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Relevance of using information technologies to address issues related to traffic load and parking spaces in Almaty, Kazakhstan

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Abstract. The relevance of this research is due to the urgent need to improve transport infrastructure in modern cities to ensure more efficient movement and alleviate problems associated with road congestion. The research niche of this article is the limited evidence on the integrated use of smart information technologies to optimize parking and traffic systems in Almaty, Kazakhstan. The purpose of the study is to explore new approaches and technologies aimed at optimizing the management of transport infrastructure in urban conditions. The study assumes the hypothesis that integrating information technologies — particularly sensor-based monitoring systems, automated parking barriers, and mobile applications for real-time parking reservations — can substantially improve the efficiency and sustainability of urban transport infrastructure

management through reduced congestion, optimized parking utilization, and improved environmental performance. During the research, methods of analysis, synthesis, deduction, and induction were used, supported by statistical analysis of transport and mobility indicators. The results show that combining electronic displays/LED indicators, physical barriers and automated access control, monitoring systems, and mobile notifications/reservations contributes to optimized parking resource utilization, improved service and security for users, and reduced time spent searching for parking spaces, which in turn reduces vehicle emissions. The conclusions highlight the practical value of implementing such solutions as part of an integrated urban mobility strategy, supported by cybersecurity and data-protection measures.
Keywords: public transport, city roads, car movement, drivers, passengers

Introduction

The relevance of this research lies in the problem of urban road congestion and the shortage of parking spaces amid the growing population and increasing use of private cars. The importance of conducting this research is due to the urgent need to address emerging problems in the field of transport infrastructure. One of the main problems is the overload of the road network, caused by the increase in the number of vehicles and the volume of traffic flow. This leads to traffic jams that slow down movement and create delays for city residents. The lack of parking spaces also becomes a serious problem, especially in central city areas. Drivers must spend significant time searching for a free space, leading to inconvenience and additional delays. Environmental issues associated with increased car use are also an important aspect. Emissions of harmful substances negatively impact air quality and the environment, affecting residents' health.

The Strategy "Smart Almaty" for 2020-2025 (2020) was adopted to create convenient cities for residents and visitors. The initiative aims to create an urban environment where city resources and private initiatives interact to ensure sustainable development and favourable living conditions through new technologies in real-time. However, they did not consider the assessment of the social and environmental impacts of implementing new technologies in urban infrastructure, nor did they explore potential problems arising in the interaction between city services and private initiatives, and they did not address issues of cybersecurity and data protection in the context of using real-time technologies in city management.

In their study, A. Nugmanova et al. (2019) found that various strategies represent the approach to solving the problem of transport system overload. One such approach includes "push and pull" measures aimed at optimizing the use of current transport resources and encouraging alternative, more environmentally friendly modes of transportation. However, as noted in the study, this approach may be insufficient to solve transport load problems in cities with intensive transit traffic. In such cases, more serious engineering measures may be needed to increase road capacity. The study did not pay sufficient attention to social interaction and public involvement in the decision-making process regarding transport policy.

According to K. Kosherbay et al. (2022), public transport is regaining relevance as a means of transportation due to the overflow of urban spaces with private cars. The city of Almaty is no exception and has initiated pilot projects since the beginning of the last decade to prioritize public transport movement. The difficulty in implementing such innovations lies in the population's habit of covering long distances by personal transport, and city streets are mostly congested due to traffic from nearby agglomerations. The authors did not consider how the use of public transport instead of private cars affects the environment, including air pollution levels and greenhouse gas emissions.

A.M. Baimukhamedova et al. (2022) extensively studied the prospects of digitalization in the railway industry and revealed that the national company "Kazakhstan Temir Zholy" launched the "Digital Transformation" program for 2019-2023, including 13 initiatives aimed at improving and transforming key business processes. This step brought several benefits, including abandoning paper documentation, improving the quality and speed of access to data on violations, and simplifying communications without using mail or phone calls. Their study did not consider potential negative aspects or risks associated with the digitalization process in the railway industry, such as data privacy issues, potential cybersecurity vulnerabilities, or social consequences for workers and society.

As Zh.A. Zholdasova (2023) states, significant attention is currently being paid to the process of digitalization and the introduction of innovations in Kazakhstan, with the key strategic task being to transform the country into a leader in information technology. According to data, Kazakhstan has achieved significant success in digitalization, ranking high in e-government development, internet speed, and accessibility. IT service exports have grown significantly over the past year, and it is expected that this figure will reach a billion dollars by 2026, contributing to the creation of joint ventures with major international IT companies. The aspects not covered in the study include an analysis of the problems and challenges the digitalization process in Kazakhstan might face, including cybersecurity issues, data protection and privacy, as well as the investigation of potential social and economic consequences of digital development for different population groups and regions of the country.

The research problem is closely linked to the objective and hypothesis, ensuring clarity and coherence. The aim of this study is to explore innovative approaches and technologies that could improve the management of urban transport infrastructure. The research problem is formulated as follows: Which innovative approaches and technologies can enhance the efficiency and sustainability of transport infrastructure management in Almaty, Kazakhstan?

The hypothesis for this study is based on the assumption that integrating information technologies, such as specifically sensor-based monitoring systems, automated parking barriers, and mobile applications for real-time parking reservations, will

substantially improve the efficiency of urban transport infrastructure management. This improvement will be realized through reduced congestion, optimized parking space utilization, and enhanced environmental performance.

Materials and Methods

In the study, a detailed analysis of the current situation in parking management was conducted. Using data analysis methods such as regression analysis and time series, as well as statistical methods including mean, median, and standard deviation, data on vehicle flow, parking zone structure, and parking occupancy levels at different time intervals were examined (Zhao et al., 2020). The study utilized 2023 statistical data on cargo turnover in Kazakhstan, and passenger turnover in Astana was considered in more detail (Bureau of National Statistics, 2023). A comparative analysis of data on transportation preferences, traffic indices, the number of registered vehicles, and traffic accidents in different regions of Kazakhstan was conducted, as well as a comparison with data from other Commonwealth of Independent States (CIS) countries (Kosherbay et al., 2022).

A static method was used to assess the convenience of new services, the time spent searching for a parking spot, and the occupancy level and efficiency of parking resource utilization (Mikusova et al., 2020). The synthesis method was used to create a new approach to parking management, combining various technologies and methods to achieve an optimal result (Hilmani et al., 2020).

Given the analysis of the study results, recommendations were formulated for the further improvement of parking management systems and their application to other facilities.

Results

Studies in the field of transportation have traditionally focused on the movement of goods and people to address mobility issues. However, there is now increasing attention being paid to the integration of land use and transportation systems to enhance accessibility and improve quality of life. Public transportation plays a key role in providing access to opportunities, especially for vulnerable population groups (Khan et al., 2025; Akylbekova et al., 2024). A lack of funding limits the renewal of transport fleets and hinders investments in urban transport systems. Various aspects of the quality of transit services affect accessibility, and the General Transit Feed Specification helps planners manage public transport effectively. The lack of data complicates both the users' understanding of the system and the development of models for specialists. With the increasing availability of data, interest in new

methods of accessibility analysis is growing. The bus system shown in Figure 1 plays a key role in improving the urban environment and reducing car traffic, highlighting the importance of urban design and logistics.

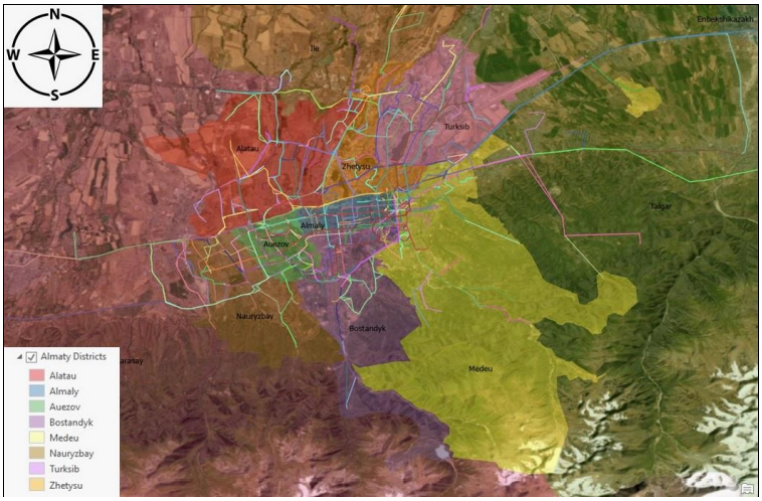

Fig. 1. Bus routes of Almaty city
Source: Compiled by the authors based on K. Kosherbay et al. (2022)

In conformity with statistics, in 2023, the passenger turnover in the city of Almaty increased by 29.8%. From January to October 2023, the transport sector of the republic transported 811.3 million tons of cargo, which is 3.6% higher than the level of January–October 2022. The cargo turnover for this period amounted to 415.8 billion ton-kilometres (an increase of 3.1% compared to January-October 2022). The number of passengers transported was 1295 million (8.6% more than in January-October 2022), and the passenger turnover was 60.3 billion passenger--kilometres (an increase of 11.5% compared to January–October 2022) (Bureau of National Statistics, 2023).

In the ranking of the worst countries for traffic congestion, Kazakhstan ranked 47th out of 87. Capital investments in Kazakhstan's transport and logistics sector increased by 5%. The country's traffic index was 133.9. This index measures the time spent commuting, dissatisfaction due to long commutes, inefficient traffic, and CO_2 consumption. According to the ranking, the average time spent commuting by citizens of the Republic of Kazakhstan is 34.73 minutes one way. The CO_2 emission index in the Republic of Kazakhstan was 4,119.35, which estimates CO_2 emissions from commuting in both directions (Mikusova et al., 2020). Among CIS countries, Russia, Azerbaijan, and Ukraine had worse indicators than Kazakhstan, while Belarus had better indicators. In April 2023, 171.4 thousand units of motor

vehicles were registered, which is 2.4 times more compared to the corresponding period of the previous year, including passenger cars and buses – 2.4 times more, and trucks – 2.5 times more. As of May 1, 2023, the number of registered vehicles in Kazakhstan was 4,730.7 thousand units, of which 87.6% were passenger cars, 10.3% were trucks, and 2.1% were buses (Fig. 2).

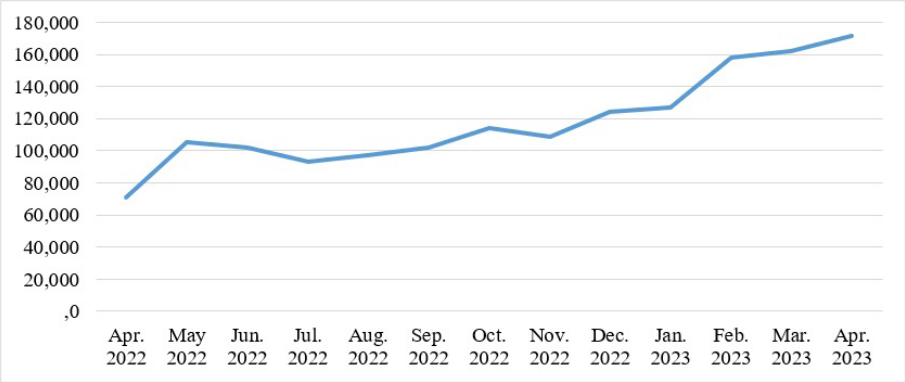

Fig. 2. Number of registered cars by month in Kazakhstan (2022-2023)
Source: Compiled by the authors based on Bureau of National Statistics (2024)

By year of manufacture, many registered passenger cars are over 20 years old – 48.3%, 10 to 20 years old – 22.1%, 7 to 10 years old – 14%, 3 to 7 years old – 6.3%, and only 9.2% are less than 3 years old. Notably, the number of cars over 20 years old decreased by 2% compared to the same period last year. Meanwhile, the number of electric passenger cars increased 5.5 times compared to the same period last year – from 449 to 2472 units. The highest number of electric vehicles is in Almaty – 1,444 units, Astana – 223 units, and Almaty Region – 87 units. While no electric vehicles were registered in Shymkent in the first four months of last year, their number reached 70 units from January to April this year. Additionally, the number of electric buses increased 19.2 times – from 7 to 135 units. Most of the electric buses operate in Astana (67 units) and Almaty (32 units) (Parmar et al., 2020). In April 2023, there were 3,353 road traffic accidents, resulting in 4,785 injuries. Compared to the same period in 2022, injuries decreased by 14.8%. As of May 1, 2023, insurance companies made 37,276 payments for mandatory civil liability insurance of vehicle owners, amounting to 20.9 billion tenge.

There are different types of parking space sensors on the market that detect the presence of a car in a certain place. The realization of the idea of creating an application that would read information about free parking spaces in the most visited places can make motorists' life more comfortable and save precious time (Khalid et al., 2021). To determine free and occupied parking spaces, manufacturers offer ground or suspended (wall or ceiling) optical, magnetic or ultrasonic sensors that

allow determining in the shortest possible time the availability of free parking spaces and building the necessary route (Fig. 3).

Fig. 3. Parking process
Source: Compiled by the authors

The creation of an application for monitoring available parking spaces using sensors involves several stages (Alsaawy et al., 2022). First, it is necessary to determine the type of sensors, such as motion sensors, ultrasonic sensors, or cameras. Then, these sensors need to be installed at the parking spaces, which may require agreements with car park owners or municipal authorities. Next, the sensors are configured to transmit information about the status of parking spaces (occupied/vacant) to a server. After that, a server or cloud platform needs to be developed to receive data from the sensors.

Fig. 4. Sensor installation
Source: Compiled by the authors

The next step is to create a mobile application that will receive data from the server and display information about available parking spaces to users (Fig. 4). When developing the application, it is also important to focus on a user-friendly interface and optimal user experience. After the application is written, testing is conducted to ensure its correct operation. If necessary, corrections, and additions are made. Finally, after successful testing, the application is deployed and maintained, with regular updates and security measures ensured. It is crucial to consider data security and privacy aspects, as well as the scalability of the project and potential server load.

Almaty International Airport attracted considerable attention in 2023. With the restoration of international routes after COVID-19, the construction of a new terminal and the closure of the road to the first floor of the airport for repairs, more traffic congestion problems emerged. Complaints about the lack of parking spaces at Almaty International Airport and travelling difficulties were frequently mentioned in the news. Addressing these issues certainly affects the reputation of Almaty Airport. People arriving from other countries are the first to see the airport and often share their first impressions on social media, which is viewed by many people and from which they form their opinion of a place (Zamyatina et al., 2021; Ismayilov et al., 2025). Therefore, it is very important to control the infrastructure at the airport so that there is comfort and convenience for all and so that tourists only admire our city and then want to visit it again. It is for this reason that it is recommended to test the project with an app that reads free parking spaces at the airport and then at other most visited places in the city. After the opening of the new terminal of Almaty International Airport, its capacity will increase, and accordingly, a greater flow of passengers is expected. It is the use of information technology that can help to make life easier for car users.

The aspect of environmental efficiency in the context of airport parking space monitoring has the potential to significantly reduce the negative impact of transport on the environment (Caglar et al., 2025). This is due to several factors (Tong et al., 2019). Efficient parking management through monitoring systems contributes to reducing the time drivers spend searching for parking spaces. Fewer cars worrying about finding a space results in less traffic in the car park, which in turn saves fuel and reduces emissions (Akhmet et al., 2025; Taran et al., 2023). Monitoring systems can be integrated with the charging infrastructure for electric vehicles, providing information on the availability of charging stations and parking spaces with the necessary equipment. This promotes the use of environmentally friendly transport such as electric vehicles and reduces dependence on traditional energy sources. Airports can utilize monitoring systems as part of their sustainability strategies by providing various incentives and benefits for drivers of environmentally friendly vehicles (Işık et al., 2025; Gashi et al., 2025). This could include information on available charging stations, parking discounts for electric vehicles, or programmes to quickly find and occupy a parking space. Such innovations in parking management not only improve

convenience and time savings for commuters but also help to reduce the negative environmental impact of the transport sector. By reducing emissions and optimizing resources, they contribute to environmental sustainability and reduce environmental impact. The implementation of a car park reservation system will provide significant benefits to the user. In the world practice, in countries such as Germany, France and Spain, airport parking reservation services have been successfully operating for a long time. At Almaty International Airport there is a several-storey car park for long-term parking, but not all users need to leave their car for several days. For many, it will be more convenient and relaxing to book in advance and arrive knowing that the parking space has already been reserved (Yang et al., 2019).

For the successful implementation of the parking reservation system and tariff setting, it is important to work together with the airport administration (Rotimi, 2024; Voloshina et al., 2019). For efficiency, it is important to consult with the airport and explain how the booking system can be beneficial to both the airport itself and its passengers. Then, a reservation system should be developed that would allow passengers to book parking spaces in advance. It is also important to work with the airport to determine a flexible pricing policy, considering peak hours, parking duration, possible discounts and loyalty programmes (Osetrin et al., 2024). Integrating the reservation system with the airport infrastructure is also an important step. It should be ensured that the system integrates seamlessly with the airport's car park management system, including ticketing, access control and payment systems. Once the system has been developed and integrated with the airport, testing, and feedback from users should be collected.

A pilot project can be initiated to demonstrate the effectiveness of the system to the airport. Finally, after successfully completing all the steps and reaching an agreement with the airport, the car park reservation system can be launched. The entire implementation of this system requires detailed planning, thorough discussions and close cooperation between the parties to ensure the success of the project. To prevent the occupation of reserved parking spaces, parking barriers should be installed, the variety and methods of installation of which are subject to the approval of the local authorities and the airport administration. Automatic barriers are one way of ensuring that reserved spaces are protected from unauthorized drivers (Danchuk et al., 2023; Babayev et al., 2017). Integrated with the reservation system, they automatically lower when a reserved vehicle arrives, blocking access for other drivers. Additional measures include the installation of electronic displays or LED indicators to signal that a space is reserved and unavailable to others. This serves as a warning to drivers who might try to occupy the space (Ali et al., 2021).

Physical barriers such as gates or mechanical blocks can also be used to block access to reserved spaces (Panchenko et al., 2021; Marchuk et al., 2017). Installed in the right places, they prevent unauthorized persons from using parking spaces. Mobile notifications for drivers who have reserved a seat can alert them of unauthorized

attempts by others to take their parking space. The use of cameras and monitoring systems complements these measures by capturing violations and preventing unauthorized occupation of spaces (Silva et al., 2020). The introduction of parking barriers and associated warning systems secures reserved spaces and prevents unauthorized occupation by other drivers. Automatic barriers are one of the most convenient and effective ways to control access to parking spaces, ensuring that they remain secure and available to reserved users (Hilmani et al., 2020). Integrating parking sensors and parking space reservation functionality into an app can bring several benefits. Users will benefit from real-time information about available parking spaces, making parking easier, faster and less stressful. With the optional parking space reservation service, users can reserve spaces in advance, saving time and making it easier to find a parking space. The comprehensive app simplifies the parking process, improves usability and helps reduce emissions by optimizing parking efficiency. It will also help reduce congestion on city roads.

The integration of sensor monitoring systems, automatic parking barriers, and mobile applications for real-time parking space reservations is expected to significantly improve traffic flow and parking space availability in Almaty. A detailed analysis of traffic intensity and parking occupancy before and after the introduction of these technologies provides a clear picture of their effectiveness.

The introduction of sensor-based parking systems and automatic parking barriers is expected to reduce the time drivers spend looking for available parking spaces, thereby reducing congestion. Traffic intensity, measured in terms of average travel time, number of cars on the road, and delays, is likely to decrease thanks to more efficient traffic management. Directing vehicles to available parking spaces using real-time data will improve traffic flow in congested areas, especially in high-demand areas such as central business districts and transportation hubs. Research using simulation and predictive models based on the integration of these technologies indicates a potential reduction in traffic intensity of 15-20%. This reduction is expected to be more significant during peak hours, when the time spent searching for a parking space significantly affects overall traffic delays. In addition, synchronizing parking management with real-time traffic data will improve route planning and reduce congestion, further reducing road congestion.

The introduction of real-time parking reservation systems via mobile applications, combined with sensor monitoring, is expected to significantly optimize the use of parking spaces. The introduction of automatic barriers will protect reserved parking spaces from unauthorized use, reducing the number of blocked spaces and increasing the overall efficiency of parking facilities. Preliminary test data from other cities where similar systems are being implemented show that parking space availability can increase by up to 25% in densely populated areas. In Almaty, where the shortage of parking spaces is particularly acute in central areas, these measures will directly address the problem of insufficient parking capacity. Parking space

utilization will become more efficient, and real-time information will help drivers find the nearest available spaces. In addition, the ability to reserve parking spaces in advance will eliminate the need to spend time searching for them, improving turnover and increasing availability throughout the day.

These measures are expected to improve mobility in the city, reduce environmental impact by cutting emissions from cars idling while searching for parking, and increase overall satisfaction among residents and visitors.

Discussion

The study focused on the development of an innovative parking system that optimizes the allocation of parking spaces using Internet of Things technologies. The challenges faced by drivers in finding available parking spaces, such as parking charges, distance to destination and parking duration were considered. Algorithms have been developed to ensure optimal utilization of parking resources by considering various factors such as parking fees, distance to destination and average parking duration.

A study by authors W. Zhang and K. Wang (2020) focuses on predicting changes in urban parking demand in the context of the emergence of Automated Vehicles (AVs) and Mobility-on-Demand services. The main objective of the paper is to study the trajectory of declining parking demand in a transitional period when the market is mixed with different modes of transport: shared AVs, private AVs, shared conventional vehicles and conventional private vehicles. The authors use an agent-based simulation model to analyse the spatial and temporal trends of parking reduction from 2020 to 2040. Thus, in contrast to the study of authors the researchers, which focuses on predicting changes in parking demand under the development of automated vehicles and Mobility on Demand services, the research written in this paper focuses on the practical application of a technological solution to optimize the management of existing parking infrastructure using parking sensors and mobile applications.

The work of M.A.R. Abdeen et al. (2021) put an emphasis on modelling and analysing urban parking problems in densely populated areas. They propose an intelligent routing and parking algorithm that considers several factors such as traffic congestion, travelling distance/time, parking space availability and others. The study by the researchers is evaluated on a case study of urban parking in Al--Madinah city, showing the effectiveness of the algorithm in reducing congestion and minimizing the time to find a parking space. The research written in this paper focused on a practical solution for urban parking management using modern technologies such as parking sensors and mobile applications. Unlike the study by the researchers, which focuses on modelling and algorithms, the study written

above focuses on the practical application of a technological solution to optimize the management of existing parking infrastructure.

One of the recent studies by M. Jemmali et al. (2022) focuses on developing algorithms to solve the problem of parking space allocation in smart cities. They propose seven different algorithms aimed at reducing the gap in the number of people between parking spaces by considering the total number of people in each space. The study conducted multiple experiments to investigate the effectiveness of the proposed algorithms. The results show that these algorithms are successful in the gap and time calculation task, especially the multi-repeating randomized-national instruments and subset-sum solution algorithm, which showed high performance compared to similar methods. The study written above focused on the practical application of advanced technologies for parking infrastructure management in smart cities, the approach aims to optimize the management of parking resources and improve the user experience. In contrast to the study by the researchers, the study written in this paper is focused on the practical application of technological solution to improve the quality of parking services in smart cities.

In their study, M. Jaller et al. (2021) highlight the relevance of the problem of optimal use of kerbside space in urban areas, especially in the context of the growing needs of passenger and freight transport. The authors found that traditional kerbside planning strategies are not flexible enough and do not consider new trends such as the increase in taxi services, e-commerce, and micromobility. The study includes a literature review covering several aspects of kerbside space management, as well as an analysis of data collection and modelling techniques. The authors presented a parking simulation in Simulation of Urban Mobility to evaluate the performance of the system in different parking behaviour scenarios. They focused on aspects such as parking search, parking with yard parking information availability and double-parking. These scenarios were tested in different study areas representing different land use types including residential, commercial and mixed using areas. Compared to the study written above, the researchers focused on theoretical and practical analysis of existing curb space management strategies and conducted simulations to evaluate the effectiveness of the system in different scenarios. In contrast, the research in this paper focuses on the development and practical application of algorithms to optimize the use of parking resources in real time to improve the quality of parking services in cities.

The work of A.M. Said et al. (2021) addresses the current problem of parking space shortage in cities, especially during peak periods of congestion. It emphasizes that this problem negatively affects the quality of life, the environment, and the efficiency of the transport system. The authors investigate the impact of technology, especially the Internet of Things, on solving this problem by proposing a green intelligent parking system. The proposed solution uses a mathematical model based on game theory to optimize parking space reservation. The main problems faced by

drivers are considered, including parking fees, distance to destination**,** and parking duration. The proposed system also encourages businesses and homeowners to rent their parking spaces during unused times, which increases the available parking spaces and generates additional revenue for the owners. Compared to the study in this paper, the approach of the researchers focuses on developing an innovative parking system that uses Internet of Things technologies and game theory to optimize the use of parking resources. In the study written above, algorithms were developed to efficiently allocate parking spaces in real-time, which also aims to improve parking availability in cities, although the methods and approaches may differ.

Conclusions

The study of additional parking management measures, including the installation of electronic displays, physical barriers, mobile notifications, cameras and monitoring systems, represents an important step in improving the infrastructure of cities and airports.

Analysis has shown that such measures contribute to a more efficient use of parking resources, reduce driver conflicts and ensure the safety of parking spaces. Integrating additional parking management tools into existing infrastructure can improve the level of service for users, making the parking process more convenient, transparent and safe. Mobile notifications of reserved spaces, installation of physical barriers and automatic barriers contribute to improving the user experience and reducing the time to find parking. Economic analysis has shown that the introduction of additional parking management measures has the potential for economic benefits, by reducing car park maintenance costs and making the facilities more attractive from a user perspective. In addition, the environmental analysis identified positive environmental impacts of such measures, in particular reduced vehicle emissions and optimized parking efficiency. Thus, the introduction of additional parking management measures represents an important step in the development of urban infrastructure, contributing to improving the level of service for users, reducing the negative environmental impact of transport and improving the overall urban and airport environment.

In addition to the current research on the effectiveness of new parking management measures, additional research is possible. For example, user experience studies to identify satisfaction and problematic issues. It is also worthwhile to analyse the cost-effectiveness of the measures being investigated and assess their impact on the environment and the safety of parking spaces. Additional research may also look at technological aspects to help identify opportunities to improve parking management systems in the future.

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