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# Parking Characteristics and Assessing the Use of Rotary Smart Parking: A Case Study

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**Abstract**

The increasing use of private cars in urban areas, driven by a rapidly growing economy and abandoned policies and allocations, is the main reason for the growth of parking lots. They are among the main concerns in transport and traffic management worldwide. Parking allocation also considers implementing rotary smart parking to enhance parking efficiency. Using rotary smart parking is expected to alleviate traffic congestion near the study area while optimizing parking bay capacity. The car park is in the Bab Al-Moatham area, a central station located north of Baghdad's center, adjacent to the College of Engineering, Mustansiriyah University. The results revealed that maximum parking accumulation typically occurs between 10:00 a.m. and 12:00 p.m., with a peak of 200 vehicles at 10:30 a.m., leading to a parking capacity utilization of 90.5%, a total parking load of 602.75 vehicle-hours, and an average duration of 3 hrs. High occupancy levels, negatively impacting traffic performance in the parking area, were observed from 10:00-10:15 a.m., reaching 73.58. In conclusion, using rotary smart parking will require fewer spaces, potentially reducing space requirements by approximately 20%.

**Keywords:** Demand Characteristics, Parking, Parking Accumulation, Rotary Smart Parking, Turnover Rates

## 1. Introduction

The increasing rate of private car usage in urban areas is a result of the fast-growing economy; this rapid increase exacerbates parking issues. This is particularly evident in commercial and central business districts, where there is a shortage of spaces to meet traffic demand. Baghdad City struggles to balance parking demand and supply, hindering the provision of convenient parking facilities near desired destinations.

Various research studies employed different techniques to implement smart parking to improve quality of life by providing better service. Smart parking is an essential service that provides enough parking spaces to ensure smooth traffic flow. Shen (1997) stated that population growth and high living standards are the main reasons for the increase in the number of cars in urban areas. The development of multi-level parking systems provides an abundance of bays as an off-street parking option, supported by parking fees. However, the central business district (CBD) lacks adequate off-street parking, which tends to increase demand for on-street parking in these areas. An average traffic volume of about (30%-50%) of total traffic is reached during peak parking time [1].

The cost of parking is competing with walking distance [2]. Several authors' research [3]-[8] focused on less realistic aspects of the parking problem, ranging from users' perceptions of safety or convenience in parking spaces to the effects of laws, regulations, and parking policies on communities and conditional choices. The system has become more efficient, as the car's travel time and search time have been significantly reduced by the information provided by the Intelligent Parking System. With this information, drivers can identify fully occupied parking areas and vacant spaces that are easily located elsewhere. The number of illegally parked vehicles on the side of the road is also reduced, which leads to fewer traffic jams, as they are absorbed into parking lots [9]. The number of unsuccessful parking spaces was reduced from 50% to 37% [10]. Important factors were studied, such as price and the walk to the final destination. The relationship between activity-travel scheduling behavior and parking choice was also developed using 2008 Organizational Development Survey data from Montreal [11]. It has been shown that activity scheduling decisions for motorists are significantly influenced by parking choices (reflected in parking type and space availability).

The smart parking systems used predominantly in Europe, the United States, and Japan are developed with support from advanced technologies and research across different academic disciplines. With its deployment in the parking lot, it is hoped that the parking problems faced by sponsors will be solved. The

Intelligent Parking System is useful for parking operators and patrons, as well as for environmental preservation [12]. For parking operators, information collected by an intelligent parking system can be used to predict future parking patterns. Unfortunately, the growth in the number of cars causes many problems, including environmental pollution, driver stress, and accidents. Also, the long time required to find a parking space can be reduced if drivers know the available parking spaces and their locations [13]. This research integrates all parking characteristics and evaluates parking demand and characteristics, including parking accumulation, volume, turnover rate, and occupancy. It investigates the implementation of smart parking to increase parking efficiency. The meters used in smart electronic parking have enabled automated fee collection and enhanced enforcement capabilities. Also enabled the provision of real-time data to drivers, navigation, available parking spaces, and reservation options [14].

The application of data analytics and artificial intelligence techniques in smart parking has advanced, enabling advanced parking optimization and other driver-related services [15], [16]. Smart Parking with an Automated Billing System is implemented with minimal human intervention to achieve efficient billing for a parking lot. The waiting time is reduced for parking users, providing a seamless, hassle-free experience [17]. A location-based Shared Smart Parking System is proposed to solve the parking problem.

The main aim of this system is to reduce the time required to find a parking slot and to avoid unnecessary travel through occupied parking slots in a parking area [18]. Several attempts have been made to enhance and improve the utility of available parking bays. One of these attempts is to develop a smart parking system with a user-friendly interface that assists users in finding parking spaces via Android and web applications [19]. This study delves into parking characteristics, including accumulation, parking index, turnover rates, and parking load, while also examining the potential of smart parking solutions to enhance efficiency and minimize space requirements.

The main objective of this study is to evaluate the operational characteristics of an existing off-street parking facility and assess the feasibility of implementing a rotary smart parking system to improve parking efficiency in a dense urban environment. The specific objectives are to:

- Evaluate the parking characteristics of the selected parking facility through field surveys, including parking accumulation, occupancy, turnover rate, parking load, and parking index.
- Identify the peak parking demand periods and assess the adequacy of the existing parking capacity.
- Investigate the potential application of a rotary smart parking system as a practical solution for improving parking utilization and reducing parking shortages.

4. Develop a conceptual layout for integrating rotary smart parking within the existing parking area and estimate its effect on parking capacity and land-use efficiency.

5. Provide recommendations for parking management and planning that support sustainable urban mobility in congested commercial and educational areas.

This study stands apart from previous research that has either concentrated on conventional parking demand analysis or the technological advances of smart parking systems by combining a field-based parking demand assessment with the implementation of a rotary smart parking concept for an existing urban parking facility. The novelty of this research is that it uses an actual off-street parking lot to evaluate the operational characteristics of the parking lot (Detailed parking accumulation, occupancy, turnover, load analysis and parking index), determines the feasibility of implementing a rotary smart parking system, proposes a practical layout of implementing a rotary smart parking system in an existing parking facility using AutoCAD, and quantifies the reduction of land utilization ratio caused by implementing vertical parking while maintaining the same parking capacity. The integrated framework provides a viable approach to intelligent parking management in a dense urban area with constrained horizontal space, offering transportation planners and decision-makers a practical way to enhance parking efficiency.

## 2. Methodology

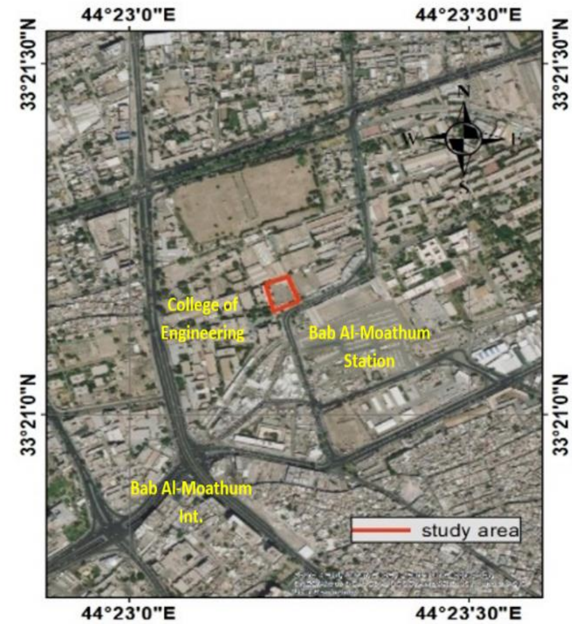
This study used a quantitative field survey to assess the operational characteristics of the parking facility, which is not on the street, and to evaluate the feasibility of implementing a rotary smart parking system.

The methodology involved four key stages: 1) Study area selection, 2) Field data collection, 3) Parking characteristics analysis, and 4) Assessment of rotary smart parking implementation.

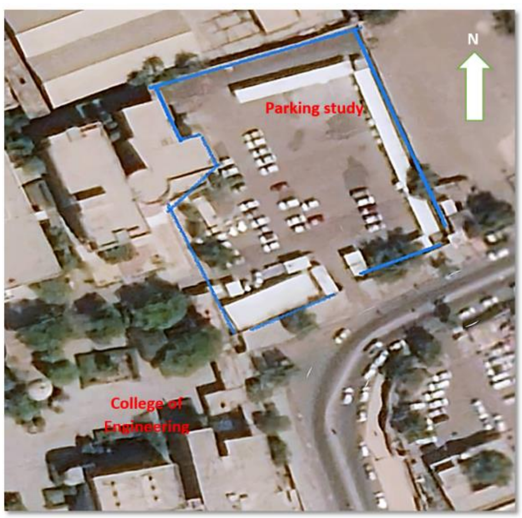
### 2.1. Study Area

The chosen parking is situated in the Bab Al-Moatham area, a central station located north of Baghdad’s center, adjacent to the College of Engineering, Mustansiriyah University. The choice of the site was based on the high parking demand resulting from the site's mixed use (educational, commercial, and administrative). The parking lot houses around 200 cars and is typical of an urban off-street parking facility, as one would find in the city, where there is a recurring congestion problem during working hours.

Fig. 1 displays the location and digital map of the selected study area.




a. Digital map of the selected study area.




b. Car parking of case study.

**Figure 1.** The Selected Study Area, a) Digital map of the selected study area b) Car parking of the case study.

### 2.2. Data collection

The survey of field data and its analysis are crucial components of the research methodology. The interpretation of research outcomes relies on the collected field data, which addresses the following key points:

1. How does the actual parking operate during peak periods?
2. How will the utilization of smart parking be an adequate design, reducing the required spaces and improving capacity to meet the demand?

The parking survey includes an assessment of existing services and physical conditions, such as the number of parking bays, their locations, and the parking system's circulation. It involves manually counting parked vehicles at specified intervals over periods. The counting method involves recording the plate numbers of vehicles parked for 8 hours, from 7:00 a.m. to 2:00 p.m., at 15-minute intervals (this method is applied only to vehicles that arrive at the parking lot selected for the case study). This approach helps us understand users' parking behavior and the park's operations over time. Parking services and programs are of great importance in traffic analysis. Most people get to urban and regional commercial centers primarily by car. The validity of such zones depends on the availability of convenient parking services neighboring the desired or easily accessible destinations, especially off-street parking facilities [20].

Depending on the research objectives and its work plan, primary (field survey) and secondary (questionnaire) sources are used to collect the required data. Since the study area is a mix of educational and commercial, the data collection period was chosen to coincide with the most active travel behavior, from 7:00 a.m. to 2:00 p.m. on the specified days as presented below:

- Monday 2021/12/20
- Monday 2022/1/3
- Sunday 2022/1/9

The parking area covers approximately 4,350 square meters and has 200 parking spaces allocated for cars between 7:00 a.m. and 2:00 p.m. on weekdays, with an average stay of 8 hours. The data collection fieldwork was conducted, involving measuring the dimensions of the land, estimating the total area to be 4,350 square meters, and determining the number of car spaces, which amounts to 200 spaces (actual spaces in the studied park). The operational hours are between 7:00 a.m. and 2:00 p.m., with a parking fee of 3,000 IQ Dinars per day. The car park is typically open to the public without restrictions and is considered a private investment catering to the needs of College of Engineering employees, students, and other visitors in the vicinity for shopping and employment purposes.

### 2.3. Analysis of Parking Characteristics

*2.3.1 Parking Accumulation*

The accumulation curve usually defines it. It is expressed as the number of cars parked at a given time. The car accumulation curve is the graph obtained by plotting the number of occupied bays over time [20].

*2.3.2. Parking Volume*

Parking is the total number of cars parked in a certain period. It is generally expressed by a bar graph called the accumulation/profile curve. It presents the difference in parking accumulation for a particular parking facility over a survey period or specific period [17].

Accumulation= summation of vehicles parked during a parking time (1)

*2.3.3 Parking Turnover Rate*

It is a ratio calculated by dividing the total number of parked cars during the survey by the total number of available parking spaces. It is the occupancy level of individual parking spaces in the parking lot. It looks at the average number of cars parked in each parking space. It can be expressed as the number of vehicles in the Bay over the time interval, according to, e.g., (2).

$$\text{Turn over} = \frac{\textbf{parking volume}}{\textbf{no.of available bays}} \text{ veh/hr/bay} \quad (2)$$

*2.3.4. Parking Occupancy*

The parking indicator, or occupancy factor, of a particular parking service is defined as the total number of cars parked during a specific period, that is, the accumulation divided by the capacity. It is also estimated by dividing the parking load by capacity over a given period. It measures the efficiency of a parking lot and its effective use [17].

Parking Occupancy = accumulation/ parking capacity (3)

*2.3.5. Parking Load*

It represents the total area under the accumulation curve. It is generally estimated by multiplying the number of vehicles occupying a parking space during a given period by that period, expressed in vehicle-hours.

Parking Load = Area under the curve of accumulation for specific periods (4)

*2.3.6. Parking Index*

It is also referred to as occupancy or efficiency. It is expressed as the ratio of the number of occupied bays in the time duration to the total available area. It defines a complete measure of how effectively the parking space is used [17].

$$Parking\ index = parling\ load \times \frac{100}{parking}capacity \quad (5)$$

**3. Results and Discussion**

**3.1. Parking Accumulation**

To enhance the operational performance of parking facilities, it is crucial to assess existing facilities across various parking characteristics, with parking accumulation being a key factor. Parking accumulation refers to the number of cars parked within a specified time frame. During the survey on different days (Sunday 19/12/2021, Monday 20/12/2021, Sunday 9/1/2022, and Monday 3/1/2022), the accumulated curve shown in Fig. 2 was generated by plotting the occupied parking bays against the designated parking opening hours. The peak parking accumulation occurs between 10:00 a.m. and 12:00 p.m., reaching a maximum of 200 vehicles at 10:30 a.m., resulting in full capacity. The total parking load is 602.75 vehicle-hours, with an average parking duration of 3 hours. At the survey commencement at 7:00-7:15 a.m., 8 vehicles were parked, occupying 4% of the available bays. Throughout the day, 201 vehicles were parked in the lot, exceeding the legal bay limit of 200. The analysis indicates that the highest number of vehicles was parked between 10:00 a.m. and 12:00 p.m., reaching the parking capacity limit during peak demand periods. Subsequently, after 12:00 p.m., the number of parked vehicles decreased significantly to 28 (14%) by 12:30 p.m. To address the demand for more than 200 parking vehicles, regulation, and management strategies are necessary to optimize the operational capacity of the existing parking facilities. Additionally, the accumulation curve highlights the morning peak period from 10:00 a.m. to 12:00 p.m., lasting less than 3 hours, which is attributed to short-term parking needs related to the College of Engineering's working hours at Bab Al-Moatham. The accumulation curves for different weekdays indicate recurring congestion periods lasting between 2.5 to 3 hours. Fig. 3 illustrates the accumulation curve as a percentage of the lot's capacity, showing fluctuations due to varying demand levels across different weekdays.

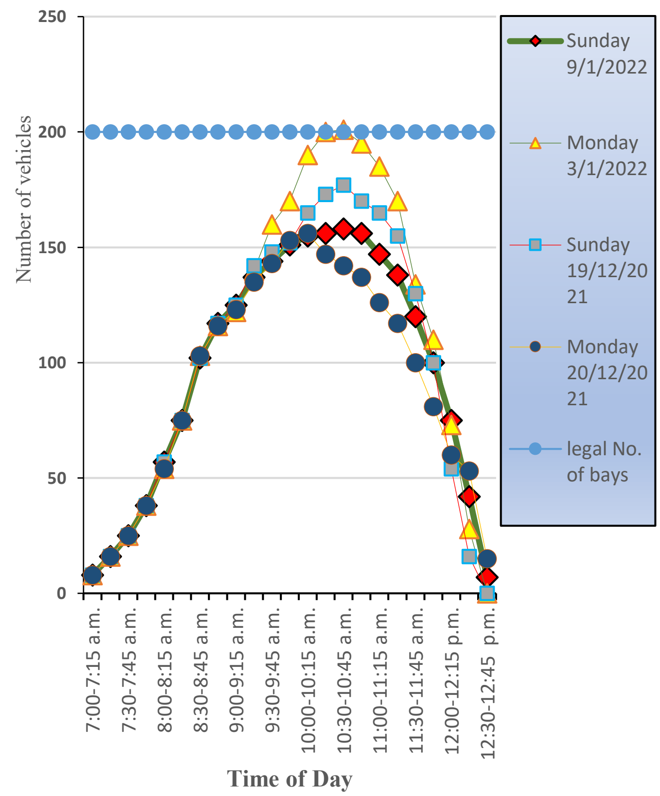



**Figure 2.** Parking accumulation curve.

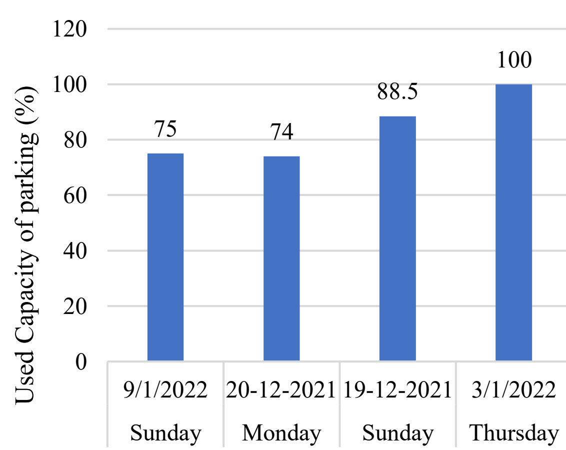



**Figure 3.** Percentage Used of the capacity of the parking lot for different working days.

### 3.2. Parking Occupancy

Fig. 4 shows parking occupancy across different periods, expressed as a percentage of the total number of bays (220). The highest occupancy was recorded from 10:00-10:15 a.m. at 73.58%, indicating a potential negative impact on traffic performance in the parking area due to increased cruising times for users. Conversely, the minimum parking occupancy from 7:00-7:15 a.m. at 7.55 indicates insufficient bay utilization.

### 3.3. Parking Turnover rate

The parking turnover rate for different study periods is depicted in Fig. 5, representing the rate of parking cars in periods to the spaces (bays) used. Overall, the turnover rates showed no significant change across the studied periods, with a maximum of 0.264. A higher parking turnover rate on Sunday (19-12-2021) is reasonable, considering the long parking duration of the case study, about 8 hours (from 7:00 a.m. to 2:00 p.m.). This is primarily due to the parking location in Bab Al-Moathum station, which is typically highly attractive for educational trips as it offers user's direct access to the College of Engineering at Mustansiriyah University.

Example of estimating Parking turnover rate= $\frac{208}{212*3.75}$ = 0.262 veh/hr/bay (6)

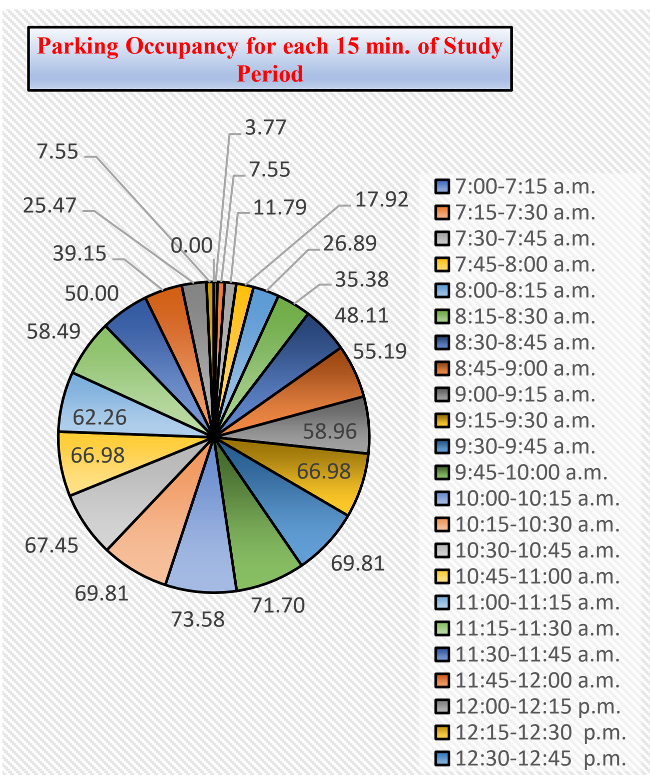



**Figure 4.** Parking Occupancy for each 15 min.

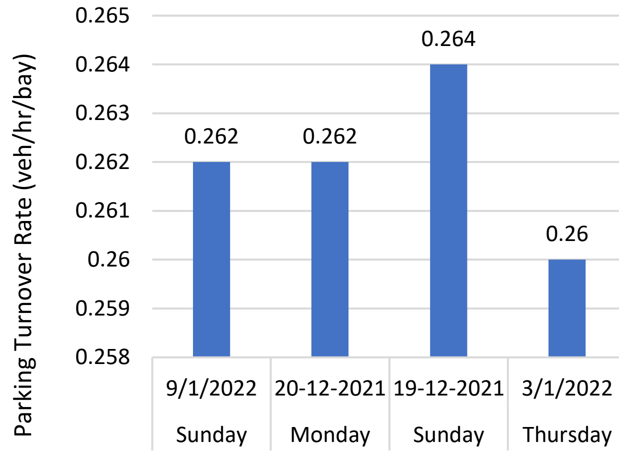



**Figure 5.** Parking Turnover Rate for Different Periods.

### 3.4. Parking Load and Parking Index

Fig. 6 illustrates the parking load across various periods in the study area, showing a range of values. To provide a comprehensive measure of the operational utilization of parking bays, the parking index is calculated as shown in Fig. 7. These results indicate the actual parking load and assess efficiency and adequacy. Also, provide an estimate of the park occupancy period. The increase in parking load reflects the impact of parking and the maximum load on Sunday, which forces drivers to move around looking for vacant bays to park and impedes traffic flow.

Example of estimating Parking Load= Total accumulation of vehicles times 15 minutes = 628 $\times \frac{15}{60}$ = 175 veh.hr (7)

Table 1 presents the parking load and parking index, respectively.

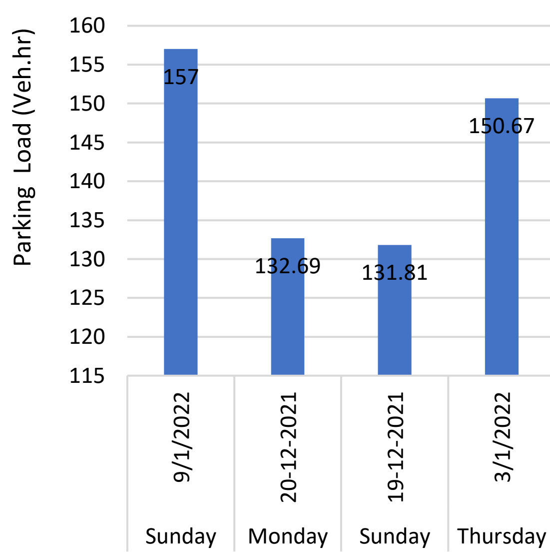



**Figure 6**. Parking Load for Different Periods.

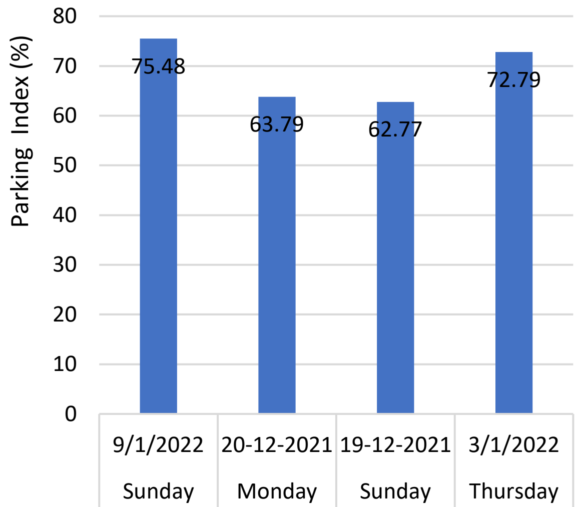



**Figure 7.** Parking Index for Different Periods.

**Table 1.** Parking Load and Parking Index Results.

| Periods | Parking Load | Parking Index |
|---|---|---|
| Sunday, 9-1-2022 | 157 | 75.48 |
| Monday, 20-12-2021 | 132.69 | 63.79 |
| Sunday, 19-12-2021 | 131.81 | 62.77 |
| Thursday, 3-1-2022 | 150.67 | 72.79 |

### 4. Implementation of Smart Parking

From the previous analysis of parking characteristics and operations, it was found that average vehicle demand for car parking is higher between 10:00 a.m. and 12:00 p.m., with a cumulative total of 200 vehicles reaching the parking capacity during the peak demand periods. This shortage of parking capacity during peak periods leaves fewer bays available for vehicles, forcing users to park on streets. This, in turn, causes traffic congestion and jams during working days, as observed through a field survey of the study area.

Using smart parking will help reduce traffic congestion in the surrounding areas with limited parking bay capacity. This technique will reduce traffic jams, save time, minimize the stress of searching for parking near the destination, and enhance safety. The significant volume of vehicles on the roads and the existing infrastructural challenges underscore the importance of managing the potential impact of these changes. Implementing a smart parking system can address these challenges effectively. This study highlights the functionality of rotary smart parking, with its components developed as a prototype, as illustrated in Fig. 8. The mechanical aspects of the design are depicted in Fig. 9.

**Figure 8.** A Prototype of a rotary smart parking system (prepared by the authors of the graduate project for the year 2021-2022).

The proposed rotary smart parking system is based on a vertical automated parking mechanism capable of accommodating ten passenger cars within a compact structural footprint. Each unit occupies substantially less land than an equivalent conventional parking arrangement because vehicles are stored vertically rather than horizontally.

The dimensions of each rotary unit were selected to meet standard passenger-vehicle dimensions and operational clearance requirements while maintaining structural stability. The proposed configuration allows efficient utilization of vertical space and minimizes the land required for parking expansion in densely developed urban environments. The design details of the smart parking system with a maximum car weight of 2 tons (smart rotary parking system) are illustrated below:

- length = 6m
- height =12m
- width =5m

The number of cars that the rotary smart parking system (RSP10) = is 10 cars.

The car dimensions:

- length=3.5m
- width=2m
- height=1.5m

The rotary room dimensions:

- length=5m
- width=2.5m
- height=2m

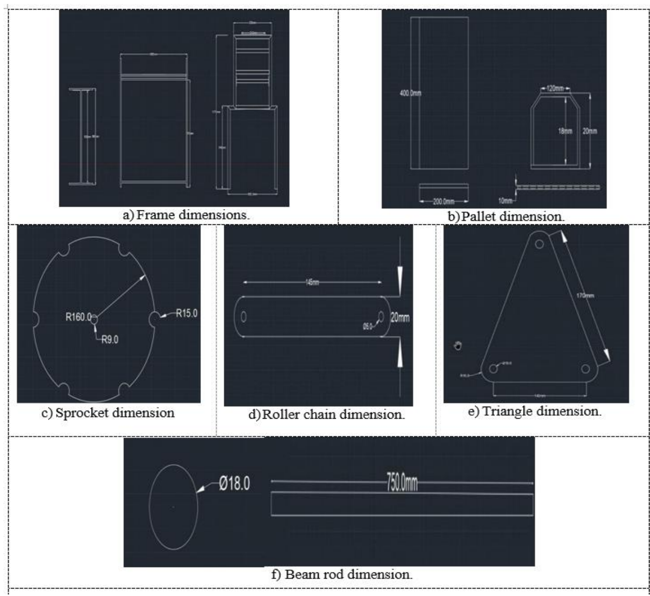



**Figure 9.** Design layout of the rotary smart park, all dimensions in (mm) (by authors).

Fig. 10 depicts the AutoCAD layout of parking with rotary smart parking (RSP) utilization.

The proposed rotary smart parking layout was tested and compared to the existing surface parking layout in terms of the parking capacity. The present facility can accommodate 200 cars on approximately 4.35 thousand m², whereas the proposed layout can make efficient use of the site by employing rotary parking units that store cars vertically. It can support up to 38 RSPs, each of which can support 10 cars per rotary smart parking, which equals a reduction of 380 car spaces.

The comparison shows that the proposed system significantly increases land-use efficiency without requiring horizontal expansion of the parking area. The more parking space that is provided, the less vehicle circulation will be seen in the parking lot, the sooner vehicles will find available parking, and localized congestion during peak parking times will be reduced. In addition, vertical parking provides even more open space to serve pedestrian circulation and internal traffic. It is concluded that using vertical space reduces the number of spaces required, saving about 20% of space through a space-saving system called rotary smart parking.

But there are a few practical aspects to take into account prior to implementation. These include the initial construction cost, the system's power requirements, maintenance requirements, user acceptance, and emergency operating procedures. In addition, the efficiency of a rotary parking system is influenced by the time required to retrieve vehicles during the rush. Consequently, the economic viability, efficiency, and users' satisfaction of this rotary smart parking system should be tested in a real operational environment in future studies.

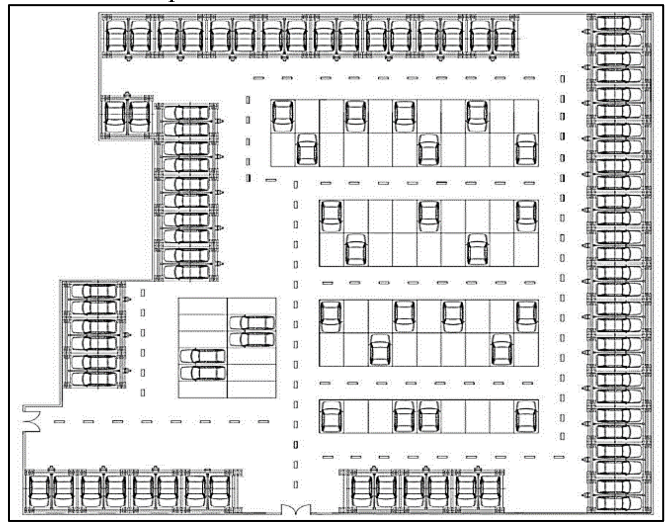


**Figure 10.** AutoCAD map for the distribution of the rotary smart parking system for the selected case study.

## 7. Conclusions

The results showed that parking demand is high between 10:00 am and 12:00 pm, with a peak of 200 cars during peak operating time; approximately 90.5% of parking spaces are used, indicating that parking space is inadequate during peak operating time. Overall, the total parking time was 602.75 vehicle-hours, with an average of around 3 hours. These findings show the frequency of parking congestion during working hours, which in turn creates extra traffic flow in the parking area—this may affect the road system surrounding the site.

Considering the observed parking demand, a vertical parking solution was proposed to improve land-use efficiency without requiring horizontal expansion of the existing parking facility: the Rotary Smart Parking System. The proposed plan demonstrated the potential to better meet future parking requirements by using vertical space and reducing the amount of surface parking needed. This could lead to better traffic conditions in dense urban areas, less time spent cruising for parking, and fewer parking issues.

Overall, the proposed system provides a feasible approach to evaluating existing parking facilities and the potential use of an automated rotary parking system in limited space.

The study has several limitations, as follows: One of the first things to note is that the analysis was conducted at a single parking facility in the city of Baghdad, which limits the applicability of the results to other cities with different travel patterns and land use. Second, the parking survey was carried out at a specific time under certain conditions, such as only on certain working days during a certain period, and did not consider any seasonal variation, weekends, or special events that may have an impact on parking demand. Third, the proposed rotary smart parking system was not implemented, and operational factors such as retrieval time, user acceptance, maintenance, and system reliability have not been experimentally investigated. Last but not least, there was no economic feasibility or life-cycle costing analysis in the study, even though such analyses are important prior to implementation.

Future studies should focus on implementing the proposed rotary smart parking system in a pilot system, analyzing the performance of the system under real traffic conditions, performing detailed cost-benefit analysis, and conducting user acceptance studies and a study of a parking management system based on the IoT and AI for parking allocation and monitoring in real time.

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## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

## Author Contribution Statement

Zainab Alkaissi presented the research idea, developed the theory and computations, performed the analysis, discussed the results, and contributed to the final manuscript. The author read and approved the final manuscript and was responsible for the financial effort for the prototype design.

Rahaf Ammar and Ryiam Dakheel collected field data and designed the prototype for smart parking.

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