International Conference on Business Research
University of Moratuwa, Sri Lanka
December 04, 2024

**https://doi.org/10.31705/ICBR.2024.18**

**Paper ID: 23**

# PARKING SPACE OPTIMIZATION USING MONTE CARLO SIMULATION: CASE STUDY AT THE UNIVERSITY OF MORATUWA

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## ABSTRACT

*With over 8.3 million automobiles in Sri Lanka as of 2022, the dominance of private vehicles in urban transportation has led to a marked increase in parking demand, frequently surpassing the available supply. This challenge is particularly pronounced within university settings, where the influx of students, lecturers, and staff often overwhelms the existing parking infrastructure. The University of Moratuwa is a representative case for studying parking optimization strategies, making it an ideal site for this research. This study utilizes Monte Carlo simulations to identify the optimal parking angle along a narrow, one-way road within the campus. By systematically evaluating various parking angles while accounting for constraints such as road width, vehicle dimensions, and necessary driving space, the research identifies parallel parking at 0 degrees as the most efficient configuration, accommodating the maximum number of vehicles. The findings provide a robust, data-driven approach to enhancing parking efficiency, with broader implications for urban traffic management and space utilization in constrained environments. Additionally, the study highlights the potential for integrating advanced simulation techniques into more complex parking scenarios, offering innovative and inspired solutions to the challenges of urban parking.*

**Keywords**: Monte Carlo Simulation, Parking Efficiency, Parking Optimization, Urban Transportation

## 1. Introduction

With 8,352,213 automobiles in Sri Lanka as of 2022, private vehicles play a significant role in urban transportation following decades of fast development (Department of Motor Traffic, 2024). Consequently, there is a rise in demand for parking, that is typically greater than supply.

Moreover, parking lots require a lot of land, that drives up construction prices. Specifically, institutions, and universities, present a major issue in managing parking spaces efficiently because of the influx of students, lecturers, and staff, that frequently surpasses the available parking capacity (Gurbuz & Cheu, 2020; Nadimi et al., 2021; Torres & Sanchez, 2019). The growing quantity of vehicles at universities has resulted in excessive search times, gridlock in the streets, issues with safety, obstructions to pedestrian traffic, air and noise pollution, fuel waste, and accessibility issues among the university community (Barata et al., 2011; Moradkhany et al., 2019; Nadimi et al., 2021). Innovative methods that optimize parking space utilization while guaranteeing user comfort and safety are needed to address this issue.

One of the most effective methods for implementing travel demand management is through parking management, that provides appropriate access to campus amenities (Dehghanmongabadi & Hoşkara, 2018; Moradkhany et al., 2015; Nadimi et al., 2021). Parking management helps universities better use existing parking capacity by adopting more organized and sophisticated strategies (Nadimi et al., 2021). This approach has shown several positive impacts, including reducing the demand for parking spaces, promoting social equity, improving service efficiency and quality, and saving costs (Aoun et al., 2013; Kingham, 2004). The parking management problem is particularly relevant for the University of Moratuwa, making it an ideal study area for this research.

It is inadequately explored in the context of universities how technologically innovative parking systems and intelligent parking guidance are applied. By examining how these technologies could be used with traditional parking optimization techniques at the University of Moratuwa, this study seeks to close this gap. An approach to parking management on campus sites (Figure 1) that is more efficient and user-friendly may result from such integration, since it may inspire more practical solutions.

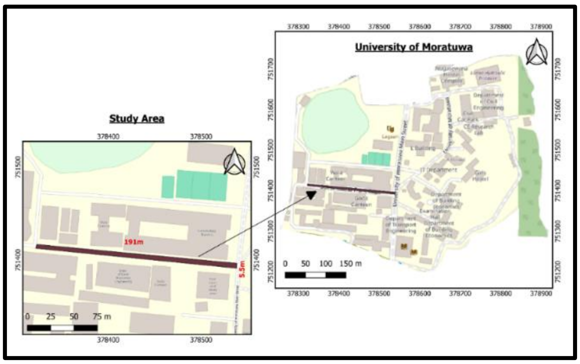


**Figure 1:** Study Area.

To tackle the intricate challenge of parking space optimization at the University of Moratuwa, we harnessed the power of Monte Carlo simulation. Using this method, which is well-known for modeling random variables and complex systems, we investigate a wide range of parking situations (Hu et al, 2016; Rubinstein & Kroese, 2016). Using simulations, we were able to determine the optimal angles and configurations to maximize vehicle accommodation, applying a data-driven methodology to address a prevalent yet crucial problem.

This study aims to optimize parking at the University of Moratuwa using a Monte Carlo simulation. By systematically varying parking angles and accounting for constraints such as road width, car dimensions, and required driving space, the simulation will determine the optimal parking angle that maximizes the number of vehicles that can be accommodated. This research provides a data-driven approach to enhance parking efficiency, ultimately contributing to better utilization of available space and improved traffic management within the university.

## 2. Literature Review

Parking has a significant impact on the overall performance of transportation systems (Bao & Ng, 2019; Mahmood et al., 2019; Young et al., 1991; Zhenyu et al., 2020). The efficiency of the transportation system is increased by well-designed parking lots (Abdelfatah & Taha, 2014). The increasing number of cars has increased the demand for parking spaces, making it difficult to make better use of the available spaces (Abbood et al., 2021; Shao et al., 2016; Torres & Sanchez, 2019). Parking lots vary in terms of layout, size, and design. They may accommodate a certain number of cars, that is determined by the parking angle (Abdelfatah & Taha, 2014). Numerous variables, such as the number of cars, parking angle, circulation system, and anticipated vehicle size, affect how a parking lot is designed (Abdelfatah & Taha, 2014; Oladejo & Awuley, 2016; Ramli et al., 2016). Optimizing capacity while maintaining easy and secure circulation is the primary objective of many previous studies (Sakib et al., 2024; Taiga et al., 2021). Problems include excessive demand, a lack of available land, and ineffective use of space (Abdelfatah & Taha, 2014).

Several studies have employed various methods to determine the optimal parking angle, a key factor in optimizing parking space utilization. To optimize parking capacity across three distinct cases; each with a distinctive circulation pattern and row arrangement a previous study used integer linear programming (ILP). The goal in every situation was to increase the overall number of parking spaces while abiding by constraints on the size of the parking lot. Using ILP, the study assessed five parking angles (30°, 45°, 60°, 75°, and 90°) and compared the outcomes with those obtained using conventional AutoCAD techniques.

The findings showed that the ILP, by permitting combinations of parking angles, offered more parking slots than the traditional approach. Specifically, for the dimension 120x110, they chose 60 degrees and 90 degrees; for the dimension 120x80, they chose 90 degrees; and for the dimension 90x60, they chose 60 degrees. The study found that combining combinations of different parking angles improves parking lot design efficiency (Abdelfatah & Taha, 2014). While permitting combinations of various parking angles have shown to be useful in optimizing parking lot design, implementing ILP in real-world settings can be difficult. Because the process calls for specialized software and knowledge, it might not be feasible for smaller projects or places with limited resources.

Another study uses Lindo software and ILP to investigate the optimization of Parking Space Units (PSU) in triangular-shaped parking lots. The study expands on the rectangular parking lot model created by Ramli et al. (2016) to include isosceles and equilateral triangle lots. The optimization model takes into account five parking angles (30°, 45°, 60°, 75°, and 90°) and four potential parking rows (complete outside, exterior, full interior, and inside). The ideal PSU arrangement for triangular isosceles consists of 134 motorbike units and 82 automobile units. The ideal arrangement for equilateral triangle lots consists of 513 motorbike units and 175 automobile units. The findings demonstrate how the model may optimize parking efficiency in triangle spaces by carrying the ideal number of cars (Syahrini et al., 2018). Despite considering variances in real-world settings, the study makes particular assumptions about the dimensions and angles of the triangle parking lots. Parking lots come in a variety of sizes and shapes. Therefore, the findings might not hold for all parking lots.

There are studies examining the crucial problem of a lack of parking spaces in small cities, using Sector-17, Chandigarh, as a case study has addressed the problem. Over three days, from 10:00 am to 10:00 pm, a thorough inventory of the parking lot, a demand-supply analysis, and accumulation research were all part of the technique. The supply was computed by figuring out the parking slot's ideal angle. The utilization rates, that range from 127.59% to 361.48% with an average of 247.54%, show that parking spaces are severely overutilized. Between 12:00 and 7:00 pm is when demand peaks, and from 3:00 to 5:00 pm is when accumulation is at its largest. According to the report, improper parking space management results in lost time and fuel, higher operating expenses, and a higher rate of accidents. The authors advise installing an Advanced Parking Management System (APMS) to improve space management, cut down on time and emissions, and lower the expense of accidents. Additionally, they advise building subterranean, roof-top, and parking garages that are integrated with APMS for best utilization (Singh & Sharma, 2012). Although the study offers workable options, the significant expense of changing the infrastructure and the requirement for collaboration amongst multiple parties may make such implementation difficult.

Large gatherings increasingly use group driving, but it is difficult to find appropriate parking for large groups of people due to limited parking places and traffic congestion. Conventional parking assignment models consider parameters like cost and distance, but group parking adds other variables including parking lot capacities, fluctuating parking rates, walking time to the destination, and arrival time balance. The classic parking lot assignment problem (PLAP) has added variable pricing and arrival time balancing. The Adaptive Ant Colony Optimization (AACO) and Standard Ant Colony Optimization (SACO) algorithms have been applied. The Hybrid Genetic Assignment Search Procedure (HGASP), AACO, and SACO have all been put to the test. Information was gathered for 100 parking spots close to Sports West Road in Guangzhou's Tianhe District. Within a 20-kilometer radius, three instances were generated, each with randomly generated destinations and driver locations. The AACO algorithm reduced the overall cost by 0.9% to 1.7% and executed faster by approximately 5 seconds on average, producing consistently superior results than SACO and HGASP. Distance and price expenses were the two most important elements that contributed to the balance cost, which made up about 23% of the total cost (Zhang et al., 2018). This study offers a comprehensive model for group parking assignment, addressing a crucial problem in urban traffic management. It shows a great deal of potential savings in terms of money, time, and traffic congestion. On the other hand, complexity, scalability, data availability, flexibility, user acceptability, and technological infrastructure provide difficulties for practical applications.

Driving past the parking space before reversing into it is frequently necessary when parking a car parallel to the road. Although longitudinal elements are sometimes overlooked, recent research has combined artificial neural networks (ANNs) with Monte Carlo tree search (MCTS) to optimize lateral parking motions. While computationally demanding, nonlinear programming-based (NPB) techniques concentrate on time-optimal parking in constrained places. A unique framework combines ANNs and nonlinear optimization to increase efficiency. Nonlinear optimization creates data offline for vehicle restrictions and minimum motion time. An improved MCTS uses the data to train ANNs, that produce almost time-optimal parking motions online. The method's performance was further validated by experiments conducted on a full-sized electric vehicle, indicating its potential for practical use. The framework performs admirably, with simulations showing a 100% success rate for parking spaces that are only 10% longer than the car's length. Experiments conducted on a full-sized electric vehicle further confirm the usefulness of the framework (Song et al., 2022).

In summary, the literature highlights the critical role of parking management in enhancing transportation system efficiency and addressing the growing demand for parking spaces. Various methods have been explored to optimize parking lot design, including integer linear programming, Lindo software, and Monte Carlo simulations, each demonstrating unique benefits and limitations. These studies underscore the importance of factors such as parking angles, circulation systems, and vehicle sizes in maximizing parking capacity. Moreover, advanced technologies like artificial neural networks and Monte Carlo tree search are being integrated with traditional optimization techniques to further improve parking efficiency. Despite the promising results, challenges remain in terms of implementation complexity, scalability, and the need for sophisticated infrastructure. Our study aims to bridge these gaps by applying Monte Carlo simulation to optimize parking at the University of Moratuwa, leveraging its strengths to develop practical, data-driven solutions that enhance parking management on campus.

## 3. Methodology

The University of Moratuwa was chosen as the study area because of its persistent parking issues, especially on peak days when the available parking capacity is insufficient to meet demand. The selected road for this study is a narrow, one-way roadway on the campus, providing an optimal environment for maximizing parking spaces. The road is 191 meters in length and 5.5 meters wide, with a 2-meter-wide driving lane designated for safety and functionality, while the rest area is reserved for parking.

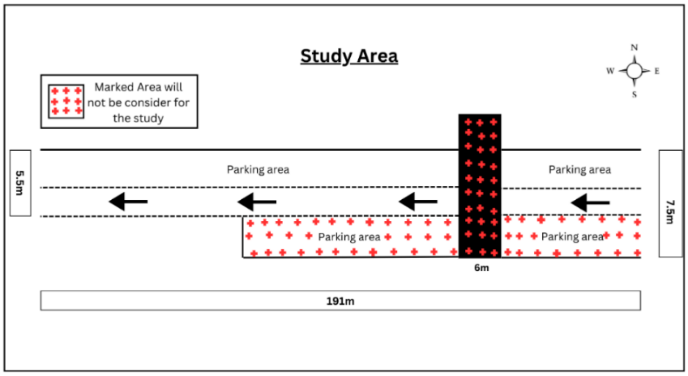


**Figure 2:** Dimensions of the Study Area.

### 3.1 Data Sources

The collection of data proceeded with a comprehensive manual assessment of the current parking arrangement, including the number of vehicles generally parked along the roadway, prevalent vehicle dimensions, and parking angles. For this study, the Toyota Axio was chosen as the representative vehicle model. The dimensions of the Toyota Axio are approximately 4.5 meters in length and 2 meters in width. These dimensions were used as the standard measurements for evaluating parking configurations. A block starting 33.9 meters from the start of the road and extending for 6 meters was identified as unusable for parking. This area was excluded from the parking calculations to simplify the optimization process and focus on feasible parking areas.

### 3.2 Data Analysis

The analysis of parking spot optimization is performed using a Monte Carlo simulation model. The model includes several variables, such as the size, angles, and types of vehicles in parking spaces. We develop several situations to mimic various parking combinations and layouts. These scenarios differ in terms of space dimensions, parking row count, and parking angles (e.g., parallel, angled, and perpendicular). To account for the unpredictability and variety of parking demand and user behavior, each scenario is repeated several times. For every situation, the simulation will produce a variety of potential results. To simulate real-life scenarios, the simulation further included uncertainties such as differences in car dimensions and small misalignments in parking. Using this method allowed the study to take into consideration the intrinsic randomness of the possible daily configurations of parked cars.

By applying Monte Carlo simulation and analyzing various parking angles, the study identified the optimal parking configuration for the selected road at the University of Moratuwa. This approach demonstrated the potential for using simulation techniques to address parking optimization issues and provided a basis for applying similar methods to other roads and parking areas.

To preserve the model's practical relevance while maintaining its simplicity, the following assumptions were made:

- Standard Vehicle Dimensions: Every vehicle was considered to be 2 meters broad and 4.5 meters long.
- Static Road Width: There were 5.5 meters of fixed road width, 2 meters for the driving lane, and 3.5 meters set aside for parking.
- Parking gap: 1 meter between vehicles parked at 0 degrees (parallel), and 0.5 meters for angled parking.
- Parking from the Center of the car: To guarantee consistency in measurements, parking spaces were determined by centering each car.

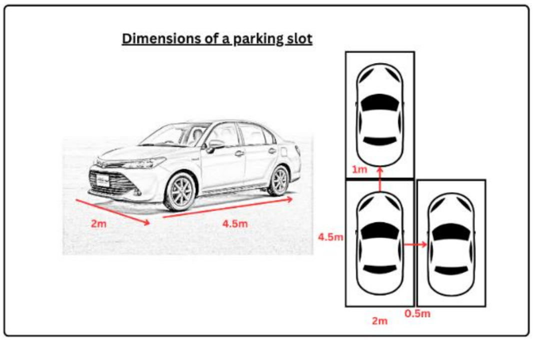


**Figure 3:** Dimensions of a Parking Slot.

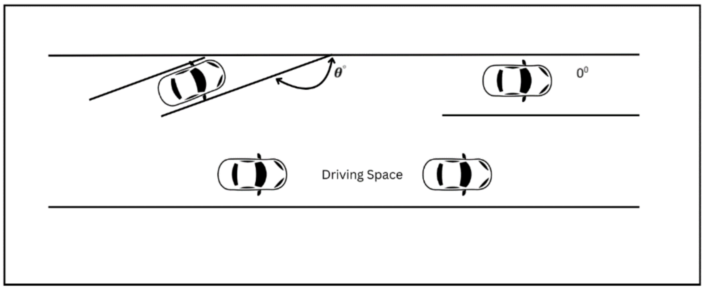


**Figure 4:** Parking slots Angle.

The primary objective of this research was to determine the optimal parking angles that maximize the number of vehicles that can be parked along the road. To achieve this, several parking angles were tested, and the results were analyzed to propose the most efficient parking layout.

The optimization process involved the following steps:

1. Calculation of Effective Parking Width: The required driving space was removed from the entire width of the road to determine the available parking width. This provides effective parking width, or the area available for parking cars. This explains why it is necessary to keep a driving lane that is 2.0 meters wide, with the remaining space designated for parking.
2. Monte Carlo Simulation: A Monte Carlo simulation was conducted with 100,000 iterations to test various parking angles ranging from 0 to 90 degrees. With the assistance of this simulation approach, a reliable way to test various angle configurations and record the variation in car layout depending on angle was made possible.
3. Angle-Specific Car Calculation: Using trigonometric relationships, the effective width and length occupied by an automobile were computed for each angle. In particular, the angle affects the car's width and length.

$$Car\ width(Angle) = Car\ width * \cos(\theta) + Car\ length * \sin(\theta)$$

$$Car\ length(Angle) = Car\ width * \sin(\theta) + Car\ length * \cos(\theta)$$

Considering the space needed for each car and the spaces between them, the maximum number of cars that could fit down the length of the road (before and after the block) was determined.

- A 1-meter space was kept between vehicles when parking at 0 degrees (parallel parking).
- Cars were spaced apart by 0.5 meters when parked at an angle.

Invalid parking configurations were also prevented by the model, which made sure that the effective parking width was not exceeded for any given angle.

4. Result Analysis: The simulation results were analyzed to identify the optimal parking angle that maximized the number of cars. The angel that generated the highest number of parked cars was deemed ideal since it best balanced the usage of the available width and length of the road.

## 4. Results and Discussion

To determine the optimal parking angle to maximize the number of vehicles parked along a narrow, one-way road at the University of Moratuwa through extensive Monte Carlo simulations testing angles from 0 to 90 degrees (Table 2), it was found that preliminary results from the Monte Carlo simulation indicated that parallel parking at 0° (i.e., vehicles parked along the road without any angle) provided the maximum parking capacity. This configuration allowed for the accommodation of most vehicles while maintaining the required driving space of 2 meters. Specifically, the simulation revealed that at 0 degrees, the road can accommodate a maximum of 36 vehicles. This is due to the alignment of cars in a parallel manner, which optimizes the linear space along the road length.

**Table 1:** Monte Carlo Simulation Results.

| Parking Angle ($\theta^{\circ}$) | Maximum number of cars |
|---|---|
| 0 | 36 |
| 1 | 36 |
| 2 | 35 |
| 3 | 35 |
| 4 | 35 |
| 5 | 35 |

| | |
|---|---|
| 6 | 35 |
| 7 | 35 |
| 8 | 34 |
| 9 | 34 |
| 10 | 34 |
| 11 | 34 |
| 12 | 34 |
| 13 | 34 |
| 13 above | 0 |

Additionally, to identify the optimal angle, the study explored the feasibility of parking vehicles at various angles. It was discovered that parking at angles up to 13 degrees is possible without interfering with the required driving space. Beyond 13 degrees, the parking arrangement begins to encroach upon the driving lane, making it impractical and unsafe. The analysis indicates that as the parking angle increases beyond this point, the effective width of the parking lane decreases, leading to fewer vehicles being accommodated and potential disruptions to traffic flow.

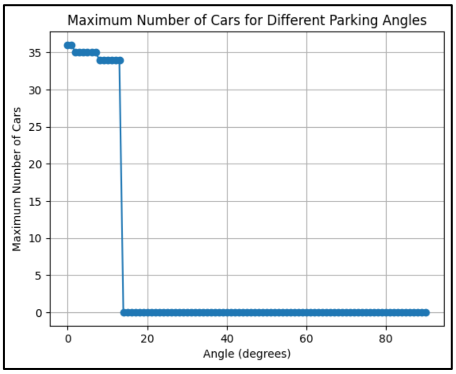


**Figure 5:** Maximum Number of Cars for Different Parking Angles.

The unusable block starting 33.9 meters from the beginning of the road and extending for 6 meters was factored into the analysis. This block created a segmentation in the parking layout, necessitating separate calculations for the effective road lengths before and after the block. Despite this constraint, the simulation effectively identified that 0 degrees remained the optimal angle for both segments. The visualization of the proposed parking layout illustrated the practical implementation of the findings. The parallel parking arrangement at 0 degrees allows for a continuous line of vehicles along the road, ensuring maximum space utilization while maintaining a safe and functional driving lane. The results underscore the efficiency of parallel parking in narrow road conditions, where maximizing the number of parked vehicles is crucial.

The findings have significant implications for parking optimization on narrow roads. The discovery that parallel parking at 0 degrees is the most efficient highlights the importance of considering spatial constraints and vehicle dimensions in parking layout designs. The ability to park vehicles at angles up to 13 degrees provides some flexibility, though the benefits diminish as the angle increases.

The simulation demonstrated that while angled parking appeared to offer greater parking density on paper, in practice, it resulted in underutilized space due to the need for precise alignment and the gaps required between vehicles. The use of Monte Carlo simulation in this context proved to be highly effective, offering a wide range of angles and configurations. The accuracy and efficiency of this approach make it a valuable tool for urban planners and traffic management authorities seeking to optimize parking layouts in constrained environments.

## 5. Conclusion and Implications

In conclusion, this research identified that parallel parking at 0 degrees is the optimal configuration for maximizing vehicle accommodation on the narrow road at the University of Moratuwa. The study demonstrated that angles up to 13 degrees are viable, but beyond this, the parking arrangement becomes impractical. The use of Monte Carlo simulation proves to be a powerful tool for addressing complex parking challenges, offering a flexible approach that could be adapted to other university campuses or urban environments facing similar parking constraints.

By optimizing parking angles and configurations through simulation, this research contributes to better space utilization and traffic management within the university setting, potentially alleviating congestion and enhancing overall accessibility. Future studies could expand on these findings by incorporating dynamic factors such as varying vehicle sizes, real-time parking demand, and pedestrian flow to develop even more sophisticated parking solutions.

## References


Abbood, A. N., Ahmed, A. R., & Ajam, H. K. (2021). Evaluation of parking demand and future requirements in the urban area. Civil Engineering Journal, 7(10), 1898-1908.

Abdelfatah, A. S., & Taha, M. A. (2014). Parking capacity optimization using linear programming. Journal of Traffic and Logistics Engineering, 2(3), 176-181.

Aoun, A., Maya, A.-Z., Isam, K., & Cynthia, M. (2013). Reducing parking demand and traffic congestion at the American University of Beirut. Transport Policy, 27, 52-60.

Bao, H. X., & Ng, J. (2019). Tradable parking permits as a transportation demand management strategy: A behavioural investigation. Behavioral & Experimental Economics eJournal, 1-33.

Barata, E., Cruz, L., & Ferreira, J. P. (2011). Parking at the UC campus: Problems and solutions. Cities, 28(5), 406-413.

Dehghanmongabadi, A., & Hoşkara, Ş. (2018). Challenges of promoting sustainable mobility on university campuses: The case of Eastern Mediterranean University. Sustainability, 10(12), 1-12.

Department of Motor Traffic. (2024, July 17). Statistics. Retrieved from https://dmt.gov.lk/images/2023/total_population/Vehicle_Population_2010-2023.pdf

Gurbuz, O., & Cheu, R. L. (2020). Survey to explore behavior, intelligent transportation system's needs, and level of service expectations for students parking at a university campus. Transportation Research Record, 2674(5), 168-177.

Hu, X., Chen, X., Parks, G. T., & Yao, W. (2016). Review of improved Monte Carlo methods in uncertainty-based design optimization for aerospace vehicles. Progress in Aerospace Sciences, 84, 20-27.

Kingham, S. (2004). Transportation and sustainable campus communities: Issues, examples, solutions, Will Toor and Spenser W. Havlick. Journal of Transport Geography, 12(3), 203-204.

Mahmood, Z., Haneef, O., Muhammad, N., & Khattak, S. (2019). Towards a fully automated car parking system. IET Intelligent Transport Systems, 13(2), 293-303.

Moradkhany, A., Yi, P., Shatnawi, I., & Xu, K. (2019). Minimizing parking search time on urban university campuses through proactive class assignments. Transportation Research Record, 2673(1), 158-166.

Nadimi, N., Afsharipoor, S., & Amiri, A. M. (2021). Parking demand vs supply: An optimization-based approach at a university campus. Journal of Advanced Transportation, 2021, 1-15.

Oladejo, N., & Awuley, B. D. (2016). Application of linear programming in optimization of parking slot: A case study of Tamale-Bolgatanga lorry station in Ghana. International Journal of Emerging Technology and Advanced Engineering, 6(7), 147-154.

Ramli, M., Sary, D. P., & Halfiani, V. (2016). Optimization model of parking charge and income using the Lagrange multiplier method. AIP Conference Proceedings, 1750(1), 1-9.

Rubinstein, R. Y., & Kroese, D. P. (2016). Simulation and the Monte Carlo method (3rd ed.). John Wiley & Sons, Inc.

Sakib, N., Bakibillah, A. S., Susilawati, S., Kamal, M. A., & Yamada, K. (2024). Eco-friendly smart car parking management system with enhanced sustainability. Sustainability, 16(4), 1-14.

Shao, C., Yang, H., Zhang, Y., & Ke, J. (2016). A simple reservation and allocation model of shared parking lots. Transportation Research Part C: Emerging Technologies, 69, 303-312.

Singh, S., & Sharma, U. (2012). Application of advanced parking management system techniques: A case study. Journal of Mechanical and Civil Engineering, 7(5), 24-28.

Song, S., Chen, H., Sun, H., Liu, M., & Xia, T. (2022). Time-optimized online planning for parallel parking with nonlinear optimization and improved Monte Carlo tree search. IEEE Robotics and Automation Letters, 7(2), 2226-2233.

Syahrini, I., Sundari, T., Iskandar, T., Halfiani, V., Munzir, S., & Ramli, M. (2018). Mathematical model of parking space unit for triangular parking area.

IOP Conference Series: Materials Science and Engineering, 332(1), 1-7.

Taiga, S., Bakibillah, A. S., Hashikura, K., Kamal, M. A., & Yamada, K. (2021). A user-oriented adaptive-optimal car parking management system towards smart living. International Journal of Engineering Materials and Manufacture, 6(4), 202-208.

Torres, R., & Sanchez, J. N. (2019). Analysis of a university parking lot system through the use of discrete-event simulation. Proceedings of the European Modeling and Simulation Symposium, 66-74.

Young, W., Thompson, R. G., & Taylor, M. A. (1991). A review of urban car parking models. Transport Reviews, 11(1), 63-84.

Zhang, Y., Zhang, Z., & Teng, S. (2018). Adaptive and colony optimization for solving the parking lot assignment problem. International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery, 14, 91-96.

Zhenyu, M., Wei, Z., Lihui, Z., & Dianhai, W. (2020). Optimization of reservation parking space configurations in city centers through an agent-based simulation. Simulation Modelling Practice and Theory, 99, 1-19.