

**Request for Research Funding for FY 2020-2021**

<b>Requesting Office</b>	D5-State Traffic Engineering and Operations Office	<b>Priority</b>	2 of 2 (projects may not have the same ranking – no ties)
<b>Proposed Title</b>	Examining the Effect of Automated, Connected, Electric & Shared (ACES) Vehicles on 2020-2045 Florida’s Land Use & Limited Access Freeways Using Machine Learning		
<b>Justification</b>	<p><b>Describe the current situation, why the research is needed, and how the research affects your office’s mission critical focus areas.</b></p> <p><b>Background and Significance</b>  Roadway infrastructure is an economically vital form of the country’s infrastructure. Americans drive nearly 3 trillion miles per year, which translates into many hours spent in traffic. This is potentially dangerous, as it increases the probability of crashes and increases air pollution and congestion. U.S. data demonstrate that automobile crashes led to 34,080 fatalities (NHTSA 2013). The U.S. petroleum usage for road transportation was also approximately 12 million barrels per day, which corresponds to about 60% of the total U.S. petroleum consumption. Also, it was reported that the average commuter is delayed by approximately 38 hours per year due to traffic congestion. The ASCE awarded U.S. road infrastructure a D+ in 2017 and predicted radical investment gaps in the highway sector. The anticipated highway infrastructure investment gaps are expected to impose significant losses to the U.S. economy, an approximately \$4 trillion damage in GDP by 2025, and an approximately \$18 trillion loss in GDP over 25 years from 2016 to 2040. It is not an exaggeration to state that highways are the arteries of the modern economy, especially in the United States, where there is weak to non-existent rail infrastructure. An increase in the population, changes brought about by e-commerce, and an almost lack of true highway upgrades in the last few decades have left our highway infrastructure in dire need of update.</p> <p>Connected and automated vehicles (CAVs) are one of the primary disruptive forces that can impact the capacity and mobility of highways. Given the impact that these factors can have on Florida’s traffic flow (and by extension on Floridians’ quality of life), individuals and businesses will find new applications for cars, and people may be willing to take more and more distant trips than they did in their traditional cars. CAVs will enhance the attractiveness of traveling by car, leading to a significant shift in travel behavior. Growing attractiveness of travelling by car triggers dynamics within the traffic network that will lead to higher traffic volumes at a comparable level of congestion and potentially a reduced public transit ridership. There will also be upward pressure on traffic volumes due to an increase in the number of trips per day per car, as well as the number of cars in the region that can be expected to be produced from new uses of automated, connected, electric, and shared (ACES) vehicles. In addition, these dynamics will drive the impacts on land use; people will be ready to drive longer distances, which will increase urban sprawl and make it more challenging to provide adequate transit services. These technologies, once incorporated into vehicles, will have a profound impact on congestion, land use, and society.</p>		

The Co-PI's doctoral thesis is about developing a model to aid decision-makers by using public-private partnerships (PPP) and incorporating the traffic growth not just from traditional sources, but also from the expected impacts of connected and automated vehicles. This thesis will be augmented by adding a system dynamics model of the ACES vehicles and traffic network model. The initial results of his study are shown in the "Preliminary Results" section of this document.

### **Current Limitations**

There is no accurate machine learning models to predict the land use pattern of the Florida considering the connected and automated vehicles (CAVs) & connected and automated trucks (CATs) impact under various scenarios.

- There is a need for an advanced integrated model which incorporates both regular and commercial ACES vehicle impacts.
- The impact of CAVs and CATs weren't investigated to identify the required limited access freeway needs in FL.
- There is a need to identify the potential policies and regulations so that CAVs and CATs can smoothly penetrate the traffic network.

### **The Florida interstates corridors are important to study due to following reasons:**

- Freight movements in Florida to, from, and within the state are expected to grow by 69% in weight and 174% in value by 2040.
- The State of Florida plays an essential role in the future population growth of the United States. Florida's population increased by 1.8% in 2016, which is significantly higher than the 0.7% national population growth rate.

### **Research Design**

The main goal of this study is to develop a model for predicting the FL land use & limited access freeways under various CAV scenarios between 2020 and 2045. From a systematic perspective, this study aims to address the following three phases:

1. Investigating the Impact of ACES Vehicles on Florida's 2020-2045 Land Use Pattern
2. Examining effect of ACES on Florida's 2020-2045 Limited Access Highways Needs
3. Examining potential policy impacts of ACES vehicles on Florida

## **Phase 1: Investigating impact of ACES vehicles on FL's 2020-2045 land use pattern**

### **Objectives:**

1. Urbanization & population growth effects on FL land use
2. Studying the traffic flow pattern in FL Highways
3. ACES vehicles impact on maximum acceptable travel time
4. Toll rates impact on FL land use

### **Dependent variables**

The primary data for this research will contain the past 19 years of Historical land use, social media data, and traffic data between 2000 & 2019 for the state of Florida.

### **Independent variables in data analysis (Predictors)**

This study will utilize a pool of 69 candidate variables as predictors, obtained from relevant resources and the previous research to project the traffic model more precisely. In this study, the researchers will employ 6 pools of candidate variables, including operational planning related variables (such as road characteristics), and strategic planning related variables (such as socio-economic, macro-economic, energy market and construction market variables), and spatio-temporal variables. Following is the list of predictors in this project:

- Construction market (7 variables, such as building permits, & construction spending)
- Energy Market Variables (8 variables, such as crude oil price, and electricity price)
- Socioeconomics Variables (10 variables, such as population, and employees FL)
- U.S. Economy Variables (32 variables, such as CPI, GDP, and DJI)
- Temporal Variables (2 variables, time and month)
- Spatial Variables (8 variables, such as county name, and interstate ID)

### **Tools for Phase 1:**

- Machine learning
- Cash flow analysis
- Cost-benefit analysis
- Sensitivity analysis

### **Step 1. Modeling the Land Use using Machine Learning**

This research will use a variety of non-linear and linear models including Random Forest (RF), Ridge, Bayesian Ridge (BR), K-Nearest Neighbors (KNN), Decision Tree (DT), Neural Network (NN), Stochastic Gradient Descent (SGD) Regression, Passive-Aggressive (PA) Regression, and Support Vector Regression (SVR), that can forecast the Land Use of Florida with better accuracy. The pipeline of this work will consist of data preprocessing, feature selection, model creation, parameter optimization, and evaluation.

During preprocessing, the data will be standardized and split into training, test, and validation sets. The training and validation sets will be fed to a feature selection module which selects the essential features within the pool of variables and removes other independent variables.

### **Step 2. Modeling the Traffic Flow using Machine Learning**

This research would also seek to utilize a variety of non-linear and linear models that can predict the traffic flow of Florida with a high accuracy. The primary data for this research will be obtained from the Florida Department of Transportation's (FDOT) historical cost database, which contains the past 19 years (from 2001 to 2019) data for the highway construction projects.

### **Step 3. Examining the ACES vehicles impact on Maximum Acceptable Travel Time**

By examining 69 variables in a system at once, rather than concentrating on relations between just a few, system dynamics tool can help to create a higher perception of the complex land use and transportation system difficulties. The increased attractiveness of travelling by ACES vehicles will be studied by investigating the following variables:

- Efficiency of vehicle operation
- Attention needed for driving: increased comfort & utility of time in car leads to a higher acceptable travel time
- Safety of vehicle operation
- Mobility for those unable to drive
- Empty vehicle mobility

The increased attractiveness of travelling by connected automated trucks (CATs) will be studied by investigating the following variables:

- Efficiency of vehicle operation
- Attention needed for driving
- Truck parking
- Safety of vehicle operation
- Empty vehicle mobility

### **Step 4. Toll rates effect on FL land use**

Connected and automated technologies are capable of altering the traffic flow and capacity while revising the maximum acceptable travel time and cost. This section of the project will analyze the impact of the CAV technologies on the max acceptable travel time and toll rates adjustments.

## Phase 2: Examining effect of ACES vehicles on FL's 2020-2045 limited access highways needs

### Objectives:

1. Optimizing the FL toll rates considering ACES vehicles
2. ACES vehicles effect on express lanes traffic in FL
3. Identifying the potential limited access freeways needs

### Tools for Phase 2:

- Scenario planning
- Machine learning
- System dynamics
- Cost-benefit analysis
- Sensitivity analysis

### Step 1. Scenario Planning

The scenario development process in this study included five sequential steps, including the identification of the critical factors and driving forces of the development of solutions, assessment of the impact and uncertainty of the driving forces, construction of the scenario matrix, estimation of the penetration rates and potential implications of CAVs in each scenario, review of the scenario and assessment of the overall impact of each scenario. **Figure 1** presents the 19 scenarios that would increase the number of trips by vehicles. Four factors were considered to generate the mentioned scenarios including ACES vehicles' impact on traffic flow, impact of trucks automation on cars' trips, shared and ownership mobility, and policies.

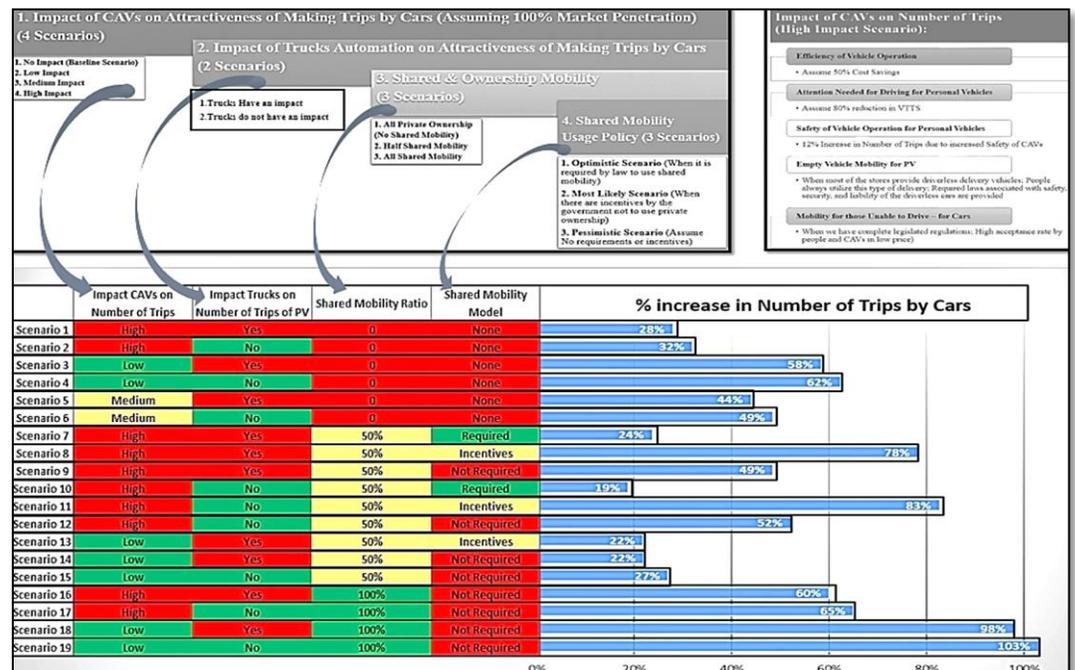


Figure 1. ACES vehicles scenarios' traffic flow adjustment factors

**Step 2. Modeling the Traffic Flow using Machine Learning (employing the ‘FL land use’ findings)**

This step would also seek to utilize a variety of non-linear and linear models that can predict the traffic flow of Florida with a high accuracy considering the identified land use patterns studied in phase 1.

**Step 3. Modeling the ACES vehicles on second step’s traffic flow model for FL limited access freeways**

**Step 4. Sensitivity Analysis**

A sensitivity analysis of all the parameters will be carried out in step three. This step is the fundamental step before calibration of the framework.

**Step 5. Identifying Potential Limited Access Highways’ Construction**

This project will deliver guidance and identify the potential need to expand limited access highways. These strategies will help FDOT in shaping the connected, automated vehicles (CAVs) implementation framework.

**Phase 3: Identifying the Potential Policies and Regulations**

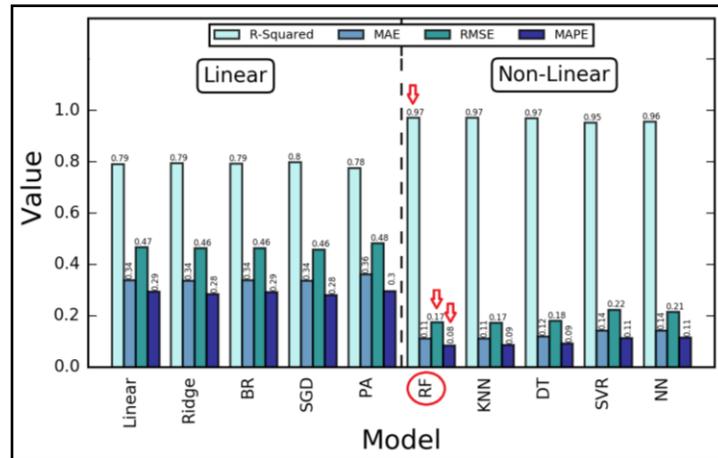
Policy networks should form quickly, and major stakeholders must inform and shape discussions at all levels of government regarding the CAVs genesis.

This project will deliver guidance and identify the potential policies to execute CAVs safely, while also improving the higher operability of the traffic flow. These strategies will help FDOT in shaping the CAV implementation framework. This research would investigate the following potential policies:

1. Increasing financial costs through road use charges or tiered road-pricing mechanisms
2. Increasing the travel time by new speed limits or lower road throughput
3. Limiting the comfort and utility of time in the car by requiring that at least one passenger pays full attention to the road
4. Making transit and other modes more attractive and encourage the use of ACES vehicles to connect to transit
5. Regulating land use to discourage long commutes and encourage other modes
6. Restricting driving amount of each individual can do, prohibit private empty car trips, limited to specific uses, or only allow rides that connect to or from transit stops

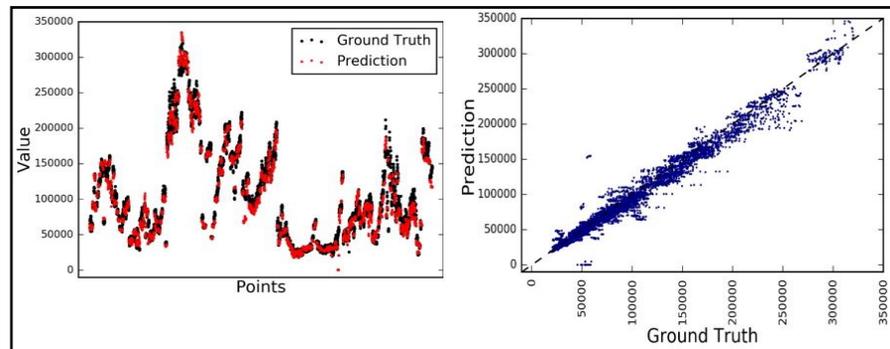
## Preliminary Results (Feasibility validation)

To demonstrate the feasibility of this proposal, the researchers conducted some preliminary analysis whose results are shown in **Figure 2**. The work described here uses Florida's interstate highways as a case study and uses historical data and machine learning methods to train and test accurate prediction models. Having found the optimum model and feature selection for the validation dataset, the Random Forest (RF) Algorithm was chosen as the most promising model with the highest  $R^2$  value and least error.



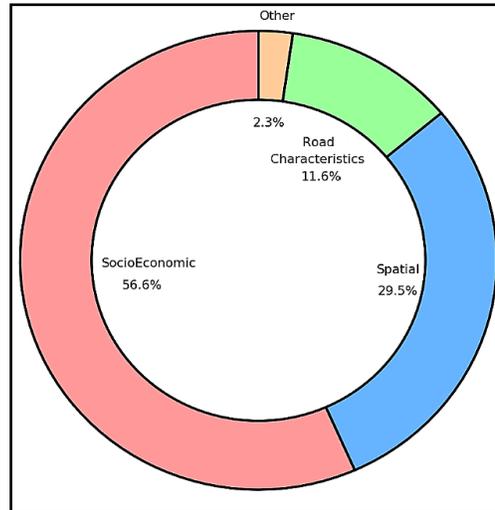
**Figure 2.** Performance of optimized models on car traffic in the test set

Ground truth and the final model's predictions in the validation dataset are shown in **Figure 3** (left), while **Figure 2** (right) presents the comparison of ground truth and prediction via putting them on each axis. The prediction closely follows the ground truth, and the points are located around the 45-degree line.



**Figure 3.** Prediction of values within the validation dataset using Random Forest (RF)

**Figure 4** presents that the critical features derived from the best performing model. Non-linear models exhibited superiority in generalization and prediction of traffic flow over linear models. The Socio-economic variables (such as population, licensed drivers, etc.) Spatial features (such as Euclidean geometry, county, etc.) and Road characteristics (Number lanes, max speed, etc.) are significant factors in personal vehicle traffic prediction models. The results show that ACES vehicles would increase traffic flow and capacity, and the increase in flow is higher than the increase in capacity. As a result, the level of service of the current infrastructure without any intervention will be decreased.



**Figure 4.** Predictor categories' importance

**How shall the results impact practice? Consequences of not doing the research?**

**Impact**

Automated, connected, electric, and shared (ACES) vehicles will increase the attractiveness of traveling by car; generating a significant shift in travel behavior. Increasing the demand of car travel triggers dynamics within the system that will produce a new equilibrium with higher traffic volumes at a similar level of congestion and with a reduced public transit ridership. There will also be upward pressure on traffic volumes due to the increase in the number of trips per day per car and the number of cars in the region that can be expected to occur from innovative new uses for cars. Apart from that, these dynamics will drive the impacts on land use and public transit: people will accept longer driving distances, which in turn, will increase urban sprawl and make it more challenging to accommodate sufficient transit services. Additionally, while vehicle sharing decreases the number of cars in the region, it also leads to higher utilization of vehicles and thus, more trips per car, per day.

Overall, the structure of these dynamics implies much higher levels of vehicle kilometers travelled (VKT) with its outcomes and risk of serious effects on land use and public transit. These risks threaten the efficiency of the transportation network and must be meticulously examined. Otherwise, congestion can have undesirable effects on the quality of the life of our citizens. Without proper planning, congestion is likely to occur, and cause undesirable effects on the economy. Considering the external and internal forces affecting the transportation network, the demand for solutions to the United States'

	<p>traffic gridlock dilemma becomes more severe each year. In many parts of the nation, traffic congestion has escalated to alarming levels. The impact of increased transportation system congestion on the economy has various negative impacts. These impacts include the deterioration of the reliability of transportation facilities. Also, freight vehicles are forced to devote more time to ensuring on-time delivery and vehicle operation costs (VOCs) increase.</p> <p>ACES vehicles are a promising technology, but to leverage their potential, we have to launch the public discussion about the desired—and undesired—long-term outcomes of their use by conducting research and investigating their impact on traffic networks right now. This project will benefit the FDOT by conducting a comprehensive study to investigate the impact of ACES vehicles on traffic networks to, first, developing an accurate land use prediction model for Florida, and second, identifying the required limited-access freeways based on the land-use model.</p> <p>We believe it is essential to keep in mind that taking a wait and see approach with ACES vehicles can come with severe results. By the time there is a critical mass of automated, connected, electric, and shared vehicles in use, it may be too late to impose corrective measures. On the other hand, pro-active action can assist in shaping a framework for ACES vehicles to become an integral part of a more sustainable transportation system we envision.</p> <p>It is also worth mentioning that the results of the proposed research will go a long way towards aiding public officials and the state leadership in evaluating the most desirable alternative from a public policy standpoint.</p>
<p><b>Affected Offices</b></p>	<p><b>Identify any office and names of office personnel that will need to be involved in the scoping or conduct of the research, will be affected by implementation of the results, or will need to participate in the implementation process—including OTIT, if enterprise data/network software application will be a deliverable, and district staff, as appropriate, e.g., through statewide meetings. If the requesting office will not be the implementing office, please identify which office and names of specific personnel which will have to serve in that capacity—have they been involved?</b></p> <p>FDOT, City, and County Traffic Engineering &amp; Operations, Planning, and Design.</p> <p>The results of this research will impact/affect all parties involved in the transportation industry countrywide.</p>
<p><b>Existing Work</b></p>	<p><b>Learning About and Using the Research in Progress (RiP) Database <a href="http://www.trb.org/main/blurbs/176215.aspx/">http://www.trb.org/main/blurbs/176215.aspx/</a> As a minimum, the Transportation Research International Documentation (TRID) and the Research in Progress (RIP) online databases should be reviewed by an expert in the research subject matter to assure research effort and resources shall not duplicate prior or ongoing work. TRID: <a href="https://trid.trb.org/Results">https://trid.trb.org/Results</a> RIP: <a href="https://rip.trb.org/">https://rip.trb.org/</a></b></p> <p>The research team has investigated the literature review of various publications, including ASCE, TRB, etc., on identifying the impacts of ACES vehicles on traffic flow and capacity, and Urban sprawl. The proposed research will be built on the relevant existing research and efforts other scholars conducted.</p>

<b>Keywords Used In Existing Work Search</b>	Automated, Connected, Electric & Shared (ACES) Vehicles; Connected and Automated Trucks (CATs); Traffic Flow; Land Use; Limited Access Freeways; Machine Learning		
<b>Related Contracts (Give contract numbers)</b>	N/A		
<b>Funding Request</b>	<b>Estimated cost:</b> \$180,000	<b>Anticipated Duration</b>	18 months
<b>Project Manager</b>	Jeremy Dilmore Jeremy Upchurch Paul Schoelzel	<b>Contracting Method</b>	Direct contract with University of Central Florida as a Task Work Order
<b>Urgency</b>	Score 1-5: 1 = highest , most immediate need	<p><b>Comments* (elaborate as appropriate on justification/impact comments to explain the urgency of the need . . . is a solution needed immediately, needed within a certain period of time or by a known or anticipated deadline, desired for enhancement)</b></p> <p>With the advent of connected, automated, electrical, and shared vehicle technology, FDOT must be ready to deploy the technology for reducing traffic congestion, enhancing the level of service, which leads to increasing the quality of the life of the citizens. As we consider potential research and policy interventions, we believe it is essential to keep in mind that taking a wait and see approach with ACES vehicles can come with severe consequences. By the time there is a critical mass of ACES vehicles in use, it may be too late to impose corrective measures. On the other hand, pro-active action can help to shape a framework for ACES vehicles to become an integral part of a more sustainable transportation system we envision.</p>	
<b>Implementability</b>	Score 1-5: 2 = greatest likelihood of and proximity to implementing results	<p><b>Comments* (consider both the likelihood of implementation and the length of time and resources required to implement the results of the research.) Identify any prerequisites to, requirements for, or barriers to implementing the anticipated results of this research (e.g., new or change to existing specifications, development of production units of prototype device, legislative change); please indicate if multiple phases of work shall be required.</b></p> <p>There is no doubt that the emergence of new technologies may affect mode choice and infrastructure in unforeseen ways; we believe that our model will allow the user to evaluate a broad range of scenarios, including mode choice. This is partly the reason we are employing system dynamics for handling a broad range of values for different parameters. This research will develop a proof-</p>	

of-concept study to test the possible ACES vehicle impact on the traffic flow and land-use model of this study as well as aid public and private leadership in evaluating the most desirable alternative from a public policy standpoint.

**Project Benefits (succinct, complete explanation)**

The main advantage of this project is the scalability and transformability feature of the models to all of Florida’s interstate highways. The insights formed by this project will have critical practical applications in managing the investment procedures of government agencies and private investors into future highway construction needs. This project will benefit the FDOT by:

- Developing an accurate land use prediction model for Florida,
- Utilizing the land-use model and historical traffic data, while considering the impact of ACES vehicles on limited-access freeway construction needs.
- Aid in public policy decisions.

Secondary benefits:

- The methodology which will be developed by this project can be extended for the deployment of DOTs country-wide.
- Efficient and rapid Planning considering the impact of CAVs on required highway construction investments. Moreover, decision-makers would be provided a tool to allocate the limited resources to expanding roads most at risk for experiencing congestion.
- Attracting private sector partnerships to foster economic development and improve safety and mobility by developing an economic feasibility aid for project evaluation.
- City planners and decision-makers would be able to visualize the impact of critical regulations & policies regarding CAVs penetration utilizing the results of this study.

<b>Project Benefits (Select all that apply and explain)</b>	<b>Quantifiable Benefits (units, dollars, etc...if applicable)</b>	<b>Methodology or Data Sources Used to Determine Quantifiable Benefits. If not applicable, please give justification of project benefits</b>
○ Materials Enhancement		
○ Materials Savings		
○ Time Savings		
○ Lives Saved/Injuries Prevented		
○ Other (Explain)		

\*Comments should explain and support urgency, financial benefit, and implementability scores

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