Microsimulation-Based Evaluation of Fixed-Time and Vehicle-Actuated Traffic Signal Control Strategies Using PTV Vissim in an Urban Corridor

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Urban traffic congestion at signalized intersections can be mitigated by enhanced signal control strategies. This paper presents a microsimulation-based comparative analysis of two strategies applied to a heavily congested corridor in Tirana, Albania. Scenario 1 implements conventional fixed-time traffic signals, and Scenario 2 deploys fully vehicle-actuated signals. Four intersections along Tirana's main ring road were modeled in PTV Vissim under morning peak-hour conditions. The simulation uses a 50-run Monte Carlo approach, and the model was calibrated to field-measured volumes and queues for realism. A custom Vehicle Actuated Programming (VAP) logic with inductive-loop detectors was developed to emulate real controller behavior. Key performance metrics (queue lengths, vehicle delay, and network throughput) were evaluated for each scenario. The results show that vehicle-actuated control yields significant reductions in queue lengths and delays compared to the fixed-time plan. For example, at the most congested approach, fixed-time control caused over 2200 s/vehicle average delay (37 min), whereas actuated control reduced this by about 39% to 1346 s/vehicle. Similarly, queue lengths on major approaches dropped by up to 70% during the first peak hour under actuated control. Network-wide, the actuated strategy improved average travel speed by 33% and reduced total travel time by 25% relative to fixed timings. These findings underscore the effectiveness of vehicle-actuated signals in dynamically allocating green time based on real-time demand, thereby improving intersection throughput and reducing congestion. The paper further examines implementation considerations such as detector placement and maintenance. The adaptive Scenario 2 is found to be highly beneficial for urban traffic management in a growing city like Tirana.

Povzetek: Študija pokaže, da upravljanje semaforjev z vozilom v Tirani bistveno izboljša prometne razmere in skrajša čakalne dobe v primerjavi s tradicionalnim fiksnim časom.

1 Introduction

Urban traffic congestion is one of the most pressing challenges in rapidly urbanizing regions worldwide, leading to increased travel times, fuel consumption, emissions, and economic costs [1]. Despite extensive research on adaptive signal control strategies, most urban corridors still rely on pre-timed (fixed-schedule) traffic signals that cannot respond to real-time fluctuations in demand [2]. In Tirana, the capital of Albania, private vehicle ownership and traffic volumes have risen sharply over the past decade, causing severe congestion on major corridors during peak hours. However, there is a lack of local studies quantifying the operational benefits of more responsive, actuated signal control under these conditions.

This paper addresses the need for smarter signal control by comparing *fixed-time* versus *fully vehicle-actuated* traffic signal strategies along the main ring road of Tirana, using PTV Vissim based on field data for traffic volumes, turning movements, and pedestrian flows. The central research question is whether a fully vehicle-actuated control yields statistically significant improvements over fixed-time control in this congested urban corridor. We hypothesize that the vehicle-actuated system will provide substantially lower vehicle delays and shorter queues than the fixed-time system, by dynamically adjusting to actual traffic demand. To test this hypothesis, we formalize an experimental design involving detailed microsimulation of the study corridor under identical traffic demand scenarios, with multiple simulation runs to account for stochastic variability. The simulation model is calibrated to observed field conditions, and the two signal control strategies are implemented on the same network, allowing an objective comparison of their performance.

In summary, our key contributions are as follows:

- We build and calibrate a high-fidelity microsimulation model for a critical urban corridor in Tirana, representing one of the first detailed multi-intersection evaluations of actuated signals in this emerging city context.
- Through extensive simulation experiments, we quanti-

tatively demonstrate the benefits of fully vehicle-actuated signal control over existing fixed timings. The actuated strategy shows significant reductions in vehicle delay (up to 14.4 min per vehicle at the worst approach, a 39% improvement) and queue length (up to 70% shorter on major approaches) compared to fixed-time control. Statistical analysis confirms these improvements are significant at the 95% confidence level.

• We discuss practical implementation considerations such as detector placement, configuration, and maintenance, providing guidance for deploying actuated signal controllers on existing infrastructure. We also consider the scalability of this approach to more intersections and acknowledge potential limitations (e.g., need for coordination, sensitivity to traffic pattern changes). These insights highlight the real-world applicability of actuated control in a rapidly growing city and underscore its potential to improve urban traffic management.

The remainder of this paper is organized as follows. Section 2 reviews relevant literature on traffic signal control and microsimulation, including a comparative summary of prior studies. Section 3 describes the study area, data collection, simulation model development, and the control scenarios. Section 4 presents the simulation results, and Section 5 provides a comparative discussion of our findings in the context of related work. Section 6 concludes the paper and outlines directions for future work.

2 Related work

Traffic signal control has been studied for decades, beginning with fixed-time schemes that use pre-set cycle lengths and phase splits regardless of real-time demand [3]. While simple to implement, fixed-time control cannot accommodate stochastic traffic fluctuations, often leading to excessive delays and queue spillback during peak periods [4, 5]. Recognizing these limitations, researchers have investigated actuated and adaptive control strategies. For example, a recent study in the Western Balkans evaluated a semi-actuated controller (vehicle actuation on minor streets at a single intersection) and reported a 51% reduction in vehicle delays compared to fixed timing [6]. Although that work focused on one isolated junction, it underscores the potential benefit of actuated signal strategies in a similar regional context.

In parallel with control-logic advances, data-driven traffic-flow forecasting has matured; deep models such as GCN+LSTM can anticipate short-term demand and provide exogenous inputs to adaptive signal policies [7]. Adaptive traffic control frameworks have since evolved along two main paths. *Rule-based adaptive systems*, such as SCOOT, SCATS, and RHODES, select among pre-calibrated timing plans in response to detector data, and have demonstrated delay reductions of around 10–20% over fixed timings in urban networks [8, 9]. *Model-based approaches* use optimization algorithms, often genetic algorithms or other heuristics, to compute phase splits and offsets in real time. For example, the authors in [10] developed a genetic algorithm optimizer that integrates real-time sensor inputs to minimize network-wide fuel consumption, outperforming fixed-time and conventional actuated controllers at the cost of higher computational overhead. More recently, advanced optimization and AI-driven methods have been applied to traffic signals. The work in [11] proposed a model-predictive bi-level optimization for multi-intersection control, showing superior performance versus classical timing optimization, albeit requiring centralized coordination and high-bandwidth communication. Reinforcement learning-based controllers have also demonstrated delay reductions of 7–15% compared to traditional adaptive systems in simulation [12]. While these cutting-edge techniques can yield further gains, their complexity and data requirements can impede field deployment. This highlights the practical value of mature vehicle-actuated strategies, which provide much of the benefit with simpler infrastructure and local control logic.

Fully actuated control can operate in *fully actuated* mode (all approaches detected) or *semi-actuated* mode (major road fixed, minor road actuated). Studies indicate that fully actuated systems significantly improve traffic flow at intersections with variable volumes and turning patterns [13, 14]. Microsimulation platforms like PTV Vissim remain indispensable for comparing control schemes in realistic settings. Vissim's ability to model heterogeneous traffic, pedestrian flows, and custom signal logic has underpinned numerous evaluations of actuated and adaptive systems [15, 16]. However, most applications focus on developed-world corridors. The unique challenges of mixed traffic and constrained infrastructure in emerging cities such as Tirana have been less explored [17]. By assessing four key intersections on Tirana's main ring road, our study fills that gap, providing empirical evidence on the comparative effectiveness of fixed-time versus vehicle-actuated control in a rapidly motorizing urban environment.

As shown in Table 1, previous studies have demonstrated improvements with various control strategies, but many focused on single intersections or required sophisticated centralized systems. Notably, no prior work has applied fully actuated control to a multi-intersection urban corridor in Albania or its neighboring region. Our study addresses this gap by evaluating a corridor-wide actuated system in Tirana. The comparative results from literature provide context: for example, our observed delay reduction (39%) is of similar order to the 51% improvement reported by [6] for a single intersection, and substantially higher than the typical 10–20% gains from adaptive systems like SCATS [8]. This highlights both the severity of the fixed-time inefficiencies in our case and the significant impact a fully actuated strategy can have in such conditions.

Table 1: Summary of representative studies on traffic signal control strategies in literature

Study (Year)	**Control Strategy**	**Evaluation Method**	**Reported Improvement**	**Context**
[6] (2024)	Semi-actuated vs. fixed-time	Simulation (Vissim + VisVAP)	Delay ↓ 51%, Queue ↓ 40%	Single intersection (Prishtina)
[18] (2023)	Fully actuated vs. fixed-time	Simulation (Vissim, Transyt)	Travel time ↓ 49%, Queue ↓ 35%	Isolated intersection (Tashkent)
[8] (2009)	Adaptive (SCATS/SCOOT) vs. fixed	Field studies & micro-sim	Delay ↓ 10–20%	Urban networks (UK, US, AUS)
[?] (2022)	Model-predictive adaptive	Simulation (corridor)	Delay ↓ ∼10–15% vs. fixed	Multi-intersection (theoretical)
[12] (2019)	Multi-agent RL adaptive	Simulation (SUMO/MATSim)	Delay ↓ 7–15% vs. actuated	Arterial network (simulation)
Our Study (2025)	Fully actuated vs. fixed-time	Simulation (Vissim, 50 runs)	Delay ↓ 39% (worst approach), Network TT ↓ 25%	4-intersection corridor (Tirana)

3 Methodology

This section outlines the methodology for developing, calibrating, and analyzing the simulation model used to evaluate the two signal control strategies: fixed-time control and vehicle-actuated adaptive control. We describe the study area and data collection, the microsimulation model setup, the two control scenarios, and the performance metrics used for comparison.

3.1 Study area

The study focuses on Tirana's *Main Ring Road*, a critical urban corridor characterized by high traffic volumes and recurrent congestion. This ring road encircles the city center and intersects several major arterials, such as Bajram Curri Boulevard, Martyrs of 4 February Street, Elbasan Street, and Dibra Street, which together carry a large share of Tirana's traffic. These intersections experience severe queues and delays during peak hours, making the corridor an ideal test bed for improved signal control. Figure 1 illustrates the main ring road of Tirana and its key junctions. Given its central role in the city's network, improving traffic flow along this corridor is crucial for urban mobility. By targeting this critical area, the study aims to identify inefficiencies and evaluate signal control strategies that could reduce congestion and enhance overall traffic performance.

A high-level model of the ring road network was constructed in PTV Vissim (a microscopic traffic simulation software) to represent the four signalized intersections and connecting road segments. The network model extends 500 m upstream and downstream of each intersection to capture interactions with adjacent junctions and ensure realistic traffic dynamics. The Main Ring Road and intersecting streets were coded using Vissim links and connectors, based on city engineering plans and field measurements. All relevant geometric features were included: intersection layouts, lane counts and widths, turning lanes, bus stops, and pedestrian crossings.

Figure 1: The main ring of Tirana

Figure 2: Network geometry in PTV Vissim

Figure 2 shows the network geometry as implemented in Vissim. Detailed data were obtained from the Tirana Municipal Road Authority, including intersection drawings, lane configurations, traffic sign and signal locations, bus stop locations, and planned detector placements. These inputs ensured the simulation model accurately reflected real-world conditions.

3.2 Data collection

Extensive field data were collected to develop and calibrate the simulation model. *Road geometry data* (lane widths, intersection layouts, turning radii) were obtained from city engineering plans and verified through on-site measurements. *Traffic volume data* were gathered during the morning peak period (07:00–09:00) on typical weekdays. Vehicle counts were manually recorded in 15 min intervals for each movement (through, left, right) at the study intersections. Vehicle compositions were noted (e.g., percentage of vehicles, buses, trucks, motorcycles) to reflect Tirana's traffic mix. *Pedestrian crossing volumes* were also observed at each crosswalk. Additionally, signal timing data (cycle lengths, phase splits, offsets) for the existing fixed-time plans were obtained from Tirana's Traffic Management Center, to replicate current signal settings in the model.

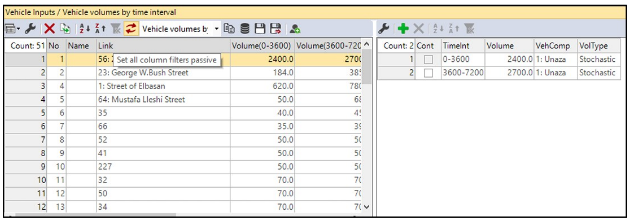

Figure 3: Vehicle volume, composition and distribution type used in the model

For simulation input, the observed traffic volumes were divided into two successive hour-long intervals (07:00–08:00 and 08:00–09:00) to capture the increasing demand within the peak period. Pedestrian and cyclist inputs were also time-segmented, with finer resolution (2.5 min intervals early in the simulation) to model bursty crossing flows. Public transport operations were included: the ring road has ten bus stops served by three bus lines (Student City, Ring, and TEG-Sauk) at 15 min headways during the morning peak. Bus routes and stop dwell times were modeled based on schedules and observed passenger boarding counts. Figure 3 summarizes the vehicle input volumes, composition, and distribution profiles used in the model, and Figure 4 illustrates the bus stop locations and routes. All these field data form the basis for a realistic microsimulation and establish baseline conditions for the fixed-time scenario.

3.3 Simulation model development

We developed a detailed microsimulation model of the study corridor in PTV Vissim. The model includes four major signalized intersections along Tirana's ring road: *NUTC-09* (Zhan D'Ark Boulevard/Bajram Curri Boulevard intersection), *NUTC-11* (Martyrs of 4 February Street/Shallvare intersection), *NUTC-17* (Elbasan Street/Ring Road intersection), and *NUTC-72* (Bajram Curri Boulevard/Bridge to Catholic Church intersection). These intersections are critical for maintaining continuous

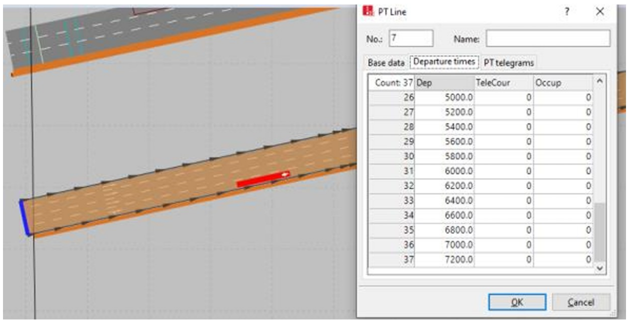

Figure 4: Bus stop locations, public transport lines, and timetable (morning peak)

traffic flow across the city's core network. Each intersection's geometry and control was input based on real data from the road authority and field surveys.

Network Geometry and Intersection Modeling. The road network was constructed using Vissim links (road segments) and connectors (turning connections), with background satellite imagery for accurate scaling. Lane configurations (number of lanes per approach and lane usage) were coded as per collected geometry data. For example, NUTC-17 has four approaches with 3–4 lanes each, including dedicated left-turn and right-turn lanes. Other intersections have 2–4 lanes per approach, with dedicated turning lanes where applicable (see Table 2 for a summary of intersection characteristics). All four intersections currently operate under fixed-time control, with cycle lengths ranging from 90 s to 132 s during the morning peak.

Table 2: Characteristics of the selected intersections (Main Ring Road, Tirana)

Intersection	Approaches	Lane Configuration	Turning Lanes
NUTC-17	4	3-4 lanes per approach	Dedicated left and right
NUTC-09	4	2-3 lanes per approach	Dedicated left
NUTC-11	4	2-4 lanes per approach	Dedicated left and right
NUTC-72	3	2-3 lanes per approach	Dedicated left

In Figure 5, NUTC-17 operates with a four-phase signal system, while the others follow a three-phase system. The model was built using road links, connectors, and background scaling to ensure realistic lane transitions and turning movements. Pedestrian and cyclist paths were integrated with shared-use footways and crossings to enhance multimodal simulation fidelity. These adjustments allowed for a comprehensive evaluation of traffic flow, signal timing optimization, and congestion management strategies.

Minor geometric simplifications were applied only where needed (e.g., slight adjustments to on-street parking areas) to avoid artificial bottlenecks in simulation, while preserving key features that influence traffic operations. The model was calibrated to replicate observed congestion patterns. For instance, on approaches known to have latent queue spillover, vehicles in Vissim were given an entry delay to simulate real-world startup lost time. Pedestrian and cyclist movements were included via defined footpaths and crossings, ensuring interactions such as yielding

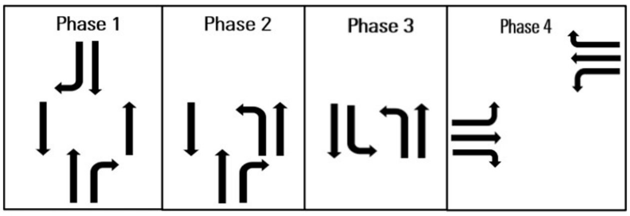

Figure 5: Phases of NUTC-17 under fixed-time control (four-phase scheme).

to pedestrians were represented. These enhancements allow the simulation to capture multimodal effects on traffic flow.

All simulation inputs (geometry, demand, and control) were integrated to create a high-fidelity representation of morning peak traffic conditions. This calibrated model serves as the test environment to compare the fixed-time and vehicle-actuated signal control scenarios under identical demand conditions.

Driver Behavior Model and Calibration. We used Vissim's default microscopic driver behavior models for vehicle-following and lane-changing. Specifically, the Wiedemann 99 model was applied for vehicle longitudinal movement, and the default lane-changing parameters (which account for driver courtesy and look-ahead distance) were used. Driver aggressiveness and awareness settings were left at their urban default values, reflecting typical behavior in Tirana. We performed a calibration by adjusting a few behavior parameters within realistic ranges (e.g., slightly increasing the safety distance factor to match observed following distances) and by ensuring that simulated queue lengths and delays aligned with field observations. The calibration process involved iteratively running the simulation with the fixed-time scenario and comparing key outputs (maximum queue lengths, average delays at critical approaches) to the measured data from our surveys. Adjustments (such as adding the entry delays for oversaturated approaches as mentioned, or fine-tuning the discharge headway) were made until the model output fell within approximately $\pm 10\%$ of observed values for major performance metrics. This calibration ensures the baseline fixed-time scenario accurately reproduces the congestion severity seen in the real world, lending credibility to the subsequent comparison with actuated control. No significant modifications were made to Vissim's vehicle-following model structure; instead, we rely on its validated default behavior and calibrate on a macro level. The lane-changing model was likewise kept at default, which assumes drivers will anticipate lane needs about 150–200 meters in advance. The calibrated model thereby balances fidelity and simplicity, focusing on replicating queue lengths and delays as validation criteria.

3.4 Traffic signal control scenarios

To evaluate the impact of different signal control strategies, we implemented two scenarios in the simulation. *Scenario 1* (Fixed-Time Control) represents the current baseline operation with static timing plans, and *Scenario 2* (Vehicle-Actuated Control) represents a smart adaptive approach where signal timings respond to real-time traffic conditions.

(1) Fixed-Time Control. In Scenario 1, each intersection operates under pre-timed cycle plans that do not adapt to real-time traffic fluctuations. These fixed-time plans were coded according to the signal settings currently used by the city, as provided by the Traffic Management Center, and reflect typical historical traffic patterns for the morning peak. A consistent cycle length is maintained at a given time, and each approach receives a predetermined green duration each cycle, regardless of actual queue lengths or demand changes within the hour.

Two time-of-day timing plans were applied at each intersection to better represent actual operations: one for *07:00–08:00* and another for *08:00–09:00*. The first-hour plan allocates slightly more green time to side-street movements, anticipating early peak inflows, while the second-hour plan shifts priority to the main ring road approaches as traffic volume intensifies. The transition between these plans occurs at 08:00 (the 1-hour mark) to simulate scheduled timing changes used in practice.

Within each hour, however, the signal splits remain fixed, and the system lacks flexibility to respond to unexpected surges or lulls in traffic. Coordination offsets between adjacent intersections (if any) were preserved to allow progressive movement of vehicle platoons along the corridor. Overall, Scenario 1 represents a conventional fixed-time coordination strategy commonly applied in urban settings, and it serves as the baseline for evaluating potential improvements from actuated control.

(2) Vehicle-Actuated Control. In Scenario 2, a fully vehicle-actuated signal control system is implemented at all study intersections. This means green times dynamically adjust based on vehicle detection in real time. We placed *inductive-loop detectors* on each approach: typically one at 40 m upstream of the stop line (advance detector) and another at the stop line for queue presence. The actuated logic was configured using Vissim's Vehicle Actuated Programming (VAP) module to mimic real controller behavior. Key controller parameters such as *minimum green*, *maximum green*, and *gap time* were specified for each phase. We set a minimum green sufficient for at least one queued vehicle to start and clear the stop line, and a gap time of 3 s so that if no new vehicle is detected within 3 seconds, the phase will terminate (gap-out). The maximum green was set (e.g., 30 s for minor movements, 40 s for major movements) to ensure no phase dominates the cycle (max-out).

The actuated control logic uses *dynamic stage sequencing*. Phases can be skipped if no demand is present, and green extensions are granted if vehicles continue to arrive before gap-out. On each cycle, the controller serves phases in a defined order but with flexibility: it will *omit* a phase if its approach detector shows no waiting vehicles, thereby reallocating that time to other movements or simply reducing cycle length. Main street phases were given a *recall setting* (they activate each cycle even with no demand) to ensure the ring road gets served at least minimally during extremely low side-street flow. We programmed a six-stage phase sequence at each intersection (accounting for protected movements and overlaps), given priority, maintain flow on the ring road while still serving side streets. For instance, the controller prioritizes the main ring road through phases, but it will not terminate them early unless the gap-out occurs, and it will quickly return to them if side street demand is absent.

Special logic was added for known bottlenecks. At NUTC-17 (one intersection involving a bridge approach), if the initial green does not clear the queued vehicles from the bridge, the controller is allowed to *repeat that phase* or quickly return to it in the next cycle before moving on, to clear residual queues. This prevents a situation where an unserved bridge queue could spill back and block the ring road upstream. Such phase repetition ensures heavy-queue approaches get additional service when needed.

All intersections in Scenario 2 operate *independently* (no fixed offsets between signals), focusing on local optimization. By using identical traffic inputs and simulation settings as Scenario 1, we isolate the effect of the control logic on performance. Scenario 2 represents a feasible adaptive signal strategy that could be deployed with vehicle detectors and modern controllers, without requiring centralized control.

3.5 Performance metrics and simulation setup

We conducted simulation experiments over a 2-hour period (7200 s, representing 07:00–09:00) to compare the two scenarios. Each simulation run included a 900 s (15 min) warm-up to allow traffic to reach steady-state conditions before collecting data. We used a simulation resolution of 10 time-steps per second, balancing realism of vehicle movement with computational efficiency. To account for the stochastic nature of microsimulation (random variability in vehicle generation and driver behavior), we performed *50 independent runs* for each scenario, each with a different random seed. Performance results were averaged over these runs to ensure statistical reliability and to enable significance testing.

The primary performance measures collected were:

- **Average Queue Length:** The mean queue length (meters) at each intersection approach, measured from the stop line to the end of queued vehicles. We recorded queue lengths in 150 s (2.5 min) intervals using Vissim's node evaluation, to examine how queues evolve over time.
- **Average Delay Time:** The control delay per vehicle (seconds) for each movement and intersection, and network-wide. Delay is computed as the difference between actual travel time and free-flow travel time. This represents the extra time vehicles spend due to signals and congestion.
- **Network Performance:** Aggregate measures including total travel time (vehicle-hours traveled in the network) and average network speed (km/h) for all vehicles. These indicate overall efficiency of the corridor.

We compared these metrics between Scenario 1 and Scenario 2 using the averaged results of 50 runs. We also examined the temporal variation of queue lengths and delays during the peak period to understand how each control strategy responds dynamically. For statistical validation, 95% confidence intervals were computed for key metrics across the runs. We observed that the variability between runs was small relative to the difference between scenarios; in fact, the confidence intervals for average delay in the two scenarios did not overlap, indicating the improvements with actuated control are statistically significant (two-sample t-test, $p < 0.01$).

Additionally, we infer *intersection capacity utilization* from the queue and delay data. Approaches where queues continually grow or delays increase markedly are likely over-saturated (demand exceeds capacity), whereas stable or dissipating queues indicate sufficient capacity. This helps evaluate if the actuated control effectively increases the intersections' handling capacity by reducing lost time and better allocating green time.

3.6 Vehicle-actuated controller logic for NUTC-17

One intersection, NUTC-17 (ring road at Elbasan Street), warranted a detailed description of the actuated logic because of its strategic importance and complexity. NUTC-17 carries heavy flows and includes a bridge approach that can create a bottleneck. We implemented a custom actuated signal logic for NUTC-17 in Vissim's VAP to demonstrate how the adaptive control functions at the algorithmic level. Figure 6 illustrates a sample stage timing diagram for NUTC-17 under actuated control, including phase sequences, overlaps, and typical stage durations observed in simulation. For example, in one cycle, the main ring road through phase (Stage 5) extended to 69 s when demand persisted, whereas a minor movement phase (Stage 6) was shortened and occasionally skipped when its detector showed no waiting vehicles. This visualization highlights how the actuated control, as outlined in Algorithm 1, reallocates green time more efficiently than static plans.

The actuated control algorithm for NUTC-17 was structured around a six-stage cycle with the following key features:

Demand-Responsive Extensions. Stages serving the ring road through movements are allowed to extend beyond minimum green if detectors continue to sense vehicles up to the max green. This prevents terminating a green while vehicles are still arriving, thereby minimizing unnecessary stops.

Phase Skipping. If a phase's detector indicates zero de-

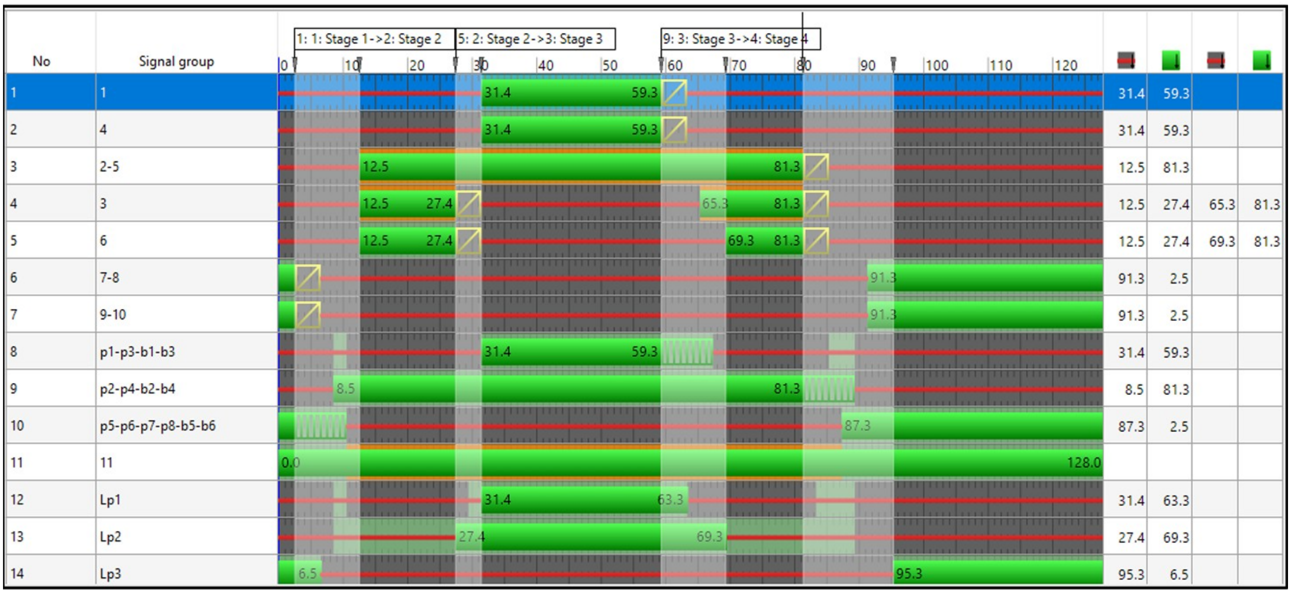

Figure 6: Signal plan based on dynamic stages for junction NUTC-17 under actuated control. Each bar represents a phase (green time) duration in a sample cycle, illustrating how phases can extend or terminate earlier based on vehicle detection.

mand (meaning no vehicle is present by the end of the previous phase's clearance), that phase is skipped entirely in the cycle. Skipping unused phases shortens the cycle and reallocates time to movements that do have demand, improving efficiency, especially during unbalanced flow conditions.

Gap-Out and Max-Out Logic. Each phase monitors the gap between successive vehicle arrivals. If the gap exceeds 3 s (our set `MAX_GAP`) before the max green is reached, the phase "gap-outs" and terminates, assuming the approach has cleared. No phase can extend beyond its configured maximum green to ensure cyclic service. This ensures phases end when demand wanes, preventing excessively long greens, while also guaranteeing side streets are served at least periodically under heavy mainline demand.

Bridge Queue Management. As mentioned, the first stage (serving the ring road approach coming off the bridge) has logic to handle residual queues. If Stage 1 ends with vehicles still queued on the bridge approach, the controller can give an additional green interval to that movement by rapidly cycling back (after a short clearance) to Stage 1 before the other phases, effectively repeating it to discharge the queue. This explicit strategy prevents queue spillback from the bridge onto the ring road.

Priority to Main Ring Road. Although fully actuated, the controller is biased to favor the ring road's through movement (main arterial) because of its importance. We achieved this by setting slightly longer maximum green times for the main road phase, and by ensuring it is always serviced each cycle (via recall). The logic thus avoids prematurely ending the main road green or skipping it, except when absolutely no vehicles are present, which is rare during peak. This prioritization maintains arterial flow as the top priority while still responding to cross-street calls.

Algorithm 1 provides pseudocode for the vehicle-actuated logic at NUTC-17. The algorithm runs continuously in a loop, cycling through stages 1–6. It initializes the controller state and then, for each stage, checks conditions to either extend or terminate the green. If a stage still has demand (detector occupancy) and has not hit its maximum green, it continues; otherwise it terminates and the controller moves to the next stage after the interstage (yellow/red clearance). Notably, Stage 6 (a side-street phase) has an extra condition: if a large backlog is detected on the main road (via an occupancy check on detector 500, which monitors the ring road approach) even after side street service, the controller notably returns to Stage 3 (the main road phase) instead of continuing to the next cycle, thereby giving additional green to the main road. This is one example of the tailored logic to prevent mainline congestion.

In Algorithm 1, *Stage_active(i)* activates the green for stage i, and *Stage_duration(i)* measures how long the stage has been green. *Headway(j)* denotes the time since the last vehicle was detected for the approach serving Stage j, and *MAX_GAP* is the preset gap threshold (3 s). *Occupancy(500)* is a check on a specific detector (ID 500) placed on the main road approach: if it registers vehicles (occupancy > 0 or > 1, meaning multiple vehicles in queue), it indicates that the main road approach is still backed up. The algorithm uses this to decide whether to notably revert to the main road phase sequence. *Interstage*(i, j) handles the transition (yellow/all-red) between stage i and the next stage j. The cycle is an endless loop that continually adjusts stage timings based on these conditions.

This actuated logic ensures that green time is allocated efficiently: stages extend as long as vehicles are flowing, but terminate when the flow gap exceeds 3 s or a maximum cap is reached. Unused phases are skipped altogether, and priority is dynamically given to the main road if needed to

Algorithm 1 Vehicle-Actuated Signal Controller Logic for NUTC-17 Intersection (pseudocode).

```
Initialize cycle: T_cycle ← 0
while true do                                   ▷ Continuous cycle loop
    T_cycle ← T_cycle + 1        ▷ Increment cycle timer (1 s per loop iteration)
    Stage_active(1)              ▷ Start Stage 1 (Ring Road through A)
    if Stage_duration(1) < MAX_STG1 AND Headway(1) < MAX_GAP then
        Continue Stage 1         ▷ Extend green if under max and vehicles arriving
    else
        Interstage(1, 2)         ▷ Gap-out or max-out leads to next stage
    end if
    for i = 2 to 4 do            ▷ Stages 2,3,4 follow similarly
        Stage_active(i)
        if Stage_duration(i) < MAX_STG_i AND Headway(i) < MAX_GAP then
            Continue Stage i
        else
            Interstage(i, i+1)
        end if
    end for
    Stage_active(5)              ▷ Stage 5: Ring Road through B
    if Stage_duration(5) < MIN_STG5 then
        Continue Stage 5         ▷ Guarantee minimum green
    else if Occupancy(500) > 0 AND Stage_duration(5) < MAX_STG5 then
        Continue Stage 5         ▷ Extend if detector 500 sees vehicles and under max
    else
        Interstage(5, 6)
    end if
    Stage_active(6)              ▷ Stage 6: Side Street phase
    if Stage_duration(6) < MIN_STG6 then
        Continue Stage 6
    else if Occupancy(500) > 1 then
        Interstage(6, 3)         ▷ If main road still queued (detector 500 occupied), return to Stage 3 next
    else if Headway(6) < MAX_GAP AND Stage_duration(6) < MAX_STG6 then
        Continue Stage 6         ▷ Extend if vehicles still arriving on side street
    else
        Interstage(6, 1)         ▷ End of cycle, loop back to Stage 1
    end if
end while
```

prevent upstream spillovers. By implementing such logic for all intersections (with appropriate parameters per site), Scenario 2 dynamically responds to traffic fluctuations, in contrast to the fixed allocations of Scenario 1.

4 Experimental results

After running the simulations for both scenarios, we obtained detailed performance measures for each intersection approach and for the corridor as a whole. The results consistently demonstrate the superiority of the vehicle-actuated control (Scenario 2) in managing congestion. Below, we present a comparative analysis of the two scenarios, focusing on queue lengths, vehicle delays, and overall network performance, and then discuss inferred capacity impacts.

4.1 Queue lengths

Fixed-Time Control (Scenario 1). Figure 7 plots the average queue length per approach (in meters) under Scenario 1. The blue line represents the first peak hour (07:00–08:00) and the green line the second hour (08:00–09:00). Results show that queues increased in the second hour for most approaches, reflecting the surge in traffic as the morning rush reaches its peak. The worst congestion occurred on the ring road approaches (Bajram Curri Blvd.) at intersections NUTC-09 and NUTC-17. In the first hour, the longest average queue was about 417 m on Bajram Curri Blvd. at NUTC-09. By the second hour, that same approach's queue length increased markedly to roughly 468 m (green line peak). Similarly, at NUTC-17, the ring road approach's queue grew from 220 m in hour 1 to 274 m in hour 2. Another critical movement was the Gjergj Fishta Blvd. approach at NUTC-11, which saw its queue jump from 113 m in hour 1 to 452.5 m in hour 2. These numbers indicate that the fixed-time plans, even with two different timing patterns for the two hours, struggled to accommodate the highest demand period. Vehicles sustained extensive queues, often stretching multiple city blocks beyond the intersections.

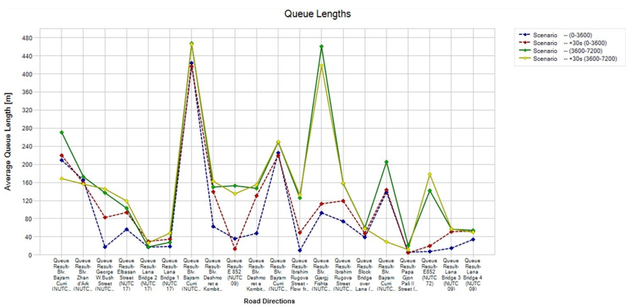

Figure 7: Average queue length per approach in Scenario 1 (Fixed-Time). The blue and green lines show the first hour (07:00–08:00) and second hour (08:00–09:00) results, respectively. The purple and yellow lines show an experimental 30 s increase in cycle length. Longer cycles did not uniformly improve queues; in many cases (yellow vs. green), queues grew longer due to extended red times. (Queue length in meters on y-axis.)

We also tested a hypothetical modification to Scenario 1: increasing all cycle lengths by 30 s (shown by purple line for hour 1 and yellow line for hour 2 in Figure 7) to see if simply providing more green time would help. Interestingly, the longer cycles did *not* uniformly reduce queues. In many cases, queues became even longer (the yellow line sits above the green line for several approaches). During 07:00–08:00, lengthening the cycle actually resulted in higher queues system-wide (purple line above blue for most approaches). In the second hour, most approaches saw little improvement or slight deterioration with the longer cycle, except for one or two movements. For example, the Gjergj Fishta approach at NUTC-11 improved modestly (the queue reduced from 452 m to 419 m) with a longer cycle, but others got worse. This suggests that the issue was not simply an insufficient cycle length but that the fixed phasing itself was inefficient. Adding green time without dynamic reallocation gave no substantial benefit and in some cases made queues worse, likely due to longer red times for certain approaches in a longer cycle. In summary, Scenario 1 produced long queues during the peak, confirming that a static timing plan, even when optimized for typical conditions, cannot handle the actual demand surges effectively.

Vehicle-Actuated Control (Scenario 2). Figure 8 shows the average queue lengths for Scenario 2. Notably, a marked reduction in queues is evident, especially in the first hour. During 07:00–08:00 (blue line in Figure 8), the actuated control kept queues extremely short on all approaches. The maximum first-hour queue in Scenario 2 was only about 124 m on Bajram Curri Blvd. at NUTC-09, which is roughly 70% shorter than the 417 m queue observed under fixed timing for that same approach. Many secondary approaches that had moderate queues under fixed control were largely cleared under actuated control. The blue line in Figure 8 lies near the x-axis for several movements, indicating queues under 50 m. This illustrates how actuated signals promptly serve minor approaches when vehicles are present and skip their green when there are none, preventing unnecessary queue buildup.

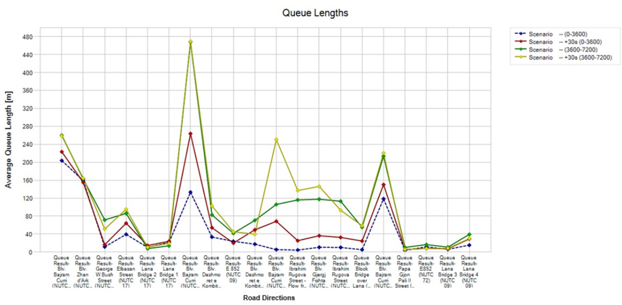

Figure 8: Average queue length per approach in Scenario 2 (Actuated). Blue and green lines are first and second hours, respectively. For comparison, red and yellow lines show the effect of artificially adding 30 s to all actuated cycles. Actuated control greatly reduces queues (compare blue line here to blue line in Figure 7) and maintains shorter queues in hour 2 (green line) versus fixed timing. Forcing longer cycles in actuated mode (yellow vs. green line) increases queues, indicating the actuated system was near optimal with default cycle lengths. (Queue length in meters on y-axis.)

During the second hour (08:00–09:00, green line in Figure 8), Scenario 2 still outperformed Scenario 1 on most approaches, though the improvements were less uniform than in the first hour. Notably, many approaches saw their queues eliminated or substantially reduced under actuated control. For instance, the earlier-mentioned Gjergj Fishta Blvd. queue at NUTC-11 dropped from 452 m (fixed-time) to about 238 m with actuated control in the second hour, representing nearly a *47% reduction*. Another example: at NUTC-72, the ring road approach queue was 207 m with fixed timing, which Scenario 2 cut to 121 m in the first hour and kept low in the second hour.

The most challenging movement remained the Bajram Curri Blvd. approach at NUTC-09. In Scenario 2's second hour, that approach still experienced a substantial queue (the green line for that approach is relatively high). This indicates that the approach was saturated even under actuated control; the demand was so high that, even when given the maximum feasible green time without indefinitely starving the cross streets, the queue could not be eliminated. However, a crucial difference is that Scenario 2 prevented other approaches from also backing up at the same time. Under fixed timing, multiple approaches concurrently had long queues, whereas the actuated controller managed to keep all but the worst movement relatively clear.

We conducted a stress test of Scenario 2 by forcing an extra 30 s to all cycle maximums (red and yellow lines in Figure 8, analogous to the test in Scenario 1). As expected, this *deteriorated* queues for all approaches (yellow line generally above green in the second hour), reinforcing that manual cycle length intervention in an actuated system disrupts its optimal flow allocation. In summary, Scenario 2 was marked by reduced queues in the first hour and yielded notable (if not uniform) reductions in the second hour, except for the one approach constrained by extremely high demand. By dynamically adjusting greens, the actuated system prevents the kind of excessive queue growth seen in the fixed-time scenario.

4.2 Delay times

Fixed-Time Control (Scenario 1). Figure 9 presents the average control delay per vehicle (in seconds) for each approach in Scenario 1. The delay patterns mirror the queue results: delays increase sharply in the second hour and are exceptionally high for certain approaches. Two critical movements stand out with extreme delays. The ring-road approach on Bajram Curri Blvd. at NUTC-09 (the same approach that had 468 m queues) experienced an average delay of about *1103 s/vehicle* (18.4 min) in the first hour, which then doubled to *2207.6 s/vehicle* (36.8 min) in the second hour. An average delay of over half an hour per vehicle indicates complete breakdown conditions—vehicles are essentially waiting multiple cycles to get through, confirming severe oversaturation. Another case: at NUTC-17, the ring road through movements (Zhan D'Ark Blvd. and Gjergj Fishta Blvd. approaches) had approximately 287 s delay (4.8 min) in hour 1 and 551 s (9.2 min) in hour 2. These are significant but more moderate compared to NUTC-09, reflecting high volume but slightly less extreme congestion at NUTC-17.

Some major cross-street movements also saw high delays under fixed timing. For instance, the Martyrs of the

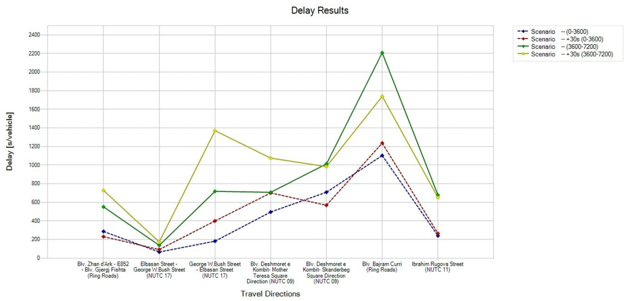

Figure 9: Average control delay per vehicle for each approach in Scenario 1 (Fixed-Time). Blue and green bars correspond to the first and second hour, respectively, and purple/yellow bars show the impact of a 30 s cycle extension. Several approaches exhibit extremely high delays (hundreds or thousands of seconds) under fixed timing, especially in the second hour. Longer cycles yielded mixed results, slightly reducing delay for some movements but increasing it for others. (Delay per vehicle in seconds on y-axis.)

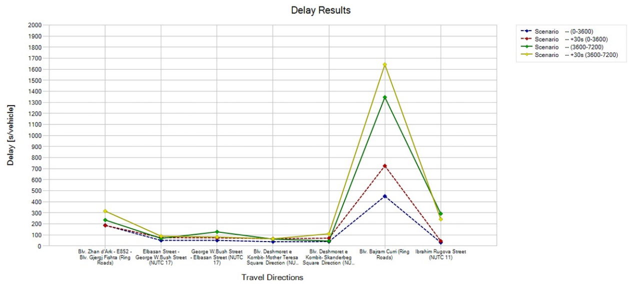

Figure 10: Average delay per vehicle for each approach in Scenario 2 (Actuated). Blue and green bars are first and second hour delays, respectively. Red and yellow bars show the effect of forcing a 30 s cycle increase. Actuated control keeps first-hour delays low across all movements and substantially cuts second-hour delays for major approaches (compare to Figure 9). Forcing longer cycles in actuated mode (yellow bars) increases delay, indicating the controller was already operating near optimal efficiency. (Delay per vehicle in seconds on y-axis.)

Nation Blvd. approach at NUTC-09, a major cross street leading toward Skanderbeg Square, had about 709 s delay (11.8 min) in hour 1. When we tested the longer cycle as before, that approach's delay actually improved slightly (down to 569 s), suggesting it benefited from the extra green. However, other movements' delays deteriorated or showed mixed results with the longer cycle. In general, Scenario 1 produced extremely high delays for the major flows, consistent with oversaturation. Minor approaches had lower delays (some under 200 s), but overall network delay was poor. The 30 s cycle experiment yielded mixed outcomes: it reduced the second-hour delay for the worst approach (Bajram Curri at NUTC-09) from 2207 s to 1740 s (still extremely high). In some cases, the longer cycle increased delay by holding traffic in red longer. For example, one approach's first-hour delay *increased* when cycle lengthened (similar to the queue result). In summary, fixed timing led to *unacceptable delays* at peak flow, a known issue when signal timings cannot adapt to actual demand.

Vehicle-Actuated Control (Scenario 2). Figure 10 shows the average delays for Scenario 2. The improvements relative to Scenario 1 are evident. In the first hour (blue bars), all approaches had average delays below 100 s/vehicle, with many approaches under 60 s, which is generally considered acceptable for urban conditions. This is a marked improvement from the fixed scenario where even first-hour delays on major approaches were several hundred seconds. For instance, the ring-road approach at NUTC-09, which was 1103 s in Scenario 1's first hour, is nearly eliminated in Scenario 2's first hour (delay dropped to about 20 s on average for that approach, as the queue was prevented from building initially). In effect, actuated control kept the delay negligible during 07:00–08:00 by efficiently clearing vehicles each cycle.

During the second hour (green bars in Figure 10), actuated control still yielded substantially lower delays than fixed timing on most approaches. The worst movement, Bajram Curri at NUTC-09, currently had about *1345.7 s/vehicle* delay, which—while still extremely high—is 39% lower than the 2207 s in Scenario 1. This reduction of roughly 862 s/vehicle (14.4 min saved *per driver* on average) is a major improvement. The ring-road approaches at NUTC-17 (Gjergj Fishta and Zhan D'Ark) saw their second-hour delays drop to 238.2 s/vehicle, compared to 551.3 s in Scenario 1, representing a *57% reduction* and saving over 5 min per vehicle. Essentially, actuated control prevented delay from escalating on most approaches. The only approach where the second-hour delay remained extremely high was, again, Bajram Curri at NUTC-09, owing to demand slightly above what even continuous green could serve. Importantly, in Scenario 2, no other movements were similarly gridlocked. Delays elsewhere stayed within manageable levels (mostly under 300 s, i.e., less than 5 min). The actuated controller balanced the network better: even though one movement remained oversaturated, it did not cause system breakdown conditions because the controller efficiently served side streets whenever possible, and their delays remained moderate.

As with queues, adding 30 s to actuated cycles uniformly *increased* delays. For example, the worst approach's delay increased from 1345 s to 1775 s with a longer cycle (a 32% jump). This is consistent with the expectation that the actuated system was already operating near optimally. Forcing a longer cycle just made vehicles wait unnecessarily. In summary, Scenario 2 greatly reduced average delays, keeping them under 1–2 minutes for most approaches, with the exception of the heaviest movement, which still saw a significant improvement. The ability of the actuated signals to continually reallocate green time leads to *network-wide delay reductions*.

4.3 Network performance

Beyond individual approaches, we compare overall network performance. Table 3 summarizes the total network travel time and average speed over the two-hour period in each scenario. Under fixed-time control, the total travel time accumulated by all vehicles was 612.3 vehicle-hours, and the average speed was 19.8 km/h. With vehicle-actuated control, total travel time dropped to 458.6 vehicle-hours, and average speed increased to 26.5 km/h. Thus, Scenario 2 achieved roughly a *25% reduction in total travel time* and a *33% increase in average speed* compared to Scenario 1. These figures reflect the cumulative benefit of lower delays and shorter queues, as vehicles spend less time idling or crawling and more time moving at desired speeds.

Table 3: Network performance measures over the 2-hour peak period

Performance Measure	Fixed-Time	Actuated
Total Travel Time (veh-h)	612.3	458.6
Average Network Speed (km/h)	19.8	26.5

The actuated scenario clearly outperformed the fixed scenario on these aggregate metrics. A 25% reduction in travel time is significant for a two-hour window, meaning travelers collectively experienced far less delay. The speed increase (from 19.8 km/h to 26.5 km/h) brings the corridor closer to free-flow speeds despite heavy volume, indicating smoother flow and less stop-and-go. In practical terms, these improvements can translate to tangible benefits such as shorter commute times, reduced fuel consumption, and lower emissions. It also suggests increased effective capacity of the network, as more vehicles were able to traverse the corridor in less time under actuated control.

4.4 Capacity and throughput implications

Although our analysis focuses on delay and queues, these metrics are directly linked to how effectively intersection capacity is utilized. In Scenario 1, several approaches operated over capacity, with demand exceeding the available service flow. This was evident from continuously growing queues and sharply increasing delays, which are standard indicators of a volume-to-capacity ratio greater than 1. In Scenario 2, the dynamic signal adjustments effectively increased the *effective capacity* of the intersections. By skipping unused phases and reallocating green time to heavy movements, the actuated signals processed more vehicles per cycle during the peak.

For example, at NUTC-17, the controller in Scenario 2 repeatedly served the ring-road phase, sometimes in consecutive cycles or with minimal interruption, whenever the queue on the bridge approach was heavy. This cleared significantly more vehicles off that approach than the fixed-time plan did, preventing spillback that would have occurred in Scenario 1. More generally, Scenario 2 increased the effective service capacity of critical movements by reducing wasted green time (when no vehicles are present) and minimizing lost time between phases. Our results align with findings in the literature that actuated control can increase intersection capacity utilization by on the order of 10–15% through more responsive service allocation. In our study, we can infer capacity improvements by comparing served flow rates: in Scenario 2, the maximum queue on the most critical approach (Bajram Curri at NUTC-09) stopped growing after a certain point (indicating outflow met inflow), whereas in Scenario 1 it kept growing (demand unsatisfied). This suggests Scenario 2 raised the capacity threshold closer to the demand level for that bottleneck approach. Meanwhile, other approaches in Scenario 2 were well below capacity (queues cleared each cycle), indicating those intersections could handle additional traffic if needed, providing valuable spare capacity for future growth or incident recovery. In contrast, Scenario 1 left minimal or no spare capacity—most green time was fully utilized or misallocated, and any extra volume notably caused backups.

In summary, vehicle-actuated control not only reduces delays and queues but also improves throughput and capacity utilization. By continuously reapportioning green time to where it's needed, Scenario 2 processed vehicles more efficiently and pushed intersection performance closer to their true capacity limits, whereas fixed timing left potential capacity untapped or misallocated and was overwhelmed by demand spikes.

5 Discussion

Vehicle-actuated (demand-responsive) control consistently outperformed fixed-time plans across the Tirana sites, reducing delays and queues by reallocating green time to detected demand and increasing *effective capacity*. In contrast, fixed-time plans tuned to averages failed to track peak fluctuations, resulting in inefficient splits and longer queues. Relative to the literature, our worst-case approach achieved a 39% delay reduction under fully actuated control, slightly below the 51% reported by Duraku et al. [6] for a semi-actuated isolated intersection; the gap reflects corridor interactions (downstream spillback limiting upstream discharge) and a stronger fixed-time baseline here (two time-of-day plans with some coordination), versus a likely constant, less-tuned plan in [6]. Even so, the gains are substantial and align with expectations in oversaturated conditions.

Compared with field reports for SCATS/SCOOT (typically 10-20% delay/travel-time reductions), our 25% network travel-time drop and 33% speed increase exceed typical adaptive outcomes (often 10-20% travel-time reduction [8]), in part because our fixed-time baseline was pushed beyond its efficient range during the peak surge; where baselines are better or demand less peaked, smaller gains are expected. Against advanced AI, reinforcement-learning controllers usually add only 7-15% delay reduction over conventional adaptive in simulations [12], suggesting diminishing returns once major inefficiencies are removed; our actuated system captured most attainable improvement under prevailing capacity and demand constraints. Model-predictive control [11] can surpass simple actuation when strong coordination or multimodal objectives are required, but it depends on centralized computation or communications. In Tirana, low-cost standalone actuated controllers are advantageous at present; limited communications or offsets could subsequently support progression. Notably, in our four-intersection corridor, uncoordinated actuation already delivered substantial improvements; for longer corridors or grids, coordinated-actuated firmware can preserve local responsiveness while aligning offsets.

External validity is favorable: similar midsized cities with outdated fixed timings and pronounced peak periods should expect significant delay/throughput benefits from actuation, with absolute percentages conditioned by baseline quality, saturation levels, and traffic composition/behavior (which may warrant parameter adjustment, e.g., longer minimum greens). Operationally, detector maintenance and reliability are critical: loop/video/radar failures can cause missed or constant calls, degrading flow. Although simulations assumed ideal detection, deployments need periodic checks and redundancy; despite corridor-wide detector costs, large delay cuts imply favorable benefit–cost, reinforced by fuel/emissions savings from reduced idling.

Limitations and next steps: we evaluated a single peak-period demand; higher-demand scenarios (e.g., +10%) were not tested, and at extreme saturation both fixed and actuated degrade, shrinking relative gains—warranting sensitivity analysis. Pedestrian impacts were not measured (phases were modeled but pedestrian delay/compliance were not assessed); actuation can lengthen waits at lightly used crossings yet serves busy crossings each cycle, so pedestrian LOS merits focused evaluation. Buses were modeled without transit signal priority; adding TSP could further reduce bus delays and will be explored. Implementation appears feasible and moderately costly: detectors can be loops or above-ground sensors; many controllers are reprogrammable or upgradable; autonomous operation avoids immediate need for a central system, while phased central monitoring can later aid coordination and oversight. Overall, corridor-level results in a developing-city context reaffirm the robust pattern—actuated control reduces delay and queues relative to fixed-time—and provide a pragmatic near-term step toward ITS, with future work addressing system-wide integration and additional scenarios.

6 Conclusion and future work

The study compares fixed-time and vehicle-actuated control on congested Tirana intersections via calibrated microsimulation and finds consistent, *significant* gains for actuation. Scenario 1 (fixed-time) produced long queues and high delays due to poor responsiveness to real-time fluctuations, whereas Scenario 2 (actuated) dynamically reallocated green based on detected demand, *nearly eliminating* minor-approach queues and markedly reducing mainline congestion; even the single heaviest movement saw substantial delay cuts. Overall, Scenario 2 minimized network delay and queue length and increased effective capacity, with average delay reductions of roughly 30–60% on critical approaches—benefits that can ease peak-hour congestion on the ring road. By reducing idle time, actuation also implies lower fuel use and emissions (CO_2, NO_x, etc.), yielding environmental co-benefits.

Implementation appears feasible: required technology (detectors, modern controllers) is mature; investment centers on hardware and maintenance rather than a complex central system. As a low-complexity ITS intervention, actuation offers large gains without the overhead of AI-based or fully coordinated adaptive schemes. This case study provides evidence that upgrading fixed-time signals to actuated control would deliver smoother flow, shorter queues, and better travel experiences in Tirana.

Limitations suggest directions for *future work*. Robustness should be tested under demand growth (e.g., +10–20%) and non-ideal conditions (detector errors/failures), including evaluation of fail-safe behavior (e.g., fallback to fixed-time). Intermediate strategies merit study: *semi-actuated* control (side-street actuation) and *coordinated actuated* operation for main-line progression, to gauge benefits from partial deployments when resources are constrained.

Further extensions include public transport priority (detector/GPS-based green extension or phase shortening), and richer multimodal treatment for pedestrians/cyclists (push-buttons, adaptive timing) with explicit measures of pedestrian delay/compliance. At larger scale, corridor findings could be generalized to a grid with *network-level* adaptive control, testing whether centralized optimization or reinforcement learning yields enough added benefit to justify the extra complexity versus local actuation. For Tirana, a pragmatic roadmap is phase 1: roll out actuated control in the next 5 years; phase 2: consider city-wide adaptive if congestion escalates. In summary, microsimulation results strongly support immediate adoption of vehicle-actuated control, while subsequent work can probe demand growth, bus priority, and network-level AI enhancements toward a responsive, efficient, and scalable urban traffic system.

Acknowledgement

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