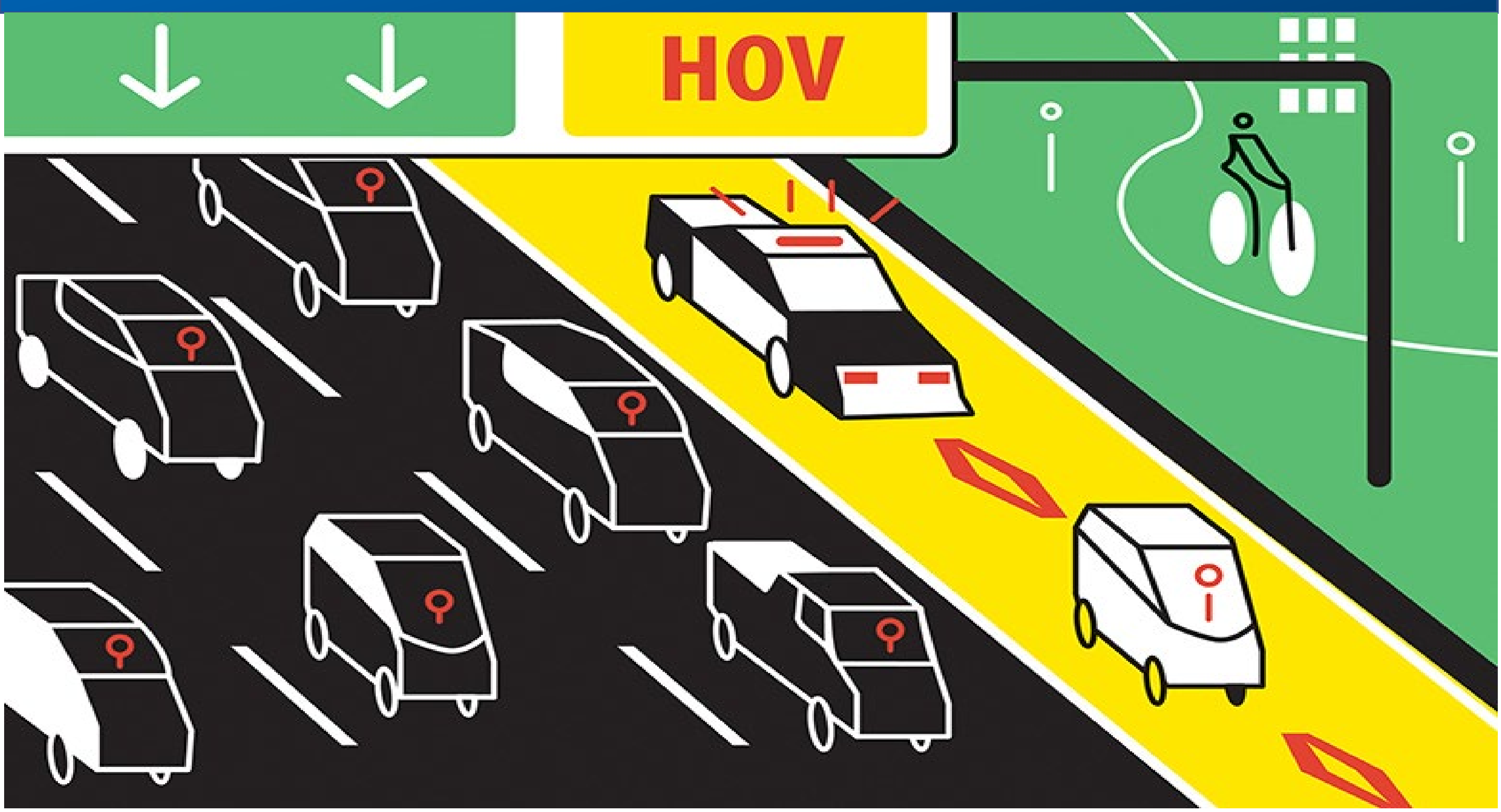
2021 NOCoE Transportation Technology Tournament

Solutions to Mitigate High-Occupancy Vehicle (HOV) Lane Violations in Nashville and Memphis



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Report:	Concept of Operations (ConOps)	
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Abstract:	This report presents a high-level concept-of-operations (ConOps) for mitigating High-Occupancy Vehicle (HOV) lane violations in Nashville and Memphis. The team developed the proposed Transportation Systems Management & Operations (TSM&O) strategies to mitigate HOV violations on study corridors to be decided in Nashville and Memphis. The ConOps identified the stakeholders involved and presented a systematic approach to deploying the proposed TSM&O strategies along the study corridors. The stakeholders include the road users, TDOT, the City of Memphis, the City of Nashville, TMC, law enforcement, and necessary technology vendors. The proposed solutions are categorized into static placed photo-enforcement cameras, HOV lane modifications, and drone photo-enforcement cameras. Deployment of the proposed TSM&O strategies is estimated to cost $xxx along the study corridors. The proposed solutions are expected to benefit all stakeholders by reducing HOV lane violations and improving communication between agencies responsible for mitigating HOV lane violations. The proposed solutions are easily implementable and can be used to help similar facilities across the country and can be adapted to address other safety concerns such as aggressive driving and failure to follow the road rules.	
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Acronyms and Abbreviations

ConOps	Concept of Operations
TDOT	Tennessee Department of Transportation
HOV	High-Occupancy Vehicle
ITS	Intelligent Transportation Systems
TSM&O	Transportation Systems Management & Operations
TMC	Transportation Management Center
VMT	Vehicle Miles Traveled

1. Overview

High-Occupancy Vehicle (HOV) lanes are defined as one or multiple lanes of a roadway with restrictions on use to encourage carpooling and can reduce vehicle miles traveled (VMT)[1]. Most HOV lanes are open to vehicles with two or more people and sometimes electric vehicles or hybrids. Places can place a 24-hour rule or only during peak hours. The purpose of the lane is to give carpool and public transportation quicker travel and help remove congestion from other lanes[1]. Most HOV violations occur at any time of the day with people not meeting requirements entering the lane and slowing down traffic for carpool and public transportation. HOV violations in Tennessee have rates up to 85-90 percent of drivers using the lane violating the two or more rule. Several states have become pioneers in mitigating HOV violations like California.

The traditional HOV lane violation countermeasures that recommend changes to roadway signage and pavement marking improvements may not work best. This calls for more detection methods to ensure drivers are notified of HOV violations and that law officials, Transportation Management Centers (TMCs), other road users, all receive real-time warnings about these violations. Some countermeasures that have been considered or used are minimum people needed in vehicle, restriping lanes with wider broken lines, and fines[2]. Some other places also redid the lane to separate it from the other lanes with solid white lines, barriers, and orange cones.

This report presents a high-level concept-of-operations for mitigating HOV lane violations. This report presents a high-level concept-of-operations for mitigating HOV lane violations on roadways. The objective of this project is to discover and propose Transportation Systems Management & Operations (TSM&O) solutions to achieve a large reduction in the number of HOV lane violations. Many states like California have used different Intelligent Transportation System (ITS) and TSM&O strategies to mitigate these violations in real-time. There are many states that have not implemented any strategies or been successful at reducing these violations.

USDOT. *High-Occupancy Vehicle Lanes*. 24 Aug. 2015, www.transportation.gov/mission/health/High-Occupancy-Vehicle-Lanes.

TDOT. *High Occupancy Vehicle (HOV) Lane*, www.tn.gov/tdot/traffic-operations-division/traffic-engineering-office/high-occupancy-vehicle-hov-lane.html.

2. Study Corridors

The research team worked with the TDOT office to identify all the arterials in Memphis and Nashville which have experienced several HOV violations. The critical corridors were identified to be I-40 E (15 mm to 22 mm), I-40 W (22 mm to 16 mm), I-55 N (0.0 mm to 5 mm), and I-55 S (5 mm to 0.0 mm) in Memphis, Tennessee. I-40 (eastside of Nashville, both directions, 216 mm to 232 mm), I-24 (eastside of Nashville, both directions, 56 mm to 81 mm), I-65 (north side of Nashville, both directions, 90 mm to 95 mm), and I-65 (south side of Nashville, both directions, 60 mm to 79 mm) in Nashville, Tennessee. These corridors are used as cases studies in this project.

I-40 E

This is a section of the interstate at the mile markers 15-22 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-40 W

This is a section of the interstate at the mile markers 22-16 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-55 N

This is a section of the interstate at the mile markers 0.0-5 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-55 S

This is a section of the interstate at the mile markers 5-0.0 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-40 (Nashville)

This is a section of the interstate at the mile markers 216-232 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-24 (Nashville)

This is a section of the interstate at the mile markers 56-81 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-65 (Nashville)

This is a section of the interstate at the mile markers 90-95 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

I-65 (Nashville)

This is a section of the interstate at the mile markers 60-79 mm where it is a one-way four-lane both directions corridor. The speed limit is 65 mph both directions.

3. Existing Scenario

The study corridors have traditional static HOV signs to direct drivers that it is only for HOV use for those carpooling with 2+ passengers. There are signs that direct what time of day the lane is in use with some being 24/7. Tennessee has the lane usage set up for mainly peak hours of traffic to reduce congestion. There is also striping on the lanes to differentiate it from the regular lanes. The existing signs and markings are not enough to keep violators out of the lanes with violation rates higher than 70%. Figure 1 shows an outline of how the HOV lanes look.

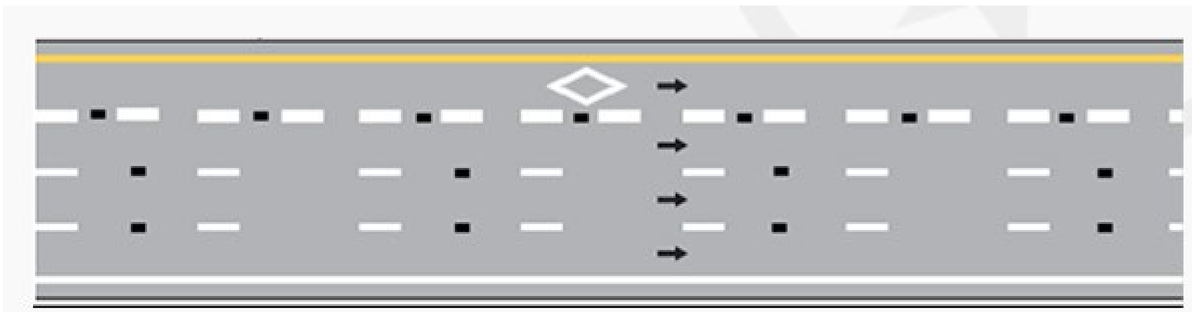

Figure 1. TN HOV Lane

An analysis of the corridors with HOV violations revealed some issues. One of the most critical scenarios is the HOV lane being violated during peak hours of traffic causing more congestion than reducing it. Another scenario is the lane being used as a high-speed lane to go through traffic leading to possible crashes. The Figure 2 shows an overview of vehicles on the HOV lane possibly violating the rules.

Figure 2. Overview of Possible Violations

4. Concepts for the Proposed System

4.1 Overview

The City of Memphis and Nashville have both witnessed countless HOV violations on these interstates. Understanding the seriousness of this issue, TDOT has undertaken multiple efforts to mitigate HOV violations, however the use of traditional signage and striping have proven to be ineffective as evidenced by the huge volume of HOV violations. Therefore, innovative strategies and design alternatives are necessary. These strategies may include quick fixes to the existing options, enhancement of existing signs, enforcement cameras, infrared enforcement cameras, in-vehicle detection systems, and/or drone photo enforcement cameras.

4.2 Stakeholders Involved

In developing the user needs, the following stakeholders involved with the proposed strategies were identified:

- TDOT
- The City of Memphis
- The City of Nashville
- Law enforcement officials
- Roadside equipment vendors
- Drone manufacturers
- Camera manufacturers
- Road users

4.3 Description of the Proposed Traditional Solutions

Traditional solutions include the use of Roadside Detection Systems or In-Vehicle Detection Systems. They also include the enhancement of signage and enhancement of lane markings. Some states choose to separate the HOV lanes from the other traffic lanes.

4.3.1 Quick Fix

The quickest fix available to TDOT is to raise the fine for HOV lane use violations. Currently the fine is $50 for violation. HOV lane violation could be significantly reduced if the fine was increased to $150 and enforced with highway patrol officers.

4.3.2 Enhancement of Existing Signs

The HOV lane signage could be improved with additional overhead lane markings at regular intervals. Additionally, there is plenty of room to enhance the current lane markings. The lane markings could be brightened significantly with fresh paint. They could also be widened in some areas.

4.3.3 Roadside Placed Photo-enforcement Cameras

Roadside detection photographic-based systems can detect the vehicle occupancy from outside the vehicle. The system can be installed along the roadside at regular intervals along the HOV lane routes. The system could then proceed to take photographs of the front and rear seats of the moving vehicles to determine occupancy. A Xerox Vehicle Passenger Detection System (VPDS) was tested by the California Department of Transportation (Caltrans). The system utilized two cameras. One camera was aimed at the front windshield, and another camera was aimed at the side of the vehicle. A laser was used to detect a vehicle in the HOV lane. Once a vehicle was detected the front and rear cameras were actuated the images were captured. The system utilized manual training data from humans and machine learning in order to determine vehicle occupancy automatically. The total accuracy of the system was 95.94% with a Declared Violator Accuracy (DVA) of 91.29%.

4.3.4 Infrared Enforcement Cameras

Another method of roadside detection involves the use of infrared sensors to determine vehicle occupancy. Similar to the photographic-based systems, the infrared sensors take images of the moving vehicles as they pass by the roadside sensors. A study was conducted by the Minnesota Department of Transportation, utilizing both near-infrared and mid-infrared cameras. The study found that the mid-infrared setup was not able to produce clear images when the vehicles were at highway speeds. Additionally, there were issues penetrating the front windshield of many vehicles with mid-infrared waves. However, the near-infrared setup was able to produce clear images in tinted windshields and side glass windows. This setup was also able to detect occupancy at highway speeds.

4.3.5 In-Vehicle Detection Systems

While most systems have focused on detection of occupancy from outside the vehicle, it is possible to determine occupancy from inside the vehicle. There are a number of sensors in modern vehicles that are also designed to detect occupancy for safety. These sensors include weight sensors, safety belt sensors, ultrasonic / radar sensors, and smart card readers. The weight sensors are typically used to detect occupancy for the air bag systems. If a passenger weighs a certain amount, then it is safe to deploy the airbag in the event of a collision. This method may not be effective because a large weight could be placed in the seat to trip the sensor. Similarly, safety belt sensors are very common in modern vehicles. These sensors could also be easily tricked for HOV lane use. Ultrasonic and radar sensors are used to detect occupants in some vehicles. This is likely the most reliable in-vehicle detection system that could be used. Lastly, smart card readers could be used in vehicles to determine the occupancy. For example, driver's licenses could be inserted into the smart card reader which would mean that the vehicle is occupied by that person. All of these systems would rely on some form of communication to an external roadside system. The occupancy information would have to be transmitted to that external roadside system in order for the data to be useful for the purpose of enforcement.

4.4 Description of the Proposed TSM&O Strategy

The proposed TSM&O solution provides a warning to all drivers to avoid the chances of the drivers violating the rules of the HOV lane, supports the detection of HOV violators, alerts other drivers, pedestrians, law enforcement officials, and the TMC about the presence of violations. The proposed system ensures active protection of all road users from the dangers of misusing the lane and causing more congestion or possible crashes. It could serve as a presence like police officials simply being on the side to scare drivers of consequences. The drone could be loaded with equipment that includes thermal imaging cameras, communication to the TMC and law enforcement, etc. The system will have three components: warning, detection, and notification.

4.4.1 System Operation

The proposed method of enforcement is a Drone Photo-enforcement camera system. The operation will involve having the HOV violation event detected by the system and activation of the signals, the TMC and law enforcement officials will be notified of the violation. A critical situation for the system deployment was where there is a high volume during the HOV hours of operations and there are multiple violations occurring. The system will operate in the following sequence, as explained in Table 1.

Table 1. System Operation

Detection of HOV Lane Violation	Step 1: The drone will fly parallel to roadway at a distance optimal for cameras and infrared sensors. Step 2: The drone will scan each vehicle in the HOV lane as it passes. Step 3: The drone will analyze the images and determine if a violation has occurred.
Verification of HOV Lane Violation	Step 4: The drone will send store the images and pertinent information to be sent to TDOT and law enforcement officials. TDOT and law enforcement will confirm the violation and issue ticket to vehicle owner.

Figure 3. Sky Guys DX-3 Drone

4.4.2 System Architecture

a) High-level Physical Architecture

The physical architecture of the proposed system includes technologies that will be installed along sections of the interstate along with the existing solutions of signage and marking, a station for the drones, and the interface between ITS equipment and the TMC. These technologies will enable the system to detect, warn, and notify all drivers and the agencies of the presence of HOV violations. Figure 4 shows the proposed system's high-level physical architecture.

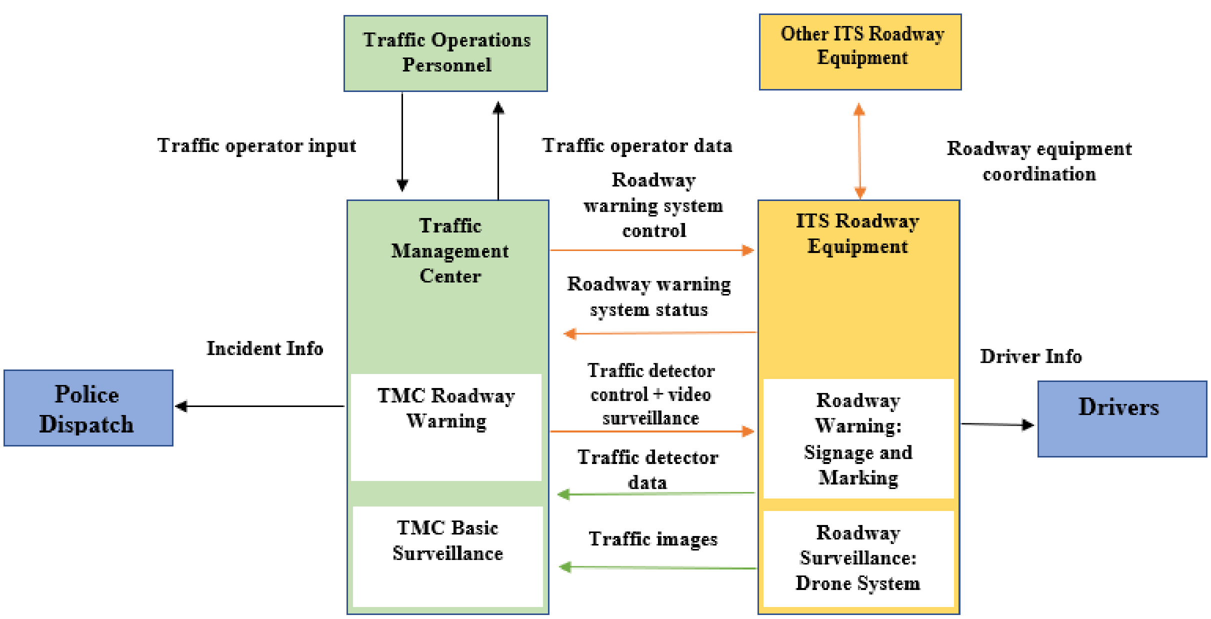

Figure 4. High-Level Physical Architecture

b) High-level Functional Architecture

Table 2: High-level Functional Architecture

Functional Object	Functional Description	Physical Object
Range-Finder	Collision avoidance using short-range lidar	Lidar Sensor
Occupancy Detection	Detection of vehicle occupancy using photographic images	Photographic Camera
Vehicle Identification	Records an image of the vehicle license plate	Photographic Camera

4.5 Deployment Constraints

The primary constraint of this system is the budget limitation. The management of traffic and the issues of congestions is expensive due to the many technologies needed to see improvements. There needs constant vigilance of TMC operations and law officials which is very costly. For the proposed solution, there would be a large initial investment to place all devices in the field and there would be maintenance costs as well. Even though there are not many locations on the interstates where the HOV lanes are located it is still a large amount of area to cover and critical parts of the lane should be analyzed. Taking such measures can potentially benefit deploying the system. This solution is more of a conceptual solution at this time as there are many regulations that could prevent this from occurring today. Court rulings and regulation changes could help bring this solution to fruition.

4.6 Technology Constraints

Thermal imaging detection along with the other sensors on the drone could have poor accuracy and present error messages transmitted to the TMC and law officials. This may falsely collect poor data and prevent there from being improvements.

4.7 Change Priorities

Of immediate attention along the study corridors are the enhancement of traditional signage and markings. These can be installed at all sections of the interstate with HOV lanes to ensure drivers have a clear indication of the HOV laws. Order of deployment must focus on sections of the interstates where there are the highest number of violations and possible crashes. It should also look to see where the most traffic congestion is happening.

4.8 Changes Considered But Not Included

Along with the proposed system, several other options were considered for reducing HOV lane violations on these interstates. One big and more advanced option was integrating vehicle sharing technology through the cloud to implement warning systems and notify them of the laws and consequences with pop up messages. The vehicles equipped with display screens could receive these messages warning the driver they are violating the lane rules during hours of operation.

5. Cost Breakdown

Traffic enforcement drones are a cost-effective way to enforce road laws. Police enforcement drones typically cost anywhere from $35,000 to $200,000 depending on the size of the drone platform and the equipment onboard. Qualified operators for such drones would need to be employed to pilot them, and some annual budgeting for maintenance would be required. Drones are still cost-effective relative to other options, especially other airborne methods of enforcement, such as helicopters.

Drones have the benefit of mobility, allowing for fewer units versus static camera enforcement systems. Such systems are costly, with red light cameras (which are less complex than automated HOV monitoring cameras) costing around $50,000 each. There would need to be many of these cameras on a given stretch of highway to properly enforce HOV laws, and the systems would require maintenance and likely a fiber system. Because of this, drones seem to be a more affordable solution.

Lynch, Morgan. "Government Saves Time, Money With Drones." *MeriTalk*, MeriTalk, 26 July 2017, www.meritalk.com/articles/government-saves-time-money-with-drones/.

Metz, Cade. "Police Drones Are Starting to Think for Themselves." *The New York Times*, The New York Times, 5 Dec. 2020, www.nytimes.com/2020/12/05/technology/police-drones.html.

Newcombe, Tod. "Traffic Cameras Make Drivers See Red." *GovTech*, GovTech, 27 July 2010, www.govtech.com/public-safety/traffic-cameras-make-drivers-see-red.html.

6. Anticipated Benefits

Implementing the proposed system has two primary benefits: HOV lanes will be able to be enforced without police officer involvement, and HOV lanes will be much more strictly enforced.

The Tennessee Highway Patrol released a statement in 2019 that informed motorists the department did not enforce HOV lane requirements partially due to safety concerns for officers. Local departments in the Nashville and Memphis areas may still enforce the requirements but negating the need for officers to perform traffic stops for HOV infractions would improve safety for both police officers and motorists. Traffic stops in the narrow-left shoulder are unsafe for the officer and the offender and present an unsafe situation for people travelling in the far-left lane.

Based on the safety concerns and priority issues presented in the Tennessee Highway Patrol's statement, officers in other departments are likely not inclined to enforce HOV infractions either. Similarly, to how speed cameras work, the proposed system would enforce the HOV requirements automatically, which would greatly increase ticketing for HOV infractions. Over time this would likely lead to more motorists using the HOV lanes as intended and potentially providing better traffic flow during peak hours as was originally intended when the HOV system was originally implemented.

Ebert, Joel. "Tennessee Highway Patrol Colonel: Dangerous to Enforce HOV Lanes." *The Tennessean*, Nashville Tennessean, 20 Dec. 2019, www.tennessean.com/story/news/politics/2019/12/20/tennessee-highway-patrol-colonel-dangerous-enforce-hov-lanes/2697818001/.

7. Summary

HOV violations in Tennessee have rates up to 85-90 percent of drivers using the lane violating the two or more rule. The City of Memphis and Nashville have both witnessed countless HOV violations on these interstates. This has led TDOT to look for ways to mitigate these violations. There were many possible solutions considered many had certain drawbacks that cause them to not be viable solutions. The best solution found was the use of drones to enforce these laws. These drones take out the danger of pulling cars over for violations and also keep a more consistent system of enforcement. These drones would be able to automatically ticket vehicles that are violating these laws by taking photographs of license plates when a violation is occurring. This new solution will force people to obey the HOV lane requirement or be forced to pay a price thus making vehicles avoid these lanes if they do not meet the requirements.

8. Acknowledgments

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