Passenger Car Unit Values of Connected Autonomous Vehicles in Urban Road Networks

Christina Gasparinatou[a], Maria G. Oikonomou[a], Athina Tympakanaki[b], Jordi Casas[b], Tamara Djukic[b], Eleni I. Vlahogianni[a], George Yannis[a]
[a]School of Civil Engineering - National Technical University of Athens, Greece
[b]Aimsun SLU, Spain

#22-00823

Abstract

Connected autonomous vehicles (CAVs) are expected to gradually penetrate in urban traffic and significantly affect traffic operations in a microscopic and macroscopic level. In this work, we aim to estimate the Passenger Car Unit (PCU) value of a CAV under different market penetration rate scenarios and further quantify its relationship between road geometry and traffic control (road type, control type etc.) using microscopic simulation. The PCU value is estimated as the capacity change observed in the (network and link) Macroscopic Fundamental Diagram (MFD) when different mixtures of vehicle technologies may exist on the road network. For the purpose of this work, eleven future mobility scenarios are executed in the Aimsun Next mobility modeling software and the resulting PCU values are estimated. Classical statistical and machine learning regression models are further developed to identify the factors that may affect the estimated PCU values. Findings show that, in a network-level, there exists a polynomial relationship between CAVs' PCU and their penetration rate in the traffic mix. In a link-level, the CAV PCU value is found to be highly affected by the observed lane flow, the section length, the control type, the road type, the number of lanes, the number of public transport lines of the road segment, as well as the market penetration rate of CAVs. The paper ends with a discussion on the implications of the results for the macroscopic modeling and the testing of CAV related management policies.

Introduction

Existing conditions

- Drivers in Athens spend 37% more time on the road due to increased traffic congestion.
- 94% of accidents are caused by human error.
- 90% of the harmful air pollutants come from 25% of cars.

CAVs can be considered a promising solution towards eliminating these percentages.

Previous studies

- *CVs' PCU estimation based on speed modeling, headway, space occupancy, time occupancy.*
- *CAVs' PCU estimation mainly in highways and signalized intersections.*

Methodological Approach

PCU values of CAVs was calculated as the proportion of capacity reached by vehicles of different types with respect to Conventional Vehicles (CV) as follows:

$$PCU_{CAV} = PCU_{CV} \frac{capacity_{CV}}{capacity_{CAV}} \quad (1)$$

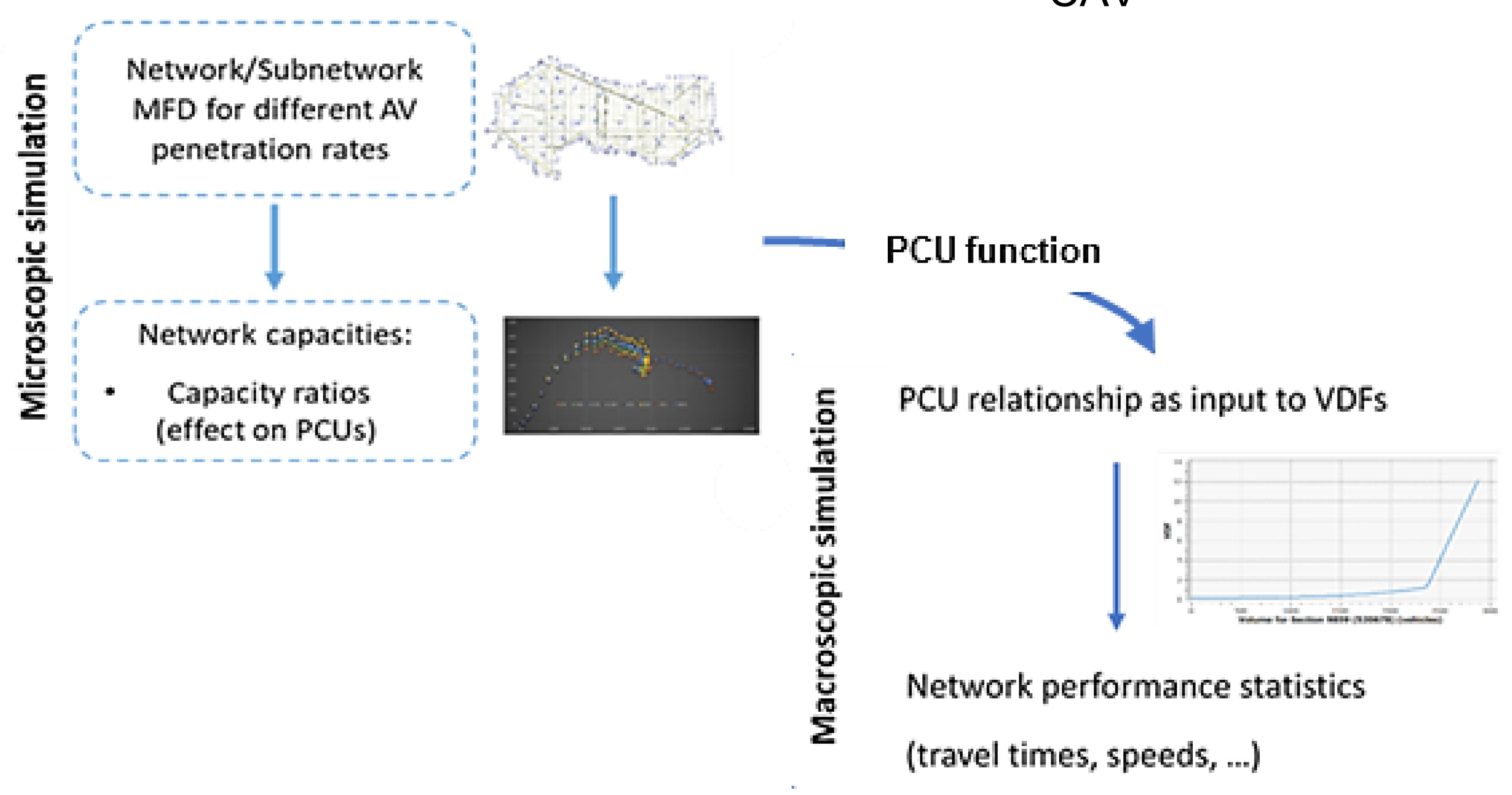

Figure 1. Transition from microscopic to macroscopic analysis using PCU function

Simulating Autonomous Vehicles

Study Network

- The microscopic model was calibrated, using data that were collected from year 2019 recording traffic volume in main roads in the network of Athens, Greece.
- It consisted of 290×292 centroids, 82,270 passenger car trips and 3,110 truck trips and 95 bus and 14 trolley lines.

Modeling CVs and CAVs

- 11 simulation scenarios were executed.
- The penetration rate of CAVs was gradually increasing in each scenario (0%-100%).
- Each scenario included 2-hour simulation (before and during morning peak).
- The simulation step was 2 minutes.

Table 1. Parameters of the Car Following and Lane Changing Model per Vehicle Type

Factor		CV	Aggressive CAV	Explanation on factors of Aggressive CAV
Reaction Time	in car following	0.8 sec	0.4 sec	Vehicle connectivity
	at STOP	1.2 sec	0.4 sec	
	at traffic light	1.6 sec	0.4 sec	
Car Following Model				
Sensitivity	Mean	100%	50%	Implication of shorter headways compared to CVs
	Min	100%	10%	
	Max	100%	90%	
Lane Changing Model				
Overtake Speed Threshold		90%	85%	Implication of caution on overtaking maneuvers compared to CVs
Cooperate in Creating a Gap		YES	NO	Smaller gaps compared to CVs
Distance Zone	Min	0.80	1.00	Longer distance at which lane change to diverge from a motorway compared to CVs
	Max	1.20	1.25	
Safety Margin		1.00	0.75 - 1.25	Longer clearance compared to CVs

Network level impacts

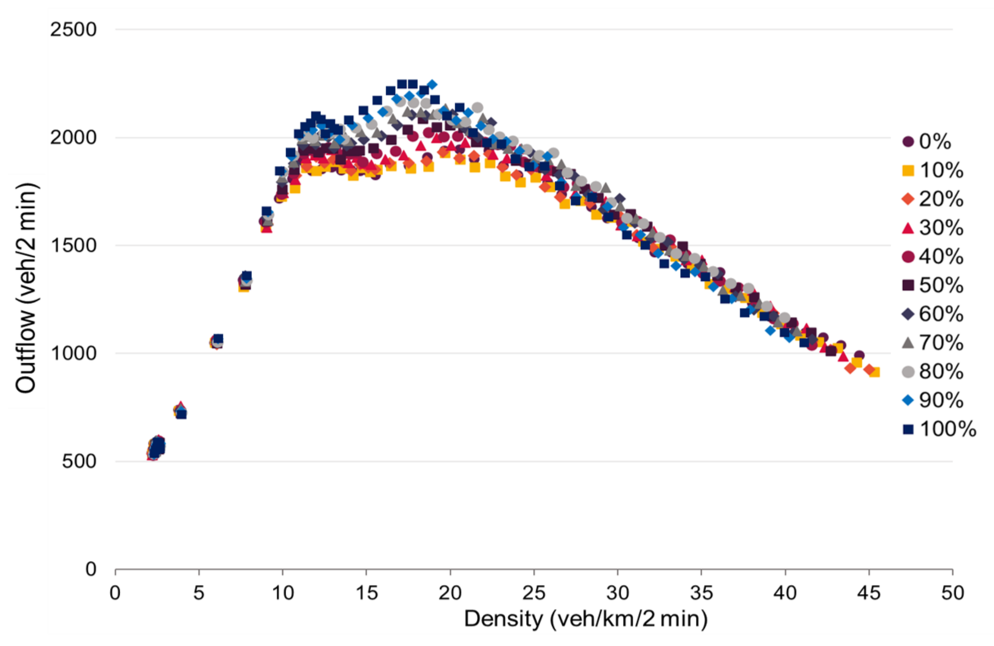

Figure 2. Network MFD for different CAV penetration rate

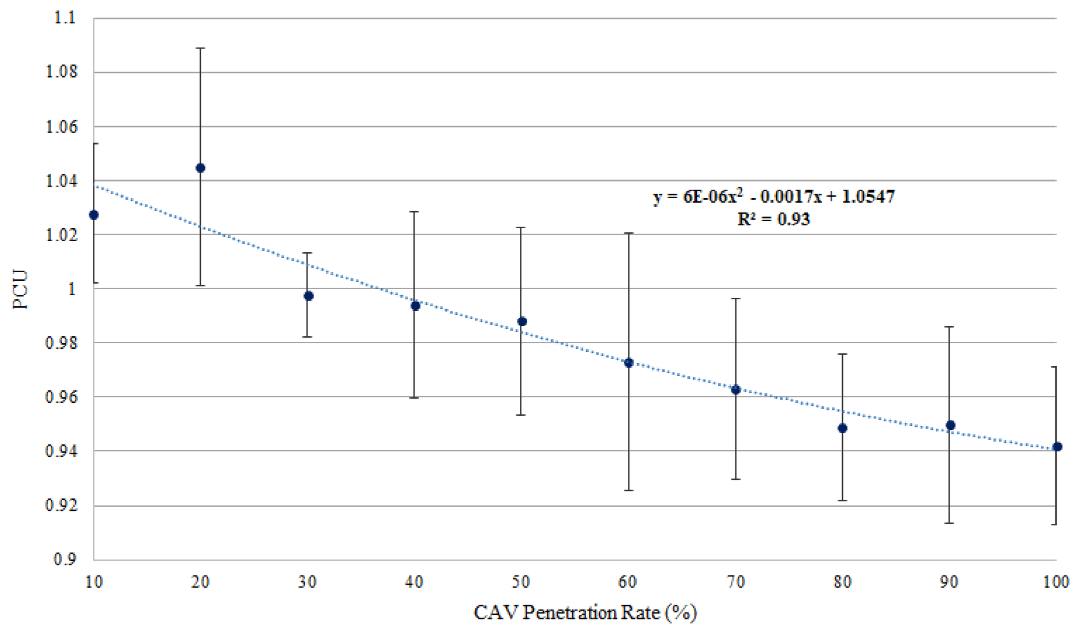

Figure 3. Estimated PCU factors versus CAV market penetration rate

- This MFD is considered to be relatively well-defined during free-flow and peak conditions.
- The increase of CAV market penetration rate leads to increased network throughput and therefore, increased capacity.

Link level impacts

Table 2. Description of variables used in the Dataframe

Variables	Description	Type/Unit
Geometry attributes		
Length	Length of road segment.	Continuous (m)
Number of lanes	Number of lanes of road segment.	Discrete
Control attributes		
Control type	0: No signal, 1: Yield sign, 2: Stop sign, 3: Traffic light	Discrete (0-3)
Road type	0: Secondary Street, 1: Signalized street - On/off ramp, 2: Arterial	Discrete (0-2)
Traffic attributes		
Lane flow	Road segment traffic flow per lane.	Continuous (veh/h/lane)
Penetration rate	Market penetration rate of CAVs.	Discrete (0-100%)
Number of PT lines	Number of public transport lines occurring in road segment.	Discrete
PCU	Passenger Car Unit factor for CAVs.	Continuous

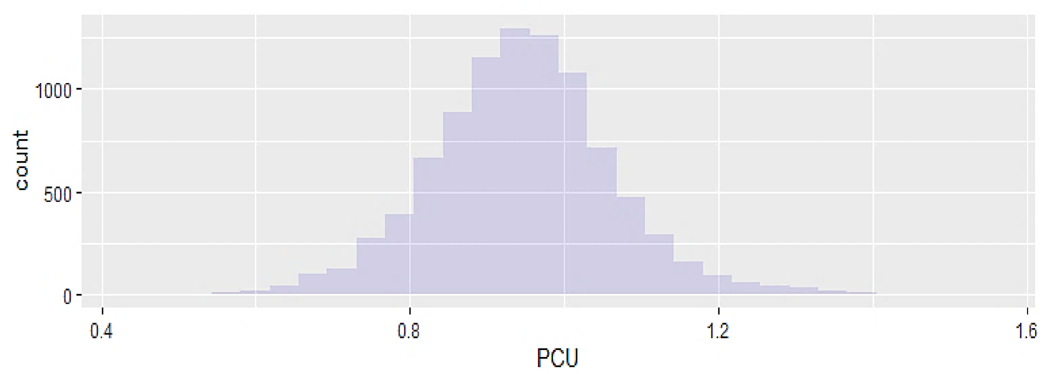

Figure 4. PCU distribution

Table 3. Random Forest Model

Var % explained	45.9%
Mean Squared Residuals	0.023
Error	8.35%

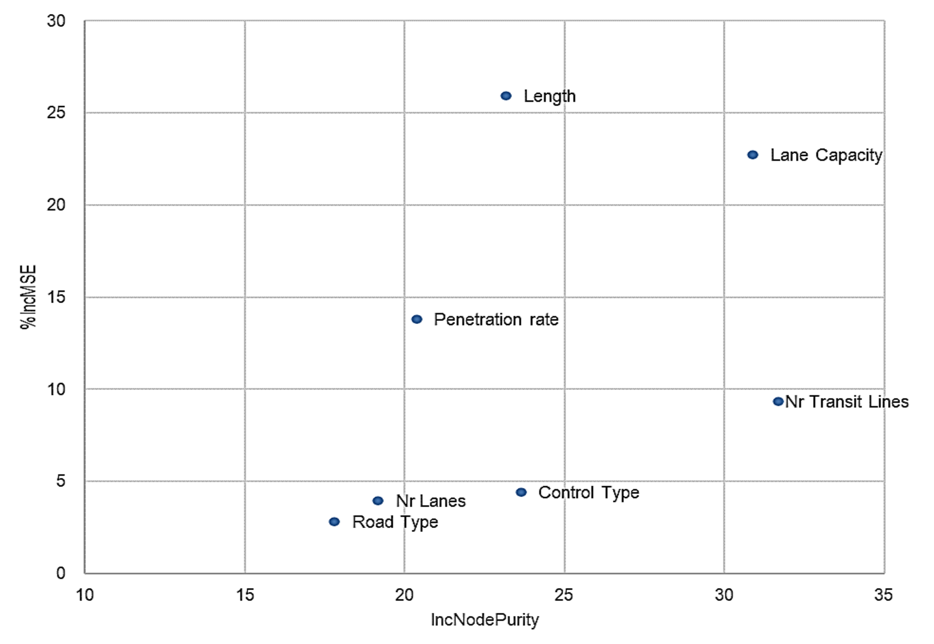

Figure 5. %IncMSE in relation to IncNode Purity

Conclusions

In the network level

- ❑ The average increase in capacity, when CAVs reach 100% market penetration rate, is identified to be 8%, compared to the capacity of no automation scenario.
- ❑ Small PCU values of CAVs are observed when their market penetration rate exceeds 40%.

In the link level

- ❑ The most significant variables affecting the PCU value of CAVs are the lane flow and length of the road segment followed by the market penetration rate of CAVs and the number of PT lines.
- ❑ The PCU values of CAVs in arterials are lower compared to those of the secondary and signalized streets.

Acknowledgements

The present research was carried out within the research project "LEVITATE - Societal Level Impacts of Connected and Automated Vehicles", which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 824361.

Contact

Corresponding Author:
Christina Gasparinatou
xrigasparinatou@gmail.com