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Rethinking Transport Systems for Low-Carbon Urban Futures

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Abstract. Transport systems are vital for urban economies yet remain major contributors to greenhouse gas emissions. This paper investigates pathways toward low-carbon mobility through literature review and applied analysis. International research highlights the importance of multimodal hubs, digitalized rail, alternative fuels, and integrated policies that combine technological innovation with social inclusion. A case study from Buzău, Romania, analyses the modernization of Line 10 through electric buses, dedicated lanes, and the UTOPIA intelligent traffic management system. Findings indicate that infrastructure improvements alone generate limited efficiency, whereas active traffic light prioritization increases commercial speed by approximately 2 km/h and reduces travel times by 8–12%, even with route extensions. The results underline that sustainable urban mobility depends on coordinated infrastructure, intelligent digital control, and inclusive governance to achieve environmental and social gains.
Keywords: *transport system, synergy, urban, law carbon economy, decarbonisation.*

Introduction

The pursuit of low-carbon urban represents a societal transformation that extend across every level of human activity, from individual mobility choices to the design of entire metropolitan systems as (Olazabal & Pascual, (2015) or Lehmann, (2013) argues. Transport presents one of the greatest challenges in this transition and it is indispensable to modern economies and social life, yet it is also among the largest and fastest-growing sources of greenhouse gas emissions. Addressing this paradox requires strategies that go beyond incremental change and instead embrace systemic innovation. Emerging pathways include reimagining urban form through new models of mobility and land use, shifting toward pulse-based or on-demand transport systems, embedding sustainability principles within education, and deploying advanced planning frameworks that anticipate long-term environmental and social needs as is highlighted in (Knoflacher, (2007); Sclar & Touber, (2011); Hook et al. (2025).

Despite the rapid expansion of scholarship on low-carbon urban mobility, three structural limitations remain visible in the existing literature. First, empirical imbalance persists in terms of urban scale and geography.

The majority of studies (Morichi, (2005); Knoflacher, (2007); Peckett & Lyons (2021); Umrigar & Pitroda, (2023); Rochaet al (2023); Casavola et al (2024); Choi et al.(2025)) focus on large metropolitan regions in Western Europe or Asia, where advanced Bus Rapid Transit systems, extensive rail infrastructure, and high institutional capacity provide favourable conditions for systemic experimentation. Medium-sized cities, particularly in Eastern Europe are significantly underrepresented and face distinct structural constraints: limited fiscal capacity, incremental infrastructure development, fragmented governance, and slower digital transformation. The absence of field-based evidence from this category of cities constitutes a notable gap, especially given their relevance for achieving European Union climate and cohesion objectives, this research provides real-world validation of partial corridor segregation, where dedicated lanes cover approximately 17% of the total route. Much of the international literature assesses either full segregation or theoretical capacity gains under idealized assumptions and analysing performance outcomes in a mixed-traffic regime with limited physical prioritization, the study offers a more realistic representation of policy implementation constraints typical of medium-sized European cities with limited spatial and financial resources. Second, the intervention logic in the literature is often system-level and fully developed as many analyses evaluate complete BRT corridors, comprehensive electrification strategies, or large-scale ITS deployments. In contrast, real-world modernization in medium-sized cities typically unfolds gradually, through partial corridor segregation, phased route extensions, and stepwise digital activation. There is limited empirical research that isolates and quantifies the relative contribution of complementary measures, specifically dedicated bus lanes and traffic signal priority, when introduced sequentially under mixed-traffic conditions. Most studies treat these interventions as integrated components of mature systems rather than as incremental measures whose individual and cumulative impacts must be distinguished.

International comparisons indicate that walking is more prevalent in Europe, Japan, and North America than in cities of the developing world (Glazebrook & Newman, 2018). Approximately 10% of all journeys in the United States, United Kingdom, and Germany are undertaken by foot, but the analogous statistic in China is estimated at only 0.5%. The cycling shares vary from 0.4% to 18%, with the largest percentages observed in China and the Netherlands (Lefèvre, 2010).

Urban planning has effectively addressed increasing urban heat, traffic congestion, transport emissions, and social isolation only via the integration of networks, land use, public social services, public open spaces, and utilities. The 'Coalition for Urban Transitions' fosters collaboration among governments, private investors, developers, and communities to promote transformative national urban development, emphasizing housing and affordability to support sustainability objectives, including decarbonization. The conventional highway paradigm of urban growth, which facilitated rising affluence, automobile ownership, and petroleum use, fails to tackle global warming, urban air pollution, the availability of cheap housing for all, or significantly diminished congestion (Glazebrook & Newman, 2018). Two options dictate the framework for new developments, districts, and suburbs: either increase density within the current urban structure to enhance social and economic sustainability or create a new urban design that reduces reliance on private automobiles. Future urban expansion is a significant problem for industrialized, growing, and developing economies, and is the focal point of Green Growth and other projects.

Transportation in urban areas unites the land-use, transportation, social, environmental, and economic facets of a metropolis. Location efficiency, excellent design, a balance of amenities and variety, and innovation are the four pillars of constrained urban growth that cities must adhere to if they are to grow efficiently and entice and manage the massive rural-to-urban movement that will occur in the next century. As a whole, low-carbon fuels, changes in travel behaviour, and improvements to vehicle economy are not going to be enough to meet transport-related climate objectives (Jia Wang & Moriarty, 2017). There are new transportation solutions that show promise for a sustainable future (Glazebrook & Newman, 2018). More adaptable and versatile infrastructures are becoming a reality in cities throughout the globe because too smart transport systems, which include smart cars, plains, and traffic conditions.

The transition toward sustainable and low-emission transport has been explored from multiple disciplinary perspectives including engineering, urban planning, and social sciences and yet most research continues to focus on large metropolitan areas in Western Europe or Asia (Orozco et al., 2021). By contrast, medium-sized cities in Eastern Europe remain underrepresented in empirical research on digitalization and transport decarbonization. These cities often face structural challenges such as limited financial capacity, fragmented governance, and slow adaptation of intelligent transport systems (ITS). This imbalance represents a significant research gap, considering that medium-sized urban centers play a crucial role in achieving the European Union's regional climate objectives (Bustos-Turu et al., 2023).

The specific research gap identified in this study concerns the lack of comparative analyses that isolate the relative contribution of two complementary interventions, dedicated bus lanes and traffic signal priority, under mixed-traffic conditions, where infrastructural improvements are introduced gradually and transit routes undergo realignment. Most existing studies have concentrated on fully developed Bus Rapid Transit (BRT) systems or theoretical simulations, without documenting the incremental or cumulative effects of these measures during transitional phases of urban modernization. Researches on Transit Signal Priority remains dominated by algorithmic modeling and simulation-based evaluations, with few field studies addressing conventional bus operations.

Accordingly, the central research hypothesis of this study is that the combined deployment of intelligent traffic management technologies and dedicated public transport infrastructure leads to measurable improvements in overall system efficiency and enhances users' perception of public transport as a reliable, sustainable alternative to private car use.

Literature review

The development of low-carbon transport systems in urban environments constitutes a complex and rapidly evolving research field, requiring the integration of technical innovation, advanced modeling methodologies, and coherent policy frameworks. This domain lies at the intersection of urban planning, energy systems, and data-driven mobility analysis, reflecting both the urgency of climate mitigation and the challenges of ensuring equitable urban transitions. The European Union's pursuit of a low-carbon transport sector is characterized by a combination of infrastructure modernization, technological advancement, and regulatory alignment, all directed toward achieving climate neutrality by 2050. This agenda recognizes the complexity of transport decarbonization and underscores the need for integrated, cross-sector approaches that link urban mobility, long-distance travel, and freight transport under a unified sustainability framework.

A central pillar of EU efforts lies in the promotion of multimodal mobility, where well-designed interchange hubs are seen as catalysts for behavioral and systemic shifts. Conticelli et al. (2021) present a methodological framework for assessing the effectiveness of policy measures and design interventions at these hubs, demonstrating how their configuration can directly influence user adoption of sustainable modes. By enabling seamless transfers between rail, bus, cycling, and other low-emission alternatives, multimodal hubs reduce the dominance of single-mode, carbon-intensive travel and promote a more balanced mobility ecosystem across European cities.

Waterborne transport, a sector integral to European trade and logistics, is another priority area for decarbonization. Fuel diversification represents a further cornerstone of the transition. Navas-Anguita et al. (2021) examine the role of hydrogen, with particular attention to blue hydrogen produced via steam methane reforming coupled with carbon capture and storage (CCS). Their modeling of Spain's transport energy system highlights how CCS retrofits could reinforce the European Hydrogen Strategy, offering a bridge solution while renewable-based green hydrogen matures. Rail transport, traditionally a lower-emission alternative to road and air, is being redefined through the application of Industry 4.0 technologies. Gerhátová et al. (2021) discuss digitalization, automation, and predictive maintenance tools that can boost operational efficiency and reduce energy consumption in railway systems.

Urban mobility presents perhaps the most immediate decarbonization challenges, as cities must reconcile rising demand with stringent emission reduction targets. Byrne et al. (2021) explore urban transport scenarios in Germany, showing that while multiple pathways exist, the optimal balance between public transport, shared mobility, and electrification remains uncertain.

Vehicle technology also continues to advance in parallel with systemic changes. Puškár et al.(2024) propose hybrid low-temperature combustion systems designed to achieve near-carbon-neutral performance. Orozco et al. (2021) stress the growing relevance of multimodal urban mobility and multilayer transport networks, pointing out that the fusion of real-world mobility data with system-level modeling provides new pathways for sustainable transportation design. Their work illustrates how insights from complex systems theory and urban data science can illuminate individual travel behaviors across diverse transport modes, which is fundamental for shaping efficient and low-emission mobility strategies in cities.

At the policy interface, Sareen et al. (2022) introduce the concept of double energy vulnerability in disadvantaged neighborhoods undergoing low-carbon transport transitions. While digitalized electric infrastructures represent a cornerstone of decarbonization, they argue that such systems may unintentionally intensify energy poverty, particularly in marginalized urban areas. This highlights the necessity of socially inclusive low-carbon policies that protect vulnerable groups while enabling systemic transformation. Similarly, Kariuki et al. (2017) expand this discussion to developing countries, emphasizing the role of integrated policy packages as levers for low-carbon transport. They argue that fragmented or isolated interventions cannot generate meaningful progress, whereas coordinated frameworks can establish robust, environmentally sustainable transport systems. Complementing this policy focus, Bustos-Turu et al. (2023) present SmartCityModel, an agent-based decision-support platform designed to simulate energy and transport electrification pathways. By accounting for diverse socio-demographic and technical variables, the model enables fine-grained scenario testing, providing a bottom-up perspective crucial for planning resilient low-carbon energy systems at the city level.

Passenger demand forecasting emerges as another decisive factor for energy optimization in transport systems. The complexity of planning large-scale transport infrastructure is illustrated by Okonta et al.(2025), who apply systems thinking to analyze stakeholder dynamics in the railway sector of Milton Keynes. Their findings show that long-term low-carbon transitions depend not only on technology but also on aligning diverse institutional and social actors. Building on this, Luo et al. (2023) advance a coordinative planning framework that integrates electrified public transport with renewable energy generation and urban energy networks. Employing optimization techniques such as Benders decomposition and Lagrangian relaxation, they demonstrate how cross-sector coupling accelerates multi-energy system decarbonization in cities.The material dimension of urban electrification also requires careful attention. Li et al. (2025) examine Beijing's electric bus fleet, assessing mineral demand and recycling potential. They reveal that resource scarcity and circularity strategies are now critical components of urban low-carbon transitions, as large-scale electrification depends not only on technological adoption but also on sustainable mineral management. Finally, Wu et al. (2025) explore hybrid passenger–freight bus operations in urban–rural settings. Their bilevel optimization model supports dynamic vehicle allocation and collaborative scheduling, improving both economic viability and low-carbon performance. This line of research highlights how system-wide resource reconfiguration can contribute to efficiency gains while simultaneously advancing environmental objectives.

2. Data and Research Methodology

This study was designed to evaluate how the introduction of dedicated bus lanes and intelligent traffic signal priority can improve the efficiency of public transport in a real urban environment

The study adopts a quasi-experimental, longitudinal before–after research design to assess the causal impact of infrastructural and digital traffic management interventions on the operational performance of urban public transport. The analytical framework is structured to isolate and quantify the individual and cumulative effects of two complementary measures: (i) the introduction of dedicated bus lanes and (ii) the activation of dynamic traffic signal priority within an intelligent transport system (ITS). Given the impossibility of implementing randomized controlled conditions in a real urban environment, a natural experiment was exploited, using temporal variation in policy implementation across three distinct operational configurations. This approach allows for inferential comparison under real-world traffic conditions while maintaining ecological validity.

Given the structural and ethical constraints that prevent randomized controlled experimentation in live urban traffic systems, the research exploits a natural experiment generated by the staged modernization of Line 10 in the municipality of Buzău between 2023 and 2025. The sequential implementation of two distinct measures—partial corridor segregation through a dedicated bus lane and subsequent activation of dynamic traffic signal priority via the UTOPIA intelligent traffic management system—provides temporal policy variation suitable for inferential comparison under real-world conditions.

The analytical framework is structured to isolate both the marginal and cumulative effects of these interventions. Three operational scenarios are defined. The baseline scenario (S_0, 2023) represents mixed-traffic operation without any form of dedicated lane or signal priority. The second scenario (S_1, 2025) introduces a dedicated bus lane along approximately 17% of the corridor while maintaining conventional signal control. The third scenario (S_2, 2025) retains the dedicated lane and activates dynamic traffic signal priority at equipped intersections. This staged configuration enables structured difference-based comparisons: the contrast between S_1 and S_0 estimates the isolated contribution of physical lane segregation; the contrast between S_2 and S_1 captures the additional marginal impact of intelligent signal priority; and the difference between S_2 and S_0 reflects the cumulative systemic effect.

The empirical investigation focuses on Line 10, a strategically important corridor connecting the southern industrial area with northern residential neighborhoods and intersecting key commercial, educational, and administrative nodes. The line was selected due to its high passenger relevance, corridor centrality within the urban transport network, and the availability of consistent operational data across comparable time intervals. Importantly, the 2025 configuration includes route extension of approximately one kilometer and the introduction of additional stations in high-demand areas. This structural expansion imposes upward pressure on total travel time and therefore reinforces a conservative interpretative logic: any reduction in travel duration or increase in commercial speed under the new configuration indicates a robust efficiency gain rather than a simplification effect.

Operational data were provided by the municipal public transport operator and include semi-trip duration (terminal-to-terminal travel time), commercial speed, station dwell times, and segment distances. Observations were recorded for both directions of operation (Ring 1 and Ring 2) and at three representative time intervals: morning peak (08:00), midday off-peak reference (12:00), and afternoon peak (16:00). This temporal stratification captures congestion variability and allows evaluation of intervention performance under heterogeneous traffic intensity conditions.

Two primary performance indicators were selected to reflect corridor-level operational efficiency. The first is semi-trip duration, defined as the total time required to complete one directional run between terminal stations, including dwell times at intermediate stops. This indicator captures cumulative delay effects arising from congestion and intersection control. The second is commercial speed, calculated as route length divided by total operational time and expressed in km/h. Commercial speed integrates both movement and stopping time and serves as a direct proxy for service competitiveness, reliability, and user-relevant efficiency. These indicators were deliberately chosen because they reflect passenger-perceived service quality and network throughput capacity rather than abstract modeling constructs.

The analytical procedure involved sequential data validation, inter-scenario comparison, and percentage-difference estimation. Distances and time measurements were cross-checked to ensure internal consistency across scenarios. No artificial normalization was applied to offset the 2025 route extension; instead, the analysis maintains structural comparability while preserving the conservative evaluation framework. Efficiency gains are therefore interpreted as net improvements occurring despite increased corridor length and operational complexity.

Under Scenario S_2, traffic signal priority operates through an integrated detection and adaptive control mechanism. Buses are identified via GPS-based tracking and intersection-level sensors, triggering a priority request to the central control system. The algorithm evaluates real-time traffic conditions and grants either conditional or absolute priority by adjusting signal phases to minimize stopping time. After bus passage, the system restores baseline signal cycles and records operational data for monitoring. Along Line 10, priority-enabled segments cover approximately 2,400 meters, corresponding to nearly 17% of the total route length, allowing assessment of localized digital intervention within a predominantly mixed-traffic environment.

Although the design enhances internal validity through staged intervention comparison and real operational measurement, certain limitations remain. The study does not model passenger demand elasticity, modal shift behavior, or lifecycle emission reductions. The focus is confined to operational efficiency indicators, which serve as necessary but not sufficient conditions for long-term decarbonization. Nevertheless, the quasi-experimental framework, combined with conservative causal interpretation and corridor-level performance metrics, provides a robust empirical basis for evaluating incremental modernization strategies in medium-sized urban environments.Still, the analysis is limited to operational performance indicators, specifically semi-trip duration and commercial speed and these metrics capture service efficiency and temporal reliability but do not directly account for passenger demand elasticity, occupancy rates, boarding/alighting dynamics, or perceived service quality. Consequently, while improvements in speed and travel time are strong predictors of increased attractiveness, the study does not empirically model behavioral shifts from private car use to public transport. The methodological approach emphasizes operational efficiency metrics rather than abstract system modeling where the semi-trip duration and commercial speed were selected because they directly reflect passenger-relevant service quality and network throughput capacity. These indicators are sensitive to both lane separation and signal delay reductions, making them appropriate for intervention-level evaluation and in this context the research design incorporates a conservative interpretative stance. Since the 2025 route configuration includes extension and additional stops, the structural conditions impose upward pressure on travel time. Therefore, any reduction in duration or increase in commercial speed is interpreted as a robust efficiency gain rather than a byproduct of route simplification. This methodological conservatism reduces the risk of overstating intervention effects.

The research design integrates staged intervention analysis, corridor-based longitudinal observation, and performance indicator comparison within a quasi-experimental framework. It is specifically tailored to evaluate incremental modernization strategies in medium-sized urban environments where digital transformation and infrastructural adaptation occur progressively rather than through comprehensive system redesign.

3. Analysis of the impact of prioritizing public transport circulation in the context of Rethinking Transport Systems for Low-Carbon Urban Futures[1]

3 .1 General analysis framework

The research analysis presents a case study focused on Line 10 in the municipality of Buzău, carried out in the context of recent infrastructure modernization interventions and the introduction of intelligent traffic management solutions. Line 10 was selected due to its high usage and extensive route, which crosses various areas of the city and connects multiple points of interest, such as residential neighbourhoods, public institutions, and commercial areas. The study aims to compare travel times in three distinct scenarios, analysed over the course of a day, at times relevant to urban traffic intensity. It takes into account the effects of route extension, the introduction of dedicated lanes, and the activation of traffic light priority on public transport operations. In the municipality of Buzău, between 2016 and 2024, a large-scale project was carried out to modernize the equipment for controlling and coordinating road traffic. The project, entitled "Intelligent traffic, management, and monitoring system based on innovative solutions for efficiency and pollution reduction in the municipality of Buzău," provided for the modernization of 24 intersections through the introduction of intelligent traffic light equipment,

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[1] This section is based on the research results carried on during the M.Sc. thesis called “Accessibility and attractiveness in sustainable urban mobility systems”, National University of Science and Technology Polytechnic Bucharest, Faculty of Transport, Master's program in Urban Transport and Traffic.

vehicle detection sensors, automatic license plate recognition (LPR) systems, video cameras, and a digital platform for real-time data control and analysis, operated from a modern command centre.

The need for the project was determined by a number of problems identified in the urban road network: traffic congestion during peak hours, long travel and waiting times for public transport, and the lack of a coherent system for coordinating traffic lights, monitoring, and real-time information. As can be seen in Figure 1, public transport is used for only about 19% of citizens' journeys, with walking and private cars being preferred. One of the reasons for this low percentage is that, in the absence of measures to prioritize public transport over private vehicles, public transport vehicles are affected by the same problems of traffic congestion, long travel times, and low traffic speeds. In this situation, citizens prefer to use their own cars for long-distance trips and walking for medium and short-distance trips.

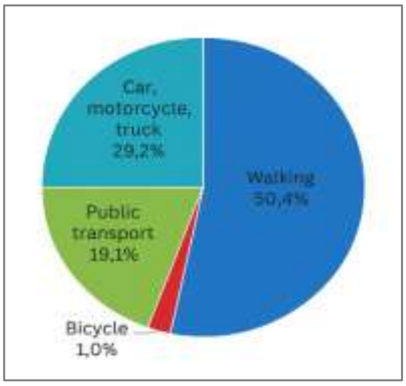

Figure 1. Distribution of trips by mode of transport in the city of Buzău, 2016. (S.C. Urban Scope S.R.L., 2017)

The main goal of implementing the intelligent traffic management system is to improve the efficiency of urban mobility by adopting modern technological solutions that meet the current needs of traffic and citizens. Expectations are primarily focused on reducing travel times, especially for public transport, which must become faster, more predictable, and more attractive to the population. Another major objective is to reduce greenhouse gas emissions and noise pollution by reducing unnecessary stops at traffic lights and encouraging the transition from private car transport to public transport. By reducing waiting times and fuel consumption, a direct impact on air quality and energy efficiency in the city is expected. In addition to environmental benefits, the aim is to increase road safety through video monitoring of intersections and the integration of warning systems for pedestrians and drivers.

The purpose of the case study is to present the impact of dedicated public transport infrastructure. TransBus operator line 10 will be analysed by comparing travel times between terminal stations before and after the project's implementation, at different times and in several scenarios, such as with or without priority at traffic light intersections. The study aims to highlight the actual impact of the investment on the attractiveness of public transport. Line 10 was selected for the study due to its strategic importance in the transport network of the municipality of Buzău. The route connects the southern industrial area with the northern residential neighbourhoods and includes several commercial and administrative points of major interest. Table 1. presents the characteristic data for the line for the year 2023, before the completion of the project.

Tables 1–4 show the semi-trip times on Line 10 in two operating scenarios: 2023 and 2025 without activating public transport priority at intersections. The values for both directions of traffic (Ring 1 and Ring 2) are included, reported for three hourly intervals: 08:00, 12:00, and 16:00. The data allow for the observation of variations in duration depending on the time of day, direction of travel, and specific operating conditions, providing an objective framework for the comparative analysis of public transport performance in the two periods analysed.

Table 1. The main characteristics of Ring 1 in 2023

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
Brăilei Road	0	0	0	0	0
Mariage Restaurant	750	2	2	2	0.25
Marghiloman Park	600	3	3	3	0.25
CFR High School	300	4	4	4	0.25
Horticulture	550	5	5	5	0.25
Mitran	450	7	7	7	0.25
High School 1	400	8	8	8	0.25
Dorobanți Market	300	9	9	9	0.25
Dorobanti intersection	400	11	11	11	0.25
Broșteni	400	12	12	13	0.25
Contactoare	700	15	14	16	0.5
Bazar	600	18	17	19	0.5
Cathedral	600	22	20	22	0.25
RAM	400	25	22	25	0.25
ACR	600	28	24	28	0.25
BIG	500	32	27	31	0.25
Drăgaică	1000	39	32	38	0.25
Alison	650	42	34	40	0.25
Gerom 1	350	43	35	41	0.25
Gerom 2	200	44	36	42	0.25
Mihai Viteazu	300	45	37	43	0.25
High School 7	400	46	38	44	0.25
Rotec	250	47	39	45	0.25
Constam	450	48	40	46	0.25
Cibela	300	49	41	47	0.25
Apcarom 2	350	50	42	48	0.25
Brăilei Road	1400	53	44	51	0.25
Total	13200				7
Total half race [min]		60	51	58	
Commercial speed [km/h]		13.2	15.5	13.7	

Table 2. The main characteristics of Ring 2 in 2023

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
Aromet	0	0	0	0	0
Apcarom 2	750	2	2	2	0.25
Cibela	250	3	3	3	0.25
Constam	300	4	4	4	0.25
Agrana	250	5	5	5	0.25
High School 7	450	6	6	6	0.25
Mihai Viteazu	400	7	7	7	0.25
Gerom	300	8	8	8	0.25
Ductile	400	9	9	9	0.25
Alison	250	10	10	10	0.25
Casa de pensii	450	13	12	13	0.5

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
BIG	1100	18	16	22	0.25
ACR	700	21	18	25	0.25
McDonald's	500	24	21	28	0.5
Bazaar	900	31	26	36	0.5
Sports Hall	750	35	29	40	0.25
Broșteni	500	36	30	41	0.25
Dorobanti intersection	400	38	32	43	0.25
Dorobanți Market	400	39	33	45	0.25
High School 1	300	40	34	46	0.25
Mitran	400	41	35	47	0.25
Horticulture	450	43	36	49	0.25
CFR High School	600	44	37	50	0.25
Marghiloman Park	300	45	38	51	0.25
Apcarom 1	450	47	39	53	0.25
Aromet	850	49	41	55	0.25
Total	12,400				7
Total half race [min]		56	48	62	
Commercial speed [km/h]		13.3	15.5	12.0	

Table 3. The main characteristics of Ring 1 in 2025

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
Brăilei Road	0	0	0	0	0
Mariage Restaurant	750	2	2	2	0.25
Marghiloman Park	600	3	3	3	0.25
CFR High School	300	4	4	4	0.25
Pitar Moș	150	5	5	5	0.25
High School 1	850	8	8	8	0.25
Dorobanți Market	300	9	9	9	0.25
Dorobanți intersection	400	11	11	11	0.25
Broșteni	400	12	12	13	0.25
Contactoare	700	15	14	16	0.25
Bazar	600	18	16	19	0.5
CEC	600	21	19	22	0.25
McDonald's	400	23	21	24	0.25
ACR	600	25	23	26	0.25
LIDL	500	27	25	28	0.25
Kaufland South/E85	700	30	27	30	0.25
CIT Buzău	200	31	28	31	3
PECO	300	32	29	32	0.25
Drăgaica	1300	38	33	37	0.25
Alison	650	41	35	40	0.25
Gerom 1	350	42	36	41	0.25
Gerom 2	200	43	37	42	0.25
Mihai Viteazu	300	44	38	43	0.25
High School 7	400	45	39	44	0.25

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
Rotec	250	46	40	45	0.25
Constam	450	47	41	46	0.25
Cibela	300	48	42	47	0.25
Apcarom 2	350	49	43	48	0.25
Brăilei Road	1400	52	45	50	0.25
Total	14300				10
Total half race [min]		62	55	60	
Commercial speed [km/h]		13.8	15.6	14.3	

Table 4. The main characteristics of Ring 2 in 2025

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8:00	12:00	16:00	
Aromet	0	0	0	0	0
Apcarom 2	750	2	2	2	0.25
Cibela	250	3	3	3	0.25
Constam	300	4	4	4	0.25
Agrana	250	5	5	5	0.25
High School 7	450	6	6	6	0.25
Mihai Viteazu	400	7	7	7	0.25
Gerom	300	8	8	8	0.25
Ductil	400	9	9	9	0.25
Alison	250	10	10	10	0.25
Casa de pensii	450	12	12	13	0.5
Kaufland South/E85	1700	19	17	23	0.25
CIT Buzau	200	20	18	24	3
PECO	300	21	19	25	0.25
LIDL	550	23	21	27	0.25
ACR	700	25	23	29	0.25
McDonald's	500	27	25	31	0.5
Bazar	900	32	29	36	0.5
Sports Hall	750	36	32	40	0.25
Brosteni	500	37	33	41	0.25
Dorobanti intersection	400	39	35	43	0.25
Dorobanti Square	400	40	36	45	0.25
High School 1	300	41	37	46	0.25
CFR High School	1000	43	39	48	0.25
Marghiloman Park	300	44	40	49	0.25
Apcarom 1	450	46	41	51	0.25
Aromet	850	48	43	53	0.25
Total	13600				10
Total half race [min]		58	53	63	
Commercial speed [km/h]		14.1	15.4	13.0	

Priority for public transport within the UTOPIA system works through an integrated mechanism for detecting, analysing, and adapting traffic lights in real time. Buses are automatically detected before they reach an intersection, either by sensors mounted in the road or by the GPS tracking system integrated into the vehicles. Once a public transport vehicle is identified, it sends a priority request to the intersection controller and the system command centre.

The algorithm analyses this request together with existing traffic flows and decides whether to grant absolute priority (by interrupting other flows) or conditional priority (inserting the bus into a green phase without significantly affecting other traffic participants). Depending on the context at the intersection, the system automatically adjusts the duration of the traffic light phases so that the bus can pass without stopping or with minimal delay. After the bus has passed, the traffic light cycle returns to normal, and data about this manoeuvre is recorded for monitoring and analysis. This approach contributes significantly to reducing delays in public transport and increasing its attractiveness, without significantly compromising the overall flow of road traffic. Along line 10, the length of the route where public transport can benefit from priority at intersections is 2400 m, which for ring 1 represents 16.8% of the total route length and 17.7% for ring 2.

Tables 5 and 6 show the semi-trip times on Line 10 in 2025, under conditions of active priority for public transport. Both directions of traffic (Ring 1 and Ring 2) are included, at 08:00, 12:00, and 16:00. The data reflects the performance of the line in a context where the extended route and dedicated lane are constant, and the distinctive element is the activation of priority at intersections.

Table 5. The main characteristics of Ring 1 in 2025 with priority at intersections

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8	12:00	4:00	
Brailei Road	0	0	0	0	0
Mariage Restaurant	750	2	2	2	0.25
Marghiloman Park	600	3	3	3	0.25
CFR High School	300	4	4	4	0.25
Pitar Mos	150	5	5	5	0.25
High School 1	850	8	8	8	0.25
Dorobanti Square	300	9	9	9	0.25
Dorobanti intersection	400	11	11	11	0.25
Brosteni	400	12	12	13	0.25
Contactoare	700	15	14	16	0.25
Bazar	600	18	16	19	0.5
CEC	600	20	18	21	0.25
McDonald's	400	21	19	22	0.25
ACR	600	22	20	23	0.25
LIDL	500	23	21	24	0.25
Kaufland South/E85	700	25	22	25	0.25
CIT Buzau	200	26	23	26	3
PECO	300	27	24	27	0.25
Dragaica	1300	33	28	32	0.25
Alison	650	36	30	35	0.25
Gerom 1	350	37	31	36	0.25
Gerom 2	200	38	32	37	0.25
Mihai Viteazu	300	39	33	38	0.25
High School 7	400	40	34	39	0.25
Rotec	250	41	35	40	0.25
Constam	450	42	36	41	0.25
Cibela	300	43	37	42	0.25
Apcarom 2	350	44	38	43	0.25
Brailei Road	1400	47	40	45	0.25
Total	14300				10
Total half race [min]		57	50	55	
Commercial speed [km/h]		15.1	17.2	15.6	

Table 6. The main characteristics of Ring 2 in 2025 with priority at intersections

Station name	Distance [m]	Time [min]			Station dwell time [min]
		Time			
		8	12:00	4:00	
Aromet	0	0	0	0	0
Apcarom 2	750	2	2	2	0.25
Cibela	250	3	3	3	0.25
Constam	300	4	4	4	0.25
Agrana	250	5	5	5	0.25
High School 7	450	6	6	6	0.25
Mihai Viteazu	400	7	7	7	0.25
Gerom	300	8	8	8	0.25
Ductil	400	9	9	9	0.25
Alison	250	10	10	10	0.25
Casa de pensii	450	12	12	13	0.5
Kaufland South/E85	1700	19	17	23	0.25
CIT Buzau	200	20	18	24	3
PECO	300	21	19	25	0.25
LIDL	550	23	20	27	0.25
ACR	700	24	21	28	0.25
McDonald's	500	25	22	29	0.5
Bazar	900	28	24	32	0.5
Sports Hall	750	31	26	35	0.25
Brosteni	500	32	27	36	0.25
Dorobanti intersection	400	34	29	38	0.25
Dorobanti Square	400	35	30	40	0.25
High School 1	300	36	31	41	0.25
CFR High School	1000	38	33	43	0.25
Marghiloman Park	300	39	34	44	0.25
Apcarom 1	450	41	35	46	0.25
Aromet	850	43	37	48	0.25
Total	13600				10
Total half race [min]		53	47	58	
Commercial speed [km/h]		15.4	17.4	14.1	

The modernization of urban infrastructure and the extension of Line 10 have led to significant changes in urban travel. However, in the absence of explicit prioritization of public transport at traffic light intersections, the operational efficiency of Line 10 remains below expectations, despite the modernization of the bus fleet and the adaptation of the route. A comparative analysis of public transport performance on Line 10 in the municipality of Buzău in 2023, and 2025, in a scenario where the UTOPIA system does not give priority to buses at traffic lights, but in which the dedicated lane is already implemented on 17% of the route, highlights a series of partial but insufficient progress to ensure integrated urban efficiency.

In 2023, public transport operated in a completely mixed traffic regime, without any form of prioritization or separation. Under these conditions, according to Figure 2, the average commercial speed of buses on the analyzed line ranged between 13.2 and 15.5 km/h on Ring 1 and between 12 and 15.5 km/h on Ring 2, depending on the time of day. The average travel time for a half-trip ranged between 51 and 60 minutes, as shown in Figure 3, due to traffic congestion during peak hours and the lack of dedicated corridors.

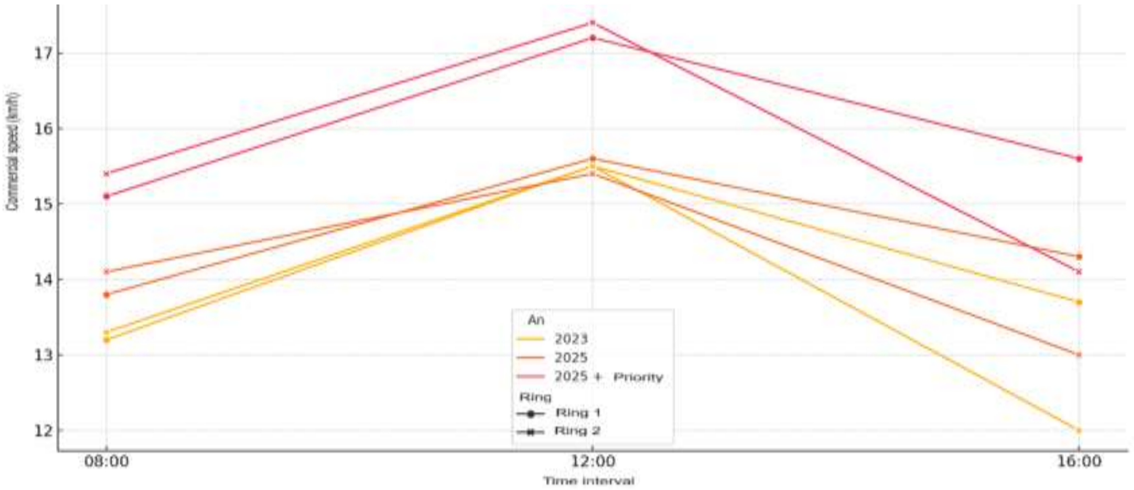

Figure 2. Variation in commercial speed

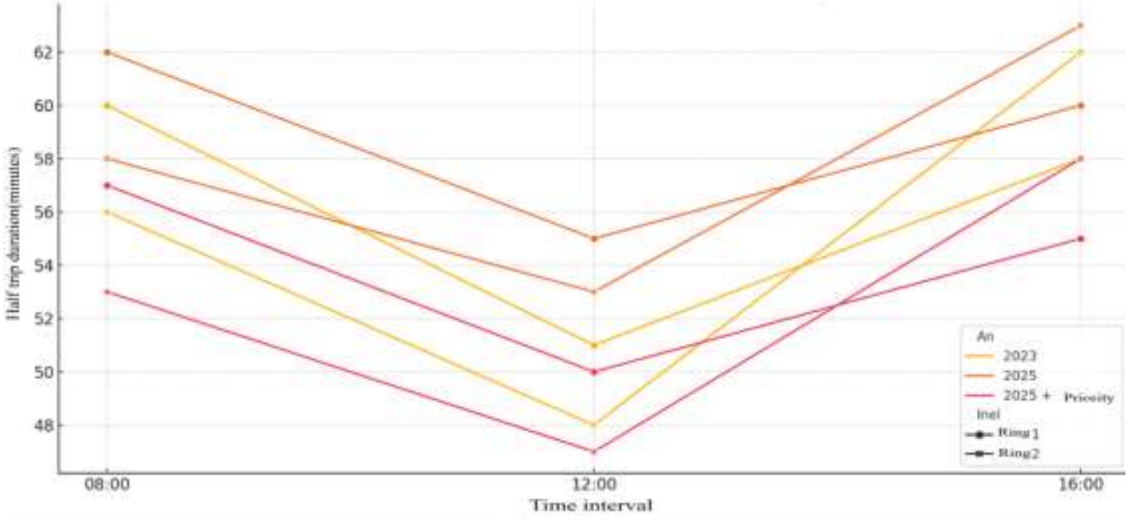

Figure 3. Duration of half-trips.

In 2025, without priority at intersections but with a dedicated lane over a length of 2,400 m (approximately 17% of the route), there is a slight improvement in traffic parameters. The average commercial speed increased during peak hours by 0.6–0.8 km/h, and the semi-trip duration remained relatively constant compared to 2023, despite the physical extension of the route by more than one kilometer. These data demonstrate that the dedicated lane has a positive impact, especially in segments where it is continuous and well-defined, reducing queueing times.

However, in the absence of dynamic prioritization at traffic light intersections, the benefits of the dedicated lane are diminished by the frequency of forced stops at red lights, which continue to affect the predictability and total duration of trips. The dedicated lane ensures smoother traffic flow in some sections, but does not completely solve the congestion at intersections, where general traffic flow inevitably interferes with that of buses. From this perspective, progress is real, but fragmented and incomplete.

It is also important to note that in 2025, the route of Line 10 includes several new stations, introduced in areas of high interest (e.g., Kaufland Sud, CIT Buzău), which generates a natural increase in total duration, but also an increased potential to attract users. In the absence of a compensation mechanism, such as intelligent prioritization, this expansion turns from an opportunity into an operational burden, which can limit the overall efficiency of the service. Compared to 2023, the 2025 scenario without the activation of traffic light priority ( ), but with the introduction of a dedicated lane, brings a partial improvement in public transport performance, highlighted in commercial speed. However, the total duration of journeys remains roughly the same or slightly longer than in the past, suggesting that the physical infrastructure, in the absence of a digital measure to coordinate flows, is not sufficient to generate systemic changes.

In 2025, in the traffic light priority scenario, an average of between 15.1 and 17.4 km/h was achieved. This increase of approximately 2 km/h compared to 2023 data indicates a considerable improvement in service efficiency, contributing to shorter travel times and more predictable schedules. Between 12:00 p.m. and 1:00 p.m., the gains are most noticeable, suggesting that outside of peak hours, the UTOPIA system manages to improve traffic light efficiency with increased performance.

Comparing the total duration of semi-trips, it can be seen that in 2025, in the prioritization scenario, the duration decreases to 53-57 minutes. This means a time saving of between 5 and 7 minutes per semi-trip compared to 2023, representing a reduction of between 8 and 12% in total duration. Given that the length of the route increased in 2025 with the introduction of additional stations, these results are even more significant. In practice, the dedicated infrastructure and priority at traffic lights compensated not only for congestion but also for the physical extension of the route. In these segments, speed and regularity are optimized, and deviations are reduced. This improves not only the duration but also the uniformity of journey times, which is essential for user loyalty. In conclusion, the implementation of the dedicated lane and the intelligent traffic management system in Buzău has led to a measurable increase in public transport performance.

In Figure 4, the 2025 scenario with priority for buses brings the greatest reductions in travel time, especially between 12:00 p.m. and 1:00 p.m., with a saving of approximately 4 minutes per half-trip. In contrast, the scenario without priority actually shows increases in travel time compared to 2023 in some intervals (for example, at 16:00, the time is more than 3 minutes longer). These data confirm that dynamic prioritization at intersections is essential for dedicated infrastructure to generate real benefits in urban mobility.

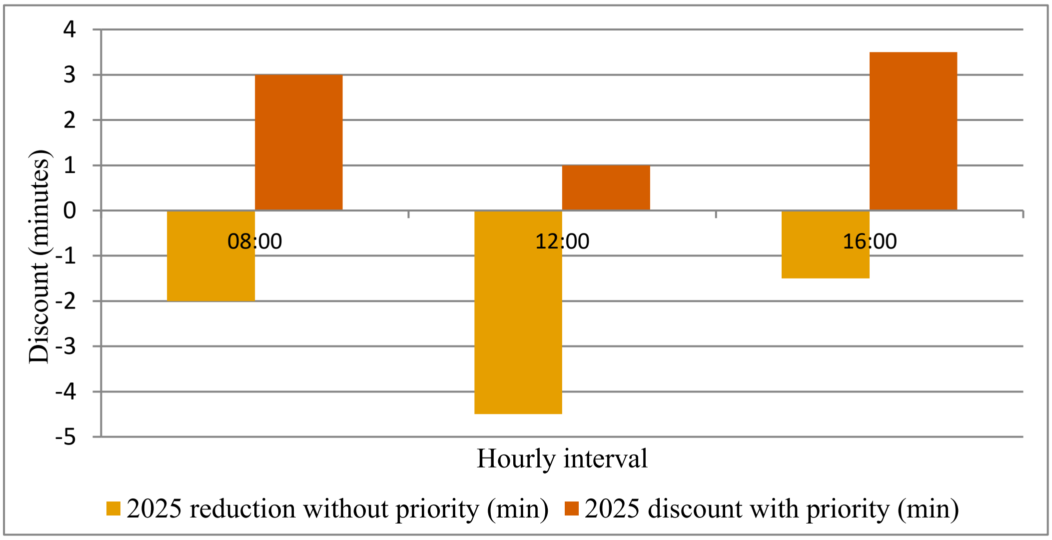

Figure 4. Reduction in semi-trip duration in 2025 compared to 2023

Based on these conclusions, it is recommended to maintain and improve the model implemented across the entire urban network, as the prioritization system is already operating on all public transport lines in the city. Continuous performance monitoring is necessary, using data provided by the NEXT platform, as well as periodic adjustment of traffic light parameters according to traffic flow developments. At the same time, a coherent public communication strategy can contribute to increasing the use of public transport and strengthening an urban culture oriented towards sustainable mobility.

Conclusions

The transition toward low-carbon urban transport requires an integrated perspective that links infrastructure, technology, and governance. The case study of Line 10 in Buzău illustrates both the opportunities and the limitations of current approaches. On one hand, the modernization of the bus fleet with electric vehicles and the introduction of dedicated lanes represents clear steps toward cleaner and more efficient mobility. On the other hand, the analysis shows that these measures alone are insufficient to achieve significant reductions in travel times and to make public transport an attractive alternative to private cars. The improvements emerged only when intelligent traffic management through the UTOPIA system was activated. By granting buses dynamic priority at intersections, commercial speeds increased by approximately 2 km/h, and average travel times fell by 8–12%, even though the route length was extended with additional stations. These results underline that digital control and adaptive coordination of traffic flows are essential complements to physical infrastructure. Without them, congestion at intersections and unpredictable delays continue to undermine the efficiency of public transport.

From a policy perspective, the Buzău case demonstrates that local governments can achieve tangible results by combining infrastructure modernization with smart digital tools and these measures must be embedded in a broader strategy that also includes continuous monitoring of system performance, periodic recalibration of traffic management parameters, and active communication with citizens to encourage behavioral shifts toward public transport. Looking ahead, further research should investigate how intelligent traffic systems can be scaled across entire urban networks and how they can be integrated with renewable energy sources to optimize both mobility and energy use. Equally important is the study of user responses: as reliability and predictability increase, public perception of public transport may shift, creating the social foundation for long-term decarbonization.

In conclusion, the evidence from Buzău reinforces the central argument of this paper: sustainable urban mobility is not the result of single interventions but of synergistic strategies. Infrastructure, digital intelligence, and governance must work together to generate lasting environmental and social benefits, transforming public transport into the backbone of low-carbon urban futures.

Limitations and Future Research Directions

This study has several limitations that constrain the scope and generalizability of its findings. The empirical analysis is based on a single medium-sized Eastern European city operating under partial corridor segregation in a mixed-traffic environment, limiting external validity given cross-city institutional and fiscal heterogeneity. The intervention focus is restricted to incremental measures—dedicated bus lanes and Traffic Signal Priority—without incorporating broader structural reforms, thereby only partially capturing system-level and long-term modal effects. The evaluation emphasizes short- and medium-term operational indicators within a quasi-experimental before–after framework; although this design strengthens internal validity, residual confounding cannot be fully excluded. Moreover, environmental, behavioral, and equity dimensions are only marginally addressed.

Future research should adopt comparative multi-city designs, extend longitudinal observation periods, and employ more robust causal inference methods to improve attribution precision. Integrating operational data with environmental, behavioral, and system-level modeling frameworks would enable a more comprehensive assessment of staged transit modernization strategies in resource-constrained, non-metropolitan contexts.

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