Exploiting Autonomous Vehicles In Improving The Driving Experience in Mixed Environments

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ABSTRACT

It is a matter of time before our roads witness a mixed driving environment, where both conventional human-driven vehicles and autonomous vehicles interact with each other and respond to traffic dynamics. This report proposes the context of a capstone project that aims not only to investigate cooperative behavior in mixed environments and model it in a simulation-based framework with the consideration of different scenarios and real-world data but also to exploit autonomous vehicles in reporting such cases according to the model. The outcome of the proposed capstone project would answer important research questions contributing to a more convenient driving environment before our roads get fully automated. Our goal is to find ways of contributing to safer and well-structured traffic dynamics while investigating the communication and interaction between vehicles with different levels of automation. Lastly, the paper provides an insight into the future work and additional improvement of the model allowing the further investigation of this research topic.

KEYWORDS

Autonomous Vehicles, AV, Aggressive Driving, Cooperative Driver Model, Traffic Simulation, PTV Vissim, Driver Behavior, DLL, Road Management, Traffic Monitoring

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1 INTRODUCTION

To avoid collisions and fatalities, research on traffic safety has emphasized the significance of monitoring and intervening in aggressive driving. Aggressive driving is difficult to define due to a variety of examples like speeding, not giving way, 'zigzagging', illegal turns and unsafe overtaking but having a clear definition is crucial for safety monitoring and legal actions. The National Highway Traffic Safety Administration (NHTSA) referred to aggressive driving as "driving a motor vehicle endangering or likely to endanger persons or property" [1]. Nonetheless, a Global Web Conference on Aggressive Driving Issues organized in Canada in October 2000 offered the following definition "A driving behavior is aggressive if it is deliberate, likely to increase the risk of collision and is motivated by impatience, annoyance, hostility and/or an attempt to save time." [2]

The goal of the ongoing development of automotive technology is to increase safety benefits and provide automated driving systems that would adequately replace a human driver when we are either not able to do it or not willing to drive on our own. Figure 1 shows six different levels of automation provided by NHTSA. Such vehicles could also contribute to smooth traffic flow and reduce traffic congestion which is considered to be one of the main contributing factors to aggressive driving. [3]

This project investigates what is the percentage of AVs required to report cooperative driving behavior in a mixed driving environment.

2 RELATED WORK

Autonomous vehicles and automation have been an interesting research topic ever since the 1990s. Partially autonomous vehicles can already be found in the market, due to the advancements in computer and sensor engineering, with fully automated ones to follow. Lu, Qiong et al. in their study from 2019 emphasize the impact of autonomous vehicles on urban traffic network capacity after an experimental analysis by microscopic traffic simulation. [5] The research showed that autonomous vehicles have significant potential to improve

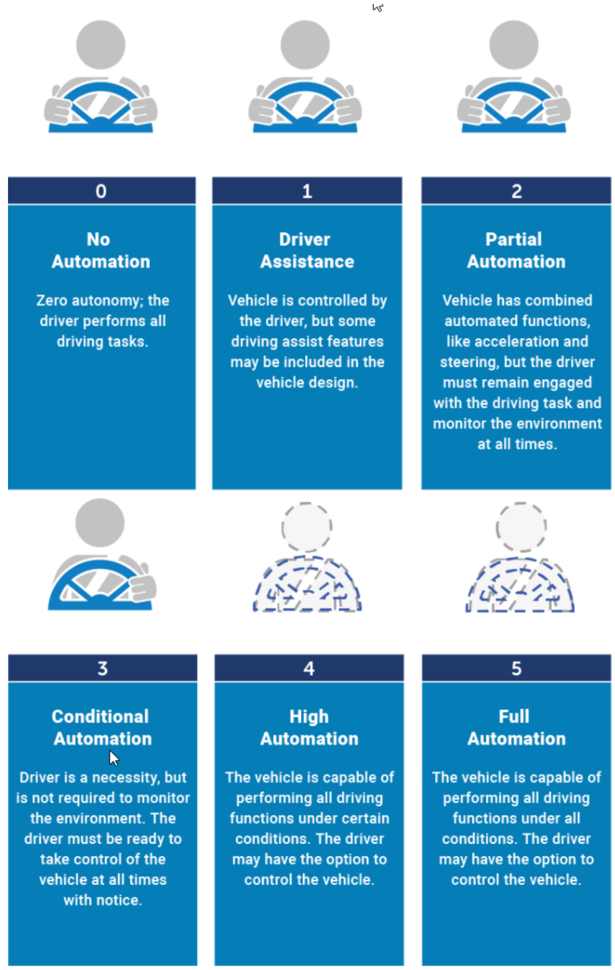

Figure 1: Levels of Vehicle Automation
[4]

traffic capacity, efficiency, stability, and safety of existing mobility systems. This is exactly what we attempted to address by running simulations.

2.1 Driver Behavior

Meiring et al. used plenty of statistical reports to present drivers' behaviors that seem to be a serious threat to road safety. [6] Here arises the modeling issue; how to realistically simulate the perception of AV and the way they respond to obstacles and the behavior of human drivers. In reality, the precautions AVs take to ensure the driver's safety include radar sensors, monitoring the position of nearby vehicles, video cameras to track traffic lights as well as road signs. [1]

2.2 Autonomous Vehicles (AV)

Many robotic systems are based on a three-phase architecture known as "sense-plan-act", also commonly used by autonomous vehicles. The main goal is to have such vehicles perceive a complex and dynamic driving environment. Bagloee et al. published a study in 2016 where they investigated the challenges and opportunities pertaining to transportation policies that may arise as a result of emerging AV technologies. One of the results showed that sharing road space with non-AVs could be quite challenging since human drivers tend to maintain their selfish, non-cooperative behavior. [7] On the other hand, a navigation plan for AVs can be programmed and modified, resulting in those vehicles behaving cooperatively. The issue might arise when we face mixed traffic pattern consisting of both cooperative and non-cooperative cases.

2.3 PTV Vissim

The objectives of the "Computer Simulation Modeling of Driver Behavior at Roundabouts" project by Clara Fang and Hernan Castaneda are to identify PTV Vissim input variables most critical to accurate modeling and provide recommendations for roundabout traffic modeling. [8] Data was collected from cameras capturing vehicle circulating activity. A simulation was built to compare both queue length and travel time predicted with the data collected. The critical gap was shown to be the most effective calibration variable in roundabout simulation. [8] Although we might not be investigating roundabouts, the research investigated a variety of simulation parameters in Vissim as calibration factors for describing driver behaviors and concluded that such simulation is a good representation of real-world situations. However, in case we decide to consider different road layouts, this research might come in handy.

A conference paper on "Sensitivity analysis of Vissim driver behavior parameters on the safety of simulated vehicles and their interaction with operations of simulated traffic" presented sensitivity analysis of twenty-one Vissim driver behavior parameters and lane-changing models on the safety of simulated vehicles along with an insight on their impact in operations of the simulated traffic, providing quantitative evaluation. [9] The results showed that the most important free lane-changing parameters of Vissim are the minimum front-rear headway (the minimum distance to the vehicle in front that must be available for a lane change in standstill condition and is 0.5 m by default), safety distance reduction factor (a multiplicative factor for cutting down the original safety distance during lane change, 0.60 by default), and the maximum deceleration for cooperative breaking that controls cooperative deceleration of a trailing vehicle to allow a leading vehicle change a lane. [9] The smaller the value of this parameter, the more aggressive vehicles appear to be.

Nevertheless, research by Farrag et al. provides an analysis based on a micro-simulation for driving behavior modeling on a congested expressway in the Sultanate of Oman while describing the necessary procedure for the calibration and validation of a microscopic model using the Vissim software. [10] This paper outlined a complete methodology for constructing, calibrating and validating a simulation model in Vissim.

PTV Vissim provides two Wiedemann car-following models for different application conditions, including the Wiedemann 74 model that can be used for urban traffic and merging areas and Wiedemann 99 commonly used for modeling freeways. [11] Autonomous modeling is possible by using the Wiedemann 99 using nine parameters shown in Figure 2 that assist the users in conducting sensitivity tests and also for trial and error of multiple parametric combinations. [11]

CC0	Standstill distance
CC1	Headway time
CC2	'Following' variation
CC3	Threshold for entering 'following'
CC4	Negative 'following' threshold
CC5	Positive 'following' threshold
CC6	Speed dependency of oscillation
CC7	Oscillation acceleration
CC8	Standstill acceleration
CC9	Acceleration at 50 mph

Figure 2: Parameters of Wiedemann 99
[11]

The CoEXist is a funded project by European Commission that prepares the concerned authorities for a transition phase during which both the AVs and conventional vehicles will coexist on the roadways. [12] The basic effort for this project is to bridge a gap between emerging AV technology, transport planning, infrastructure development, and enabling city authorities to effectively deploy AVs using the best practices. Since PTV Vissim is used in this project for modeling AVs, it is useful to consider two parameters that the project suggest AVs should have [12]:

- **Cooperative lane-change** that facilitates the process of a lane change in such a way that the trailing vehicle in the target lane would move to another side of a lane and providing room for lane change-vehicle, and
- **Advanced merging** where a lane-changing vehicle would initiate the process earlier so that no disruption of the traffic occurs and therefore the capacity of the network increases

Basic cooperation features are implemented in PTV Vissim already. However, taking into account that these have been introduced to replicate how humans cooperate, cooperation beyond that scope needs to be reflected another way. It is expected that automated vehicles will behave deterministically instead of stochastically like human drivers. This might have implications on the acceleration and deceleration behaviours. [13] Based on this assumption, we can reduce the spread of values for individual vehicles for desired acceleration/deceleration as well as their maximum values.

3 METHODOLOGY

This research study refers to running computer simulations of realistic traffic flows as its main methodology, precisely the PTV Vissim simulator. PTV Vissim is a microscopic multimodal traffic flow simulation tool that provides a virtual testing environment for the evaluation of autonomous and human-driven vehicles. [14] The microscopic modeling approach provides an accurate description of the traffic dynamics, allowing detailed analysis.

The main objectives of this project are:

- **Modeling cooperative driving behavior according to the road layout**, and
- **Modeling AV monitoring according to the surrounding environment**

3.1 Modeling Cooperative Driver Behavior

Figure 3 shows a simple road layout of a 988m long freeway with two lanes, the main/top lane and the merge/bottom lane. About halfway through the freeway, after merging area, the road reduces to one lane.

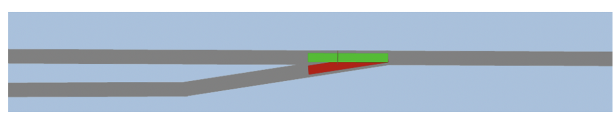

Figure 3: Road layout

Having this layout in mind, we attempted to define three types of vehicles:

- **Autonomous Vehicles (AVs)** according to existing definition of fully automated vehicles in PTV Vissim,
- **Conventional Cooperative Cars (CCs)** that start decelerating when they recognize a vehicle trying to merge, and
- **Conventional Normal Cars (CNs)** that are human-driven non-cooperative and non-aggressive vehicles.

To achieve this, we believe that the above definitions require resetting speed and acceleration while the simulation is running. This manipulation of Vissim objects cannot be directly done during a simulation, thus an additional interface that allows inter-process communication between software is needed. The external Driver Model DLL interface in PTV Vissim provides the option to replace the internal driving behavior by a fully user-defined behavior for some or all vehicles in a simulation run. [13] It allows users to replace various vehicle-related information such as velocity, acceleration, location, lane-changing signal, and intersection signals. The user-defined algorithm must be implemented in a DLL written in C/C++ which contains specific functions. The entire code is placed in MoveDriver command. Before Vissim requests execution of one of the available commands (Init, CreateDriver, MoveDriver, KillDriver) there are always several calls of the DLL function DriverModelSetValue, one for each data item that might be used by the DLL when executing the command. After the command MoveDriver has finished computation, the resulting state of the vehicle is fetched from the Driver Model in a similar manner again by several calls of DriverModelGetValue. During a simulation run, Vissim calls the Driver Model code for each affected vehicle in each simulation time step to determine the behaviour of that vehicle. Vissim passes the current state of the vehicle and its surroundings to the Driver Model that computes the acceleration or deceleration of the vehicle and the lateral behaviour, mainly for lane changes. Later on, DLL passes the updated state of the vehicle back to Vissim.

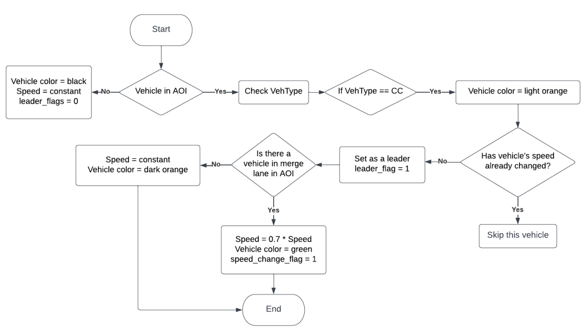

Figure 4: Cooperative driver model algorithm

The flowchart shown in Figure 4 displays our cooperative driver model algorithm. It starts by checking if the vehicle following this external model is in our Area of Interest (AoI) and if it's not, the vehicle color is set to be black and the desired speed stays unmodified. However, in case a vehicle is in AoI, we proceed to check its type and, if it's a CC, we change it's color to light orange. This is followed by checking if the vehicle has already decelerated to cooperate. We want to prevent the model to keep continuously altering the speed of the vehicle and when this happens once, the car's flag, a Boolean variable indicating the change, becomes 1. If the

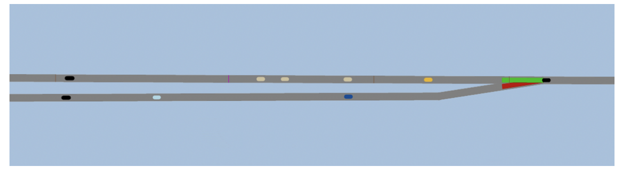

Figure 5: Network setup - AoI

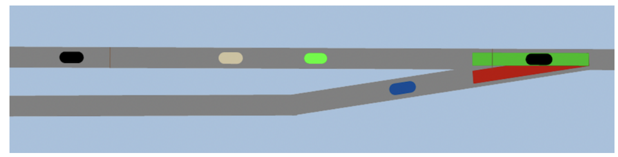

Figure 6: Cooperative vehicle in action

vehicle already cooperated, then we just move on to another, otherwise we change its color to dark orange. the next step is to check if there is a vehicle in the merge lane in the AoI trying to merge. If not, our CC's speed is not altered, it does not decelerate and does not behave cooperatively since there is no reason for such an action. On the other hand, if there is a vehicle trying to merge, it decelerates to assist merging process and indicates this by changing its color to green. Once the vehicle leaves the AoI, the cooperation process has finished and we go back to the loop, setting the vehicle color to be black again. Figures 5 and 6 help in understanding this process better.

3.2 Modeling AV monitoring

The Vissim COM interface allows manipulation of functions and parameters of the simulator provided by the GUI through code and programming. [15] We used COM interface to count the amount of total cooperative cases happening in a simulation run as well as the amount of reported cooperative cases by autonomous vehicles. This allowed us to calculate the percentage of reported cases by AVs.

In reality, various sensing possibilities allow AVs to observe the area in more than one direction. However, in this simplified model, we consider them to observe only their lane and vehicles in the front. The way we monitor cooperation is shown in Figure 7. If there is a vehicle V1 approaching merging area, we check if there is another vehicle on the main lane within AoI and check its type. If it's our CC, we can count this as a cooperation case. Only in this case we proceed to check if there are any vehicles behind the CC and if there's an AV, we check if the CC is within the sensing range and then count the amount of vehicles between them. We assume that the cooperation case can only be reported when there is zero, one or two vehicles between the AV and CC. When all these conditions are satisfied, we can count

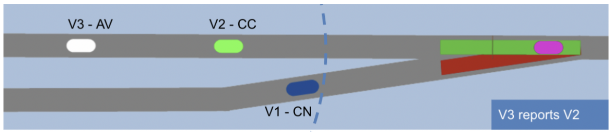

Figure 7: AV successfully reports cooperation

this as a reported cooperative case, similar to what is shown by Figure 7.

4 EVALUATION

To begin with, Figure 8 displays the simulation settings.The length of the road is almost one kilometer (988m). Maximum speed of the vehicles is 80km/hr and we monitor the simulation for 25 minutes. The sensing range of AVs is set to 100m as well as the distance from the intersection point, referred to as AoI.

Setting	Value
Road layout	988m long highway
Maximum Speed	80km/h
Simulation duration	26 min
Monitoring duration	25 min
Number of runs	5
AV sensing range	100m
Area of Interest (AOI)	100m

Figure 8: Simulation setup

Additionally, Figure 9 shows our vehicle composition. In the top/main lane, the volume of vehicles is 1800veh/hr and all three vehicle types (CC, AV, SN) are present in different percentages depending on a scenario. On the other hand, bottom/merge lane consists of only human-driven conventional vehicles (CN) for now and the volume is 600veh/hr.

Position	Vehicle types	Volume
Top/Main lane	CC + CN + AV	1800 veh/hr
Bottom/Merge lane	CN	600 veh/hr

Figure 9: Vehicle composition

While testing the autonomous vehicles, different penetration rates are often of interest. In our scenarios, as previously mentioned, only CNs are present in the merge lane making 100% of the lane's traffic, while in the main lane we change the percentage of all three vehicle types. Figure 10 presents all the scenarios we considered. Finally, by counting the cooperative cases and those reported by AVs, we are able to get

		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
L1 - merge	CNs	100%	100%	100%	100%	100%	100%
L2 - main	CNs	45%	40%	30%	20%	10%	0%
	CCs	50%	50%	50%	50%	50%	50%
	AVs	5%	10%	20%	30%	40%	50%
L1 - merge	CNs	100%	100%	100%	100%	100%	100%
L2 - main	CNs	55%	50%	40%	30%	20%	10%
	CCs	40%	40%	40%	40%	40%	40%
	AVs	5%	10%	20%	30%	40%	50%
L1 - merge	CNs	100%	100%	100%	100%	100%	100%
L2 - main	CNs	65%	60%	50%	40%	30%	20%
	CCs	30%	30%	30%	30%	30%	30%
	AVs	5%	10%	20%	30%	40%	50%
L1 - merge	CNs	100%	100%	100%	100%	100%	100%
L2 - main	CNs	75%	70%	60%	50%	40%	30%
	CCs	20%	20%	20%	20%	20%	20%
	AVs	5%	10%	20%	30%	40%	50%

Figure 10: Simulation scenarios

the results for a case when AVs can report cooperation only if there is a maximum of 1 vehicle between them and that CC, and when there is a maximum of 2 vehicles in between.

The results are shown below.

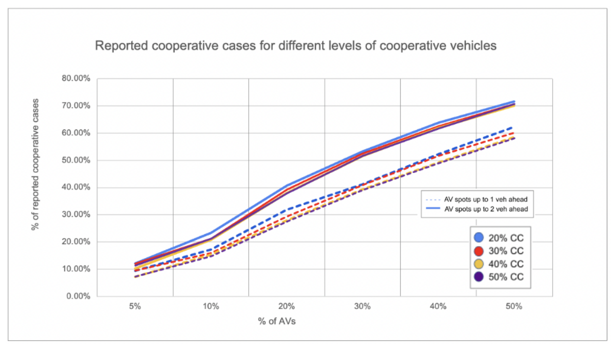

Figure 11: Reported cooperative cases for different levels of AVs

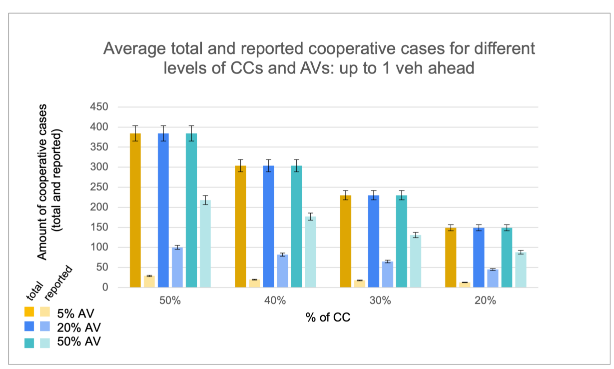

Figure 12: Average total and reported cooperative cases: AV sensing up to 1 vehicle ahead

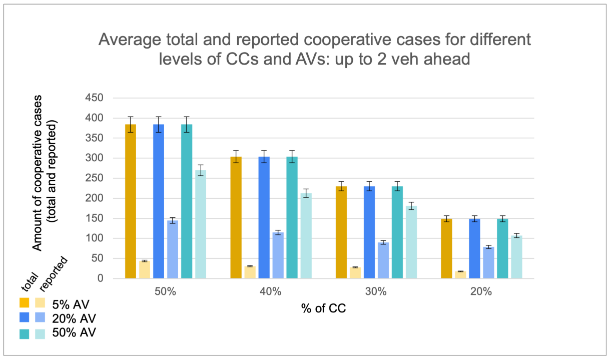

Figure 13: Average total and reported cooperative cases: AV sensing up to 2 vehicles ahead

Figure 11 shows that the relationship between amount of AVs and amount of reported cooperative cases is linear. Having less percentage of CCs seem to help AVs in reporting more cooperative cases. When monitoring up to 2 vehicles ahead, with 50% of AVs we can report more than 70% of cooperative cases and with only 10% of AVs, we can report around 20% of cases. Figures 12 and 13 display both average total and reported amount of cooperative cases for different levels of CCs and AVs when AVs can sense up to 1 and up to 2 vehicles in between. We see that with an increase in AVs we are able to report more cooperative cases and this number is bigger for the case AVs can see up to 2 vehicles in between. However, we expect less percentage of AVs to be required for reporting high percentage of cooperation in a city layout. This is because in reality AVs would be able to monitor the vehicles in multiple directions, more lanes and intersection areas. Nevertheless, our results show that more complicated modeling is beneficial for more realistic AV monitoring. Further evaluation is needed to show the impact of more cooperative cases. Higher levels of cooperation under high congestion conditions might only worsen the overall congestion level.

Besides focusing on modeling and evaluation in a city-scale scenario, another interesting idea for the future work would be to keep track of the amount of cooperative cases and discuss the ways to possibly reward such drivers. We have already completed the first step of this, designing a more complex road layout of a downtown Athens, Greece, shown in Figure 15. The idea is to consider each road layout, test driver models and make improvements. The reason of choosing this area is the open large-scale dataset that we can access, pNEUMA. It is a dataset of naturalistic trajectories of half a million vehicles that have been collected by a one-of-a-kind experiment by a swarm of drones in the congested downtown area of Athens, Greece. [16] It offers a unique observatory of traffic congestion which we decided to use for

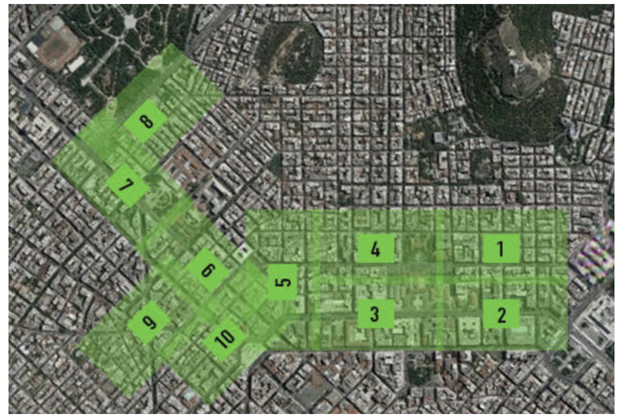

Figure 14: pNEUMA data collection area
[16]

developing and testing our models. The data was collected using 10 drones hovering over the central business district of Athens over five days to record traffic streams in a congested area of a 1.3km2 area with more than 100 km-lanes of road network, around 100 busy intersections (signalized or not) as shown in Figure 14. [16]

To have a better understanding of junctions and edges for network modeling, we used OpenStreetMap data to export the map in xml format. Xml is accepted by a microscopic and continuous traffic simulation package designed to handle large networks, SUMO (Simulation of Urban Mobility), precisely, Netedit that enabled us to check the parameters and fix the road layout. The future work consists of using this dataset to set the traffic demand, origin, destination and distribution at each intersection. Then, ways of improving the cooperative driving model according to different road layouts should be considered and followed by the evaluation of the new model in a city-scale scenario.

5 CONCLUSION

We are close to experiencing mixed driving environments across the world, where both conventional human-driven vehicles and AVs interact with each other and respond to traffic dynamics. AVs provide a great potential to safer roads. If we exploit their technology creatively and effectively, we could greatly improve the efficiency of our roads.

The aim of this project is to investigate cooperative behavior in mixed driving environments, model it in a simulation-based framework while considering a variety of scenarios and exploiting AVs in reporting such cases. This would allow us to create a system where cooperative drivers could be rewarded and thus enforced to maintain or start cooperative behavior. I expect this project to answer important research

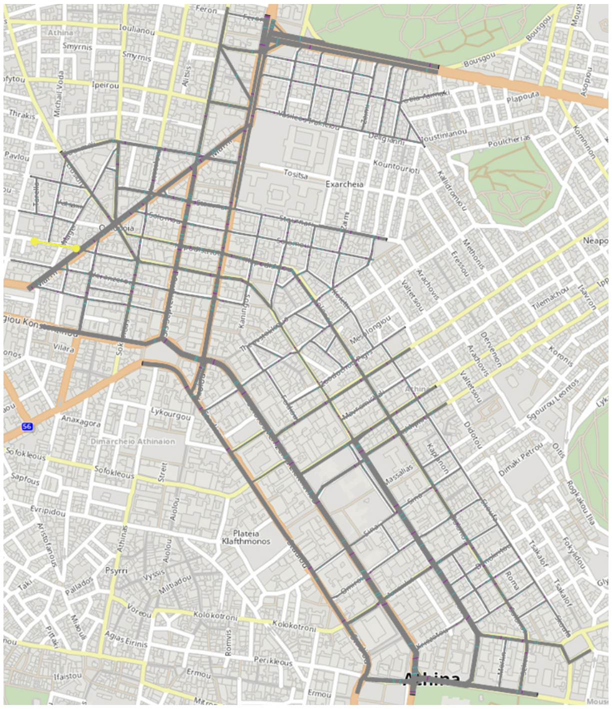

Figure 15: Athens network in PTV Vissim

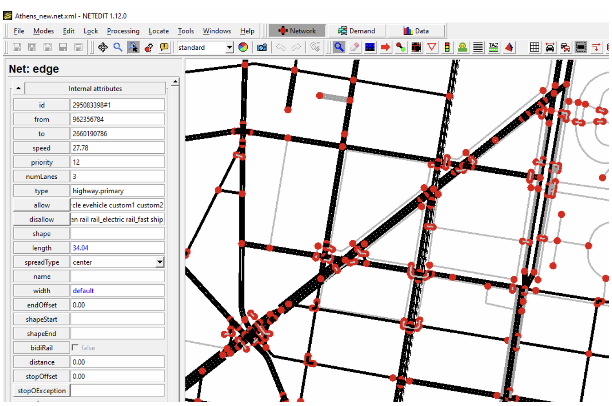

Figure 16: Athens map in Netedit

questions, contributing to a more convenient driving environment before our roads get fully automated. Finding ways of contributing to safer and well-structured traffic dynamics while investigating the communication and interaction between vehicles with different levels of automation is our main focus.

REFERENCES

[1] Stuster Jack. "Aggressive Driving Enforcement: Evaluation of Two Demonstration Programs". In: National Highway Traffic Safety Administration, 2004. URL: https://www.nhtsa.gov/sites/nhtsa.gov/files/809707.pdf.

[2] United Nations Economic Commission for Europe (UNECE). "Aggressive driving behaviour". In: 2004. URL: https://unece.org/aggressive-driving-behaviour-background-paper.

[3] Francisco Alonso et al. "Conceptualization of aggressive driving behaviors through a Perception of aggressive driving scale (PAD)". In: 2019. DOI: https://doi.org/10.1016/j.trf.2018.10.032. URL: https://www.sciencedirect.com/science/article/pii/S1369847818302961#b0205.

[4] United Nations Economic Commission for Europe (UNECE). "Automated Vehicles for Safety". In: URL: https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety.

[5] Qiong Lu et al. "The impact of autonomous vehicles on urban traffic network capacity: an experimental analysis by microscopic traffic simulation". In: vol. 12. 8. Taylor Francis, 2020, pp. 540–549. DOI: 10.1080/19427867.2019.1662561. URL: https://doi.org/10.1080/19427867.2019.1662561.

[6] Gys Albertus Marthinus Meiring and Hermanus Carel Myburgh. "A Review of Intelligent Driving Style Analysis Systems and Related Artificial Intelligence Algorithms". In: 2015. DOI: 10.3390/s151229822. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4721742/.

[7] Saeed Asadi Bagloee et al. "Autonomous vehicles: challenges, opportunities, and future implications for transportation policies". In: vol. 24. 8. Taylor Francis, 2016, pp. 284–303. DOI: 10.1007/s40534-016-0117-3. URL: https://doi.org/10.1007/s40534-016-0117-3.

[8] F. Clara Fang and Hernan Castaneda. "Computer Simulation Modeling of Driver Behavior at Roundabouts". In: vol. 16. 8. 2018, pp. 66–77. DOI: 10.1007/s13177-017-0138-2. URL: https://doi.org/10.1007/s13177-017-0138-2.

[9] Filmon Habtemichael and Luis Picado Santos. "SENSITIVITY ANALYSIS OF VISSIM DRIVER BEHAVIOR PARAMETERS ON SAFETY OF SIMULATED VEHICLES AND THEIR INTERACTION WITH OPERATIONS OF SIMULATED TRAFFIC". In: Jan. 2013. URL: https://www.researchgate.net/publication/268036204_SENSITIVITY_ANALYSIS_OF_VISSIM_DRIVER_BEHAVIOR_PARAMETERS_ON_SAFETY_OF_SIMULATED_VEHICLES_AND_THEIR_INTERACTION_WITH_OPERATIONS_OF_SIMULATED_TRAFFIC.

[10] Moulay Youssef Farrag Siham G.and El-Hansali et al. "A microsimulation-based analysis for driving behaviour modelling on a congested expressway". In: vol. 11. 8. 2020, pp. 5857–5874. DOI: 10.1007/s12652-020-02098-5. URL: https://doi.org/10.1007/s12652-020-02098-5.

[11] Ying Huang Hafiz Usman Ahmed and TPan Lu. "A Review of Car-Following Models and Modeling Tools for Human and Autonomous-Ready Driving Behaviors in Micro-Simulation". In: 2021. URL: https://doi.org/10.3390/smartcities4010019.

[12] *CoExist*. CoExist. 2021. URL: https://www.h2020-coexist.eu/resources/.

[13] "CoExist - Micro-simulation guide for automated vehicles". In: PTV Group, 2020. URL: https://www.h2020-coexist.eu/wp-content/uploads/2020/04/D2.11-Guide-for-the-simulation-of-AVs-with-microscopic-modelling-tool-Final.pdf.

[14] "PTV Vissim New". In: PTV Group, 2021. URL: www.ptvgroup.com/en/solutions/products/ptv-vissim/.

[15] PTV Group Traffic. *Webinar: Scripting in PTV Vissim using the COM interface*. Youtube. 2017. URL: https://www.youtube.com/watch?v=mhFI-DQZ5og.

[16] *pNEUMA*. pNEUMA EPFL. 2020. URL: https://open-traffic.epfl.ch/.