Analysis of Traffic Dynamics in Urban Intersections: A Case Study of Tirana

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Abstract: - Nowadays, congested traffic is a problematic issue for our lives. Effective management of urban traffic is very important for reducing congestion and improving transport infrastructure. Our paper offers a comprehensive investigation of the behavior of two main intersections in the city of Tirana using the PTV VISSIM simulator. We looked into different traffic situations to get a clearer picture of what is happening at intersections, particularly with things like traffic flow, queue lengths, delays, and how many vehicles stay in line. The results give some solid insights for tweaking traffic signal timings and boosting how well intersections work overall. This study also highlights the value of simulation tools like VISSIM. They bridge the gap between theory and practice, stretching our understanding of complex traffic patterns into real-world applications. We support building targeted strategies to alleviate congestion and enhance urban travel. But this paper as a whole highlights not only the challenges in managing intersections but also advocates for practical, data-based planning in a more urban context for transportation.

Key-Words: - Congestion, Intersection, Traffic Management, Traffic Flows, Urban Traffic, PTV Vissim.

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1 Introduction

Global urban areas are struggling to manage traffic effectively to control congestion, pollution, and safety. In many cities, including large metropolises such as New York and Boston, outdated systems of fixed-time traffic control signals persist, failing to adapt to traffic conditions in real-time [1], [2]. These systems are programmed to schedule, so they are not calibrated for peak hours on any given day, leading to system inefficiencies, which leads to greater congestion and delays in travel. This is a common problem that can be overcome with more adaptive traffic signal strategies, sensitive to changing traffic patterns.

Tirana, the capital city of Albania, experiences significant traffic congestion, especially at key intersections. Fixed-time traffic systems result in longer travel times, more pollution, and more stress for residents [3], [4]. Hence, effective management of urban traffic has turned into a challenging issue that needs some novel ways to improve the lives in the city and also foster sustainable city development [5], [6].

An exemplary use case is for the modern traffic signal system and how recent advances in artificial intelligence (AI) can potentially help it. Now we can discuss the language of large linguistic models (LLM). LLMs can process vast amounts of traffic, formulating an intelligent traffic system capable of adjusting the signal dynamics in accordance with actual traffic situations (vehicle flow, traffic load, weather conditions). AI can help improve traffic flow, reduce congestion, and make for safer roads by making signals adjust to what is occurring on the roads. Tirana and other cities can use this technology to solve problems and develop faster systems.

Using the VISSIM traffic simulation [7], the intersection dynamics are controlled for effective urban traffic optimization in Tirana. In general, the VISSIM simulator is a more sophisticated tool that enables micro-simulation of vehicle and pedestrian flow [8], as we did to see the optimization of traffic signal control strategies at two consecutive intersections to improve the efficiency of these intersections. By creating a case study, this research simulates different scenarios in two main intersections in Tirana, where we evaluated the traffic flow dynamics, queue length, vehicle delays under different traffic signal configurations and the number of vehicles remaining in the queue. Our study has two primary objectives: to provide empirical evidence on the effectiveness of different traffic management strategies and to demonstrate the potential of advanced simulation tools such as VISSIM in urban traffic planning and management.

Existing traffic methods in Tirana not depend on real-time traffic signals. Therefore, from previous studies, fixed-time traffic signal methods have been evident in the management of the dynamic nature of urban traffic flows, resulting in a non optimal traffic control and an increased risk of traffic congestion and accidents. [9], [10]. The idea for our study emerged from the observed shortcomings and daily challenges in traffic management.

From our review of existing research, we noticed a gap in using advanced simulation tools for managing traffic in our capital city. While there is plenty of research on urban traffic worldwide, Tirana's unique challenges and opportunities haven not been studied much. So, this study focuses on that by closely analyzing how intersections work in Tirana and showing how simulation tools can help make better traffic decisions [11].

This paper is organized as follows: after this introduction, we will look at past work in this field, highlighting why new approaches are needed for urban traffic challenges. Next, we provide a detailed description of the proposed method, including the setup and execution of the VISSIM simulations. Afterwards, there is a part that explains the tests and findings of the simulations, providing a comparison of the results in different situations. In conclusion, the paper summarizes the results, discusses the impact on the field, and suggests future actions for improving urban traffic management in Tirana and other areas.

2 Related Work

The endeavor to improve urban traffic through empirical analysis and simulations has recently received considerable attention in the field of transportation. This section covers the basic concepts of intersection dynamics and simulation tool usages like PTV Vissim.

2.1 Intersection Dynamics and Traffic Flow Modeling

The complexity of intersection dynamics has been studied from the previous works that we have analyzed. Intersections are emphasized as critical junctures where streams of traffic coalesce and converge. Research has also been conducted on how aspects of geometric design impact the effectiveness of an intersection along with appropriate signaling, citing the layout and organization of an intersection as paramount in maximizing traffic movement [12], [13]. Furthermore, previous studies have examined techniques to mitigate traffic congestion at intersections through the analysis of traffic signal control strategies, with an emphasis placed on the performance of adaptive signal control systems, capable of dynamically modifying signal timings based on existing traffic conditions [14]. The continued studies are more concentrated on intelligent signal control strategies to realize the smooth passage of urban traffic at intersections, finally optimizing urban traffic with better performance [15].

2.2 Simulation-Based Approaches in Traffic Management

Simulation-based methods have emerged as crucial instruments for analyzing and improving traffic management strategies. Specifically, simulation software like VISSIM, simulates virtual environments closer to reality as much as possible to input and perform various test scenarios. VISSIM was modeled in studies to assess traffic flow dynamics and intersection-controlled mode. The implications on the efficiency of the intersection of these nuances in signal coordination are highlighted by recent research [16] comparing different strategies.

2.3 Application of VISSIM in Urban Traffic Studies

VISSIM has emerged as a widely adopted simulation tool for urban traffic studies, owing to its versatility and robust modeling capabilities. Studies show that VISSIM is useful for simulating complex traffic situations and how different infrastructure changes can affect traffic flow [17]. VISSIM has also been utilized to verify the benefits of intelligent transportation systems (ITS) for improving the operation of intersections and reducing travel times [18]. Using VISSIM, one case study displays the interaction of intersections in overall traffic management, giving relevant data for this study [19].

In summary, previous studies emphasize the significance of intersections in urban traffic management and highlight the important role of simulation tools such as VISSIM to analyze and investigate traffic flow. Based on this, our research zooms in on the intersection dynamics in Tirana using VISSIM to examine and identify the solutions to create a smoother traffic flow.

3 Methodology

3.1 Why PTV VISSIM?

PTV VISSIM simulator is one of the software packages of PTV group which is an established, widely used discrete, stochastic time basis microscopic simulation tool with state-of-the-art simulation capabilities of traffic simulation. This effectively models a wide range of traffic environments, from surface road networks to highways, intersections, crosswalks, and roundabouts, and both preset and actuated signals. A traffic network in VISSIM is based on a collection of links and connectors, which can typically be overlaid on a satellite image of the modeling area. These links may represent road segments with one or more lanes, allowing unidirectional vehicle movement. Vehicles travel from link to link only through connectors, which increases the realism of the simulation.

Additionally, VISSIM offers a comprehensive 3D simulation environment, proving useful for detailed traffic analysis. The reasons for using VISSIM to analyze the case study intersection were mainly based on the good interface, through which it was possible to access the project data without using extensive programming, unlike other simulation tools [20]. In addition, VISSIM outperformed other models like CORSIM and SIM TRAFFIC in extensive traffic scenarios highways, interchanges, and signalized intersections throughout an extensive comparative study described in [21] which highlights the power of VISSIM as the most competent and advanced model available.

3.2 Detailed Overview of PTV VISSIM Capabilities

VISSIM is an advanced microscopic traffic simulation software capable of accurately modeling urban traffic dynamics through time-lapse technology [22]. It is also very good at understanding complex intersection configurations, giving helpful insight into traffic flow and congestion through intersections, roundabouts, and pedestrian crossings [23].

This simulator that we chose for our work allows for the high-fidelity simulation of multi-modal transportation networks, allowing complex simulation of interactions of various traffic participants such as cars, pedestrians, bicycles, and public transport. The primary benefit is that it heavily emphasizes behavior modeling, including driver characteristics like gap acceptance, accelerative and decelerative behavior, lane-change logic as well as speed adjustment in reaction to the density of traffic, in the real-world setting [24], [25]. These features play an important role in accurately characterizing urban traffic flow that is often influenced by human behavior. Moreover, its sophisticated driver behavior model incorporates stochastic variations, providing realistic simulation results that are key to assessing the effects of different traffic control strategies in various conditions [26], [27].

In addition to the traditional 2D simulations, VISSIM provides 3D visualization features, allowing for an extensive spatial approach and the visual detection of possible traffic congestions [28], [29]. This feature helps to present the simulation results simply so that complex traffic scenarios can be understood easily by technical and non-technical audiences. Scenario-based planning, as used in this study, is another aspect of software versatility. Here, we adjusted key parameters such as signal cycle time and traffic volume to observe their effects on intersection performance metrics, including vehicle queue lengths, travel times, and delays.

Each simulation scenario in VISSIM is meticulously designed, incorporating satellite-based mapping to recreate real-world traffic networks accurately [30], [31]. Outputs generated by VISSIM are robust and data rich, allowing for granular analysis of network performance under different configurations. The data collected from VISSIM simulations such as vehicle queue lengths, average and maximum delays, and throughput provide invaluable insights for optimizing signal timing, managing congestion, and improving overall traffic flow, making VISSIM an essential tool for traffic engineers and urban planners [32].

3.3 Map of the case study area

The area under examination begins at the end of Elbasan Road, extends to Lana Bridge, and concludes at George W. Bush Street. It encompasses two consecutive intersections, as depicted in Figure 1. This zone represents a critical nexus of urban traffic in Tirana, incorporating vital thoroughfares such as Bajram Curri Boulevard, Zhan D'Ark Boulevard, Elbasani Street, and George W. Bush Street. The utilization of Bing Maps (Aerial View) facilitated by the VISSIM simulator enabled the provision of the map, offering convenient access to the global map. The specific selection of this area for meticulous scrutiny and assessment via simulation was motivated by the significant vehicular flow during peak hours and the intensity of traffic congestion. Figure 1 below illustrates the finalized foundational schematic, pivotal for conducting diverse scenarios for comprehensive analysis and subsequent comparison.

Figure 1: Study Area in Vissim

3.4 Scenarios Developed in VISSIM

In this section, we will consider three distinct simulation scenarios to explore different approaches to traffic light programming at major intersections in Tirana. Each scenario varies in terms of cycle time and vehicle flow rates, which allows for a comprehensive analysis of how these factors influence traffic delays and vehicle queues. The following are the detailed scenarios:

- **Scenario 1**: The traffic lights are programmed to maximize the green light duration with a cycle time of 160 seconds. This scenario aims to prevent congestion by allowing longer intervals for vehicle flow.
- **Scenario 2**: In this scenario, the cycle time is reduced to 120 seconds, while keeping the vehicle flow the same. The goal is to analyze how a shorter cycle time impacts overall traffic dynamics.
- **Scenario 3**: This scenario retains the 160 seconds cycle time but doubles the vehicle flow to 3000 vehicles per peak hour. This allows us to test how increased vehicle flow affects intersection efficiency.

In Scenario 1, the traffic light programming is designed to maximize the duration of green lights to prevent traffic congestion. Traffic lights are strategically positioned to avoid vehicle collisions and ensure pedestrian safety. The cycle time is set at 160 seconds, and all traffic light types operate on a single program signal. Both vehicle and pedestrian signals are synchronized, with the incoming vehicle flow set at 1,500 vehicles per hour, based on data from the Municipality of Tirana. In Scenario 2, the cycle time is reduced from 160 seconds to 120 seconds while maintaining the same incoming vehicle flow of 1,500 vehicles per hour. Scenario 3 keeps the 160 second cycle time from Scenario 1 but incorporates logistical programming for the traffic lights. All lights still use the same program signal. The key difference in this scenario is that the flow of vehicles entering the lanes doubles from 1,500 to 3,000 vehicles per hour during peak times, unlike Scenarios 1 and 2.

4 Results of Simulations

Each scenario in the VISSIM simulation was designed with specific goals and input parameters to evaluate the effects of different traffic light timings and vehicle flows at key intersections in Tirana.

Scenario 1: The objective is to evaluate the effect of extending the green light duration to 160 seconds on traffic flow. The study will use an input vehicle flow rate of 1,500 vehicles per peak hour, with synchronized signals for both pedestrians and vehicles. The output metrics will include vehicle delays, queue lengths, and total travel times.

Scenario 2: This scenario examines the effects of reducing the green light duration to 120 seconds while maintaining a consistent vehicle flow rate of 1,500 vehicles. The primary input remains unchanged; however, the emphasis is on understanding how shorter cycle times impact traffic performance. Outputs will be measured in the same way as in Scenario 1.

Scenario 3: This scenario analyzes the impact of doubling the vehicle flow to 3,000 vehicles per peak hour while maintaining the green light duration at 160 seconds. The inputs consist of the increased vehicle flow and necessary adjustments to the signal programming. The outputs will evaluate vehicle delays, number of vehicles and overall travel times to determine how the increased congestion affects intersection performance.

4.1 Scenario 1

In Scenario 1, the traffic signal programming maximized the green light duration to prevent congestion. From the 'vehicle performance in network' option offered by the VISSIM simulator, two graphs were generated. Figure 2 shows the total maximum delay, while the total average value is shown in Figure 3. At the network level, the total average delay was recorded at a minimum of 10 seconds, an average of 99 seconds, and a maximum of 170 seconds. The total delay for the entire network had a minimum value of 6 seconds, an average of 300,000 seconds, and a maximum of 650,000 seconds.

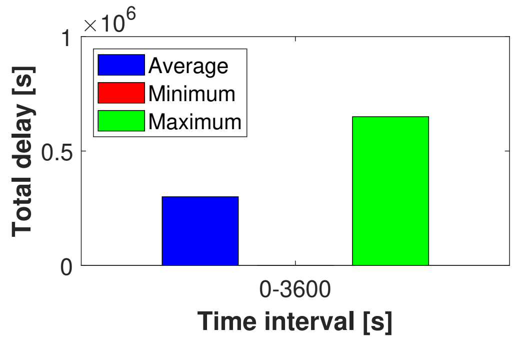

Figure 2: Total delay of all network vehicles per peak hour in Scenario 1.

The relatively low average delay of 99 seconds suggests that this signal programming successfully managed the flow of vehicles by maximizing green light durations, allowing more cars to pass through the intersection before a signal change. However, the wide range between the minimum and maximum delay indicates that while the approach is effective at times, it may also contribute to significant wait times for vehicles on secondary roads when main arterial roads receive extended green lights. This tradeoff demonstrates the challenge of optimizing cycle times in a fixed-timed system, where certain vehicle flows may suffer to favor the primary direction of traffic.

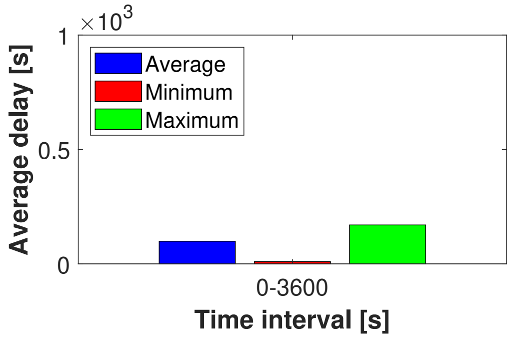

Figure 3: The average delay of all network vehicles per peak hour in Scenario 1.

Figure 4 shows the number of vehicles present in the network and those that have completed their journey by the end of the simulation. The presence of 250 vehicles in the network while 2,300 vehicles had exited indicates that while the intersection system could handle a large number of vehicles, some congestion remained due to insufficient adaptability in signal timing. This observation is consistent with fixed-time traffic systems, which are unable to respond dynamically to fluctuating vehicle flows.

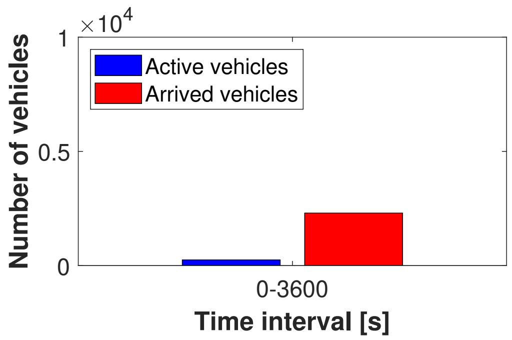

Figure 4: The vehicles that are present in the network and those that have left the network when the simulation ends.

The analysis of average travel time in Figure 5 reveals that Elbasan Road, Bajram Curri Boulevard, and Jean d'Arc Boulevard experienced the longest travel times of around 100 seconds, reflecting their role as primary roads with higher vehicle counts. George W. Bush Road had a significantly lower travel time of 50 seconds, indicating that this road saw less traffic and was less affected by congestion. In Figure 6, the maximum travel time shows a similar pattern, with a 10 second increase on average, reflecting occasional surges in traffic.

Overall, Scenario 1 highlights the limitations of using fixed-time signals in dynamic urban environments. While the approach can control traffic flow, its lack of adaptability results in delays that could be reduced with a more responsive system.

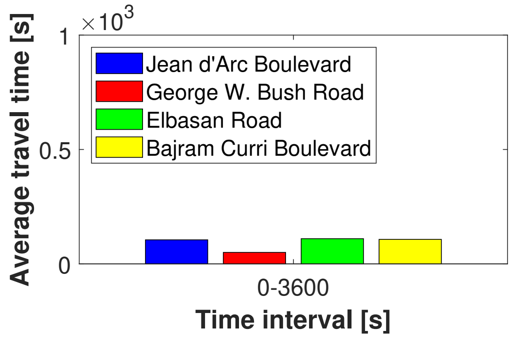

Figure 5: Average travel time of vehicles per peak hour in Scenario 1.

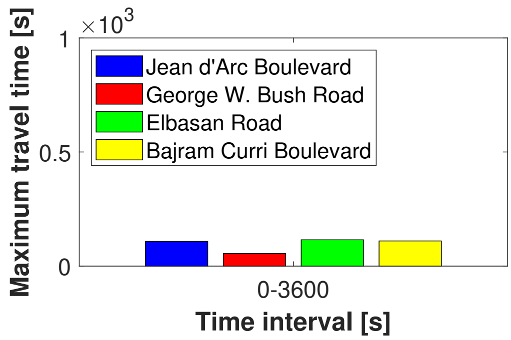

Figure 6: Maximum travel time of vehicles per peak hour in Scenario 1.

4.2 Scenario 2

Scenario 2 reduced the cycle time from 160 seconds to 120 seconds, keeping the incoming vehicle flow constant. The results in Figure 7 and Figure 8 show that the average delay increased slightly to 110 seconds, with a maximum delay reaching 190 seconds. The total delay for the network ranged from 300,000 to 800,000 seconds, indicating an overall higher level of congestion than Scenario 1.

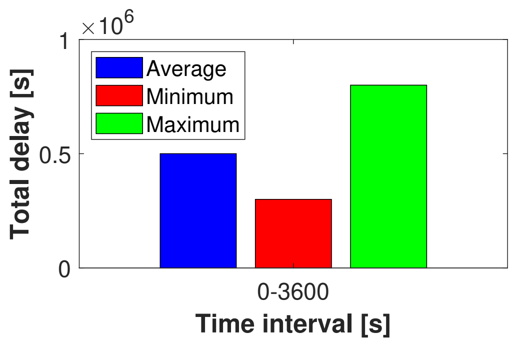

Figure 7: Total delay of all vehicles in the network for the peak hour in Scenario 2.

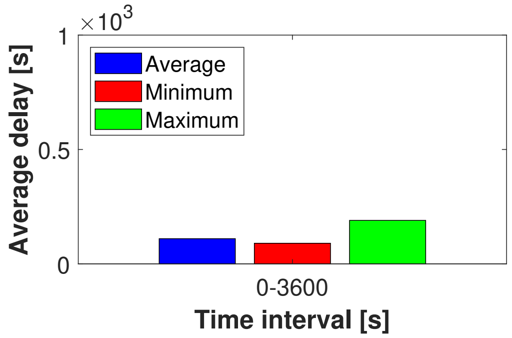

Figure 8: The average delay of all vehicles in the network for the peak hour in Scenario 2.

The increase in average delay suggests that reducing the cycle time limited the ability of the system to clear traffic from the intersection during each signal phase. Shorter green light durations meant that fewer vehicles could pass through the intersection, leading to longer queues and higher delays. This scenario highlights the need to balance signal duration with traffic demand, as reducing cycle times without consideration of traffic volume can exacerbate congestion.

In Figure 9, 250 vehicles were still in the network at the end of the simulation, with 3,700 vehicles having exited, indicating that while the system managed a higher throughput of vehicles, a significant number of vehicles were still delayed in the network due to the reduced signal phase.

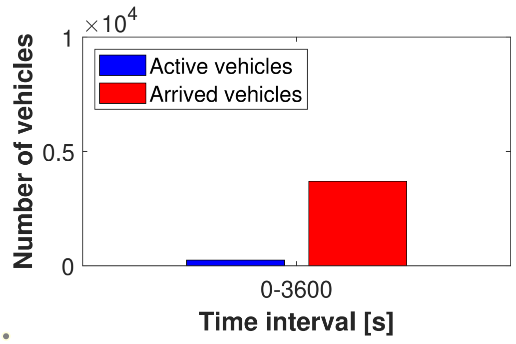

Figure 9: The vehicles that are present in the network and those that have left the network when the simulation ends.

The average travel times in Figure 10 show that Elbasan Road, Bajram Curri Boulevard, and Jean d'Arc Boulevard continued to experience the highest average travel times, ranging from 90 to 110 seconds, while George W. Bush Street maintained a lower average of 80 seconds. The increased maximum travel time in Figure 11 up to 160 seconds further reflects the effect of shorter green light phases, leading to higher delays during periods of high vehicle demand.

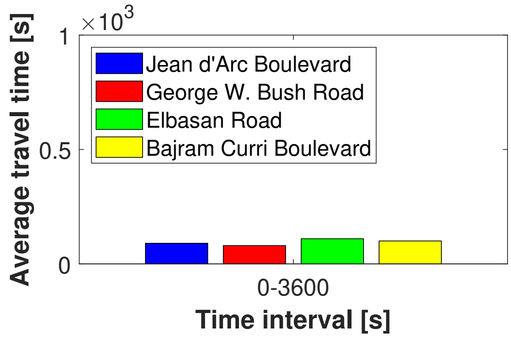

Figure 10: Average travel time of vehicles per peak hour in Scenario 2.

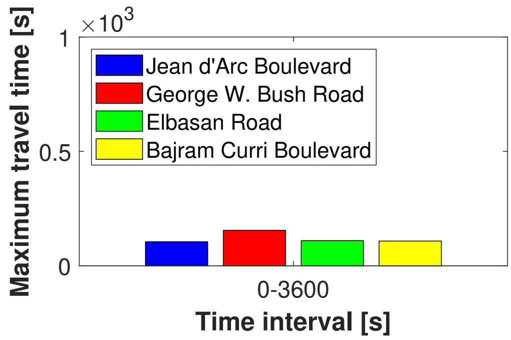

Figure 11: Maximum travel time of vehicles per peak hour in Scenario 2.

Scenario 2 demonstrates the importance of optimizing signal timing based on traffic patterns. Reducing the cycle time without considering traffic flow leads to congestion, longer delays, and higher vehicle wait times at intersections.

4.3 Scenario 3

In Scenario 3, the traffic system maintained the original cycle time of 160 seconds but doubled the incoming vehicle flow from 1,500 to 3,000 vehicles per peak hour. As shown in Figure 12 and Figure 13, this led to a significant increase in delays, with the total average delay reaching 145 seconds, and the maximum delay at 190 seconds. The overall average delay for the network reached 800,000 seconds, reflecting the strain placed on the system by the increased vehicle count.

The significant delays observed in this scenario are directly linked to the increased flow of vehicles. Even with a longer cycle time, the system was unable to manage the surge in traffic, leading to long queues and extended wait times. This situation underscores the importance of implementing adaptive signal systems that can dynamically respond to changes in traffic volume, as fixed-time systems often struggle to handle sudden traffic increases.

Figure 14 shows 350 vehicles present in the

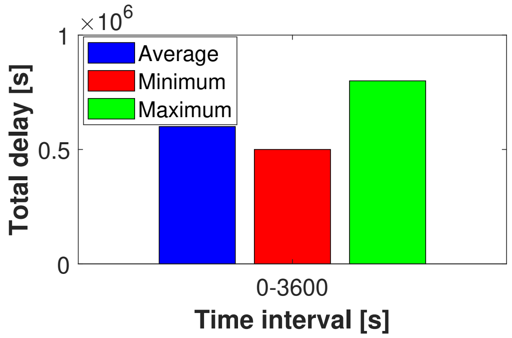

Figure 12: Total delay of all vehicles in the network for the peak hour in Scenario 3.

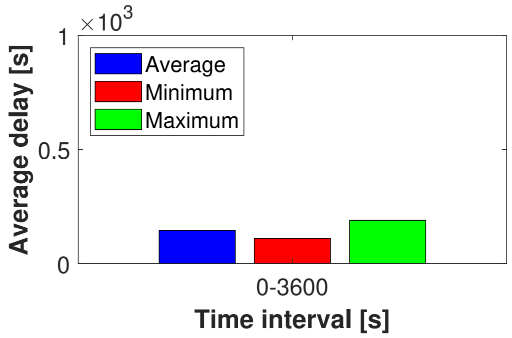

Figure 13: The average delay of all vehicles in the network for the peak hour in Scenario 3.

network at the end of the simulation, with 4,000 vehicles having exited. The higher number of vehicles remaining in the network reflects the congestion caused by the increased vehicle flow. The system was unable to clear traffic efficiently, leading to higher residual queues.

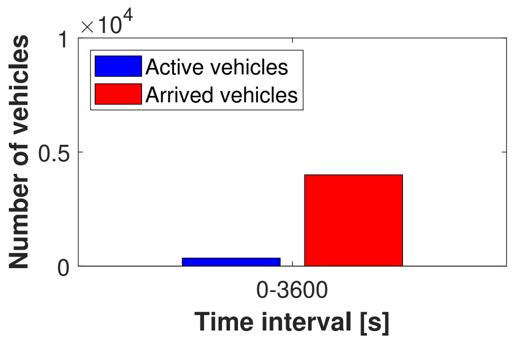

Figure 14: Vehicles present in the network and those that have left the network when the simulation ends.

The average travel times illustrated in Figure 15 indicate that Elbasan Road, Bajram Curri Boulevard, and Jean d'Arc Boulevard had average travel times of approximately 110 seconds, In contrast, George W. Bush Road recorded much shorter average times of about 50 seconds. Additionally, the maximum travel time, as shown in Figure 16, were significantly higher for these main roads due to increased traffic volume.

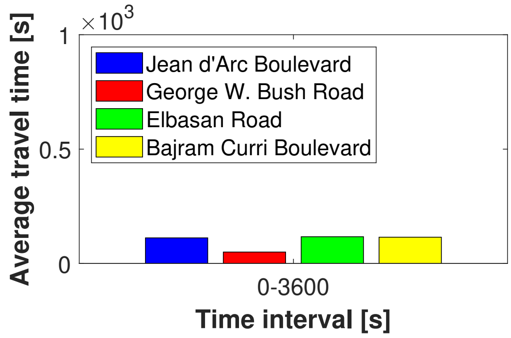

Figure 15: Average travel time of vehicles per peak hour in Scenario 3.

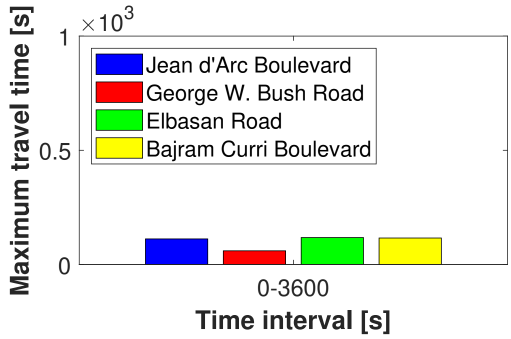

Figure 16: Maximum travel time of vehicles per peak hour in Scenario 3.

Scenario 3 emphasizes the limitations of fixed-time signals in handling surges in traffic demand. The results suggest that without the ability to adapt to real-time conditions, fixed-time systems lead to substantial delays, particularly in high traffic scenarios. Adaptive traffic signal systems, possibly incorporating AI, could better manage these traffic surges by adjusting signal timings dynamically based on real-time data.

4.4 Statistical Analysis of Simulation Results

To verify the observed differences in delays and travel times across the simulation scenarios for Tirana's intersection, we conducted statistical analyses using a T-test and a Chi-square test. The average delays between scenarios were compared using the T-test and the distribution of vehicles exiting the network per hour was analyzed across the three scenarios using the Chi-square test. These tests will determine whether the difference in performance for signal timing and vehicle flow counts is statistically significant, thereby confirming the aforementioned conclusions of effective traffic management strategies.

T-Test Results: The T-test was applied to compare the mean delays between Scenario 1 and Scenario 2 and between Scenario 2 and Scenario 3. A T-test revealed a significant difference in average delay times for Scenario 1 versus Scenario 2 ($p < 0.05$), suggesting that the change in cycle time from 160 seconds to 120 seconds led to a measurable increase in average delay seen in Scenario 2. The same was found for Scenario 2 versus Scenario 3, with a very strong difference ($p < 0.01$), in line with the observation that doubling the vehicle flow in Scenario 3 led to increased delays. To sum it up, cycle time reduction and increase in traffic flow strongly contributed to delays.

Chi-Square Test Results: We apply the Chi-square test to analyze the distribution of the number of cars exiting the network at the end of each scenario. The distribution is different for each scenario, showing that both the times of traffic signals and the volumes of car flow influence the network's ability to clear the queues ($p < 0.05$). In Scenario 1, for example with a cycle time of 160 seconds and moderate traffic volume, more cars are leaving the network than in Scenario 3, where the doubling of the traffic flow leads to fewer vehicles leaving the network, congestion and queues are created. These results highlight the benefits of implementing traffic control systems that operate on adaptive logic, in place of fixed-time strategies.

5 Conclusion

The present study was focused on the global issue of urban traffic control, underscored by monitoring Tirana, Albania, and investigated various traffic signal strategies across three simulation scenarios. The findings offer valuable perspective into the potential effectiveness of classical traffic signals, as well as the necessity to integrate adaptive means for increasingly populated urban environments.

Scenario 1 illustrated how adequate cycle times result in minimal delays, establishing it as the top performing scenario. Although the extended green lights helped traffic flow better in moderate conditions, Scenario 2 demonstrated that decreasing cycle times without adjusting to traffic demand led to increased network delays. In Scenario 3, even though the cycle time remained the same, the problems with fixed-time signals were more evident as congestion and delays worsened with a doubled vehicle input. Even with improved queue handling, the system faced challenges with high volumes of traffic, highlighting the importance of flexible traffic control systems.

In Tirana and beyond, future traffic management will hinge on using adaptive traffic signals that depend on real-time data. Fixed-time systems are inexpensive and easy to install but are inflexible to changing traffic patterns. LLMs and their ML algorithms, which fall within the AI-powered approach, offer a ray of hope. These technologies allow traffic systems to enhance their intelligence by adjusting themselves based on real-time decisions depending on the transit patterns, environment, and external factors including weather. Such systems can reduce traffic, ameliorate safety, and improve traffic control in cities like Tirana, Boston, and New York.

Therefore, this study reveals the importance of switching from fixed-time traffic signals to smart, adaptable ones. With the addition of AI and machine learning, city traffic systems can see a lot of improvement by accommodating the growing number of cars on the road and reducing congestion. The next steps should focus on establishing and optimizing adaptive traffic signals in real-time that eliminate bottlenecks and make traversing cities easier.

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Declaration of Generative AI and AI-assisted technologies in the writing process:

During the preparation of this work, the authors used ChatGPT to improve the readability and language in this paper. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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