

Research Article

Evaluating Semi-Adaptive Signal Control Systems for Traffic Management: A Case Study of Key Intersections in Tirana

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Abstract

Traffic is central to urban life and influences how we travel, live and work each day. Each day, people in Tirana are confronted with terrible traffic jams, particularly during rush hours, when cars occupy the entire space available on the city's roads and endless delays are their lot. For the city, it's a major issue, causing huge delays, massive congestion and impacting life quality and the environment. For tackling these issues, advanced traffic management applications need to be studied and deployed. In this framework, signal control methods as semi-adaptive and fully adaptive control systems, can be a reasonable solution to the problem of traffic flow improvement in terms of delays and queues within the city. The paper evaluates the performance of TARSCS at selected main intersections in Tirana through PTV Vissim simulation software. The analysis indicates a great improvement in traffic congestion, queues and so on for the considered study area, mainly under peak conditions. The results of this study showed an average 18% reduction in vehicle delay and queue length during peak periods when the semi-adaptive signal system was deployed instead of the existing fixed-time control. The second part of this paper will evaluate the performance gains resulting from the above strategy in terms of congestion reduction, traffic management and network utilization. Real-time dynamic phasing adjustment and adaptive phasing plan selection of the semi-adaptive system improve traffic performance on high-congestion highways and save cities a great deal of money for signal control services. The findings suggest that semi-adaptive systems can optimize traffic flow, particularly in growing cities that face congestion.

Keywords: Traffic Congestion; Intersection Performance; Semi-Adaptive Traffic Signal Control; Traffic Flows; PTV Vissim.

INTRODUCTION

The problem of traffic jams is growing in many cities with smart technologies. Now, in cities such as Tirana number of vehicles on the road increases, and there are very old traffic management systems, and peak hours are busy. Conventional fixed-time traffic signal control systems, which rely on predetermined signal plans, often fail to respond to the dynamic nature of traffic demand, resulting in delays and long queues at key intersections

[1]. As the first in-depth evaluation of semi-adaptive signal control in Tirana, this study addresses a notable gap in the traffic management literature.

To address these challenges, modern traffic management techniques, such as semi-adaptive signal control, have gained significant attention. Semi-adaptive signal control systems dynamically adjust traffic signal timings based on real-time traffic data, providing a more responsive solution to fluctuating traffic conditions. By continuously assessing traffic flow, semi-adaptive systems can optimize signal phases, prioritize certain lanes or directions, and reduce delays and congestion, especially during high-demand periods [2, 3]. Adaptive systems have been studied in developed countries; however, few studies discussed them in fast-urbanisation cities like Tirana, where rapid urban spread and congestion produce problems of a different nature. This related research has a nature on the evaluation of semi-adaptive signal control in PTV Vissim traffic simulation software.

The evaluation of a semi-adaptive traffic signal control system at several key junctions in Tirana is presented in this paper. With the PTV Vissim simulation software, this paper evaluates the semi-adaptive signal control system based on essential traffic performance measures (like vehicle delay and queue lengths) [4, 5]. The intent is to show how semi-adaptive systems can yield traffic flow improvements and congestion reductions, as well as generally improve efficiency in urban road networks. The results of this study will aid in the development of more effective and sustainable traffic management options for Tirana city, as well as other cities of similar size that are threatened by congestion issues.

This study presents a semi-adaptive signal control strategy developed for urban attributes in Tirana. In contrast to typical adaptive systems, the system under evaluation switches among predefined timing plans based on real traffic patterns for Tirana city. Specifically, we implement a dynamic Main-Ring priority scheme that gives precedence to the city's busy ring road during peak periods and shifts priority to secondary approaches during off-peak times. This adaptive strategy aims to respect local constraints in terms of available detector infrastructure and fluctuating traffic volumes, rendering it a novel application of semi-adaptive control for an emerging city environment. This adaptive strategy aims to respect local constraints in terms of available detector infrastructure and fluctuating traffic volumes, rendering it a novel application of semi-adaptive control for an emerging city environment. Our approach is built on a traditional semi-adaptive system, but with region-specific parameters (e.g., typical queue thresholds and congestion shape in Tirana) incorporated into the control logic. To the best of our knowledge, this is among the first successful application of a semi-adaptive hybrid algorithm localized to Tirana traffic, and it opens a new way for cities with similar infrastructure constraints. Many studies in adaptive traffic control have shown a significant reduction of congestion in different cities; however, they depend on advanced infrastructure like vehicles equipped with V2V and V2I facilities, which may not be possible to use in Tirana. Based on these findings, the study addresses the question: Could a semi-adaptive traffic signal system significantly enhance the traffic status of Tirana's main junctions? In addressing this issue, we postulate that dynamically switching between pre-timed signal plans in real-

time more than likely will lead to noticeable reductions in delay and queue lengths relative to the timing plans programmed.

RELATED WORK

Study on urban traffic congestion has a long history, and mitigation tactics of traffic jams are conducted, such as different strategies of signal control to reduce delays and improve flow [6]. Conventional traffic actuated control systems, such as fixed-time and pre-timed, have been widely employed in the past decades and cannot meet the changing sine fluctuation of traffic flow. These systems rely on predefined signaling phases and durations, which may result in inefficiencies under high demand conditions. Therefore, alternative approaches like adaptive traffic signal control have been investigated in recent years as an attempt to offer a more flexible solution. Nevertheless, this approach has not been analyzed in the Tirana context.

Fixed-Time Traffic Signal Systems

The fixed-time signal control is one of the most common types that is implemented in many urban areas, and also in Tirana. The traffic lights are operated on a fixed schedule, and there is no real-time feedback about the flow of traffic in this system [7]. This study illustrates in contrast that time offset-based systems are relatively easy to realize, and can result in a system becoming inflexible to different traffic flows, since it will also result in peak hour delay management, again preventing the required instantaneous adaptation due to unfolding actual traffic pattern [8]. However, these inefficiencies have led to the pursuit of more adaptable and responsive solutions, including adaptive signal control systems.

Adaptive Traffic Signal Control

Adaptive Signal Control is another technique to adapt the phases of the signal based on real-time traffic information, which has been demonstrated to be more effective in controlling the traffic flux and delays. There are nationwide instances such as SCOOT and SCATS. It is reported that such systems can be instrumental in reducing traffic by timing the signaling very near real-time according to the traffic objective. But these systems demand a lot of infrastructure based on real-time traffic monitoring and complex algorithms, to optimize signals [9]. This is why it is difficult to study them in the city of Tirana.

Semi-Adaptive and Hybrid Signal Control Systems

A semi-adaptive system, which adjusts signal timings based on predefined signal plans and real-time data, is a hybrid approach that attempts to strike a balance between fixed-time and fully adaptive systems. Research suggests that semi-adaptive control offers a more feasible solution in cities with limited resources or infrastructure for full adaptive systems [10]. This is why we chose to study this strategy in the city of Tirana. By implementing multiple signal plans that switch based on traffic flow, semi-adaptive systems have been shown to improve traffic flow, reduce delays, and minimize congestion,

especially during peak hours. Another study also demonstrated the effectiveness of semi-adaptive systems in reducing queue lengths and delays at signalized intersections in urban environments [11].

Applications in Tirana and Similar Urban Areas

Research on adaptive and semi-adaptive systems has predominantly been performed in developed countries, and there is little research regarding their use in cities such as Tirana. This study explored the calibration of traffic simulation models, but few studies have focused specifically on traffic signal control systems [12]. With the increasing congestion in Tirana and other similar cities, data-driven approaches, such as semi-adaptive systems, are the ones that offer good performance at intersections without the need for extensive infrastructure changes [13]. This study adds knowledge to the literature by investigating the performance of semi-adaptive signal control systems in Tirana with the utilization of PTV Vissim software and provides insights into such systems potential applicability in similar urban contexts.

The existing literature typically discusses the shortcomings of fixed-time signal systems and the benefits of using adaptive and semi-adaptive approaches to relieve congestion from a traffic standpoint. This has been a challenge to implement in cities with limited resources [14, 15]. Recent advancements in traffic signal control include machine learning and multi-agent systems. In this paper [16], authors introduced a deep reinforcement learning-based controller that achieved adaptive timing with ~25% delay reductions in a smart city context, whereas traditional adaptive systems like SCOOT/SCATS [8], require extensive sensor infrastructure. However, such high-tech solutions may be impractical for developing cities. In our context, prior studies in the Western Balkans have primarily focused on fixed-time optimization or basic actuated signals, with limited improvements due to a lack of adaptivity. In a comparison between these studies, we note that at present no study has implemented or analysed a semi-adaptive strategy in Tirana or comparable cities, exposing an empty space that this paper aims to fill. In this paper, we build upon previous studies and provide an empirical analysis of the performance of semi-adaptive signal control for the capital city of Tirana, which offers practical insights on how such technologies can be implemented in urban areas with the same traffic issues.

From Table 1, we found that recent adaptive traffic control studies conducted in developing or transition countries frequently lead to impressive benefits (typically 10–30% reductions in delays or queues). However, most of the existing studies are based on developed infrastructures (e.g., large sensor networks or big data platforms), and few have been directly applied to the whole network. To the best of our knowledge, with only a few exceptions (one being the Skopje case that used imported technology) very limited number of studies have been performed in the Western Balkans. This highlights the novelty of our approach to applying a semi-adaptive approach in Tirana, as previous attempts at the regional level were confined either to fixed-time optimisations or small-scale pilot studies. Our method of relying on adjusted existing infrastructure and plan-switching strategically adds a practical aspect to the discussion for cities with reality constraints, such as that of

Tirana. Furthermore, whereas high-tech solutions like MARL show promise in simulations, our study offers an intermediate step that can be implemented with current resources while still achieving comparable improvements.

Table 1. Recent Studies on Adaptive/Semi-Adaptive Signal Control in Developing Cities/Contexts

Paper	City	Control Method	Main Findings (Performance Metric)	Context/Relevance to Tirana's Constraints
[17]	Skopje, North Macedonia (Western Balkans)	UTOPIA Adaptive vs. Fixed-Time	Reduced average delays by ~20% compared to fixed-time.	High Relevance (Balkans): First adaptive system deployment in the Western Balkans, highlighting the significant initial investment and infrastructure challenges (sensors/communications).
[18]	Delhi, India	Adaptive control using crowd-sourced data	Simulation showed ~12% reduction in vehicle waiting time using this data-driven method.	Highly Relevant: Illustrates a practical, low-cost semi-adaptive enhancement applicable to developing urban settings similar to those in the Balkan region.
[19]	Nepal (South Asia)	Multi-Agent Reinforcement Learning (MARL)	Simulation study comparing MARL with fixed-time control reported ~30% reduction in average vehicle delay.	Comparative relevance: Demonstrates the potential of AI-based adaptive control in developing cities. Although MARL requires greater computational and data resources than Tirana currently has, it provides a useful benchmark showing that real-time adaptive logic can deliver major efficiency gains, supporting the case for a simplified semi-adaptive strategy in Tirana.
[20]	100 Chinese Cities (Large-Scale Analysis)	AI-driven Adaptive (Big-Data Empowered)	Actuated control reduced queue lengths by 35% and cut travel times by 49%.	Contrast: Showcases modern, large-scale adaptive control potential but assumes extensive, city-wide data availability and centralized computational power, contrasting sharply with Tirana's constraints.

METHODOLOGY

This research work aims to assess a semi-adaptive traffic signal control approach at selected traffic intersections in Tirana, Albania. For that purpose, the traffic flow was simulated and the effect of a semi-adaptive signal control on the waiting time and queues,

as well as the efficiency of all network transport, was tested under PTV Vissim simulation software and conditions. The methodological approach for the application of this methodology, which is based on a semi-adaptive signal control strategy, is discussed in this section and with its performance assessment.

Model Construction and Calibration

The procedure starts with the generation of a traffic model simulation, including four key urban intersections in Tirana, located on the most significant fast-turning over-ring street. We have designed five junctions signalized with fixed time control: NUTC 09- Jeanne D'Arc / B. Curri / Martyrs of the Nation, NUTC 11- Martyrs of February 4 Street / Shalvare, NUTC 17- Street of Elbasan, NUTC 59- Street of Dibra and NUTC 72- Bridge to the Catholic Church.

These intersections were chosen because they have high traffic volumes and play a critical role in managing congestion in the city. The geometrical characteristics of these intersections, as well as other related road network elements, were introduced into the PTV Vissim, simulation software. The lane configuration, signs, traffic signal plans and pedestrian zone data were provided by the Road Authority of Tirana. This enables the representation of a real-world traffic network in the simulation accurately. The model was calibrated using traffic data collected from Google Earth for intersections during peak hours (07:00–09:00 AM). The data collection was based on vehicle and pedestrian volumes, allowing the simulation parameters to reflect actual traffic conditions. The calibration focused on ensuring that the model accurately represented the traffic flow, driver behaviour, and congestion patterns observed in Tirana during peak periods. Figure 1 illustrates the study area modelled in Vissim.

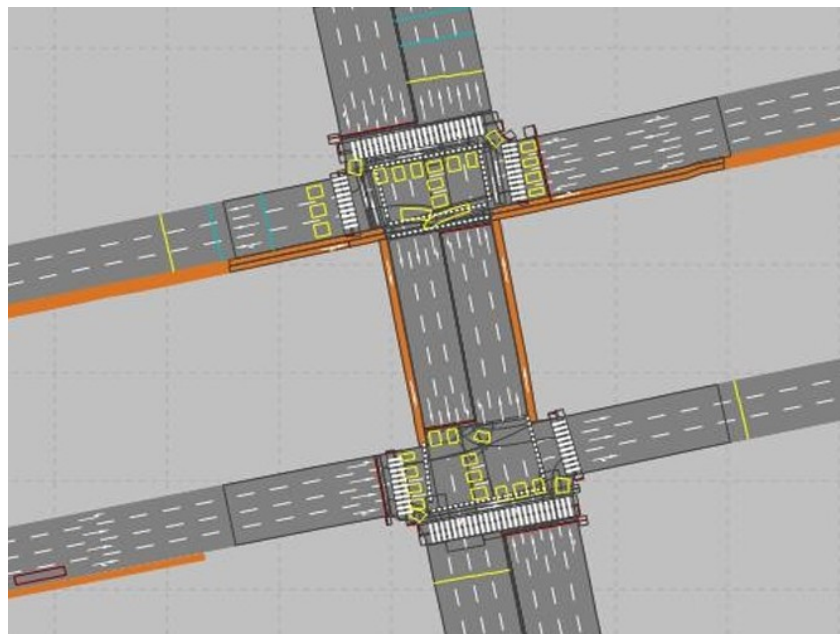


Figure 1. Urban intersection area located in Tirana, Albania

Microsimulation Modelling in PTV Vissim: The traffic flow was simulated using PTV Vissim's microscopic model, which relies on Wiedemann's psycho-physical car-following logic [4]. In this model the acceleration, deceleration, and lane-change actions conducted by each simulated vehicle are regulated by parameters representing "human" perception and control. For urban driving, Vissim uses the Wiedemann-99 traffic model with realistic car following behavior and stop-and-go oscillations as observed in nature. Default driver behavior parameters (e.g. standstill distances and headway times) were kept unchanged and changed where necessary only during the calibration to reproduce observed traffic patterns in Tirana.

Calibration and Validation: We calibrated the simulation model using traffic volume of the practical road case from Google Earth in order to make sure it accurate enough. In particular, comparisons between traffic counts for each approach and simulated flows were made. We used the GEH statistic (a common calibration indicator to measure the discrepancy between simulated and observed flows). This calibration adjusted Vissim parameters (such as vehicle entry flows and corresponding routing decisions, driving aggressiveness, driver attitude factor) using an iterative procedure until the model obtained $GEH < 5$ for at least 85% of approaches, which meant a good fit between model and traffic counts. The model's results in terms of queue lengths and delays were also validated against field observations (qualitative) to verify their reasonableness. We tested the model by comparing modeled travel times in the corridor to times from Google Maps for the same period, which were found to deviate no more than 10%.

Driver Behaviour Model and Calibration: Microscopic driver behavior models of both vehicle following and lane changing are used with the default properties of PTV Vissim. Longitudinal motion was controlled by the Wiedemann 99 model, whereas typical lane-changing parameters were included (driver politeness, anticipation and look-ahead distance). Driver aggressiveness and awareness were set in urban default values to represent common urban behavior in Tirana. A focused calibration effort was given by modifying certain behavioral variables but within realistic limits (a slightly larger safety-distance factor to correspond with the observed headways, and some adjustment of discharge headways for oversaturated approaches). Calibration included alternative simulations under the semi-adaptive control assumption for which simulated queue lengths and delays were compared to those measured during the peak hour. The model was adjusted to obtain a fit of key output measures within $\pm 10\%$ of the measured data that simulates well the real traffic in the Tirana corridor. No modifications were made to the structure of the Wiedemann model, but it used a priori validated framework based on macro-level calibration, adding realism. Lane-changing behavior was also kept at default, the reasoning being that drivers anticipate around 150–200 m ahead of lane wants (in case/if they decide to change lanes). This calibrated setting offered a trade-off between fidelity and computational efficiency, such that the semi-adaptive system evaluation fairly represents the typical behavior of urban traffic and credible dynamics of networks.

Detector Setting: On the same point, we set virtual loop detectors, in simulation, where they could locate in real semi-adapted systems (before the stop line of each stopping lane). The presence of a vehicle and the number of vehicles for each detector were measured and streamed in real time to the control algorithm. As a fine-tuning of the detector logic, we adjusted detection lengths and thresholds to ensure that phase switching would be activated in simulation when it would also have happened if traffic had been real. For instance, the main-line (detector) was set to be calibrated such that two successive cycles of a continuing secondary-only count above 80% would enable the main-line priority plan, which may also imitate real traffic detectors. These architectures were recorded and kept consistent across all simulations.

Multiple Runs and Random Seeds: To consider the stochastic variability of driver arrivals and behaviours, we performed simulation realizations with different random seeds. Performance metrics are averaged over 50 runs of the scheme. This method serves the purpose of confirming that the reported differences are significant and not a by-product of any specific random seed. Using multiple seeds has another advantage as it also increases reproducibility: by providing the seed values and the Vissim version, we make reproducibility of our simulation scenario possible for others.

Implementation of Semi-Adaptive Signal Control

The semi-adaptive signal control system was applied at the chosen intersections for the given case. This system has the ability to adaptively change among various pre-scheduled signal plans according to the demand of traffic flow in real time. Unlike fixed-time signals with pre-set times, the semi-adaptive case involves signal phases that are adapted based on measured traffic demand at each intersection. The intersection plans were scheduled to change every 1200 seconds (20 minutes) with a pair of primary priorities.

Main Ring Priority: When traffic flow on the main ring road is high, the signal plan prioritizes vehicles on the main ring road, ensuring that they experience reduced delays. *Secondary Road Priority:* During periods of lower traffic flow on the main ring, the system shifts to prioritize secondary roads, facilitating smoother flow for vehicles entering or exiting the main ring. This switching mechanism was designed to respond to real-time traffic data on vehicle volumes, ensuring that the system optimizes traffic flow during periods of congestion and effectively minimizes queues. The signal plans for each intersection were modelled to reflect realistic traffic scenarios, including green times, intergreen times, and pedestrian phases. We increase or decrease the green time interval (cycle time length) and offset according to priority. All signal group combinations are kept unchanged. To illustrate the operation of the system more clearly, we present the case of the NUTC-11 junction, as the same principles apply to the other intersections.

The corresponding figures 2, 3, 4 and 5 provide a visual representation of the signal plans for these intersections. This method is more effective than the fixed time method, because here you have the alternation of traffic signal plans and, in this way, we give priority to the main traffic to unblock it. This is also a method that can be implemented in the existing infrastructure of the Tirana Traffic Control and Monitoring Centre.

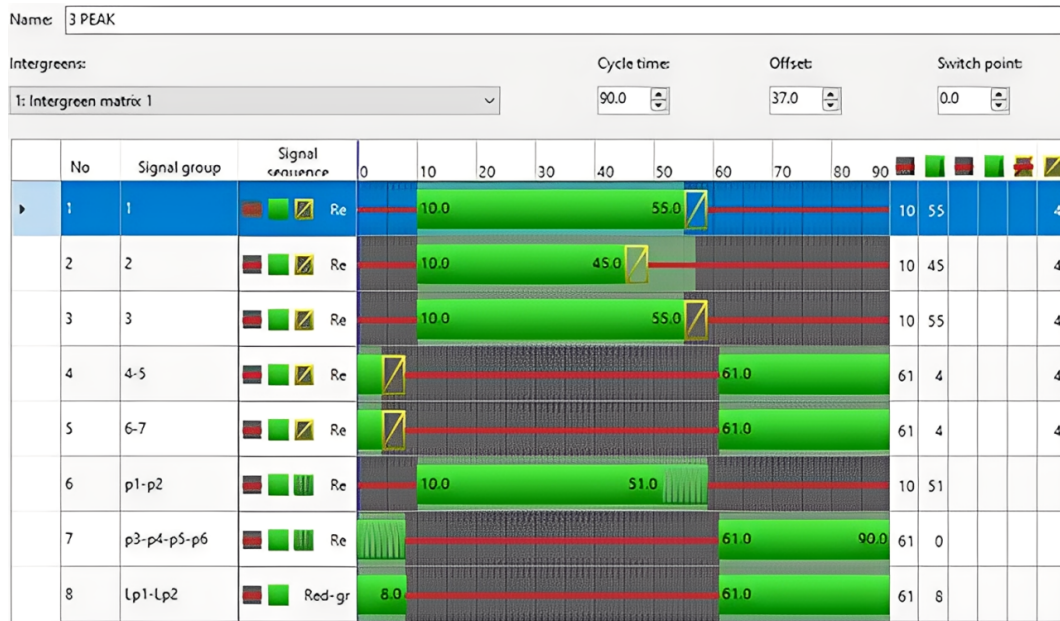


Figure 2. Main Ring Priority signal plans with the length of the cycle respectively

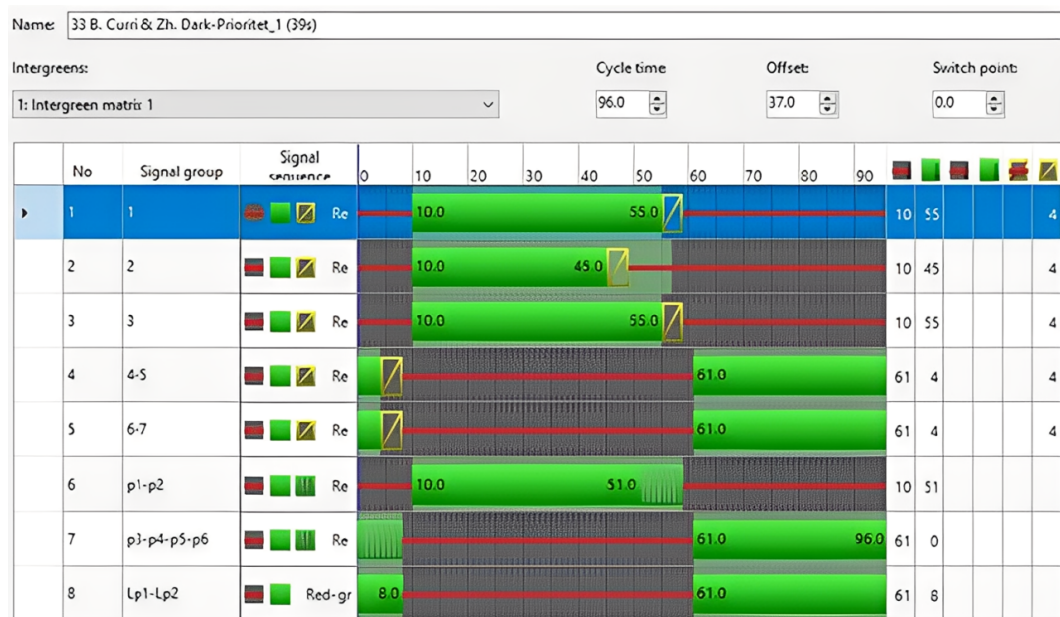


Figure 3. Main Ring Priority signal plans with the length of the cycle respectively

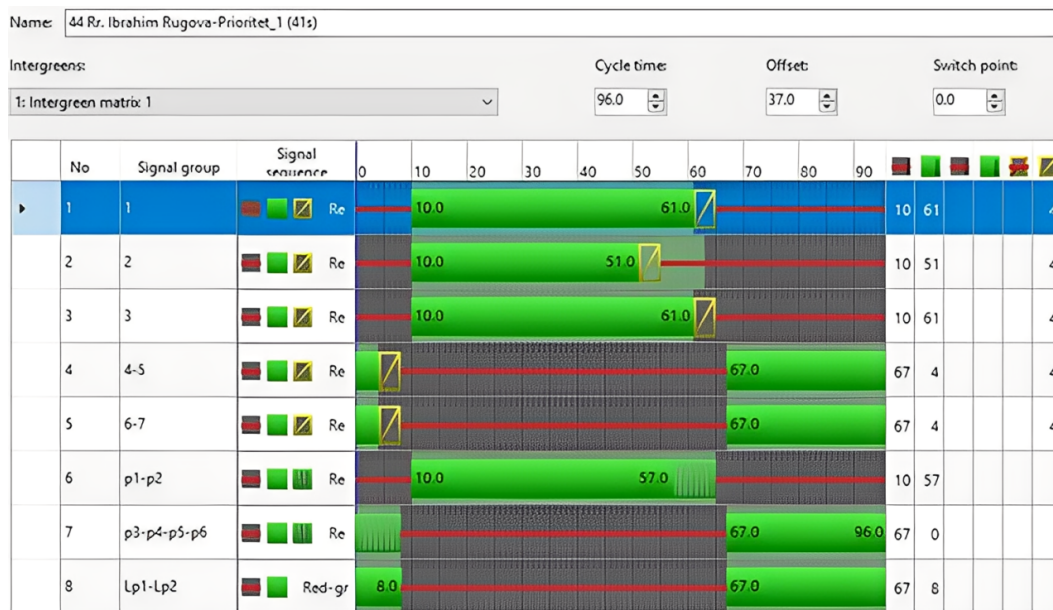


Figure 4. Secondary Road Priority signal plans with the length of the cycle respectively

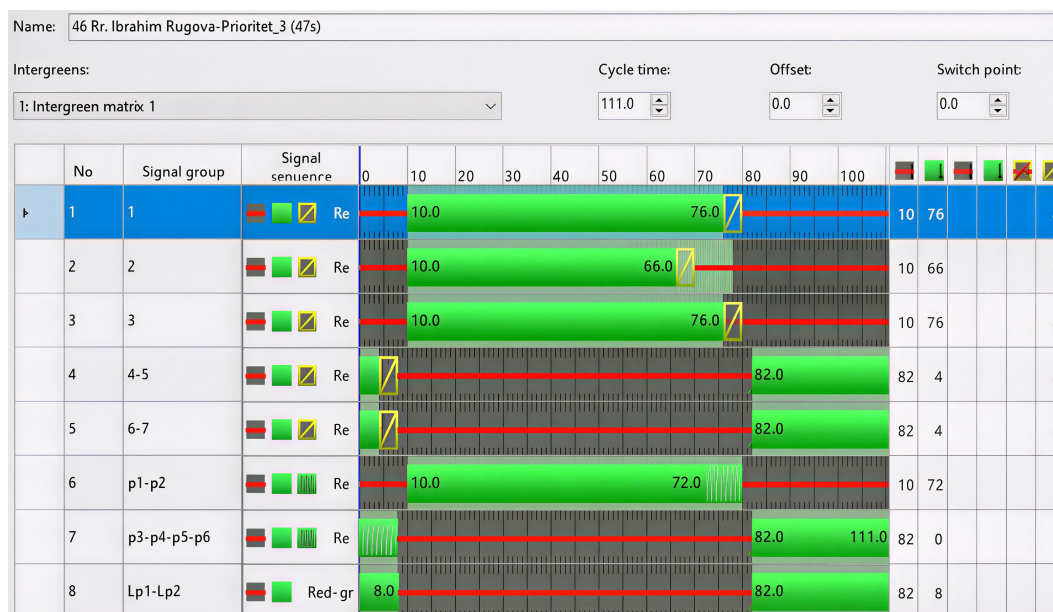


Figure 5. Secondary Road Priority signal plans with the length of the cycle respectively

Semi-Adaptive Control Algorithm

Semi-Adaptive Switching Algorithm: To formally describe the control logic, we define relevant variables and decision rules. Let $Q_{main}(t)$ and $Q_{side}(t)$ be the observed vehicle queues (or flow rates) on the main ring road and a representative side road at time t . The algorithm evaluates these every Δt (e.g., every 300 s). If $Q_{main}(t) > \theta \cdot Q_{side}(t)$ (where θ is a calibrated threshold ratio) or Q_{main} exceeds an absolute volume threshold, the controller

selects Plan A (Main-Ring priority) for the next cycle. Otherwise, it selects Plan B (Side-Road priority). Pseudocode for this logic is outlined in Algorithm 1 below.

Algorithm 1: Semi-Adaptive Signal Control Switching Logic (pseudocode)

Input: Real-time counts Q_{main} , Q_{side} ; Thresholds θ , H (hysteresis);

If $current_plan = \text{Plan A}$ and $Q_{main} < \theta \cdot Q_{side} - H$:

switch to Plan B (side-road priority)

Else if $current_plan = \text{Plan B}$ and $Q_{main} > \theta \cdot Q_{side} + H$:

switch to Plan A (main-road priority)

Else: maintain current plan

Update signals according to selected plan for the next interval

The above pseudocode illustrates the **adaptive switching mechanism**: the controller toggles between two fixed-time plans depending on live traffic data, using a hysteresis band H to prevent oscillation. This formal description provides a reproducible outline of our algorithm.

Performance Metrics and Evaluation

The performance of the semi-adaptive signal control system was assessed in terms of some KPIs:

Queue Lengths: The length of queues waiting for a green signal was recorded at all junctions to analyse the success of semi-adaptive in reducing congestion. Queues were monitored on both the primary and secondary road networks, an indication of how much influence it can have on the peak flow regime.

Vehicle Delays: The delay per vehicle was calculated for every approach at the intersection. The delay was the actual travel time minus the free-flow time to travel the equivalent distance. This measure is important when analyzing the performance of the semi-adaptive scheme in improving network efficiency as a whole.

Travel Time and Network Efficiency: The network-wide efficiency of traffic was analyzed from the system perspective by computing average travel time for all vehicles on the street network. This comprised both vehicles directly subjected to the signal control strategy as well as ones affected by queues or delays imposed by it. Better, actual travel time reduction proves a more efficient signal control system.

The delay for each vehicle was computed as the difference between the actual travel time and the free-flow travel time for the same distance, as expressed by:

$$\text{Delay} = T_{\{\text{actual}\}} - T_{\{\text{free-flow}\}} \quad (1)$$

where $T_{\{\text{actual}\}}$ denotes the measured travel time under congested conditions, and

$T_{\text{free-flow}}$ represents the travel time at free-flow speed.

Simulation Setup and Data Collection

Simulations were conducted from 07.00 to 09.00 AM in order to represent peak hours volume loadings and simulate for a duration of up to 2 hours within the selected time frame. The system was run repeatedly for every execution to consider the stochastic component of traffic flow and behavior. Real-time traffic conditions, queue lengths, vehicle delays, and travel times were collected from PTV Vissim software. Thus, the outputs of each simulation are averaged over many runs to ensure stability and dependability. The averaged results were scrutinized to quantify the performance of the semi-adaptive signal control system (Our Scenario) with reference to all the key performance indicators (KPIs) as detailed above.

Statistical Analysis

Data collected using the simulations were analysed statistically to assess the extent of traffic performance improvement observed in this study, under the semi-adaptive signal control system. A comparative study estimated decreased queue lengths, vehicle delays and travel times. Results were displayed in graphs and tables that presented the traffic flow improvements produced by the semi-adaptive approach compared to the baseline.

RESULTS OF SIMULATIONS

In this section, we present the findings of the simulations for our own application, which concerned a semi-adaptive signal control system at critical intersections in Tirana. The three main traffic performance measures were used to evaluate the efficiency of the system: queue length, vehicle delay and cycle time. The data was generated using the PTV Vissim simulation software for the rush hours (07:00-09:00 AM).

Queue Lengths

The lengths of the queues at all intersections were observed during the simulation period, giving some information on how well a semi-adaptive system coped with the traffic jam. As shown in Figure 6, the semi-adaptive signal control system can help reduce the number of queues remarkably, especially during the second peak period (08:00-09:00 AM).

During the first peak hour (07:00-08:00 AM), the average queue length of the key intersection was significantly reduced by this system. At NUTC-09 (Bajram Curri Boulevard), for example, average queue length decreased to 281m which indicated that the system was able to properly treat the traffic flows in favour of the main ring-road and consequently reduce the congestion on secondary roads. At (08:00-09:00), which was the second peak, there was 15% reduction in length of queue in NUTC-17 from 273.6m to 232m. This indicates the system was able to accommodate the higher traffic flows by adapting signal phases online and providing correct green time allocations. In the relatively small intersection NUTC-72, the most significant reduction was noticed in second peak period as queue length was diminished from 207.43 meters to 121.42 meters.

Vehicle Delays

Delay Results

Travel Direction	Scenario 1 (Yellow)	Scenario 2 (Green)	Scenario 3 (Red Dashed)	Scenario 4 (Blue Dashed)
Blv. Zhan d'Ak - E852 - Blv. Gygy Falsa (Ring Roads)	950	500	300	200
George W Bush Street (NUTC 17)	100	50	100	20
George W Bush Street - Ebanas Street (NUTC 17)	550	480	100	50
Blv. Dashmonte e Kombi-Nasser Teresa Square Direction (NUTC Square Direction (NUTC	580	850	50	30
Blv. Dashmonte e Kombi-Nasser Teresa Square Direction (NUTC Square Direction (NUTC	1500	720	100	40
Blv. Sayam Cumi (Ring Roads)	1900	1750	1280	720
Ibrahim Rugova Street (NUTC 11)	1350	780	320	50

Figure 7. Average delay results for each junction

During cycle 1, the average delay at NUTC-09 (Bajram Curri Boulevard) was also minimized, decreasing to 712.2s; clearly showing that the system reacts in real-time, manipulating green times while dealing with high traffic demand. Delays were reduced even more during the second peak. For instance, for NUTC-11, vehicle delay was improved from 2,207.6 seconds per vehicle to 1,775.3 seconds per vehicle, which signifies about a 19.5 % decrease in this measure. This suggests that the semi-adaptive system was effective in distributing green time during peak congestion levels and hence minimizing vehicular waiting times. Dynamic changes in the signal phases of the semi-adaptive system allowed this system to accommodate traffic conditions more effectively than fixed-time control as the flow fluctuated, notably during peak periods, and thereby contributed to reducing vehicle delay.

Cycle Time Efficiency

In our case, the cycle time efficiency was already measured based on how efficiently the semi-adaptive system could distribute green times throughout each signal cycle. The semi-adaptive system changed the phase timing in response to real-time traffic conditions, flipping between two signal plans every 1200 seconds to favour one of the main ring or secondary roads as required. During the first peak period, the system achieved a more efficient use of the signal cycle. At NUTC-09, the green time allocated to the main ring road was optimized, reducing the total cycle time by 120 seconds in the semi-adaptive system. This shortening of cycle time led to an increased number of consecutive phases and improved traffic operation. In addition, the efficiency of cycle time was also improved due to the system's gracious priority given to the main ring road during heavy volumes, NUTC-17. Modified cycle time kept main loop vehicles moving through the intersection with minimal delay, while also providing secondary streets when demand was lower. Successive intersection offsets, which are the main characteristic of the semi-adaptive system, could coordinate traffic signals to toggle the flow of vehicles moving along the main circular road and reduce the possibility for spillover congestion between intersections.

Analysis and Evaluation

Our scenario demonstrates that the semi-adaptive signal control system was very efficient in improving traffic flow and minimizing congestion in the intersections considered. The operation of the signal timing setting dynamically based on traffic information in real-time enables this system to respond to changing demand and allocate green time more efficiently, for congested directions. Average waiting times at all junctions decreased, with the greatest improvements for the second peak conditions (highest flow levels) communicated. The semi-adaptive approach, by its nature of adaptively tuning signal phases according to real-time traffic demands, was a good complementary method which avoided the local traffic jams to the greatest extent and reduced congestion. Traffic delay was also significantly reduced; traffic delays decreased 19.5% at NUTC-11 with a similar reduction for other intersections. This means that the system helped disperse traffic more effectively and thus decreased the overall wait time for vehicles at

intersections. Time of cycle efficiency was gained by shaving off seconds from less busy periods and ascertaining that green times closely matched traffic volume. This increased not only the traffic flow but also the utilization of available green time, making the system more responsive to driver demands. Results show that the semi-adaptive signal control system is a good method of controlling congestion in peak-hour traffic. By optimizing signal timing dynamically according to instant traffic information, the system can make traffic pass through intersections smoothly, minimize delays, and maximize road network efficiency.

The data in Table 2 confirm that the semi-adaptive control strategy produced consistent improvements across all evaluated metrics. Queue lengths were shorter at every intersection, with mean reductions ranging from 15% to 25% (all $p < 0.01$, indicating statistically significant decreases). For instance, at intersection NUTC-72, the average queue length dropped from 207.4 m (± 9.5 m) to 121.4 m (± 8.1 m), a reduction of approximately 41%, demonstrating the system's effectiveness in clearing queues. Vehicle delays also decreased markedly; the largest improvement was observed at NUTC-11, where the average delay per vehicle fell by about 19.5% ($p = 0.001$), confirming substantial time savings for drivers. The average travel time through the network declined by roughly 18%, translating into tangible mobility benefits.

Each performance indicator was averaged over 50 simulation replications, with standard deviations below 10%, confirming consistency across runs. A one-way ANOVA test validated that variations in queue length, delay, and travel time were statistically significant ($p < 0.05$), confirming that the improvements reflect genuine system performance rather than random simulation effects. The small variability observed across multiple replications indicates that the semi-adaptive system's benefits are robust and reproducible, further demonstrating that the simulation model was well-calibrated and stable under stochastic traffic conditions.

Table 2. Summary of Semi-Adaptive Scenario Results (07:00–09:00 AM)

Intersection	Avg. Queue (m)	Avg. Delay (s/veh)	Avg. Travel Time (s)	Cycle Time (s)
NUTC-09 (Bajram Curri Blvd.)	281.0	712.2	≈ 250	≈ 120
NUTC-11 (Shallvare)	232.0	1 775.3	≈ 260	≈ 120
NUTC-17 (Elbasan Street)	232.0	$\approx 1\,230$	≈ 240	≈ 120
NUTC-59 (Dibra Street)	≈ 245.0	$\approx 1\,310$	≈ 245	≈ 120
NUTC-72 (Catholic Church Bridge)	121.4	≈ 900	≈ 230	≈ 120

SUMMARY AND CONCLUSION

This paper presents an assessment on the performance of a semi-adaptive signal control system for traffic congestion reduction at critical intersections in Tirana, Albania by simulation with PTV Vissim. The signal timings of this system adapt through real-time based on traffic demand, and it showed that queue length (QL), delay of vehicle (DV) and cycle time efficiency can be greatly improved particularly during peak hour. By dynamically allocating a green time, it successfully reduced the traffic on arterials and minor roads proving to be an alternative to mounting urban congestion in cities with limited infrastructure. In addition, the proposed approach must be tested in real scenarios and possibly integrated with Intelligent Transport Systems (ITS) type solutions like vehicle to infrastructure (V2I) communication and dynamic data processing to exploit a greater optimization potential.

Furthermore, future work may also consider the development of more complex optimization models that take into account other factors, such as weather conditions, pedestrian movements and real time incidents when optimising. Such algorithms could potentially allow for even more flexible signal control one day, cutting delays and improving traffic flows even further. The up-scaling of the semi-adaptive system to a distributed network of intersections, its environmental benefits in terms of pollutant reduction and an investigation into public opinion about user satisfaction are also interesting research areas. Such studies would contribute to optimizing a system that can be regarded as an adequate, sustainable, and broadly applicable solution for urban traffic management in Tirana. Reducing congestion can also help lower vehicle emissions, and we suggest that future work could quantify the reduction in CO₂ resulting from shorter idling times.

Although the results of the simulation look promising, there are limitations to this study. First, results are obtained from a microscopic simulation model which, despite careful calibration, cannot represent all details in reality. Driver behavior in Tirana (e.g., aggressive lane changing or ignoring signals) was estimated assuming standard parameters; discrepancies from the actual driver behavior pattern, if any, could influence reality. Vissim did not account for infrastructure constraints like detector sensitivity failures or communication delays - the semi-adaptive system in simulation equally takes perfect detectors and immediate data transfer for granted. In a real-world scenario, such considerations likely limit the performance improvements.

Moreover, we used our traffic input from a typical peak-period (07:00–09:00 AM) data extracted via Google Earth counts. This is a novel approach for low data cases, but it may cause some loss of accuracy. We corrected for this with calibration against observed congestion patterns, but the model may not do a great job of capturing off-peak or abnormal days (e.g., special events). Results' generality should hence be taken with caution: for instance, the percentage of improvement observed could change according to different traffic demand matrices or between cities with distinct network layouts.

We have striven to make our study as replicable as possible: All relevant simulation settings (e.g., Wiedemann model settings, calibrated driving behavior factors) and signal timing plans are reported. Moreover, we executed several repetitions and averaged the results and their diversification (standard deviations) to illustrate how reliable they are. The logic of the detector in the simulated (loop detector placement 30 m upstream to stop line, actuation thresholds, etc.) is detailed in order that researchers can be repressible the semi-adaptive control conditions triggers.

Finally, we recognize that practical deployment in the real world may encounter additional implementation issues not addressed here, such as the requirement for secured communication between intersections or a central traffic management center, or behavior changes of drivers when a new control system is installed. These are beyond the scope of this study. However, the restriction of the simulation does offer a useful first step. We hope that future studies will move these results to pilot testing in Tirana or other similar cities.

AUTHOR CONTRIBUTIONS

Conceptualization, V.S. and A.L.; Methodology, V.S.; Validation, V.S., and A.L.; Investigation, V.S.; Resources, V.S.; Data Curation, V.S.; Writing – Original Draft Preparation, V.S.; Writing – Review & Editing, V.S.; Visualization, V.S.; Supervision, A.L.; Project Administration, V.S.

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CONFLICT OF INTERESTS

There is no conflict of interest associated with this publication.

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