Research Article

Efficient on-Street Parking Management: Priority Parking Permits for Residents Integrated with Digital Systems, Case of Istanbul

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Abstract: Managing on-street parking in city centers has become a significant challenge, especially in areas where mixed use (commercial – residential) and high intensity commercial zones. Uncontrolled use of parking spaces by non-resident vehicles severely limits parking availability for residents, reducing their quality of life. Additionally, long-term stationary and abandoned vehicles take up limited space, exacerbating congestion and inefficiency. This paper proposes a new business model that integrates Lidar-based license plate recognition technology to grant priority parking permits for residents. The model includes a structured enforcement mechanism with progressive warnings and fines for unlicensed parking, as well as an automated system for detecting and removing abandoned vehicles. The financial and operational benefits of the system, including cost savings and revenue generation, are also analyzed. In addition, the mathematical model and system flow that demonstrate how the proposed model can be implemented are presented, and parking data in Istanbul was examined and a case analysis was studied for Zeytinlik Neighborhood in Bakırköy District**.**

Keywords: Urban transportation management, residential parking permits, intelligent transportation systems, enforcement mechanism, cost efficiency

Etkili Yol Üstü Araç Park Yönetimi: Dijital Sistemlerle Entegre Edilmiş Mahalle Sakinleri için Park Önceliği, İstanbul Örneği

Özet: Şehir merkezlerinde yol üstü araç park yönetimi, özellikle karma imarlı (ticaret – konut) ve yoğun ticari faaliyet içeren alanlarda önemli bir sorun haline gelmiştir. Mahalle sakinlerine ait araçlar dışında park alanlarının kontrolsüz şekilde kullanılması, mahalle sakinleri için park yeri bulma imkanlarını ciddi şekilde kısıtlayarak yaşam kalitesini düşürmektedir. Ayrıca, uzun süre hareketsiz kalan ve terk edilmiş araçlar kısıtlı park alanlarını işgal ederek sıkışıklığı ve verimsizliği artırmaktadır. Bu çalışma, Lidar tabanlı plaka tanıma teknolojisini entegre eden ve mahalle sakinlerine öncelikli park izinleri tanıyan yeni bir iş modeli önermektedir. Model, izinsiz parklanmalar için kademeli uyarı ve ceza mekanizmalarını içeren yapılandırılmış bir denetim sürecini ve terk edilmiş araçları tespit ederek otomatik olarak kaldırmayı sağlayan bir sistemi kapsamaktadır. Önerilen sistemin mali ve operasyonel faydaları, maliyet tasarrufu ve gelir oluşturma potansiyeli açısından analiz edilmiştir. Ayrıca, modelin uygulanabilirliğini ortaya koyan matematiksel model ve sistem akışı sunulmuş, potansiyel uygulama alanlarından biri olan İstanbul'daki park verileri incelenmiş, Bakırköy İlçesi Zeytinlik Mahallesi için bir vaka analizi çalışılmıştır.

Anahtar Kelimeler: Kentsel ulaşım yönetimi, mahalle sakinleri için park alanları, akıllı ulaşım sistemleri, denetim mekanizması, maliyet verimliliği

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1. Introduction

On-street parking management in urban areas presents major challenges due to increasing vehicle density, limited parking supply, and conflicts between commercial and residential demands. Local residents often struggle to find available parking spaces as visitors and non-resident vehicles occupy these spots for extended periods. Furthermore, long-term stationary or abandoned vehicles further reduce the already limited parking capacity, leading to inefficiencies and public dissatisfaction. In neighborhoods where residential and commercial spaces are shared between streets, uncontrolled on-street parking spaces are used inefficiently. Various occupations and illegal use negatively affect the quality of life of neighborhood residents. In particular, when area visitors who do not pay for commercial parking, lots use these limited uncontrolled parking spaces, residents have difficulty finding suitable parking spaces for their vehicles. Traditional enforcement mechanisms, such as manual inspections and ticketing, are labor-intensive and inefficient, necessitating a transition to digital solutions. This paper presents a model that leverages Lidar-based license plate recognition systems to optimize parking allocation and enforce regulations through automated warnings, penalties, and abandoned vehicle removal.

2. Literature Review

Technological developments have reduced vehicle prices, while rising income levels and a preference for comfort, coupled with a car-centric transportation system, have encouraged private vehicle ownership. In recent years, there has been a significant increase in vehicle ownership in developing countries (OECD, 2013). This situation has developed in a similar way for Türkiye, as it has for various developing countries around the world. According to TurkStat, the total number of vehicles reached 31,301,389 in 2024, up from 18,828,721 in 2014—a 66% increase over the past decade. This increase has led to issues such as traffic congestion and parking challenges, which are interconnected. For example, private vehicles are parked over 90% of the time, highlighting the significance of parking in transportation management (Ibeas and Moura, 2018).

Historically, parking challenges were addressed by expanding parking availability (see Figure 1). This traditional approach as prioritizing drivers within the transportation system (Litman, 2017). However, this strategy led to increased automobile usage, further escalating the demand for parking spaces. Drivers often spend extended periods searching for available parking, developers are compelled to provide more parking than necessary, and traffic managers face difficulties managing congestion resulting from the heightened parking demand (Weinberger et al, 2010).

Recent studies have revealed that increasing parking supply does not alleviate traffic congestion; instead, it exacerbates the issue in high-traffic areas. For instance, research indicates that a significant portion of urban traffic consists of drivers searching for parking spaces, contributing to congestion and diminishing the appeal of popular areas. This situation leads to environmental concerns, including air pollution and environmental degradation. The increase in automobile usage has unintended consequences, such as traffic congestion, air pollution, and greenhouse gas emissions.

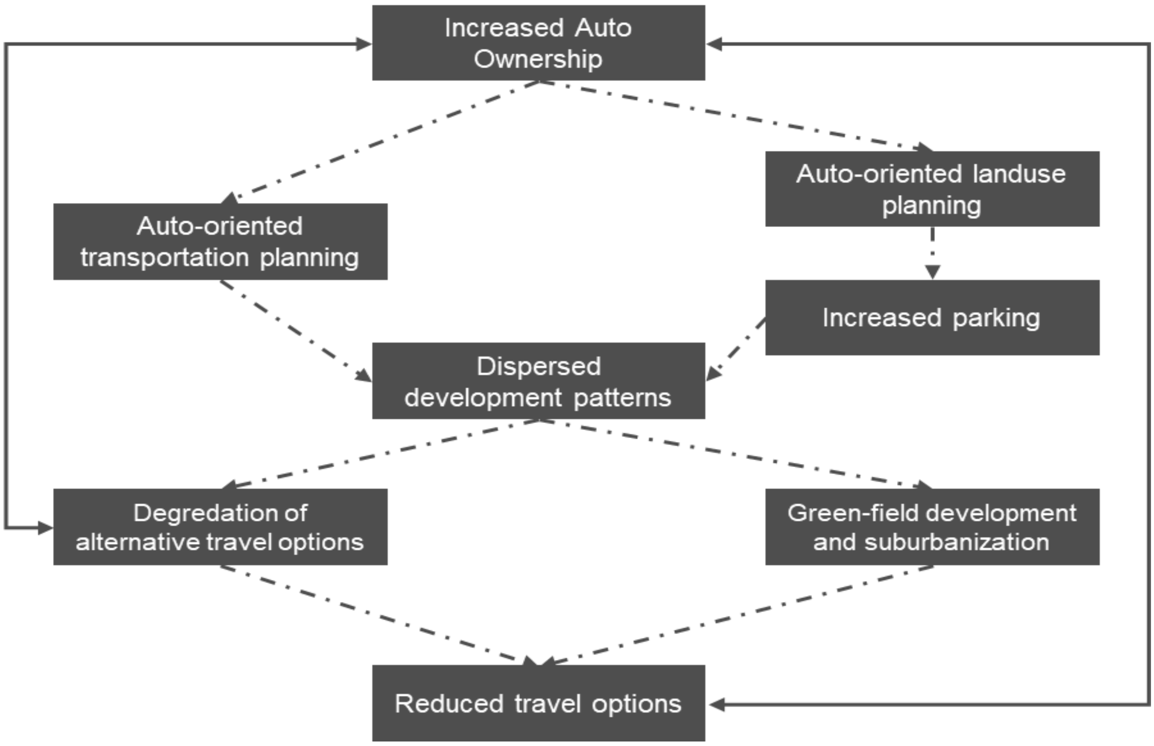

Figure 1. Vehicle dependency cycle (Weinberger et al, 2010).

Authorities have recognized that merely increasing parking supply does not alleviate traffic congestion and may, in fact, exacerbate it. This realization has prompted a paradigm shift in transportation planning, emphasizing accessibility over private car use. Consequently, the focus has transitioned from expanding parking availability to implementing parking management strategies, such as setting maximum parking limits and optimizing existing spaces

Parking management policies and programs can enhance the efficient use of parking resources (Litman, 2006). When properly implemented, these strategies can reduce the number of parking spaces needed, yielding economic, social, and environmental advantages. Additionally, parking management is the optimal approach to ensure user service quality, promote more accessible land use patterns, and decrease motor vehicle traffic (Litman, 2016). This reduction in traffic can lead to less congestion, fewer accidents, and lower greenhouse gas emissions, thereby creating more attractive neighborhoods and improving accessibility for non-drivers Furthermore, identifying potential solutions is essential. parking management principles should be considered before determining suitable parking management strategies (see Figure 2).

Consumer choice	Sharing	User information	Efficient utilization	Flexibility
Prioritization	Pricing	Peak management	Quality vs. quantity	Comprehensive analysis

Figure 2. Parking management principles (Litman, 2016).

Recently, the concept of parking management has evolved into smart parking management. As a part of smart mobility, smart parking management includes strategies and systems that enhance social, environmental, and economic aspects through technology. Improving the connection between Information and Communication Technologies (ICTs), the urban environment, and accessibility- and sustainability-related parameters is essential for an effective smart mobility index (Battarra et al, 2018).

Smart parking management includes both strategies and systems. Before discussing campus parking management, it is important to distinguish between the two. While both aim to improve economic, environmental, and social outcomes, their roles differ. Parking management systems, driven by technological advancements, enhance the efficiency of strategies and parking operations. As technology has become essential, sustainability has evolved into smartness, integrating ICT.

2.1. Parking Management Strategies

The traditional approach focused on building new parking facilities or expanding parking areas. However, this did not solve traffic congestion. Although parking spaces were available, accessing them caused congestion in central business districts and urban areas. Since most parking issues arise in city centers, this outdated approach has shifted toward supporting parking management strategies to address parking-related issues, management strategies are essential. These strategies include policies and programs that optimize parking supply. Effective parking management can reduce the need for additional parking spaces (Litman, 2017).

2.2. Parking Maximums

Parking maximum sets an upper limit on parking supply to reduce car use in high-demand areas and promote alternative modes like public transport, shuttles, walking, or cycling. Limiting parking availability decreases personal vehicle use (Christiansen et al, 2017). Reducing parking supply encourages public transport use and active travel for short trips (Bond, 2006). However, simply reducing parking supply is not enough; it must be supported by well-designed walking and cycling infrastructure and efficient transportation services. The parking maximum strategy is more effective when these alternatives are well-developed (Delaware ,2004).

An excessive parking supply weakens the effectiveness of parking pricing (Christiansen et al, 2017). Therefore, parking management strategies should be implemented together. Additionally, reducing parking supply can lower demand by 10-15%, particularly near transit or when combined with shared parking and pricing strategies.

2.3. Remote Parking

Remote parking lots are located away from central districts to reduce car use in these areas and limit cruising. Areas within limited parking, drivers may avoid visiting despite available spaces due to uncertainty about finding free parking (Kent, 2007). This uncertainty leads them to seek parking in other areas with a higher chance of availability. Remote parking could be defined as off-site parking facilities (Litman, 2006). To encourage usage, it must be supported by efficient shuttle or public transport services. Today, park-and-ride facilities are the most common type of remote parking. Estimating demand for park-and-ride lots requires considering the relationship between land use, public transport, and parking availability (Özen et al,2016).

2.4. Parking Regulations

Parking regulations optimize parking use by controlling who can park, when, and for how long (Litman, 2017). Parking restrictions become an important strategy for managing supply effectively. However, restrictions are less effective when parking lots are far from city centers but work better in compact neighborhoods (Christiansen et al, 2017). Absence of reserved workplace parking discourages driving, as drivers are less likely to commute by car without a dedicated space.

2.5. Parking Management Systems

Parking management systems rely more heavily on technological advancements than on parking management strategies. Initially, their primary function was to issue entry tickets to estimate parking duration. However, as vehicle ownership has grown, these systems have become increasingly complex. Drivers can spend up to 25% of their travel time searching for parking, which significantly adds to urban congestion during peak hours. Research estimates that parking-related traffic contributes to 25% to 50% of congestion during peak periods (Shaheen, 2005). The primary objective of these systems is to minimize travel time caused by cruising for parking. Nevertheless, real-time parking apps are not widely adopted in Hong Kong, largely due to drivers' lack of familiarity with them, highlighting uncertainty about the public's understanding of the smart city concept (Ma et al, 2018).

2.6. Parking Guidance and Information Systems

The primary objective of introducing Parking Guidance Information (PGI) systems is to reduce traffic caused by drivers searching for parking in urban centers and large parking facilities. A standard PGI system, installed at entrances, exits, or individual parking spots, is effective in collecting data on the number of occupied spaces and displaying the availability of parking spots within lots. Additionally, these systems can guide drivers directly to open parking spaces, enhancing efficiency and convenience

Parking Guidance and Information Systems aim to provide benefits such as reducing travel time, vehicle miles traveled, congestion, driver frustration, fuel consumption, and air pollution while increasing parking revenue (Shaheen, 2005). However, 72.8% of Hong Kong residents are unaware of parking apps, indicating that real-time parking solutions, a key aspect of smart mobility, are not yet widely adopted (Ma et al, 2018).

Transit-Based Information Systems

Transit-Based Information (TBI) systems differ from parking management systems but are closely connected to them. In park-and-ride facilities, TBI systems are essential for diverting drivers away from central business districts by offering real-time transit updates and promoting the use of public transportation.

TBI systems are a more advanced version of parking guidance and information systems. They provide real-time data on parking availability at park-and-ride lots and display schedules for buses, shuttles, trains, or subways based on location and purpose. Additionally, they offer arrival and departure times for different transit modes. These smart parking systems aim to increase public transit use, reduce car travel, lower fuel consumption and air pollution, and boost transit revenue (Shaheen, 2005).

Smart Payment Systems

Innovations in smart payment systems, including smart meters, smart cards, mobile payments, and e-parking, improve payment convenience while cutting down on operational, maintenance, and enforcement expenses (Shaheen, 2005). In Turkey, fee collection is often managed through workplace or valet parking systems, and in many parking facilities, payments are still processed by cashiers. Alongside conventional parking meters, new payment options have emerged as alternatives. Customers can make quick payments using smart cards, credit cards, or mobile transfers, enabling transactions via the Internet or mobile devices.

Regardless of whether parking apps are used, system security remains a major concern for users, as they seek reassurance that their personal data is safeguarded (Ma et al, 2018). Furthermore, Smart payment systems not only streamline transactions but also aid in identifying parking violations by capturing images of unauthorized vehicles (Idris et al, 2009).

Parking Reservation Systems

Parking Reservation Systems allow drivers to check parking availability, reserve a spot, and pay upon departure using web-based tools, apps, or phone calls. An advanced version, known as e-parking, also guides drivers to available spaces (Shaheen, 2005). This reduces the time spent searching for parking and may influence drivers to change destinations if no spaces are available.

2.7. Parking Pricing

Parking pricing is a key parking management strategy. It helps reduce congestion caused by cruising and generates revenue for maintaining parking facilities. Parking pricing policies influence users' mode choices (Shoup, 2011).

Parking pricing can reduce demand by 5% to 30%, which discourages driving. However, workplace parking limits are more effective than pricing alone and that reducing parking spaces strengthens pricing effects (Christiansen et al,2017). Also, free workplace parking can greatly increase demand, and free parking encourages car use, while removing it leads more people to choose public transport, walking, or cycling (Fei, 2016). Higher parking prices further reduce car usage.

Parking fees should keep 15% of spaces available, so drivers can find parking or choose another option if they don't want to pay. Therefore, willingness to pay depends on factors like tiredness, time, weather, safety, and carrying heavy items (Shoup, 2006).

Parking pricing should be based on occupancy rates, with central areas designated for paid parking. Priced parking is mainly used by short-term parkers, carpoolers sharing costs, and those valuing time savings (Shoup, 2008). However, pricing may lead to illegal parking or congestion as drivers search for free spots (Litman, 2020). Illegal parking in Hanoi, Vietnam, is common due to weak enforcement (Thanh et al, 2017). Therefore, improving regulations, providing user information, and enforcing rules are essential for effective parking pricing.

In recent years, there has been a fundamental shift in how parking challenges are identified and addressed. The traditional focus on the scarcity of parking spaces has evolved to include broader concerns such as the excessive allocation of urban space to parking, inefficient management practices, and the prevalence of underpriced parking facilities. This expanded perspective has led to the development of diversified solutions, including integrated transportation and parking management strategies aimed at optimizing the use of streets and public spaces.

Rather than aiming to eliminate parking spaces, this new paradigm focuses on maximizing the value derived from each vehicle trip and parking spot for both drivers and non-drivers. Cities are increasingly recognizing the importance of not just expanding parking capacity to meet demand but also managing existing parking resources more efficiently through strategic pricing and policy integration within broader transportation planning goals.

The accompanying graph illustrates the dynamics between parking demand, supply, and pricing. When parking is underpriced—as indicated by the area below the equilibrium price—demand significantly exceeds supply. This situation leads to congestion, as more people are incentivized to drive, even for short trips, due to the low cost of parking. Conversely, as parking prices rise toward the equilibrium level, demand decreases, aligning more closely with the available supply. This shift encourages more efficient parking behaviors, such as opting for alternative transportation modes, reducing parking durations, or choosing off-street parking options.

Importantly, those who continue to drive despite higher parking costs will benefit from improved availability, as spaces are less likely to be occupied by drivers making unnecessary trips. At the equilibrium price, parking supply meets demand without the need for additional infrastructure, promoting a more sustainable and balanced urban environment.

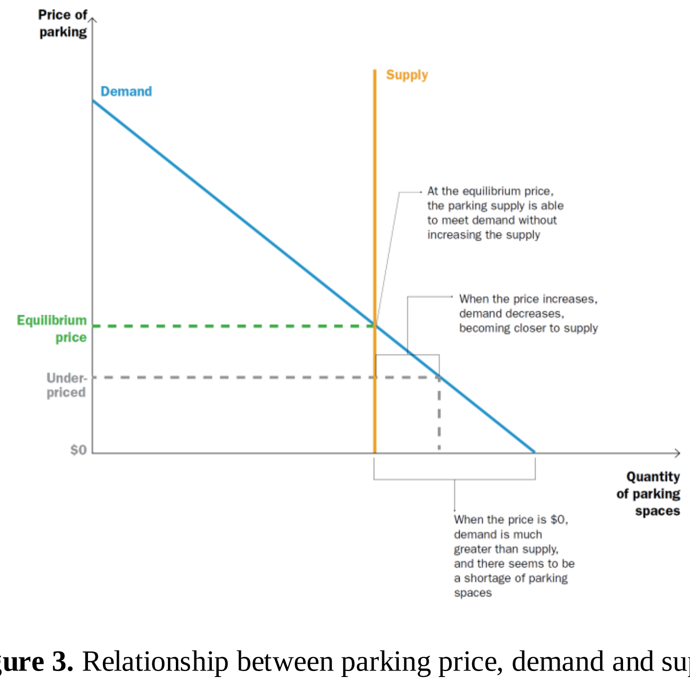

Figure 3. Relationship between parking price, demand and supply

3. Global Case Studies: Parking Management Practices in Major Cities

Urban parking policies have been widely studied in academic research, emphasizing the need for efficient and equitable parking management. Negative effects of free parking policies on urban traffic congestion and advocated for structured parking regulations (Shoup, 2005). How digital permitting and dynamic pricing could significantly enhance the allocation of parking spaces (Marsden et al,2020). Role of IoT and data analytics in smart parking management, proposing AI-assisted monitoring to improve efficiency (Geng et al, 2013). Lidar and AI-based systems in parking enforcement, emphasizing their potential for reducing unauthorized use and optimizing urban mobility (Zhang et al, 2019).

Several global cities have implemented innovative parking solutions to manage congestion and unauthorized parking. London employs a digital permitting system, where residents receive exclusive parking rights and unauthorized vehicles face substantial fines. Berlin has introduced sensor-based monitoring that tracks vehicle movement and parking duration, ensuring fair usage. New York uses time-based parking restrictions to allocate space dynamically between residents and visitors at different hours. Amsterdam integrates dynamic pricing models and real-time digital permit verification to balance parking demand and supply efficiently.

3.1. Regulatory Framework and Legal Considerations

Parking enforcement regulations vary across jurisdictions. London enforces immediate fines for unauthorized parking, whereas Berlin removes long-term stationary vehicles through municipal action. In the United States, certain states have strict neighborhood parking permit rules with immediate towing policies for violators. Turkey's Highway Traffic Law No. 2918 permits administrative fines for unauthorized parking and mandates the removal of abandoned vehicles from public spaces. This suggests that the proposed model would be compatible with existing legal frameworks and could be seamlessly integrated into municipal regulations.

4. A New Business Model Approach for Street Parking Management

The proposed system utilizes Lidar-based license plate recognition technology to automatically detect and regulate vehicle parking in residential areas. Residents are granted priority parking permits, while unauthorized vehicles are subject to a structured enforcement mechanism, including progressive warnings, fines, and potential removal for repeated violations. Additionally, abandoned and long-term stationary vehicles are detected and reported for removal, ensuring optimal utilization of parking spaces.

4.1. Enhanced System Flowchart for the Proposed Business Model

This advanced system flowchart includes additional decision-making steps, such as checking whether a vehicle has previously violated parking rules (see Figure 4). If a vehicle is registered as a resident, the system logs parking usage statistics for data-driven urban mobility decisions. Unauthorized vehicles are checked for prior violations and follow a structured warning and penalty mechanism.

The implementation of automated parking management systems has become integral to supporting data-driven urban mobility decisions. These systems facilitate real-time monitoring of parking compliance, detection of violations, and the collection of statistical data to inform policy and infrastructure planning.

The process begins with the scanning of roadside parked vehicles using Light Detection and Ranging (LiDAR) technology. LiDAR employs laser beams to measure distances and vehicle positions with high precision, enabling rapid and accurate detection, particularly in densely populated urban environments. Following the initial detection, optical character recognition (OCR) technology is utilized to read vehicle license plates, which are then cross-referenced with a central database. This database contains critical information, including vehicle registration status and records of prior parking violations.

Subsequently, the system verifies whether the detected vehicle is registered as belonging to a resident. For resident vehicles, parking usage statistics are systematically recorded. These data sets are invaluable for urban mobility planning, providing insights into parking demand patterns and supporting future infrastructure development strategies. In contrast, if a vehicle is not registered as a resident, the system conducts an additional check for any history of parking violations.

For non-resident vehicles with no prior violations, the system issues a warning notice as an initial corrective measure. Vehicles with a documented history of violations are subjected to a formal penalty process. A second recorded violation results in the imposition of a fine, serving as a deterrent to promote compliance with parking regulations. In cases of repeated non-compliance, more stringent penalties, such as vehicle towing, may be enforced to address persistent infractions effectively.

Furthermore, the system continuously monitors the duration of each parking event, identifying vehicles that exceed the designated time limits. This feature is particularly critical in high-demand areas to ensure equitable access to parking spaces. All detected violations, including instances of prolonged parking, are automatically reported to municipal authorities, enabling timely enforcement actions.

The integration of such automated systems has proven effective in addressing urban parking challenges, enhancing regulatory compliance, and contributing to the broader goals of sustainable traffic management in metropolitan areas.

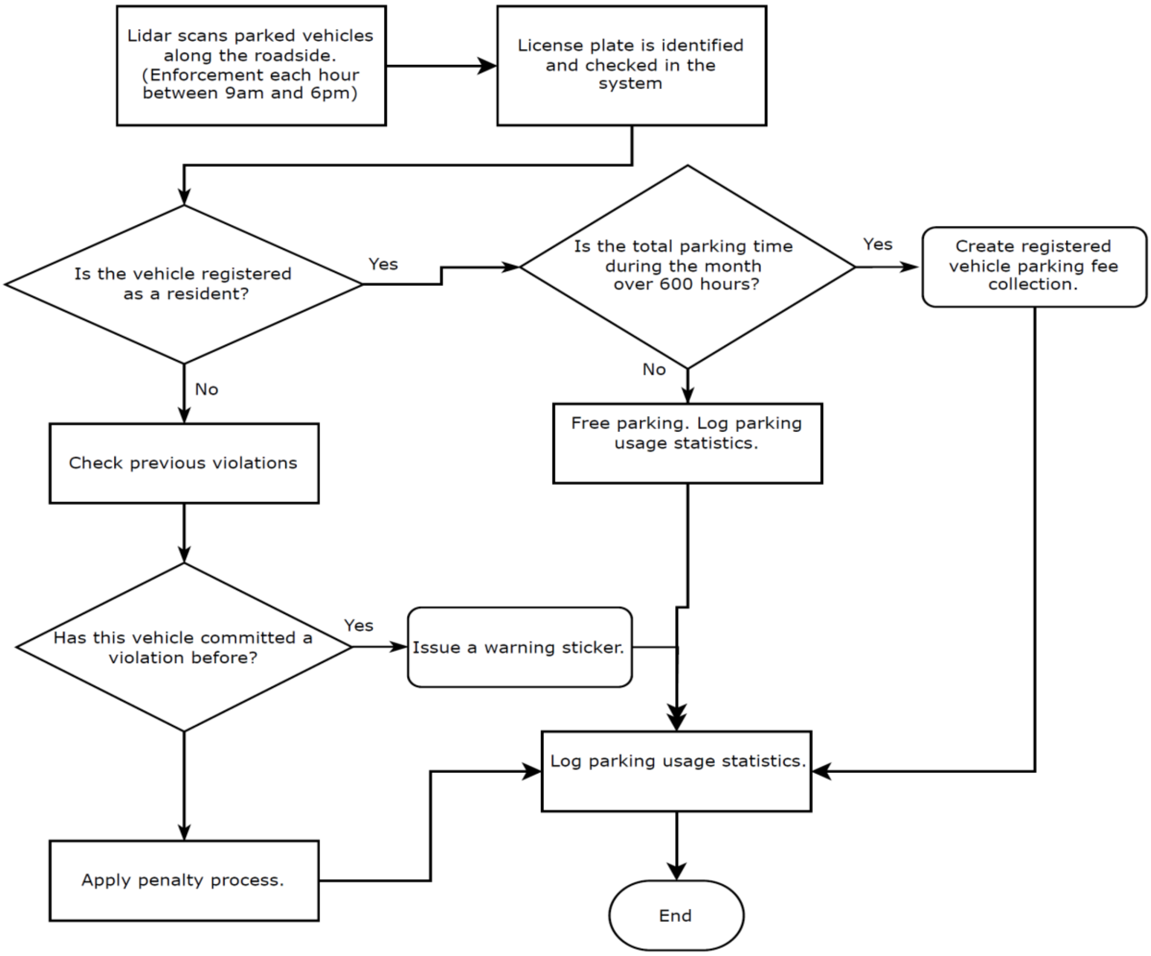

Figure 4. System flow chart of bussiness model

4.2. Cost Efficiency, Utilization Optimization, and Sustainability in Parking Permit Systems

This study analyzes the cost efficiency of parking permit systems and presents an optimized model that balances low fees, high utilization, and sustainability. The model incorporates revenue, operating costs, initial investment, pricing flexibility, and alternative transportation integration.

Mathematical Structure of the Model

Definitions and Variables

The fundamental components and variables of the proposed model are defined as follows:

- E: Cost efficiency score (evaluation metric)
- G: Annual parking revenue (thousand $)
- M: Annual operating cost (thousand $)
- C: Initial investment cost (thousand $)
- T: Technology integration coefficient (between 0 and 1)
- A: Alternative transportation integration coefficient (between 0 and 1)
- P: Dynamic pricing coefficient (between 0 and 1)
- D: License plate recognition and automated enforcement coefficient (between 0 and 1)
- U: Utilization rate (parking space occupancy, between 0 and 1)
- S: Sustainability coefficient (environmental impact and public transport contribution, between 0 and 1)
- L: Low-fee coefficient (pricing flexibility, between 0 and 1)

Cost Efficiency, Utilization, and Sustainability Model

Cost efficiency is calculated as the ratio of revenue minus operating cost to the initial investment, adjusted with a weighted coefficient that accounts for utilization rate and sustainability.

The mathematical representation of the model is as follows:

$$E = ((G - M) / C) \times (1 + w1 * T + w2 * A + w3 * P + w4 * D + w5 * U + w6 * S + w7 * L)$$

Where:

- (G - M) / C → Ratio of revenue minus operating costs to initial investment (basic efficiency measure)
- T, A, P, D, U, S, L → Coefficients representing system digitization, utilization, and sustainability levels
- w1, w2, w3, w4, w5, w6, w7 → Weights for each coefficient (normalized to sum up to 1)

Conditions for Optimal Cost Efficiency

To achieve maximum cost efficiency, the following conditions must be met:

1. Revenue must be at least three times the operating cost:

   $G \geq 3M$

2. Initial investment should not exceed 50% of the total annual revenue:

   $C \leq 0.5G$

3. The sum of digitalization and automation coefficients must be at least 0.7:

   $T + D \geq 0.7$

4. Utilization rate must be at least 70%:

   $U \geq 0.7$

5. Sustainability score must be at least 0.6:

   $S \geq 0.6$

6. Pricing flexibility must be at least 0.5:

   $L \geq 0.5$

Meeting these conditions ensures maximum cost efficiency, sustainability, and utilization effectiveness.

Model Optimization

The mathematical optimization for cost efficiency is represented as follows:

$$\max E = ((G - M) / C) \times (1 + w1 * T + w2 * A + w3 * P + w4 * D + w5 * U + w6 * S + w7 * L)$$

Constraints:

- $G \geq 3M$
- $C \leq 0.5G$
- $T + D \geq 0.7$
- $U \geq 0.7$
- $S \geq 0.6$
- $L \geq 0.5$

This model identifies the most cost-efficient parking permit system while maximizing utilization and sustainability.

The analysis concludes that a system incorporating dynamic pricing, digital permits, measures to enhance utilization, and sustainable transport integration is the most efficient model for parking permits.

4.3. Financial Benefits and Cost Efficiency

The adoption of smart parking enforcement systems offers significant financial benefits and cost reductions for municipalities. Replacing manual enforcement with digital automation leads to the following savings and revenue enhancements:

- Reduction in Enforcement Costs
- Automated monitoring reduces reliance on field personnel, cutting annual operational expenses by 30%.
- Increase in Revenue:
- Fines for unauthorized parking contribute to a 15-20% rise in municipal parking-related income.
- Lower Traffic Congestion:
- Optimized parking allocation reduces unnecessary vehicle movement, cutting fuel waste and emissions by 10-15%.
- Improved Parking Space Utilization:
- Removing abandoned vehicles increases available parking capacity by 5-10%.
- Environmental Gains:
- Reducing vehicle idling times results in a 5-8% drop in urban air pollution and CO_2 emissions.

5. Potential Implementation of the Proposed Model in Istanbul

Istanbul, as one of the most densely populated metropolitan areas in the world, faces significant challenges in managing its on-street parking spaces due to limited parking availability, high vehicle ownership rates, and complex urban infrastructure. The efficient management of curbside parking is crucial for mitigating traffic congestion, optimizing urban mobility, and ensuring sustainable urban development. The proposed mathematical model, which integrates cost efficiency, utilization optimization, and sustainability, provides a structured framework that can be adapted to various districts within Istanbul to enhance parking management and policy planning.

Given the city's heterogeneity in terms of population density, urban layout, and transportation demand, a district-specific application of this model would be necessary. Districts such as Şişli, Beşiktaş, Bakırköy, Kadıköy, Fatih, and Beyoğlu, which exhibit high commercial activity, dense residential settlements, and significant parking demand, represent prime candidates for the implementation of this optimized parking permit system. Furthermore, sub-district level analysis can refine the model's applicability by targeting specific neighborhoods within these districts, such as Mecidiyeköy (Şişli), Levent (Beşiktaş), Zeytinlik (Bakırkoy), Moda (Kadıköy), and Taksim (Beyoğlu), where limited parking supply and high vehicular inflow necessitate more efficient regulatory mechanisms.

To further refine and validate the model's implementation, a data-driven approach should be adopted, incorporating real-time occupancy rates, parking demand fluctuations, and enforcement efficiency across different urban zones. The availability of parking occupancy data, traffic flow analyses, and socio-economic factors can be utilized to fine-tune the weight parameters in the model to ensure the highest cost efficiency while maintaining equitable access to parking facilities. Additionally, the model's dynamic pricing and technological integration features can be adapted based on Istanbul's evolving transportation policies, aligning with the city's broader sustainability goals.

Given these considerations, future research should focus on conducting spatial and temporal analyses of Istanbul's parking infrastructure, identifying high-demand locations where the model's principles can be most effectively implemented. Integrating IoT-based parking sensors, license plate recognition technologies, and mobile payment systems into the existing regulatory framework would enhance enforcement capabilities and reduce unauthorized parking. Moreover, by incorporating alternative transportation incentives, such as discounts for electric vehicles and integrated public transport passes, the model can support Istanbul's long-term urban mobility objectives.

Thus, this study highlights the urgent need for a structured, data-driven approach to managing curbside parking in Istanbul. The proposed mathematical model serves as a robust foundation for addressing the city's parking challenges, but its successful deployment necessitates further empirical research, policy alignment, and technological infrastructure investments. By leveraging district-level micro-modeling and adaptive pricing mechanisms, Istanbul can enhance the efficiency, sustainability, and accessibility of its urban parking system, ultimately contributing to a more resilient and well-regulated transportation ecosystem.

5.1. Demand Forecast Model for Parking Choice: A Case Study in İstanbul Provinces

The Data-Driven Management Model (VDYM) research in Istanbul aims to generate data that will serve as a basis for strategies related to investments and services by identifying the general sociodemographic and socioeconomic profile, needs, and tendencies of Istanbul's population. For this purpose, face-to-face interviews were conducted with 50,000 households across the city using a survey method. The number of surveys was distributed proportionally based on the number of households in each neighborhood, ensuring at least 12 surveys per neighborhood.

To ensure the results are representative of Istanbul, the households to be surveyed were selected using a stratified random sampling method at the neighborhood level. The fieldwork, during which the finalized survey form—refined through workshops and meetings—was implemented, was carried out between November 29, 2021, and March 7, 2022 (IMM-ODP,2023).

Parking preferences in urban environments are shaped by a combination of socio-economic factors, infrastructure availability, and regulatory frameworks. In Istanbul, a city characterized by high population density and increasing vehicle ownership, roadside parking emerges as the most preferred option among households. This trend is not unique to Istanbul but is observed in many metropolitan areas where the convenience and cost-free nature of on-street parking outweigh other considerations (Shoup, 2006).

According to data from the Istanbul Metropolitan Municipality's Open Data Portal and İSPARK (2021-2022), free on-street parking remains the dominant choice for residents across various districts. This preference is particularly pronounced in densely populated areas such as Bağcılar, Esenyurt, and Fatih, where limited off-street parking infrastructure compels residents to rely on curbside spaces (Figure 5). While on-street parking offers immediate accessibility, it also contributes to significant urban challenges, including traffic congestion, reduced road safety, and inefficient land use (Litman, 2021).

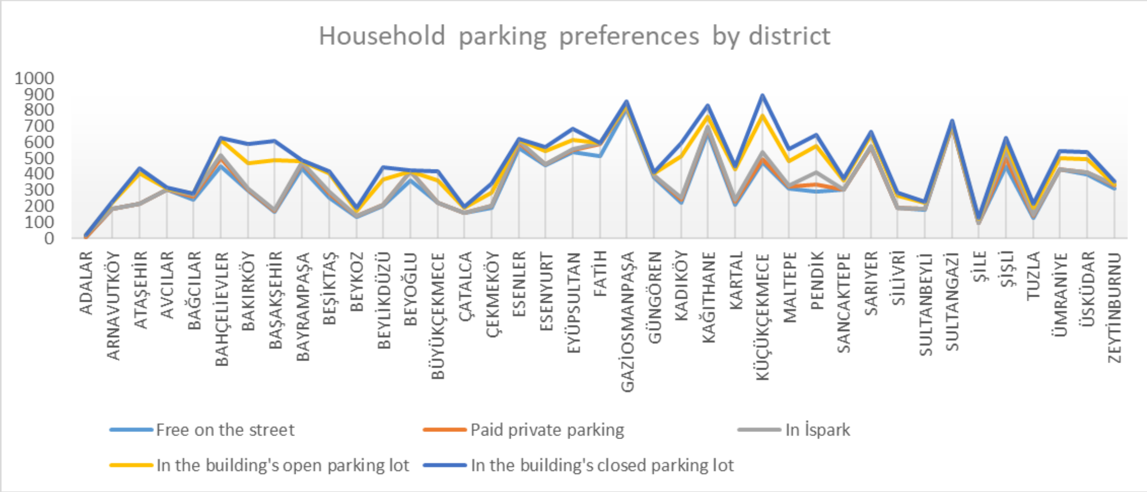

Figure 5. Household parking preferences by district.

The issue is further complicated by the fact that unregulated or underpriced roadside parking encourages excessive vehicle use, even for short trips, exacerbating congestion and environmental impacts (Arnott and Inci,2006). In Istanbul's context, the absence of dynamic pricing mechanisms for on-street parking leads to high demand and inefficient turnover rates, especially in commercial districts where parking spaces are frequently occupied for extended periods.

Addressing these challenges requires a shift towards data-driven parking management strategies. The VDYM (Data-Driven Management Model) research highlights the importance of integrating household parking preferences into urban mobility planning. By leveraging detailed data on parking behaviors, city authorities can develop targeted policies that balance the demand for curb space with broader objectives such as reducing traffic congestion and promoting sustainable transportation modes.

Moreover, the İSPARK 2021-2022 data underscores the need for differentiated parking strategies across districts. For instance, while central areas may benefit from stricter regulations and higher pricing to manage demand, peripheral districts could focus on expanding off-street parking options to alleviate pressure on public spaces (IBB, 2021).

In conclusion, Istanbul's reliance on free on-street parking reflects broader urban dynamics that necessitate comprehensive policy interventions. Integrating insights from data sources like the VDYM research and İSPARK statistics can support the development of more effective, equitable, and sustainable parking management practices.

6. Case Study: Addressing Parking Challenges in Zeytinlik Neighborhood, Bakırköy

Zeytinlik Neighborhood, located in Istanbul's Bakırköy district, is heavily influenced by its proximity to major arterial roads such as the E-5 Highway (D-100), Kennedy Avenue (Sahil Yolu), and İncirli Avenue. These main transportation routes serve as critical connections to the wider city, facilitating access to Ataköy, Florya, Bahçelievler, and Zeytinburnu, yet also contributing to significant traffic congestion. The neighborhood's southern boundary along Kennedy Avenue connects to the coastal road network, while its northern end links directly to E-5, creating high levels of vehicle flow, particularly during peak commuting hours.

Traffic congestion in Zeytinlik is particularly severe on İncirli Avenue, Cevizlik Avenue, Zeytinlik Avenue, and Yakut Street, where narrow, single-lane roads struggle to accommodate both moving vehicles and parked cars. The one-way street system, combined with insufficient parking spaces, exacerbates mobility issues, often leading to illegal or double parking, further restricting traffic flow. Additionally, the high density of commercial areas and shopping malls (e.g., Capacity AVM, Carousel AVM) generates substantial traffic surges, particularly during weekends and rush hours, making parking even more challenging.

The visualization of the connection roads to Zeytinlik Neighborhood, particularly during peak traffic hours on weekends, is presented in Figure 5 based on Google Maps data.

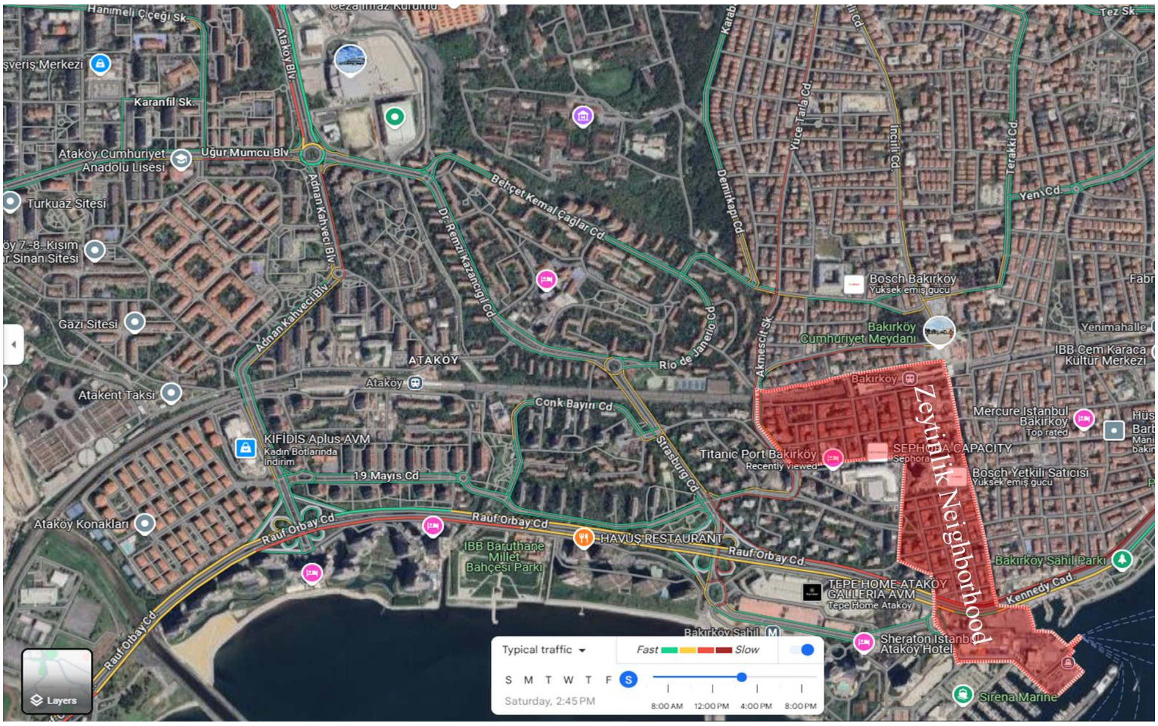

Figure 6. Zeytinlik neighborhood Google Maps based weekend traffic density data

The combination of limited parking capacity, narrow streets, and high traffic density severely impacts mobility within Zeytinlik, causing bottlenecks and restricting access to main roads. These conditions not only slow vehicular movement but also affect pedestrian safety, public transport efficiency, and emergency vehicle accessibility. Addressing these issues requires a LiDAR-based smart parking system, dynamic traffic regulations, and prioritized parking policies for residents, which could significantly improve traffic flow and overall urban mobility in the area.

Zeytinlik Neighborhood, located in Bakırköy, Istanbul, faces significant parking challenges due to its high population density, increasing vehicle ownership, and limited public parking infrastructure. With a total population of 5,146 residents, consisting of 2,440 males and 2,706 females, the area represents a mix of young and middle-aged working-class individuals, with an average age of 31 years. The neighborhood's demographic structure, where 48% of residents are married and the average household income stands at 21,641 TL per month, suggests a substantial demand for vehicle ownership and parking spaces. Furthermore, with 32% of the population having completed only primary education, socioeconomic factors must also be considered in parking allocation and pricing policies.

The demographic and vehicle ownership data for Zeytinlik Neighborhood were obtained through a combination of official statistical sources, municipal records, and field surveys. Population data were sourced from the Turkish Statistical Institute (TÜİK) and Bakırköy Municipality, providing insights into household structures, income levels, and residential density. Vehicle ownership estimates were derived from İstanbul Metropolitan Municipality's (İBB) traffic and vehicle registration databases, supplemented by field observations and resident surveys conducted within the neighborhood. This approach allowed for a detailed understanding of parking demand, enabling the formulation of a data-driven pricing model that aligns with real-world usage patterns and socio-economic conditions.

Although specific data on vehicle ownership in Zeytinlik is scarce, general statistics from Istanbul indicate that approximately 38% of households own at least one car. Applying this to Zeytinlik, it is estimated that 590 households own at least one vehicle, with anecdotal evidence suggesting that many households own two or more. This growing demand significantly outweighs the available parking infrastructure. Publicly accessible parking facilities in Bakırköy, such as the Bakırköy İDO Open Parking Lot (160 vehicles), Bakırköy Open Parking Lots 1 & 2 (40 vehicles each), and Bakırköy Şenlikköy Parking Lot (384 vehicles), provide some capacity. However, they remain inadequate given the increasing number of residents who require daily and long-term parking. Additionally, commercial parking structures such as Capacity AVM's 2,500-space parking facility cater primarily to visitors rather than neighborhood residents, further limiting available options.

6.1. Mathematical Model for Parking Cost Efficiency and Fee Estimation

This analyze presents the mathematical model used to estimate parking subscription fees for Zeytinlik Neighborhood. The model calculates cost efficiency while incorporating factors such as digitalization, sustainability, and utilization. The estimated fees are based on operational and investment costs, ensuring financial sustainability and accessibility.

The cost efficiency score (E) is calculated using the following formula:

$$E = ((G - M) / C) \times (1 + w1 * T + w2 * A + w3 * P + w4 * D + w5 * U + w6 * S + w7 * L)$$

Where:
- G = Annual parking revenue (5,000,000 TL)
- M = Annual operating cost (1,500,000 TL)
- C = Initial investment cost (2,000,000 TL)
- T, A, P, D, U, S, L = Coefficients for technology integration, alternative transport, dynamic pricing, enforcement, utilization, sustainability, and pricing flexibility
- w1, w2, w3, w4, w5, w6, w7 = Weights assigned to each factor (normalized to sum up to 1)

Table 2. Cost efficiency fee estimation value

Metric	Value
Cost Efficiency Score (E)	3,04
Estimated Yearly Parking Subscription Fee	55,555. 56 TL
Estimated Hourly Parking Fee	185.18 TL

The parking subscription fees for Zeytinlik Neighborhood have been converted to U.S. dollars based on the Central Bank of Türkiye exchange rate as of February 11, 2025, to facilitate international comparisons and financial analysis. On this date, the selling rate for USD/TL was 36.0781 (Central Bank of Türkiye). Accordingly, the monthly parking subscription fee, originally set at 55,555.56 TL, corresponds to approximately 1,539.8 USD, while the hourly parking fee, calculated at 185,18 TL, translates to approximately 5.13 USD. These values are subject to fluctuations in exchange rates, and adjustments may be required to ensure financial stability and affordability in response to currency volatility. Integrating exchange rate considerations into the pricing model can further enhance its adaptability and long-term sustainability in an international economic context.

The model shows a cost-effectiveness score of 3.04, which ensures financial viability. The estimated monthly subscription fee and hourly parking fee are calculated according to the usage and cost-effectiveness principles. For the effectiveness and sustainability of the model, it is recommended that parking fees should be affordable for the neighborhood residents and should be income-based. These values can be improved according to real-time demand and policy adjustments. Therefore, more detailed analysis is performed and presented in the next section.

6.2. Proposed Smart Parking Model for Zeytinlik Neighborhood

To address these pressing concerns, a LiDAR-based smart parking system is proposed, emphasizing resident-prioritized parking allocation, dynamic pricing, automated enforcement, and progressive penalty mechanisms. By designating a specific percentage of public parking spaces for residents only, the system ensures that local drivers have priority access to limited parking resources. Drawing from İSPARK's existing pricing model in Bakırköy, a competitive rate of 100 TL per hour (compared to İSPARK's current 80 TL) is recommended, alongside a monthly resident subscription fee of 3,000 TL to provide affordable long-term parking solutions.

Furthermore, automated enforcement mechanisms utilizing LiDAR sensors and Automatic Number Plate Recognition (ANPR) technology will monitor real-time parking occupancy and detect violations, reducing the need for manual oversight. To discourage non-resident parking and illegal use of designated spots, a progressive penalty system will be introduced, with fines starting at 993 TL, escalating with repeat violations. Additionally, abandoned vehicle tracking will be implemented to prevent inefficient occupation of parking spaces, ensuring optimal usage of available infrastructure.

The anticipated benefits of this model include enhanced parking availability for residents, reduced traffic congestion, optimized revenue generation for municipal authorities, and lower enforcement costs due to automation. However, implementation challenges may arise, including public resistance from non-resident drivers, the financial burden of infrastructure adaptation, and concerns regarding data privacy and regulatory compliance.

In conclusion, the findings of this case study highlight the urgent need for structured, technology-driven parking solutions in Zeytinlik Neighborhood. The proposed LiDAR-based smart parking system, with its focus on resident prioritization, real-time enforcement, and dynamic pricing, presents a scalable and sustainable solution to existing urban mobility challenges. If successfully implemented, this model has the potential to serve as a precedent for other densely populated areas facing similar parking crises, ultimately improving the quality of life for local residents and ensuring a more efficient urban traffic system.

6.1. Mathematical Model for Monthly Subscription Fee

To determine the monthly parking subscription fee for residents in Zeytinlik Neighborhood, we use a cost-recovery and demand-based pricing model, which accounts for operational costs, available parking capacity, expected demand, and enforcement revenues. The model is as follows:

$M = ((C + R * U * 24 * 30 - P) * N) / D$

Where:

- M = Monthly parking subscription fee
- C = Monthly operational cost of the parking system (assumed 500,000 TL)
- R = Hourly parking fee (100 TL per hour)
- U = Average utilization rate (10 hours/day)
- N = Total number of designated resident parking spaces (200)
- D = Total number of residents applying for subscriptions (300)
- P = Projected penalty revenue from violations (50,000 TL)

Using these values, the optimal monthly parking subscription fee is calculated as **3,000 TL per vehicle**, ensuring cost recovery, fair allocation, and financial sustainability of the system.

6.2. Income-Based Parking Fee Model: Mathematical Justification and Detailed Explanation

In an urban setting like Zeytinlik Neighborhood, where parking demand exceeds supply, a fair and sustainable pricing strategy is essential. The goal of the income-based parking fee model is to ensure affordability for all income groups while maintaining the financial sustainability of the parking system. This section presents a detailed mathematical model, its rationale, and its impact on different income groups.

The model is designed based on the following key parameters:
1. Operational Costs (C): Monthly maintenance, security, and enforcement costs of the parking system.
2. Base Hourly Rate (R): Standard hourly rate charged for parking, derived from İSPARK's pricing structure.
3. Utilization Rate (U): The estimated daily average usage of a parking spot.
4. Capacity (N): The number of available parking spots designated for residents.
5. Resident Demand (D): The number of residents applying for parking subscriptions.
6. Penalty Revenue (P): Expected revenue from parking violations, used to offset operational costs.
7. Property Tax Limit (T): The maximum allowable annual parking fee, ensuring affordability relative to property tax obligations.
8. Income-Based Adjustment Factor (L): A corrective factor ensuring that lower-income households pay a reduced fee while higher-income households contribute proportionally.

The annual parking subscription fee (M) is calculated as:
$M = \min(((C + R \times U \times 24 \times 30 - P) \times N / D), T \times L)$
Where:
- M = Annual parking subscription fee per household
- C = Monthly operational cost (500,000 TL)
- R = Hourly parking fee (100 TL/hour)
- U = Average daily utilization per vehicle (10 hours/day)
- N = Number of parking spaces allocated to residents (200)
- D = Total number of applicants for subscriptions (300)
- P = Expected penalty revenue (50,000 TL)
- T = Property tax benchmark (10,000 TL annually)
- L = Income-Based Adjustment Factor:
  - 0.8 for low-income households (≤ 60% of avg. income)
  - 1.0 for middle-income households (60%-150% of avg. income)
  - 1.2 for high-income households (>150% of avg. income)

The model ensures financial sustainability while maintaining fairness. It incorporates a revenue-based cost-recovery approach and protects households from excessive financial burdens by setting a cap based on property tax obligations. An example calculation is given in Table 1.

Table 2. Proposed income-based annual parking fee for Zeytinlik neighborhood

Income Group	Annual Parking Fee Calculation	Final Fee
Low-Income (≤ 60% of Avg. Income)	M = min(8,000, 8,000)	8,000 TL/year
Middle-Income (60%-150% of Avg. Income)	M = min(10,000, 10,000)	10,000 TL/year
High-Income (> 150% of Avg. Income)	M = min(12,000, 12,000)	12,000 TL/year

This model presents a scalable, fair, and financially sustainable approach to parking management in Zeytinlik Neighborhood. By incorporating demand-based pricing, cost-recovery strategies, and income-sensitive fee structures, the system ensures accessibility for all while maintaining urban mobility efficiency.

7. Conclusion

In this article, case study presents a cost efficiency model for optimizing parking subscription fees in Zeytinlik Neighborhood, integrating financial sustainability, digital enforcement, and dynamic pricing. The cost efficiency score of 3.04 confirms the model's viability, balancing revenue generation with affordability while enhancing parking utilization and congestion management. Demographic and vehicle ownership data were obtained from the Turkish Statistical Institute (TÜİK), Bakırköy Municipality, and İstanbul Metropolitan Municipality (İBB), supplemented by field observations and resident surveys. These data provided insights into household structures, income levels, and vehicle density, ensuring an evidence-based pricing strategy. The proposed model offers a scalable framework for urban parking management, integrating real-time enforcement, sustainability considerations, and socio-economic factors. Its adaptability allows for broader applications in high-density urban districts, with potential refinements incorporating real-time congestion pricing and multimodal transport strategies to enhance long-term mobility planning.

Generally, the escalating number of vehicles coupled with limited parking infrastructure has intensified the challenges associated with on-street parking management like rapidly urbanizing cities as Istanbul. This scenario not only exacerbates traffic congestion but also contributes to environmental degradation and diminishes the quality of urban life. Addressing these multifaceted issues necessitates the adoption of innovative solutions that prioritize efficiency, sustainability, and the well-being of residents.

The proposed LiDAR-based smart parking system emerges as a comprehensive strategy to mitigate these challenges. LiDAR (Light Detection and Ranging) technology utilizes laser pulses to generate high-resolution, three-dimensional representations of the environment. By deploying LiDAR sensors along urban streets, the system can accurately monitor real-time parking space occupancy, detect unauthorized parking activities, and assess the duration of vehicle stays. This precise data collection facilitates dynamic management of parking resources, ensuring optimal utilization and reducing instances of illegal parking.

A critical component of this model is the prioritization of parking access for local residents. Given the scarcity of available parking spaces in Istanbul, it is imperative to conduct detailed analyses to identify areas where the implementation of this model would be most effective. By designating specific zones as priority parking areas for neighborhood residents, the system ensures that locals have reliable access to parking near their homes. This targeted approach not only alleviates daily parking challenges for residents but also fosters a sense of community well-being.

The integration of automated enforcement mechanisms further enhances the system's efficacy. Equipped with cameras and automatic number plate recognition (ANPR) technology, the system can swiftly identify vehicles parked in restricted zones or those exceeding allotted time limits. This automation reduces the reliance on manual monitoring, thereby decreasing enforcement costs and allowing municipal authorities to allocate resources more efficiently.

To encourage compliance and optimize parking space usage, the system incorporates a framework of progressive penalties and financial incentives. Implementing escalating fines for repeat offenders serves as a deterrent against parking violations, while offering financial incentives—such as discounted rates during off-peak hours or for short-term parking—can influence driver behavior positively. Dynamic pricing models, which adjust parking fees based on real-time demand, have been successfully employed in various cities to maintain parking availability and reduce congestion.

Another significant advantage of the LiDAR-based system is its capability to detect abandoned vehicles. By identifying cars that remain stationary beyond a reasonable period, the system can alert authorities to potential cases of vehicle abandonment. Prompt removal of such vehicles ensures that valuable parking spaces are not occupied unnecessarily and contributes to the overall aesthetics and safety of urban environments.

The benefits of implementing this LiDAR-based smart parking system are multifaceted:

- Improved Urban Mobility: Real-time data allows drivers to locate available parking spaces efficiently, reducing the time spent searching for parking and thereby decreasing traffic congestion.

- Enhanced Municipal Revenue: Effective enforcement and dynamic pricing strategies increase compliance and optimize fee collection, bolstering city revenues.
- Reduced Enforcement Costs: Automation minimizes the need for manual patrols, enabling more efficient allocation of municipal resources.
- Environmental Benefits: By reducing traffic congestion and optimizing parking space utilization, the system contributes to lower vehicle emissions, supporting environmental sustainability initiatives.

In conclusion, the adoption of a LiDAR-based smart parking system represents a scalable and sustainable solution to the complex challenges of on-street parking management in urban centers like Istanbul. By prioritizing resident access, integrating automated enforcement, and employing dynamic pricing models, this approach not only addresses current parking issues but also lays the foundation for a more efficient, livable, and environmentally friendly urban future.

Researchers' Contribution Rate Statement

All stages of the study were carried out by the corresponding author.

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References

Arnott, R. & Inci, E. (2006). An Integrated Model of Downtown Parking and Traffic Congestion. Journal of Urban Economics, 60(3), pp. 418 – 442.

Battarra, R., Gargiulo, C., Tremiterra, M. R. & Zucaro, F. (2018). Smart Mobility in Italian Metropolitan Cities: A comparative analysis through indicators and actions. Sustainable Cities and Society, 41, pp. 556-567.

Bond, A. & Steiner, R. (2006). Sustainable campus transportation through transit partnership and transportation demand management: A case study from the University of Florida. Berkeley Planning Journal, 19(1).

Christiansen, P., Engebretsen, O., Fearnley, N. & Hanssen, J. U. (2017). Parking facilities and the built environment: Impacts on travel behavior. Transportation Research Part A: Policy and Practice, 95, pp. 198-206.

Delaware (2004). Parking Management Strategies.

Idris, M. Y. I., Leng, Y. Y., Tamil, E. M., Noor, N. M. & Razak, Z. (2009). "Car park system: a review of smart parking system and its technology". Information Technology Journal, 8(2), pp. 101-113.

Fei, S. (2016). Parking versus public transport subsidies: case study of Nanjing, China. Transportation Letters, 8(2), pp. 90-97.

Geng, Y. & Cassandras, C. G. (2013). New Smart Parking System Based on Resource Allocation and Reservations. Ieee Transactions on Intelligent Transportation Systems, 14(3).

Ibeas, A. & Moura, J. L. (2018). Parking Behavior and Policy. Journal of Advanced Transportation.

Istanbul Büyükşehir Belediyesi Açık Veri Portalı (IMM-ODP) (2023). Parking Usage and Management Data.

Kent A. (2007). The Psychology of Downtown Parking. ULI.

Litman, T. (2006). Parking Management: Strategies, Evaluation and Planning.Victoria Transport Policy Institute, Victoria, Canada,pp. 29.

Litman, T. (2016). Parking management: strategies, evaluation and planning. pp. 2.

Litman, T. (2017). Comprehensive Implementation Guide. Victoria Transport Policy Institute.

Litman, T. (2020). Parking Pricing Implementation Guidelines. Victoria Transport Policy Institute.

Litman, T. (2021). The Business Case for Parking Management Best Practices. Victoria Transport Policy Institute.

Ma, R., Lam, P. T. & Leung, C. K. (2018). Potential pitfalls of smart city development: A study on parking mobile applications (apps) in Hong Kong. Telematics and Informatics, 35(6), pp. 1580-1592.

Marsden, G., Docherty, I. & Dowling, R. (2020). Parking futures: Curbside management in the era of 'new mobility' services in British and Australian cities. Land Use Policy, 91, 104012.

OECD (2013). Long Run Trends in Car Use. Retrieved February , 2025 from https://www.oecd.org/content/dam/oecd/en/publications/reports/2013/12/long-run-trends-in-car-use_g1g31398/9789282105931-en.pdf

Özen, H., Saraçoğlu, A., Boz, F. & Kusakci, S. (2016). Evaluation of Park and Ride Facilities in Istanbul Using Geographic Information Systems (GIS). Sigma Journal of Engineerıng and Natural Sciences-Sigma Mühendislik ve Fen Bilimleri Dergisi, 7(1), pp. 79-88.

Weinberger, R., Kaehny, J. & Rufo, M. (2010). US Parking Policies: An Overview of Management Strategies.

Shaheen, S. (2005). Smart parking management field test: A bay area rapid transit (Bart) district parking demonstration.

Shoup, D. (2005). The High Cost of Free Parking. Journal of Planning Education and Research.

Shoup, D. (2006). Cruising for parking. Transport Policy, 13(6), pp. 479-486.

Shoup, D. (2008). The politics and economics of parking on campus. The implementation and effectiveness of transport demand management measures: an international perspective, 12.

Shoup, D. (2011). The High Cost of Free Parking. American Planning Association, Planners Press, Chicago.

Thanh, T. T. M. & Friedrich, H. (2017). Legalizing the illegal parking, a solution for parking scarcity in developing countries. Transportation research procedia, 25, pp. 4950-4965.

Zhang, Y.,Carballo, A., Yang, H. & Takeda, K. (2019). Perception and sensing for autonomous vehicles under adverse weather conditions: A survey. ISPRS Journal of Photogrammetry and Remote Sensing. 196, pp. 146-177