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Controlling Traffic Congestion in a Residential Area via GLOSA Development

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Abstract: The phenomenon of traffic congestion started in the second half of the twentieth century. This arose because of our society's constant increase in demand for mobility. The excessive traffic of vehicles attempting to use the same infrastructure at the same time is what causes congestion. The consequences are well-known: delays, air pollution, reduced speed, and dissatisfaction (which may lead to risky maneuvers, reducing pedestrian and other driver safety). Our objective is to simulate the change in traffic patterns brought about by app users in residential areas (using navigational tools like Google Maps and Apple Maps), where the majority of navigational tools provide shortcuts that go through residential areas. In addition to discouraging navigation apps from directing drivers through residential areas during peak hours to mitigate pollution levels, by developing an algorithm based on the technology of Green Light Optimized Speed Advisory (GLOSA) and implementing it in a simulated environment (VISSIM), we can see the effect of changing the duration of red lights while keeping green lights constant. Overall, this solution can be implemented to change the times of traffic lights without the need for supplies, additional equipment, or warning signs because most cities' traffic lights are already remotely controlled. In addition, this procedure is temporary to provide some freedom and does not adhere to the speed specified for drivers who wish to pass through residential areas outside of rush hour.

Keywords: intelligent transportation systems (ITS); navigation applications; GLOSA; VISSIM; residential area; CTCRA algorithm

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1. Introduction

It is crucial to have a deep understanding of the challenges presented by the increased use of residential roads as shortcuts by drivers who rely on navigation applications like Apple Maps and Google Maps. This issue has become a problem for residents who struggle to access their homes due to heavy traffic. The problem started with the widespread use of these apps, which offer drivers real-time routing of shortcuts through residential areas. With the increasing use of the Internet, communications, and the development of the Internet of Things (IoT), approximately 50 million drivers in the United States alone use these applications [1,2]. In addition to the increasing number of vehicles and the heavy reliance on navigational applications by vehicle drivers while on the move, the importance of conducting a study on the impact of these applications on the quality of life and the level of pollution in cities appears. As a result, traffic jams now occur unexpectedly in previously quiet neighborhoods. Residents have expressed dissatisfaction with the prevalence of speeding vehicles, especially during peak hours, with many drivers engrossed in their phones while navigating. The once-secret London shortcuts, traditionally known to black-cab drivers, are now experiencing congestion due to the influx of app users [3,4]. Unfortunately, this issue is escalating.

Globally, urban planners have relied on residential density to predict traffic patterns, anticipating the need for real-time adjustments in specific scenarios. To manage these changes, they have implemented tools such as traffic lights, embedded loop sensors, and surveillance cameras [5,6]. In challenging situations like obstructions, events, or emergencies, city managers may deploy police officers to direct traffic.

However, the surge in popularity of online navigation apps is exacerbating rather than resolving the problem. These apps prioritize minimizing individual travel times without considering whether residential streets can accommodate the increased traffic or if unforeseen factors may compromise safety. The basic concept of an interaction between infrastructure components and vehicles, such as vehicle to infrastructure (V2I) and the vehicle, is the continuous exchange of data and information in order to improve traffic flow quality and, ultimately, traffic safety [7]. Many ITS services are presently being implemented, including new features for optimizing traffic control, due to the tremendous potential that may be realized through cooperation, collaboration, and digitization.

Green Light Optimized Speed Advisory (GLOSA) uses real-time traffic light timing data as well as information on the speed and position of individual cars to generate the ideal speed advisory for each vehicle approaching their next traffic light. In principle, GLOSA intends to minimize fuel consumption and emissions while enhancing traffic flow and safety by providing drivers with the statistics and information described above [8,9]. From the point of view of researchers, it is important to add maps that indicate the level of environmental pollution in residential areas and link them with an application that works on smartphones, integrated with GLOSA technology. This approach goes beyond the predominant focus on improving fuel consumption rates and reducing average travel time for vehicles in existing studies, addressing the critical aspect of environmental pollution. The integration of environmental pollution maps into a smartphone application connected to GLOSA technology holds the potential to reduce pollution and promote environmentally friendly transportation choices, particularly encouraging bicycle riders to choose routes with cleaner surroundings [10].

Because of this, there is a greater need for simulation platforms that can test intelligent transportation systems (ITS) methods and techniques more effectively. Up until now, commercial simulation tools like Trazer, SUMO, and OMNET++ have been based on traditional simulation models [11]. However, many of these tools are designed for specific purposes and lack native tools for implementing agent-based solutions.

1.1. Traffic Management System

Simulating a real smart city environment for testing the effects of navigation applications on traffic can provide valuable insights into how such technologies can improve traffic flow and reduce congestion in urban areas, which has important implications for urban planning and transportation policy. The assumption is that drivers assigned routes via navigation apps will strictly adhere to the instructions. The navigation applications give preference in the options for the shortcut route to shorten the time, and this feature is very useful. Drivers may choose to deviate from the route for various reasons, such as avoiding heavy traffic, taking a more scenic route, or stopping at a particular location. But this is at the expense of pass-through residential areas and traffic congestion, which can have negative impacts on the quality of life for residents in those areas.

This could include incorporating data on residential areas and their potential sensitivity to increased traffic flow into the algorithm used to generate route suggestions or providing alternative routes that prioritize residential areas and work towards finding a balance between efficiency and quality of air. We are mainly interested in diverting traffic away from residential roads, effectively reducing GHG emissions in such locations.

One potential solution to the problem of vehicles using shortcuts through residential areas is to implement dynamic road infrastructure and adjust traffic light timings to discourage this behavior during rush traffic periods (adaptive or intelligent traffic lights). By changing the duration of red lights at traffic lights that lead to shortcuts passing through residential areas, drivers may be deterred from taking these routes during rush hours. In Table 1, a comparison is made between routing applications and GLOSA. Note: This (*) means that this technology supports.

Table 1. Comparison between Google Maps and GLOSA.

	Shortcut	Travel Time	Environmental Pollution	Fuel
Navigation applications	*	*		
GLOSA			*	*

1.2. Related Work

In a 2020 study exploring the shortcut roads phenomenon and its impact on traffic trends, disruptions to mobility, and congestion patterns over one year, researchers discovered that an increasing number of drivers may be taking shortcuts, resulting in a 4X increase in flow in some locations and a 25% fall in speed on some main roadways. This underscores the necessity for traffic management applications to collaborate with the current urban infrastructure to optimize the movement of traffic effectively [12]. Furthermore, the use of navigation apps like Google Maps and Apple Maps has led to an increase in traffic congestion in residential neighborhoods as drivers are being routed through these areas as shortcuts to their destinations [13]. This has resulted in negative impacts on residential areas, including increased noise pollution, safety concerns for pedestrians and cyclists, and decreased quality of life for residents. While the underlying routing algorithms are advantageous to consumers in the near term, they can have significant negative impacts on the places used as shortcuts [14].

In recent years, researchers have proposed techniques to estimate emissions using Global Positioning System (GPS) data from vehicles. These methods evaluate fuel use and emissions using models that presumptively depend primarily on a vehicle's path, distance traveled, and journey time [13]. Utilizing GPS data for traffic volume, these methods enable the evaluation of traffic-related emissions through the analysis of sampled vehicle tracks [15].

Trajectory data from various vehicle types have become a standard data source for monitoring traffic, fuel consumption, and emissions. Given their integral role in urban transportation networks and their significant contribution to urban traffic flows, data on trajectories from all types of cars are commonly used for such calculations. Gühnemann et al. [16] used GPS data from a fleet of vehicles to estimate traffic NOx emissions using an average-speed-dependent estimating technique. Researchers used taxi GPS trajectory data to examine trends in fuel consumption and emissions in Beijing. For every liter of gasoline, a vehicle uses, it generates about 2.3 g of CO_2 [17].

In a previous study in 2023, surveillance cameras and radar sensors communicated with the control processing unit using the Internet Protocol Version 6 (IPv6) communication protocol. While the control processing unit collects data and photographs, analyzes them using algorithms, and decides the speed at which vehicles must travel to avoid stopping at traffic signals, it broadcasts this information to nearby vehicles through Wi-Fi [7]. This has the potential to ultimately decrease travel duration, diminish fuel consumption, and lower CO_2 emissions. Additionally, the public stands to gain from this solution by receiving timely information on incidents and traffic congestion, enabling them to make informed decisions about their travel plans [5]. Implementing straightforward measures, such as enhancing roadwork planning through intelligent transportation systems (ITS) and optimizing the full capacity of the road, can contribute to maintaining a reasonable traffic flow. Intelligent transportation systems (ITS) can be realized by integrating cars with technology, surveillance cameras, and sensors, thereby using their sensing, monitoring, and communication capabilities [18]. FDM's study highlights that traffic delays caused by roadwork, uncoordinated traffic lights, and improper traffic rerouting are common causes of congestion [19]. To address these issues, traffic management apps need to consider the capacity and characteristics of the road network when suggesting routes to users [20,21].

Additionally, local governments can implement traffic-calming measures such as speed bumps, traffic circles, and road narrowing to discourage cut-through traffic in residential areas. These measures can help improve the quality of life for residents and reduce the negative impacts of traffic congestion on the environment.

2. Materials and Methods

2.1. Case Study

This work is focused on a highway road and a residential road, with a focus on vehicles. Figure 1A,B depict a map of a significant road in Baghdad that connects the provinces in the southwest to the city center. Residents of the area complain of heavy traffic on a continuous basis. The study focuses on a segment of this road that runs between points A and B. Point A consists of an intersection of four legs. Two of these lanes lead to point B, one of which passes through the residential area, spanning 2.6 km in distance. It takes a vehicle approximately 4 min to cover this distance on the highway. In contrast, the same vehicle only takes 3 min to traverse the residential road, which is relatively short, as per Google Maps. The city suffers from high levels of pollution due to population growth over the past years, with a population of 9 million people. By focusing on traffic routing conditions, for example, eco-driving and eco-routing, governments seek to reduce the generation of pollutants and energy use by reducing traffic congestion and improving other factors [22]. Therefore, there has been a need to conduct more relevant research to improve the level of air quality. We propose a simulation model to study how to improve the level of air quality in residential areas by diverting vehicles outside the area at peak times and use the results of this simulation in order to generalize them to all regions.

Figure 1. (**A**) Map of Baghdad showing traffic details and location of the section in the city. (**B**) Information and distance between point A and point B.

2.2. Software VISSIM

In this context, VISSIM version (PTV 2022 Student) has emerged as a user-friendly platform that addresses these limitations. It models traffic actors like drivers, traffic lights, and autonomous vehicles as autonomous agents and uses AI techniques to enable short-term traffic light control, route replanning, and demand–supply coeffects studies [12]. With the increased dissemination and computing power of mobile devices, distributed AI applications like intelligent routing algorithms and distributed optimization of traffic lights have become feasible. The goal is to use a simulation to improve transportation in a target area and keep vehicles away from residential areas during rush hours to reduce sources of pollution [23]. The target group of this research is drivers.

PTV Group created VISSIM, which is a straightforward traffic simulation program. VISSIM stands for simulation model, which translates to Traffic in Cities Simulation Model. It is widely used by transportation planners, engineers, and researchers to model and analyze various traffic scenarios. It simulates individual vehicles and their interactions with each other and the road network, providing detailed information about traffic flow, travel times, delays, and safety. This software uses advanced algorithms to model complex traffic situations, including signalized and unsignalized intersections, roundabouts, and highway networks. It also supports the integration of public transport, pedestrians, and bicycles into the simulation.

In addition, VISSIM is a powerful tool for transportation planning and analysis, allowing users to evaluate and optimize traffic operations, safety, and environmental impact [24]. It is widely used in research, urban planning, and traffic engineering in smart city projects worldwide.

2.3. The Equations

Our analysis includes *Highway Capacity Manual* (HCM) equations [20]. These three equations indicate the travel time for a link or corridor calculated between two points, A and B, at different times according to the congestion hours. There are various reasons why time is used as a measurement standard:

a. Based on experience; time is the most essential factor influencing traffic flow on road segments.
b. Additional congestion factors exhibit a close correlation with the time measurement index, following a similar pattern of peak and decline.
c. Undoubtedly, time is the most straightforward variable to measure among congestion factors, rendering it valuable for practical applications.

The travel time for traffic flow along a road segment is the duration spent on that segment under continuous traffic conditions. However, this ideal scenario is not practical due to intersections and signal lights in the urban road network.

Consequently, traffic flow becomes intermittent on busy road segments, exhibiting two states: the driving state and the queue state. The travel time for intermittent traffic flow on the road segment is determined by both "distance" and "speed," as per traffic flow theory. Therefore, the distance between points A and B is divided into two parts: the driving section and the queuing section.

As illustrated in Figure 1B, a vehicle follows the path $(a\ )$ between points A and B. The traffic flow departs from the route point (A) at $v_a^m(t)$, and upon reaching the path point (B), the vehicle enters a queue due to the influence of the signal light. If the queue length is $L_a^q(t)$, the distance covered on road segment a is $L_a^m(t)$, with the overall length of the road segment being L_a:

$$L_a = L_a^m(t) + L_a^q(t) \tag{1}$$

where $v_a^m\ (t)$, L_a^m, and $L_a^q(t)$ represent time-dependent functions. Similarly, it is posited that the time the vehicle spends traversing segment a is denoted as T_a^q, the delay induced by the queue (encompassing stop-and-go situations) is T_a^q, and the total travel time on section a is designated as $T_a(t)$; hence:

$$T_a(t) = T_a^m(t) + T_a^q(t) \tag{2}$$

were

$$T_a^m(t) = \frac{L_a^m(t)}{v_a^m(t)} = \frac{L_a - L_a^q(t)}{v_a^m(t)} \tag{3}$$

Equations (2) and (3) illustrate that to compute the road capacity $T_a(t)$, it is necessary to ascertain both the travel time $T_a^m(t)$ for the trip segment a the delay time $T_a^q(t)$ of the queue component independently.

The queue length $L_a^q(t)$ can be used to calculate the travel time $T_a^m(t)$.

As a result, finding $T_a^m(t)$ is turned into determining the real-time queue length $L_a^q(t)$, which can then be studied and validated.

According to the final two equations, the speed limit has no effect if congestion naturally slows traffic down to a lower speed yet imposes a hard limit on the maximum speed. Analyzing traffic flow is an important task for ensuring the efficiency of the road network. A crucial element in analyzing traffic flow is the road capacity, defined as the highest number of vehicles that can traverse a specific road section within a specified timeframe [21].

2.4. Data Collection

Through the available data and information as shown in Figure 1, and data from the general traffic data (GTD) [10], as per Lomax et al., calculating congested travel by vehicle miles involves multiplying the congested segment length by the vehicle volume summed across all congested segments. Show the Figure 2 average traffic volume.

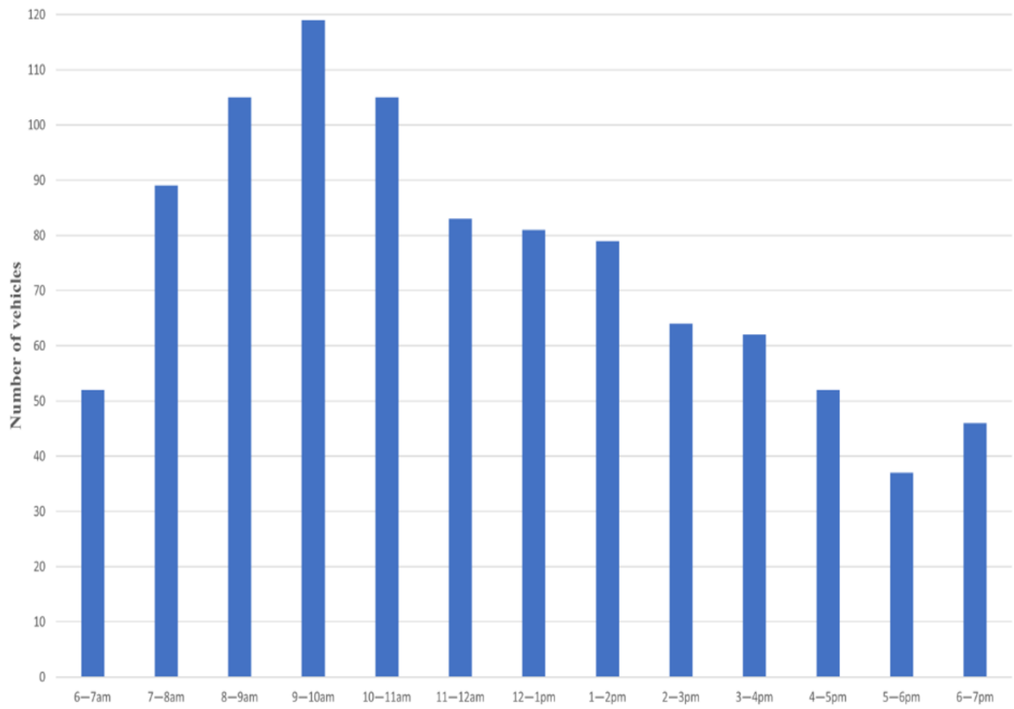

Figure 2. Average traffic volume for the actual state.

The percent of congested travel is an expansion of the congested travel measure, providing an assessment of the extent of congestion [25,26]:

- In Figure 1A, a section is shown in red, which runs between point A (33.30229621555221, 44.3564187464969) and point B (33.281860, 44.347720).
- Rush time is from 7 am to 10 am (3 h).

- The cross-sectional area of the road is 10.5 m.
- The vehicle length and safety distance 6 m.
- Each road has three lanes, and the width of the lane is approximately 3 m.
- Vehicle travel time for the distance between the two points is 4 min during the rush time.

Using the previous equations, we can calculate the maximum traffic volume during rush hour. Since the rush congestion time is 3 h, the total number of minutes is 180 min. If the vehicle travel time for the distance between the two points (2.6 km) is 4 min, then the total number of vehicles that can pass through the road during rush hour is as follows:

- Capacity of one lane = (2.6 × 1000/6) = 433 vehicles.
- Total capacity of road = 433 × 3 = 1299 vehicles.
- Therefore, the total capacity of each lane is approximately (240/433) = 1 vehicle per 2 s.

This is much higher than the maximum traffic volume, which means that the road is experiencing congestion during rush hours. To this congestion, several measures can be taken, such as increasing the traffic volume, implementing traffic management strategies, and encouraging the use of public transport.

Figure 3 illustrates the basic parameters involved in the simulation procedure, which includes the following:

- Number of simulations run to collect data; the time interval is the time between each simulation run.
- Vehicle travel time evaluation is the method used to evaluate the travel time (average).
- The number of vehicles recorded is the total number of vehicles recorded during the simulation.
- Average travel time(s) of vehicles in the network is the average travel time for all vehicles in the network.
- Distance traveled is the total distance traveled by all vehicles in the network.

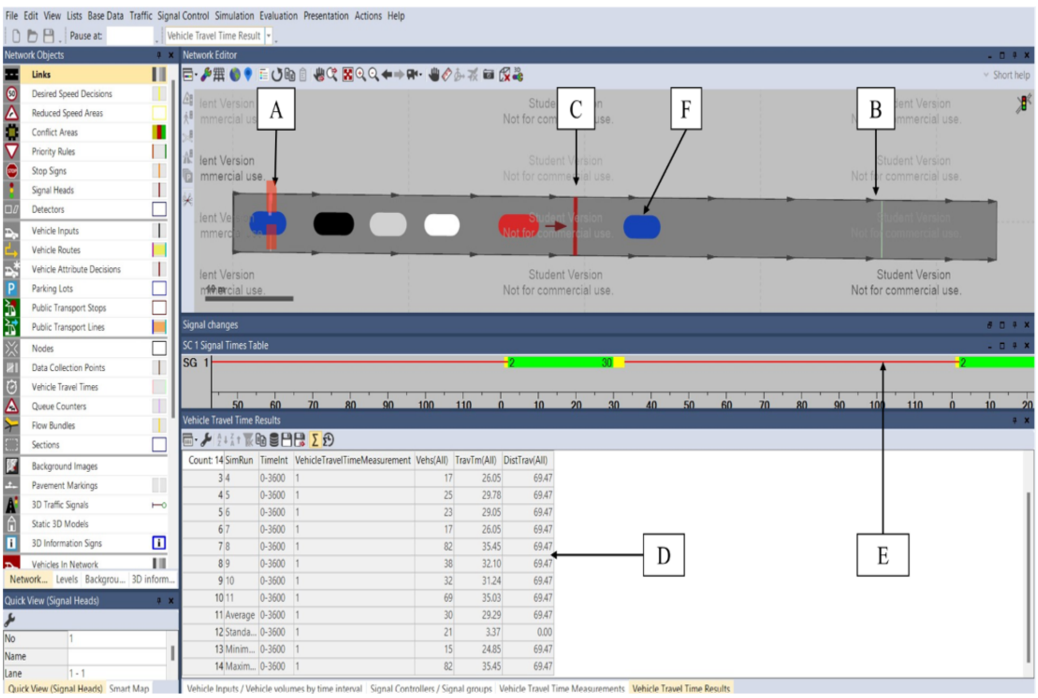

Figure 3. Basic parameters (A: vehicle input start; B: vehicle input end; C: signal heads; D: vehicle travel time results; E: signal times table windows; F: vehicle).

2.5. Simulation Scenario

The algorithm controlling traffic congestion in residential areas (CTCRA) is shown in Figure 4, which was developed. To implement the algorithm in a simulation environment like VISSIM, the algorithm collects information about all drivers (vehicles) who communicate with navigation applications and plan to take a shortcut through the residential area. The algorithm determines a range of air quality levels (pollution levels) within the residential area, which, if the minimum of these levels is reached, will allow the driver to take a shortened route (this limit is often outside peak times). Therefore, the algorithm only affects vehicles that intend to take the shortened route at peak time.

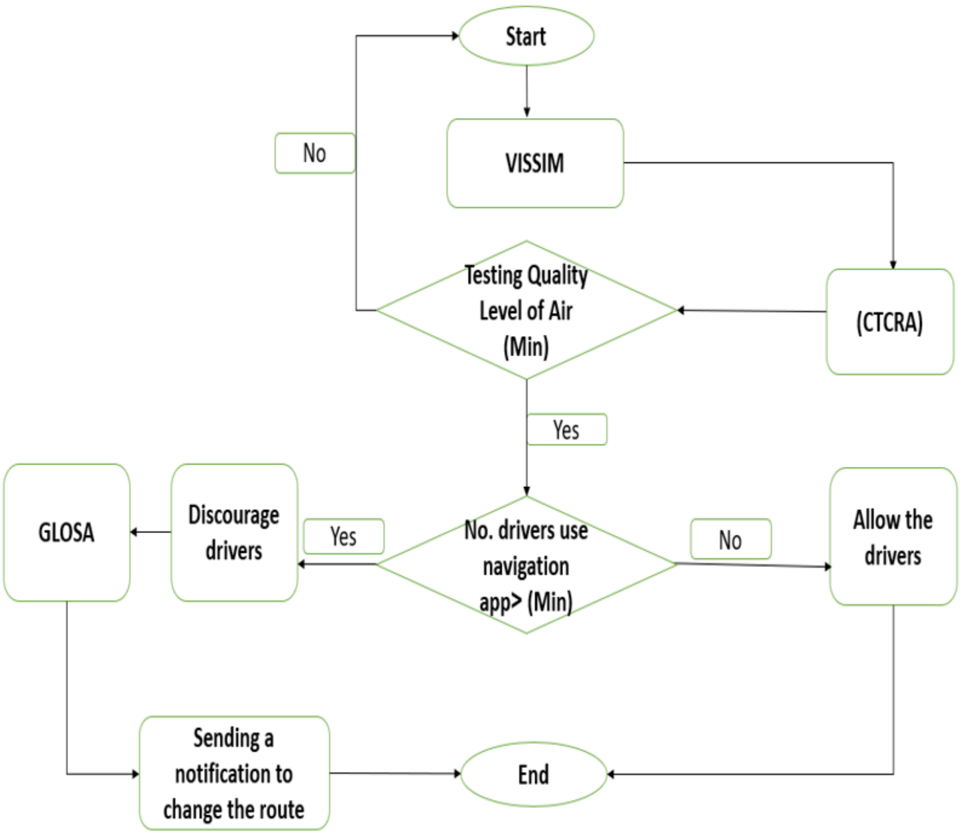

Figure 4. Algorithm controlling traffic congestion in residential areas (CTCRA).

A scenario was implemented in which the percentage of users of the navigation application changed. An evolution in travel times was observed with the increase in users of the application. While the travel time remains constant for the main road, the travel time increases through the residential area for the first 25% of application users. The reason behind the increase in travel time is the presence of the majority of drivers on the main road. When using the app, drivers take the shortcut through the residential area. Whenever the percentage of drivers using the application is high, the route through the residential area becomes very crowded.

3. Results and Discussion

Our analysis indicates the immediate impacts of simulations obtained using VISSIM and the developed algorithm (CTCRA). It covers rush hours in residential areas and their relationship with travel times for analysis and assessment.

As a result, we gather sets of result data corresponding to each traffic volume group, travel time, traffic load, red light duration, and number of vehicles, and through data from the general traffic data (GTD), Figure 5 shows the vehicle's structure.

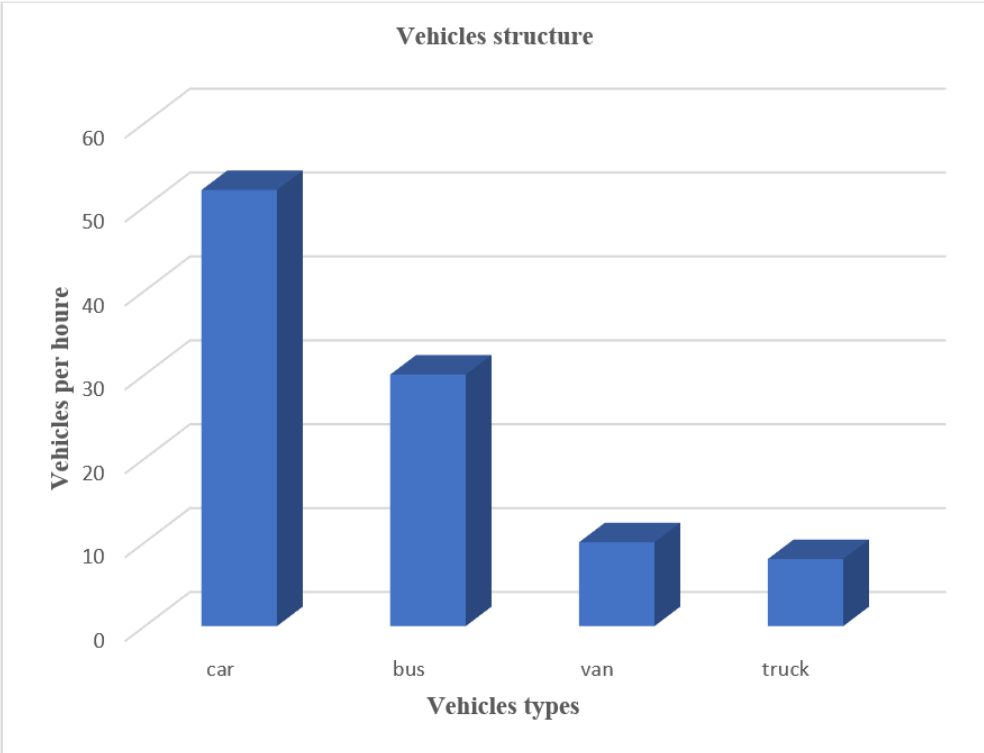

Figure 5. Vehicles' structure.

Figure 2 shows the results of collecting data for two weeks through inspection of the target area (the section leading to the residential area) and calculating the average traffic density in the section for drivers who want to take the shortcut in addition to determining peak times during work hours.

Figure 6 shows the simulation results for the variant (v0), which represents the actual case, while the other parts of (v) represent the 10% increase from (v0) for each variant (vehicles). Therefore, when referring to Figure 2 (the actual state), we notice that the important changes are with the increase in the percentage of the variant (v0) when it is 25%, as previously determined during peak hours.

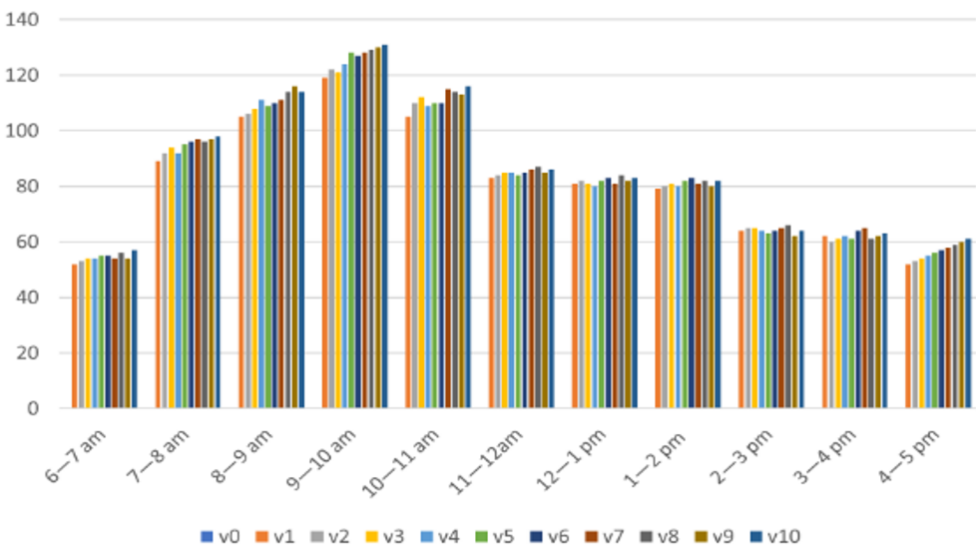

Figure 6. Average traffic volume (all variants).

The results presented in Table 2 provide insight into the impact of the simulation using VISSIM and the implemented algorithm on travel times between points A and B. The table highlights the travel time before and after the simulation process. The significant difference in travel time between points A and B indicates that the simulation and algorithmic interventions have a tangible effect on the overall traffic flow.

Table 2. Measure of effectiveness simulation (CTCRA).

Before Simulation (CTCRA)			After Simulation (CTCRA)		
No. Vehicles	**Speed (km/h)**	**Average Travel Time (s)/Shortcut**	**No. Vehicles**	**Speed (km/h)**	**Average Travel Time (s)/Shortcut**
100	40	3.21	89	40	3.20
150	40	3.25	133	40	3.25
200	40	3.45	178	40	3.50
250	40	3.60	222	40	3.63
300	40	3.55	267	40	3.60
350	40	3.80	311	40	4.00
400	40	4.29	356	40	4.38
450	40	4.58	400	40	4.67
500	40	4.62	445	40	4.98

The integration of the algorithm responsible for calculating air quality levels in the residential area with a parallel navigation application is a noteworthy approach. Sending notifications to redirect drivers away from the residential area demonstrates a proactive strategy to minimize congestion, and improving air quality is an inevitable result of the reduction in the number of vehicles. The results presented in Table 2 suggest that imposing a speed limit on the residential area shortcut can have a discernible impact on traffic flow.

The observation that exceeding 40 km/h has no effect on the trade-off indicates that congestion becomes the primary driver of travel time, overshadowing the influence of speed limits. The data indicate that imposing a 30 km/h speed limit can successfully remove traffic. This finding is crucial for balancing traffic reduction with acceptable travel times through the residential area. We recognize the importance of considering commuters' decisions when implementing speed limits. Lowering the speed restriction to an extent that would have little influence on commuters' decisions is acknowledged, ensuring that the shortcut remains a viable option despite the imposed limit. All of these results reflect a thoughtful approach to balancing the needs of residents and commuters. Minimizing additional annoyances for residents during less congested periods showcases a consideration for the diverse temporal patterns of traffic.

4. Future Work

Several suggestions can be applied to identify the most effective strategies for reducing traffic on residential roads. Some potential strategies that we intend to test in future work include the following:

- Implementing traffic fees or congestion fees in residential areas in order to discourage drivers from taking shortcuts.
- Developing a plan to determine the speed of vehicles within residential areas and the possibility of linking the results with this research.
- Improving public transportation options along the highway to encourage commuters and drivers to use public transit instead of driving their own vehicles.
- It is important to note that the decrease in the number of vehicles taking the shortcut does not necessarily translate to a decrease in overall traffic flow. Other factors, such as the number of vehicles using alternative routes or the number of vehicles entering the road from other directions, can also impact traffic flow.

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