MASTER'S THESIS

The effects of vehicle automation on network capacities: A microscopic simulation approach

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INTRODUCTION

Traffic congestion is a typical phenomenon in the urban environment. The traffic complexity and the constantly increasing demand created by the urbanization trend are the main factors causing it. Congestions lead to delays, huge economic losses, negative environmental effects, and other impacts.

Munich is the most congested city in Germany and the 51st most congested city in the world, where drivers lose 87 hours in traffic annually. Additionally, the cost of congestion was estimated to be more than €405 million. On a national level, the total cost of congestion for Germany was €2.8 billion (INRIX, 2020).

2019 CONGESTION RANK (2018)	URBAN AREA	HOURS LOST IN CONGESTION	2018-2019 CHANGE	2017-2018 CHANGE	INCIDENT IMPACT	COST OF PER DRIVER	COST PER CITY	LAST MILE SPEED (MPH)
1 (1)	München	87	-1%	-4%		€ 774	€405M	11
2 (2)	Berlin	66	0%	-6%		€ 587	€792M	13
3 (4)	Dusseldorf	50	11%	-2%		€ 445	€98M	17
4 (3)	Hamburg	48	-10%	0%		€ 427	€280M	16
5 (4)	Stuttgart	42	-7%	-5%		€ 374	€85M	18

INRIX Top 5 Most Congested Cities in Germany (INRIX, 2020)

Congestion happens when the traffic demand exceeds the system supply, which is determined by the network capacity. However, its increase by constantly building new roads and infrastructure is very expensive. The network capacity can also be improved with more efficient usage of the existing network, where technologies can play a crucial role. Autonomous vehicles (AVs) and telematics solutions are considered to start this new evolution of mobility.

PROBLEM STATEMENT AND GOALS OF THE STUDY

The development of autonomous vehicles might have a significant effect on traffic in urban conditions. However, it is still unclear if the integration of full autonomy will lead to more congestion or will reduce it. Different studies have shown the positive and negative impacts of AVs depending on their penetration rate. Addressing this problem will have huge benefits in the development of different traffic management strategies and solving congestion problems.

This thesis investigates the effects of vehicle automation on network capacities in urban conditions.The main goals of this research are:

1. Analyze the effects of different penetration rates of AVs on network performance.
2. Investigate the impact of dedicated AV lanes on network capacities.

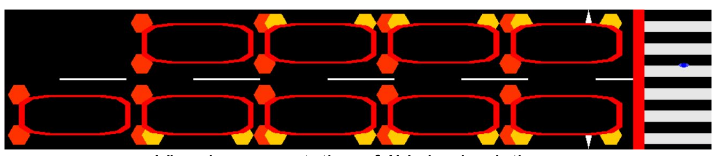
METHODOLOGY

From the network perspective, capacities were described by the Macroscopic Fundamental Diagram (MFD), showing the relationship of vehicle accumulation to network production. A typical grid urban network resembling the Maxvorstadt area of Munich was created. The traffic demand for the off-peak and peak hour was generated.

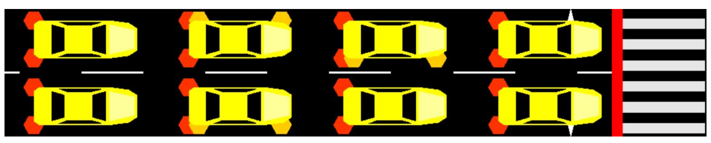
Five scenarios, where the AVs penetration rates varied from 0% to 100% with a 25%-step, were simulated in SUMO traffic simulation software. Different parameters of the car-following model were used for regular cars and AVs.

Levels of automation	Mingap (m)	Acceleration (m/s^2)	Deceleration (m/s^2)	Emergency deceleration (m/s^2)	Sigma (driver imperfection)	Tau (Time headway) (s)
No automation	2.5	2.9	4.5	8	0.5	1
Full automation	0.5	3.8	4.5	8	0	0.6

Vehicle parameters used in SUMO simulations (Lopez et al., 2018; Atkins Ltd, 2016; Kudarauskas, 2007)



Visual representation of AVs in simulations

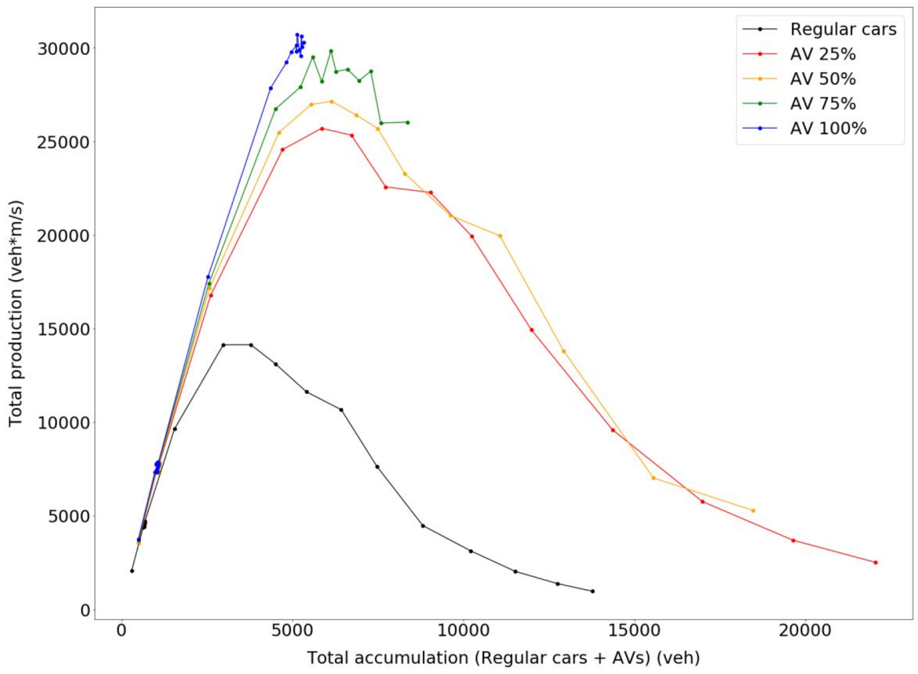


Visual representation of regular cars in simulations

Additionally, the same scenarios with an additional AV-lane as one of the traffic management strategies were simulated. The simulation results were obtained from the SUMO's floating car data (FCD) and built-in average speed data from SumoGui. The FCD was evaluated in the Spyder integrated development environment in the Python language. The results were compared to understand the difference in network capacities for different penetration rates of AVs and dedicated AV lanes.

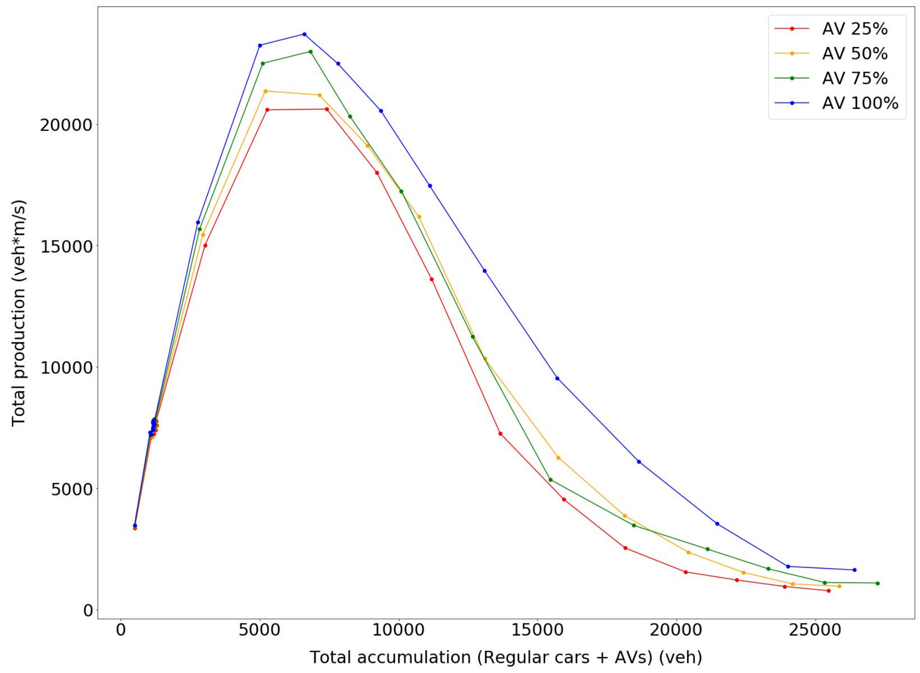
RESULTS

The obtained results showed that the maximum network production significantly increases with a higher penetration rate of AVs. The 81.71%-increase in capacity was achieved with only 25% of AVs in the total traffic flow. The peak-hour congestion was fully solved with a 75%-penetration rate. The scenario with 100% of AVs operates at the production rate which is 117.13% higher than the base scenario. Based on the production trend of the last scenario, the simulated traffic demand did not allow AVs to reach the maximum capacity as the final drop of values was not observed. Therefore, fully autonomous vehicles can meet even higher traffic demand without any congestion.



2D-MFD graphs for five scenarios without dedicated AV lanes

The results for scenarios with dedicated AV lanes were worse than the results for scenarios without them, showing a 20% drop in the maximum vehicle production for all penetration rates. The comparison between scenarios with dedicated AV lanes did not display a substantial increase in network performance with the integration of higher percentages of AVs.



2D-MFD graphs for four scenarios with dedicated AV lanes

CONCLUSIONS AND RECOMMENDATIONS

The given study shows the positive effect of autonomous vehicles on network capacities. Based on the MFD data, the maximum vehicle production increases with a higher penetration rate of AVs.

The results for the scenarios with dedicated AV lanes were expected to be better than the results for the scenarios without them. However, they showed a negative impact. The reason for that was the conflicts for the left turn from a dedicated AV lane with other users, creating congestion inside intersections. Therefore, the implementation of dedicated AV lanes alone was not useful. A separate traffic signal phase for AV lanes must be added. The standard NetEdit tools do not allow this solution. Therefore, future research should analyze the effect of AVs with dedicated AV lanes and a separate traffic signal phase. This could be achieved with the help of TraCI (Traffic Control Interface), an additional SUMO tool, which was not included in the scope of this research. In addition, the impact of AVs should be further investigated in a real-world network with the actual demand data of Munich.

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