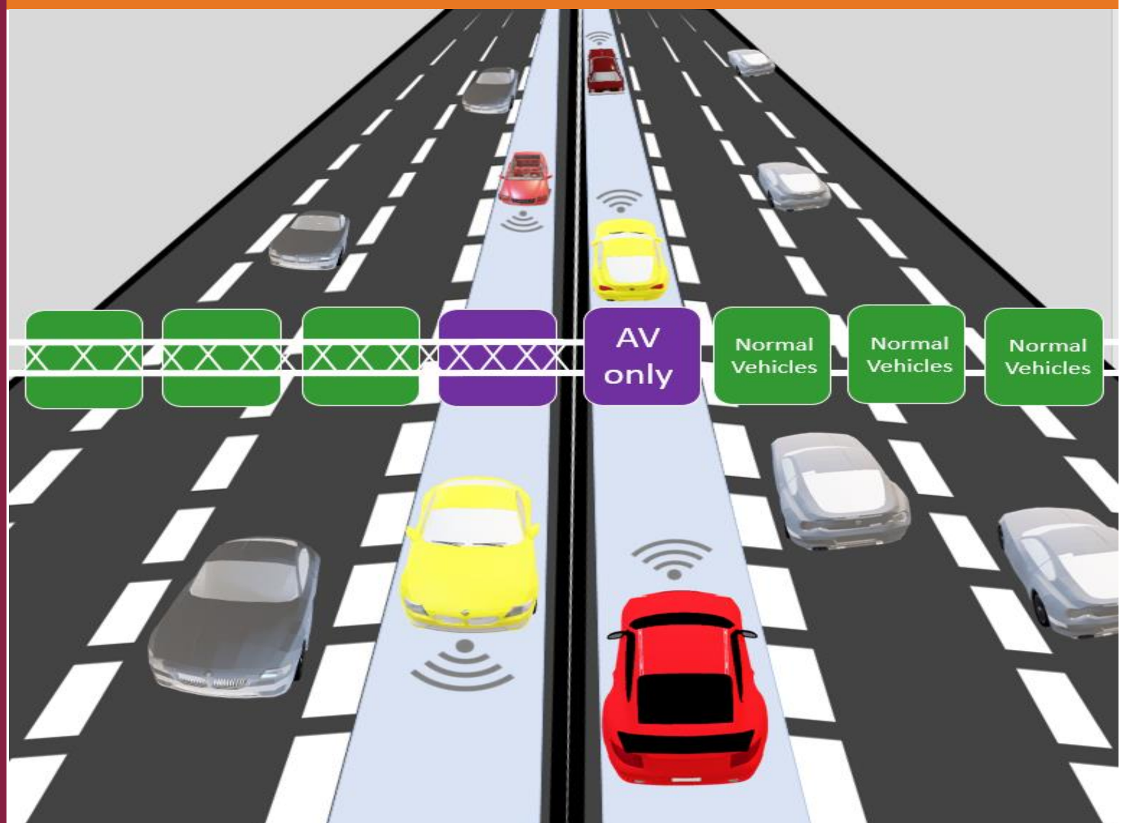
Safe-D UTC

Fueled by the inevitable changes in our transportation system, the Safety Through Disruption (Safe-D) University Transportation Center (UTC) endeavors to maximize the potential safety benefits of disruptive technologies through targeted research that addresses the most pressing transportation safety questions.
Safe-D is a collaborative effort between Virginia Tech Transportation Institute, Texas A&M Transportation Institute, and San Diego State University.

For more Safe-D information please visit www.vtti.vt.edu/utc/safe-d

The project under which these recommendations were developed is titled "Safety Impact Evaluation of a Narrow Automated Vehicle (AV)-Exclusive Reversible Lane on an Existing Smart Freeway."
Link to the project webpage

RECCOMENDATIONS FOR A NARROW AV-EXCLUSIVE LANE



BACKGROUND

The operational features and logic of automated vehicles (AVs) are different from human-driven vehicles where operational decisions are made based on driver capabilities and behavioral characteristics. AVs' lane-keeping capabilities could allow for infrastructure standard adjustments, such as narrower lanes, fewer lanes, and smaller and less signage, which could result in more efficient mobility. A full infrastructure adaptation will not take place quickly, especially given that the transportation system will be serving both AVs and human-driven vehicles for quite some time. Therefore, a mix of dedicated AV lanes and normal vehicle lanes seems to be a viable solution. This study investigated traffic implications of a narrow AV-exclusive lane on a freeway and shed light on the barriers AVs might face and benefits they could have on the existing infrastructure.

Interstate 15 Corridor:

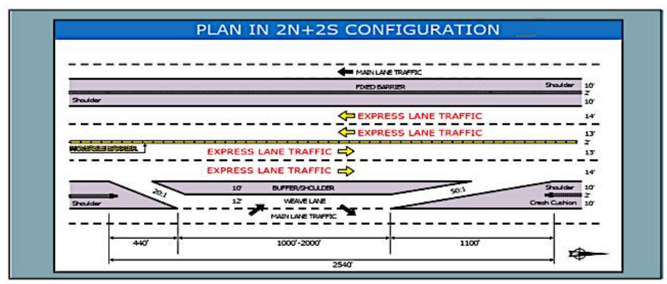
The I-15 Express Lanes provide 20 miles of flexible travel between State Route 78 in Escondido and State Route 163 in San Diego to ease congestion and keep travel times reliable.

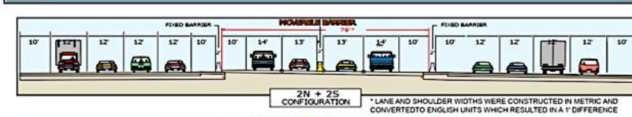
For more information, visit: https://www.keepsandiegomoving.com/I-15-Corridor/I-15-intro.aspx

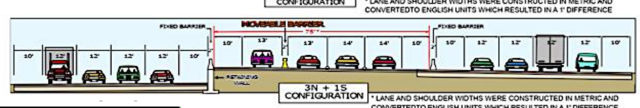
CASE STUDY

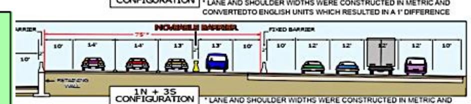
To evaluate implications of a narrow exclusive-AV lane, a case study on Interstate 15 (I-15) in San Diego County was conducted. The I-15 Express Lanes (EL) Corridor, between State Route 163 (SR-163) and Via Rancho Parkway, currently provide 4 HOV and toll-paying FasTrak lanes divided by a moveable barrier that allows reversible operation to accommodate peak hour movements. The lane combinations that can be provided, depending on peak direction and position of the moveable barrier that separates the northbound (NB) and southbound (SB) EL traffic, are 2 NB and 2 SB, or 1 NB and 3 SB, or 3 NB and 1 SB. Caltrans is seeking efficient ways to handle more traffic in the ELs, especially during rush hours or during major incidents when ELs are open to all traffic. In the available width between the fixed concrete barriers that separate the EL facility from the regular lanes, it would be possible to add a narrow reversible lane to be used only by AVs. This reversible AV lane for travel in the peak traffic direction would be 9 feet wide and located next to the moveable barrier. In both the NB and SB directions of the EL, there would be two 12-foot wide lanes for HOV and FasTrak vehicles and the outside shoulder next to the fixed barrier would be 8 feet wide. Considering this new configuration, we explored the traffic implications and considerations of AV lanes and whether AVs could operate safely in a 9-foot lane.

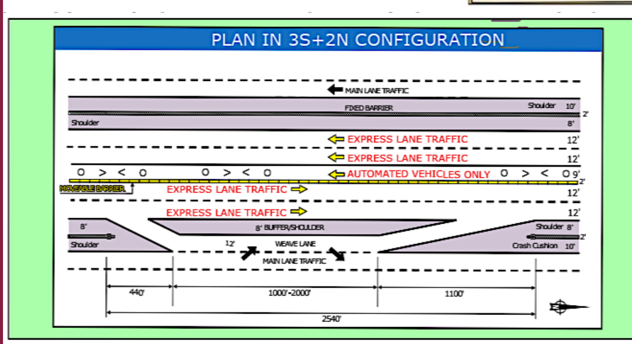
Existing configuration



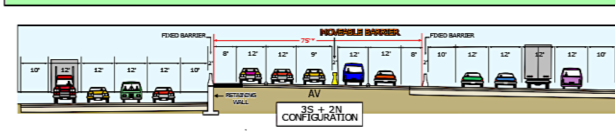


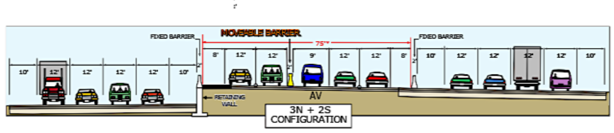






Proposed configuration





LDW

Lane Departure Warning (LDW) systems, one of the oldest and most developed autonomous vehicle attributes, only warns the driver that their vehicle is departing from the intended lane.

LKAS

Lane Keeping Assist Systems (LKAS) was the next step in autonomous lateral control development. These systems both warn and then assist the driver to return to the center of the lane if drifting is detected.

LC

Lane Centering (LC) systems provide lane detection and tracking, and is also capable of providing active steering using vehicle drivetrain and handling characteristics to keep the vehicle automatically centered.

EVALUATION FRAMEWORK

Literature Review

- AV systems (LDW, LKAS, LC)
- Impact of lane width on safety
- AV specific studies and AV research abroad

AV Manuals/Websites Review

- 15 different AV manufacturers
- AVs between 2014-mid 2019
- Assess the general capabilities of AVs

Experts' Opinions on AV-exclusive Lanes

- Comprehensive Questionnaire for two groups: a) Transportation officials/Academia, b) Manufacturers/Technologists
- Obtain holistic perspectives on the feasibility, safety, operational impacts and lane infrastruture requirements

Consumers' Opinions on AVs' Lateral Control Systems

- Source:NHTSA Website, AV manufacturers 2014-2019
- Extracted based on specefic keywords and make, model, and year
- Understand frequency of isues related to lateral vehicle control technology

Investigation of I-15 Express Lanes Crash History

- Source: SWTIRS
- Ten years (2009-2018) data
- Investigate history of different crash types and and potential causes that are partially attributable to AV system

Impacts Analysis Using Microsimulation

- Caliper TransModeler SE
- Three scenarios with/without AV adoption and AV-exclusive lane
- Investigate flow, density, speed, and speed diffrential

Conclusions and Recommendations

NHTSA

National Highway Traffic Safety Administration (NHTSA)
Source for consumer complaints:
https://www.nhtsa.gov/recalls

SWITRS

Statewide Integrated Traffic record System (SWITRS)
Source for I-15 crash history:
https://tims.berkeley.edu/help/SWITRS.php

GENERAL RECCOMENDATIONS

1. Standardization of lane markings, signage, mapping of roads, speed limits, and geometries for AV operations on exclusive lanes are recommended across the nation, while still accounting for non-AV compatibility.
2. Highly reflective, clearly visible, and distinct lane markings and signage are required for proper AV sensor operation since reliability, accuracy, and communication latency in AV systems are critical.
   a. White lane markings surrounded by black paint could be effective.
   b. Improved striping, such as that suggested in the marking language by NCUTCD on gore and ramp areas that includes 8-inch lines and dashed striping, could enhance machine vision systems' performance in AVs.
   c. Wet reflective markings are recommended as they aid machine vision systems to improve their performance, especially during nighttime.
   d. Signage such as "Keep Lane Assist On" are recommended for all levels of automation, especially for lower levels of automation.
3. Same direction physical barriers between AV-exclusive and adjacent lanes are recommended to prevent crashes due to improper turning and swerving. Also, barriers with active sensors may aid in lateral control of AVs by providing clear physical signals continuously measured by AV sensors.
   a. Lane friction (difference in average speeds of AV-exclusive lane and adjacent lane) could be used to determine if barriers are warranted; there are recommendations indicating speeds ≥ 30 mph warrant physical barriers/separators; however, lane friction of 10-15mph does not warrant physical barriers/separators, but rather buffer separated double solid lines.
4. Nighttime restrictions should be considered, as vision-based sensor systems are vulnerable to low light conditions, especially in wet pavement conditions.
5. Infrastructure non-idealities, such as potholes, non-uniform lane markings, etc., should be minimized, as AVs are vulnerable to these non-idealities.
6. Widening the lanes around curves is recommended, especially for a "narrow" AV-exclusive lane, as generally AVs are susceptible to turning errors (particularly in adverse weather conditions).
7. Operation of heavy AVs is challenging, especially for a "narrow" AV-exclusive lane, due to their bulkiness, proximity to non-AVs, turning radius, and GPS accuracy, and hence specific restrictions for heavy AVs should be developed.
8. To support safe operation of AVs, roadside units that facilitate vehicle to infrastructure (V2I) communications can be implemented to provide real time critical traffic information to AVs.
9. The access points from/to the AV-exclusive lane need to be carefully designed and monitored to prevent unsafe lane changes as well as manage traffic flow distribution on all freeway lanes.
10. Depending on traffic conditions and MPR, restrictions should be placed to designate the lane as AV-exclusive, shared with HOVs, or open to all traffic.
    a. There are expert recommendations suggesting that an MPR of 10% to 30%

For more information, please contact:

Sahar Ghanipoor Machiani
Associate Professor
San Diego State University
sghanipoor@sdsu.edu

Acknowledgements

This project was funded by the Safety through Disruption (Safe-D) National University Transportation Center, a grant from the U.S. Department of Transportation – Office of the Assistant Secretary for Research and Technology, University Transportation Centers Program.

may be sufficient to make AV-exclusive lanes viable, and that an MPR over 50% may warrant decommissioning of AV-exclusive lanes.

11. AV application limitations should be taken into considerations.
    b. For example, some AV lateral control systems, such as lane departure warning systems, are effective above certain speeds (e.g., 30 mph, 38 mph, and 44 mph), are operational for certain speed range (e.g., 37 mph–112 mph or 40 mph–110mph), only work if lane width is between 10 and 15 feet, operate if only two lane markings are detected, and do not perform well in sharp turns, during low visibility, or in foul weather conditions.
    c. There are consumer reports of AV lateral system features not working properly or of AVs swerving into other lanes.
12. Early education and training at the driver's license level as well as extensive public outreach via internet, social media, and other campaigns are recommended to explain how the lanes should be used or not used by AV and non-AV drivers.
13. Simulation modeling with real-world traffic data (volume, MPR, etc.) specific to the candidate site could significantly aid in making informed decisions on feasibility, limitations, and specifications of AV-exclusive lanes.

RECCOMENDATIONS SPECIFIC TO I-15

1. According to crash data analysis, unsafe speed was the most recurring PCF on I-15 ELs. The majority of unsafe speed events resulted in rear end collisions. Implementation of an AV-exclusive lane could potentially reduce this type of crash, since AVs are expected to follow proper speed discipline with less variability and maintain sufficient bumper to bumper spacing.
2. Improper turning and unsafe lane change were the next two most recurring PCFs, the majority of which resulted in hit-object and sideswipe collisions. AVs' automated lateral control systems (e.g. LKA) could potentially reduce these collisions on an AV-exclusive lane. However, high reflective, clearly visible, and distinct lane markings, barriers, and signage are required for proper AV sensor operation. Also, the points of access from/to the AV-exclusive lanes need to be carefully designed and monitored.
3. Microsimulation findings indicated an AV-exclusive lane may increase traffic flow and density by up to 14% and 24%, respectively. This is achieved with lower vehicle headways and more stable flow afforded by AV driving dynamics and technology.
4. Microsimulation findings also indicated an AV-exclusive lane has better speed limit compliance and therefore average speed is reduced. The lower speed may contribute to lower crash severity. However, the study reveals the importance of understanding the impact of roadway characteristics. Specifically, the speed differential between the exclusive lane and adjacent lane should be considered. An AV-exclusive lane introduces a distinction between lane characteristics that may result in an increase in speed differential, which will require careful consideration if additional treatments or barriers are required.