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Executive Summary

HOT lanes permit certain categories of high-occupancy vehicles to use those lanes at either no charge or a reduced toll rate. This requires effective enforcement to ensure that the promised performance is delivered. Manual enforcement of HOV lane occupancy requirements has not been very effective. Enforcing HOT lane eligibility is more complicated, since both toll-paying vehicles with transponders and toll accounts, as well as HOVs meeting the occupancy requirement, must be distinguished from other, ineligible vehicles. As HOT lanes become larger and more complex, effective enforcement becomes even more difficult.

This study first reviews current efforts to develop technology-based approaches to occupancy enforcement (either roadside or in-vehicle). It suggests that these efforts are not likely to prove cost-effective over the next several decades, a time period during which complex networks of HOT lanes are planned for implementation. It then develops a policy-based approach to HOT lanes enforcement, aimed especially at more complex HOT lanes and HOT networks. The first policy change would require all vehicles using the HOT lane to be equipped with transponders, with eligible carpool vehicles' transponders charged zero toll during peak periods (which could be implemented in the toll-collection software). The second policy change would require pre-registration of eligible carpools with an employer or ride-sharing agency, similar to current practice with vanpools.

This approach would reduce the problem of on-road occupancy enforcement to what is already needed for electronic enforcement of toll collection, with significant savings in equipment and enforcement costs. Enforcement would be shifted off-road, and would consist of periodic audits of employer-sponsored carpools by the local ride-sharing agency (which already audits employer-sponsored vanpools). It would end eligibility for free or discounted use of the HOT lane by casual carpools and most "fam-pools." These changes represent a return to the original purpose of carpooling programs: to stimulate shared commuting to and from workplaces, thereby reducing the number of vehicles on the roads during peak periods.

The first example of a HOT lanes project with pre-registered carpools is the I-95 Express Lanes in Miami, which began operation at the end of 2008; a registered-carpool approach has also been proposed for a HOT lanes project under development on I-85 in Atlanta. As metro areas move forward with plans for extensive networks of HOT lanes, cost-effective enforcement of zero or discount tolls for eligible carpools will be critically important. The registered carpool approach suggested here appears to be superior to other proposed approaches for automated enforcement.

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Part 1

The HOV/HOT Enforcement Problem

Enforcement of the occupancy restrictions on high-occupancy vehicle (HOV) lanes has always been done visually, by patrol officers external to the vehicles using the HOV lane. Manual enforcement is labor-intensive, costly, and sometimes has negative safety implications. Consequently, few HOV lanes have high levels of enforcement on an ongoing basis. Violation rates are often in the double-digit percentage range, except for occasional periods of intensive patrol-car enforcement.

With the emerging shift from HOV to HOT (high-occupancy toll) lanes, enforcement becomes more complex, because vehicles can be in the lanes legally either by meeting an occupancy requirement or by paying the electronically charged toll. Purely toll lanes enforce toll payment by detecting the presence or absence of a transponder and checking the status of the toll account linked to that transponder. Vehicles either lacking a transponder or having an invalid or inadequate toll account are defined by the system as violators, and a video recording is made of their license plate. But those systems cannot tell if a vehicle without a transponder has a legal right to be in the HOT lane thanks to having the required number of occupants. Even manual verification becomes extremely challenging if the occupancy requirement is three or more people.

Two rather different types of managed lanes have both been dubbed “HOT lanes.” The first type, which transportation consultant David Ungemah has termed HOT 1.0, consists of lanes converted from HOV-2 lanes, such as those on I-15 in San Diego or I-394 in Minneapolis.[1] In most of these HOT lanes, the lanes are still conceived of primarily as HOV lanes that sell whatever excess capacity they have to paying single-occupant vehicles (SOVs). Their primary purpose is to increase vehicle occupancy, while making full use of their capacity and generating ancillary revenue by selling excess capacity. For HOT 1.0, if demand for HOV usage reaches capacity at some pre-defined level of service, SOVs are no longer allowed access.

The second type of HOT lane, dubbed HOT 2.0 by Ungemah, is conceptually different. Generally consisting of new capacity, it is a congestion-relief lane offering reliable, high-speed service to paying customers, while also allowing certain categories of HOVs free or reduced-rate passage. Examples include the 91 Express Lanes on SR 91 in Orange County, California and the I-495 HOT lanes under construction in northern Virginia. For HOT 2.0, revenue generation is very important, since toll revenues are typically bonded against to pay for most or all of the construction costs. In addition, since the business of these lanes is offering reliable time savings to paying customers, their ability to do that via pricing depends on the majority of vehicles paying tolls.

Table 1: Two Different Types of HOT Lane

	HOT 1.0	HOT 2.0
HOV free passage	HOV-2+	HOV-3+
Infrastructure	Conversion of HOV	New construction
Configuration	One lane per direction	Two lanes per direction
Examples	I-15, I-10, I-394, I-25, SR 167	SR 91, I-495, I-95, I-635, NTE
Percent of traffic tolled	32.5%	83%
Annual revenue	$1.7 million*	$35.5 million**
Main use of revenue	Transit operations	Debt service

*average of four projects

** SR 91 only (others not yet in operation)

Lack of rigorous enforcement (as opposed to occasional periods of intense enforcement) may be tolerable for HOV lanes (and perhaps HOT 1.0 lanes), as long as violators do not become so numerous as to cause congestion in those lanes, since these lanes' primary purpose is to serve HOVs. But enforcement is essential for a HOT 2.0 lane to be successful, given its need for revenue and its dependence on pricing to manage traffic flow. Hence, it is important in HOT 2.0 to limit the number of non-paying vehicles to those legally qualified to be in the lanes.

This study proposes a new approach that permits automated enforcement of both types of users (paid and non-paid) in HOT lanes, focusing primarily on the case of HOT 2.0. The next section reviews the types of enforcement used on early HOT 1.0 lanes and summarizes their limitations, especially if used in HOT 2.0 settings. The following section then provides an overview of technology-based approaches to automated vehicle occupancy detection, weighing them against the requirements of HOT 2.0 lanes and networks. That sets the stage for a policy-based approach, that would eliminate the need for occupancy-detection technologies, which is proposed in Part 4. The final section then presents a summary and conclusions.

Part 2

Enforcement in First-Generation Hot Lanes

A. Enforcement Zones

What we might call first-generation HOT lanes are physically simple facilities, generally with an entrance at one end and an exit at the other. For enforcement purposes, a set of overhead gantries mounted with toll collection and enforcement equipment is placed at an intermediate location. For many of these projects (including SR 91/Orange County, I-25/Denver, and I-10/Houston), an "enforcement zone" is located adjacent to the tolling gantry. An extra lane is provided there, and HOVs are directed to move into that lane rather than using the toll lane(s) on that portion of the HOT lane. As vehicles pass through this part of the HOT lane, the HOVs in their separate lane are observed visually to verify that they have the required number of occupants, while paying vehicles are enforced electronically, as on any other toll road equipped with electronic toll collection lanes.

The two principal requirements for implementing this approach are land and labor. First, there must be enough right of way to expand the width of the freeway to permit an additional lane in each direction (unless the HOT lanes are reversible, in which case only one additional lane is needed). Second, as with conventional HOV lane occupancy enforcement, this approach depends on some combination of spotters (to count heads) and patrol officers to issue citations for violations. In some cases, the patrol officers handle both tasks.

B. Manual Enforcement with Technical Aids

At least two of the newer first-generation HOT lanes—I-394/Minneapolis and SR 167/Seattle—have departed from the separate HOV enforcement lane approach. Both have opted for technology whose aim is to assist patrol officers in their enforcement tasks.

Minnesota's MnPASS system had to be designed to cope with a more complex HOT lanes configuration than other first-generation projects. The I-394 HOT lanes have several ingress and egress points, as well as two different lane arrangements: an eight-mile portion with a single HOT lane in each direction, separated from the general-purpose lanes only by a double-white line; and a three-mile, barrier-separated portion consisting of two reversible lanes. There was no room to add a lane for enforcement purposes in either portion.

Visual enforcement by patrol officers is assisted by three new devices, as follows:[2]

- Enforcement transponders: These devices are installed in patrol cars and allow officers to determine whether a single-occupant vehicle (SOV) has a valid transponder and account; if not, the device emits an audible beep.

- Mobile enforcement readers: This device, installed only in certain patrol cars, allows the officer to read the transponders of passing vehicles, to make sure that they have not been disengaged when passing a toll gantry.

- Enforcement beacons: These are flashing lights mounted on the gantry over each HOT lane; if the light does not flash when a vehicle passes underneath, it means the vehicle does not have a valid transponder, and the officer should visually inspect to determine if it has the required two or more occupants.

The HOT lanes on the Seattle area's SR 167, like those in Minneapolis, were converted from previous HOV lanes. There is one lane in each direction, likewise separated from the general-purpose (GP) lanes only by a double-white line. Washington State Department of Transportation has equipped each toll gantry with an enforcement beacon, which operates in the same manner as those on the I-394 HOT lanes: it flashes if the vehicle has a valid transponder. If the light does not flash, a patrol officer (if one is present) will visually count the number of heads and, if it is not two or more, will pull the vehicle over as a violator.[3]

Note that in both of these cases, the technology aids are basically used to enforce toll-paying by detecting the absence of a valid transponder/account. *Occupancy* detection is still entirely manual and visual, requiring the presence of patrol officers full-time (during toll collection periods), a high level of visual accuracy in counting heads, and safe places from which to make those observations and to pull over violators.

C. Limitations of First-Generation Enforcement Approaches for HOT 2.0

As noted previously, enforcing HOT lanes using enforcement zones and patrol cars is a costly proposition. In most urban areas, especially those with serious recurrent congestion problems, land is very costly. If HOT lanes require a wider freeway, even just for periodic HOV enforcement lanes, the cost of acquiring additional right of way will be high, increasing the project's capital costs. Indeed, in some cases additional right of way is simply not an option. And since all first-generation approaches implemented thus far depend on manual, visual enforcement of occupancy, we know that this will be labor-intensive and hence costly, if rigorous enforcement is (as posited above) essential for HOT 2.0 lanes' success. Moreover, on freeways whose GP lanes have been narrowed in order to squeeze in HOV or HOT lanes (e.g., Los Angeles, Miami), there may not be a full breakdown shoulder adjacent to the HOT lane into which potential violators can be pulled over.

A number of transportation planners think the real potential for HOT lanes is not individual stand-alone projects such as those described above as first-generation. Much greater potential arises from implementing a seamless, region-wide network of HOT lanes, serving not only as a congestion-relief alternative for motorists but also as an uncongested guideway for express bus service.[4] Studies of such networks, some of them assisted by Federal Highway Administration (FHWA) Value Pricing grants, have been carried out for the Atlanta, Dallas, Denver, Houston, Miami, Minneapolis/St. Paul, San Diego, San Francisco, Seattle and Washington, D.C. metro areas, and such networks are already included in the long-range transportation plans of Atlanta, Dallas, Houston, San Diego, San Francisco and Seattle.

A HOT *network* is far more complex than a HOT lane on a single freeway. The network will have numerous ingress and egress points, and its electronic toll system will likely charge either by the mile (from point of entry to point of exit) or for each link traversed. Since some of the freeways that make sense as part of the network lack existing HOV lanes that could be converted to HOT, developing a HOT network will involve lane additions (unless political support could somehow be developed for converting existing GP lanes to HOT lanes, which seems unlikely). In the largest urban areas, such lane additions could cost between $10 million and $56 million per lane-mile.[5] In addition, for the network to be seamless and free-flowing, the HOT lanes on one freeway must be connected to those on an intersecting freeway by means of flyover ramps—another very costly element.

The size and complexity of a HOT network means that continually enforcing occupancy requirements based on patrol cars adjacent to every tolling point would carry a very high operating cost. And the already high capital cost of a network that requires many lane-miles of new urban capacity plus numerous flyover ramps will be a challenge to finance, let alone having to add and pay for even more lane-miles of HOV enforcement lanes. Yet the inescapable fact of high capital cost puts a premium on not losing any legal toll revenue; hence such networks will almost certainly use the HOT 2.0 model. Accomplishing their revenue goal will require rigorous enforcement of both occupancy and toll payment. And that in turn leads to a search for a more cost-effective method of enforcing occupancy.

Part 3

Technology-Based Approaches to Occupancy Enforcement

Considerable research is being carried out on automated vehicle occupancy verification (AVOV), both in Europe and in the United States. An excellent overview of current AVOV possibilities was released by FHWA in 2007; it is referred to as the White Paper on this subject, and is drawn upon for most of the descriptive material in this section.[6] The White Paper divides the technology approaches into two broad categories: roadside systems and in-vehicle systems. This section describes the principal devices being considered under each heading, and their limitations (in an HOV lanes context) as described in the White Paper. This is followed by a further assessment of their limitations in the context of HOT networks.

A. Roadside Systems

The White Paper identified five technologies for roadside vehicle occupancy detection: video, microwave, ultrawideband (UWB) radar, single-band infrared and multi-band infrared.

- Video is commercially available, but suffers from poor resolution and inability to operate under low-visibility conditions (darkness, fog); it is definitely inferior to direct visual inspection. San Diego tried using video on its I-15 HOT lanes, but found it to be unworkable.[7]

- Passive microwave systems are usable under all lighting conditions, but have several significant drawbacks for HOV occupancy detection. The White Paper found that they have poor resolution, slow imaging speed, cannot penetrate metallic window tint, and are very large and expensive.

- UWB is a commercially available technology using nanosecond pulses to do object detection at short-range. It works under all lighting conditions, but like passive microwave, has several major drawbacks for vehicle occupancy detection. It cannot penetrate metallic window tints and is too slow for imaging fast-moving vehicles.

- Single-band infrared showed initial promise, being usable under all lighting conditions. A prototype developed at Georgia Tech was field-tested in 1998, detecting vehicle occupants at speeds up to 80 mph.[8] However, it could not distinguish human skin and therefore could potentially be fooled by the use of dummies.

- Multi-band infrared is the most promising of the roadside technologies, and the only one that has led to a product that is close to being marketed. It can distinguish human skin under all lighting conditions. Minnesota DOT developed and field-tested a prototype in 2000; it was claimed to be effective at detecting front-seat passengers through the windshield of vehicles driven at 50 mph, with an accuracy equal to that of human visual observation.[9]

Subsequent research and development in the United Kingdom produced a prototype multi-band system using near-infrared and visible wavelengths to count front-seat occupants through the windshield at highway speeds. The system was tested on the HOV lane in Leeds in 2005, claiming a 95% success rate in detecting human occupants and rejecting decoys such as dummies.[10] A commercial product first called Cyclops Vehicle Occupancy System and later renamed *dtect* is being offered by start-up company Vehicle Occupancy Ltd.[11] The company website reports a unit cost of $150,000 as of November 2010 per unit; one unit would be needed for each lane at each tolling/enforcement point.[12]

The White Paper summed up its assessment of roadside technologies by citing four main challenges such systems must meet:

- Cabin penetration, especially tinted and metalized windows;
- Environment—all-weather and night-time operation;
- Image resolution;
- Speed of image acquisition.

All approaches except infrared fall short on one or more of these criteria. The White Paper also notes that the most advanced systems, such as Cyclops/*dtect*, "have focused only on through-the-windshield monitoring, which is only effective for detecting front-seat occupants." Since there is now significant emphasis on HOT lanes requiring three or more occupancy to qualify for discounts, this is a major shortcoming. Also, in assessing the outlook for such systems, the paper concludes that "the chief barrier to their implementation appears to be their high cost."

B. In-Vehicle Systems

The White Paper judged four technologies to be of high interest: occupant weight sensors, electric field sensors, monocular vision sensors, and three-dimensional, time-of-flight sensors. All are being developed in connection with air-bag deployment systems for future new vehicle production.

- Weight sensors are already deployed in some newer vehicle front seats. Cushion-based pressure sensors are deployed on some cars from a number of auto companies, but only on front seats. Frame-based strain sensors, not yet in production, can only be used on front seats, because those seats are individually bolted to the car's frame. Back seats are almost always a single unit seating two or three passengers, therefore, a frame-based system could not determine how many people were sitting on it.

- Electric field sensors detect bodies by measuring changes in a low-level electromagnetic field generated by the system. This approach can accurately distinguish between a person and many other types of objects, due to the relatively unique dielectric constant of the human body. The White Paper reports one current production example, available at the time of that report on Honda and Acura vehicles, also used only for front seats.

- Monocular (two-dimensional) sensors, either optical or near infrared, are in the R&D stage, with recent tests achieving 91% and 97% correct classification of occupants. These systems must have line-of-sight access to each seating position, which may require multiple systems to handle back-seat as well as front-seat occupants.

- Three-dimensional, time-of-flight sensing uses active illumination and sensors to measure the time of flight between a light source and an object. These systems are intended for both occupant classification (adult, child, etc.) and head position—again, for use in airbag deployment. None is currently in production.

After an in-vehicle system determines how many bodies are present in the vehicle, that occupancy information must be transmitted from the vehicle to a roadside reader, so that the vehicle may be categorized as legally or non-legally in the HOV or HOT lane. This turns out to be a legal and policy challenge.

As the White Paper explains, the auto industry and privacy organizations consider the transmission outside the vehicle of data retrieved from the airbag deployment system to be a "severe threat to privacy." In addition, auto manufacturers are also opposed to such external uses of airbag-system data on liability grounds, in part because it is not known how the performance of such systems will hold up over time. There is also a legal issue noted by the White Paper. Since automated vehicle occupancy verification is "not considered a safety issue, it is very unlikely that AVOV applications could simply be mandated by regulatory action. Instead, legislative action at the state or federal level would be required."

Vehicle to roadside communication is, of course, an integral aspect of the planned Vehicle Infrastructure Integration (VII) vision, so it would seem that any needed legislation to facilitate VII could address the communication of occupancy data for purposes of HOV/HOT enforcement. But a basic tenet of VII development is that VII not be used for enforcement purposes. This principle has been agreed to on the grounds that the public is likely to reject VII if it is used to go after drivers for various violations. Personal privacy protection has likewise been a core principle for VII, and various measures are being included to maintain vehicle and driver anonymity and to prevent the tracking of specific vehicles. These two principles present serious obstacles to the idea of using airbag-deployment system data to verify vehicle occupancy for HOT lane purposes.

C. Limitations of Technology-Based Approaches for HOT Lane Enforcement

The context of this paper's discussion is verifying vehicle occupancy in future second-generation HOT lanes and region-wide HOT networks. Consequently, the roadside and in-vehicle technologies summarized above must be assessed in this larger context, rather than in the more limited context of first-generation HOV or HOT lane facilities.

A HOT network consists of HOT lanes on multiple freeways, interconnected by flyover ramps and accessible from numerous points, including direct-access ramps. Hundreds of different possible trips, from ingress point to egress point, must be individually charged for, requiring potentially hundreds of tolling/enforcement points. The majority of all vehicles using a HOT 2.0 network must be paying customers, both to provide enough revenue and to ensure sufficient pricing power to maintain uncongested traffic flow. Therefore, such networks will almost certainly require a minimum of three-person carpools for free passage. This is the case on nearly all of the HOT lanes that have involved adding capacity (as opposed to pure conversions of HOV lanes) thus far: the 91 Express Lanes (Orange County), 95 Express Lanes (Miami), Capital Beltway HOT Lanes (northern Virginia), LBJ I-635 HOT Lanes (Dallas), and North Tarrant Express HOT Lanes (Ft. Worth).

Therefore, the occupancy verification system needed for HOT 2.0 networks must be able to verify back-seat occupants as well as front-seat occupants. The White Paper found that neither the leading roadside system (Cyclops/*dtect*) nor any of the most promising in-vehicle systems addresses back-seat passengers. The federal requirement that all new vehicles have advanced airbag systems (and hence in-vehicle occupancy detection systems) as of the 2009 model year applies only to front seats.

Another problem with relying on data from advanced airbag systems is the vehicle turnover problem. It takes approximately 20 years for 95% of the personal vehicle fleet to turn over. Thus, even if verifying only front-seat occupancy were sufficient, a system of HOV/HOT verification based on that approach could not be effective for at least 20 years. VII researchers expect that the full fleet will not be equipped with VII capabilities—and hence the communications needed to transmit occupancy data—until 2035.[13] HOT 2.0 lanes are under construction today, and HOT networks are in the planning stage. They will need reliable enforcement from the day they open, not 20 or 30 years from now. Retrofitting vehicles after sale is not an option, since, as the White Paper notes, "Given the critical safety role of AAS [advanced airbag systems], aftermarket 'hacks' should be avoided since they do not include design input from the OEM [original equipment manufacturer] and may therefore adversely affect AAS operation or long-term reliability."

A third problem with existing technologies is cost. Given the many shortcomings of in-vehicle systems, the roadside approach appears more likely to be technically feasible, assuming it can be adapted to verify back-seat occupants. But the current cost of more than $150,000 per enforcement site per lane may well prove prohibitive in a HOT network requiring many hundreds of such units.

This overview of the current status of technology-based approaches for verifying vehicle occupancy for HOT 2.0 lanes and networks suggests that no current approach meets the requirements. Hence, the next section discusses an alternate approach based on a change in policy.

Part 4

Policy Change Approaches

A. Basic Concept for Electronic Enforcement

The core concept that would permit automated, electronic enforcement of occupancy relies on changing the definition of an eligible carpool. Instead of allowing any vehicle with three or more occupants, a revised policy would limit eligibility to pre-registered carpools. Such carpools would be required to have a transponder, identical to those used by toll-paying customers. The account number associated with that transponder would be flagged by the tolling software as qualifying for a zero (or reduced-rate) toll during rush-hour periods. Thus, the only enforcement required on the HOT lane itself would be ordinary electronic toll enforcement: communications equipment to interface with the vehicle-mounted transponder and video cameras to make an image of the license plate of any vehicle without a valid transponder/account combination. The only other enforcement required would be periodic verification that the carpool is still in operation, as originally registered. Thus, enforcement would be off-road, not on-road (as discussed below).

Shifting from casual to registered carpools would return to the original trip-reduction purpose on which the creation of HOV lanes was based: providing an incentive for fellow employees to share rides to work, leaving one or more vehicles at home and thereby reducing congestion on the roads during peak periods. Over the last several decades, a number of studies have found that large fractions of those traveling to work as carpools were in fact "fam-pools"—members of the same family who would be traveling together in any case (and whose carpooling therefore does not reduce peak-period vehicle use). For example, one analysis of data from the National Personal Travel Survey and the National Household Travel Survey found that fam-pools constituted 75.5% of all journey-to-work carpools in 1990 and 83% in 2001.[14] To be sure, in some cases two spouses may work at the same location and be able to ride together to work, but large numbers of fam-pools consist of a parent taking a child to school or day-care. Such uses of HOV lanes do not reduce the number of vehicles on the road at rush-hour.

Metro-area ride-sharing agencies are the most likely entity to register eligible carpools and to work with employers to audit their continuing existence (and hence eligibility for free or reduced-rate access to HOT lanes). Such agencies already have experience working with employers on carpooling and vanpooling programs. The ongoing existence and operation of vanpools is monitored and audited, since the vehicles are often provided by a public agency and must be retrieved if the vanpool ceases to operate or drops below a threshold number of participants. Many of these agencies are supported, in whole or in part, by the state DOT or other public agency, so this new role could become part of their ongoing contractual obligations.

Since members of carpools often take turns driving and providing the vehicle, the registered carpool program would be most flexible if each member of the carpool is issued a transponder. (That is especially important for toll systems that shift from portable transponders to relatively new "sticker tags" that are permanently affixed to the vehicle's windshield.) In this case, the toll system software would be programmed to recognize the three transponder account numbers as a set, only one of which would be eligible for zero or reduced-rate tolls during the peak periods of any given weekday. Any use of the second or third of this set of transponders on that day would be charged a toll at the normal rate.

B. Current Interest in Registered Carpools for HOT Lanes

At least two state transportation agencies have begun developing HOT lane systems that will make use of registered carpools, the Georgia State Road and Tollway Authority and the Florida Department of Transportation. Both included this approach in their proposals to the U.S. Department of Transportation's 2007 Urban Partnership Agreement Competition. Neither agency opted to combine registered carpools with the fully automated approach to enforcement outlined above, however.

Georgia's proposal calls for converting existing HOV lanes (one per direction) on I-85 in Atlanta to HOT lanes on which vehicles with three or more occupants could travel at no charge. Those likely to be frequent carpool users would be issued transponders "with default account settings identifying their vehicles as carpoolers," while those who usually are paying customers "will be able to identify themselves as carpoolers when appropriate by deactivating their transponders."[15] Since this proposed HOT lane would also feature a non-transponder (pay-by-plate) payment option, eligible (three-person) carpools would be allowed to register in advance to use the lane at no charge.

The Georgia I-85 HOT lane concept would still rely on manual enforcement by patrol officers, aided (as in Minneapolis) by mobile enforcement readers and (unique to this proposed project) by patrol-car-mounted automated license plate readers. The need for manual enforcement stems from two factors: the lack of an audit requirement for registered carpools and the ability of occasional carpools to register and use the lanes without a transponder.

While the Georgia project is still being implemented, the Florida approach has been in operation since the end of 2008, as part of FDOT's Urban Partnership Agreement 95 Express project. The project converted two existing HOV lanes on I-95 in Miami-Dade County and the southern portion of Broward County into four HOT lanes (thanks in part to reducing lane widths on this freeway from 12 feet to 11 feet). Simultaneously with this conversion, the occupancy requirement for free passage was increased from two to three, and the policy change to registered carpools was made.

The local ride-sharing agency—South Florida Commuter Services—is providing outreach and carpool registration services for the 95 Express lanes.

Eligible carpools must register, obtaining a form from SFCS (either online or in person). The assumption is that one person will be the principal driver; hence, data on that person's vehicle must be provided, along with home and work locations and work schedule. The other carpool participants must sign the form, providing their home and work information. Registered carpools do not, however, receive zero-toll transponders. Instead, they receive a special "3+" decal, valid for six months at a time. If not renewed, the carpool will be considered inactive and the license plate will be removed from the eligible list.[16] This approach therefore still requires manual enforcement by patrol officers.

In the Florida case, there is no technical reason that transponders could not be issued to all registered carpools. Apparently, FDOT made a policy decision not to do so at this stage, perhaps deciding that the extent of change being made in this project (from HOV to HOT, from HOV-2 to HOV-3, and from casual to registered carpools) was enough change all at once. In the Georgia case, zero-toll transponders were proposed for regular carpoolers, but without an audit requirement and with the added complication of allowing just-before-use registration of infrequent carpools. Those policy choices precluded fully automated HOT lane enforcement.

C. A Possible Alternative: Declaration Transponders

For the I-495 Capitol Beltway HOT Lanes project and for possible HOT lanes in the Puget Sound region, a different policy-related approach is being considered. It would also require carpool users of the HOT lanes to acquire a transponder, but in this case the transponder would include a switch by which the driver would declare whether the vehicle was currently operating as an eligible carpool or not. In order to get around the "honor system" problem, the "declaration transponder" would be designed so that it would alert the toll system if its setting were changed from carpool to non-carpool while on a HOT lanes facility. That vehicle's license plate number could then be relayed to patrol cars for enforcement purposes. Another version would be designed to work with mobile enforcement readers in patrol cars.

Thus far, declaration transponders have not been subjected to testing under real-world HOT lane conditions. They still appear to depend considerably on on-road enforcement by patrol officers, which is problematic for reasons discussed earlier in this paper.

D. Advantages and Disadvantages of the Registered Carpools Approach

One of the biggest advantages of the proposed electronic enforcement approach is cost savings. No additional roadside equipment is required beyond what is already needed for electronic toll collection from the HOT lane's paying customers. Nor is any additional in-vehicle equipment required beyond an ordinary transponder, identical for paying customers and eligible carpoolers. There would be one-time software development costs, to add to the conventional toll billing software provisions for special handling of the linked sets of transponder/account numbers of the members of registered carpools.

As for operating costs, there would be additional workload (and some modest software development) for the ride-sharing agency, plus added costs for the ride-sharing agency to engage in periodic employer audits of the status of the registered carpools (an expansion of already existing audits of employer-based vanpool programs). Offsetting those new agency operating costs would be potentially large savings in patrol officer enforcement costs. A recent Transportation Research Board paper provides data on the annual enforcement costs for three HOT lanes currently in operation: I-15 in San Diego, I-394 in Minneapolis, and SR 91 in Orange County.[17] Data from 2004 put the enforcement costs at $3,700 per lane-mile for I-15, $8,900 per lane-mile for I-394, and $9,000 per lane-mile for SR 91. The authors note that the lower cost for I-15 reflects a lower level of effort: one officer providing three four-hour shifts per week. At the other end of the scale, SR 91 funds 14 eight-hour shifts per week, with two officers on duty during both morning and evening peak periods. They also note that HOV lanes with fairly high-level enforcement can have comparable costs, citing the Long Island Expressway HOV lanes at $8,600 per lane-mile. To put this in the context of a HOT network, a 400 lane-mile network at $10,444 per lane-mile ($8,500 adjusted from 2004 to 2010 at 3.5% inflation) would cost over $4 million per year to enforce via patrol officers.

A second benefit would likely be reduced violations. Visual enforcement—especially at high speeds and without separate enforcement lanes—is not likely to be highly reliable, especially on a whole network of HOT lanes. The search for automated occupancy enforcement technology, as described earlier, is motivated not only by cost savings but also by the limited reliability of visual enforcement.

A third benefit would be increased revenue, thanks to more effective enforcement that reduces the fraction of vehicles in the lanes illegally. As noted previously, while revenue is considered a secondary benefit in HOT 1.0 lanes created by the conversion of HOV lanes, it is of vital importance when a seamless network of HOT 2.0 lanes must be financed and built. Aside from a handful of very large metro areas that already have extensive HOV lane-mileage that can be converted to HOT, most metro areas will have to build a large fraction of their HOT networks as new capacity. And nearly all will have to add flyover connectors for their HOT lanes wherever two freeways intersect. A 2003 conceptual study of potential HOT networks in eight major metro areas estimated their construction costs at from $2.7 billion to $10.8 billion each, in 2000 dollars.[18]

Another benefit of the automated enforcement approach proposed here is that it avoids the privacy concerns raised by both roadside (camera) and in-vehicle technologies, as discussed previously. Those privacy concerns could turn out to be serious obstacles to the actual implementation of those technologies for occupancy enforcement. Even in England, where there is extensive use of closed-circuit TV cameras for surveillance in urban areas, a recent headline on proposed HOV and HOT lanes there read "Watch Out, Another Traffic Spy Is Heading Your Way," in reference to the proposed use of the Cyclops/*dtect* infrared camera system for enforcement use.[19]

On the other hand, it is quite possible that the requirement for registered carpools will face opposition from some existing carpoolers. Many fam-pools will not qualify, and will therefore have to either go back to using congested lanes, find another rider in order to qualify, or pay the toll. Likewise, since casual carpooling will no longer qualify, those who now carpool in this manner, especially the organized "slugs" in northern Virginia, will likely oppose a registration requirement. In the case of the Virginia slugs, those who already do work at the same location (e.g., the Pentagon), may find it feasible to establish and register formal carpools. It should be noted that there has been negligible backlash against registered carpools in Miami, the first metro area to implement this policy for HOT lanes.

There might also be opposition from highway patrol agencies to the loss of work that would result from automation of occupancy enforcement. This may not be a large problem, since such patrol agencies would still have normal policing duties on the freeways hosting HOT lanes and networks, and in fact few metro areas have high-level HOV enforcement during all the hours of HOV lane operation today. What is at stake here is not a loss of significant existing patrol work, but rather the non-expansion of manual enforcement (as HOT lanes develop into networks) if an automated approach is chosen instead.

Finally, the viability of the registered carpool/zero-toll transponder approach depends critically on some form of ongoing audit, to ensure that the registered carpools in fact remain in operation and do not become a means by which clever people can arrange to steal HOT lane services. While vanpool monitoring and audit capabilities exist, a far larger carpool audit capability remains to be developed.

Part 5

Summary and Conclusions

Visual enforcement has worked tolerably well for HOV lanes and simple first-generation HOT lanes. But the development of more complex HOT lanes with multiple ingress and egress points, and networks of HOT lanes, calls into question the continued viability of manual enforcement, especially for lanes and networks designed as HOT 2.0. Most freeways where current HOV lanes will be converted to HOT lanes lack the room to add separate enforcement lanes and may even lack room for patrol officers to be stationed to watch for violators. And patrol cars in slow-moving congested lanes adjacent to fast-moving HOT lanes will have difficulty carrying out visual enforcement.

Current research on automated occupancy enforcement has produced prototypes that have serious limitations for complex HOT lanes and HOT networks. Roadside infrared systems are costly and thus far can image only front-seat passengers, whereas HOT 2.0 lanes and networks will likely require at least three-person occupancy for zero or reduced-rate tolls. The most promising in-vehicle approaches would rely on using data from airbag deployment systems. Those systems are required and being planned only for front seats, and there are legal and policy reasons making it unlikely that such data can be transmitted from the vehicle to use for enforcement purposes. Both roadside and in-vehicle occupancy verification systems also raise serious privacy concerns. Declaration transponders, while more promising than these other approaches, would still rely to a considerable extent on patrol officer enforcement.

The alternative presented in this study would rely on two policy changes—transponders for all HOT lane users and registered carpools—to simplify the occupancy verification and enforcement problem for HOT lanes and HOT networks. Its aim is to reduce enforcement of eligibility for free or reduced-rate passage to the same enforcement used for electronic toll collection, by requiring all eligible carpools to be registered and have transponders. The toll collection software would be written so as to charge the zero or reduced-rate toll to vehicles identified as registered carpools when their transponder is detected in the lanes during peak periods. Initial and ongoing eligibility would be handled by existing ride-share agencies, working with cooperating places of employment as they do now.

This approach to automated HOT lanes enforcement would eliminate the need for additional roadside or in-vehicle equipment beyond what is needed in any case for electronic toll collection and enforcement. It would also eliminate the need for special highway patrol occupancy enforcement activity, resulting in large savings in operating costs (which would be partly offset by increased operating costs for ride-share agencies). This full-time approach to enforcement represents an increase beyond the level of enforcement typical of current HOV and first-generation HOT lanes, and is also likely to result in increased HOT lanes revenue. It would also avoid the privacy concerns inherent in proposed roadside or in-vehicle approaches to automated occupancy verification.

Against these benefits, policymakers must weigh the potential opposition of those favoring casual carpooling and possibly of highway patrol agencies not happy about less need for their services. In addition, reliable audit methods to ensure that registered carpools remain in operation are yet to be developed.

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About the Author

Robert W. Poole, Jr. is the director of transportation policy and Searle Freedom Trust Transportation Fellow at Reason Foundation, the free market think tank he founded. Poole, an MIT-trained engineer, has advised the previous four presidential administrations on transportation and policy issues.

In the field of surface transportation, Poole has advised the Federal Highway Administration, the Federal Transit Administration, the White House Office of Policy Development, National Economic Council, Government Accountability Office and state DOTs in numerous states.

Poole's 1988 policy paper proposing privately financed toll lanes to relieve congestion directly inspired California's landmark private tollway law (AB 680), which authorized four pilot toll projects including the successful 91 Express Lanes in Orange County. More than 20 other states and the federal government have since enacted similar public-private partnership legislation. In 1993, Poole oversaw a study that coined the term HOT (high-occupancy toll) Lanes, a term which has become widely accepted since.

California Gov. Pete Wilson appointed Poole to the California's Commission on Transportation Investment and he also served on the Caltrans Privatization Advisory Steering Committee, where he helped oversee the implementation of AB 680. In 2008 he was appointed by Texas Gov. Rick Perry to that state's Legislative Study Committee on Private Participation in Toll Projects. He is a member of the Transportation Research Board's Congestion Pricing Committee and Managed Lanes Committee and is on the board of the Public Private Partnerships division of the American Road & Transportation Builders Association. He edits the Reason Foundation e-newsletter *Surface Transportation Innovations* and writes a monthly column for the newsletter *Public Works Financing*.

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