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A FUEL–EMISSION MODEL FOR REDUCING CONGESTION AND CO_2 AT A MAJOR URBAN NODE IN TASHKENT THROUGH INTELLIGENT TRANSPORT SYSTEMS AND GREEN LOGISTICS: THE CASE OF THE TEMUR MALIK – MIRZO ULUGBEK INTERSECTION (ECOBOZOR AREA)

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ABSTRACT

Rapid motorisation in Tashkent has turned several arterial nodes into chronic bottlenecks where peak-hour traffic alternates between short running bursts and long idling periods. This study quantifies how intelligent transport system (ITS) and green logistics measures affect travel time, fuel consumption and carbon dioxide (CO_2) emissions on a ~2 km corridor of Temur Malik Street (from the Do'rmon Yo'li junction) and Mirzo Ulugbek Street, which serves the Ecobozor market and Shahriobod metro station. Corridor travel time is decomposed into a running phase and an idling phase. Fuel use in the running phase is estimated with a speed-dependent model, $Q = \alpha_0 + \alpha_1/v + \alpha_2 v^2$, idling fuel with a time-proportional model, and CO_2 with the IPCC default emission factor for gasoline. A baseline of 2,000 veh/h, a mean travel speed of 13.3 km/h and 6 min of idling per vehicle is compared with three cumulative scenarios: adaptive signal control, a smart loading zone in front of Ecobozor, and transit signal priority (TSP) with a modest 5% modal shift. The full ITS package reduces corridor travel time by 32.2% and hourly CO_2 emissions from 1,112 kg to 915 kg (−17.7%), or about 205 t CO_2 per year over peak periods. Reduced idling accounts for most of the saving, while running-phase consumption changes little because the eco-optimal running speed implied by the model is about 38 km/h. At the assumed idling rate, the conventional average-speed approach underestimates baseline fuel use by 9.5% and misstates the benefit of the measures. The findings support a phased roll-out that starts with adaptive signals and curbside management at the Ecobozor node, with field calibration from Tashkent CCTV counts.

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Keywords: *intelligent transport systems; adaptive signal control; transit signal priority; loading zone; urban freight; idling; fuel consumption model; CO_2 emissions; Tashkent.*

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1. Introduction

The intersection of Temur Malik and Mirzo Ulugbek streets in north-western Tashkent performs three functions at once. It is a through arterial linking the Katta Halqa Yo'li ring road with Do'rmon Yo'li, a freight delivery point for the Ecobozor retail complex, and an access node for pedestrians and buses

heading to Shahriobod metro station on the ring metro line. These functions collide on a single section of about 2 km, so during peak hours the travel speed falls to 12–15 km/h and each vehicle spends up to 6 min standing with the engine idling.

Digitalising urban mobility has become a policy priority in the capital. In June 2025 the city opened an AI-based Situational Monitoring Center intended for real-time monitoring, analysis and management of traffic flows (Kun.uz, 2025). From April 2026 a large-scale replacement of signal heads began: the new controllers detect traffic volumes with sensors, give green time to the approach where queues build up and can extend the green phase for approaching buses (Kun.uz, 2026). Urban air quality adds to the urgency: field measurements have detected cadmium in the atmospheric air and other elements of the ecosystem of Tashkent (Ergashev et al., 2022), and road transport is one of the main urban sources of such pollutants. These measures are being rolled out city-wide, but few studies quantify what they deliver in fuel and CO_2 at a specific node, and therefore which measure should be implemented first where budgets are limited.

Research gap. Local studies have focused on vehicle counting with video detection (Kutlimuratov et al., 2023) or on the energy saving of a single vehicle's start-stop system (Yusupov & Inoyatkodjaev, 2023). International studies usually evaluate adaptive signals, transit signal priority (TSP) and loading zones separately. The three measures have not been assessed together at one mixed-function node with a fuel–emission model adapted to Uzbek conditions. In addition, the widely used average-speed approach, in which a fuel–speed curve is evaluated at the mean travel speed of the corridor, blends idling and running into one number and does not capture stop-and-go operation adequately.

Aim and objectives. The aim of the study is to quantify the effect of ITS and green logistics measures on travel time, fuel consumption and CO_2 emissions on the Temur Malik – Mirzo Ulugbek corridor using a phase-decomposed model. The objectives are: (1) to describe the corridor and its peak-hour baseline; (2) to formulate a fuel–emission model that treats running and idling phases separately; (3) to compare adaptive signal control, a smart loading zone and TSP as cumulative scenarios; and (4) to derive practical recommendations on the sequence of implementation.

Novelty. First, the cumulative effect of three ITS measures at a mixed-function Tashkent node is assessed within a single model. Second, phase decomposition reveals a bias of the average-speed method whose size grows as the measures take effect. Third, an eco-optimal running speed of about 38 km/h is derived from the model parameters and proposed as the design speed for green-wave coordination on the corridor.

1.1. Literature review

Adaptive signal control. Systems such as SCOOT and SCATS recompute splits, cycle length and offsets from detector data in real time. In congested corridors their main benefit is to postpone the onset of oversaturation and to shorten recovery after the peak; once demand exceeds saturation flow, signal timing alone cannot remove queues. Recent research has moved towards learning-based controllers. Wei et al. (2021) classify reinforcement-learning (RL) signal control by state, action and reward design and by evaluation practice, and Noaeen et al. (2022) show in a systematic review that most RL controllers are still evaluated in simulation, with few field deployments. For Tashkent this implies that adaptive control should be judged mainly by its effect on stopped delay at the node rather than by assumed free-flow gains.

Transit signal priority. TSP grants extra green time or an early green to approaching buses. Imran et al. (2022) distinguish passive priority, based on historical timing, from active priority triggered by bus detection, and discuss conditional priority that is granted only to late buses. Moghimi and Kamga (2021) review predictive and connected-vehicle TSP in smart cities. Iqbal et al. (2022) combine simulation with a decision-tree algorithm to define where TSP and freight signal priority should be activated. Chen et al. (2024) review transit priority control in a connected-vehicle environment and explicitly relate signal priority to carbon emissions at intersections, which is the perspective adopted in this paper.

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Urban freight and loading zones. Boysen et al. (2021) survey last-mile delivery concepts from an operational research perspective, and Lyons and McDonald (2023) note that safety remains under-evaluated in last-mile strategies. At street level the critical resource is curbside space. Comi et al. (2022) propose a simulation-based method to size on-street delivery bays and validate it in Santander. Kalahasthi et al. (2022) jointly model vehicle arrival rates and parking durations at freight loading zones. Muriel et al. (2022) use traffic microsimulation to show that loading-zone strategies can yield outcomes that benefit both carriers and general traffic, and Fransoo et al. (2022) measured the benefit of dedicated unloading bays in a field experiment in Querétaro. Together these studies indicate that double parking of delivery vehicles in front of a market such as Ecobozor removes an effective traffic lane, and that a managed loading zone can return it to traffic.

Fuel and emission modelling. Macroscopic models express fuel use per kilometre as a function of average speed, and CO_2 is then obtained from fuel through a carbon-content emission factor (IPCC, 2006). Such models are easy to calibrate, but when applied to the mean travel speed of a congested corridor they merge idling and running into a single value and misrepresent stop-and-go conditions.

Studies in Uzbekistan. Kutlimuratov et al. (2023) developed a YOLOv5 and DeepSort vehicle-counting system on Tashkent CCTV video that reached 98.1% counting accuracy, which provides a ready data source for calibrating adaptive control. Yusupov and Inoyatkodjaev (2023) assessed an intelligent start-stop system in drive cycles of Tashkent and Andijan. At engine level, Musabekov et al. (2021) formulated differential equations for calculating gas exchange in an internal combustion engine, which underpin estimates of fuel use in low-load and idling modes. Musabekov et al. (2023) showed that adding hydrogen to the primary fuel increases the energy efficiency of a Sano automobile engine, and Musabekov, Tillahodjaev, et al. (2026) proposed a mathematical model for enhancing car engine performance in sustainable transportation development. Musabekov, Khakimov, et al. (2026) obtained theoretical and analytical results from the diagnosis of exhaust gases of an internal combustion engine. These works address the vehicle side of fuel and emission reduction, whereas the present study addresses the traffic-management side. None of these studies links node-level ITS measures to corridor fuel use and CO_2, which is the gap addressed here.

Table 1 summarises how the present study differs from the works reviewed above in object, method and outcome.

Table 1

Comparison of previous studies with the present study

Study	Object/location	Method	Measure(s) studied	Main output	Difference in this study
Kutlimuratov et al. (2023)	Tashkent roads, CCTV video	YOLOv5 detection; DeepSort tracking	Vehicle counting for traffic management	Counting accuracy: 98.1%	Uses such counts as input; adds fuel and CO_2 assessment of measures
Yusupov & Inoyatkodjaev (2023)	Tashkent and Andijan drive cycles	Experimental and statistical analysis	Intelligent start-stop system (vehicle level)	Annual economic effect per vehicle	Corridor level instead of single vehicle; infrastructure measures
Wei et al. (2021)	Review (no site)	Survey of RL models and evaluation	RL traffic signal control	Taxonomy of RL methods	Applies signal control to a real node and quantifies CO_2
Noaeen et al. (2022)	Review of 160 articles	Systematic literature review	RL network signal control	Research trends; few field tests	Provides a site-specific, field-calibratable assessment
Imran et al. (2022)	Review (no site)	Literature review	Bus signal priority strategies	Classification of active/passive priority	Combines TSP with signal and freight measures

Study	Object/location	Method	Measure(s) studied	Main output	Difference in this study
Chen et al. (2024)	Review (no site)	Literature review	TSP in connected-vehicle environment; carbon emissions	Research progress and gaps	Quantifies emissions for a Tashkent case
Comi et al. (2022)	Santander, Spain	Discrete event simulation	Sizing of on-street delivery bays	Delivery bay supply method	Links loading zone to traffic idling and CO_2
Kalahasthi et al. (2022)	Vic, Spain (8 loading zones)	Joint count–survival model	Arrivals and parking durations at loading zones	Demand and dwell-time models	Uses loading zone as one measure in a package
Muriel et al. (2022)	Simulated urban network	Traffic microsimulation	Last-mile delivery strategies; loading zones	Effects on delivery vehicles and traffic	Adds signal control and TSP; emission output
Musabekov et al. (2021, 2023, 2026)	Uzbekistan, passenger car engines	Modelling, experiments; exhaust gas diagnostics	Engine processes, hydrogen additive, engine performance	Engine efficiency and emissions	Traffic-level measures instead of vehicle-level; corridor CO_2
Fransoo et al. (2022)	Querétaro, Mexico	Field experiment	Dedicated unloading bays	Measured delivery benefits	Applies the idea to a Tashkent market node
This study	Tashkent, Temur Malik–Mirzo Ulugbek (Ecobozor), ~2 km	Phase-decomposed fuel–emission model; cumulative scenarios	Adaptive signals + loading zone + TSP	Travel time, fuel, CO_2; average-speed bias	—

2. MATERIALS AND METHODS

2.1. Study area

The study corridor runs along Temur Malik Street from its junction with Do'rmon Yo'li north-west to the intersection with Mirzo Ulugbek Street, and continues along Mirzo Ulugbek Street past the Ecobozor market towards Shahriobod metro station and the Katta Halqa Yo'li ring road. Its length is taken as L = 2.0 km. The section combines (i) a signalised four-arm intersection with heavy turning flows, (ii) curbside freight activity in front of Ecobozor, where delivery vans frequently stop in the outer lane, and (iii) bus and minibus stops that serve transfers to the metro. A map of the corridor with the positions of signals, stops and the proposed loading zone should be included as Figure 1 in the final submission (prepared by the authors from their own survey).

2.2. Phase-decomposed fuel–emission model

The time a vehicle needs to traverse the corridor, T (min), is split into a running phase, in which the vehicle moves at an average running speed vrun (km/h), and an idling phase of duration tidle (min), in which the vehicle is stationary with the engine running:

$$t_{run} = 60L / v_{run}; \quad T = t_{run} + t_{idle}; \quad v_{avg} = 60L / T \tag{1}$$

Fuel consumption per 100 km in the running phase is described by the speed-dependent model:

$$Q_{avg} = \alpha_0 + \alpha_1/v + \alpha_2 v^2 \tag{2}$$

where Qavg is fuel consumption, L/100 km; v is the running speed, km/h; α0 (L/100 km) represents speed-independent losses (rolling resistance, accessories); α1 (L·km/h per 100 km) captures the time-proportional component that dominates at low speed, because engine friction and auxiliary loads are paid

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per unit of time rather than per kilometre; α2 (L·h²/km² per 100 km) captures aerodynamic drag, which grows with the square of speed. Fuel used in the running phase is Frun = Qavg(vrun)·L/100.

Because the model has a single minimum, setting dQ/dv = 0 gives the eco-optimal running speed:

$$v^* = (\alpha_1 / 2\alpha_2)^{(1/3)} \quad (3)$$

Fuel consumed while idling is proportional to idling time:

$$F_{idle} = q_{id} \times t_{idle} \quad (4)$$

where qid is the idling fuel rate, L/h, and tidle is the idling time, h. Total fuel per vehicle is Ftotal = Frun + Fidle, and CO_2 emissions follow from the carbon content of the fuel:

$$E_{CO_2} = F_{total} \times EF_{CO_2} \quad (5)$$

where EFCO2 is the CO_2 emission factor, kg/L. Corridor totals per hour are obtained by multiplying by the flow N (veh/h), and annual peak-period totals by the number of peak hours per day hp and working days D:

$$E_{year} = N \times E_{CO_2} \times h_p \times D / 1{,}000 \quad (6)$$

For comparison, the conventional average-speed estimate evaluates Eq. (2) once at vavg from Eq. (1), without a separate idling term. The relative difference between that estimate and Ftotal is reported as the bias of the average-speed method.

2.3. Parameters and data

Model parameters are listed in Table 2. The coefficients α_0–α_2 were chosen so that the curve reproduces consumption typical of a 1.5–2.0 L gasoline passenger car in urban use: about 7.5 L/100 km at steady 40–50 km/h and about 11 L/100 km at a stop-and-go mean speed of 13 km/h. The idling rate is governed by the engine's working process at low load, including gas exchange in the cylinders, which can be described with the differential equations proposed by Musabekov et al. (2021). The idling rate and the coefficients are therefore assumptions for a gasoline-equivalent passenger car unit and must be calibrated with on-board (OBD) measurements and exhaust gas diagnostics (Musabekov, Khakimov, et al., 2026) on the corridor before the results are used for investment decisions. The emission factor follows the IPCC (2006) default carbon content of motor gasoline.

Table 2

Model parameters

Parameter	Symbol	Value	Unit	Basis
Corridor length	L	2.0	km	Map measurement
Peak-hour flow (baseline)	N	2,000	veh/h	Field estimate
Constant term	α_0	4.0	L/100 km	Assumed, to calibrate
Low-speed term	α_1	90	L·km/h per 100 km	Assumed, to calibrate
Drag term	α_2	0.0008	L·h²/km² per 100 km	Assumed, to calibrate
Idling fuel rate	q_id	0.9	L/h	Assumed (1.5–2.0 L engine)
CO_2 emission factor	EF_{CO_2}	2.31	kg/L	IPCC (2006), gasoline
Peak hours per day	h_p	4	h	2 h morning + 2 h evening
Working days per year	D	260	days	Weekdays

Note. q_id, α_0, α_1, and α_2 are assumptions for a gasoline-equivalent passenger car unit; idling-rate sensitivity is tested in Section 3.3.

2.4. Baseline and scenarios

The baseline reflects peak-hour conditions: 2,000 veh/h, a total corridor time of 9.0 min (mean travel speed 13.3 km/h), of which 6.0 min is idling. The remaining 3.0 min of movement over 2 km corresponds to a running speed of 40 km/h, which reflects short accelerations between queues. Three cumulative scenarios were defined (Table 3):

- **S1 —** adaptive signal control. Detector-based (or CCTV-based) adaptive control at the Temur Malik – Mirzo Ulugbek intersection and adjacent signals; idling time is reduced by 25% (6.0 → 4.5 min) and progression lifts the running speed to 42 km/h.
- **S2 —** S1 + smart loading zone. A time-windowed, camera-enforced loading zone of 3–4 bays in front of Ecobozor (deliveries before 07:30 and 10:00–16:00, booking through a mobile application) removes double parking and restores the outer lane; idling falls to 3.9 min and running speed rises to 45 km/h.
- **S3 —** S2 + transit signal priority. Conditional active TSP for buses approaching Shahriobod metro station, combined with improved bus reliability, is assumed to shift 5% of car trips to public transport (N = 1,900 veh/h); idling falls to 3.6 min and running speed reaches 48 km/h.

Table 3

Scenario inputs

Scenario	Measures	N (veh/h)	t_idle (min)	v_run (km/h)
Baseline	Fixed-time signals; curbside double parking	2,000	6.0	40
S1	Adaptive signal control	2,000	4.5	42
S2	S1 + smart loading zone at Ecobozor	2,000	3.9	45
S3	S2 + conditional TSP; 5% modal shift	1,900	3.6	48

Note. The scenario reductions in idling time are design assumptions consistent with the qualitative findings in Section 1.1; replace them with microsimulation or before–after field observations when available.

Figure 2 shows how the scenarios build on one another and how each is passed through the same model. Each scenario keeps all measures of the previous one, so the difference between consecutive scenarios isolates the marginal effect of the added measure.

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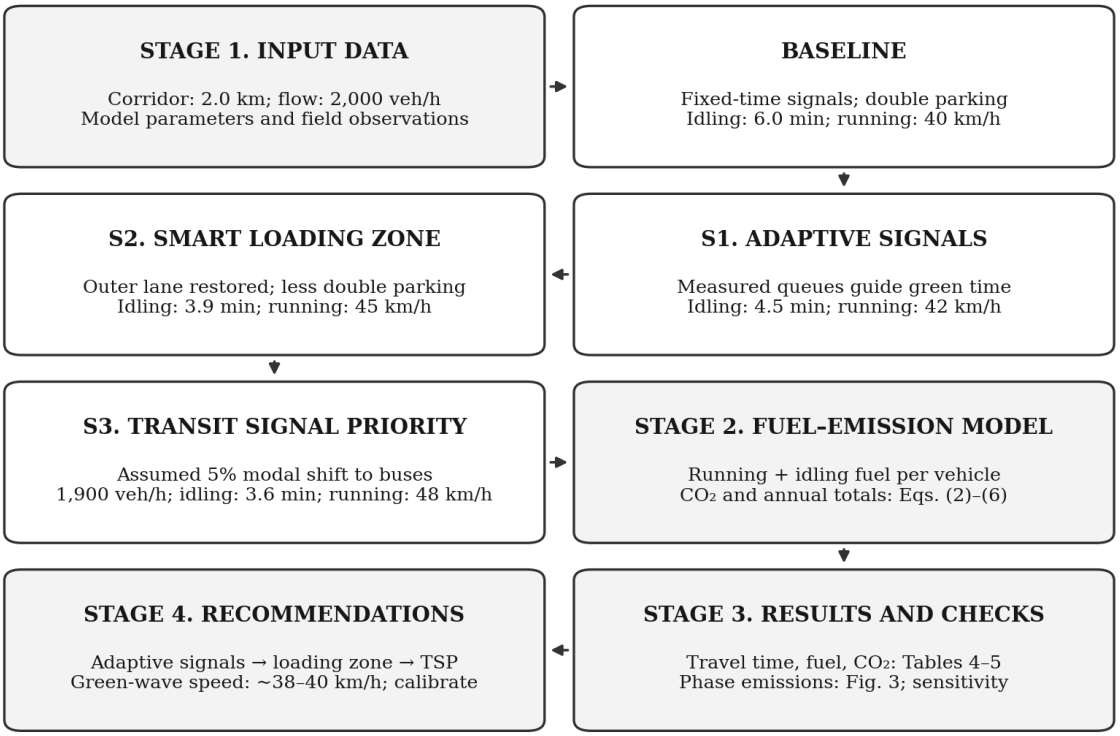
Figure 2

Research framework: Cumulative scenarios S1–S3 and the phase-decomposed fuel–emission model



Note. Each scenario retains measures introduced in previous scenarios. Values are the model assumptions reported in Tables 2 and 3.

3. RESULTS

3.1. Travel time, fuel and CO_2 by scenario

Table 4 reports the results of Eqs. (1)–(6). In the baseline a vehicle needs 9.0 min to cross the corridor and uses 241 mL of fuel, of which 37.4% is burnt while idling. The corridor emits 1,112 kg CO_2 per peak hour. Adaptive signal control alone (S1) cuts travel time by 18.3% and emissions by 9.2%. Adding the loading zone (S2) raises these gains to 27.0% and 12.3%. The full package (S3) reduces travel time to 6.1 min (−32.2%), raises the mean travel speed to 19.7 km/h and lowers hourly emissions to 915 kg (−17.7%).

Table 4

Comparative results for the corridor (L = 2 km, peak hour)

Scenario	t_run (min)	T (min)	v_avg (km/h)	Q (L/100 km)	F_total (mL/veh)	Fuel (L/h)	CO_2 (kg/h)	CO_2 (t/year)	ΔT (%)	ΔCO_2 (%)
Baseline	3.00	9.00	13.3	7.53	241	481	1,112	1,156	—	—
S1	2.86	7.36	16.3	7.55	219	437	1,010	1,050	−18.3	−9.2
S2	2.67	6.57	18.3	7.62	211	422	974	1,013	−27.0	−12.3
S3	2.50	6.10	19.7	7.72	208	396	915	951	−32.2	−17.7

Note. Q is evaluated at the running speed v_run. Annual values cover 4 peak hours per day on 260 working days.

Over a year of peak periods the full package saves about 205 t CO_2 and 88,721 L of fuel. Vehicle-hours spent on the corridor per peak hour fall from 300 to 193 (−35.6%), which is the main benefit for road users.

3.2. Structure of emissions

Figure 3 splits hourly emissions into the running and idling phases. Almost all of the reduction comes from idling, which drops from 416 to 237 kg/h (−43.0%). Running-phase emissions stay between

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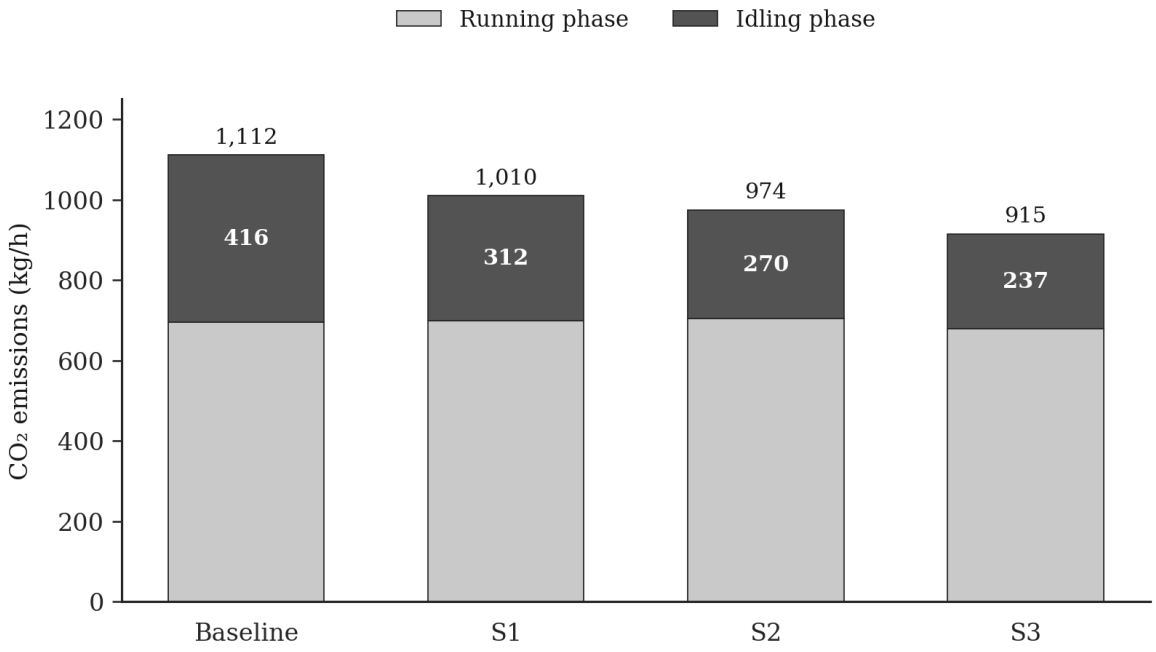
678 and 704 kg/h: higher running speeds slightly increase consumption per kilometre in S1 and S2, and only the smaller flow in S3 brings this component down.

Figure 3

Hourly CO_2 emissions on the corridor by phase and scenario



Note. The total hourly emissions appear above each bar (kg/h). Values within dark-gray segments identify idling-phase emissions. Running-phase emissions are the lighter segments. Scenarios are cumulative.

The reason is visible in Figure 4. Eq. (3) gives an eco-optimal running speed of v* = 38.3 km/h. The running speeds of all scenarios (40–48 km/h) lie on the flat part of the curve just above this optimum, where Q changes by less than 0.2 L/100 km. In contrast, the mean travel speed of the baseline (13.3 km/h) lies on the steep left branch of the curve.

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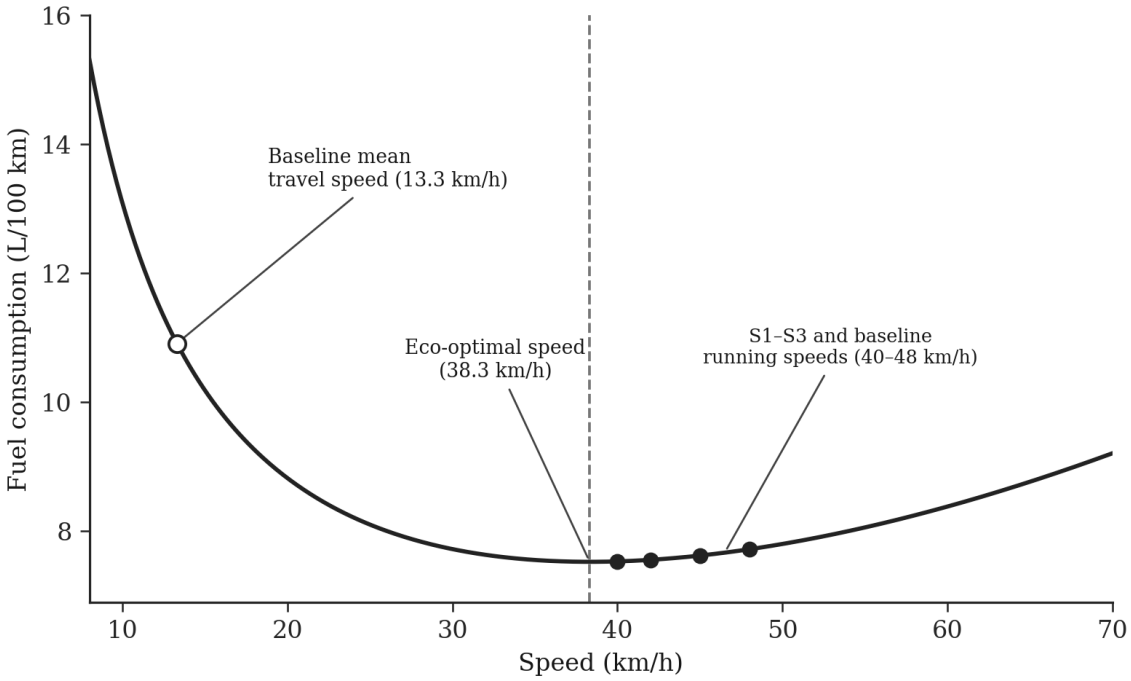
Figure 4

Speed-dependent fuel consumption, eco-optimal speed, and scenario running speeds



Note. The model is $Q = 4 + 90/v + 0.0008v^2$ (L/100 km). The dashed vertical line marks the calculated optimum $v^* = 38.3$ km/h; filled circles mark scenario running speeds.

3.3. Average-speed bias and sensitivity

Table 5 compares the phase-decomposed fuel estimate with the conventional estimate obtained by evaluating Eq. (2) at the mean travel speed. With an idling rate of 0.9 L/h the average-speed method underestimates fuel by 9.5% in the baseline and by 14.7% in S3. Because the bias grows as idling is reduced, the average-speed method would report a different saving than the phase-decomposed model.

Table 5

Fuel per vehicle: Phase-decomposed model versus average-speed method (idling rate 0.9 L/h)

Scenario	v_avg (km/h)	Average-speed estimate (mL/veh)	Phase-decomposed F_total (mL/veh)	Difference (%)
Baseline	13.3	218	241	−9.5
S1	16.3	195	219	−11.0
S2	18.3	184	211	−12.8
S3	19.7	178	208	−14.7

The idling fuel rate is the least certain parameter. Repeating the calculation with idling rates of 0.6 and 1.2 L/h gives a baseline of 973 and 1,250 kg CO_2/h and a reduction under S3 of 14.1% and 20.5% respectively. The direction of the result is therefore robust, while its size depends on the idling rate. The sign of the average-speed bias, however, is not robust: at 0.6 L/h the average-speed method slightly overestimates baseline fuel (+3.4%), at 1.2 L/h it underestimates it by 19.5%. This confirms that the idling rate must be measured locally rather than implied by a speed curve.

4. DISCUSSION

The results show that at a saturated mixed-function node the CO_2 benefit of ITS is delivered mainly by cutting idling, not by raising cruising speed. This agrees with the view in the adaptive-control literature that signal optimisation acts on stopped delay and on the duration of oversaturation (Noaeen et al., 2022; Wei et al., 2021). It also means that green-wave coordination on Temur Malik and Mirzo Ulugbek streets

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should target a progression speed close to v* ≈ 38–40 km/h; designing for higher speeds would add little time saving on a 2 km section and would slightly increase consumption per kilometre.

The loading zone contributes a further 3.1 percentage points of CO_2 reduction (S1 → S2) at a cost far below that of signal hardware. This is consistent with studies showing that properly sized and enforced delivery bays reduce the traffic impact of freight vehicles (Comi et al., 2022; Fransoo et al., 2022; Muriel et al., 2022). The effectiveness of the zone depends on enforcement: if private cars occupy the bays, delivery vans return to double parking. Arrival and dwell-time data of the kind modelled by Kalahasthi et al. (2022) should be collected at Ecobozor to size the zone and its time windows.

TSP has the smallest direct effect on car traffic in the model, but it is the only measure that reduces vehicle numbers. Its main value lies in bus reliability for metro transfers at Shahriobod, which the model does not monetise. Conditional priority, granted only to buses behind schedule, limits the penalty for cross-street traffic (Imran et al., 2022), and the new Tashkent controllers already support green extension for buses (Kun.uz, 2026). Linking TSP with emissions, as proposed by Chen et al. (2024), provides an argument for including bus-priority settings in the city's ITS performance indicators.

Limitations. First, the model uses a single gasoline-equivalent vehicle unit; the Tashkent fleet includes a large share of vehicles running on compressed natural gas and propane, as well as diesel buses and trucks, whose emission factors and idling rates differ. Second, the scenario reductions in idling are assumptions rather than measured or simulated values. Third, the macroscopic model omits acceleration events, which are significant in stop-and-go traffic, and does not account for induced demand if the corridor becomes faster. Fourth, only the peak hours of working days are counted. Vehicle-level measures, such as hydrogen-enriched fuel (Musabekov et al., 2023) or improved engine models (Musabekov, Tillahodjaev, et al., 2026), would shift the fuel–speed curve itself and could be combined with the traffic measures studied here. Future work should calibrate the parameters with OBD data, obtain idling times from CCTV-based tracking (Kutlimuratov et al., 2023), and test the scenarios in a microsimulation model.

5. CONCLUSION

A phase-decomposed fuel–emission model was applied to a ~2 km corridor of Temur Malik and Mirzo Ulugbek streets in Tashkent. The main conclusions are as follows.

1. Under the stated assumptions, a package of adaptive signals, a smart loading zone at Ecobozor and conditional TSP reduces corridor travel time by 32.2% and peak-hour CO_2 emissions by 17.7%, or about 205 t CO_2 per year.

2. Most of the saving comes from reduced idling (−43% in the idling component); running-phase consumption is nearly constant because running speeds stay close to the eco-optimal speed of about 38 km/h.

3. The conventional average-speed method misestimates fuel use by an amount whose size and sign depend on the idling rate; idling should be modelled explicitly at congested nodes.

Recommendations. (1) Prioritise the Temur Malik – Mirzo Ulugbek intersection in the current city-wide signal replacement programme and set coordination for a progression speed of 38–40 km/h. (2) Introduce a camera-enforced, time-windowed loading zone in front of Ecobozor with a booking application for carriers. (3) Activate conditional TSP for routes serving Shahriobod metro station. (4) Use CCTV counts and OBD measurements to calibrate the model and monitor the results annually.

Future research. Extension of the model to a mixed fleet including CNG, propane and electric vehicles; microsimulation of the scenarios; and evaluation of RL-based signal control on the corridor.

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