Investigating the Effect of Autonomous Vehicles on Average Speed of a Motorway

Panagiotis Papantoniou, University of West Attica, Greece, ppapant@uniwa.gr

Armira Kontaxi, National Technical University of Athens, Greece

ABSTRACT

The objective of the present research is to investigate the effect of autonomous vehicles on the average speed on a motorway. For this purpose, simulation scenarios will be developed in a specific part of Attiki Odos motorway, a modern motorway extending along 70 km, which constitutes the ring road of the greater metropolitan area of Athens. For the purpose of the present research, peak hour traffic demand is estimated from 7:00 to 9:00, while both congested, as well as uncongested conditions will be simulated. To achieve this objective, five simulation scenarios are developed, including different percentages of automated and human driven vehicles (0%, 25%, 50%, 75% and 100% of AVs). According to the obtained results, Autonomous vehicles show significantly increase of the average speed on the motorway, which leads to the improvement along with AVs penetration growth. In addition, the exact percentage of increase per lane is estimated in all different scenarios of autonomous vehicles' percentages in mixed traffic indicating that the new era of Autonomation will significantly affect the capacity of the networks.

Keywords: Autonomous vehicles, traffic simulation, capacity, motorway.

INTRODUCTION

After decades of research, Autonomous Vehicles have already been part of our lives aiming to change the way we are thinking about transport (Fagnant and Kockelman, 2015). Autonomous vehicles operations are inherently different from human driven vehicles and have the potential to offer several important benefits while still encounter several limitations. Within this framework, microscopic and macroscopic simulation models are often used to estimate the impact of automation on a broad perspective and on a strategic level (Delis et al., 2016; Patel et al., 2016; Çolak et al., 2016; Makridi et al., 2020)

Van Arem et al. (2006) used the MIXIC microscopic simulation to investigate the traffic throughput and stability impacts of CACC, incorporating good vehicle dynamics and driver behavior models and found that the average speed increased with higher market penetrations of CACC. Furthermore, Schakel et al. (2010) used a modified version of IDM and included results of a field experiment using 50 vehicles equipped with that controller showing reductions in variability of speeds and gaps between vehicles.

Based on the above, the objective of the present research is to investigate the effect of Autonomous Vehicles on average speed of a motorway in mixed traffic conditions. For this purpose, five simulation scenarios will be developed in a specific part of a motorway including different percentages of automated and human driven vehicles. The paper is structured as follows. In the next section, the methodological approach is presented including details regarding the implementation of the simulation scenarios, characteristics of the motorway as well as the theoretical background of the analysis. The results are presented in the third section whilst general conclusions are stated alongside with proposals for further research.

METHODOLOGY

2.1 Motorway case study

For the purpose of the present research, simulation scenarios are developed in a specific part of Attiki Odos motorway. Attikes Diadromes SA, also known as Attica Tollway Operations Authority, is the Operating and Maintenance Company of the Attiki Odos Motorway (Attica Tollway) in Athens, Greece. The Tollway is a 70 km-long urban Motorway, fully access-controlled through 39 toll barriers (6 mainline barriers at the extremities plus 33 entry ramps). The Company activities cover full operation and maintenance including the 12.60 km of tunnels and cut-and-covers with the longest twin-bore tunnel having a length of about 1 km (total unidirectional length).

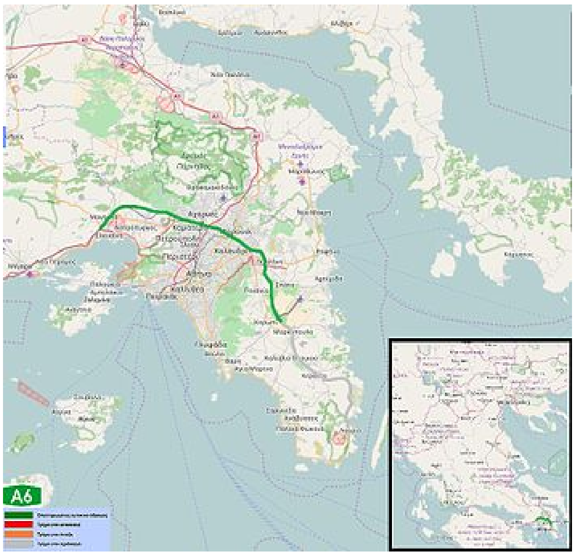

Figure 1. Motorway case study

2.2 Simulation Characteristics

SUMO (Simulation of Urban Mobility) is an open source, highly portable, microscopic and continuous traffic simulation package designed to handle large road networks. It is mainly developed by employees of the Institute of Transportation Systems at the German Aerospace Center.

SUMO road networks represent real world network graphs, where nodes are inter-sections and roads are represented by edges. Intersections consist of a position, a shape, and a right of way rules, which may be overwritten by a traffic light. Edges are unidirectional connections between two nodes and contain a fixed number of lanes. SUMO road networks can be imported as a digital road map using netconvert which converts networks from either other simulations or from other sources..

2.2.1 Vehicles and Routes

Two types of vehicles are used in the current simulation network: Human-driven vehicles and AVs, where the human driven cars are not responsible for regaining control at any point of their trip. Below there is a small description of the models used for the simulation of the above-mentioned vehicle types.

- Human-driven Vehicles: For the simulation of manually driven vehicles, the default option from SUMO is a modified Krauss car-following model (Krauß 1998)
- Autonomous vehicles: For no and full automation vehicles, the deceleration and the emergency deceleration remained the same, considering the safety. The emergency deceleration was set to 8 m=s2. This value was based on the study of Kudarauskas (2007). While the mingap, acceleration and time headway were taken from Atkins Ltd (2016).

Table 1. Simulator parameters

Vehicle type	MinGap	Accel	Decel	Max decel	Sigma	tau
manual	2.5	3.5	4.5	8.0	0.5	1
AV	0.5	3.8	4.5	8.0	0	0.6

- Mingap: the offset to the leading vehicle when standing in a jam (m).
- Accel: the acceleration ability of vehicles of this type (m/s2).
- Decel: the deceleration ability of vehicles of this type (m/s2).
- Emergency Decel: the maximum deceleration ability of vehicles of this type in case of emergency (in m/s2).
- Sigma: the driver imperfection (between 0 and 1).
- Tau: the driver's desired (minimum) time headway (reaction time) (in s).

Demand is setting up by the use of some available applications by utilizing differ-ent source of information. For large-scale scenarios the so-called Origin-Destination (O/D) matrices are used. For the specific case study, since a small part of Attiki Odos is simulated data from detectors were used. Based on the fact that, most of highways are well equipped with induction loops, which measures the number of vehicles enter-ing and leaving the motorway, it is assumed that flows are known in the motorway. The algorithm namely DFROUTER, provided by SUMO, uses the information collect-ed from induction loops to build the vehicle amount and routes.

SUMO has the possibility to produce the emission is each simulation step. Values for each vehicle are calculated and will be recorded and can be further researched. For the specific case study, this output is quite useful since it is possible to compare the benefits of a more sustainable traffic consisting of autonomous/electric cars.

2.2.2 Vehicles and Routes

Five different scenarios have been developed in the present research in order to es-timate the impact of automation on the motorway. For the mixture of vehicles, 5 different cases were studied, creating all possible combinations of penetrations of each vehicle type ranging from 0 to 100% with intervals of 25% as shown in the table below. Each scenario was running for two hours with the second hour being the net-work's peak hour.

2.3 Theoretical background

While a histogram is an approximate representation of the distribution of numerical or categorical data, a box plot is a method for graphically depicting groups of numerical data through their quartiles. Box plots may also have lines extending from the boxes (whiskers) indicating variability outside the upper and lower quartiles, hence the terms box-and-whisker plot and box-and-whisker diagram (Williamson et.al., 1989)

With regard to the interpretation of boxplots, it should be noted that the spacing between the different parts of the box plot indicates the degree of dispersion (spread) and skewness in the data and identifies outliers. More specifically:

- The line in the middle of the boxes is the median
- The bottom of the box indicates the 25th percentile. Twenty-five percent of cases have values below the 25th percentile.
- The top of the box represents the 75th percentile. Twenty-five percent of cases have values above the 75th percentile.
- Half of the cases lie within the box.

RESULTS

In figure 2 the boxplot regarding all deferent scenarios is presented.

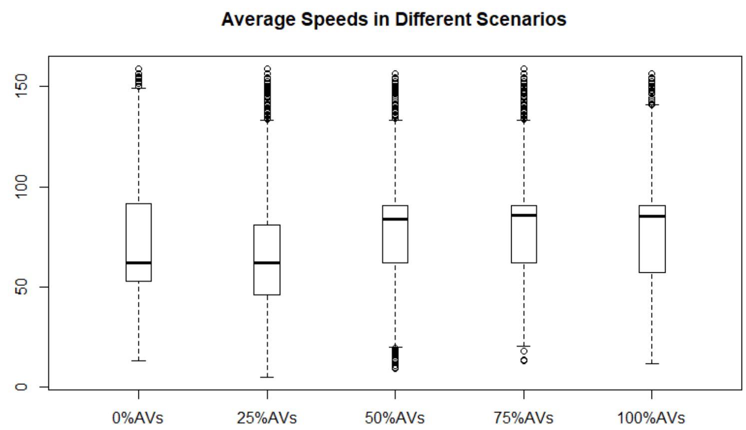

Figure 2. Boxplot of Average Speed

Results indicate that the average Speed is higher in the scenario of 100% Autonomous with similar results in the scenarios of 75% and 50% of AVs while there is a significant decrease in the scenarios with more human drivers than AVs. In the next figure, 5 different histograms are presented aiming to explore the average speed individually in each scenario.

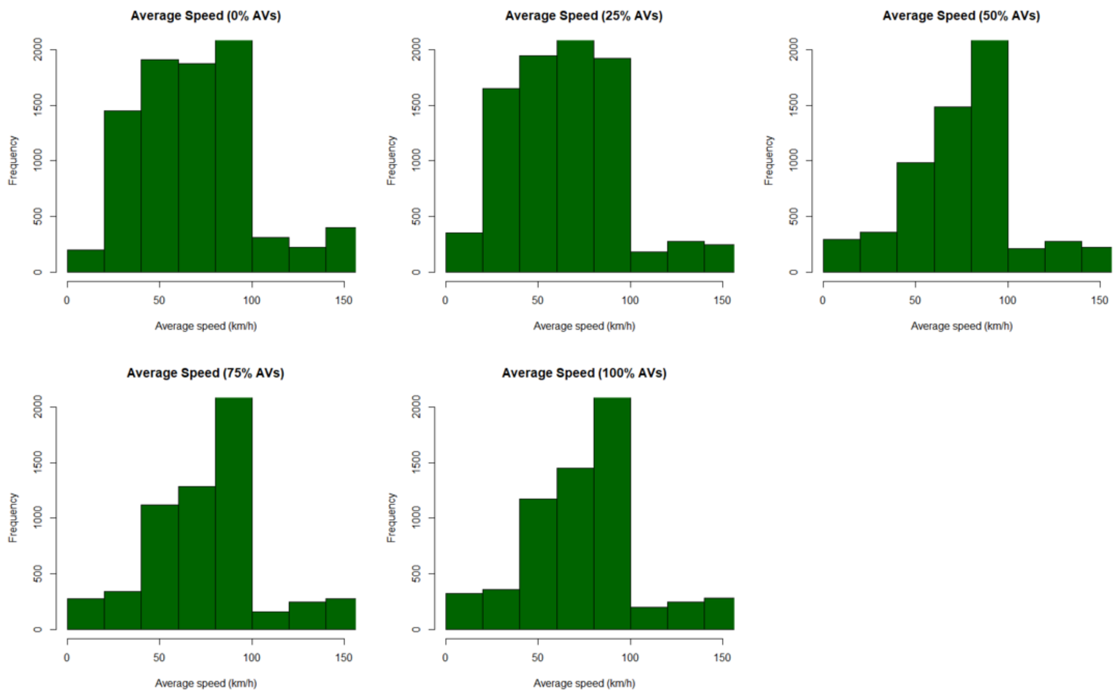

Figure 2. Histograms of Average Speed

The histograms of the five scenarios illustrate interesting patterns in Average speeds per scenario examined. Results indicate that in the scenario of 100% Autonomous vehicles, the highest frequency of speed in the 80-100 km/h. On the other hand, in the scenario of 100% human drivers, a very similar frequency is shown in three speed gaps, 40-60, 60-80 and 80-100 km/h respectively.

CONCLUSIONS

Considering that for the next decades human drivers and autonomous vehicles will be sharing the roads, mixed traffic conditions will be a high priority for both industry, policy makers as well as users. Within this framework, the objective of this research was to investigate the speed behaviour of vehicles in 5 different conditions with different penetrations percentages of Autonomous Vehicles.

Results confirm the initial hypothesis, found in recent literature, that Autonomous Vehicles can achieve higher average speeds either being alone in a motorway or in mixed conditions with human drivers. In addition, focusing on the different penetrations rates of Autonomous Vehicles in the network, results of the present study indicate that the higher percentage of autonomous vehicles leads to higher average speed. Moreover, there is substantially less speed variation during scenarios with 100% AVs which varies mainly from 80-100 km/h whereas for the rest scenarios ranges from 40-100 km/h.

In conclusion, the findings of this study highlight the fact that the different driving performance of AVs will have a significant effect on speed and a consequence on the capacity of a motorway. Moreover, considering that speeding is one of the most important contributory factors on road safety, the increase in average speed, in connected with higher risk on the motorway for the human drivers, a parameter that should be definitely be further investigated in future research.

AKNOWLEDGMENT

The research is based on the HumAV (Human Like Autonomous Vehicles) research project which has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 754462.

REFERENCES

Atkins Ltd. 2016. Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow, Technical Report. Department for Transport.

Çolak, S., Lima, A., González, M.C., 2016. Understanding congested travel in urban areas. Nat. Commun. 7, 10793.

Delis, A.I., Nikolos, I.K., Papageorgiou, M., 2016. Simulation of the penetration rate effects of ACC and CACC on macroscopic traffic dynamics, 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC). Presented at the 2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 336–341.

Fagnant, D., Kockelman, K. (2014). The travel and environmental implications of shared au-tonomous vehicles, using agent-based model scenarios. Transport Research Part C: Emer-gency Technology, 40, 1–13.

Krauß, S. 1998. Microscopic modeling of traffic flow: Investigation of collision free vehicle dynamics. PhD dissertation, Universitat zu Koln.

Kudarauskas, N. 2007. Analysis of Emergency Braking of a Vehicle. Transport 22 (3): 154–159.

Makridis, M., Mattas, K., Mogno, C., Ciuffo, B., Fontaras, G. 2020. The impact of automa-tion and connectivity on traffic flow and CO2 emissions. A detailed microsimulation study, Atmospheric Environment 226

Patel, R., Levin, M.W., Boyles, S.D., 2016. Effects of Autonomous Vehicle Behavior on Arterial and Freeway Networks. Transp. Res. Rec. J. Transp. Res. Board 2561.

Schakel, W. J., B. van Arem, and B. D. Netten. Effects of Cooperative Adaptive Cruise Control on Traffic Flow Stability. Proc., 13th International Annual Conference on Intelligent Transportation Systems, Madeira Island, Portugal, IEEE, 2010, pp. 759–764.

van Arem, B., C. J. G. van Driel, and R. Visser. The Impact of Cooperative Adaptive Cruise Control on Traffic-Flow Characteristics. IEEE Transactions on Intelligent Transportation Systems, Vol. 7, No. 4, 2006, pp. 429–436.

Williamson, D., Parker, R., Kendrick, J. (1989). The box plot: A simple visual method to in-terpret data Annals of internal medicine 110(11):916-21