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ASSESSING THE ENVIRONMENTAL BENEFITS OF AGGRESSIVE AUTONOMOUS VEHICLES IN URBAN TRAFFIC

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Abstract:

This paper examines the impacts of different levels of aggressive autonomous vehicle (AV) penetration on emissions, fuel consumption, and travel time within urban traffic environments under different volumes of traffic. The paper uses the PTV VISSIM traffic simulation model to analyze light, moderate, and heavy traffic volumes to gauge the impacts of AV penetration rates from 0% to 100% on important indicators: carbon monoxide, nitrogen oxides, volatile organic compounds, fuel consumption, and travel time. Therefore, the rising trends in the typical context are rather evident that the more the AV penetration, the better the emissions and fuel consumption indicators. Notably, the forces from the increase in AV penetration show important impacts on the indicators CO, NOX, and VOC emissions indicators, as well as fuel consumption, which evidence significant decreases. In addition, better traffic flow with increased AV penetration is associated with a reduction in travel time. The study therefore finds the benefits in such a scenario to be always there, but the improvement level varies with the volume of traffic. The network to be used in the traffic model consists of three roundabouts and one unsignalized intersection, thereby offering a realistic urban traffic scenario for simulation. The demonstrated results of this paper have shown that aggressive AV technology can bring benefits to both the environment and operation; strategic implementation, in the case of an urban area, will also cause a significant reduction in urban traffic emissions, fuel consumption, and travel time. Thus, this paper gives an overall thorough analysis of the AV effects to enlighten policymakers and urban developers about the potential of such vehicles in the case of a sustainable urban mobility strategy.

Keywords: Autonomous Vehicles, Emissions Reduction, Fuel Consumption, Traffic Simulation, Urban Mobility.

Introduction

The rapid advancement of autonomous vehicle (AV) technology presents a transformative potential for urban transportation systems [1-4]. With the increasing adoption of AVs, understanding their impact on traffic flow, emissions, fuel consumption, and overall transportation efficiency becomes crucial [5, 6]. Autonomous vehicles, especially those programmed with aggressive driving behaviors, have the potential to significantly alter traffic dynamics [7, 8]. This study focuses on examining these impacts under varying levels of AV penetration in urban traffic environments characterized by different traffic volumes.

Traffic congestion in urban areas is a chronic issue, leading to large emissions and fuel consumption. In this context, the potential of AVs to mitigate congestion traffic and reduce emissions within these areas has been acknowledged. Even with this important potential, it remains an open question in the research how much magnitude and variation the results exhibit, stemming from different levels of AV saturation and traffic volumes. To overcome this gap, this research uses the PTV VISSIM traffic simulation model and assesses the influence of AV saturation on the following main environmental indicators: CO, NOX, VOC, fuel consumption, and travel time.

The simulation scenarios considered in this study include light, moderate, and heavy traffic volumes, with AV penetration rates ranging from 0% to 100%. By focusing on aggressive AV driving behaviors, this research seeks to provide a comprehensive understanding of how such driving patterns affect urban traffic performance and environmental outcomes.

The traffic model considered for this experiment involves a network configuration of three roundabouts and one unsignalized intersection. The configuration of this model presents a real urban traffic scenario for simulation. Thus, this study will present its findings to stakeholders and urban planners in relation to the possible opportunities and challenges of integrating aggressive AVs in an urban traffic system. This background introduces and gives a pathway towards detailing the influence of aggressive AVs in urban traffic, highlighting that avowed knowledge of these influences is vital for planning sustainable urban mobility.

1. LITERATURE REVIEW

In recent years, an increasing wave of studying the potential impacts that might be brought by autonomous vehicles on several aspects related to the traffic system, including environmental effects, urban spatial planning, and traffic flow characteristics, has emerged. These are being carried out by means of various methodologies and tools, application means conducted, in most cases, with the help of traffic simulation models that assess the advantages and problems that the integration of AVs within the current traffic network leads to. The major findings of some studies regarding their research aims, methods, and the main results derived are summarized in Table 1.

Table 1. Summary of Studies Investigating the Impact of Aggressive Autonomous Vehicles on Urban Traffic.

Reference	Year	Objective of The Study	Methodology/Tools Used	Key Findings
[9]	2019	Carbon Footprint of autonomous vehicles at the urban mobility system level: A traffic simulation-based approach.	Traffic simulation-based approach; Life cycle impact evaluation.	AVs in urban traffic reduce Total Time Spent and increase speed; 100% AV penetration scenario decreases environmental impact by 60%.

[10]	2019	On exploring the potentialities of autonomous vehicles in urban spatial planning.	Modelling interaction between urban space and autonomous vehicles mobility; Network design problem to identify superfluous road links for elimination.	Identifies unnecessary road links for soft mobility enhancement; Implemented and analyzed real-world case study to evaluate model performance.
[11]	2020	On Urban Traffic Flow Benefits of Connected and Automated Vehicles.	Investigated Level 4&5 AVs and Connected AVs in urban networks; Quantified impact on traffic congestion, speed, and trip time.	CAVs reduce congestion, increase speed, improve traffic flow; Average flow speeds of CAV group can be up to 300% greater than human-driven vehicles.
[12]	2020	Autonomous Vehicles in Urban Traffic.	Describes levels of autonomy, technologies, impacts, and consequences on infrastructure.	Highlights consequences of autonomous and connected vehicles on road infrastructure; Impacts of autonomous vehicles on urban transport.
[13]	2021	Impacts of Autonomous Vehicles on Traffic Flow Characteristics under Mixed Traffic Environment: Future Perspectives.	Reviews expected impacts of AVs and RVs in traffic flow; Discusses policy implications for future practice and research interests.	AVs improve traffic capacity and stability; Critical penetration rate for traffic improvement is above 40%.
[14]	2022	The coordinated scheduling of autonomous vehicles considering traffic.	Mathematical model for coordinated autonomous vehicles scheduling; Optimization problem solved using GAMS software.	Minimizes traffic flow, maximizes V2G facilities, satisfies traffic constraints; Successful scheduling of autonomous vehicles.
[15]	2022	Evaluating the Impact of Autonomous Vehicles on Traffic Flow at a Stillwater Intersection.	Traffic modeling and simulation using the PTV VISSIM microscopic simulator; Collection of field traffic counts, signal timings, and intersection geometry.	AVs significantly reduce queue delay, travel time, and improve traffic flow; AVs improve traffic flow and mobility at the intersection.
[16]	2023	Performances and Environmental Impacts of Connected and Autonomous Vehicles for Different Mixed-Traffic Scenarios.	Microsimulation-based approach on urban motorway in Rome using PTV VissimTM 21.	Improved road capacity, mean speeds, and environmental impacts in congestion; Traffic fluidification can counteract environmental performances in lower-congested situations.
[17]	2024	Impact of Aggressive HGV Platoons and Human-Driven Heavy Goods Vehicles on Signalized Intersections Performance.	PTV VISSIM microscopic traffic flow model; Comparison of human-driven HGVs with fully automated aggressive platoon HGVs across various traffic volumes.	Autonomous aggressive platoon HGVs show significant improvements in queue length, stops, and queue delay; Lower emissions and better flow for platoons as traffic volume increases.

2. METHODOLOGY

2.1 Study location

The simulation has been done on a network of three roundabouts and one unsignalized intersection in Kirkuk City, Iraq, as shown in the Figure 1. It gives a typical urban traffic scenario and has the potential to represent a realistic environment in studying the effect of varying levels of aggressive autonomous vehicle penetration on traffic flow, emissions, and fuel consumption.

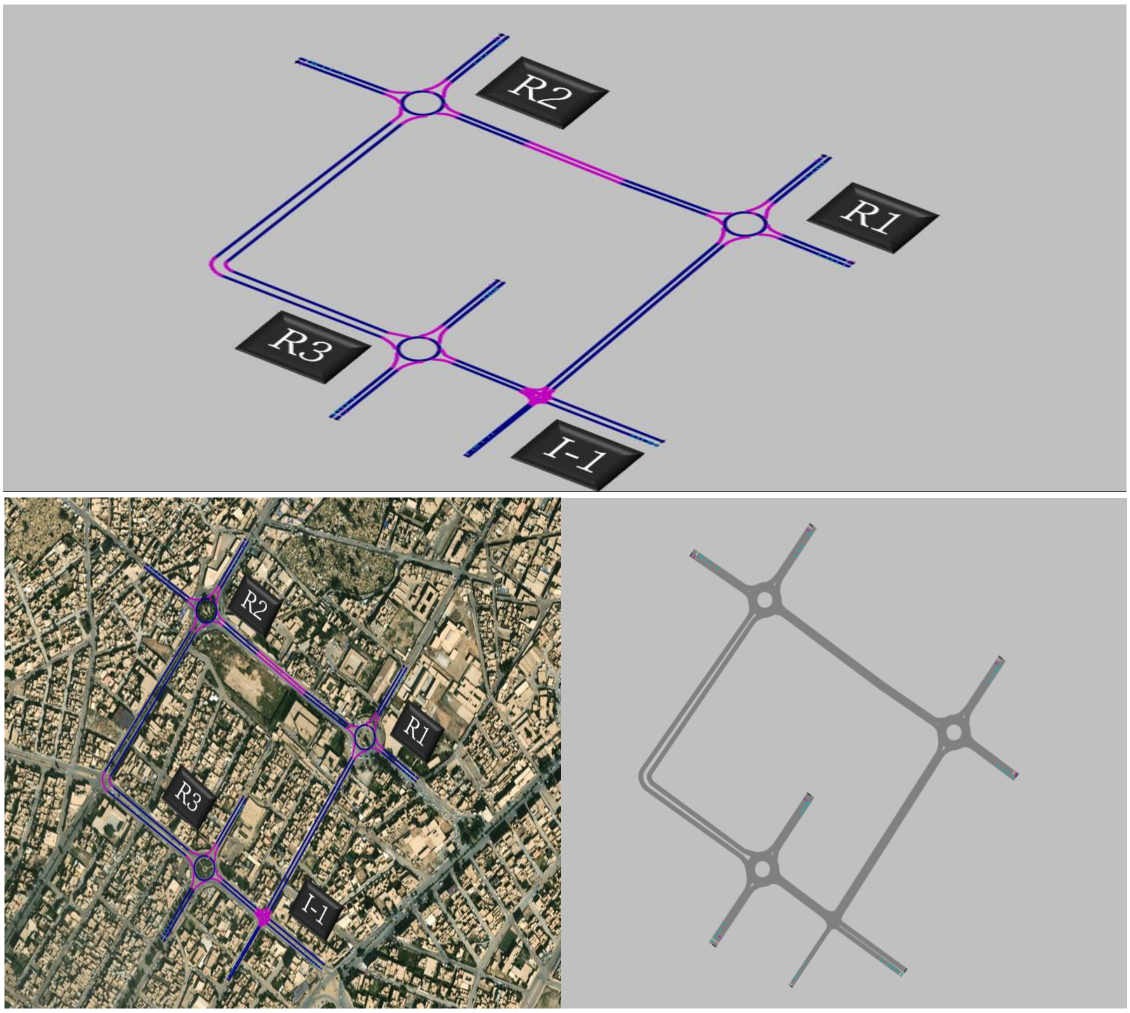


Fig 1. Network Configuration of Three Roundabouts and One Unsignalized Intersection in Kirkuk City, Iraq.

2.2 Examined Traffic Volumes

This work presents an investigation into the impacts that aggressive AV penetration would have on traffic volume for light, moderate, and heavy scenarios. These integrative effects will be regarded because these packages of induced traffic include light, moderate, and heavy intensities of urban traffic congestion.

- Light Traffic Volume: This scenario represents low-demand conditions with minimal congestion, allowing for the assessment of AV impacts in relatively free-flowing traffic environments. The total traffic volume (TTV) for this scenario is set to 200 vehicles per hour.

- Moderate Traffic Volume: This scenario reflects medium-demand conditions with moderate congestion, offering insights into AV performance in more typical urban traffic situations. The TTV for this scenario is set to 800 vehicles per hour.
- Heavy Traffic Volume: This scenario simulates high-demand conditions with significant congestion, providing an understanding of AV impacts under intense traffic pressure. The TTV for this scenario is set to 1600 vehicles per hour.

The intention is to capture the full range of AV integration effects in the network by considering these three traffic volume scenarios: from the minimum effect in the reduction of congestion to severe congestion within the Kirkuk City, Iraq, urban traffic network.

2.3 Speed Distribution

Figure 2 cumulated as a distribution of the desired speed among the vehicles for the traffic simulation, from 40 km/h to 68 km/h. The graph gives an impression that most of the vehicles are at that range; thus, the curve is a bit cumulated in a low slope for the higher speeds. The peak for this distribution is telling that the most part of the vehicles in the whole model have the same travel speed, while traveling more in the same cluster ranges. The same number tends to go at the minimum or maximum speed; other than that, there are few traveling at the lowest or peak speed. This pattern is essential for understanding how different penetration rates of aggressive autonomous vehicles (AVs) influence overall traffic dynamics and efficiency.

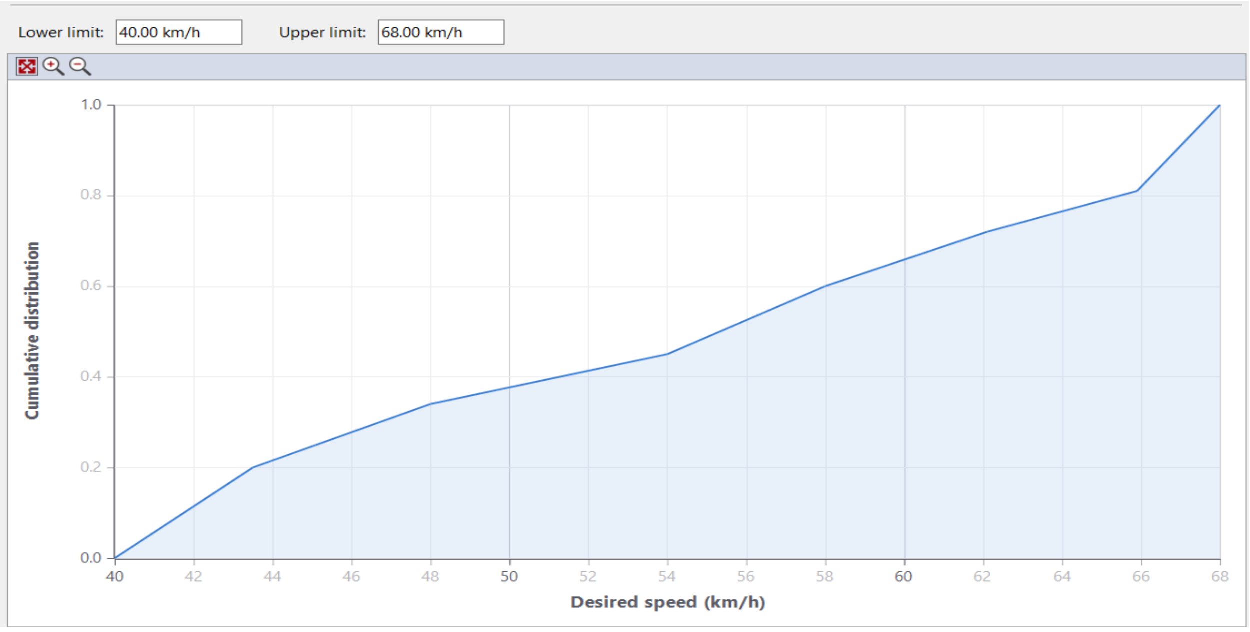


Fig 2. Cumulative Distribution of Desired Speeds in the Traffic Simulation Model.

2.4 Reduced Speed Areas

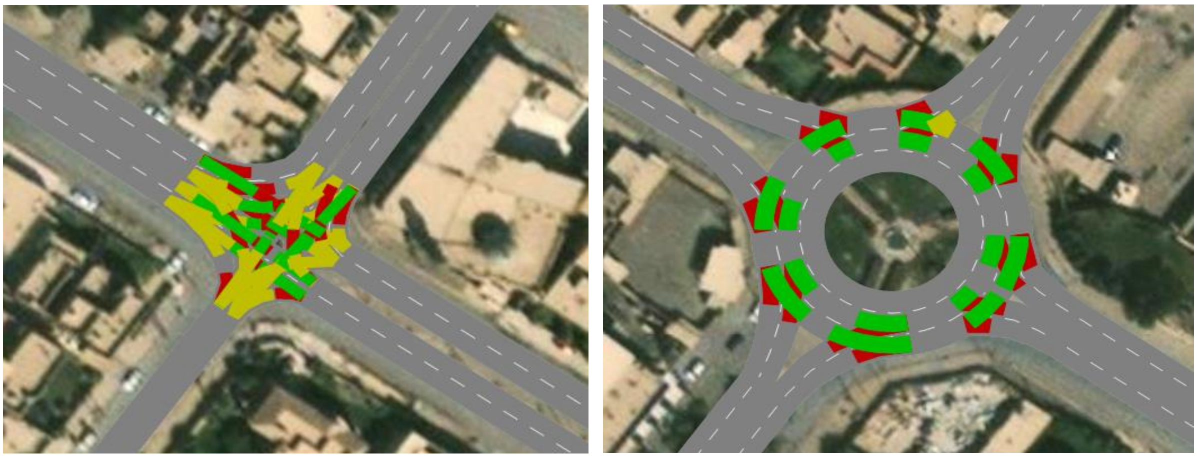
Figures 3 illustrate key locations within the traffic network where speed reduction measures are implemented to enhance safety and traffic flow efficiency. These reduced speed areas are strategically placed at critical points within the network, specifically at the roundabout entries and exits, as well as near the unsignalized intersection.

(a) (b)

Fig 3. (a) Reduce Speed Areas in the Unsignalized Intersection. (b) Reduce Speed Areas in the roundabouts.

2.5 Conflict Areas

Figure 4 illustrates the conflict areas identified within the traffic network, specifically at a roundabout and an unsignalized intersection in Kirkuk City. These conflict areas represent points of potential vehicle interactions where traffic safety and efficiency are critical.



(a) (b)

Fig 4. (a) Conflict Areas in the Unsignalized Intersection. (b) Conflict Areas in the roundabouts.

2.6 Car Following Models

The Car Following models used in this study are critical for accurately simulating the behavior of both human-driven and autonomous vehicles (AVs) in the traffic network. Two different models were employed: the Wiedemann 99 model for aggressive AVs and the Wiedemann 74 model for human-driven vehicles.

Table 2 outlines the parameters for the Wiedemann 99 following model applied to aggressive AVs. Besides that, other key thresholds relate to speed differences and include the threshold for entering 'Following', identified as CC4, for positive speed difference; for negative speed difference, it is identified as CC3. Such other additional parameters identified include the dependencies of oscillations on the distance, identified as CC6; oscillation acceleration, identified as CC7; acceleration from standstill, identified as CC8; and acceleration at 80 km/h, identified as CC9. This parameter list runs quite long, forming a very comprehensive vehicle behavior description for AV.

Table 2. Car Following Model Parameters for AV Aggressive.

Wiedemann 99 following model parameters	AV Aggressive
CC0 Standstill distance	1.00 m
CC1 Gap time distribution	0.6 s
CC2 ‘Following’ distance oscillation	0.00 m
CC3 Threshold for entering ‘Following’	-6.00
CC4 Negative speed difference	-0.10
CC5 Positive speed difference	0.10
CC6 Distance dependency of oscillation	0.00
CC7 Oscillation acceleration	0.10 m/s2
CC8 Acceleration from standstill	4.00 m/s2
CC9 Acceleration at 80 km/h	2.00 m/s2

Table 3 presents the parameters for the Wiedemann 74 model, which is used for human-driven vehicles. There are three parameters available within this model: Average Standstill distance, Additive part of safety distance, and Multiplicative part of safety distance. The average standstill distance is 2.00 m to assure the modelling of realistic human driving. A 2.00 m value is considered for the additive part of the safety distance. It is 3.00 m for the multiplicative part considering the vagaries that can be there in human driver responses to different traffic conditions.

Table 3. Car Following Model Parameters for Human Vehicles.

Wiedemann 74 following model parameters	AV Aggressive
Average standstill distance	2.00 m
Additive part of safety distance	2.00 m
Multiplicative part of safety distance	3.00 m

2.7 Lane change Model Parameters

The parameters applied in the lane change model are necessary for both simulating the type of behavior exhibited by aggressive AVs and human-driven vehicles during the process of moving into the desired lane. Table 4 illustrates the elaboration on different parameters with the application of driving styles.

Table 4. Lane change Model Parameters for Different Driving Behavior.

Parameter's	AV aggressive	Human
Advanced merging	on	on
Cooperative Lane change	on	off
Safety distance reduction Factor	0.75	0.60 m
Min clearance (front/rear)	0.50 m	0.50 m
Maximum deceleration for Cooperative braking	-6.00 m/s2	-3.00 m/s2

For aggressive AVs, the developed lane change model includes advanced merging and cooperative lane change functionalities, such that an AV always behaves more aggressively. These features permit going deeper into more effective and coordinated behaviors to be followed and benefit overall traffic flow. The factor considered for the reduction of safety distances between vehicles is set at 0.75 for AVs, which leads to a more aggressive result. The main clearance for both front and rear is set at 0.50 m for both cases of driving behavior. The maximum deceleration for AVs to be applied during lane changing is -6.00 m/s^2 to achieve an aggressive deceleration that can rapidly decrease the vehicle's speed if needed, thus avoiding collisions. This high level of deceleration is implemented to ensure the safety of the vehicle during complicated maneuvers inside the city. The model for the AV lane changing also includes cooperative braking, which is a characteristic that further enhances the model regarding the previous ones, supporting all the coordinative maneuvers necessary between vehicles.

The remaining parameters, applied to the human-driven vehicles, are set in such a way as to follow conservative behavior. Even though advanced merging and cooperative lane change functionalities are considered, their presence is disabled so that humans will not initiate synchronized lane-changing behaviors. The factor implemented for the aggressive approach is 0.60, so that a human will try to keep larger safety distances between him and others. The maximum deceleration is -3.00 m/s^2 for human drivers; however, this type of value still represents a more conservative approach to sudden braking experienced during lane changes.

With these discrete parameters for the developed lane change model, a realistic simulation is ensured for each case of an aggressive AV and human driver. The first set of parameters is used to investigate the influence of different AV penetration rates on traffic dynamics, emissions, and fuel consumption in an urban traffic network in Kirkuk City, Iraq.

2.8 Scenarios

The study examines the impacts associated with various levels of the penetration of aggressive AV, in other words, the described traffic dynamics, emissions, fuel consumption, and travel time under various traffic volumes. The scenarios are framed to cater to the penetration rate, ranging from 0% to 100%, under light, moderate, and heavy traffic conditions. Details for these scenarios are summarized in Table 5.

Table 5. Summary of Scenarios

Scenario	AV Penetration Rate	Traffic Volume	Description
No. 1	0% (100% Human)	Light	Baseline scenario with only human-driven vehicles
No. 2	25% AV	Light	Mixed traffic with 25% AV and 75% human-driven vehicles
No. 3	50% AV	Light	Mixed traffic with 50% AV and 50% human-driven vehicles
No. 4	75% AV	Light	Mixed traffic with 75% AV and 25% human-driven vehicles
No. 5	100% AV	Light	Only autonomous vehicles in traffic
No. 6	0% (100% Human)	Moderate	Baseline scenario with only human-driven vehicles
No. 7	25% AV	Moderate	Mixed traffic with 25% AV and 75% human-driven vehicles
No. 8	50% AV	Moderate	Mixed traffic with 50% AV and 50% human-driven vehicles
No. 9	75% AV	Moderate	Mixed traffic with 75% AV and 25% human-driven vehicles
No. 10	100% AV	Moderate	Only autonomous vehicles in traffic
No. 11	0% (100% Human)	Heavy	Baseline scenario with only human-driven vehicles
No. 12	25% AV	Heavy	Mixed traffic with 25% AV and 75% human-driven vehicles
No. 13	50% AV	Heavy	Mixed traffic with 50% AV and 50% human-driven vehicles
No. 14	75% AV	Heavy	Mixed traffic with 75% AV and 25% human-driven vehicles
No. 15	100% AV	Heavy	Only autonomous vehicles in traffic

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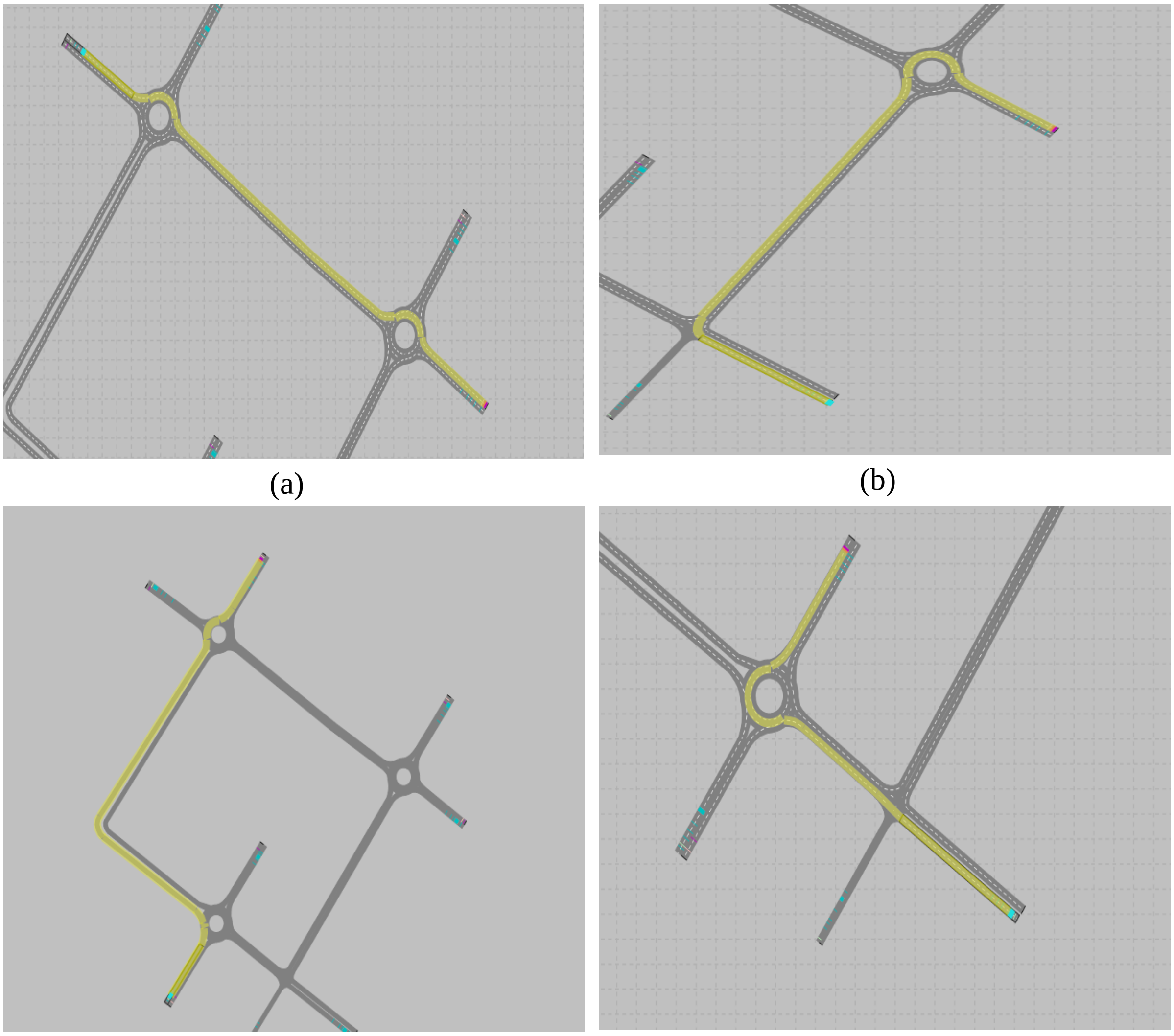
Each scenario is simulated using the PTV VISSIM traffic model to assess the impact of varying AV penetration rates on the urban traffic network. The scenarios allow for a comprehensive analysis of how the integration of aggressive AVs affects key traffic performance indicators across different traffic conditions.

3. RESULTS AND DISCUSSION

The analysis of travel time for different scenarios and movements under light traffic volume (low demand) conditions is depicted in Figure 6. This figure presents the travel times across four movements (R1-R2, R1-R4, R2-R3, and R3-R4) as shown in Figure 5 for varying levels of AV penetration, ranging from 0% to 100%. The scenarios include 100% human-driven vehicles, mixed traffic with 25%, 50%, and 75% AVs, and 100% AVs.



(a) (b) (c) (d)

Fig 5. (a) R1-R2 Movement. (b) R1-R4 Movement. (c) R3-R4 Movement. (d) R3-R4 Movement.

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The results indicate a general trend of decreasing travel time with higher AV penetration rates. The average travel time for each scenario is also shown, providing a clear comparison of the overall efficiency improvements brought by increasing the number of AVs. Notably, the travel times for the 100% AV scenario are consistently lower than those for the 100% human-driven scenario, highlighting the efficiency gains achieved through the integration of aggressive AVs into the traffic flow.

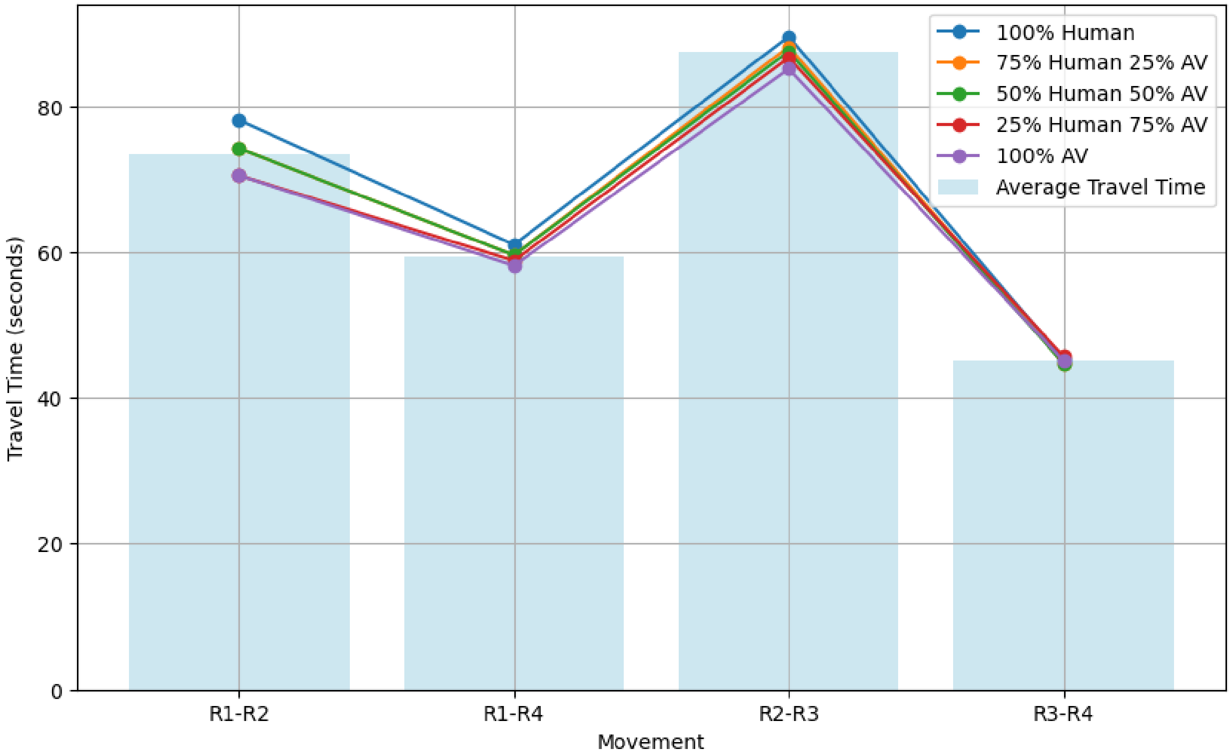

Fig 6. Travel Time for Different Scenarios and Movements for Light Traffic Volume (Low Demand) --- TTV= 200 Veh.

For movement R1-R2, the travel time significantly decreases as the AV penetration rate increases, with the 100% AV scenario showing the shortest travel time. Similarly, movements R1-R4 and R3-R4 exhibit reduced travel times with higher AV penetration, although the differences between scenarios are less pronounced compared to R1-R2. The movement R2-R3 shows a more variable trend, with travel times fluctuating across different scenarios but generally following the overall decreasing trend.

Under moderate traffic volume the results reveal a consistent trend of decreasing travel time with higher AV penetration rates as depicted in Figure 7, similar to the findings under light traffic conditions. The average travel time for each scenario shows clear efficiency improvements with the integration of AVs. Specifically, the 100% AV scenario consistently exhibits the lowest travel times across all movements, demonstrating the superior efficiency of AV-dominated traffic.

For movement R1-R2, travel time reduces significantly as the AV penetration rate increases, with the 100% AV scenario showing the shortest travel time. Movement R1-R4 also displays a reduction in travel time with higher AV penetration, though the differences between scenarios are more subtle. The movement R2-R3 shows a notable decrease in travel time with higher AV penetration, particularly between the 50% and 75% AV scenarios. Movement R3-R4 consistently follows the overall trend of decreasing travel time with increasing AV penetration, highlighting the efficiency gains achievable with AV integration.

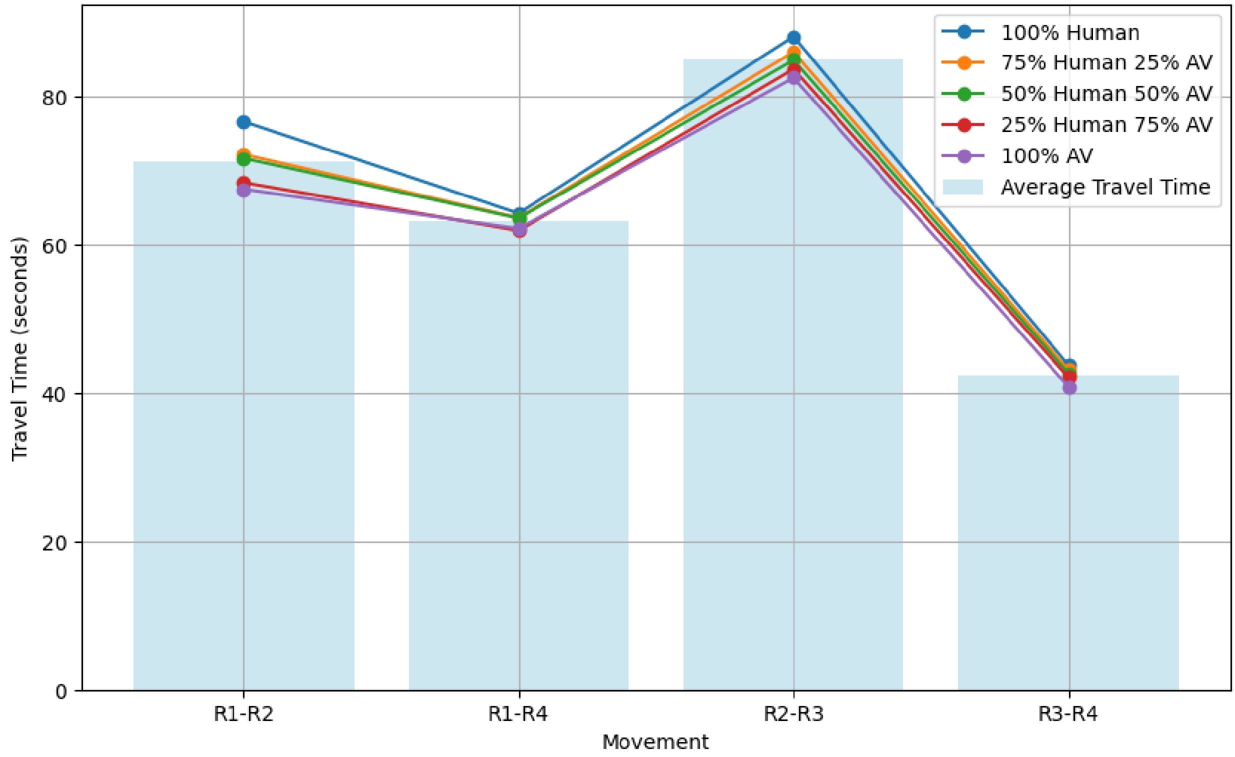

Fig 7. Travel Time for Different Scenarios and Movements for Moderate Traffic Volume (Medium Demand) --- TTV= 800 Veh.

Under heavy traffic volume (high demand) The results indicate that higher AV penetration rates generally lead to reduced travel times as depicted in Figure 8, even under high demand conditions. The average travel time for each scenario highlights the efficiency improvements associated with increased AV integration. Notably, the 100% AV scenario consistently exhibits the shortest travel times across all movements, demonstrating the superior efficiency of AVs in managing heavy traffic volumes.

For movement R1-R2, there is a clear decrease in travel time as the AV penetration rate increases, with the 100% AV scenario showing the lowest travel time. Movement R1-R4 follows a similar trend, with a notable reduction in travel time for higher AV penetration scenarios. The movement R2-R3, which initially shows higher travel times, exhibits a significant decrease as AV penetration increases, particularly between the 50% and 100% AV scenarios. Movement R3-R4 also displays reduced travel times with higher AV penetration, underscoring the consistent benefits of AV integration.

These findings underscore the potential of AV integration in reducing travel times and enhancing traffic flow efficiency, even under heavy traffic conditions. These improvements are evident for all movements, which indicates a general applicability of AV technology for all types of traffic scenarios. The present analysis provides robust evidence on the advantages of aggressive AVs in improving urban traffic dynamics, supporting strategic implementations of aggressive AVs for more efficient and sustainable urban mobility.

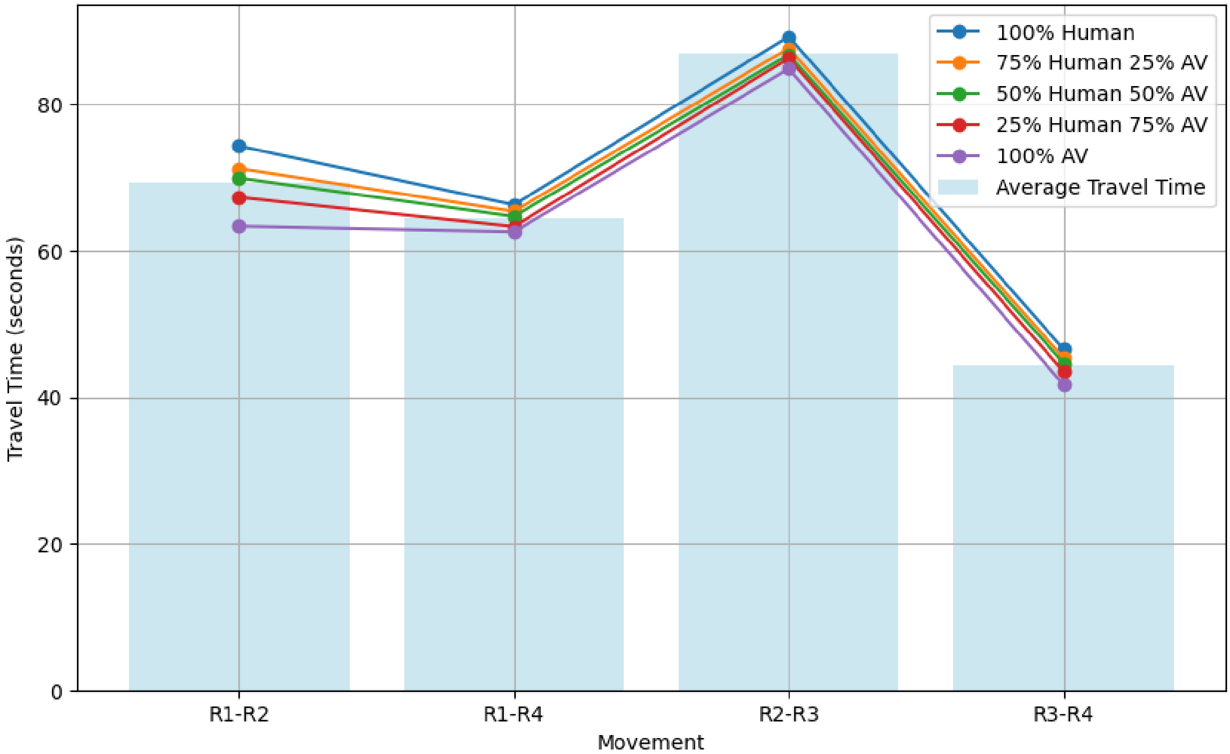

Fig 8. Travel Time for Different Scenarios and Movements for Heavy Traffic Volume (High Demand) --- TTV= 1600 Veh.

Figure 9 presents emissions and fuel consumption at various penetration levels for aggressive AVs under light traffic volume conditions (low demand). The figure is a combination of four graphs, which show carbon monoxide (CO) emissions, nitrogen oxides (NOX), volatile organic compounds (VOC), and fuel consumption vs. aggressive AV penetration from 0% to 100% of the traffic.

The CO emissions graph shows a slight increase in emissions with increasing AV penetration, peaking at 25% AV penetration before decreasing and stabilizing at higher penetration rates. This pattern suggests that while the introduction of AVs initially leads to higher CO emissions, further integration helps stabilize and reduce these emissions.

An equally almost constant trend is shown in the NOX emissions graph: the peak is marked at 25% AV penetration. NOX first continually increased with AV penetration, then finally declined, which demonstrated such stabilization effects at high penetration levels. This means that early penetration of AVs increases NOX emissions, while higher penetration would effectively mitigate an increase.

The VOC emissions graph also shows an increase in emissions at 25% AV penetration, followed by a decrease and another slight rise at higher penetration rates. This fluctuating pattern suggests that VOC emissions are sensitive to changes in AV penetration, with initial increases being offset by further AV integration.

The fuel consumption graph shows a peak around 25% AV penetration, which corresponds to emissions. The fuel consumption tends to increase, following the emissions, and decreases at high penetrations. Therefore, this implies that AVs would lead to higher fuel consumption at first introduction; increasingly used fuel would be used more efficiently as the share of AVs increased.

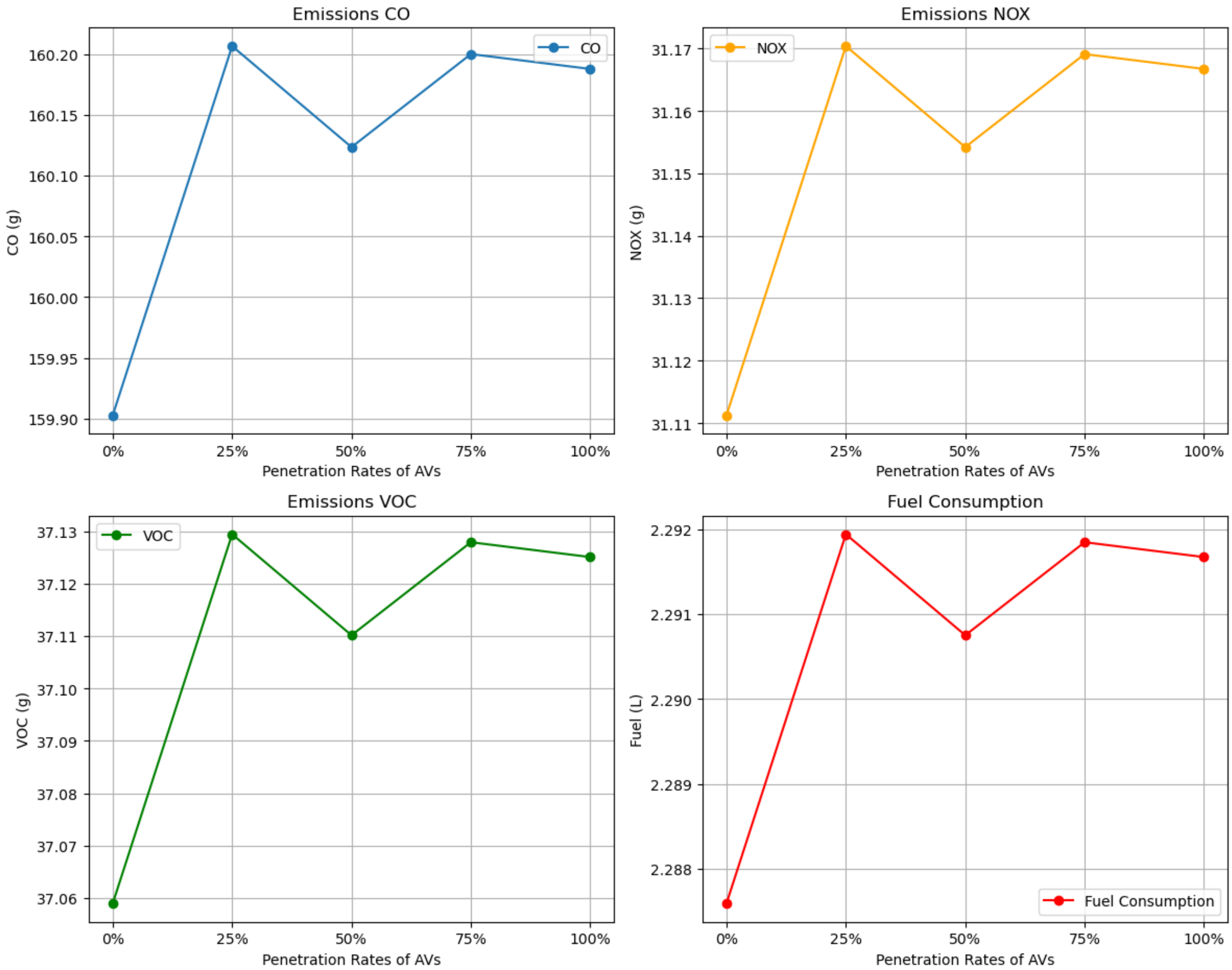

Fig 9. Emissions and Fuel Consumption for Different Scenarios (Light Traffic Volume).

Figure 10 below portrays the analysis of emissions and fuel consumption for aggressive AVs under medium traffic volume, or in other words, moderate demand. Figure 10 consists of four plots that depict the emissions of CO, NOX, VOC, and fuel consumption for different penetration rates of aggressive AVs, varying from 0% to 100%.

The CO emissions graph shows a clear trend of decreasing emissions with increasing AV penetration. Starting at 676 g for 0% AV penetration, the CO emissions drop significantly to about 668 g at 50% AV penetration and continue to decrease, reaching the lowest value at 100% AV penetration. This trend indicates that higher AV penetration rates lead to more efficient traffic flow, thereby reducing CO emissions.

similar manner. Clearly, a decrease in emissions can be noticed with increasing AV penetration. It started recording at around 131.75 g with 0% AV penetration and decreased gradually to around 129.75 g with 100% AV penetration. This decrease proves that the smoother and more predictable driving patterns of AVs reduce the NOX emissions.

The VOC emissions graph also shows a decrease in emissions with higher AV penetration rates. From an initial value of 157.0 g at 0% AV penetration, VOC emissions decline to around 154.5 g at 100% AV penetration. This trend underscores the environmental benefits of integrating AVs into the traffic system, as their efficient driving behaviors reduce VOC emissions.

In a similar manner, the trend in the graph for fuel consumption also kept falling with AV penetration. It started at a quantity of around 9.68 L with 0% AV penetration and recorded close to 9.54 L with 100% AV penetration. This descent in fuel consumption followed the general trend produced by high AV penetration, showing improved traffic efficiency.

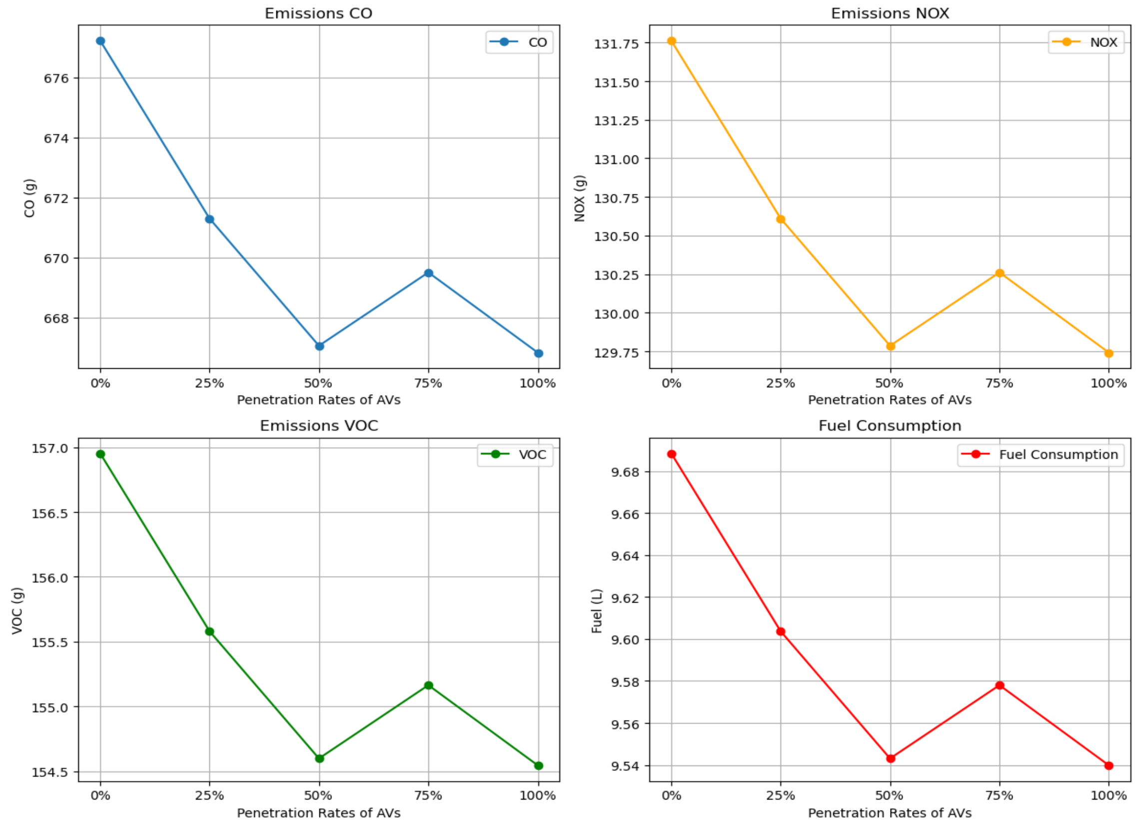

Fig 10. Emissions and Fuel Consumption for Different Scenarios (Moderate Traffic Volume).

The emissions analysis along with the fuel consumption for the aggressive AV penetration rates at significantly high demand conditions is shown in the following Figure 11. The figure combines four plots in one, plotting the emissions for CO, NOX, VOC, and fuel consumption for different penetration rates of aggressive AVs from 0 to 100%. Corresponding scenarios under heavy traffic volume are also evaluated.

The CO emissions graph shows a clear and consistent decrease in emissions with increasing AV penetration rates. Starting at approximately 1445 g for 0% AV penetration, CO emissions drop steadily, reaching the lowest value of about 1389 g at 100% AV penetration. This trend highlights the significant reduction in CO emissions achievable with higher levels of AV integration.

The graph for NOX emissions exhibits almost a similar trend, with the emissions decreasing as AV penetration increases. In a range of about 281 g from the base case of 0% AV penetration, NOX emissions decrease linearly across to around 270 g at 100% AV penetration. This just points out the positive aspect of reducing NOX emissions from the use of AVs, possibly resulting from smoother and efficient driving behaviors.

The VOC emissions graph also shows a decrease in emissions with higher AV penetration rates. From an initial value of about 335 g at 0% AV penetration, VOC emissions drop to around 321 g at 100% AV penetration. This trend further supports the environmental benefits of integrating AVs into urban traffic systems.

The fuel consumption graph indicates a similar trend of decreasing with increased AV penetration. Starting from around 20.6 L in the case of 0% AV, the fuel consumption reduces progressively to around 19.8 L in the case of 100% AV penetration. The significant drop in fuel consumption tends to offer rather good fuel economy through AV technology, especially under heavy traffic conditions.

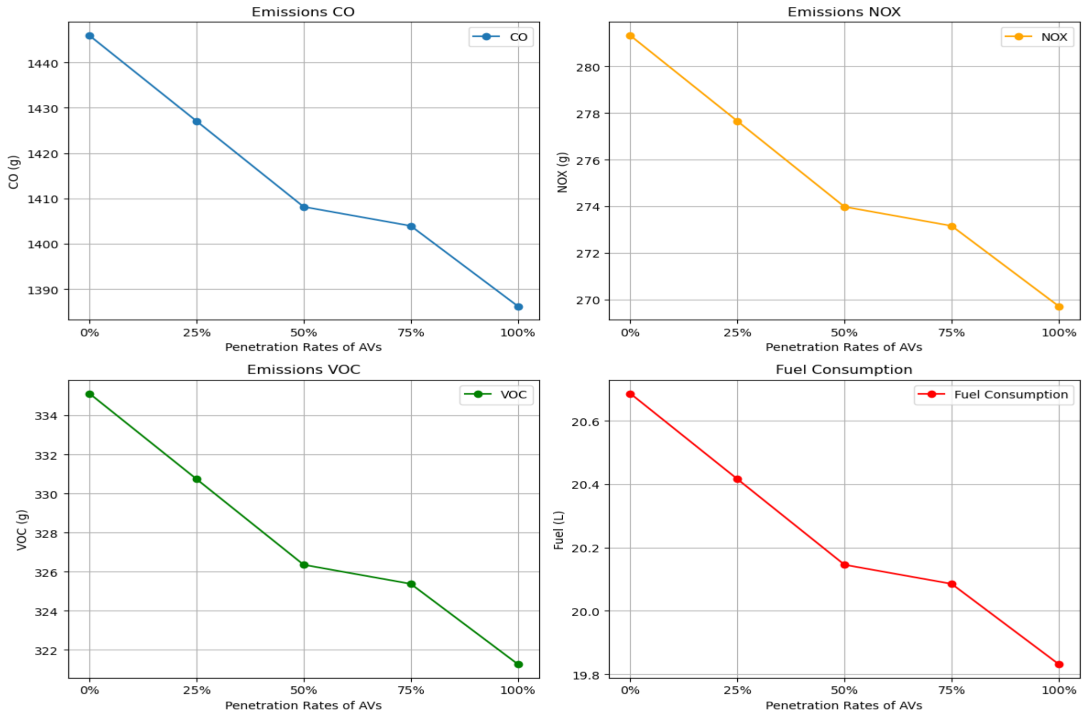

Fig 11. Emissions and Fuel Consumption for Different Scenarios (Heavy Traffic Volume).

It is therefore evident from these results that there would be a massive environmental and efficiency benefit that would accrue from an aggressive push of AV penetration rates under severe traffic conditions. From the recorded trends of the indicators in the graphs for emissions and fuel consumption, a demonstration of one simple issue can be made: intensive use of AV technology would deliver enormous improvements in urban traffic efficiency and bring down the environmental impact of urban traffic congestion. This is further support for the evidence in place for the strategic place of AVs in moving toward more sustainable urban mobility.

4. CONCLUSION

This study evaluated emissions, fuel consumption, and travel times for drivers under various levels of penetration of aggressive autonomous vehicles in an urban traffic environment with different volumes of traffic. The results are unmistakable in showing the trend of penetration levels in providing great reductions in CO, NOX, VOC, and fuel consumption. These environmental benefits are observed across light, moderate, and heavy traffic volumes, although the magnitude of the improvements varies with traffic conditions. Notably, travel time decreases as AV penetration increases, demonstrating the efficiency gains achievable through the integration of AV technology. The study highlights that while initial stages of AV penetration may result in slight increases in emissions and fuel consumption, higher penetration rates consistently lead to substantial reductions. These results underscore the potential of AVs to improve urban traffic efficiency and sustainability. On the analysis, this paper finds that the wise implementation of AVs in urban areas holds a great potential to make the dropping of traffic emissions more emphasized and improve fuel use and hence the fluency of traffic in urban road networks. The study emphasizes a sustainable transition to AV for reduction of the.

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