Service Level Evaluation of Florida's Highways Considering the Impact of Autonomous Vehicles

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Abstract –

Automated vehicles (AV) are undergoing development at a remarkable pace and have the potential to revolutionize the existing transportation system. The ASCE [1] evaluated the United States' infrastructure as a D+ grade. Moreover, they predicted radical infrastructure investment gaps in the surface transportation sector in the upcoming years. Some new urbanized regions might require new highways. Meanwhile, many other highways are reaching the end of their service life and will need significant repairs or even replacement. However, this seems to be unrealistic to happen until having a high market penetration of Fully Connected and Autonomous vehicles on the road to benefit from the capacity expansion benefits. Regarding the funding related issues of highway construction in the U.S. and the emergence of AVs, having a better understanding of the future's traffic status is a must. This study investigates the impact of autonomous vehicles on Florida's district five of I-95 highway traffic including three counties: Flagler, Volusia, and Brevard. This research is the first study to develop a fusion model considering the impact of both traffic flow and capacity adjustments based on the literature review to forecast the traffic from 2020 to 2040 by considering the increasing AV market penetration. The proposed approach provides a more realistic plan for government agencies and private investors, and as a result, significant savings financially and resource-wise can be achieved. The findings of the study confirm that autonomous vehicles will increase traffic flow and capacity, and the increase in flow is higher than the increase in capacity.

Keywords –

Autonomous Vehicles; Traffic Flow and Capacity; Long-term Planning; Highway

1 Introduction

Civil infrastructure systems are an integrated system of engineered systems and people within an ecological context. It is critical to keep resiliency of these complex systems in mind during their design, operation, and maintenance to ensure their efficient operation. Differing perspectives are required to understand the system dynamics of such complex systems correctly to achieve effective and stable operation. Highway Infrastructures constitute an economically vital form of transportation infrastructure. They have the potential to contribute to the productivity and economic growth of states economies. ASCE gave U.S. infrastructure a D+ in 2017. They also predicted radical investment gaps in the highway sector. Mobility is the lifeblood of our cities and a crucial aspect of urban life. U.S. automobile incidents are mostly related to human errors and the US petroleum use for road transportation corresponds to approximately 60% of the total U.S. petroleum consumption. Moreover, the average commuter gets delayed 38 hours per year due to traffic congestion. By revolutionizing the nature of personal mobility and removing the need for passengers to be in the car at all times, AVs have the potential to dramatically affect roadway usage and the built environment to yield urban spaces that are safer, more efficient, and attractive. As a result, there is a possibility that the highways that are under construction or soon their construction will commence could be obsolete by the time that they become operational due to the impact of the autonomous vehicles on effective road-capacity and shared mobility travel behavior. However, the chance of occurrence of this scenario is slim before having a high market penetration of fully Connected Autonomous Vehicles (CAVs) on the road to fully take advantage of the capacity expansion benefits.

Then again, the number of trips increases substantially due to various disruptive forces such as the increased population, increased urbanization, increased vehicle miles traveled (VMT) for AV cars as a result of easier trips, and, new consumers such as children, disabled and senior people. Truck-related travels also have a pivotal role in transportation planning as their impact on the transportation system could also be significant which in turn would affect the overall infrastructure costs. There is a positive relationship between the size of the economy and truck VMT. The size of the U.S. economy is expected to double from 2017 to 2045 which will lead to the continuous expansion of truck VMT reflecting increased productivity and population.

Even though several studies have investigated the impacts of Connected and Autonomous Vehicles (CAVs) adoption on travel behavior, much remains to be explored regarding the different ways in which upcoming disruptive forces such as CAVs, urbanization, and, the increasing population could affect the highway infrastructure level of service and their respective cost and benefit streams for the stakeholders. Considering the impact that these forces can have on the societies' quality of life, postponing decision making and quantifying their impact to the time when a significant number of CAVs are operating, and higher urbanization occurs, would be most likely too late for any remedial actions. CAVs in all likelihood will have the most significant and earliest impacts on highway capacity and traffic volume. The number of trips increases substantially due to the mentioned disruptive forces. Impact of increased congestion on the economy decreases the reliability of transportation facilities, increases vehicle operation cost, increases environmental and safety costs, and, deteriorates the roadway conditions. In this study, first, appropriate scenarios based on the literature review are devised and used to project the traffic flow. Then, the capacities of the selected highways are adjusted by considering the market penetration of AVs. Lastly, it is shown that which highways will operate under, at, or over capacity. The output of this study will eventually help long-term planning for infrastructures in Florida. Moreover, this study can be used by policymakers and researchers as an input in disaster management and planning for resilient communities.

2 Literature Review

This study applies a data-driven model to examine the impact of AVs on Florida's district five I95 highway traffic, analyzing the effect under different scenarios considering the increasing AV market penetration. The market penetration of the AVs and the corresponding travel consequences in future are of great interest to researchers and companies. Also, if AVs enter new vehicle markets in the 2020s, it will be the 2040s or 2050s before most vehicles can be Connected and autonomous driving of level four and five [16]. The market penetration assumptions used in this study is based on the literature review [15] and is summarized in Table 1. Two pessimistic and optimistic market penetration scenarios are defined for each specific time being studied in this modeling based on the [15].

Table 1. Optimistic and pessimistic CAV market penetration

2020		2025	
Pessimistic	Optimistic	Pessimistic	Optimistic
0%	10%	10%	20%
2030		2035	
Pessimistic	Optimistic	Pessimistic	Optimistic
15%	30%	30%	40%
2040			
Pessimistic	Optimistic		
35%	45%		

Highways' characteristics should improve to increase its capacity to be able to adjust CAVs in the traffic system [7]. Studies revealed that the capacity of the network could grow two to four time more than current capacity, based on the CAV fleet size [7, 22]. Improvements in the network capacity are the result of the enhanced reliability of travel time, the precision of CAV controls and the communication features [27]. [19] estimated that decreased headways could nearly double or triple roadway capacity. VMT increase concerning road capacity is 30% to 60% (short-term) and 60% to 100% (long-term). [23] also predicted that vehicle-to-vehicle (V2V) coordination of adaptive cruise control could improve capacity by 21% with 50% of all vehicles using this technology, or up to 80% capacity expansion with a 100% coordinated vehicle fleet based on empirical examination.

Due to the new category of users, vehicle automation can improve the mobility of currently underserved populations, namely, those with travel restrictive medical conditions, and seniors. Speculation based studies by different authors show that AVs would add some trips to the traffic network by providing mobility for disabled people and children [27]. [3] speculated that level four vehicles (fully automated) would considerably increase the number of trips because it provides mobility for those groups which are not able to drive using conventional vehicles. AVs could be especially transformative for one group of people in particular: those who are physically incapable of driving. [19] estimated 10% to 14%, [8] estimated

14%, Brown et al. estimated (40%), and [10] estimated 10% to 20% increase in VMT due to the new categories of users. CAV can also increase empty vehicle travel while dropping off or Picking up travelers, or during waiting to be called. It is argued that it is more reasonable for a car to drive around than to pay parking charges [24]. Furthermore, experts predict that there will be an increase in goods delivery by AVs on the roads as well.

Regarding the ownership, total travel effects will depend on the extent that households move from owning to sharing vehicles. Changes to shared mobility lead to a decrease in overall vehicle travel. It is not clear that AVs increase or reduce total vehicle travel. Lovejoy, [14] predicted that Households tend to significantly decrease their vehicle travel, by 25-75%, when they move from owning a vehicle to sharing it. Regarding safety, it is claimed that because human error is the reason for 90% of crashes. Autonomous vehicles full adoption will decrease crash rates and costs associated with insurance companies by 90% [9].

3 Methodology

The research includes the application of input-output modeling technique to conduct a traffic analysis on I-95 Highway in district five of Florida Department of transportation, counties of Flagler, Volusia, and Brevard. Weighting method is used to have a normalized Annual Average Daily Traffic (AADT) for all the segments of each county calculated by FDOT Hybrid model from 2020 to 2040, recently developed by the forecasting engineering team. In this study, the sections of the FDOT final report in 2015 are being used. There are 38 stations in total defined for the Highway I-95 in District five. Each station has information regarding the state road no., start, and end of the segment, length, level of service and so forth. [11] used systems dynamics modeling to generate three scenarios that describe the possible negative and positive outcomes of the broad adoption of AVs. They defined three scenarios to predict the future's impact of AV adoption on traffic. Likely profits include cheaper and safer travel by car, with enhanced mobility for those who do not have access. They also consider the ownership behavior of the passengers. Figure 1 illustrates the summary of the parameters used in this research for adjusting traffic volume and capacity. In this study, the optimistic and pessimistic thresholds are chosen to be used as special cases due to the suggested model by [15] regarding the AV market penetration. In the modeling procedure, the traffic capacity is adjusted by the method proposed by [17]. The inputs and outputs of this study presented in Table 2. The inputs data include the FDOT's traffic-related data and the literature information to build the fusion model regarding the various studies in this modeling. Moreover, this study includes six outputs as shown in Table 2.

Table 2. Inputs and outputs of the model

Inputs	
FDOT's Inputs	Traffic Flow Forecast Data (Average Annual Daily Traffic)
	Traffic Capacity information
Literature's input	Impacts of AV on Traffic Flow and Capacity

Outputs	
Outputs 1	Fusion Model, Defined Scenarios base on the impacts of AV on Traffic
Outputs 2	Impact of New categories of users on V/C Ratio
Outputs 3	Impact of Shared or Private Ownership on V/C Ratio
Outputs 4	Impact of Time Gaps-Capacity on V/C Ratio
Outputs 5	Impact of Behavioral Scenarios (Base-Disruptive-Adaptive) on V/C Ratio
Outputs 6	Impact of Construction scenarios on V/C Ratio

This study uses the input-output modeling technique to conduct a series of scenario analysis. Scenario analysis is the process of evaluating potential future events through the consideration of feasible alternatives, though, not equally likely, states of the world. Figure 1 shows the assumptions regarding different scenarios of the model based on the literature review that accounts for adjustments for traffic flow and capacity.

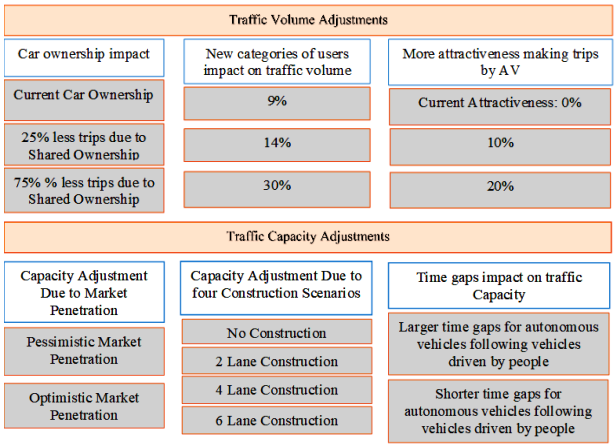

Figure 1. Traffic volume and capacity parameters

assumptions in this study.

4 Results

There are five pivotal aspects related to volume/capacity ratio (V/C) discussed in this section. Namely, the impact of new categories, the shift of the ownership, large and short time gaps, three different behavioral scenarios, and constructing of new lanes based on the Volume/Capacity (V/C) ratio.

Table 3 shows the assumptions and traffic information data regarding the study of the impact of various new categories of users on volume/capacity ratio. This study assumes a pessimistic market penetration of autonomous vehicles. Moreover, the impact of shared ownership and the attractiveness of having more trips by AV is not considered.

Table 3. Information regarding the data and the assumptions used in Figure. 2

County	Brevard County
I-95 segment #	15
Market penetration	Pessimistic
Variable under study	Impact of New categories of users
Variable's impact 1	0%
Variable's impact 2	9%
Variable's impact 3	14%
Variable's impact 4	30%
Impact of Shared or private ownership	0%
Impact of More attractiveness of making trips by AV	0%

The impact of new categories of user increase from 3% in 2025 to 18% in 2040 considering four different scenarios on the V/C ratio is depicted in Figure 2. The results show that the difference between the V/C ratio increases between different scenarios as the time passes. It is evident that higher percentage new user scenarios (more evident for the 30% scenario) start departing from the baseline earlier. The growing distance between the scenarios shows that there is a critical need for federal government to pass limiting laws (Licencing) to manage the probable new users efficiently to avoid lower service level and high congestion level. Furthermore, this study did not consider the children under 18, a tech-savvy market that mobility service start-ups are already tapping, in the calculations which have the potential to worsen the traffic congestion.

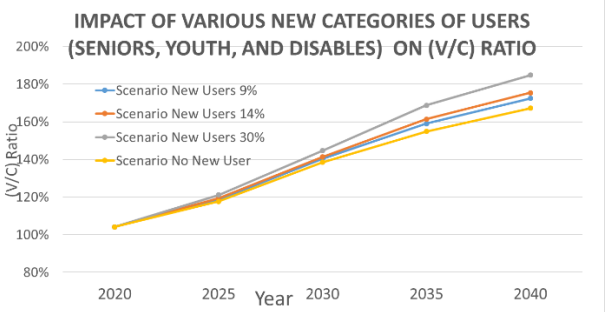

Figure 2. Impact of new categories of users on (V/C) ratio.

Table 4 shows the assumptions and traffic information data regarding the study of the impact of shared and private on volume/capacity ratio. This study assumes an optimistic market penetration of autonomous vehicles. Moreover, the impact of shared ownership and the attractiveness of having more trips by AV is not considered.

Table 4. Information regarding the data and the assumptions used in Fig. 3

County	Brevard County
I-95 segment #	15
Market penetration	Optimistic
Variable under study	Impact of Shared Ownership
Variable's impact 1	0%
Variable's impact 2	25%
Variable's impact 3	75%
Impact of New categories of users	0%
More attractiveness of making trips by AV impact	0%

Figure 3 shows the crucial impact of the shift of the ownership from private cars to shared mobility on the service level of the highway. It can be inferred that shared ownership can significantly increase the service level of the highway and delay the overflow of the highway. For instance, %75 shared ownership would delay the overflow of the highway by six years. CAVs are a naturally attractive type of transportation. The results from figure 3 stresses the importance of planning to encourage people using different kinds of shared mobility as the primary transportation means.

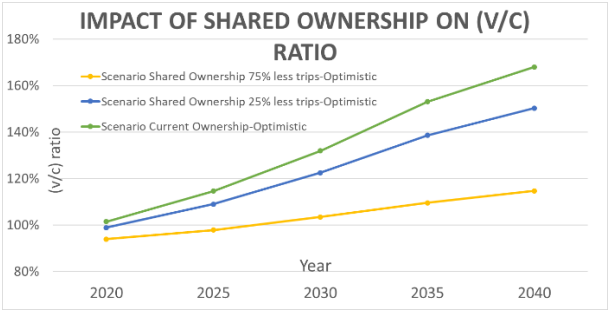

Figure 3. Impact of various shared car ownership on (V/C) ratio.

Table 5 shows the assumptions and traffic information data regarding the study of the impact of larger and shorter time gaps for autonomous vehicles following vehicles driven by people on volume/capacity ratio. This study assumes both pessimistic and optimistic market penetration of autonomous vehicles. Moreover, the impact of shared ownership and the attractiveness of having more trips by AV is also included.

Table 5. Information regarding the data and the assumptions used in Fig. 4

County	Brevard County
I-95 segment #	15
Market penetration	Pessimistic & Optimistic
Variable under study	Impact of Time Gaps of AV Following Vehicles driven by People
Variable's impact 1	Shorter Time Gaps in Optimistic Scenario
Variable's impact 2	Larger Time Gaps in Optimistic Scenario
Variable's impact 3	Shorter Time Gaps in Pessimistic Scenario
Variable's impact 4	Larger Time Gaps in Pessimistic Scenario
Impact of New categories of users	14%
Impact of Shared or private ownership	25%
Impact of More attractiveness of making trips by AV	20%

Figure 4 depicts the impact of large and short time gaps on the capacity regarding both optimistic and pessimistic market penetration. The mentioned time gap can have a 20% impact on (V/C) ratio in 2040. Automated technologies allow shorter headways between the vehicles, which in turn have the potential to increase the capacity of the freeway network and reduce traffic delays significantly. But it is important to remember that small market penetration rates of automated vehicles do not lead to noticeable capacity increase. The potential benefits are likely to be realized at higher penetration into the traffic mix. As a result, it is a crucial variable to consider in modeling for further studies.

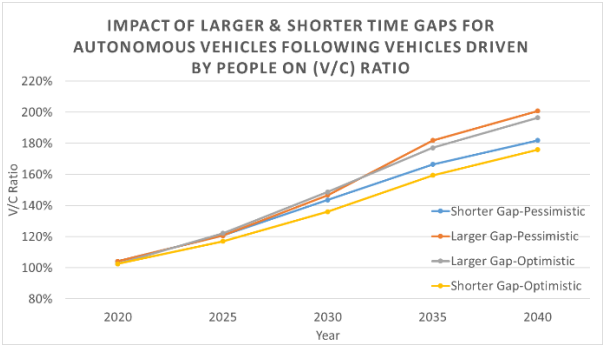

Figure 4. Impact of large and short time gaps for autonomous vehicles following vehicles driven by people on capacity.

Table 6 shows the assumptions and traffic information data regarding the study of the impact of different behavioral scenarios on the volume/capacity ratio. This study assumes an optimistic market penetration of autonomous vehicles. Moreover, the effect of variously shared ownership, the attractiveness of having more trips by AV and the new categories of users is considered.

Table 6. Information regarding the data and the assumptions used in Fig. 5

County	Flagler County
I-95 segment #	5
Market penetration	Optimistic
Variable under study	Behavioral Scenarios
Impact of Time Gap regarding the capacity adjustments	Shorter Time Gaps

Variable's impact 1, **Baseline Scenario**	Variable's impact 2, **Adaptive Scenario**	Variable's impact 3, **Disruptive Scenario**	
9%	9%	30%	New users
0%	75%	0%	Shared or private ownership
0%	0%	20%	More attractiveness

Figure 5 illustrates the impact of three different

behavioral scenarios of the future on the (V/C) ratios. As shown in that figure, the gap between the disruptive scenario and the adaptive or baseline scenario exceeds as passing the time. The gap between the scenarios is showing a critical issue of how proper planning and taking essential measures ahead regarding the adaptive scenario can delay or even enhance the traffic status. Figure 6 shows the threshold (Maximum and Minimum) range of the possible scenario of the future.

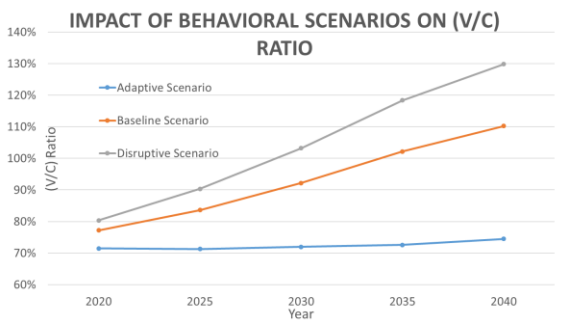

Figure 5. Impact of different behavioral scenarios on (V/C) ratio.

Table 7 shows the assumptions and traffic information data regarding the study of the impact of construction scenarios on the volume/capacity ratio. This study assumes an optimistic market penetration of autonomous vehicles. Moreover, the effect of variously shared ownership, the attractiveness of having more trips by AV and the new categories of users is considered.

Table 7. Information regarding the data and the assumptions used in Fig. 6

County	Brevard County
I-95 segment #	15
Market penetration	Optimistic
Variable under study	Impact of Construction Scenarios
Variable's impact 1	No Lane Construction
Variable's impact 2	2 Lane Construction%
Variable's impact 3	4 Lane Construction%
Variable's impact 4	6 Lane Construction
Impact of New categories of users	14%
Impact of Shared or private ownership	25%
Impact of More attractiveness of making trips by AV	20%

Figure 6 illustrates the impact of constructing new lanes on the (V/C) ratio. As shown, in 2030 there is a need to build two new lanes to have under capacity status, but if instead, four lanes are constructed, the issue will be solved until 2040. It is evident that as the number of lanes increases the impact on the V/C ratio decreases. In other words, the first extra two lanes would provide more utility compared to the next extra lanes. This figure can also be used as a tool to find the optimized time of adding more lanes to the highway not to face congestion issues.

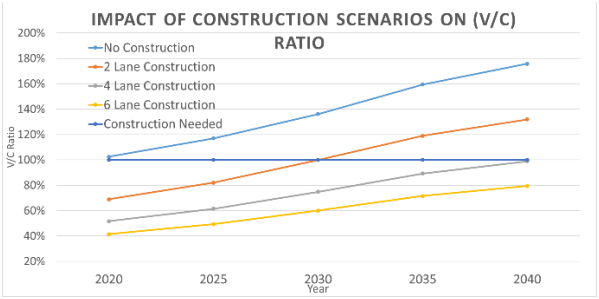

Figure 6. Impact of construction scenarios on (V/C) ratio.

5 Conclusion

This study presents a comprehensive analysis of finding the impact of connected and autonomous vehicles on traffic flow and capacity. This research is develops a fusion model considering the impact of both traffic flow and capacity adjustments based on the literature review. This research not only contributes to the body of knowledge in the transportation field by conducting a comprehensive study to develop a fusion model considering the impact of both traffic flow and capacity adjustments based on the literature review for the highways, but also has important practical applications in managing the investment measures of government agencies and private investors. The insight into the upcoming highway construction needs, with a focus on understanding the disruptive impact of CAVs on highways' performance provided by this study, would improve the resiliency of transportation systems. The findings of the study confirm that connected and autonomous vehicles will increase both traffic flow and capacity, and the increase in flow is higher than the increase in capacity. Shared ownership of passenger vehicles has been found to mitigate the traffic flow. The growth in projected demand for AVs will not be accommodated by a similar increase in the capacity that currently exists, resulting in even greater congestion of the market penetration of AVs. The time to plan the infrastructure necessary for smooth deployment of AVs and avoid congestion due to the projected traffic flow is passing. Meanwhile, the proposed approach provides a more realistic plan for

government agencies and private investors, and as a result, significant savings financially and resource-wise can be achieved. Based on the preliminary results presented in this paper, it can be concluded that federal and local governments should take a proactive approach and began to act. It is a critical issue to think ahead and plan to use limited resources efficiently. Researchers can further investigate the impact of the involved parameters on the emerging technologies to address the upcoming challenges. The directions for future research includes considering the impact of urbanization in dense cities around the world. Some States, due to their logistics and critical location, are subject to facing hurricanes, wildfires, heat waves and other natural disasters, especially regarding the severe climate change predictions, studying the impact of this parameter on the necessary highway infrastructure for the emergency evacuation situations is a must. Moreover, assessing AV impact's sensitivity to different shared use, Public Transportation behavior and urban sprawl growth are also required in better realizing the impact of AVs on the highways' service level.

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