The Impact of Intelligent Parking Systems on Urban Mobility and the Role of Innovations in the Spectrum of Artificial Intelligence in the Electric Vehicle Industry

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Abstract

In this paper, we investigate the impact of Smart Parking Systems (SPS) on urban mobility and the incorporation of technological innovations within the electric vehicle (EV) industry, focusing on Petrosani, Romania. As urban areas grapple with the challenges of rapid development, such as traffic congestion and inefficient use of parking spaces, SPS emerge as a crucial solution. This research presents a comprehensive analysis of Petrosani's current traffic and parking conditions, leveraging public opinion surveys and traffic flow studies to propose an efficient integration of smart parking systems. The study reveals significant public support for SPS, highlighting a community eager to embrace solutions that enhance urban mobility, reduce environmental pollution, and improve the quality of urban life. Our findings suggest that adopting SPS in Petrosani could lead to more effective traffic management, better utilization of parking resources, and a shift towards sustainable urban development. The paper underscores the need for strategic planning and community involvement in transitioning towards smarter, more sustainable urban ecosystems, setting a precedent for similar initiatives in other cities. This work contributes to the discourse on sustainable urban planning, emphasizing the practical implications and benefits of intelligent parking solutions in enhancing urban mobility and environmental sustainability.

Keywords: sustainable development, traffic optimization, smart cities, energy efficiency, congestion management

JEL classification: R41: Transportation: Demand, Supply, and Congestion; Travel Time; Safety, Q55: Environmental Economics: Technological Innovation

Paper type: Research article
Received: 10 February 2024
Accepted: 28 May 2024

DOI: 10.54820/entrenova-2024-0041

Introduction

In the context of rapid urbanization, the efficient management of vehicular traffic flows, parking spaces, and electric vehicle charging facilities becomes essential for urban mobility. Smart Parking Systems (SPS) or other smart systems for managing facilities adjacent to the automotive industry play a crucial role in alleviating traffic congestion, improving the utilization of parking spaces, and enhancing urban life quality. These systems are part of the transition towards smart cities, integrating technology into urban infrastructure to simplify city living. In Petrosani, a city with a rich mining heritage in Hunedoara County, Romania, the adoption of SPS is vital for modernizing urban mobility and promoting sustainable development. By analyzing current traffic flows and conducting public opinion surveys, this paper details the necessary steps for efficiently integrating SPS in Petrosani. This effort addresses not only traffic congestion and environmental impact but also signals the city's commitment to a green and sustainable future. Current innovations in parking systems and new technologies specific to artificial intelligence, increasingly encountered in the electric vehicle industry or in new-generation vehicles, underline the city's commitment to improving urban efficiency, reducing emissions, and promoting an enhanced quality of life.

Literature review

In this section, we will review existing research addressing the various aspects of SPS, from their initial concept to recent implementations that have significantly transformed the management of urban parking spaces. We will review studies that have documented the benefits of SPS, including reducing time spent searching for a parking space and reducing greenhouse gas emissions, thereby contributing to sustainable development goals. We will also discuss the different technologies and sensor systems used, highlighting the advancements in IoT and interactive mobile applications. Special attention will be paid to how artificial intelligence (AI), through its advanced algorithms and real-time data processing and analysis capability, can improve the experience of electric vehicle users in a city. We will also explore how electric vehicle (EV)-specific innovations, such as battery health and EV range monitoring, can be integrated into smart charging networks, thus helping to increase the efficiency and sustainability of smart parking systems. We will also present several specialized works that focus on the city of Petrosani and on the issues associated with pollution factors.

The paper by Diaz Ogas et al. (2020) outlines the evolution and classification of smart parking systems (SPS) to address parking issues in cities, reducing traffic, fuel use, and emissions. It reviews 274 studies from January 2012 to December 2019 on SPS types, vehicle detection techniques, and optimization methods. SPS types include Parking Reservation Systems, Parking Guidance and Information Systems, and Electric Vehicle Parking Systems. The paper discusses static, dynamic, and real-time algorithms for SPS and calls for more integrated solutions and future research on IoT and machine learning to improve parking efficiency. Biyik et al. (2021) focus on the IoT's role in urban traffic management, particularly in smart parking to ease parking availability issues, reduce search times, and cut emissions. It details technical aspects and classifications of smart parking systems and sensors. Kalasova et al. (2021) share findings from a traffic study in Zilina, Slovakia, suggesting a new intelligent parking system to enhance efficiency, reduce city congestion, but also noting high implementation costs. Srhir et al. (2024) present an IoT-based smart parking system to optimize parking space use, improve traffic flow, and enhance driver experience through a multi-agent intelligent parking approach, promising reduced search time, less congestion, lower emissions, and increased revenue for operators. Raj et al. (2024) review Smart Parking Systems within smart cities, emphasizing IoT and Machine Learning technologies to manage parking spaces efficiently, thereby enhancing urban mobility, reducing emissions, and improving life quality. Khatermohammadi et al. (2024) explore parking management optimization using reinforcement learning to maximize limited urban parking resources. This includes directing drivers to optimal spots and considering parking availability, walking distances, and travel times, while acknowledging challenges like high costs and sensor network needs. Sakti et al. (2024) aims to develop a smart parking system for campus settings using IoT and wearable technology, enabling parking spot location and management through smartphones or smartwatches.

Petrosani, a city nestled in the heart of the Jiu Valley and renowned for its extensive mining tradition, faces a multitude of ecological challenges in addition to vehicular traffic pollution. As coal mines reduce their operations or shut down, the city grapples with the legacy of significant industrial pollution (Gaman et al., 2024). Beyond mining, the inhabitants of Petrosani contend with air pollution from various other sources: the burning of textile waste for home heating is an unsustainable practice that releases hazardous emissions into the atmosphere (Lorint et al., 2024). In the context of these multiple sources of pollution (Patrascoiu et al., 2020), finding ways to reduce vehicle emissions is critical to improving urban air quality (Calamar et al., 2019). Strategies could include improving public transportation (Mihailescu, 2023), increasing the number of bike lanes, developing electric vehicles and charging stations (Rus et al., 2021), and implementing public awareness programs about the benefits of green transportation (Samuil et al., 2023). At the same time, it would be vital to improve the waste management system, to promote more and more their recycling in accordance with the notions of sustainable development (Marcus et al., 2022).

Methodology

In the study conducted within the urban limits of Petrosani, a city with a population of 31,044 inhabitants, our methodology was rooted in a multifaceted approach aimed at understanding and subsequently improving urban mobility through the potential introduction of a smart parking system. This approach was meticulously designed to capture both qualitative insights from city residents and quantitative data on the current state of traffic flow.

To assess community perspectives on urban mobility, parking issues and responsiveness to smart parking solutions, we implemented an online survey. This survey reached 379 participants in Petrosani, providing a statistically significant snapshot of local opinion with a margin of error of ±5%. This margin signifies that the results we obtained provide a viable representation of the views of the wider population within the stated confidence interval, thus laying a solid foundation for further analysis.

Complementing the survey, our traffic flow analysis employed a comprehensive manual and computational monitoring strategy. Initially, a manual monitoring exercise was carried out on a 7.3 km critical route crossing the city from the entrance near Deva to the exit towards Targu Jiu. This route, which includes a crucial 1.8km stretch through the city centre, was meticulously observed to assess vehicle movement and identify congestion patterns. In parallel, traffic flow was also monitored along the 6.6 km bypass belt around Petrosani, providing comparative data on the distribution of traffic between the main arteries and the peripheral belt.

To augment our data collection efforts, a computerized analysis program was developed using an API key from Google Maps. This tool was used at regular intervals to collect real-time traffic information, allowing the generation of detailed traffic intensity graphs for Petrosani. This innovative use of technology enabled enriched analysis, providing insights into traffic dynamics that manual monitoring alone could not provide.

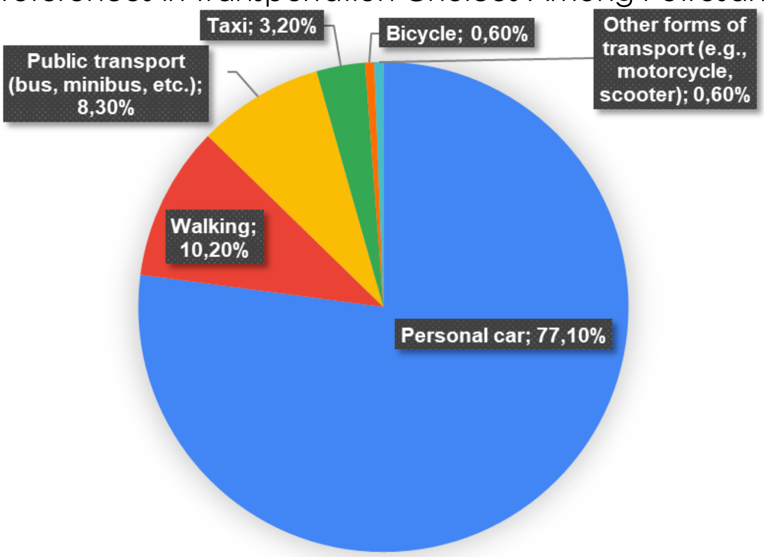
Together, these methodologies – comprising a direct survey of residents' attitudes and a dual traffic monitoring approach – provided a holistic view of the current landscape of urban mobility in Petrosani. This comprehensive data set serves as a cornerstone for our recommendations regarding the implementation of a smart parking system aimed at improving traffic flow, reducing environmental pollution and ultimately promoting a more liveable urban environment in Petrosani.

Results

Analyzing the results of the questionnaire, it can be seen that the age distribution of the respondents indicates a varied participation, with the highest proportion in the age group 25-34 years (28.2%), followed by the groups 18-24 years and 45-54 years (both with 19.2%) . This suggests that the survey attracted both young and middle-aged adults, reflecting diverse interests in parking and urban mobility.
The majority of respondents are male (64.7%), with a significant representation from women (34.6%). This distribution shows that the issue of smart parking is of interest to everyone, regardless of gender.

Only 8.3% of the survey participants utilize public transportation on a daily basis, highlighting a significant underuse of these services. In stark contrast, a substantial majority of respondents (77.1%) opt for personal cars for their daily commutes. This preference underscores the critical need for enhancing parking solutions as a means to alleviate traffic congestion and advance urban mobility. The data clearly illustrates a pronounced reliance on private vehicles over public transport options (Figure 1).

Figure 1
Preferences in Transportation Choices Among Petrosani Residents



Source: Authors' work

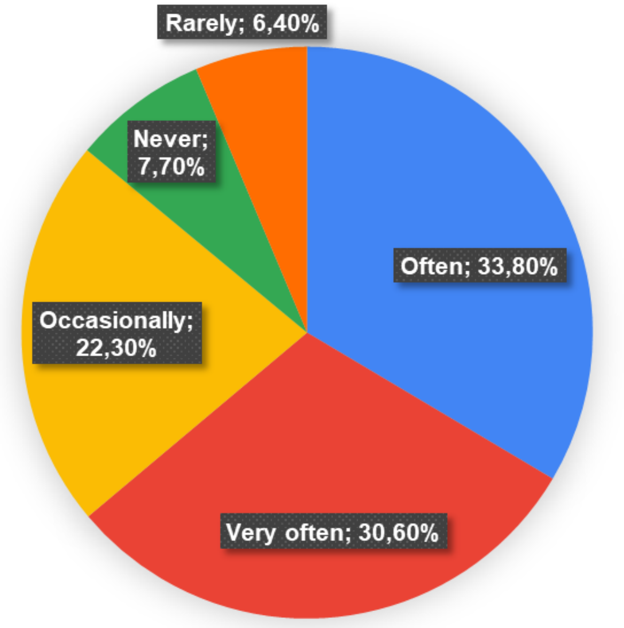
The majority of respondents (89.7%) do not have access to electric or hybrid vehicles, which highlights a possible need for improved infrastructure and incentives to adopt these more environmentally friendly technologies.

Trips outside the municipality are relatively frequent, with 34% of respondents traveling monthly and 33.3% rarely. This suggests a mix of mobility needs, both within and outside the city.

Half of the participants are moderately concerned about the impact of their trips on the environment, and 31.4% are very concerned, indicating a significant awareness of the environmental issues associated with transportation.

Almost 79% of respondents are active drivers and difficulties in finding a parking space are frequent, with 33.8% experiencing these difficulties often and 30.6% very often. This highlights a critical need for more efficient parking solutions (Figure 2).

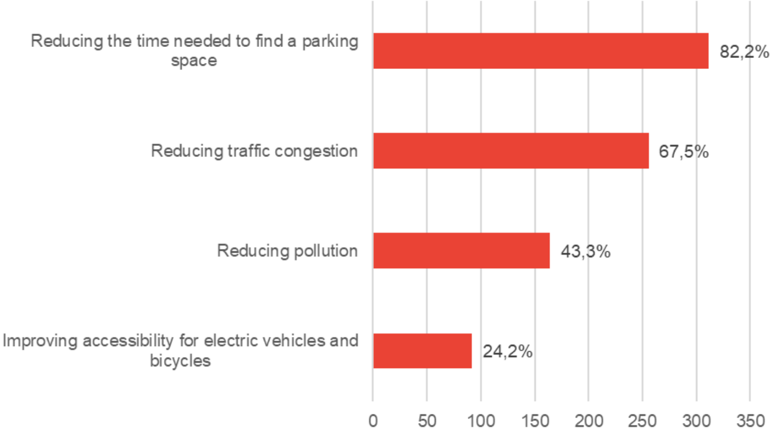
Figure 2
Frequency of Parking Space Challenges in Petrosani



Source: Authors' work

The majority (82.2%) believe that a smart parking system would significantly reduce the time spent looking for a parking space, which indicates a positive attitude towards the adoption of innovative technologies in parking management (Figure 3).

Figure 3
Public Opinion on Smart Parking Solutions in Petrosani and Their Potential Impact



Source: Authors' work

Over 87% of survey respondents are interested in a mobile app for real-time parking availability, signalling a strong preference for mobile technology solutions to ease parking searches. Less than 13% show low interest, potentially due to unfamiliarity or satisfaction with current parking methods. Nearly half view reducing traffic and pollution with smart parking as very important, and over a third consider it important, highlighting awareness of its broader benefits. The majority prioritize features like availability updates (87.8%), electronic payment (59.6%), and monitoring for eco-friendly vehicle spaces (52.6%) in a smart parking system. Many are willing to pay for these conveniences, though cost is a consideration for some.

There's optimism about smart parking boosting local economy, with over 30% expecting it to increase shopping time and about 30% foreseeing moderate economic benefits. Cultural and tourism improvements are also anticipated.

Many would redirect time saved by smart parking to shopping (56.4%), cultural events (44.2%), and outdoor activities (55.1%). Over half would recommend the system to others for its time-saving and economic benefits.

Integration with other transport forms is broadly supported, aligning with desires for integrated, sustainable urban mobility. The interest extends to solutions favouring eco-friendly vehicles.

In summary, the Petrosani community shows readiness for smart parking, recognizing its value for personal ease, environmental health, and local commerce. There's a clear trend towards embracing technology that enhances urban mobility and quality of life, with a focus on environmental sustainability and economic vitality.

In our quest to quantify the vehicular flux through Petrosani, we adopted a comprehensive approach that involved strategic placement of enumerators along two distinct routes. These routes were carefully chosen to capture the contrast between city traversal and peripheral bypassing.

The first trajectory, spanning 7.3 km (Figure 4 – left), sliced through the urban landscape of Petrosani, with a critical stretch of 1.8 km running through the bustling city centre. This central segment, dense with pedestrian crossings, offered a vantage point for observing the pulse of the city's traffic. The second route diverged from the city's core, encompassing the 6.6 km (Figure 4 – right) of the circumferential beltway designed to facilitate smoother transit around Petrosani. This bypass route served as a crucial comparator to the urban thoroughfare, providing insights into the volume of traffic that prefers the periphery to avoid the city centre congestion.

Figure 4
Monitored in-City Traffic Route in Petrosani (left) and Monitored Bypass Route Around Petrosani (right)

Source: Authors' work

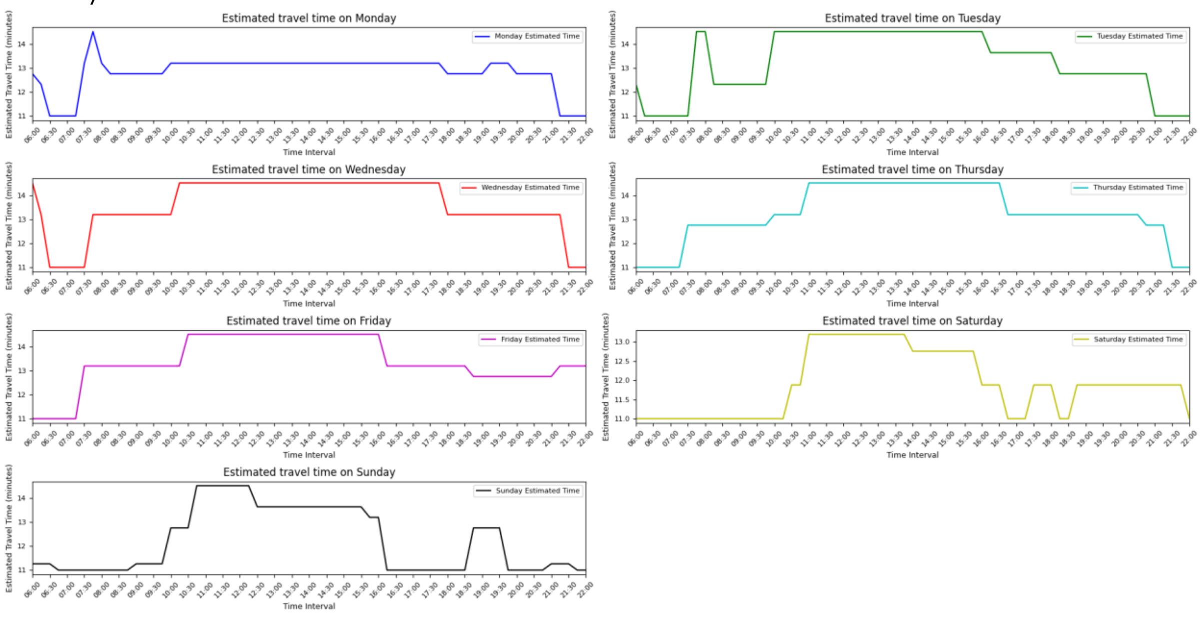
Enumerators at these strategic pedestrian crossings diligently recorded vehicular flow, capturing the nuanced patterns that emerged at different times of the day. This bifurcated approach across the two routes allowed us to distinguish between the inner-city traffic dynamics and those prevailing on the outskirts.

Merging the data from both the inner-city route and the beltway provided a holistic view of the traffic. Our calculations estimated that approximately 3828 unique vehicles course through the city daily, offering a multi-dimensional perspective on urban mobility in Petrosani.

Our entire analysis was also supported by the creation of Python applications that integrated a specific Google Maps API with the help of which more detailed analyses could be performed in real time.

Examining the graph depicting estimated travel times through the city centre across the week reveals distinct daily traffic patterns (Figure 5). Monday displays a relatively stable traffic level, suggesting a consistent flow. Tuesdays and Thursdays experience periodic increases in travel time, pointing to potential rush hours. Wednesday shows a significant drop for a period, likely due to a temporary traffic decrease or vehicular flow adjustments. Friday is marked by notable travel time increases, possibly indicating typical end-of-week congestion. Saturday's marked fluctuations suggest greater traffic variability, perhaps due to weekend activities. Sunday, conversely, exhibits the lowest traffic, with consistently reduced travel times characteristic of non-working days. This overview suggests that traffic management and urban mobility planning could benefit from adapting to these weekly patterns, focusing congestion mitigation efforts on weekdays, particularly during peak times.

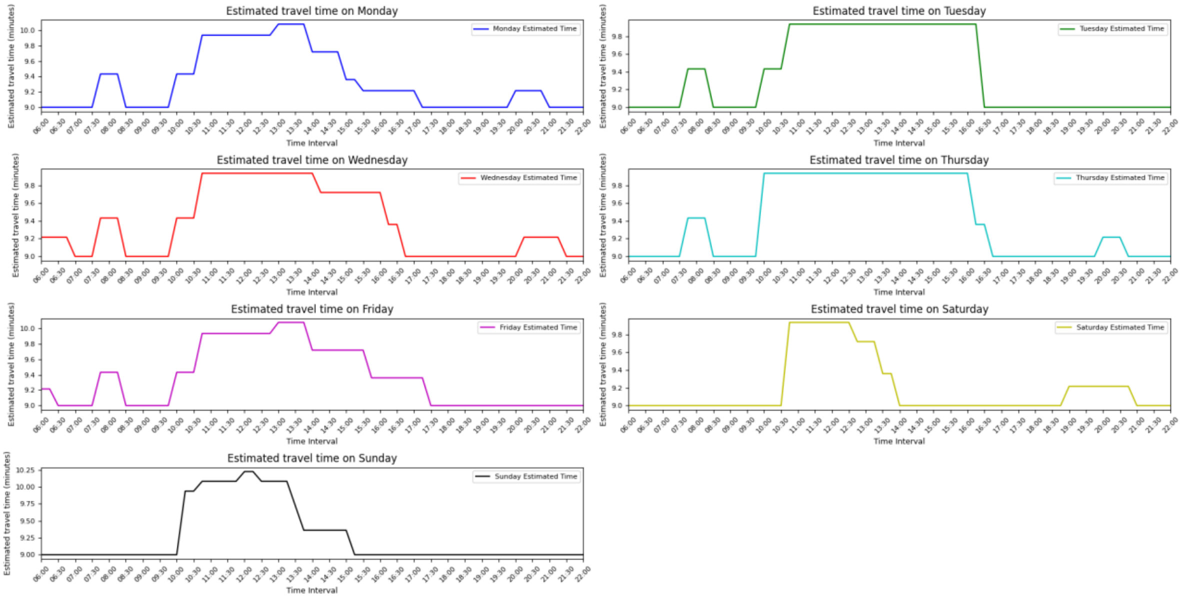
Figure 5
Weekly Traffic Flow Patterns in Petrosani



Source: Authors' work

The analysis of Petrosani's ring road traffic graph also indicates characteristic daily traffic fluctuations (Figure 6). Throughout the weekdays, a gradual escalation in travel times is observed, with significant peaks on Tuesday and Thursday, indicative of heavy traffic periods. Over the weekend, traffic patterns become less predictable, displaying variability potentially due to irregular activities or local events. Unlike the city centre, the ring road traffic profile may reflect the transit of heavy vehicles or movement to external destinations. Such insights are crucial for planning infrastructure and traffic management strategies on the ring road to ensure flow and mitigate the impact on the urban traffic of the city's core.

Figure 6
Weekly Traffic Flow Patterns on the Beltway in Petrosani

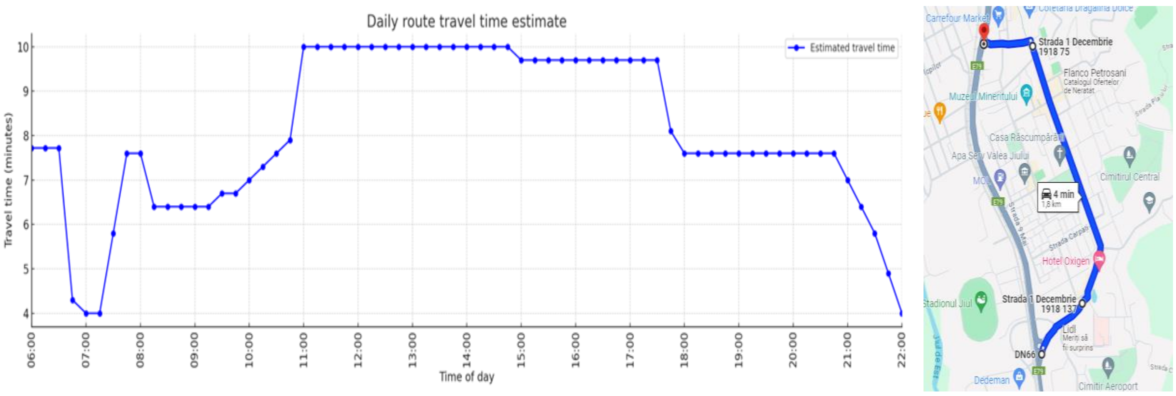


Source: Authors' work

Integrating Google Maps API data provides an enriched, real-time perspective, supporting the development of proactive traffic models. These patterns and tech-augmented insights emphasize the value of intelligent traffic systems for Petrosani, promising optimized flows, reduced congestion, and an enhanced commuting experience.

The temporal analysis of traffic flows in the urban centre of Petrosani (Figure 7 right) reveals congestion characteristics during daylight hours, with peaks in the time intervals of 07:00-09:00 and 17:00-19:00, corresponding to the opening and closing routines of professional entities (Figure 7 left).

Figure 7
Traffic Flow on December 1, 1918 Street (Downtown Petrosani)

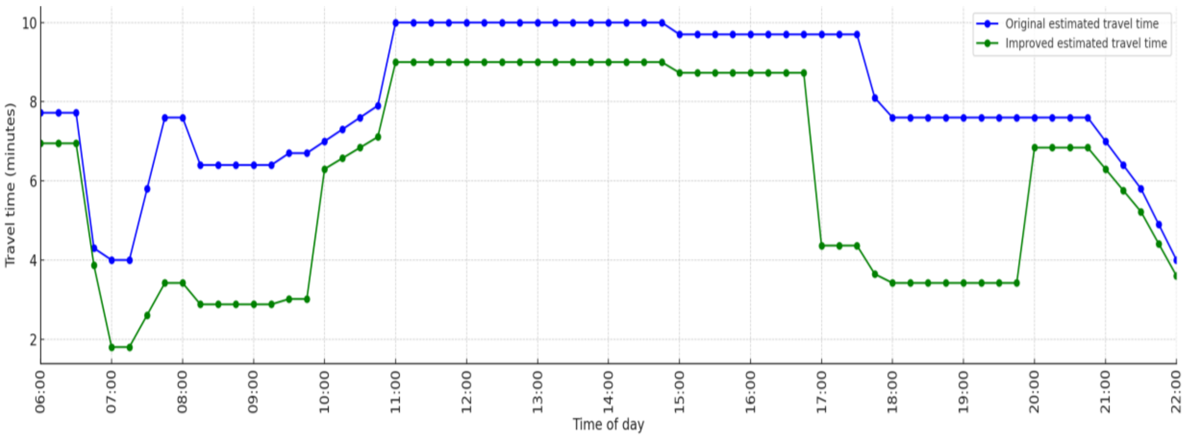


Source: Authors' work

This accentuation of transit durations on the road arteries is attributable to the concentration of primary urban functions - banks, administrative-government institutions, health facilities - within a confined perimeter. The observed oversaturation of the transport infrastructure results from urban planning that did not anticipate the escalation of mobility demand concurrent with population growth and service diversification. Concurrently, the graph shows a stabilization of the transit interval post-peak hours, indicating a constant frequency of public transportation network usage. In the presented context, the development of an integrated traffic management system is proposed, incorporating adaptive traffic light technologies and sensor-based parking systems. Adaptive traffic light control, based on real-time data processing algorithms, will adjust circulation and stoppage intervals according to traffic intensity, contributing to the fluid movement of vehicles. Sensor-based parking systems, accessible through mobile applications, will inform users about the immediate availability of parking spaces, thus reducing search times and potential blockages caused by parking manoeuvres. Additionally, the promotion and integration of an application dedicated to monitoring the charging of electric vehicles, in sync with the four charging stations in Petrosani, will enhance their usage efficiency and stimulate the adoption of electric mobility. This set of measures is anticipated to improve travel times, reduce carbon dioxide emissions, and strengthen the quality of the urban environment.

The adoption of an integrated traffic management system in Petrosani has the potential to significantly streamline urban circulation, with an estimated improvement in travel times ranging between 15% - 25% (Figure 8). This system, which would include adaptive traffic light control and smart parking systems, would allow for smoother traffic flow and more efficient management of existing infrastructure. By dynamically adjusting traffic light cycles in accordance with actual traffic volume and by indicating in real-time the availability of parking spots, both the time spent in traffic and the time associated with searching for a parking spot would be reduced. Thus, such an integrated system proposes a viable solution for improving urban mobility and enhancing the quality of life in the city.

Figure 8
Estimating the Improvement of Road Traffic in the Center of Petrosani Following the Implementation of an Intelligent Parking System



Source: Authors' work

Regarding electric mobility, in the city of Petrosani, current data indicate the presence of 64 electric vehicles, a figure that highlights the growing trend of sustainable mobility among the population. However, the support infrastructure for these vehicles is currently limited to just 4 charging stations, one of which is offered free of charge to the public by the Petrosani City Hall. This reality underscores an imperative need for the expansion and improvement of charging facilities, to keep pace with the increasing adoption of electric vehicles and to promote the continued transition towards eco-friendly transport solutions. The implementation of an integrated traffic management system, which includes optimizing the use of existing charging stations, would contribute to the efficiency of circulation and support the city's environmental initiatives.

Based on a simplified simulation, the use of a charging monitoring application for electric vehicles could reduce the average time spent by each vehicle for charging by about 30%, simply by notifying the user of how long it will take for the battery's charge capacity to reach the desired level. This means a time saving of approximately 23 minutes per vehicle, resulting in a total saving of 1470 minutes for the 64 electric vehicles in Petrosani. This improvement in charging efficiency could help reduce congestion in areas near charging stations and could offer users a significant benefit in managing their time.

With the help of new software technologies (Python, Google Maps API and other software libraries) we have created an example of a monitoring application. The smart traffic monitoring system app (STMSApp) (interface in Figure 9) exemplifies a contemporary approach to urban traffic management, specifically designed to mitigate congestion and streamline the commuting experience in Petrosani. This system provides a comprehensive solution by integrating real-time monitoring of electric vehicle (EV) charging stations and parking lot occupancy, coupled with live traffic information.

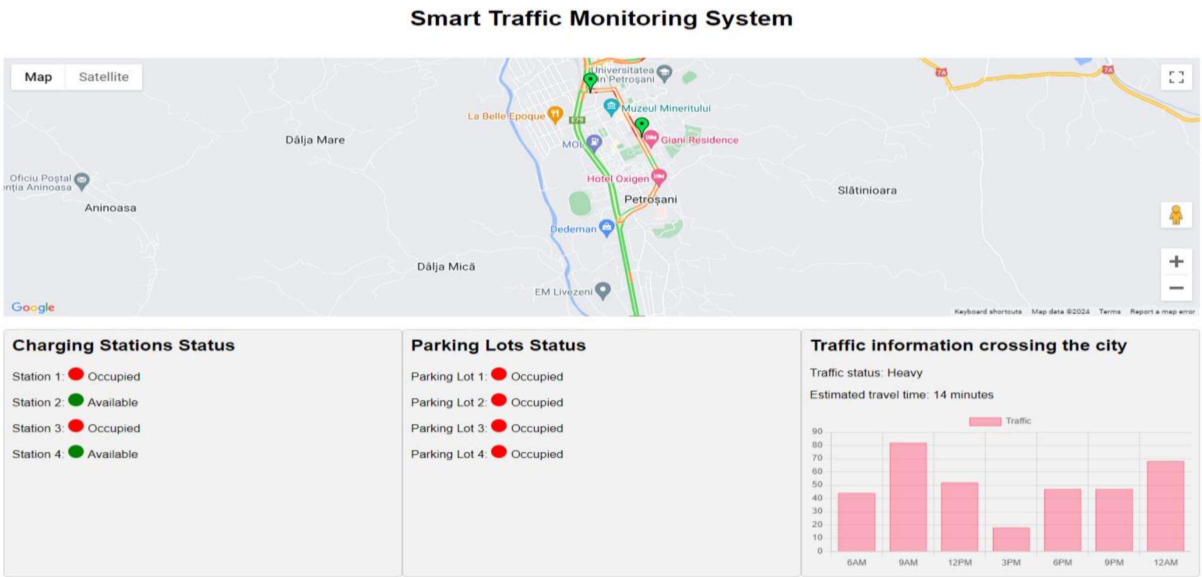
The application employs an interactive map interface, leveraging Google Maps API, which clearly displays the geographical positioning of EV charging stations across the municipality. This user-friendly interface is designed to indicate the real-time status of each station, signifying availability or occupancy through a color-coded indicator system. Such a feature is instrumental for EV users, enhancing their charging experience by reducing wait times and facilitating efficient energy management.

Complementing the charging station data, the system also encompasses a real-time parking lot status module. Each parking space is monitored for occupancy, providing immediate updates to the system's users. The integration of this feature addresses a significant urban issue by potentially decreasing the time spent by drivers in search of parking spots, thereby reducing traffic congestion around high-demand areas.

A crucial component of STMSApp is the traffic information panel, which offers a snapshot of current traffic conditions. This includes an adaptive estimation of travel times based on the density of traffic, allowing for predictive journey planning.

Figure 9

Example of implementation of a road traffic monitoring application that also incorporates traffic monitoring services and electric vehicle charging station monitoring



Source: Authors' work

The STMSApp serves as a prototype for smart city initiatives aimed at enhancing the efficiency of urban transport infrastructure. By providing real-time data and leveraging adaptive algorithms, the system stands as a testament to the potential of integrating technology into urban planning and management, which could significantly improve commute times, reduce environmental impact, and elevate the overall quality of urban life.

Amidst urbanization, addressing parking and vehicle flow efficiently is crucial. Integrating Vehicle-to-Vehicle (V2V) and Vehicle-to-Grid (V2G) technologies, along with Artificial Intelligence (AI) and the Internet of Things (IoT), marks a significant advancement in intelligent parking systems, enhancing urban mobility.

V2V communication enables real-time vehicle interactions, streamlining parking and traffic flow, thereby reducing congestion. V2G technology integrates electric vehicles into the urban energy grid, allowing them to supply energy during peak times, thus stabilizing the grid and encouraging renewable energy use. Additionally, AI and IoT enhance parking management through predictive analytics and real-time monitoring, improving efficiency and user experience. Collectively, V2V, V2G, AI, and IoT technologies transform intelligent parking systems into holistic solutions for sustainable urban mobility, addressing urbanization challenges and fostering smarter, cleaner cities.

Discussion

Although our research is based more on the observation of specific road traffic phenomena and shows the realization of several simulations, it emphasizes an important point: modern urban environments require an intelligent and sustainable infrastructure, not as a simple convenience, but as a necessity for ecological and economic health of a city (Rus et al., 2019). The case of Petrosani municipality exemplifies the wider applicability of such systems in the context of urbanization and environmental awareness. A road traffic management system designed to encapsulate adaptive traffic light control and sensor-based parking solutions promises not only to alleviate traffic congestion but also redefine the use of urban space. It is important to recognize that the effectiveness of this system lies not only in its technological sophistication, but also in its integration with the fabric of the community. The overwhelming local support (revealed by the applied questionnaire) for a road traffic management system indicates a willingness to adopt sustainable practices, revealing a community aware of the need for environmental management. This paper also addresses a critical facet of urban mobility - electric vehicles (EVs). Our findings suggest a pressing need to expand and improve Petrosani's EV infrastructure to meet the growing demand for sustainable transportation options. By incorporating real-time data processing algorithms, such a system would not only optimize the flow of vehicles but also improve the overall quality of urban life. This represents a paradigm shift in traffic management, leveraging data and technology to promote a responsive and adaptive urban environment.

It is also worth discussing the potential barriers to implementing such systems, including financial constraints, technical challenges and the need for public-private cooperation. The transition to smart urban infrastructure is a complex, multifaceted endeavour that requires concerted efforts from various stakeholders.

Since cities like Petrosani are in a delicate balance between tradition and innovation, implementing a road traffic management system could provide an advanced approach to urban planning. It could be a stepping stone towards an integrated and smart urban ecosystem, setting a benchmark for other cities facing similar challenges. Thus, the entire research extends beyond the borders of the city of Petrosani, serving as a case study for sustainable urban development and the role of AI and IoT in creating the cities of the future.

Conclusion

The implementation of a smart road traffic management system in all its meanings can improve travel time by 15% - 25%, demonstrating a significant progress in urban traffic flow and mobility efficiency. Given the current trend towards sustainable mobility, the introduction of such smart systems is essential in supporting the growing number of electric vehicles, with the current infrastructure indicating a pressing need for expansion. Our research anticipates a positive environmental impact by adopting an integrated smart road traffic management system, including reducing carbon emissions and promoting cleaner transport options, aligned with the city's aspirations for sustainability. The survey results reflect strong local community interest in adopting smart technology solutions for parking and traffic management, indicating readiness for technological advancement. A smart road traffic management system not only promises to make vehicle movement more efficient, but also has the potential to boost the local economy by reducing the time spent searching for a parking space, indirectly encouraging more commercial activity. The introduction of an integrated system that combines adaptive traffic lights and sensor-based parking solutions as well as an integrated system for monitoring electric charging stations represents a holistic approach to modernizing the city's traffic infrastructure.

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