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RESEARCH ARTICLE

Enhancing parking and traffic efficiency through discrete event simulation: A case study at Universiti Malaysia Pahang Al-Sultan Abdullah

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Abstract – University campuses, such as University Malaysia Pahang Al-Sultan Abdullah face recurring challenges in managing traffic and parking due to increasing vehicle numbers and limited infrastructure. This study addresses these issues by employing Discrete Event Simulation to evaluate and enhance parking and traffic efficiency at Block Z, University Malaysia Pahang Al-Sultan Abdullah, Gambang Campus. It aims to identify the primary problems of insufficient parking spaces and traffic congestion that led to significant delays and inconvenience for students, staff, and visitors. The objectives of this study are to develop a simulation model of the current parking and traffic system, assess its efficiency, and recommend improvements. The ARENA software was used to run several simulation scenarios that integrated input gathered through observations, interviews, and records from University Malaysia Pahang Al-Sultan Abdullah Holding. The simulation performance was evaluated through metrics such as waiting times, parking utilisation, and vehicle flow. Validation and verification techniques, including Mean Absolute Percentage Error and face validation, were done to ensure the model's accuracy and reliability. Key findings suggest that reorganising parking layouts and adding parking spaces closer to Block Z significantly reduce waiting times and traffic congestion. Scenario 2, involving eight additional organised parking spaces near Block Z, proved most effective, achieving a reduction in waiting times by 75% and eliminating parking shortages. The study highlights the value of Discrete Event Simulation as a decision-making tool for optimising campus infrastructure, offering practical insights and scalable solutions for University Malaysia Pahang Al-Sultan Abdullah and similar institutions.

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1. Introduction

Urban and economic development has led to a rapid rise in the number of vehicles, ultimately contributing to severe traffic congestion and parking shortages. These issues are not alien to University Malaysia Pahang Al-Sultan Abdullah (UMPSA), whereby insufficient parking spaces have been causing traffic congestion, particularly around Block Z of the Gambang Campus. Research suggests that the inability of existing parking spaces to meet escalating demand may lead to delays and frustration for various stakeholders (Chomiak-Orsa et al., 2023). Traffic congestion can also increase the likelihood of accidents and hamper campus mobility (Black, 2023). Irregular occupation of parking spots is another contributing factor to the problems of insufficient parking spaces in urban areas, suggesting the need for better distribution of parking resources (Kirschner, 2021). This study was conducted in response to the challenges in managing traffic and parking spaces at University Malaysia Pahang Al-Sultan Abdullah (UMPSA). It employed Discrete Event Simulation (DES) to simulate and analyse current traffic and parking flows on campus before proposing possible improvements. The objectives are (1) to develop a simulation model of parking and traffic flow within the campus, (2) to evaluate the efficiency of the current system using the model, and (3) to recommend strategies for improvement. The findings are significant for campus administrators and facilities managers, as the developed simulation model can support resource allocation and informed decision-making in implementing specific measures, such as parking policies, technological solutions, and road redesigns. Furthermore, the study adds to the existing literature by exploring the application of DES in campus parking and traffic management. It also focuses on the specific parking requirements of users, such as instructors, staff, and students, to create effective parking plans that allocate spaces equitably while emphasising accessibility. This detailed analysis seeks to establish localised problems and offer specific solutions to enhance parking management and service quality (Chomiak-Orsa et al., 2022). This paper begins with an introduction to the study, which outlines the research background and objectives. It is followed by a literature review that contains a thorough discussion of various theories and techniques relevant to the study. The methodology section explains the methods employed to conduct the research, followed by a discussion of the findings. Key terms in the study include DES, parking capacity, traffic flow, efficiency, simulation model, peak hour, waiting time, and queuing. This structure allows for a better systematic analysis of the problems and the proposal of feasible solutions (Black, 2023).

1.1 Literature Review

This section provides a comprehensive overview of the literature on parking and traffic management to help readers understand the underlying concepts and processes involved in efficient management. It also outlines the key issues faced by university campuses, such as waiting times and full parking, which are critical to the study. Finally, this section introduces the methodologies used in this study, including DES and the optimisation methods.

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1.1.1 Overview of parking and traffic management

A proper parking and traffic flow is important for the development of urban infrastructure. The components of parking management include physical infrastructure like on-street and off-street parking, multi-storey car parks, and special areas for certain types of vehicles. Parking rules and policies like permits, time limits, and zoning are highly effective in the management of parking space (Forbus et al., 2022). Smart parking systems with sensors and automatic payment systems can improve user comfort and efficiency. Traffic management concerns vehicle flow control, traffic lights, roundabout signalisation, and traffic signs. Subsequently, measures that can alleviate congestion, including dedicated bus and taxi lanes, are key to keeping traffic moving. Real- time vehicle movement data from monitoring technologies like CCTV and traffic counters is equally critical for the effective management of traffic (Jiang et al., 2023). Incident management systems enable rapid response to accidents and disruptions, thus reducing their effects on traffic flow (Sinning & Zhang, 2023). Some of the issues faced at UMPSA are inadequate parking, traffic congestion during peak hours, and the necessity of stricter enforcement of parking laws. This is made worse by the congestion at tortuosity level-2, which prohibits the flow scientifically and affects the traffic flow and user experience. Addressing these issues requires a comprehensive approach that incorporates the key components of parking and traffic management, along with innovative solutions tailored to the specific needs of the campus (Forbus et al., 2022).

1.1.2 Process of traffic and parking management

Parking and traffic administration systems utilise an encompassing approach that ensures effective movement of vehicles and appropriate usage of parking spaces. The process gives rise to access and resources planning, which entails collating data on traffic patterns, intensity of parking at designated peak periods, and proprietors (Jiang et al., 2023). Surveys and observations can assist users' expectations and appreciation of the activities. The use of modelling and simulation tools also facilitates the analysis of traffic and its direction in diverse areas to spot prominent difficulties and anticipate future congestion trends. The effective implementation of these measures involves building new multi-level parking spaces (Ghizzawi et al., 2024). Additionally, technological advancement in locating car spaces through sensors and real-time information can also enhance parking management (Paudel et al., 2023). Strict enforcement of parking policies, such as fines and towing, is also crucial to ensure public adherence to the traffic and parking rules. The daily operations of traffic and parking management include controlling signals and signs for vehicular movement, distributing parking spaces depending on the number of vehicles, and estimating and controlling traffic using cameras and sensors (Sinning & Zhang, 2023). Moreover, engaging users is done via straightforward instructions, online applications, and receiving feedback information (Paudel et al., 2023). Self-service kiosks can also be installed to provide users with real-time information on available parking slots. Continuous improvement involves measuring performance based on pre-defined parameters such as the percentage of vehicles parked, the amount of time spent waiting, and users' level of satisfaction after using the service. Subsequently, existing policies and physical settings can be altered and improved based on actual data to ensure effective management of parking and traffic.

1.1.3 Issues of parking and traffic management

Traffic congestion and the lack of parking space are among the serious problems in UMPSA, which further aggravate the long waiting times for drivers. Long waiting times arise when drivers need to circle around looking for available spaces or when the traffic is extremely congested (Lu et al., 2024). Driver frustration and tension, along with high petrol consumption, can dampen the user experience on campus. These traffic issues become even harder to handle during rush hours due to the high volume of traffic, resulting in the waste of time and resources. Ineffective traffic control, such as excessive signal timing intervals and insufficient signboards, leads to traffic logic and time loss (Ghizzawi et al., 2024). Additionally, the manual operation of mechanised systems, such as ticket sales or payment systems, at the entry points also increases the movement of vehicles. Traffic congestion and the demand for parking spaces also rise during major events like graduation, which often requires more time to clear (Lu et al., 2024). The issue of limited parking availability is made worse by the permanent occupancy of parking slots, forcing others to park their vehicles far from their intended destinations. The large amount of traffic on campus and improper parking habits further corroborates the issue (Paudel et al., 2023). Solving these problems entails a better design and construction of parking facilities and signage, the implementation of enforcement and relevant policies, and the use of technology.

1.1.4 Techniques to solve problems in parking and traffic management

Various methods can be employed to address the issues associated with parking and traffic control. It includes the use of smart parking systems, which employ cameras and data to determine the best ways to fully utilise parking spaces and minimise the amount of time to look for a parking spot. Another measure is using automatic traffic light control, which incorporates real-time requirements to control traffic lights (Xu et al., 2022). Constructing new parking spaces and remodelling the existing ones is equally crucial for meeting the increasing demand. Nevertheless, some methods of gaining space, such as surface parking expansion, can have negative impacts on the environment, including reducing green spaces and increasing heat effects (DeFilippis et al., 2024).

Therefore, more sustainable approaches are preferred, such as multi-level parking structures and green parking solutions. Optimisation and simulation are particularly effective in developing efficient parking and traffic management strategies. Optimisation techniques, such as linear programming and integer programming, help allocate resources effectively and meet specific objectives. Simulation models, including DES, provide valuable insights into system behaviour and potential improvements. These models allow for testing different scenarios and strategies without the need for physical changes, thus saving time and resources (Xu et al., 2022). Combining optimisation and simulation enables the development of comprehensive solutions to address the unique challenges of parking and traffic management at UMPSA.

1.2 Queuing Theory

The queuing theory is a mathematical study that analyses waiting lines or queues to understand their behaviour and occurrence in various systems, such as transportation, service lines, and telecommunications. Key components of the queuing theory include the arrival process, service process, queue discipline, line capacity, and the number of servers. The arrival process describes how entities, such as vehicles, arrive at the queue, which can be scheduled or random. In the context of UMPSA, student and staff vehicles are entities that arrive at the campus gates during peak hours, thus causing queues. Service time includes the time taken to park a car or to pass through a traffic signal. The duration of service time may vary depending on time, place, and place of parking. Queue discipline arranges entities in a certain discipline such as first-come, first-served, which means that the entity that arrived first is given first service. Queue capacity entails the number of entities in a queue at any given time. The limited availability of parking at UMPSA usually warrants waiting lines once the number of arriving vehicles exceeds the available parking spaces. Overflow parking lots are used when the normal parking spaces are full, thus escalating the parking queuing system and the distance walked to the destination (Paudel et al., 2023). Finally, the number of servers refers to individuals like parking attendants and security personnel, which determines how quickly cars can access the campus or find a parking spot.

1.3 Optimisation

Optimisation is defined as searching for the most favourable solution when utilising a range of feasible solutions to achieve target goals, such as minimising waiting time or optimising the use of car parks. This technique is important in the management of parking and traffic systems as they assist in the determination of resource optimisation and enhancement of systems. Optimisation can be achieved using various methods depending on the nature of the problem and goals (Gu et al., 2023). Linear programming is one of the commonly utilised methods of optimisation. It has a linear objective function and involves a collection of linear constraints. The objective function can be thought of as the goal (e.g., waiting time or the number of parking spaces to be occupied), while the constraints are the conditions (e.g., the number of parking spaces available or funds available for parking lots). Integer programming (IP) is similar to linear programming but with the restriction that some or all the variables must be integrally valued (Gu et al., 2023). It is ideally useful for problems involving integer characters like numbers, such as the number of parking spaces or the number of security personnel required at one time or within the premises. Facility location problems are another area of integer programming, such as the best locations for new parking facilities, so that parking users do not have to walk long distances. Non-Linear Programming (NLP) refers to problems that involve optimising an objective function, where the constraints involved are non-linear. Such a programming method is useful in traffic flow control since the relations between matters (e.g., volume, speed, and congestion) are nonlinear (Gu et al., 2023). For instance, NLP can be employed to identify the right time to change the traffic signal lights to reduce the concentration of vehicles, thus easing the movement of traffic on campus.

1.4 Discrete Event Simulation

Simulation creates digital models of real-world systems to analyse behaviours and predict outcomes (Rybczak, 2024). Discrete Event Simulation (DES) is a type of simulation technique widely used for modelling complex systems, such as traffic and parking management, by representing events as sequences in time. This simulation technique is often utilised for simulating the performance and behaviours of real-world systems, particularly those with time-based and dynamic processes (Forbus et al., 2022). It allows researchers to assess system performance and test alternate scenarios without interfering with ongoing operations, which represents a system as a sequence of events that take place at distinct times in time. This makes DES particularly useful for systems that include sequential operations, like production systems, parking management systems, and traffic flow systems (DeFilippis et al., 2024). It is appropriate for studies on parking and traffic management since it offers a complete environment for model construction, animation, and analysis. Users can depict complicated systems in a modular style using DES hierarchical modelling approach, which breaks down difficult issues into manageable parts.

DES has been widely used in the healthcare industry. For instance, Forbus et al. (2022) conducted a thorough analysis of 231 studies and found that DES is primarily utilised in emergency rooms and medical facilities to improve time efficiency and resource allocation. They also observed an increasing tendency in hybrid models that combine DES with other analytical methods. Despite its benefits, DES also has drawbacks, especially when incorporating human behaviour and implementing it in the actual world. These limitations were noted as major challenges in a qualitative evaluation by Forbus et al. (2022), which recommended that future studies should concentrate on adding behavioural components and creating frameworks for hybrid models. They also suggest that DES models must consider healthcare worker behaviour and address cultural barriers to improve implementation effectiveness (Forbus et al., 2022).

2. Materials and Methods

2.1 Data Collection Method

Data collection is a key step in research methodology because it provides the researcher with valuable input for validating or refuting the research hypothesis and drawing conclusions about the situation (Jiang et al., 2023). There are two types of data: primary and secondary, both offering diverse perspectives and helping to gather accurate and comprehensive input (Dias et al., 2022). Selecting the appropriate data collection method is important to ensure that the information gathered is authentic, credible, and relevant to the research goals. This study utilised both primary and secondary data to gather insights for creating a robust simulation model and to obtain a comprehensive understanding of the traffic and parking issues at UMPSA.

2.2 Primary Data Collection

The primary data of this study entailed both qualitative and quantitative data. The former was collected through interviews with security guards stationed at UMPSA's main gate. The aim was to gain insights into vehicle movement patterns, peak hour traffic flow, and existing challenges in parking and traffic management (Zhang et al., 2024). The security guards shared valuable information about the overall flow of vehicles entering the campus and highlighted specific times when congestion was most prominent. Meanwhile, the quantitative data were collected through on-site observations and recording the number of vehicles arriving at UMPSA during peak traffic hours. These observations focused on vehicle movement patterns, congestion points, and parking availability to gain a comprehensive understanding of current traffic and parking conditions on campus (Soini et al., 2022; Zhang et al., 2023). The combination of qualitative and quantitative data provided a crucial foundation for developing a realistic and effective simulation model that accurately reflected traffic and parking conditions at UMPSA. Table 1 presents the data collection activities conducted at the UMPSA Gambang Campus.

Table 1. Data collection activities were conducted at the UMPSA Gambang campus

Who in charge	Date	Information obtained
Staff UMPSA Holding	27 June 2024	Collection information about the number of parking and traffic available on campus
Staff UMPSA Holding	28 June 2024	Gather information on challenges, obstacles, and issues to generate solution ideas
Staff UMPSA Holding	29 June 2024	Calculate the number of cars waiting and how long it takes to find parking
Staff UMPSA Holding	4 July 2024	Calculate the number of cars waiting and how long it takes to find parking
Staff UMPSA Holding	5 July 2024	Ensure that the data collected is accurate

2.3 Secondary Data Collection

The secondary data of this study involved utilising information previously gathered by other researchers and conducting interviews with relevant personnel at UMPSA. This type of data was particularly useful in providing valuable context and background information for the study (Soini et al., 2022). The sources included academic journals, government reports, industry reports, and online databases, which provided insights into transportation, traffic, and urban planning trends that complemented the primary data. Meanwhile, several interview sessions were conducted with UMPSA Holding staff responsible for parking data management to gather critical information, including the total number of parking spaces available at Block Z and a layout overview of the Block Z parking area. These data were essential for developing a detailed simulation model and understanding the current parking infrastructure and its limitations, ensuring that the simulation model effectively addressed the key problems of traffic congestion and parking inefficiencies at UMPSA (Soini et al., 2022).

2.4 Components of Discrete Event Simulation

DES can simulate the behaviour of a real-life system by modelling entities, resources, and variables to study the system's dynamics. Entities represent individual elements such as vehicles and pedestrians; resources include parking spaces and enforcement personnel; and variables capture the current state of the system, such as parking occupancy and vehicle queues. These components are essential for creating an accurate simulation model of the parking and traffic systems at UMPSA. Entities are the most critical components in DES, as they represent the individual elements that move through the system (Forbus et al., 2022). In the context of this study, entities include vehicles, pedestrians, and other objects within the parking and traffic systems at UMPSA, controlled by attributes such as arrival time, departure time, destination, vehicle type, and parking options. By modelling these entities, the simulation can accurately represent their movement, interaction, and behaviour within the system. Meanwhile, resources are the elements that manage the behaviour of entities. In this study, resources include parking spaces, parking attendants, entrances and exits, and enforcement personnel. These resources are not individually modelled but rather treated as computable items whose behaviour is not tracked (Forbus et al., 2022). Variables reflect the system's current state and may vary. For instance, variables can include the state of parking lots, the number of cars in a line, or the state of the entry/exit. These variables allow the simulation to assess the efficiency of the traffic and parking systems and analyse the effects of intervention.

2.5 Steps in Simulation

Since this study was modelled on a simulation of the decision-making process, it was necessary to identify the specific problem in traffic management and define possible goals, such as reducing traffic congestion and increasing the effective use of parking space. The next step was to construct the conceptual model of the parking and traffic systems, followed by data collection and confirmation. Various situations were then developed to observe their effects on the system. The outcomes of the simulation study were used to assess the impacts of varying approaches (Dias et al., 2022). Finally, the findings were summarised and reported to offer recommendations for further enhancements. Additionally, the general problems in which the simulation process was involved must be defined to outline the research objectives. This involved understanding the key issues affecting traffic and parking at UMPSA and determining the simulation's goals.

Once the objectives were defined, this study proceeded to develop a conceptual model of the parking and traffic systems. This model identified the entities, resources, and variables required for use in the simulation. Valuable information was extracted from the primary and secondary data to feed the simulation model. Once the data were validated, several possible settings were created to test different approaches to enhance traffic and parking conditions. Several of these methods were simulated to assess their feasibility on the system, and the results were evaluated to assess the efficacy of each approach (Palmi et al., 2021). The final step was to report the output together with suggestions for further enhancements. This information is highly useful for understanding current traffic and parking conditions at UMPSA and for proposing simple, practical recommendations. Figure 1 illustrates the steps taken to execute the simulation.

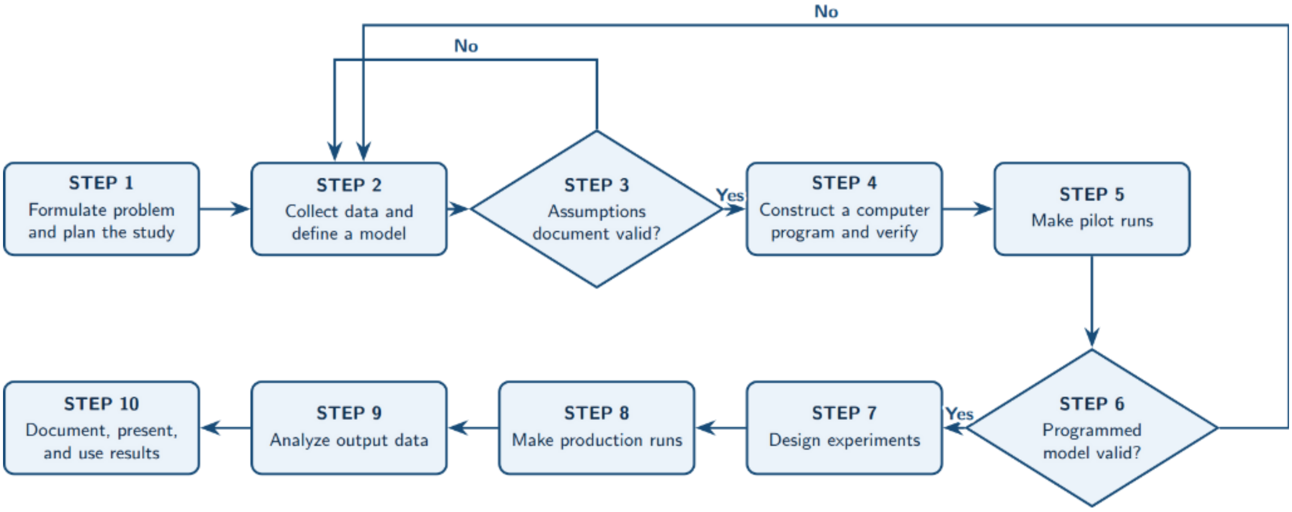

Figure 1. Diagram for simulation steps (Law, 2015)

2.6 Simulation Software

Simulation software is vital to create a model of a real system that can be used for behaviour analysis and further prediction of results without the need for real experiments. The simulation in this research was conducted using Arena, a software famous for object-oriented programming and hierarchical modelling (Dias et al., 2022). Arena provides an interface for designing, executing, animating, validating, and analysing the simulation model. This makes the simulation results more accurate and allows the researchers to develop and validate their models. Aside from its flexibility and work-friendly interface, Arena also facilitates object-oriented programming and hierarchical modelling, enabling users to build precise simulation models.

2.7 Validation and Verification

Validation and verification are important steps to ensure the simulation model is accurate and reliable. Validation checks if the simulation model correctly represents the real-world system that it is meant to simulate (Paudel et al., 2023). This involved testing the model's logic, algorithms, and equations to ensure they match the actual parking and traffic operations at UMPSA. One way to validate the model is by using the Mean Absolute Percentage Error (MAPE), which measures the model's prediction accuracy. MAPE shows accuracy as a percentage, with values below 10% indicating the forecast is very accurate; values between 11% and 20% are good; values between 21% and 50% are acceptable; and values above 51% are considered inaccurate. This method ensures that the simulation model yields reliable and precise results, which can help with decision-making. Equation (1) shows the formula of MAPE, while Table 2 presents the percentage of accurate prediction (Khairina et al., 2019).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Actual_i - Forecasted_i}{Actual_i}\right| \times 100 \quad (1)$$

where, n: Number of observations; Actual Value$_i$: Observed value from real-world data, Simulated Value$_i$: Predicted value from the simulation

On the other hand, verification involves evaluating the simulation model to ensure it behaves as expected and produces results consistent with real-world data. This process involves comparing the simulation model's output with historical records, expert opinions, and real-world data to ensure the model's reliability (Fujimaki et al., 2023). Verification also involves checking the model's ability to replicate observed patterns, trends, and phenomena in parking and traffic at UMPSA. By thoroughly validating and verifying the simulation model, the study ensures that the results are credible and can be used to develop effective strategies for improving traffic and parking management (Xu et al., 2022).

Table 2. Level of accuracy for MAPE (Khairina et al., 2019)

MAPE Value	Level of Accuracy
MAPE ≤ 10%	Very accurate
10% < MAPE ≤ 20%	Accurate
20% < MAPE ≤ 50%	Medium
50% ≤ MAPE	Less accurate

2.8 Face Validation

Face validation is a qualitative method used to ensure that the simulation model appears reasonable and logical to experts familiar with the system. This method relies on subjective judgment and involves collecting high-quality information from knowledgeable individuals to gain acceptance of the model (Paudel et al., 2023). Face validation is crucial for ensuring that the model reflects the real-world system accurately and is credible to stakeholders. One approach to face validation is to conduct interviews and discussions with traffic engineers, university planners, and parking management staff (Fujimaki et al., 2023). These experts provide valuable insights into the system's dynamics and help identify any discrepancies or inaccuracies in the model. Finally, animations are used to visualise the simulation model's behaviour, helping to identify any invalid assumptions and increase the model's credibility. Feedback from stakeholders is used to refine the model and correct any errors.

3. Results and Discussion

This study used DES to develop a car movement simulation that mirrored real-life conditions, based on the parking layout and traffic flow within Block Z at the UMPSA Gambang Campus. It enabled detailed tracking of vehicle movements and precise time calculations, providing valuable insights and recommendations for optimising the parking layout in Block Z. Developing a simulation using DES required designing a logical model that systematically organised all processes, from input through to output.

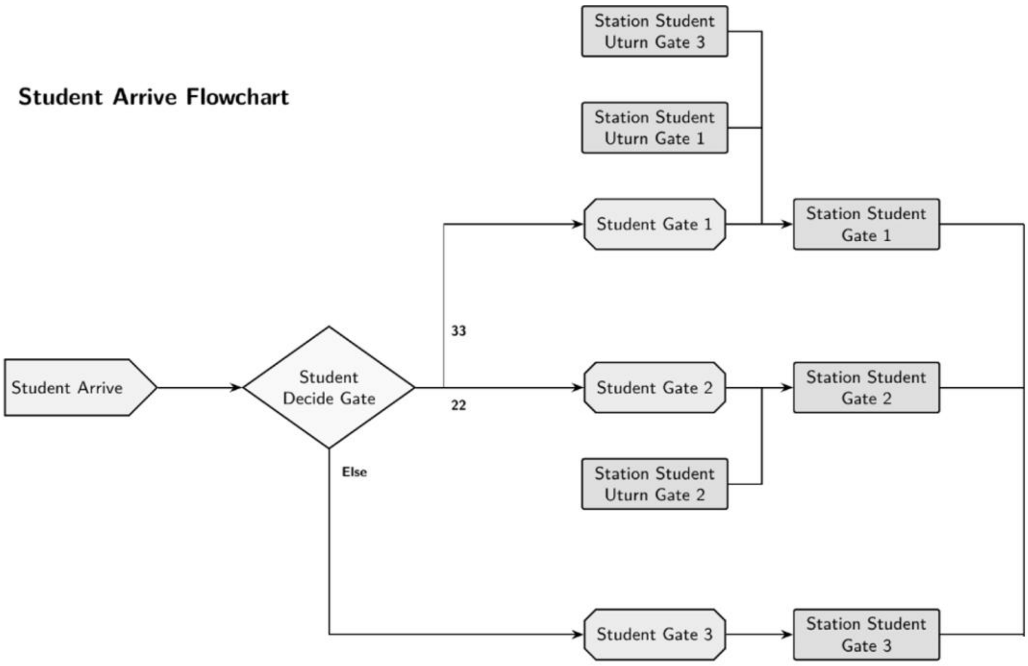

Figure 2. The process of student arrival via the UMPSA main gate

3.1 Model Logic for Parking Process and Traffic Improvement at Block Z

This study used a baseline model as an experimental framework, serving as a benchmark for comparing results obtained through DES in analysing parking metrics, such as waiting time, total parking time, and the number of checkouts. As shown in Figure 2, the logic model began with the input of arriving students, regulating the number of entities entering the simulation. This input could also schedule entry intervals, with up to 150 entities scheduled per hour, allowing for 16 and 8 entities to enter each interval. In this model, each entity represented a student, as defined by the study's test parameters. Upon entering, students encountered a decision node, represented by a diamond shape, which directed them along one of three designated paths: Gate 1, Gate 2, or Gate 3. This differentiation aligned with Block Z's layout, which included three separate entryways leading to the parking area. Following this, a module called "Station" (symbolised by a pink rectangle) represents the movement of entities exiting the parking area. There were three "Stations" for each gate and three "Student U-Turn Stations", where students, upon finding limited parking availability, would circle back in search of open spaces.

In Figure 3, each student proceeded to the parking lot and encountered a diamond-shaped "Decision" module indicating the availability of parking spaces. This module was split into 17 potential routes: 16 direct routes to available parking spaces and 1 route that allows the student to turn back if all spots are occupied. Following the Decision module, students moved to the “Route” module, which linked stations and illustrated movement between locations. For instance, students entering from Gate 1 would follow Route 8, which leads to Parking Station 8. In this base model, 16 designated parking routes connected each parking station, facilitating the simulation of parking movements. In Figure 4, when all parking spaces were occupied, students were guided by a decision module to determine whether to make a U-turn. Students were then routed through one of three modules: U-turn Route Station for Gate 1, Gate 2, or Gate 3. Each route was connected to the corresponding U-turn station shown in Figure 1, where students re-entered the search process for an available parking spot. This cycle would repeat within the simulation until an empty parking space was located.

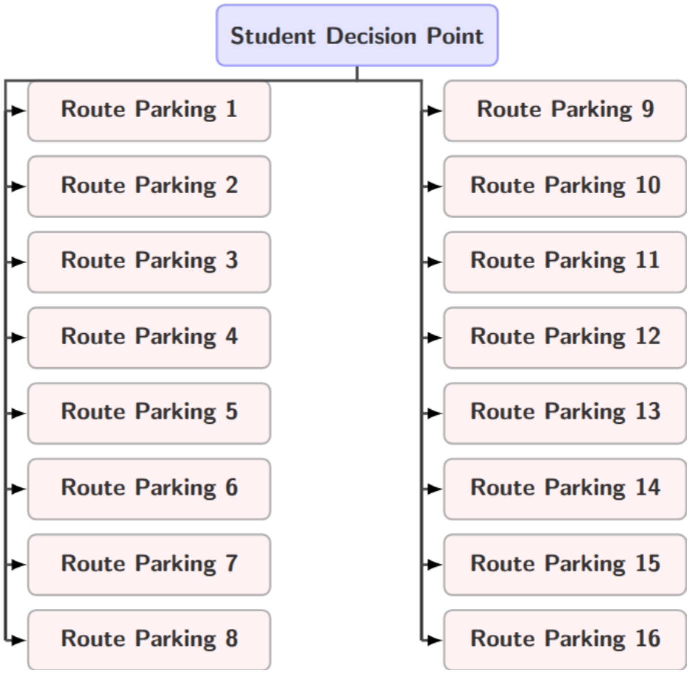

Figure 3. The process of students deciding where to park

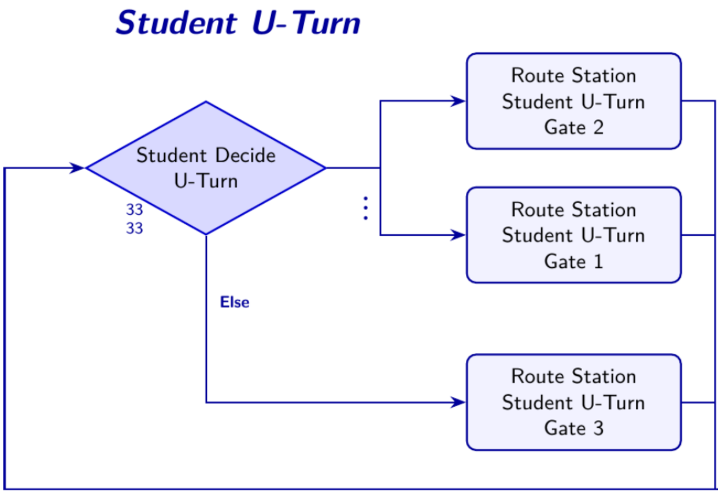

Figure 4. The process of students making a U-turn when parking is full

Subsequently, in Figure 5, each student proceeded to an available parking station module and entered the “Process” module, which determined the duration of their stay in the parking spot. In the base model, there were 16 parking station modules and 16 corresponding process modules. The process module was configured with a parking duration range of 15 minutes to 2 hours, reflecting the variable time that students typically spent in the Block Z parking lot. Finally, students exiting the parking lot were processed through the "Dispose" module, which served as the simulation’s output stage. This module recorded the number of students who completed their parking duration, providing a final count for analysis.

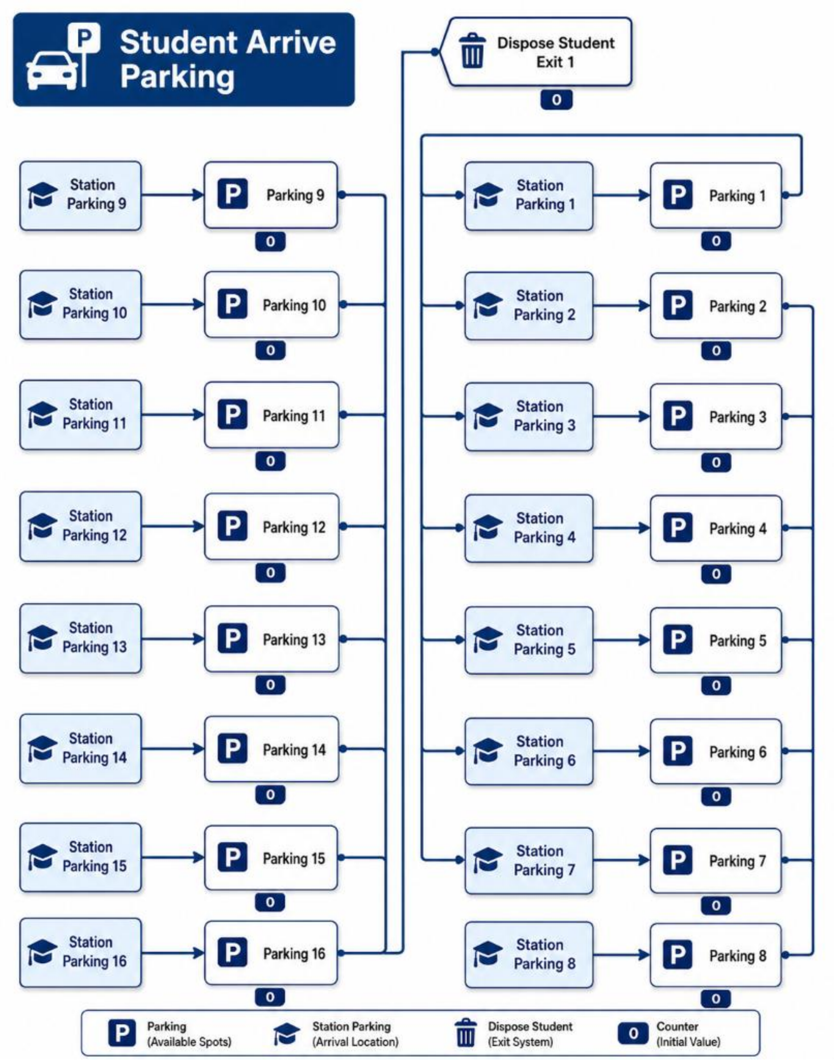

Figure 5. The process of students arriving at the parking lot

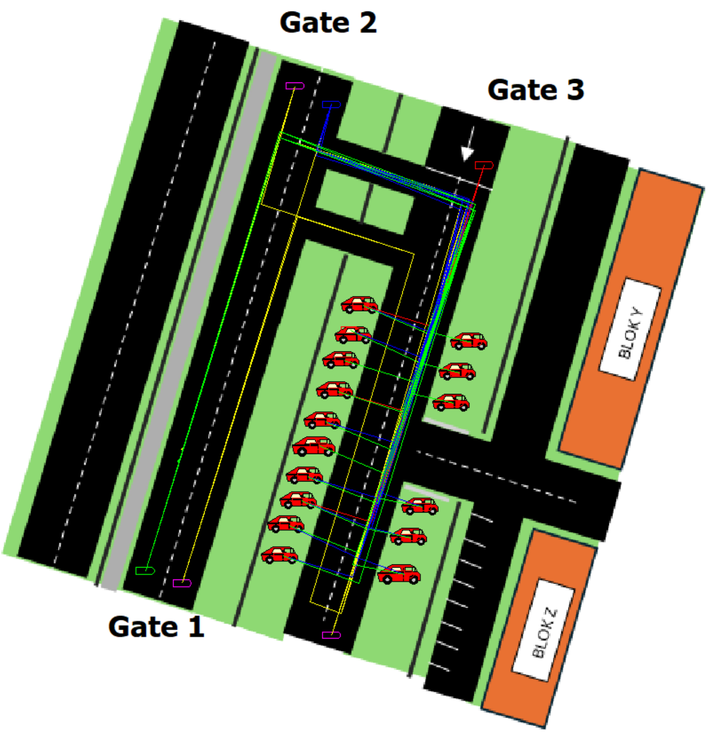

Figure 6. Animation for the process of student car parking at Block Z

3.2 Animation of Process Parking and Traffic at Block Z

Figure 6 illustrates the parking layout for Block Z, which the simulation revealed was designated only for student parking, underscoring the area's limited capacity. The layout featured three primary access roads from Gate 1, Gate 2, and Gate 3, which served as the main entryways for students commuting to Block Z. As students drove along these routes towards the parking area, any full parking lot forced them to make a U-turn and continue circling to locate an available spot. The scarcity of parking spaces led to increased traffic congestion in Block Z, causing delays for students on their way to class. Additionally, the current parking arrangement lacks structure, with vehicles parked on grassy surfaces without marked lines or an organised layout, thus complicating parking management. Parking on the grass not only risks damaging the grounds but also creates puddles and mud during rain, further reducing the area's quality and accessibility.

3.3 Base Case

Once the animation was executed, the DES generated output data derived from the simulation. Several key results were recorded, including waiting time, total parking time, and the number of checkouts. The waiting times for students entering Gates 1, 2, and 3 were 58.52, 66.02, and 33.99 minutes, respectively. The total parking times for each gate were 152.91 minutes, 171.65 minutes, and 135.2 minutes, respectively. Meanwhile, the total number out for each gate was 42 student cars from student gate 1, 37 from student gate 2, and 45 from student gate 3, for a total of 124 student cars out of 150 in the entire study. These outputs are analysed and compared in Table 3. The results demonstrated that students had difficulty locating parking, which was time-consuming and caused them to be late for class. It highlights the need for a better parking system to increase productivity, reduce wait times, and ensure that students can get to class on time. Addressing these problems will provide students with a better overall experience. Further analysis of data collected from the parking area at Block Z revealed that 150 cars entered during operating hours, from 8:00 AM to 5:00 PM. For the simulation, the base study generated a result of 124 cars exiting the parking lot. The simulation's accuracy was measured using MAPE, an essential metric for evaluating its precision (Song & Bae, 2023). As shown in Figure 8, the MAPE value was 17.33% and ranged between 11% to 20%, which was good for forecasting. It indicates that the data were reliable for forecasting and that the simulation model produced accurate, suitable results for this study.

3.4 Scenario Analysis

Scenario analysis is a powerful technique for assessing probable future outcomes by comparing various scenarios or events. It helps organisations identify and assess potential risks and uncertainties by analysing various scenarios, so they can be better prepared for adverse situations and make informed decisions to reduce risk. Such insights also inform decision-makers about how different variables or circumstances might influence results. This helps make more solid conclusions, especially when there is uncertainty or a lack of accurate facts. In this study, two scenarios were tested to improve the layout analysis of process parking and traffic near Block Z. The first scenario added 8 parking lots farther from Block Z. In contrast, the second added 8 parking lots closer to Block Z.

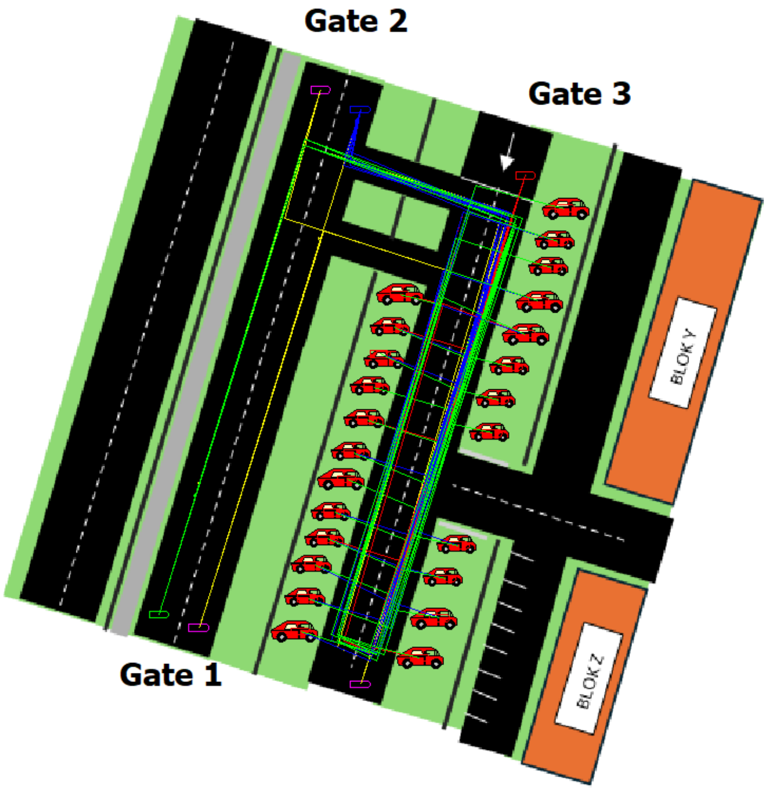

Figure 7. Animation for Scenario 1, where 8 new parking lots were added from Block Z

3.4.1 Scenario 1: Adding 8 new parking lots located further away from Block Z

Due to the issues of longer waiting times and limited parking spaces identified in the base study, several scenarios were developed to explore potential improvements for parking at the Block Z area. Figure 7 illustrates the animation for Scenario 1, where the parking capacity was expanded by adding 8 additional parking spaces, extending into the Block Y area. This scenario offered students more parking options, though the additional spaces were farther from Block Z, increasing the time required to reach the parking lot. While this expansion reduced traffic congestion, it also increased parking utilisation due to the greater distance to parking spaces.

Scenario 1 maintained the same issues observed in the base study, as no marked parking spaces or organised parking lines were provided. Consequently, students parked in an unstructured manner on grassy areas, leading to inefficient use of the available spaces. As shown in Table 3, the DES results for Scenario 1 indicated that the waiting times for students at Gates 1, 2, and 3 were 20.64, 29.24, and 18.81 minutes, respectively. The total times for these gates were 87.21, 99.40, and 87.37 minutes, respectively. Furthermore, the total number of student cars out at each gate was 50 at student gate 1, 47 at student gate 2, and 42 at student gate 3. The total number of students in this study was 149, out of 150.

3.4.2 Scenario 2: Adding 8 new parking lots nearer to Block Z

Figure 8 shows the animation for Scenario 2, where 8 parking lots were added closer to Gate 1 road and Block Z. It allowed students from Gate 1 to park their vehicles more easily and quickly due to its proximity to Block Z. There were also additional tarred roads and parking lines for the parking lot, making it easier for students to park their vehicles. This scenario reduced traffic and parking utilisation.

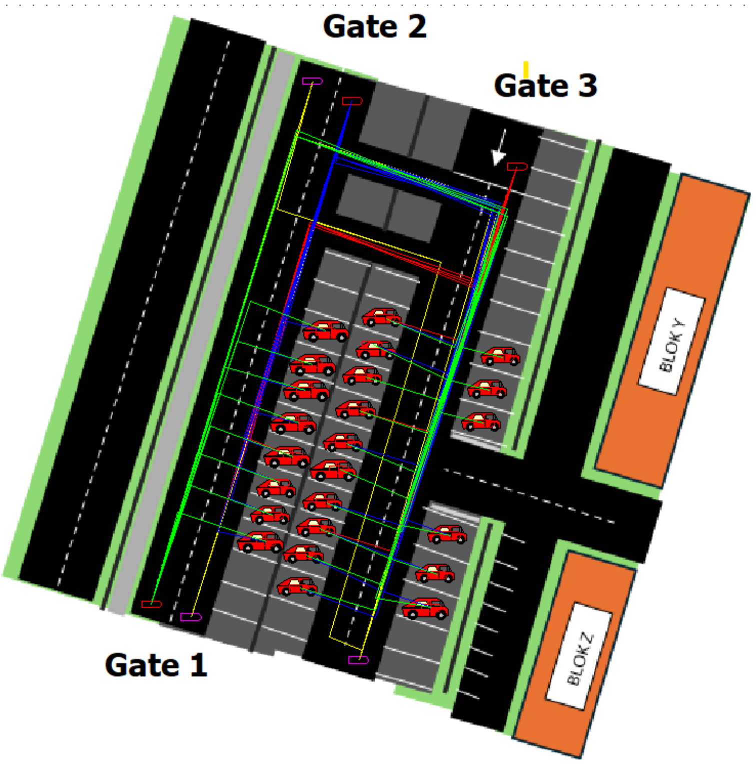

Figure 8. Animation for Scenario 2 where 8 new parking lots were added nearer to Block Z

As shown in Table 3, the DES results for animation scenario 2 demonstrated that the waiting times for students from Gates 1, 2, and 3 were 15.63 minutes, 10.96 minutes, and 10.91 minutes, respectively. The total times for each gate were 78.23, 75.61, and 75.37 minutes. On the other hand, the total number out for each gate was 51 students from student gate 1, 39 from student gate 2, and 60 from student gate 3. The total number of student cars in this study was 150.

3.5 Key Output Performance

Table 3 compares system performance across the base case and the two scenarios. The metrics for this comparison are the average student waiting time to reach the parking area, the total waiting time for students to secure a parking space, and the number of students waiting to exit the parking area.

Table 3. Key output performance for Base Case, Scenario 1, and Scenario 2

Metrics		Base case	Scenario 1	Scenario 2
Waiting time (Minute)	Student gate 1	58.52	20.64	15.63
	Student gate 2	66.02	29.24	10.96
	Student gate 3	39.99	18.81	10.91
	Total	164.52	68.68	37.50
Total time (Minute)	Student gate 1	152.91	87.21	78.23
	Student gate 2	171.65	99.40	75.61
	Student gate 3	135.20	87.37	75.37
	Total	459.76	273.98	229.21
Number out (Total students = 150)	Student gate 1	42.00	50.00	51.00
	Student gate 2	37.00	47.00	39.00
	Student gate 3	45.00	52.00	60.00
	Total	124.00	149.00	150.00

3.6 Discussion

The primary issue addressed in this study is the inefficiency in parking and traffic management at UMPSA. The campus faces significant challenges, including insufficient parking spaces, long waiting times, and traffic congestion, particularly during peak hours. DES was employed using ARENA software to model and analyse the current system and to propose improvements to enhance parking and traffic efficiency at UMPSA. The comparison of the three scenarios highlights the impact of different strategies on parking and traffic efficiency at UMPSA. The base-case scenario revealed critical issues in the current system, including long waiting times and inefficient use of parking spaces. Scenario 1 showed that increasing the number of parking spaces can reduce waiting times and improve overall efficiency, but the distance to the parking spaces remains a challenge. Scenario 2 demonstrated that an organised parking layout, with additional spaces closer to the main area, can significantly enhance efficiency, reduce waiting times, and accommodate more vehicles. The findings suggest that UMPSA should consider implementing an organised parking layout with additional spaces near high-demand areas. This will not only address the parking issue but also reduce traffic congestion, improving the experience for students, staff, and visitors. The use of DES and ARENA worked well for modelling and studying parking and traffic systems, providing useful information for decision-making and planning future improvements (Forbus et al., 2022).

Based on the simulation results and the comparison of the three scenarios, Scenario 2: Organised Parking Layout emerged as the best option for improving parking and traffic efficiency at UMPSA, as it demonstrated the most significant reduction in waiting times and total parking times. Waiting times were reduced to 15.63, 10.96, and 10.91 minutes for Gates 1, 2, and 3, respectively. The total parking times were also significantly lower at 78.23, 75.61, and 75.37 minutes. Additionally, all 150 cars exited the parking lot, indicating highly efficient use of parking spaces. This study proposes four key recommendations for improvement. First, as indicated by the simulation results in Table 3, adding 8 parking spaces near Block Z would make it easier for students to access parking and reduce the stress associated with finding parking. Second, UMPSA should consider providing free shuttle bus service for students. This initiative may significantly alleviate traffic congestion at Block Z and minimise car usage in the area. It also offers students a convenient alternative to commuting to classes at Block Z without the concern of finding parking. Another suggestion is to paint the parking lines in the grassy parking area to organise the parking layout so that drivers can park more neatly and efficiently.

4. Conclusions

This study has successfully achieved all the objectives outlined in the research. The primary objective was to develop a simulation model of the parking and traffic flow within the campus, focusing on the actual layout of the parking area at Block Z. The second objective involved evaluating the efficiency of the current parking system, which was accomplished by creating an alternative simulation layout for Block Z that is more suitable for students. Lastly, the study recommended strategies for improvement by simulating scenarios that incorporated additional parking spaces and optimised parking arrangements. These recommendations demonstrated the most effective solutions for enhancing parking and traffic processes at Block Z. This study underscores the importance of implementing an organised parking layout with additional spaces near high-demand areas to improve parking efficiency, reduce traffic congestion, and enhance the user experience at UMPSA. The optimisation of the parking system resulted in reduced waiting times, making parking more effective and reducing campus congestion. This improvement not only benefits students, staff, and visitors by providing more convenient parking options but also enhances their overall satisfaction and perception of campus facilities. Furthermore, the use of DES and ARENA software for modelling and analysis is proven crucial in making data-driven decisions for continuous improvement. These strategies and methodologies are scalable and adaptable, offering flexible solutions for future needs and similar challenges at other institutions. Thus, adopting these changes based on accurate data and realistic scenarios ensures effective and efficient optimisation of campus infrastructure.

However, this study is limited by its focus on Block Z, which may not accurately reflect parking dynamics across the entire campus. Findings from one location may not generalise to another because parking habits and traffic patterns may vary greatly across blocks. Adding more blocks to the simulation would provide a more thorough knowledge of parking problems on campus. The simulation may have overlooked staff and visitor actions because it focused mostly on student parking patterns. Overall parking efficiency may be impacted by the frequently disparate parking needs and usage patterns of employees and guests. Future simulations would offer a more comprehensive understanding of parking demand and utilisation if these user groups were included. Future research can provide a campus-wide perspective on parking patterns by running models that cover several blocks, including Blocks X and Y. This method will facilitate finding systemic problems and creating a complete remedy. To capture a wider range of parking behaviours and needs, future research should incorporate staff and tourists into the simulation models. Creating inclusive and successful parking initiatives requires an understanding of the parking habits of various groups.

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CRediT Authorship Contribution
Ahmad Mujahid Ishak: Conceptualisation; Methodology; Writing - original draft
Jack Kie Cheng: Conceptualisation; Resources; Investigation; Validation; Writing- Revise & Reviewing
Freselam Mulubrhan: Analysis; Writing- Revise & Reviewing

Availability of Data and Materials
The data supporting this study's findings are available on request from the corresponding author.

Ethics Declarations
This study was conducted in accordance with ethical standards.

Generative Artificial Intelligence Declarations
The authors claim that artificially intelligent-assisted technologies in the form of generative AI were not used to generate content, ideas, or theories. AI is only used to enhance readability and refine the language. This was used with extreme human control and oversight. The authors take full responsibility for reviewing and approving the content.

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