On The Relative Impact Of Autonomous Vehicle Penetration In Intelligent Transportation Systems

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*Abstract*—This is an abstract, it should contain a summary. Define AV and ITS acronyms her

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# Introduction

The transportation sector has undergone rapid transitions over the past decade, driven largely by the development of Intelligent Transportation Systems (ITS). ITS leverage data analytics, communication technology, and traffic management technologies to optimize the efficiency, safety, and efficacy of transportation infrastructure. With the emergence of technologies like 5G and advanced cloud computing, ITS continue to evolve to more drastically transform how transportation systems are designed and operated. Demand for further implementation and optimization of these systems only grows as cities around the world face challenges related to congestion and sustainability [SOURCE].

The emergence of autonomous vehicles (AVs) presents both significant opportunity and challenge to existing transportation systems. The adoption of AV technology stands to revolutionize the relationship between society and transportation, generally improving the safety and efficiency of transportation networks. However, the introduction of autonomous vehicles to existing transportation networks raises complex questions about the potential impact of this exceedingly new technology. One such question is the relative impact of AVs on congestion, especially in dense urban settings.

Discussion around the integration of AVs to traffic systems includes the question of ITS might moderate the relative impact of the transition. ITS can theoretically leverage introduction of connected, precise vehicles to a traffic system to improve the overall efficiency of a traffic system beyond the threshold achievable for normal cars/drivers. Therefore, understanding the extent to which ITS can enhance the impact of AV integration can aid in maximizing the potential for both technologies to improve urban mobility.

This project seeks to understand the relative impact of AV penetration rates on congestion and the potential moderation of this impact by ITS. This will be studied by simulating an urban traffic environment with varying AV penetration rates with both normal and ‘smart’ traffic systems. The data derived from these simulations will inform further research and development around these emerging technologies.

# Related Work

## Impact on Human Drivers

There exists extensive literature on the potential for autonomous vehicles to impact the traffic system as a whole even at low penetration rates. A 2018 article from the International Conference on Robotics and Automation, “Stabilizing Traffic with Autonomous Vehicles”, by Wu et al. [SOURCE -WU] models this impact mathematically across varying AV penetration rates. The article concludes that a penetration rate as low as 6% can significantly stabilize traffic and reduce congestion. This effect is explained as the relative impact of more precise and controlled autonomous vehicles in limiting the behavior of human drivers sharing the road.

The premise that autonomous vehicles can directly impact the behavior of human drivers was further specified and corroborated by a 2022 study on the impact of autonomous vehicles on the car-following behavior of human drivers [SOURCE- ZHANG]. By analysing real and simulated datasets of mixed vehicle interactions, Zhang et al. conclude that the platoon behaviour of autonomous vehicles affect the car-following behaviour to a statistically significant degree.

## ITS Moderation

A 2023 study by Andreotti et al. attempts to study the impact of autonomous vehicles on a traffic system and the relative moderating factor of ITS [SOURCE – ANDREOTTI]. The study was conducted using real traffic data in the Simulation of Urban Mobility (SUMO) simulation tool. The relative challenges faced in this investigation highlight the importance of context-appropriate definitions of ITS and AV behavior in building accurate simulations.

# Environment

The project will simulate a traffic system with varying levels of autonomous vehicle penetration, moderating for the implementation of ITS. The simulation will be run using the SUMO simulation tool [SOURCE - SUMO]. The scope of the simulation will be limited to a busy two-lane road, with three four-way intersections with single lane roads running perpendicular to the main road. Traffic lights will control all three identical junctions.

The scope will also be limited to two classes of car, autonomous and normal. The autonomous vehicle will be defined in SUMO as having a lower *sigma* and higher *tau* value than the normal vehicle. These respectively imply a higher driver accuracy and an increased desired headway for autonomous vehicles. Autonomous vehicles will also be defined with specific lane-changing parameters to reflect the distinctive approach of autonomous vehicles to lane-changing.

The moderation of ITS will be simulated by an intelligent queue-based traffic light algorithm juxtaposed with a static, time-based algorithm.

# Hypotheses

This project aims to address the following research questions on the relative impact of autonomous vehicles on a traffic system and the moderating effect of ITS.

RQ1: How do higher penetration rates of autonomous vehicles impact congestion in a traffic system?

RQ2: To what extent do Intelligent Transportation Systems moderate the impact measured in RQ1?

# Implementation

## Route Generation

Two classes of vehicles were defined in the route document. The standard vehicle was defined as follows:

<vType id="normal" accel="2.6" decel="4.5" sigma="0.7" tau=”1.2” length="5" maxSpeed="33.33" guiShape="passenger"/>

The autonomous vehicle definition was derived from the normal vehicle, but with the notable changes to *sigma*, *tau,*and the lane-changing parameters.

<vType id="autonomous" accel="2.6" decel="4.5" sigma="0.0" length="5" maxSpeed="33.33" guiShape="passenger" color="0,255,0" lcStrategic="5.0" lcCooperative="5.0" lcSpeedGain="5.0" lcKeepRight="1.0" />

Routes were randomly generated by a python script based on the possible arrival and departure edges, with greater weight given to routes on the main road. The departure time for routes was incremented by a random value between 1 and 3 inclusive. The class of vehicle was then randomly assigned based on the relative desired penetration rate as specified by the simulation. Each simulation contained 1000 routes.

Once the start and end of each route was defined, the specific route of each car was enumerated by SUMO’s duarouter tool. This tool used the network structure to exhaustively list the order of edges necessary for a vehicle to travel to complete its route. These routes could then be used to run a simulation in SUMO.

## Traffic Light Control

The traffic light control algorithms were developed in python using SUMO’s native Traffic Control Interface (TraCI) library. TraCI provides methods and hooks for python scripts to observe and control SUMO simulations in real time. In this implementation each simulation was initialized from a python script using TraCI and then stepped through while evaluating and controlling each junction with custom traffic light algorithms.

The ITS traffic light algorithm functions by periodically evaluating the queue lengths at the intersection using TraCI. Based on the relative queue lengths of the main and side roads, the algorithm then triggers a traffic cycle that favors whichever is more congested. In contrast, the static algorithm simply steps through a series of states at defined intervals.

## Output

Each simulation output all trip data into an xml file. These data were then aggregated using the pandas library in python to extract the average throughput per minute and the average waiting time in seconds. These values were stored with simulation parameters to be compared against other runs.

# Examples

Six runs were conducted across each simulation type, with AV penetration rates increasing incrementally by 20% from 0 to 100%. The throughput per minute and average waiting time for each simulation was calculated and recorded in Table 1.

1. Simulation Results

| run | % AV | control\_type | throughput | waiting time |
| --- | --- | --- | --- | --- |
| 0 | 0 | basic | 29.64 | 110.89 |
| 1 | 0.2 | basic | 32.17 | 105.60 |
| 2 | 0.4 | basic | 32.15 | 106.33 |
| 3 | 0.6 | basic | 32.72 | 106.15 |
| 4 | 0.8 | basic | 35.95 | 101.48 |
| 5 | 1 | basic | 39.19 | 101.58 |
| 6 | 0 | intelligent | 43.17 | 115.19 |
| 7 | 0.2 | intelligent | 40.08 | 126.47 |
| 8 | 0.4 | intelligent | 39.71 | 109.19 |
| 9 | 0.6 | intelligent | 44.51 | 102.56 |
| 10 | 0.8 | intelligent | 47.47 | 97.29 |
| 11 | 1 | intelligent | 47.36 | 91.71 |

A higher throughput in this context means that more vehicles are completing their routes through the simulation per minute. A lower average waiting time indicates that vehicles are spending less time waiting at red lights.

A graph with blue and orange lines

Description automatically generated

Figure 1: Average Waiting Time vs AV Weight

The graph in Figure 1 shows the average waiting time decreasing across the board as autonomous vehicle penetration. It also indicates that the average waiting time decreases faster in the ITS simulations (Orange line) than in the normal simulations (Blue line).

A graph with blue and orange lines

Description automatically generated

Figure 2: Throughput Per Minute vs AV Weight

The graph in Figure 2 illustrates an increase in throughput penetration rate as the AV penetration rate increases. However the rate of this increase appears uniform across simulation types, with no visible moderation for ITS simulations.

These results provide a preliminary answer to RQ1, implying a general decrease in congestion within a traffic system as a direct impact of increasing the percentage of autonomous vehicles in the system. They also address RQ­2, implying a minimal yet present moderation of this impact by the implementation of ITS.

However, limitations in the quantity of executed simulations mean that no statistically significant conclusions can be drawn from the simulations. All conclusions discussed are simply observations of general trends in the visualized output data. To further investigate these conclusions, more simulations would need to be run across each penetration rate and each simulation type.

# Conclusion

Conclusion goes here, kind of a what did we learn deal.

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##### References

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