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ARTIFICIAL INTELLIGENCE IN THE FUNCTION OF A SUSTAINABLE TRANSPORT SYSTEM AND ENVIRONMENTAL PROTECTION

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Abstract:
Modern urban transport requires increased efficiency alongside a reduction in its ecological footprint, which is why artificial intelligence (AI) is taking a key role in the development of intelligent traffic management systems. The aim of this paper is to investigate the potential of AI algorithms in sustainable transport, focusing on the reduction of traffic congestion, energy consumption, and greenhouse gas emissions. A systematic literature review confirms that these intelligent systems significantly improve traffic flow and environmental sustainability through real-time data processing. However, it is concluded that the success of their implementation directly depends on the development of digital infrastructure and data quality, which remains a key challenge for smart cities.

Keywords: *Artificial intelligence, intelligent traffic management systems, sustainable transport, CO_2 emissions*

Introduction

Contemporary urbanization and the growth of motorization have positioned the transport sector as one of the most complex challenges for sustainable development. Transport accounts for approximately one quarter of total greenhouse gas emissions in the EU, with road traffic generating more than 70% of that share [1]. Traditional control systems based on fixed signal plans show serious limitations under dynamic conditions, resulting in frequent congestion and increased concentrations of harmful substances at intersections due to the idling of vehicle power units [2].

The concept of smart cities (Smart Cities) relies on Intelligent Transport Systems (ITS) as a key tool for achieving environmental goals and the digitalization of infrastructure [10]. Artificial intelligence (AI) enables the transformation of passive systems into adaptive ones, capable of optimizing traffic flows in real time on the basis of large volumes of data

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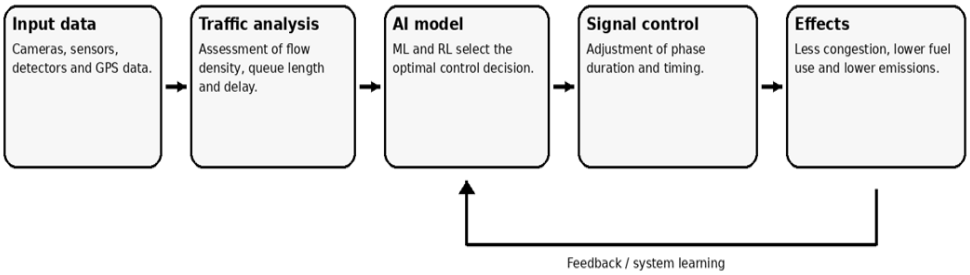
collected from sensors and cameras. This paper aims to analyze the scope of the application of AI algorithms in the function of sustainable transport, with a particular focus on environmental effects and the challenges of implementation under specific infrastructure conditions [12]. Although the existing literature provides valuable insights into adaptive traffic control, most studies examine algorithmic efficiency, signal optimization, or environmental effects separately. A clearer interdisciplinary synthesis linking traffic engineering performance, environmental protection outcomes, and implementation constraints in less digitally developed urban contexts is still limited. In that respect, this paper contributes by integrating these dimensions into a single analytical framework and by discussing their relevance for Serbia and the wider Western Balkans region.

1. Artificial Intelligence in Intelligent Traffic Management

Traditional approaches to traffic signal control have relied on static models for decades. These models, known as fixed-time control systems, are optimized on the basis of data collected at specific time intervals. Although they are simple to implement, their efficiency declines sharply under saturated conditions or in the event of unforeseen circumstances, such as traffic accidents or roadworks, because they lack the ability to adapt to the current state of the network [4].



Picture 1. *Conceptual illustration of the role of artificial intelligence in sustainable traffic system management, Source: Author*

1.1. Architecture of Intelligent Management Systems

Artificial intelligence (AI)-based intelligent systems operate on the principle of a "closed-loop system," in which decisions are made on the basis of continuous feedback from the field. The architecture of these

systems relies on three interconnected layers that function as an integrated whole.

Everything begins at the sensor level, that is, the data acquisition layer, where technologies such as inductive loops, video detection, LiDAR sensors, and data from connected vehicles (V2I) monitor conditions in real time. These devices continuously record information on vehicle counts, travel speed, and queue lengths, while also detecting the presence of vulnerable road users, such as pedestrians and cyclists. This raw information is then forwarded to the processing and decision-making layer, which represents the central brain of the entire system. At this level, algorithms assume the main role. Unlike conventional approaches, artificial intelligence has the ability to effectively process nonlinear and chaotic traffic data, recognizing subtle patterns that could easily escape a human operator or a simpler (linear) algorithm [6].

Finally, the decisions made are implemented through the execution layer, also known as the control level. Local traffic signal controllers receive direct instructions from AI models and, based on them, dynamically adjust green-light duration, modify phase sequences, or optimize coordination between adjacent intersections, thereby enabling the system to respond actively and efficiently to current street conditions.

1.2. Overview of Key AI Methodologies

The scientific literature and practice identify three key AI approaches in intelligent traffic management. The first is reinforcement learning, which uses a “trial-and-error” system to simulate scenarios in order to make decisions that maximize traffic flow and address the complex coordination of traffic corridors [5]. Next, fuzzy logic is widely applied in the processing of imprecise field data. Relying on linguistic variables rather than strict binary rules, this model makes rapid optimization decisions that emulate human judgment. Finally, deep learning, through the use of neural networks, enables highly accurate video-based vehicle detection and classification. This is of crucial importance for assigning priority to public transport, thereby making a direct and measurable contribution to sustainable transport objectives [7].

1.3. System Integration and Adaptability

One of the greatest challenges is the question of system adaptability—how an AI system that performs exceptionally well at a single intersection can be scaled up to the level of an entire smart city. Integration with IoT

(Internet of Things) platforms enables traffic signal devices to function not as isolated entities, but as part of a broader digital network that also includes parking management, public transport, and driver information delivered through digital panels and navigation devices.

This technological foundation directly leads us to the environmental effects, since every second saved in traffic flow represents a direct reduction in harmful gas emissions, which will be analyzed in greater detail in the following chapter together with the accompanying table.

2. The Contribution of Artificial Intelligence to Environmental Protection in the Traffic System

The transport sector is recognized as one of the most significant generators of environmental problems in urban areas, where congestion, frequent stops, and uneven driving patterns have become an everyday reality. According to data from the European Environment Agency, transport is one of the leading sources of greenhouse gas emissions in the European Union, with road traffic accounting for the dominant share. In addition to climate change, the impact on local health is critical; the World Health Organization (WHO) emphasizes that emissions from transport directly contribute to poor air quality, with serious consequences for the health and overall quality of life of the urban population.

2.1. Mechanisms for Reducing Harmful Emissions through AI

The contribution of artificial intelligence (AI) to environmental protection is achieved primarily through the indirect optimization of vehicle movement dynamics. Implementing AI in intelligent traffic signal control enables the precise alignment of green phases with actual traffic intensity, which reduces waiting times and idling-related emissions at intersections. Furthermore, AI algorithms minimize the frequency of stops through improved signal coordination, avoiding the high energy and fuel demands of start-stop cycles compared to continuous driving. By ensuring a more uniform traffic flow, emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), and particulate matter are directly reduced.

3. Analysis of Optimization Effects and Discussion of Results

Existing research and pilot projects around the world provide measurable evidence of the effectiveness of smart systems. Signalized intersections represent critical points in the network where pollution is most concentrated, and their optimization is therefore the fastest route

to improving the local microclimate. Table 1 presents a comparative overview of the results obtained under different scenarios and approaches, illustrating the potential of these solutions.

Table 1. *Effects of signal control optimization on emissions and fuel consumption*

Location / scenario	*Approach*	*Indicator*	*Before optimization*	*After optimization*	*Effect*
Bologna – Andrea Costa	coordinated signal control	CO_2 [kg] / fuel [L]	4753 / 2043	770 / 331	−83.8% / −83.8%
Bologna – Pasubio	coordinated signal control	CO_2 [kg] / fuel [L]	5129 / 2204	921 / 331	−82.0% / −85.0%
Shanghai – mixed traffic flows	signal plan optimization	CO (HDV) [g/h] / NOx (HDV) [g/h]	3129.98 / 542.88	2512.07 / 411.60	−19.74% / −24.18%

Source: Author

The analysis of the data presented in Table 1 indicates that the application of artificial intelligence not only brings minor improvements, but also enables a significant reduction in negative environmental impacts.

1. The Bologna case: In the "Andrea Costa" scenario, a dramatic reduction in CO_2 emissions was recorded (from 4,753 kg to 770 kg), meaning that nearly 4 tonnes of carbon dioxide emissions were prevented at a single micro-location. Fuel savings of more than 1,700 liters confirm that the AI system practically eliminates unnecessary engine idling through the establishment of coordinated traffic signals.
2. The Shanghai case: In the case of heavy-duty vehicles (HDVs), which consume significantly more fuel when starting, a reduction in nitrogen oxide (NOx) and carbon monoxide (CO) emissions by approximately 20–24% represents a major contribution to public health. At a single intersection alone, emissions of toxic CO gas were reduced by nearly 600 grams per hour.

3.1. Thermodynamic and Environmental Aspects of Savings

These Pictures confirm that the greatest polluter in the city is a vehicle operating in a "stop-and-go" driving regime.

- Energy losses: AI minimizes unnecessary braking and acceleration, thereby preventing the loss of kinetic energy in the form of heat and reducing the fuel consumption required to overcome inertia.
- Particulate matter emissions: Traffic flow optimization reduces brake and tire wear, which are the primary sources of hazardous PM2.5 and PM10 particles that impair the respiratory system.

Although the intensity of the achieved effects varies depending on network topology, the share of heavy-duty vehicles, and the quality of the AI model itself, the results unequivocally confirm the enormous environmental potential of these systems. Even in complex, mixed traffic flows, the savings are highly significant for the sustainability of urban space. Based on the Pictures presented, it may be concluded that the application of similar models in cities across the region with comparable spatial characteristics would lead to cumulative fuel savings amounting to tens of thousands of tons on an annual basis, together with a proportional reduction in healthcare costs. In this way, artificial intelligence ceases to be merely a tool for increasing traffic flow efficiency and becomes a fundamental pillar in the development of "green" mobility.

Technical challenges directly undermine environmental goals through an "environmental rebound effect," whereby a system failure evolves into an environmental risk. Any algorithmic error that disrupts the "green wave" drastically increases CO and CO_2 emissions due to the energy-intensive stop-and-go driving regime, while an incorrect priority assessment creates local "hot-spot" zones with high concentrations of NOx and particulate matter in narrow urban streets surrounded by tall buildings. In addition, without strategic planning, increased traffic flow may paradoxically induce a higher volume of traffic, thereby offsetting the initial benefits. Therefore, reliable infrastructure and stable software are not merely technical requirements, but a prerequisite for making a real contribution to environmental protection.

4. Possibilities for Application in Serbia and the Region

In Serbia and the Western Balkans region, the application of AI systems in traffic primarily depends on the degree of infrastructure digitalization. The most realistic implementation model involves pilot projects on key urban corridors, enabling technical verification under local conditions and a precise assessment of environmental effects at the most vulnerable micro-

locations. Such an approach serves as the basis for the gradual expansion of a network of "smart" corridors, the strengthening of professional capacities, and adaptation to regional infrastructural specificities.

5. Conclusion

Artificial intelligence represents an indispensable direction in the development of modern transport systems, as it enables the transformation of static control into a dynamic, so-called adaptive process. The analysis conducted in this paper confirms that the application of AI algorithms can lead to measurable improvements in terms of reducing congestion, fuel consumption, and greenhouse gas emissions, thereby directly supporting sustainable development goals.

However, the actual reach of AI solutions is always conditioned by the quality of input data, the level of development of digital infrastructure, and adequate professional support. Therefore, artificial intelligence should not be viewed as an isolated solution, but rather as a powerful tool which, together with classical engineering methods and broader sustainable mobility measures, significantly contributes to the environmental transformation of urban transport.

Future research should move beyond predominantly review-based insights and focus on pilot applications in real urban corridors, especially in cities with transitional and unevenly digitalized infrastructure. Particular attention should be given to before-and-after measurements of traffic flow, fuel use, and pollutant emissions, as well as to the robustness of AI models under incomplete or low-quality data conditions. Such research would provide a stronger basis for technical guidelines and evidence-based implementation in regional transport systems.

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