# Capacity Analysis of Freeway with Connected and Autonomous Vehicles (CAVs)

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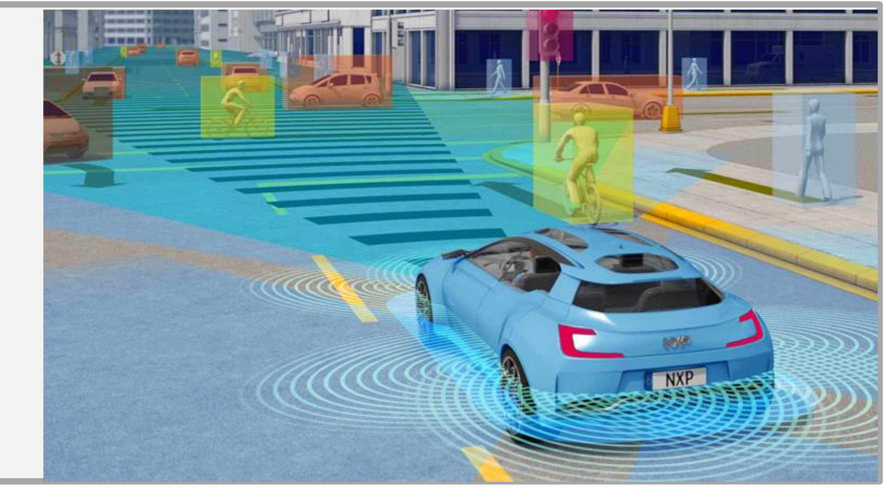


## Introduction

This research assesses the characteristics and operations of Connected and Autonomous Vehicles (CAVs) that has impact on traffic operations using traffic simulation method. The use Connected and Autonomous Vehicles is gradually evolving in the Automotive industry, undergoing various testing processes before it is made available for public use. The integration of CAVs into the existing traffic system is bound to cause changes in the system; there are so many aspects of the technology that needs to be examined by researchers, to understand its probable effects on traffic operations, safety and policies. it is quite unclear how exactly these vehicles will operate, hence the proposition of various assumptions and their corresponding effects. Connected Autonomous Vehicles (CAVs) have gained the interest of researchers in the field of engineering, psychology, and business. This study focuses on examining CAVs' impact on the freeway capacity.

## Objective

The objective of this paper is to evaluate the effect of Connected and Autonomous Vehicles (CAVs) on the freeway capacity using traffic simulation, by considering the behavior of conventional vehicles and CAVs, and determining if the introduction of CAVs at various market penetration rates could result in a significant improvement in capacity. This study has currently considered only the 100% penetration.

## HCM Estimated Flowrates

The HCM presents the capacity of a freeway as the flowrate of the freeway when it is operating at LOS E, these flowrates however varies with the average speed of the traffic stream. Beyond the flowrates at LOS E, the freeway experiences a breakdown and reduction in speed.

Therefore the values of the flowrates at LOS E has been tentatively chosen as the target MOEs for calibrating for freeway capacity in VISSIM, the model parameter to be adjusted is the Headway time denoted as CC1, based on the fact that it is the parameter that affects the capacity of freeway the most.

Table 1: HCM ESTIMATED FLOWRATE AT CAPACITY.

| Speed | Capacities(pc/hr/ln) |
|---|---|
| 75 | 2400 |
| 70 | 2400 |
| 65 | 2350 |
| 60 | 2300 |
| 55 | 2250 |

## Methods

**Overview**

The objective of this research was achieved using traffic simulation method, using the microsimulation modeling tool VISSIM version 8.0.15. Relevant data were collected and used in creating a simulation model; the most critical parameter of the model was calibrated to reflect the data collected, and the maximum flowrates generated by conventional vehicles were statistically compared with those generated by CAVs.

**Measure of Effectiveness**

In estimating the quality of performance of a transport facility or the evaluation of traffic operations on a freeway, there are specific measures of effectiveness that can be used, examples of these measures of effectiveness (Dowling, 2007)[2] are Flowrates, Travel time, Speed, Delay, Queue, Stops, Density, Travel-Time Variance, in this study the measure of effectiveness is **Flowrate** (*which is the number of vehicles passing through a designated point on a freeway facility*) based on the fact that the maximum flowrate represents the capacity of a freeway.

**Model development**

Model setup – The setup commenced with the collection of relevant traffic data to be used as input, and setting up the scenarios

Network data – These are the geometric characteristic of the segment to be analyzed which can be sourced from maps, prescan, concept station, carmaker.

Traffic data which includes traffic volume Speed, distance. The gathered data are then used in building the model. Scenario setup involves the creation of what-ifs in the model by variations within possible limits of the real-life situation. Some assumptions made during the model setup includes,

- The use of only passenger cars,
- Basic freeway segment is considered, no influence of merge or diverge,
- Free-flow speeds are between 54mph and 65mph.
- 0.5seconds time headway is used for CAVs
- CAVs behavior reflects connectivity, i.e., A CAV following another CAV accelerates to meet up and keep the minimum time headway.
- CAVs travel at a speed close to the speed limit, therefore their average speed of a CAV stream is higher than Conventional vehicle stream.

## Model Input Data

Table 2: Model Input Data

| Vehicle Speed/headway time | 54 – 65mph/ 0.5s -1s |
|---|---|
| Demand Flowrate | 9200pc – 14400pc |
| No of lanes | 5 lanes |
| Vehicle types | Conventional, Connected Autonomous vehicle |
| Freeway facility | Basic freeway segment (no merge, diverge, weaving) |
| Length | 3737.718ft |
| Lane width | 11.48feet |

The above table represents the base model created to model a freeway operating at capacity based on data collected from I-95 Fort Lauderdale

Fig 1: Freeway model created in ViSSIM.

Table 3: Traffic data obtained from radar detector at Fort Lauderdale.

| | |
|---|---|
| Detector information | Radar: FLD4095NB031.8 |
| Direction | Northbound |
| Zone ID | 1854/I-95 |
| No of lanes | 5 lanes |
| Max 15min Volume | 2387vehs |
| Max hourly Volume | 9321vehs/hr |
| Speed limit, Average Speed | 65mph, 54.14mph |
| PHF | 0.97 |

## Calibration of model using CC1

Table 4: Simulation results of flowrates obtained by varying the headway time parameter CC1

| | Target | 0.7s | 0.8s | 0.9s | 1.0s | 1.1s |
|---|---|---|---|---|---|---|
| Hourly Volume(vph) | 9321 | 9923 | 9910 | 9776 | 9915 | 9910 |
| Hourly Volume/lane | 1864 | 1985 | 1982 | 1955 | 1983 | 1982 |
| Speed | 54.14 | 51.04 | 50.98 | 51.2 | 51.1 | 50.98 |
| Chi-square | | 0.07224 | 0.06812 | 0.04333 | 0.07142 | 0.06812 |

From the above table the headway time selected to represent conventional vehicles is 0.9 seconds. The CC1 parameter has the greatest effect on flowrate.

*According to Dr. Dave Williams (ATKINS project manager) – There are lots of uncertainties around the future Connected and Autonomous vehicles; ..it is often assumed that CAVs will be able to travel at shorter headways.*

The headway time selected for CAVs in simulation is 0.5 seconds to indicate the assumed shorter headway when compared with conventional vehicles

## Results

Fig 2. Output flow with conventional vehicles

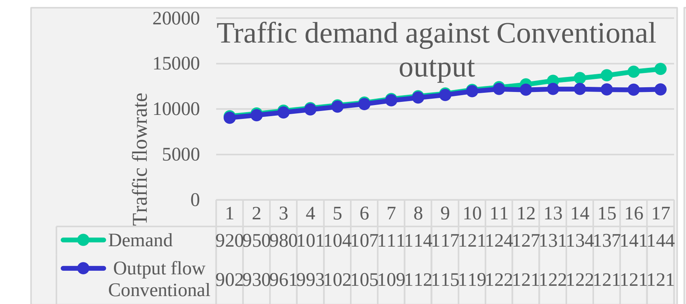
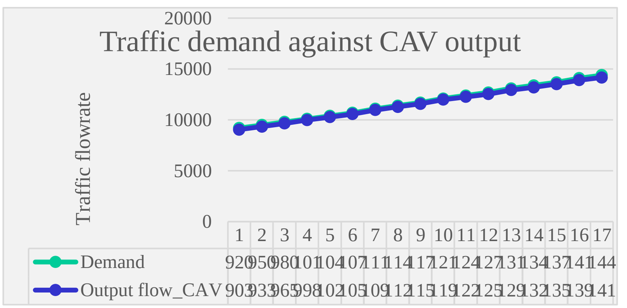



Fig 3. Output flow with CAVs




- Increasing the traffic demand by adding more vehicles, capacity is reached with conventional vehicles at 12400 vehicles, however for connected vehicles, flowrate continues to increase.
- Average speed of traffic stream decreases to 57 mph at capacity for conventional vehicles, but remains relatively the same at 65 mph.

Table 5: Simulation results of flowrates obtained after reaching capacity with Conventional vehicles

| S/N | Traffic demand | Conventional vehicles | CAVs | Difference | Percentage increase in capacity |
|---|---|---|---|---|---|
| 1 | 12400 | 12204 | 12261 | 57 | 0.46% |
| 2 | 12700 | 12117 | 12543 | 426 | 3.49% |
| 3 | 13100 | 12203 | 12931 | 728 | 5.96% |
| 4 | 13400 | 12200 | 13202 | 1002 | 8.21% |
| 5 | 13700 | 12147 | 13517 | 1370 | 11.22% |
| 6 | 14100 | 12112 | 13912 | 1800 | 14.74% |
| 7 | 14400 | 12154 | 14172 | 2018 | 16.54 |

## Conclusions and Future Research

The capacity of a freeway segment was determined from the simulation by the maximum output flow in one hour, after increasing traffic demand successively. Presence of the CAVs improved capacity and also maintained the average speed.

The study plans to investigate further the following:

- The influence of specific penetration rates of the CAVs, ranging from0% to 100% at 25% increments.
- Effects on the travel times at each penetration rate.
- Effects on the average speed at each penetration rate.

## References

[1] Ben-Edigbe, J., Alhassan, H., Aminu, S., 2013. Selective estimations of empirical roadway capacity. J. Eng. Appl. Sci. 8, 71–76.
[2] Highway Capacity Manual, 2010, Chapter 10 -- Freeway Facilities.
[3] Dowling, R., 2007. Traffic analysis toolbox volume vi: Definition, interpretation, and calculation of traffic analysis tools measures of effectiveness.
[4] Dowling, R., Skabardonis, A., Alexiadis, V., 2004. Traffic analysis toolbox volume III: guidelines for applying traffic microsimulation modeling software.
[5] Friedrich, B., 2016. The Effect of Autonomous Vehicles on Traffic, in: Maurer, M., Gerdes, J.C., Lenz, B., Winner, H. (Eds.), Autonomous Driving. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 317–334. doi:10.1007/978-3-662-48847-8_16
[6] Gomes, G., May, A., Horowitz, R., 2004. Calibration of VISSIM for a Congested Freeway. Calif. Partn. Adv. Transit Highw. PATH.
[7] Google self driving.pdf, n.d.
[8] impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf, n.d.
[9] Kim, K.-H., Yook, D.-H., Ko, Y.-S., Kim, D.H., 2015. An analysis of expected effects of the autonomous vehicles on transport and land use in Korea. Working Paper Marron Institute of Urban Management.