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Investigating the effect of Automated Vehicles and Connected and Automated Vehicles on the capacity of freeways using microscopic simulation

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ABSTRACT: Congestion is one of the problems that has bothered many countries in recent decades and has imposed huge costs on many countries. For this reason, many researchers are looking for ways to reduce congestion in transportation networks. On the other hand, it is predicted that the emergence of Automated Vehicles and Connected and Automated Vehicles can be effective in reducing congestion on the roads and increasing the capacity of the roads. For this reason, this study investigates the effect of Automated Vehicles and Connected and Automated Vehicles on the capacity of roads. In this study, a freeway network with the Merge section is used and the simulations are implemented using SUMO microscopic simulator software. In this study, to determine the driving behavior, the car following model for longitudinal movements and the lane changing model for lateral movements have been used. The Krauss car-following model and the LC2013 lane-changing model were used to determine driving behavior in this study. The simulation results show that Automated Vehicles can increase road capacity by up to 52% and Connected and Automated Vehicles can increase road capacity by up to 65%, which indicates the potential of these vehicles to increase capacity and reduce congestion. The results also show that these vehicles can have a significant impact on capacity when the presence of these vehicles on the road is significant.

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1- Introduction

Over the past decades, traffic jams have become a major problem in large cities. Traffic problems in cities may be even greater in the future, as an increasing share of the world's population lives in urban areas [1,2]. One of these innovative ideas is the advent of Connected and Automated Vehicles (CAVs), which are predicted to be able to be a response to the problem of congestion due to automation characteristics and connection, and have a great effect on increasing capacity and reducing congestion.

There are several studies that investigated the impact of Automated vehicles (AVs) or CAVs on the capacity of transportation networks and their results often show AVs and CAVs can increase the capacity [3,4]. However, these studies have not considered the impact of AVs and CAVs on the capacity of roads simultaneously and these studies have not compared the effect of AVs and CAVs on the capacity of roads. Thus, this study evaluated the impact of CAVs and AVs on the capacity of a freeway.

2- Methodology

This study is based on microsimulation which microsimulation is based on car following and lane-changing model. This study's microsimulations are implemented in Simulation of Urban Mobility (SUMO) simulation software which is an open-source traffic simulation. This study uses the Krauss car following model which is the default car following model in SUMO. Krauss car following model is based on safe speed and equation (1) shows the speed. Where v_{safe} is safe speed, $V_l(t)$ is the speed of leading vehicle i in time t, t_r is reaction time(s), $g(t)$ is leading vehicle gap in time t, b is the vehicle maximum deceleration (m/s^2) [5].

$$v_{safe} = v_l(t) + \frac{g_l - v_l(t)\, t_r}{\frac{v_l(t) + vf(t)}{2b} + t_r} \tag{1}$$

Also, the Krauss car following model describes another speed called desire speed (v_{des}) which is the minimum of safe speed. speed affected by acceleration (a) and maximum speed (v_{max}). Equation (2) shows the desire speed [5].

$$v_{des} = min\left[v_{max},\ v + at, v_{safe}\right] \tag{2}$$

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Table 1. Car following parameters for RVs, AVs and CAVs.

	Vehicle type		
Car following parameter	RVs	AVs	CAVs
Acceleration	3.5	3.8	3.9
Deceleration	4.5	4.5	4.5
Emergency Deceleration	8	8	8
Driver imperfection	0.5	0	0
Minimum headway	0.9	0.6	0.5
Minimum space gap	1.5	0.5	0.5

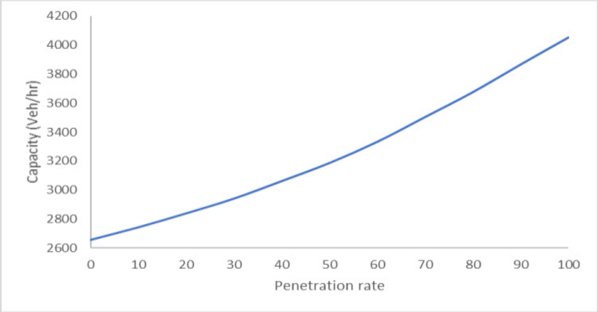

Fig. 1. Impact of AVs on the capacity of merge section

CAVs and AVs, because of automation and connectivity, benefit from better driving behavior than Regular vehicles (RVs) Table. Thus, the parameters of car following of RVs, AVs and CAVs are different. Table 1 shows the car following model parameters of RVs, AVs and CAVs. all car following parameters of AVs and RVs are taken from [4]. For CAVs, Acceleration, Deceleration, Minimum headway and minimum space gap are taken from [3] and the driver imperfection parameter is taken from [6]. To comply with safety regulations Deceleration, Emergency Deceleration are equal for all vehicle types [4].

To show the lateral behavior of CAVs, AV and RVs, we used the default lane-changing model in SUMO called LC2013. This model defines the lateral behavior of vehicles and in this study, one parameter of the lane-changing model is modified. To determine the lane-changing parameters, TransAID carried out a study [8], which is based on different simulations and sensitivity analyses. They realized that the most important parameter that has a great impact on lane change behavior is the lcAssertive parameter that low values of lcAssertive mean a greater tendency to accept the gap reduction. The value of this parameter is 1.3 for RVs, 0.9 for AVs and according to the study [7], the value of this parameter is 0.7 for CAVs.

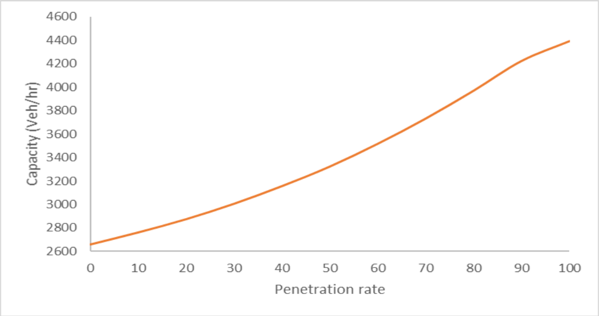

Fig. 2. Impact of AVs on the capacity of merge section

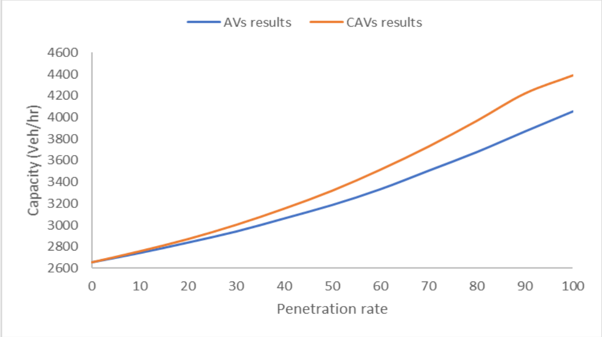

Fig. 3. Impact of AVs on the capacity of merge section

3- Results and Discussion

The network in these simulations is the freeway network with the Merge section of 1.95 km. This freeway is four lanes with a maximum speed of 100 km/h. The penetration rate (PR) of AVs and CAVs is considered at 10%, and a total of 22 simulations are considered to achieve the results. According to Figure 1, which shows the effects of AVs on merge section network capacity, it can be seen that AVs have the potential to increase freeway network capacity by 52.5% and increase its capacity from 2657 vehicles per hour per lane to 4054 vehicle per hour per lane, which shows that AVs can be a good answer to the problem of congestion. To show the effect of CAVs on capacity of merge section, Figure 2 shows the changes in road capacity due to the presence of CAVs. The results show that CAVs can increase the capacity of freeways up to 65.37% and this change in capacity shows that CAVs can increase the capacity of roads to a desirable level due to CAVs characteristics. Figure 3 shows a comparison between CAVs and AVs results, which clearly results show that these two types of vehicles have the potential and ability to reduce the congestion problem. On the other hand, this figure shows that CAVs increase the capacity of the freeway even more than AVs due to the connection feature between vehicles, which shows the importance of connecting between vehicles.

4- Conclusion

This study investigates the impact of AVs and CAVs on the capacity of a merge section. The simulations of this study are implemented in SUMO simulator software. The simulations are based on car following model and the lane change model. In this study, the Krauss car following model and the LC2013 lane change model have been used to implement the behavior of RVs, CAVs and AVs in a simulation environment.

The results showed that AVs can increase the capacity of the merge section to 52.50 percent, which is a significant increase when the penetration rate of these vehicles on the road is over 50 percent. The results also show that CAVs can increase the capacity of the merge section by 65.37%, which is even more than the impact of AVs because CAVs benefit from the connection feature. In general, the results show that AVs and CAVs have a high potential to reduce congestion and increase capacity and can be effective in improving traffic conditions.

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