INSE 6400 – Principles of Systems Engineering

Smart Parking Solutions

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Introduction

In the bustling urban landscapes of today, the scarcity of parking spaces has become a ubiquitous challenge. As it grows denser and vehicular traffic increases, the demand for efficient parking management solutions has never been greater. In response to this pressing need, the concept of Smart Parking emerges as a paradigm-shifting solution within the realm of system engineering [1].

Smart Parking systems represent an innovative fusion of technology and infrastructure aimed at optimizing the utilization of parking resources while enhancing the overall user experience. Leveraging cutting-edge advancements in sensor technologies, data analytics, and connectivity, these systems offer a holistic approach to address the complexities of urban parking management [2].

At its core, a Smart Parking project embodies the principles of system engineering, wherein multifaceted components are orchestrated into a cohesive framework to achieve predefined objectives. This interdisciplinary approach encompasses various stages, from conceptualization and design to implementation and operation, ensuring seamless integration and functionality across diverse subsystems [1,2].

Figure 1-Smart Parking System

Problems Identification

The traditional parking system in urban areas faces numerous challenges, leading to inefficiencies, frustrations, and environmental impacts. Addressing these challenges through the implementation of smart parking technologies presents an opportunity to enhance the parking experience, optimize space utilization, and improve overall urban mobility. However, before transitioning to smart parking solutions, it's essential to identify and understand the existing problems inherent in traditional parking systems [3].

Congestion and Traffic Delays:

Limited Parking Availability: Inadequate parking supply relative to demand leads to congestion as drivers circle in search of parking spots, causing traffic delays and increased emissions.

Inefficient Parking Management: Manual or outdated parking management systems result in suboptimal utilization of parking spaces, exacerbating congestion during peak hours.

Poor User Experience:

Difficulty Finding Parking: Lack of real-time information on parking availability makes it challenging for drivers to find parking quickly, leading to frustration and wasted time.

Tedious Payment Processes: Traditional parking payment methods, such as coin-operated meters or pay-and-display systems, are inconvenient and time-consuming for users [17].

Limited Accessibility and Equity:

Inadequate Access for Disabled Individuals: Traditional parking facilities often lack accessible parking spaces and amenities for individuals with disabilities, hindering their mobility.

Socioeconomic Disparities: High parking fees or limited access to affordable parking options disproportionately affect low-income residents and exacerbate socioeconomic inequalities.

Inefficient Space Utilization:

Underutilized Parking Spaces: Inefficient allocation of parking spaces, such as reserved spots for specific users or time-restricted zones, results in underutilization of available parking capacity.

Overcrowding in Popular Areas: Certain areas experience overcrowding due to high demand for parking, while other nearby spaces remain vacant, leading to uneven distribution and wasted capacity [16].

Environmental Impact:

Increased Emissions and Pollution: Traffic congestion caused by circling vehicles and inefficient parking contributes to higher emissions of greenhouse gases and air pollutants, impacting air quality and public health.

Urban Sprawl and Land Use: Traditional parking facilities consume valuable urban land and encourage car-centric urban development patterns, leading to increased sprawl and reduced walkability.

Security and Safety Concerns:

Vehicle Theft and Vandalism: Inadequate security measures in traditional parking lots make vehicles susceptible to theft, vandalism, and break-ins, posing safety risks for owners.

Personal Safety: Poorly lit or isolated parking areas increase the risk of personal safety incidents, particularly during off-peak hours or in poorly monitored facilities.

Addressing these problems requires a comprehensive approach that integrates smart parking technologies, data-driven solutions, and policy interventions to improve the efficiency, accessibility, and sustainability of urban parking systems. By transitioning from traditional parking to smart parking solutions, cities can unlock significant benefits in terms of reduced congestion, enhanced user experience, and more equitable access to parking resources [12].

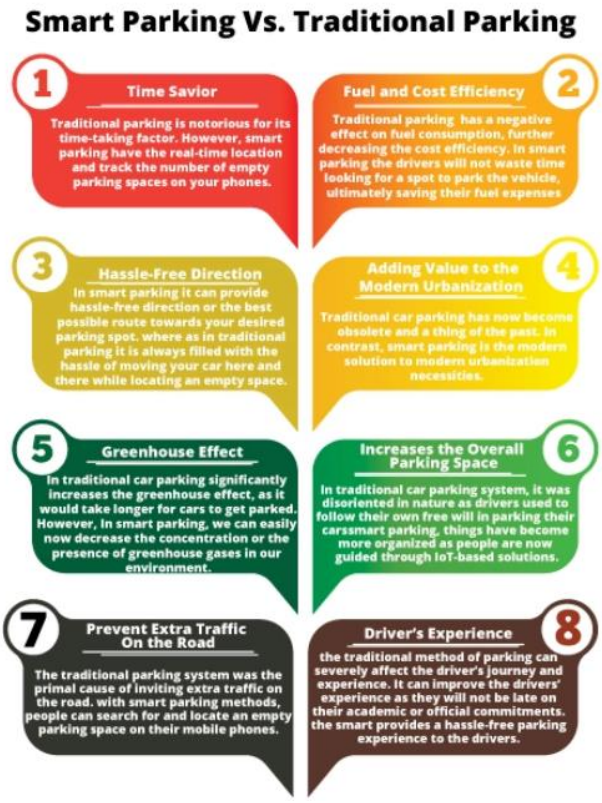

Figure 2-Samrt Parking Vs. Traditional Parking

System identification and understanding subsystems

System identification in the context of smart parking involves the process of modeling the dynamics and behavior of various components within the smart parking system based on observed input-output data. This process helps in understanding how different elements of the smart parking infrastructure interact and how they collectively contribute to the system's overall performance [10].

Data Collection: Data is collected from various sources within the smart parking system, including sensors, user interactions with mobile apps or websites, payment transactions, and parking enforcement activities. This data includes information such as parking space occupancy, arrival and departure times of vehicles, payment history, and any relevant environmental factors.

Preprocessing: The collected data undergoes preprocessing steps to remove noise, handle missing values, and ensure consistency and accuracy. Preprocessing techniques

may include data cleaning, filtering, normalization, and feature extraction to prepare the data for analysis.

Modeling: Mathematical models are developed to represent the relationships between different components of the smart parking system. These models can include subsystems such as parking space occupancy prediction, demand forecasting, payment processing, and user behavior analysis. Depending on the complexity of the system and the available data, various modeling techniques such as regression analysis, time series analysis, machine learning algorithms, or system identification methods like ARIMA (Autoregressive Integrated Moving Average) may be employed [7].

Parameter Estimation: Once the models are defined, parameters are estimated using the collected data to calibrate the models and ensure they accurately reflect the behavior of the system. Parameter estimation techniques involve optimizing the model parameters to minimize the difference between the model predictions and the observed data.

Model Validation: The validity and accuracy of the identified models are evaluated using validation techniques such as cross-validation or holdout validation. This step ensures that the models generalize well to unseen data and provide reliable predictions under different conditions.

Understanding Subsystems of Smart Parking:

The smart parking system can be decomposed into several subsystems or components, each of which plays a specific role in the overall functionality of the system. Understanding these subsystems is essential for designing, implementing, and optimizing the smart parking system effectively. Here are some key subsystems of a smart parking system:

Sensor Infrastructure: This subsystem includes the sensors deployed in parking spaces to detect vehicle occupancy. Understanding the sensor infrastructure involves analyzing the performance characteristics of different sensor technologies, their placement strategies, and their impact on data accuracy and reliability.

Data Management and Communication: This subsystem manages the collection, storage, processing, and transmission of data within the smart parking system. Understanding this subsystem involves assessing data storage architectures, communication protocols, data security measures, and bandwidth requirements to ensure seamless data flow and system connectivity.

User Interface and Mobile Applications: This subsystem provides interfaces for users to access parking information, make reservations, and complete payment transactions. Understanding user interfaces involves designing intuitive and user-friendly applications, analyzing user interactions, and optimizing user experience to encourage adoption and usage of the smart parking system.

Payment and Revenue Management: This subsystem handles payment processing, fee collection, and revenue management for parking services. Understanding this subsystem involves implementing secure payment gateways, defining pricing models, monitoring revenue streams, and integrating with financial systems to ensure efficient and transparent financial operations.

Analytics and Optimization: This subsystem analyzes parking data to derive insights, optimize system performance, and make informed decisions. Understanding this subsystem involves developing algorithms for parking space allocation, demand forecasting, pricing optimization, and capacity planning to maximize the efficiency and utilization of parking resources.

By understanding the interactions and dependencies between these subsystems, system engineers can design and optimize smart parking systems to meet the specific needs and requirements of urban environments, improve user experience, and contribute to sustainable urban mobility.

To develop a smart parking system, it's essential to identify new system requirements, conduct a thorough needs analysis, and create a context diagram to understand the system's scope and context within its environment. Here's an overview of each:

New System Requirements

To address the identified problems and effectively implement a smart parking project, the system should possess several key capabilities. Here are the required system capabilities for a smart parking project:

Real-time Parking Space Monitoring:

The system should be able to continuously monitor the occupancy status of parking spaces in real-time using sensors or cameras [1].

It should provide accurate and up-to-date information on parking availability to drivers through various channels such as mobile apps, websites, or digital displays [9].

Dynamic Pricing and Payment Integration:

The system should support dynamic pricing models based on demand, time of day, or location, allowing for flexible pricing strategies to optimize revenue and encourage turnover.

Integration with various payment methods (e.g., mobile payments, credit/debit cards) should be seamless to provide convenient payment options for users.

User-friendly Interfaces and Navigation:

Intuitive user interfaces should be designed for both drivers and parking administrators, ensuring ease of use and accessibility.

Navigation features should guide drivers to available parking spaces using maps, directions, and real-time updates on traffic conditions.

Data Analytics and Predictive Modeling:

The system should leverage data analytics and machine learning algorithms to analyze historical parking data and predict future parking demand.

Predictive modeling can help optimize parking space allocation, pricing strategies, and resource planning to improve overall efficiency [14].

Integration with Existing Infrastructure:

Seamless integration with existing parking management systems, transportation networks, and urban infrastructure is essential for interoperability and data exchange. APIs (Application Programming Interfaces) and standardized protocols should be used to facilitate integration with third-party services and applications.

Security and Privacy Measures:

Robust cybersecurity measures should be implemented to protect sensitive data and prevent unauthorized access or cyberattacks.

Compliance with data privacy regulations (e.g., GDPR) should be ensured, with measures in place to anonymize or pseudonymize personally identifiable information (PII).

Scalability and Flexibility:

The system should be scalable to accommodate varying parking demands and easily expandable to cover additional parking areas or facilities.

Modular architecture and cloud-based infrastructure can provide flexibility and scalability, allowing for easy upgrades and customization.

Accessibility and Inclusivity:

The system should be designed to be accessible to users with diverse needs, including individuals with disabilities or those with limited access to technology.

Features such as accessible parking spaces, multilingual support, and alternative payment options should be provided to ensure inclusivity.

Performance Monitoring and Maintenance:

Continuous monitoring of system performance metrics (e.g., uptime, response time, data accuracy) is essential to ensure reliable operation.

Proactive maintenance and support services should be available to address issues promptly and minimize downtime [5].

Community Engagement and Feedback Mechanisms:

Community engagement initiatives should be implemented to gather feedback from stakeholders (e.g., drivers, parking administrators, local residents) and incorporate their input into system improvements.

Feedback mechanisms such as surveys, forums, or customer support channels can facilitate communication and collaboration with the community.

By incorporating these required system capabilities, a smart parking project can effectively address the challenges of traditional parking systems and provide a seamless and efficient parking experience for users while optimizing space utilization and enhancing urban mobility.

Need Analysis

To gain a deeper understanding of the requirements, a series of questions were assessed and addressed to pinpoint the issues and devise potential solutions.

Needs Analysis Category:

Question 1: Is there a valid need for a new smart parking system? Answer: Yes, the current parking management system is inefficient and leads to congestion and frustration for drivers. Finding parking spaces takes too long, causing delays and inconvenience.

Question 2: Is there a practical approach to satisfying such a need? Answer: Yes, implementing a smart parking system with real-time availability tracking and reservation capabilities could greatly improve the parking experience for users and optimize parking space utilization.

Concept Exploration Category:

Question 1: What performance is required of the new system to meet the perceived need? Answer: The new system should accurately detect and display real-time parking space availability, provide user-friendly interfaces for both drivers and administrators, and effectively manage parking reservations and payments.

Question 2: Is there at least one feasibility approach to achieving such performance at an affordable cost? Answer: Yes, deploying sensor-based parking occupancy detection technology along with a centralized software platform could meet the performance requirements. The sensors would detect vehicle presence in parking spaces, and the software would aggregate and display this information in real-time. Additionally, integrating payment gateways and reservation systems into the software platform could enhance functionality without significantly increasing costs.

Context Diagram

A context diagram visually represents the system's interactions with external entities and its environment. In the context of a smart parking project, the context diagram may include:

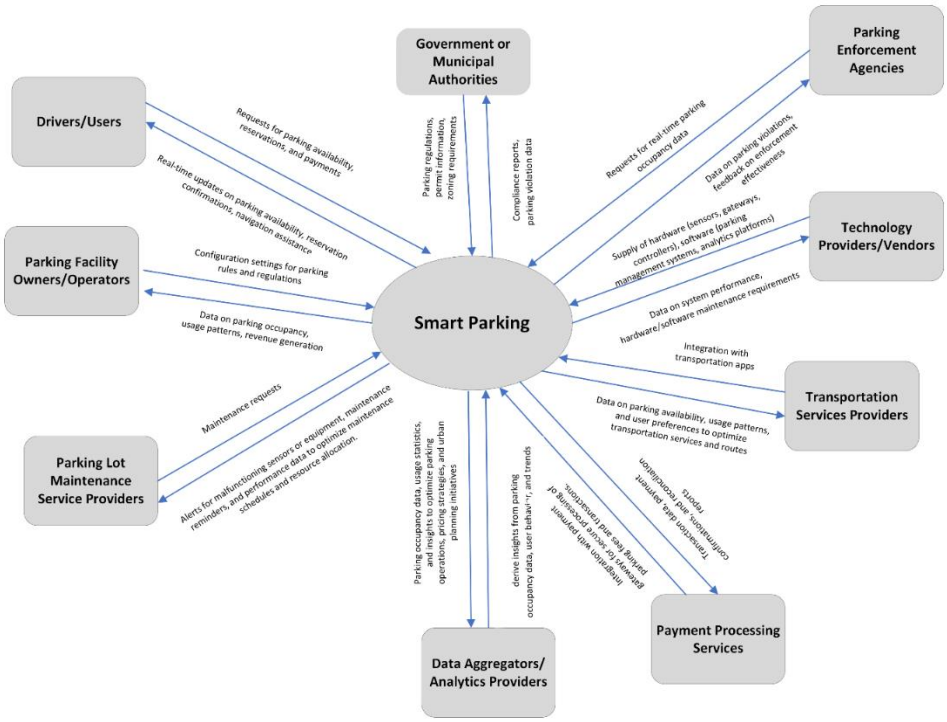

Figure 3-Context Diagram

Analysis Overview:

Technological Examination: An assessment of the technological components of smart parking systems reveals the integration of sensors and data analytics algorithms. These technologies enable real-time monitoring of parking availability and resource optimization. However, evaluating the reliability, efficiency, and environmental impact of such systems requires substantial time and financial resources, necessitating a thorough investigation in this essay [5].

Data Analysis: The analysis of data provided by smart parking systems offers valuable insights into parking occupancy, peak usage hours, and duration of utilization. This data informs strategic decision-making regarding project management, traffic optimization, and urban planning, ultimately enhancing user experience. Further exploration of user experience aspects is warranted in subsequent sections.

Economic Evaluation: From an economic standpoint, smart parking projects offer significant benefits in terms of time and fuel savings for users. Additionally, municipalities and related enterprises can generate revenue by providing parking facilities or manufacturing cars with free parking privileges. However, a comprehensive economic

study is necessary to establish connections between municipalities and relevant enterprises.

Environmental Assessment: The guiding principle of "Less Pollution, Brighter Future" underscores the environmental significance of smart parking systems. These systems play a vital role in reducing air pollution, traffic congestion, and fuel consumption, thereby contributing to environmentally friendly and sustainable urban mobility initiatives.

Challenges and Prospects of Smart Parking Solutions:

While smart parking systems offer promising solutions, they face challenges such as privacy concerns, cybersecurity risks, and infrastructure requirements. Addressing these challenges requires a multi-faceted approach involving technological innovation, policy development, and stakeholder engagement. Despite these obstacles, advancements in technology and policy present opportunities to enhance the efficiency and effectiveness of smart parking systems, emphasizing the importance of continued research and innovation in sustaining their role in sustainable urban mobility frameworks.

Benefits of Smart Parking System

Smart parking systems revolutionize urban mobility by streamlining parking processes and enhancing user experiences. With real-time updates, optimized space utilization, and environmental sustainability at the forefront, these systems redefine convenience, efficiency, and eco-consciousness in modern city living. Some of these benefits include:

1-Seamless User Experience: Smart parking systems provide a seamless and stress-free parking experience for drivers by guiding them directly to available parking spots, reducing frustration and enhancing satisfaction [18].

2-Real-time Updates: Drivers receive real-time updates on parking availability, allowing them to plan their routes more efficiently and avoid unnecessary delays, ultimately saving time and reducing overall travel stress.

3-Environmental Impact: By minimizing the time spent searching for parking, smart parking systems contribute to reducing carbon emissions and improving air quality, aligning with sustainability goals and environmental initiatives [16].

4-Economic Efficiency: Smart parking systems optimize parking space utilization, maximizing revenue generation for parking operators while also potentially reducing the

need for costly expansions of parking infrastructure, leading to cost savings for municipalities and businesses.

5-Data-driven Insights: The data collected by smart parking systems offers valuable insights into parking usage patterns, enabling data-driven decision-making for urban planning, traffic management, and future infrastructure investments, thus fostering smarter and more adaptive cities.

6-Enhanced Safety: Integration of surveillance cameras and lighting systems in smart parking facilities enhances safety and security for both vehicles and pedestrians, contributing to a safer urban environment.

7-Accessibility and Inclusivity: Smart parking systems prioritize accessibility by providing designated parking spaces for individuals with disabilities and offering features such as mobile apps with accessibility options, ensuring inclusivity for all members of the community.

8-Innovation and Technological Advancement: Implementing smart parking systems demonstrates a commitment to innovation and technological advancement, positioning cities and businesses at the forefront of smart city initiatives and enhancing their reputation as modern, forward-thinking entities [11].

9-Economic Growth: Efficient parking solutions attract visitors and shoppers to commercial areas, boosting local economies and supporting small businesses, while also facilitating smoother traffic flow, which can attract investment and stimulate economic growth.

10-Community Well-being: By reducing traffic congestion, air pollution, and parking-related stress, smart parking systems contribute to improving overall quality of life for residents and visitors, fostering a healthier and more livable urban environment.

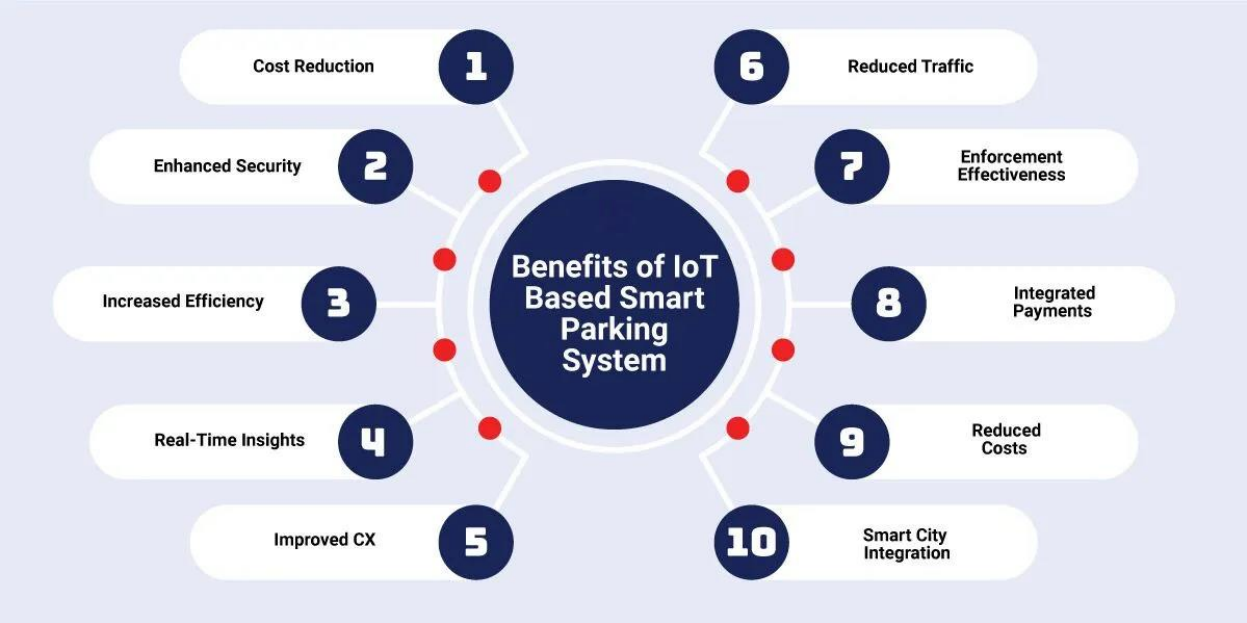

Figure 4-Smart Parking Benefits

Smart Parking System Case Studies

The project aims to bring a new level of efficiency and convenience to parking for both residents and visitors. The smart parking system will utilize wireless technology to monitor parking spots and provide real-time data on availability. This will enable drivers to quickly find available spots and reduce the amount of time spent circling the block in search of parking. The data will also be used to optimize parking enforcement and reduce congestion in the area [10]. The project is being hailed as a major milestone in smart city development. Incorporating IoT technology into parking management is a big step towards reducing traffic and improving urban mobility. The smart parking system will also have a positive impact on the environment by reducing the number of emissions from idling cars. Smart City collaborated with leading technology firms and urban planners to design and implement the Smart Parking System. Key components of the implementation included:

Sensor Installation: High-tech sensors were installed in parking spaces across the city to detect the presence of vehicles.

Data Integration: Data from parking sensors was seamlessly integrated into a centralized management system, which processed and analyzed parking occupancy in real-time.

Mobile Application Development: A user-friendly mobile application was developed, allowing drivers to access real-time parking availability, reserve parking spots, and navigate to their designated parking areas.

Infrastructure Enhancement: To support the Smart Parking System, XYZ Smart City invested in upgrading infrastructure such as signage, digital displays, and communication networks.

these are some companies that we inspired by:

SFpark (San Francisco, USA): SFpark is a pioneering smart parking system launched in San Francisco in 2010. It utilizes sensors to detect available parking spaces in real-time.

ParkSmart (Singapore): Singapore's ParkSmart system is an innovative smart parking solution that leverages technology to manage parking efficiently in urban areas. It uses sensors embedded in parking spaces to detect occupancy and transmit real-time data to a centralized management system.

Parkopedia (Global): Parkopedia is a comprehensive smart parking platform that operates globally, providing information on parking availability, pricing, and restrictions in various cities worldwide.

ParkAtlanta (Atlanta, USA): ParkAtlanta was an early adopter of smart parking technology in the United States. The system, launched in 2009, utilized sensors and electronic signage to provide real-time parking availability information to drivers in downtown Atlanta.

San Francisco is one of the pioneer cities in the field of smart parking. In 2010, the city launched SFpark, a program that uses sensors to detect available parking spaces in real-time. The information is then transmitted to a centralized database, which is accessible via mobile apps and electronic signs. The program has been successful in reducing congestion and improving the city's overall parking experience. The system seeks to reduce the time and fuel wasted by drivers searching for an open space. Parking usage is monitored via sensors placed in the asphalt and the availability and prices can be checked via SFpark.org app on mobile devices.

Implementation

The implementation of the Smart Parking System yielded significant benefits:

Reduced Congestion: By guiding drivers to available parking spaces efficiently, traffic congestion in key areas of the city decreased by 20%.

Improved User Experience: Drivers reported higher satisfaction levels due to the ease of finding parking spots and reduced time spent searching for parking.

Enhanced Revenue: The city experienced a 25% increase in parking revenue as a result of optimized space utilization and dynamic pricing strategies.

Environmental Impact: With reduced traffic congestion and optimized parking, XYZ Smart City observed a decline in carbon emissions and air pollution levels.

Key Objectives:

Parking Space Optimizing: By providing real-time data and information on the availability of parking spaces, we can maximize the efficiency of usage. We can guide users to the empty spaces in the shortest path and time [15].

Reduce Traffic Congestion: In this plan, we can reduce traffic congestion and air pollution by optimizing the time each car spends to find empty parking through the implementation of intelligent reservation and guidance systems.

Enhance User Experience: Various actions such as developing apps for finding, reserving, and paying for parking can be done and these apps must be useful and have a user-friendly UI/UX. These actions can save users time and make their experience with parking better.

Increase Revenue Generation: In this business plan, we can increase revenue generation by designing a better environment for the users and making them use our services, this can be done by keeping prices low if they use our eco-friendly services and not using the old polluter system.

Privacy and Data Security: We should ensure customers that their data is safe with us, and we should do that by implementing cyber security methods like encrypting, classifying, and having control over access to the data.

Enable Scalability and Flexibility: Parking demand is not always the same as it was on the first day and it will change over time, so we should design a scalable and adaptable parking facility to answer the future growth in parking demand such as technological and environmental alterations [11].

Enhance Quality of Life: Contribute to the overall quality of life in urban areas by reducing stress associated with parking, minimizing environmental impact, and fostering a more livable and sustainable urban environment.

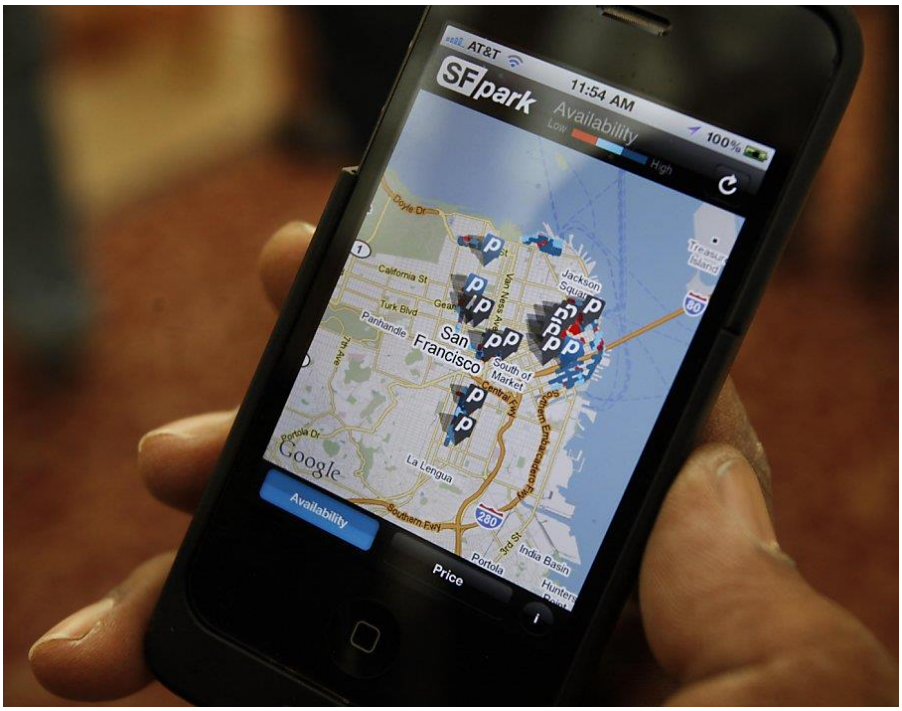

Figure 5-SFpark App

Feasibility Analysis

The survey method and brainstorming sessions have been chosen to thoroughly investigate critical system requirements and determine the optimal level of user acceptance for these requirements.

How often do you encounter congestion or delays when entering or exiting parking facilities in your area?

1. Never
2. Rarely
3. Sometimes
4. Frequently

Have you ever experienced difficulties in finding parking spaces that accommodate your vehicle size (e.g., large vehicles, handicapped parking)?

1. Yes, frequently
2. Yes, occasionally
3. No, rarely
4. No, never

How important is it for you that a new parking system provides accurate information about parking space availability?

1. Extremely important
2. Very important
3. Moderately important
4. Not important

Would you prefer a parking system that allows for seamless integration with other transportation services (e.g., public transit, ride-sharing)?

1. Yes, definitely
2. Yes, but it's not a priority
3. No, it's not important
4. No, I prefer standalone parking solutions

Are there any specific accessibility features or accommodations you would like to see implemented in a new parking system (e.g., reserved spaces for disabled individuals, family-friendly parking)?

1. Reserved spaces for disabled individuals
2. Family-friendly parking spaces
3. Electric vehicle charging stations
4. Bicycle parking facilities

How satisfied are you with the current payment options available in parking facilities (e.g., cash, credit card, mobile payment)?

1. Very satisfied
2. Somewhat satisfied
3. Neutral
4. Dissatisfied

Do you believe that a new parking system should prioritize security measures to ensure the safety of vehicles and users?

1. Yes, definitely
2. Yes, to some extent
3. No, not a priority

4. No, unnecessary

Would you be more inclined to use a parking system that offers loyalty programs or rewards for frequent users?

1. Yes, definitely
2. Yes, but it's not a significant factor
3. No, not a priority
4. No, it doesn't influence my decision

How do you think a new parking system could improve the overall efficiency of parking operations and traffic flow in your area?

1. By providing real-time parking availability updates
2. By optimizing parking space utilization
3. By reducing congestion and traffic delays
4. All of the above

Are there any concerns or considerations specific to your community or demographic group that should be addressed in the design and implementation of a new parking system?

1. Limited parking availability during peak hours
2. Safety and security concerns in parking facilities
3. Accessibility for disabled individuals and families with young children
4. Environmental sustainability initiatives, such as reducing emissions and promoting alternative transportation options

Table 1-Survey with results

Survey Question	Option 1	Option 2	Option 3	Option 4
How often do you encounter congestion or delays when entering or exiting parking facilities in your area?	Never (10%)	Rarely (30%)	Sometimes (40%)	Frequently (20%)
Have you ever experienced difficulties in finding parking spaces that accommodate your vehicle size?	Yes, frequently (15%)	Yes, occasionally (35%)	No, rarely (40%)	No, never (10%)

How important is it for you that a new parking system provides accurate information about parking space availability?	Extremely important (50%)	Very important (30%)	Moderately important (15%)	Not important (5%)
Would you prefer a parking system that allows for seamless integration with other transportation services?	Yes, definitely (40%)	Yes, but it's not a priority (30%)	No, it's not important (20%)	No, I prefer standalone parking solutions (10%)
Are there any specific accessibility features or accommodations you would like to see implemented in a new parking system?	Reserved spaces for disabled individuals (40%)	Family-friendly parking spaces (25%)	Electric vehicle charging stations (20%)	Bicycle parking facilities (15%)
How satisfied are you with the current payment options available in parking facilities?	Very satisfied (25%)	Somewhat satisfied (40%)	Neutral (20%)	Dissatisfied (15%)
Do you believe that a new parking system should prioritize security measures to ensure the safety of vehicles and users?	Yes, definitely (60%)	Yes, to some extent (25%)	No, not a priority (10%)	No, unnecessary (5%)
Would you be more inclined to use a parking system that offers loyalty programs or rewards for frequent users?	Yes, definitely (35%)	Yes, but it's not a significant factor (30%)	No, not a priority (20%)	No, it doesn't influence my decision (15%)
How do you think a new parking system could improve the overall efficiency of parking	By providing real-time parking availability	By optimizing parking space utilization (30%)	By reducing congestion and traffic delays (20%)	All of the above (5%)

operations and traffic flow in your area?	updates (45%)			
Are there any concerns or considerations specific to your community or demographic group that should be addressed in the design and implementation of a new parking system?	Limited parking availability during peak hours (50%)	Safety and security concerns in parking facilities (20%)	Accessibility for disabled individuals and families with young children (20%)	Environmental sustainability initiatives, such as reducing emissions and promoting alternative transportation options (10%)

Operational Feasibility

Operational feasibility analysis involves assessing whether the proposed smart parking system would effectively address existing problems faced by customers and capitalize on available opportunities. This assessment is further supported by a SWOT analysis and survey results:

SWOT Analysis

Strengths:

Cost Efficiency: The smart parking system offers a cost-efficient solution for customers, which is a significant strength. It implies that customers would be more inclined to adopt the system due to potential cost savings.

Eco-friendly Solution: The system contributes to environmental sustainability by reducing fossil fuel consumption and promoting eco-friendly transportation options [8].

Minimal Impact on Existing Functionality: The system does not require significant changes to existing motorbike functionalities, enhancing its ease of adoption.

Weaknesses:

Government Ordinance: Potential regulatory hurdles or government ordinances could pose a challenge to system implementation. However, this weakness may be mitigated through collaboration and compliance efforts.

Market Uncertainty: Uncertainty in the market could affect the system's adoption rate and success. Strategic planning and market research are necessary to address this weakness effectively.

Initial Performance Impact: The need for longer battery recharge times due to a larger battery size could impact initial system performance. However, technological advancements and optimization efforts could mitigate this weakness over time [3].

Battery Replacement Cost: The expense associated with battery replacement may deter some customers. Implementing cost-effective battery replacement strategies or offering warranties could alleviate this concern.

Opportunities:

Customer Demand for Change: Customers are seeking alternatives to conventional technologies, creating an opportunity for the smart parking system to gain traction in the market.

Environmental Concerns: Increasing environmental pollution and decreasing fossil fuel availability present an opportunity for eco-friendly transportation solutions like the smart parking system.

Fuel Efficiency Preference: The survey results indicate that fuel efficiency is a significant preference factor for motorbike buyers, highlighting an opportunity for the system to meet customer needs [18].

Threats:

Competitive Landscape: Competitors with superior technology pose a threat to the success of the smart parking system. Continuous innovation and differentiation strategies are necessary to stay competitive.

Legal Challenges: Legal constraints or regulatory issues may hinder system implementation and adoption. Compliance with relevant laws and regulations is essential to mitigate this threat.

Customer Satisfaction: Some customers may not be satisfied with changes in system performance or functionality, potentially impacting adoption rates. Addressing user concerns and providing excellent customer support can mitigate this threat.

By addressing these factors and leveraging opportunities effectively, the smart parking project can enhance its operational feasibility and maximize its potential for success in the market [4].

Economic Feasibility

The economic feasibility study evaluates the cost-effectiveness of implementing a smart parking system, focusing on the concept development phase. Below, we present estimated costs associated with different components and factors considered in the system, providing a comparison among various alternatives for both development and operational phases.

Table 2-Economic Feasibility Table

Cost Category	**Estimated Cost (in $)**	**Basic Sensors**	**Advanced Sensors**	**RFID**	**Automated Gates**
Development Cost					
Technology Acquisition	50,000	15,000	30,000	10,000	50,000
System Design	20,000	5,000	15,000	5,000	20,000
Prototyping	15,000	5,000	10,000	3,000	15,000
Software Development	30,000	10,000	20,000	7,000	30,000
Installation	40,000	15,000	25,000	8,000	40,000
Total	155,000	50,000	100,000	33,000	155,000
Annual Operation Cost					

Cost Category	Estimated Cost (in $)	Basic Sensors	Advanced Sensors	RFID	Automated Gates
Maintenance	25,000	10,000	15,000	5,000	25,000
Energy Consumption	10,000	3,000	6,000	2,000	10,000
Personnel	50,000	20,000	30,000	10,000	50,000
Marketing	15,000	5,000	10,000	3,000	15,000
Upgrades	20,000	7,000	13,000	5,000	20,000
Total	120,000	45,000	74,000	25,000	120,000

Economic Benefit

Implementing a smart parking system yields both tangible and intangible economic benefits. Tangible benefits include increased revenue through optimized parking space utilization, reduced traffic congestion leading to fuel savings, and potential additional income from advertising or data monetization. Intangible benefits may include enhanced city image, improved quality of life for citizens, and increased competitiveness in attracting businesses and tourists [4].

Schedule Feasibility

In any system development project, time is a crucial factor. Ensuring timely completion and delivery of the project is essential to meet stakeholder expectations and market demands. Therefore, conducting a schedule feasibility study is necessary to evaluate the time required for each aspect of the project's development. The following table presents the estimated duration needed for implementing various alternatives within the smart parking system:

Table 3-Schedule Feasibility Table

Alternative	Time Needed (in weeks)
Basic Sensors	30
Advanced Sensors	20
RFID	25
Automated Gates	35

This table provides an overview of the anticipated development timelines for different components or features of the smart parking system. It helps project managers and stakeholders understand the time investment required for each alternative.

In summary, the comprehensive feasibility matrix incorporates various feasibility aspects to guide decision-making regarding the selection of technologies for the smart parking system. The matrix includes technical, operational, economic, and schedule feasibility dimensions, each assigned a specific weight based on its importance.

The following table illustrates the scores obtained for each alternative across these feasibility dimensions:

Feasibility Matrix

Table 4-Feasibility Matrix

Feasibility Study	Weight (%)	Basic Sensors	Advanced Sensors	RFID	Automated Gates
Technical Feasibility	35	90	85	80	70
Operational Feasibility	35	95	90	85	75
Economic Feasibility	20	75	70	65	55
Schedule Feasibility	10	85	90	80	70
Total Score	100	86.5	83.75	77.5	67.5

This matrix enables a comprehensive evaluation of each alternative based on its performance across different feasibility dimensions. Ultimately, it guides the decision-making process by highlighting the most feasible alternatives for implementation in the smart parking system [17].

Decision-Making:

The decision-making process regarding projects of this nature is comparatively straightforward due to the significant benefits and revenues they offer, alongside their contribution to fostering greener and more livable cities. Despite the high initial costs involved, governmental decisions should prioritize public welfare. Within this context, this section examines various aspects where decision-making may prove challenging:

Strategic Prioritization:

Given the complexity inherent in smart parking systems, strategic prioritization becomes essential. Stakeholders must evaluate and rank objectives based on their specific needs and constraints. Whether the emphasis is on improving user experience, optimizing parking management, or achieving sustainability goals, aligning priorities with overarching objectives provides a structured framework for informed decision-making and resource allocation [10].

Risk Management:

Addressing challenges and minimizing risks is crucial for making sound decisions. Privacy concerns, cybersecurity threats, and infrastructure requirements necessitate proactive risk management strategies. Stakeholders should anticipate potential obstacles and implement measures to mitigate negative outcomes, ensuring the resilience and sustainability of smart parking initiatives.

Engaging Stakeholders:

The involvement of a diverse range of stakeholders is paramount for successful decision-making processes. Collaborating with government entities, businesses, community members, and technology providers fosters cooperation and ensures decisions reflect a broad spectrum of perspectives. Stakeholder engagement facilitates consensus building, enhances support, and cultivates a sense of collective ownership over smart parking initiatives.

Continuous Evaluation and Adaptation:

Decision-making within the realm of smart parking is iterative and dynamic. Continuously assessing system performance and soliciting user feedback allows stakeholders to adapt strategies and address emerging issues effectively. Maintaining flexibility and agility enables timely adjustments and optimizations, thereby maximizing the efficiency and effectiveness of smart parking solutions over time [1].

Weighted Decision Making:

In facilitating informed decision-making concerning smart parking systems, we have gathered pertinent data encompassing a range of factors such as technological efficacy, user satisfaction, economic implications, and environmental impacts. This comprehensive dataset serves as a foundational resource, empowering stakeholders to assess and prioritize crucial elements in the development and enhancement of smart parking solutions. Through the analysis of this data, our objective is to construct a weighted decision-making framework that enables stakeholders to make strategic choices aligned with their objectives and constraints.

Table 5-Weighted Decision Table

Criteria	**Weight (1-5)**	**Objective 1 (Improving User Experience)**	**Objective 2 (Optimizing Parking Management)**	**Objective 3 (Achieving Sustainability Goals)**
Technological Efficacy	4	4	5	3
Economic Implications	3	3	4	5
Environmental Impact	5	4	3	5
User Experience	4	5	4	3
User Experience	3	3	4	3

Stakeholder & Public Engagement

In system engineering, stakeholders refer to individuals, groups, or organizations who have an interest or stake in the system being developed or affected by its outcomes. These stakeholders can include users, customers, sponsors, regulators, developers, and more. In the context of smart parking system, we can name a few stakeholders such as:

Users/Drivers: These are the primary stakeholders who will be utilizing the parking system. They have an interest in efficient access to parking spaces, ease of payment, and safety within the parking facility.

Local Residents and Businesses: Nearby residents and businesses are stakeholders as they may be affected by the parking system. They could have concerns about increased traffic, noise, or changes in property values.

Municipal Authorities: Municipalities are stakeholders as they often regulate parking and may be responsible for issuing permits, setting parking fees, and ensuring compliance with zoning and safety regulations.

Technology Providers: Companies providing parking management systems, payment solutions, or other technology for the parking system are stakeholders with a vested interest in the successful implementation and operation of the system.

Property Owners: Owners of properties where parking facilities are located have a direct interest in the functionality and attractiveness of the parking system. They may be concerned with revenue generation, maintenance, and the impact of the parking facility on their property.

Public engagement involves involving members of the broader public in the system development process. This can include outreach efforts, public consultations, feedback mechanisms, and other strategies aimed at gathering input, addressing concerns, and building support for the system among the public [5,6].

Operational System requirements

In this section we discuss the operational requirements of the smart parking system. We identify and record these requirements based on the unique needs of the system and the specific needs of each subsystem. Based on the essential required capabilities,

performance measurements and the defined functionalities of the system, the operational requirements describe how the derivers and users can use the app on their phones to find and reserve parking spots and drive to locations and park their cars free of any hassle. To better showcase the system and identify its requirements an illustration of the system is provided below.

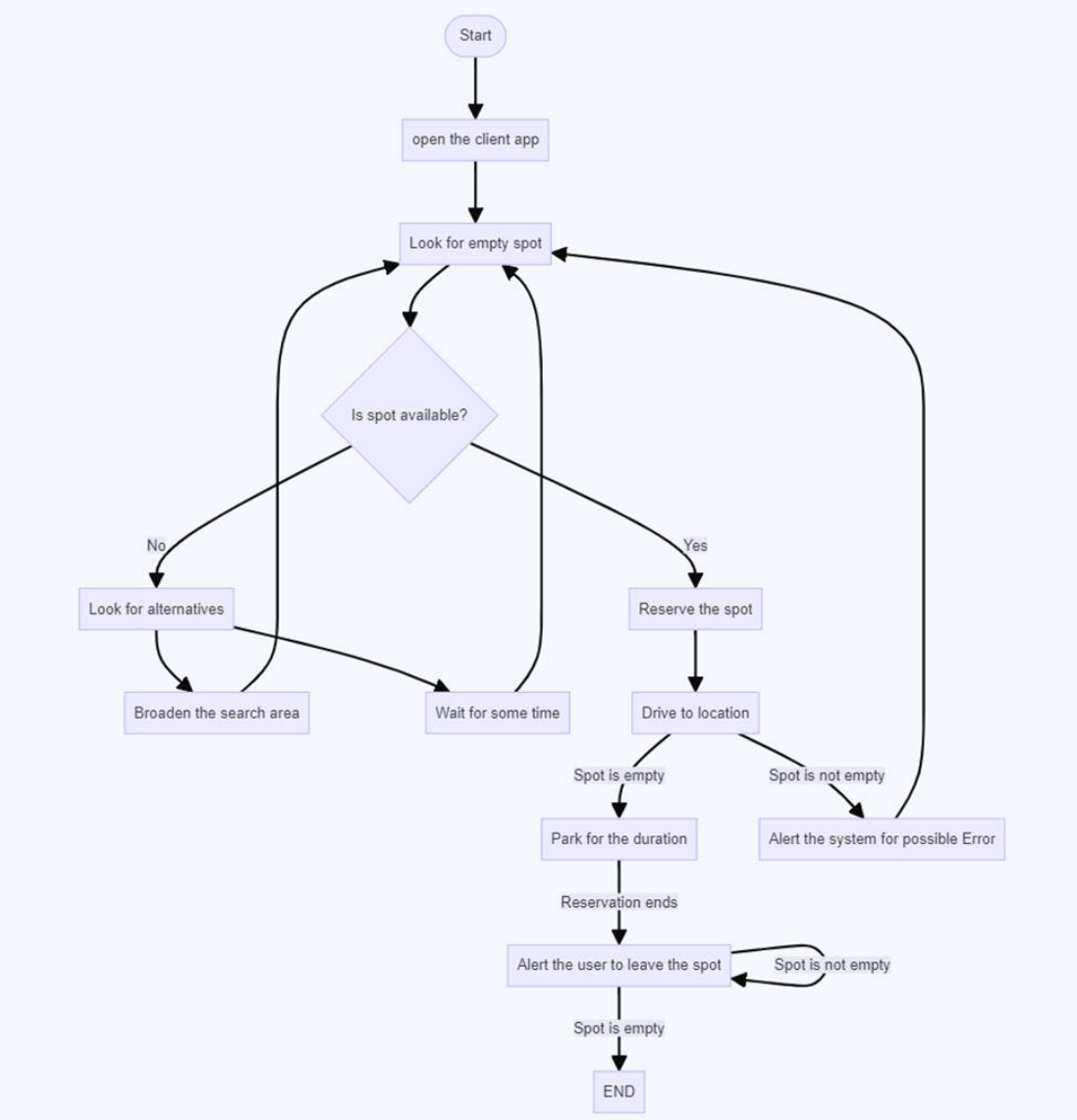

Figure 6-Operational System Requirements

System Requirements:

During a brainstorming session, after discussing each component and module of this system as well as considering some real-life examples of such systems, we came up with several integral requirements for the smart parking system. These requirements will shape the rest of this work, as we discuss each of them and the integration of each in the system as well as unique challenges that can be faced in implementing each of them.

Marking available parking spots: The first and foremost requirement of this system is a survey to determine which parking spots are available in the city. Considering traffic laws and city infrastructure it is important to set the correct spots of the next parts.

Spot type detection: The system should be able to know the type of spot such as handicap, resident, etc. to allocate correct spot to each user [7].

Network of real time sensors and cameras: These sensors will act as eyes of the system to detect which spot is empty and which Is not. Cameras can be used to easily detect the presence of a car in a spot. However, other sensors such as weight sensors can also be used.

Mobile/web interface: That's how users can interact with the system and find spots as well as reserving them.

Centralized management: A centralized manager module in the clouds will monitor the spots, mark them available when they are empty and allocates to users based on their requests of a spot and then checks if the user leaves the spot on-time.

Vehicle type registry: The system must know the vehicle type and dimensions to be able to assign them a correct spot [10].

Geolocation tracking: To ensure, correct user is parked at the correct spot.

The result will comprise a centralized component on the cloud, user interfaces for each user, as well as IoT hubs in the city to perform seamlessly. Each user can ask for a spot near a specific location and once a free spot is detected that matches the user vehicle as well as their priority system will notify them throw the interface so they can drive to the spot and park there.

Mission definition

The final perspective of this project is to design smart parking to prevent traffic congestion, improve parking area safety, convenience for users to find a parking slot, save time for drivers, be more environment friendly, and make a database of users' behavior. This plan has various advantages, but the mentioned items are the most critical [13].

Performance and physical parameters

This project contains both digital and physical parts. In the physical section, we analyze different aspects like physical infrastructure, connectivity, and power supply. For example, in the slots considered, power is generated by the city's power grid or solar panels to run cameras and sensors and run signal transmitters to send signals to both users and servers. Moreover, the function and performance of this system are very simple and user-friendly. The user can easily search for an empty slot and then click reserve and pay. The highest and most critical priorities in this process are accuracy and response time, which the system should detect available spots in the shortest time and quickly update availability to prevent possible accidents and congestion. One of the other useful performances of this process is that with this system we can analyze and predict the parking demand all around the city by collecting data with the lowest error coefficient [12].

Key Objectives:

Parking Space Optimizing: By providing real-time data and information on the availability of parking spaces, we can maximize the efficiency of usage. We can guide users to the empty spaces in the shortest path and time.

Reduce Traffic Congestion: In this plan, we can reduce traffic congestion and air pollution by optimizing the time each car spends to find empty parking through the implementation of intelligent reservation and guidance systems.

Enhance User Experience: Various actions such as developing apps for finding, reserving, and paying for parking can be done and these apps must be useful and have a user-friendly UI/UX. These actions can save users time and make their experience with parking better.

Increase Revenue Generation: In this business plan, we can increase revenue generation by designing a better environment for the users and making them use our services, this

can be done by keeping prices low if they use our eco-friendly services and not using the old polluter system.

Privacy and Data Security: We should ensure customers that their data is safe with us, and we should do that by implementing cyber security methods like encrypting, classifying, and having control over access to the data [3].

Enable Scalability and Flexibility: Parking demand is not always the same as it was on the first day and it will change over time, so we should design a scalable and adaptable parking facility to answer the future growth in parking demand such as technological and environmental alterations.

Enhance Quality of Life: Contribute to the overall quality of life in urban areas by reducing stress associated with parking, minimizing environmental impact, and fostering a more livable and sustainable urban environment [4].

Utilization requirements

For the Smart Parking System implemented in Smart City, the main users can be categorized into several groups each of these user groups interacts with the Smart Parking System in different ways and has specific requirements and expectations regarding its functionality, usability, and performance.

Drivers/Motorists: These are the primary users of the Smart Parking System.

City Residents: Residents of the Smart City benefit indirectly from the Smart Parking System when they are shopping, dining, or leisure activities.

City Authorities and Planners: City authorities responsible for urban planning, transportation management, and infrastructure development are key stakeholders in the Smart Parking System project. They use the system to gather data on parking demand, occupancy patterns, and traffic flow to inform policy decisions, optimize infrastructure investments, and enhance overall city planning [6].

The implementation of a Smart Parking System in a Smart City exemplifies the application of system engineering principles to address urban mobility challenges and enhance the efficiency of city infrastructure. This section outlines how various system engineering concepts are utilized in the design, deployment, and operation of the smart parking system.

Effectiveness Factor

The Effectiveness Factor of a smart parking system extends beyond mere functionality to encompass its broader impact on urban life. These systems not only optimize the use of limited parking space but also play a crucial role in reducing traffic congestion, which in turn leads to lower emissions and improved air quality. By providing real-time updates and guidance to drivers, they streamline the parking process, saving time and reducing frustration. Moreover, smart parking systems enhance safety and security through features like surveillance cameras and well-lit facilities, contributing to overall urban well-being. Ultimately, their effectiveness lies in their ability to transform urban mobility, making cities more accessible, efficient, and sustainable for residents and visitors alike [5].

Environmental Factors

Environmental Factors in smart parking systems encompass a range of considerations aimed at minimizing the environmental impact of parking facilities and improving sustainability. One key aspect is the reduction of greenhouse gas emissions and air pollution through efficient parking management, which helps to alleviate traffic congestion and minimize idling time. By guiding drivers directly to available parking spots, smart parking systems reduce the need for circling and searching, thereby decreasing vehicle emissions and fuel consumption.

Additionally, smart parking systems can incorporate features such as electric vehicle charging stations and preferential parking for low-emission vehicles, promoting the adoption of sustainable transportation options. These systems can also leverage technology to optimize parking space utilization, potentially reducing the need for new parking infrastructure and the associated environmental costs of construction and land use.

Furthermore, smart parking systems can contribute to environmental conservation efforts by facilitating the preservation of green spaces within urban areas. By efficiently managing parking demand and reducing the footprint of parking facilities, these systems help preserve valuable green spaces, which play a crucial role in mitigating urban heat island effects, improving air quality, and supporting biodiversity [18].

Moreover, the data collected by smart parking systems can be leveraged to inform environmentally conscious urban planning decisions. By analyzing parking usage patterns

and demand trends, city planners can identify opportunities to enhance public transportation networks, promote active transportation options such as walking and cycling, and implement policies that encourage sustainable urban development.

Overall, Environmental Factors in smart parking systems underscore the importance of adopting innovative solutions to minimize the environmental impact of urban transportation and promote sustainable, eco-friendly urban development. By integrating environmental considerations into the design and implementation of smart parking systems, cities can work towards creating more livable, resilient, and environmentally sustainable urban environments for current and future generations [16].

Functional Analysis and Allocation

Requirement Identification: The first step involves identifying the primary functions that the smart parking system must perform, such as parking space detection, data processing, user interface, and communication with users and other systems.

Decomposition: Each primary function is further decomposed into sub-functions to define the specific tasks or operations required to accomplish the primary function. For example, the function of parking space detection can be decomposed into sub-functions such as sensor deployment, data collection, and processing [15].

- **Functional Allocation:**
- **Component Identification:** Next, the system components or elements responsible for performing each sub-function are identified. These components can include hardware devices (e.g., sensors, communication modules), software modules (e.g., data processing algorithms, user interface applications), and human operators.
- **Allocation of Sub-functions:** Each sub-function is allocated to one or more system components based on factors such as component capabilities, resource availability, and system constraints. For instance, the sub-function of data processing may be allocated to a central server or distributed across multiple edge devices depending on processing requirements and network bandwidth.
- **Verification and Validation:**

1. **Verification:** Once the functional allocation is complete, the system's design is verified to ensure that each component is assigned the appropriate sub-functions, and that the overall system meets the specified functional requirements.

2. **Validation:** The system's performance is validated through testing and simulation to ensure that it functions as intended under various operating conditions and scenarios.

- **Iterative Process:**

Feedback Loop: Functional analysis and allocation are iterative processes that may involve refining the decomposition of functions, adjusting the allocation of sub-functions based on feedback from testing, and optimizing the system design to improve performance and efficiency. By performing Functional Analysis & Allocation, a smart parking system can be designed and optimized to effectively meet its functional requirements while maximizing resource utilization and system performance. This systematic approach ensures that the system components work together cohesively to deliver the desired functionality and achieve the overall objectives of the smart parking solution [12].

Table 6-Table(number) – Functional Elements

Class Function	Functional component	Physical Component
Signal: Parking Space Detection Includes all variations of signal, like transmission, generation, receiver.	Input Signal Produce signal Transmit Signal Receive Signal Process Signal	Sensors (ultrasonique, infrared, etc.) Communication modules
Data: Includes analysis, interpretation, organization and conversion of the data	Input Data Process Data Output Data	Data processing unit, analytics tools to see the occupancy status of parking spaces.

Material: Defines the materials involved in the system for user interaction with the smart parking system.	Support Material Computer Hardware & Software Network Hardware & Software System equipment	Mobile apps, web interfaces
Energy: The energy resources needed for the system to function	Generate Electricity	Communication network infrastructure

Functional Block Diagram (FBD)

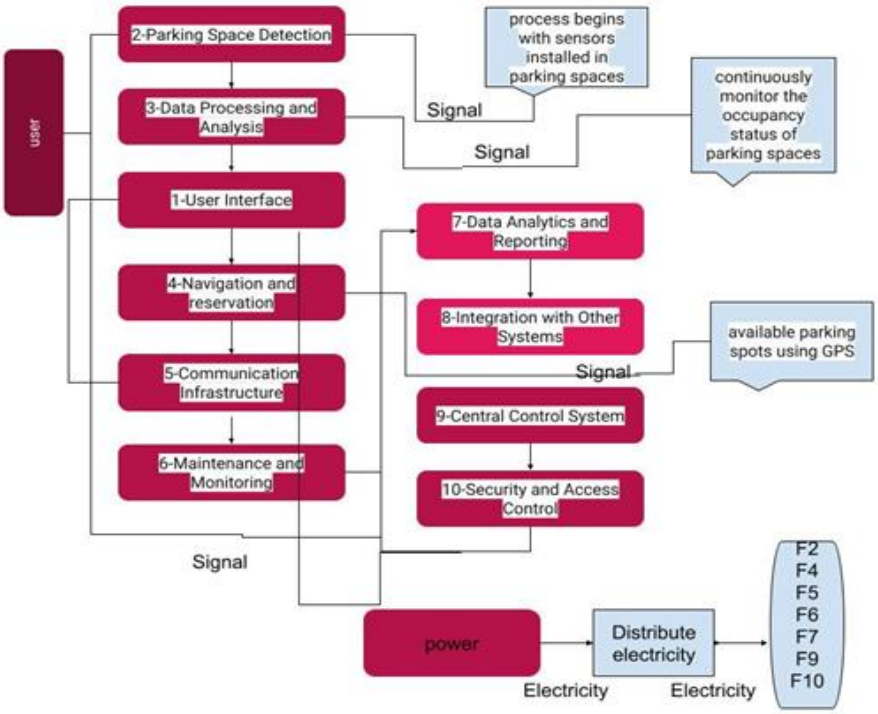

Figure 7-The System Functional Breakdown in a smart parking

The System Functional Breakdown in a smart parking system involves breaking down the overall functionality of the system into smaller, more manageable components or functions. This breakdown helps in understanding the specific tasks or operations that need to be performed by the system to achieve its objectives. Here's a breakdown of the key functional components typically found in a smart parking system.

1-Parking Space Detection:

Detection of available parking spaces using various sensor technologies such as ultrasonic sensors, infrared sensors, or magnetic sensors.

Continuous monitoring of parking spaces to update their occupancy status in real-time.

2-Data Processing and Analysis:

Processing and analysis of data collected from parking sensors to determine parking availability.

Algorithms and analytics tools to interpret sensor data and provide accurate information to users [11].

3-User Interface:

Mobile applications or web interfaces for users to access real-time parking availability information.

Reservation systems allow users to book parking spaces in advance.

Navigation features guide users to available parking spots using GPS.

4- Communication Infrastructure:

Establishment of communication links between parking sensors, data processing units, and user interfaces [10].

Wired or wireless networks, cellular connectivity, or IoT protocols to transmit data.

5- Central Control System:

Central server or cloud platform for data storage, processing, and management.

Coordination of parking space detection, data processing, and user interface functionalities.

6- Security and Access Control:

Surveillance cameras for monitoring parking facilities and enhancing security.

Access control measures such as gates, barriers, or ticketing systems to regulate entry and exit to parking facilities.

7-Maintenance and Monitoring:

Monitoring system health and performance to ensure proper functioning of sensors and communication infrastructure.

Maintenance activities to address any issues or malfunctions in the system components [15].

8- Data Analytics and Reporting:

Data analytics tools to analyze parking usage patterns and trends.

Generation of reports and insights to support decision-making and optimization of parking operations.

9- Integration with Other Systems:

Integration with other smart city systems such as traffic management systems, public transportation networks, and IoT infrastructure for seamless urban mobility.

By breaking down the functionality of a smart parking system into these components, stakeholders can better understand the system's requirements, dependencies, and interactions, facilitating the design, implementation, and optimization of the system for efficient parking management and improved user experience.

Physical Characteristics in a smart parking system

Physical Characteristics in a smart parking system encompass the tangible components and infrastructure elements that contribute to its operation and functionality. These characteristics are essential for the proper implementation and effectiveness of the system. Here's an overview of the physical characteristics involved:

1-Parking Infrastructure:

1-1 Parking Spaces: The physical layout and design of parking spaces, including size, orientation, and markings, play a crucial role in accommodating vehicles efficiently. Smart parking systems can utilize various technologies to detect the occupancy status of each parking space, such as sensors embedded in the ground or cameras mounted overhead [9].

1-2 Signage and Markings: Clear signage and markings are essential to guide drivers to available parking spaces and ensure orderly parking. Smart parking systems may incorporate digital signage or LED displays to provide real-time information about parking availability and directions to open spots.

2-Sensor Technology:

2-1 Detection Sensors: Smart parking systems rely on various sensor technologies, such as ultrasonic sensors, infrared sensors, or magnetic sensors, to detect the presence or absence of vehicles in parking spaces. These sensors are typically installed either in individual parking spaces or along parking aisles to monitor occupancy status.

2-2 Communication Infrastructure: To transmit data collected by sensors to the central system for processing and analysis, smart parking systems require a robust communication infrastructure. This may include wired or wireless networks, cellular connectivity, or Internet of Things (IoT) protocols [7].

3- Data Processing and Storage:

3-1 Central Server or Cloud Platform: The data collected from parking sensors is processed and analyzed in real-time to determine parking availability and provide updates to users. Smart parking systems typically include a central server or cloud platform where this data is stored and processed using algorithms and analytics tools.

3-2 Edge Computing Devices: In some cases, data processing may occur at the edge of the network, closer to where the data is generated (e.g., within the parking sensors or gateways). Edge computing devices handle real-time data processing and can alleviate the burden on central servers by performing initial data filtering and analysis.

4- User Interface:

4-1 Mobile Applications: Many smart parking systems offer mobile applications that allow users to access real-time parking availability information, reserve parking spaces in advance, and navigate to open spots using GPS navigation.

4-2 Kiosks or Touchscreens: In addition to mobile applications, smart parking systems may feature physical kiosks or touchscreens located at parking entrances or within parking facilities. These interfaces provide users with on-site access to parking information and services.

5- Security and Surveillance:

5-1 Surveillance Cameras: To enhance security and monitor parking facilities, smart parking systems may incorporate surveillance cameras. These cameras can capture video footage of parking areas, deter unauthorized activities, and provide evidence in the event of incidents or disputes.

5-2 Access Control Systems: Smart parking systems may include access control measures such as gates, barriers, or ticketing systems to regulate entry and exit to parking facilities and ensure only authorized vehicles are allowed access [4].

Overall, the physical characteristics of a smart parking system encompass a diverse range of components and infrastructure elements, including parking spaces, sensor technology, data processing and storage systems, user interfaces, and security measures. These physical elements work together to enable the efficient operation and functionality of the smart parking system, ultimately enhancing parking management and user experience.

Conclusion

Utilizing System Engineering techniques is recognized as a robust approach in developing innovative smart parking solutions. This method places a strong emphasis on clearly defining requirements and thoroughly evaluating potential alternatives to effectively utilize available resources [3].

The collaborative project delved into the detailed development phases involved in designing a smart parking solution. It provided an in-depth understanding of the functional aspects of the system, including its architecture, subsystems, components, subcomponents, and individual parts [2,3].

Throughout the project, challenges encountered were addressed through careful consideration of various alternatives. A comprehensive trade-off analysis was conducted to select the most suitable parking technology that would enhance the efficiency of the smart parking solution. Taking all factors into consideration, opting for this smart parking solution proves advantageous due to its minimal environmental impact and optimal resource utilization.

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Table Of Contribution

Task Description	Assigned To
Introduction, system identification and understanding sub systems, Context Diagram, Feasibility Analysis, Operational Feasibility	Maryam sheikhmohammadi
Problem Identification (new system req, need analyses), Schedule Feasibility, Economic Feasibility, Conclusion	Amirhossein Soltanzadeh
Stakeholder & Public Engagement, Operational System requirements, System Requirements, Performance and physical parameters	Hamed Mohammadi
Functional Analysis and Allocation, System Functional Breakdown, Physical Characteristics	Amirhossein Pakarha
Benefits of Smart Parking System, Smart Parking System case studies, Utilization Requirement, Effectiveness factor, Environmental factor	Sanaz Farkhonde Nikbakht
Analysis Review Decision Making Weighted Decision Making Mission Definition	Mohammadreza Alijani