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A MATHEMATICAL MODEL FOR THE OPTIMIZATION OF PARKING LOT DESIGN

Nur Zafirah Mohd Sidek[1*], Siti Rahimah Batcha[2] and Mohd Najir Tokachil[3]

[1, 2] School of Mathematical Sciences, College of Computing, Informatics, and Mathematics, Universiti Teknologi MARA (UiTM), Selangor Darul Ehsan, Malaysia*

[3] School of Mathematical Sciences, College of Computing, Informatics, and Mathematics, Universiti Teknologi MARA (UiTM), Seremban, Negeri Sembilan, Malaysia

[1*]nurzafirah@uitm.edu.my, [2]rahimahbatcha@uitm.edu.my, [3]najir2992@uitm.edu.my

(indicates the corresponding author)*

ABSTRACT

A car is one of the modes of transportation that is usually used to move from one place to another. The number of cars has increased due to economic growth and the demand to own a car for a living. The parking problem is one of the crucial problems that the architect has to face to design the parking lot to fit as many cars, especially in a narrow area. Pizza/KFC outlets at Seremban 2, Negeri Sembilan, Malaysia are very suitable for improving the parking lot design since this place has limited space. Therefore, in this study, the mathematical model purpose is used to improve the number of parking, suitable for limited areas, and make the parking lot easy to design. The parallelogram concept is used to maximize the number of parking. The area occupied by the parking lot depends on many factors such as width, length, area of place, and angle of parking lot design. The angle of the parking lot is 90°, 60°, 45°, and 30° is used for easy exit and entry. Thus, the design is identified based on the parallelogram concept. This study found that the change in the angle of the parking for Pizza/KFC outlets will influence the number of parking lots. The angle of 40 degrees will provide 26 parking lots which is this angle is suitable for that area. In the future, the mathematical model might be useful to determine the number of parking in certain areas especially in limited areas.

Keywords*: Parking, Optimization, Parallelogram, Area*

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1. Introduction

A parking lot or car park is an area where people can leave their cars in the provided area. In congested and limited areas, it could be hard to find a single parking lot and the people need to cope with the madness situation. In the capital area, people need to understand and cope with the environment that the land is not enough to develop more parking areas. Thus, the architect needs to organize and design the resources efficiently to ensure that the problem faced by the community is solved. As a mathematician, to choose the best design, the theorem and the equation that had been invented need to be verified step by step for the best result that could be useful by the community.

There are two types of parking lots which are on-street parking and off-street parking (Parmar et al., 2020). On-street parking is where vehicles park their cars on the street's side. This common type of parking lot is controlled by government agencies. Meanwhile, off-street parking means vehicles are parked off the street and commercial agencies will control it. After that, these two types of parking lots consist of different types of parking angles. Different articles give different values of parking angles (Chyn Ira. Crisostomo & Dr. Renann G. Baldovino, 2019). This study decided to take 90°, 60°, 45°, and 30°. For easy exit and entry to a certain place, the reasonable traffic lane width, the 60° parking angle is the best one. Meanwhile, a 90° parking angle is suited for all-day parking because of the difficulty of entering and leaving the parking lot (Abdelfatah & Taha, 2014).

Each parking lot angle has a different stall length, width, and depth. According to Jabatan Perancangan Infrastruktur Dewan Bandaraya Kuala Lumpur, they have given fixed measurements for different types of vehicles. Table 1 is the measurement for a standard parking lot.

Table 1. Dimension for standard parking space

Parking angle	**Width (ft)**	**Length (ft)**	**Access lane of any width (ft)**
90°	9’	18’	42’
60°	9’	21’	39’
45°	9’	19’10”	34’10”
30°	9’	16’10”	28’10”
Lateral	8’	24’	36’

(Sources from Guidelines for Car Parking and Internal Traffic Circulation, 2014)

Meanwhile, one car will only occupy one space parking lot. Therefore the parking lot capacity is equal to the number of accessible spaces of certain places (Bingle et al., 1987). In this study, a mathematical that proposed by them is used to determine the number of parking lots. By using this mathematical model, the best design can be achieved and the number of parking lot spaces can be maximized. The best place to study this mathematical model is the limited area of parking lots that high demand for people to park their cars.

Besides that, the width and length of a parking lot space need to identify whether the design of the parking lot used the standard measurement of the parking lots as shown in Table 1. The aisle also plays a main role in the parking lot design because the wider the aisle the easier the car to park. However in some parking areas, the width of the aisle is neglected, and people could take some time to park their cars perfectly in the provided parking lot space (Liu et al., 2021). And it could be uneasy if this problem frequently occurs. Thus the Pizza/KFC outlet at Seremban 2, Negeri Sembilan, Malaysia was chosen because it has all the characteristics that this study needs (Bingle et al., 1987b).

2. Methodology

In this study, diagonal parking will be referred to as long as the angle is less than 90 degrees ($\theta < 90^{\circ}$). The study done by Bingle et al. (1987), their study is about designing the optimal placement of space in a parking lot, the factors that influence parking lot design are an access lane of any width, *R*, length of parking space, *L*, the width of parking space, *W* and angle of parking space, θ. The formula to calculate the area, *A*, occupied by a car of any angle is:

$$A(\theta) = W\left[L + R\cos ec(\theta) + (2W - R)\cot(\theta)\right] \tag{1}$$

The parallelogram concept (Bingle et al., 1987) will be referred to in this study to calculate the area occupied by a car.

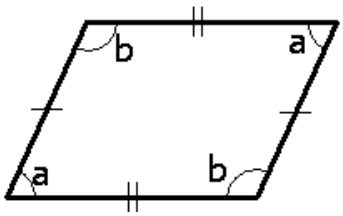

Figure 1. Parallelogram shape

Therefore Equation (2) can be used to calculate the number of parking lots:

$$\text{The number of parking lot} = \frac{\text{Total Area}}{\text{Area occupied by a car}} \tag{2}$$

Figure 2 shows the design of the parking lot. Equation (1) is obtained from this figure by considering the parallelogram concept. The total area for one space parking has been considered the space for a car to enter and leave the park.

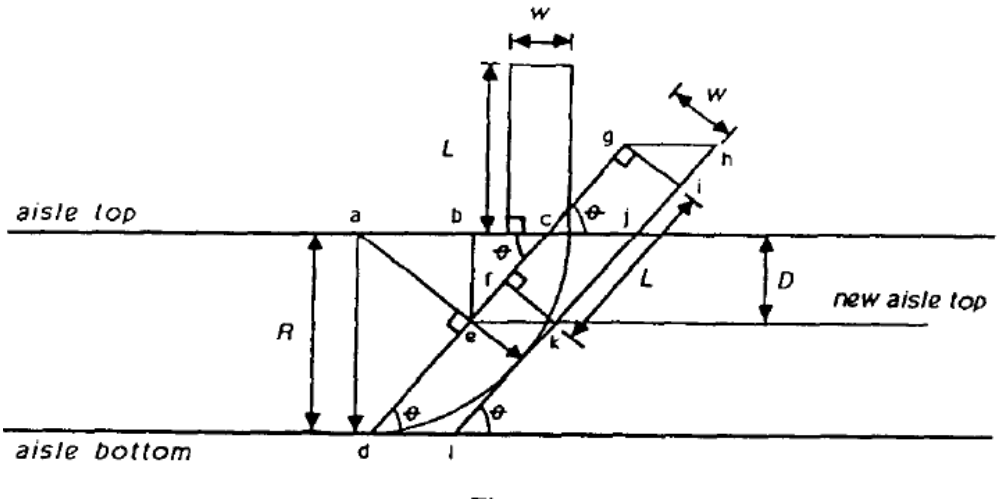

Figure 2. Parking Lot Design

(Sources from Bingle et al., 1987)

To prove Equation (1), the angle must be less than 90 degrees ($\theta < 90°$). From Figure 2, three information that need to be considered are:

i. $\angle bce = \theta$, $\angle aec = 90^\circ$, $\angle cae = 90^\circ - \theta$
ii. $\overline{dg}$ is parallel to $\overline{lh}$
iii. $\overline{lh} = W$, therefore $\overline{ae} = R - W$ and $\overline{be} = D$

The data had been collected from KFC‘s manager. The information that had been collected was width, length, and area of place. Meanwhile, the angle of the parking lot is obtained from Kinovea Software by capturing the picture of the parking lot. The information that has been collected is:

Table 2. Data Collection

Information	Value
Total area of Pizza/KFC building (ft²)	: 10,090.3
Total area for parking lot space (ft²) (24 space – standards car) (2 spaces – a parking lot for disabled people)	: 3970.9
Length of parking space (ft), L	: 16
Width of parking space (ft), W	: 8
The angle of parking space, θ An access lane of any width, R	: 40° : 35.8

2.1 To Calculate the Number of Parking Lots

In this study, the total area occupied by a car (for one space of angle) at Pizza/KFC outlets at Seremban 2, Negeri Sembilan, Malaysia is obtained as follows by substituting the data collection in Equation (1).

$$\begin{aligned} A\left(40^\circ\right) &= 8\left[16+35.8\cos ec\left(40^\circ\right)+\left(2\left(8\right)-35.8\right)\cot\left(40^\circ\right)\right] \\ &= 384.79 \end{aligned}$$

Next step by using Equation (2), the number of the parking lot is obtained.

$$\begin{aligned} \text{The number of parking lot} &= \frac{\text{Total Area}}{\text{Area occupied by a car}} \\ &= \frac{10,090.30}{384.79} \\ &\approx 26 \end{aligned}$$

Hence, by using all the data collection, the number of parking lots obtained is 26. Therefore, to obtain a greater number of parking lot a few changes such as the angle of parking space and an access lane of any width is needed. Since the length and width of the parking lot have followed the standard measurement, these two factors do not need to change.

2.2 Change in the Angle of Parking Space, θ

In this study, the access lane of any width *R* is 35.8 feet, width *W* is 8 feet, and length *L* is 16 feet and these values are fixed.

When substituting all values in Equation (1) and Equation (2), the area occupied by a car and the number of parking lots are obtained as shown in Table 3.

Table 3. Change in the angle of parking space, θ

Angle, θ	**Area occupied by a car (ft²)**	**The number of parking lot**
30°	426.44	23
45°	374.63	26
60°	367.25	27
90°	414.4	24

Hence, when the angle of the parking lot is changed to 60°, the number of parking lots is 27. The number of parking lots increases by as much as 1. Therefore, by using an angle of 60°, the parking lot can be maximized at Pizza/KFC outlets. Hence, 60° is the suitable angle to be designed at Pizza/KFC outlets.

2.3 Change in the Length, *L*, Angle, θ, and Access Lane of Any Width, *R* Follow Standard Measurement

Meanwhile, in this study, only width *W* is fixed. The value of length, *L*, the access lane of any width, *R*, and angle, θ is changed because the access lane of any width, *R*, at Pizza/KFC, has not followed the standard measurement. When substituting all values from Table 1 into Equation (1) and Equation (2), the area occupied by a car and the number of parking lots are obtained as shown in Table 4. with $W = 9$ feet,

Table 4. Change in the length, *L*, angle, θ and access lane of any width, *R* follow standard measurement

Angle, θ	**Length, L (ft)**	**An access lane of any width, R (ft)**	**The area occupied by a car**	**The number of parking lot**
30°	16.83	28.83	501.59	20
45°	19.83	34.83	470.31	21
60°	21.00	39.00	485.18	20
90°	18.00	42.00	540	18

Different lengths, angles, and access lanes of any width give different values of parking space. This is because of the limited area at Pizza/KFC.

3. Results and Discussions

The results in session 2.2 and 2.3 are described by plotting the graph. The model is initially tested by using original data which are $R = 35.8$ feet, $W = 8$ feet, $L = 16$ feet but changes in angle, θ. The result obtained is as follows.

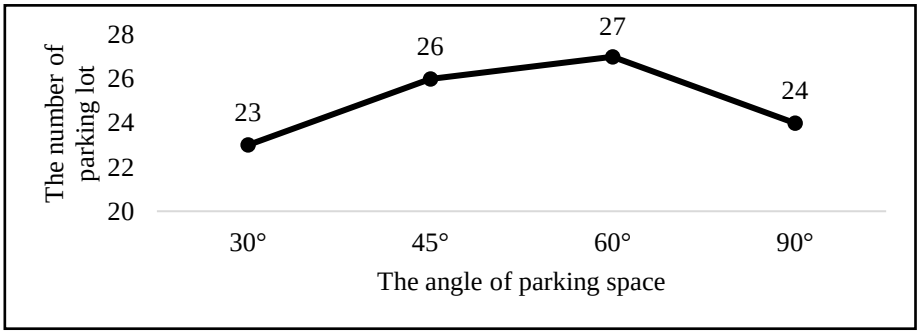

Figure 3. Relationship between the angle of parking space and the number of parking lots when the angle of parking space, θ changes.

Figure 3 shows the relationship between the angle of parking space and the number of parking lots when the angle of parking space, θ is changed. As shown in Figure 3, when the angle changes to 30° the number of parking lots obtain is 23. There are 26 parking lots obtained when the angle changes to 45° and 1 parking lot becomes 27 parking lot when the angle is increased to 60°. Meanwhile, the number of parking lots will decrease by 24 parking lots when the angle increases to 90°.

However, from the result shown in Figure 3, the measurement of parking lot space does not follow the standard measurement even though the angle of the parking lot is changed. As stated in Table 1, different angle of parking lot space has a different width, length, and an access lane of any width. Although the angle of parking lot space changed to 60° with the original measurement giving the highest number of parking lot spaces, there must be a reason why this Pizza/KFC outlet does not use the standard measurement and angle.

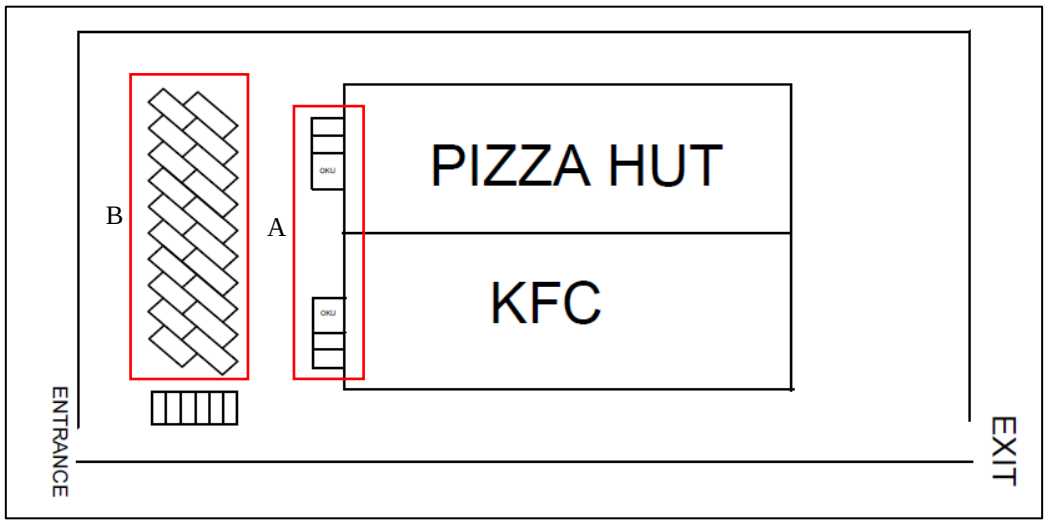

Figure 4. Parking Design at Pizza/KFC outlets at Seremban 2, Negeri Sembilan, Malaysia.

Figure 4 shows the original parking lot design at Pizza/KFC outlets at Seremban 2. Since another 6-parking lot space at A has followed the standard measurement (θ = 90°, W = 9 feet, L = 18 feet, R = 42 feet), this study only focuses on the parking lot at label B. Therefore, the number of parking lot spaces should be considered only at label B.

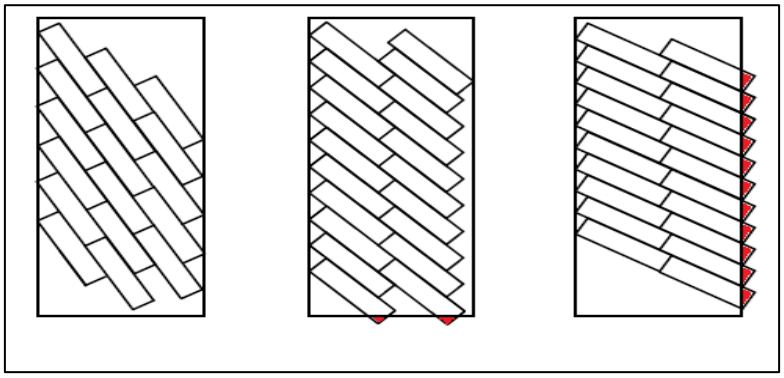

Figure 5. Parking lot design with different angles using original measurement.

As shown in Figure 5, the result obtained in Table 3 was designed by using AutoCAD 2016 software. When the angle of the parking lot is changed to 30°, the number of parking lot spaces is 17 which must be designed at label B in Figure 4. To fit label B space, the design is overlapping and not suitable to be implemented since the overlapping design will affect the way of entering and leaving the parking lot.

Meanwhile, when the angle of parking lot space is changed to 45° and 60°, the number of parking lot spaces is 20 and 21 which must be designed at label B space. Although the design is fit there are a few spaces that exceed the B space. This will affect the aisle space and the way of entering and leaving the parking lot if these two designs are still used.

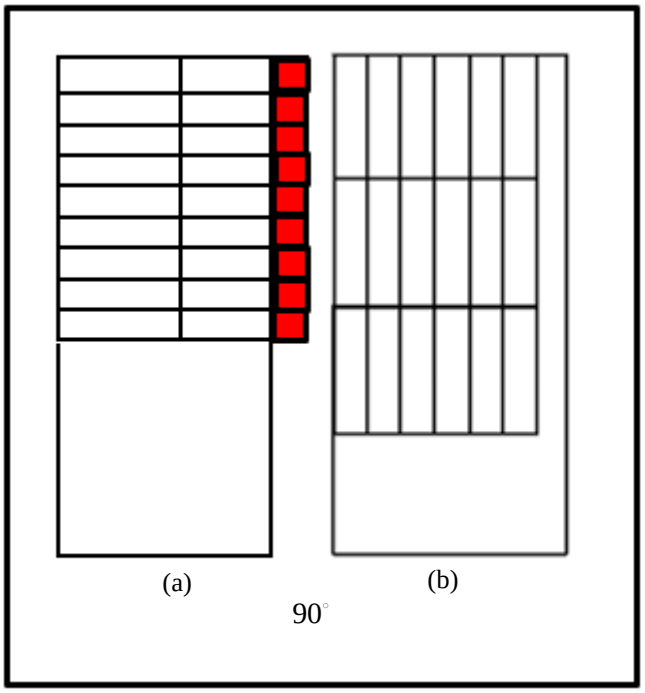

Figure 6. Parking lot design for the angle of parking lot space, 90° with original measurement.

As shown in Figure 6(a) design, many spaces exceed the label B space (referring to Figure 4) which will affect the aisle space. But if design Figure 6(b) is implemented, the parking lot will overlap, and will be difficult to enter and leave the parking lot.

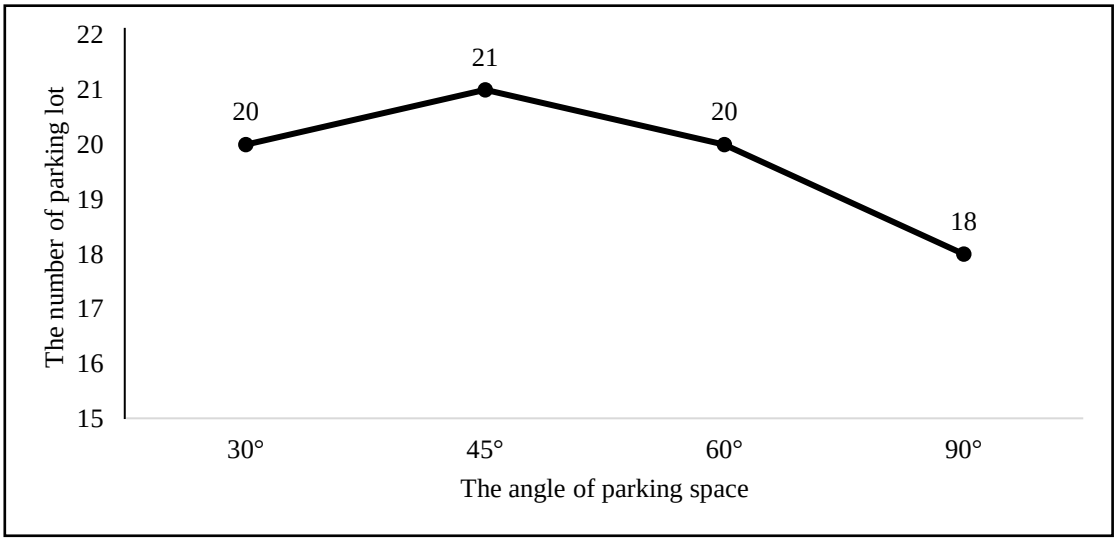

Figure 7. Relationship between the angle of parking space and the number of parking lots when the standard measurement is used.

Figure 7 shows the relationship between the angle of parking space and the number of parking lots when the standard measurement is used. When the angle of parking lot space is

30° and 60°, the number of parking lot spaces is 20. There are 18 parking lots obtained when the angle changes to 90°. Meanwhile when the angle of the parking lot is 45°, the number of parking lot increase to 21.

The reason why standard measurement is not used at Pizza/KFC outlets at Seremban 2 is because of limited space. Moreover, if the standard measurement is used, the number of parking lots obtained is less than the original number of parking lots.

4. Conclusion

The results of this study suggest that the formulation of optimization for parking lot give significantly different results when the formulation consider various factors such as different angle of parking lot space, width, length, and an access lane of any width. To maximize the number of parking lots, this study changes the angle of parking space, θ, and changes in the length, L, angle, θ, and access lane of any width, W following standard measurement. Based on the calculations, the parking lot gives a smaller number of parking lots compared to the original number of parking lots when using standard measurement.

By using the mathematical model purpose by Bingle et al., (1987) the measurement in Pizza/KFC outlets at Seremban 2 shows that the angle of the parking lot for 40-degree angle is suitable for the area provided for parking area. The number of parking when the angle is 40 degrees is 26 parking lots. Meanwhile if using the standard measurement, the number of parking lots is less than the original number of parking lots. But, the design is essential for the people to enter and exit the parking lots.

This project might be beneficial for future work at certain places so that the congestion problems especially in parking can be solved efficiently. For future work, the mathematical model can be used to design parking lots by considering different values of width, length, and angles of the parking lot. This mathematical model is helpful and might be used to reduce parking lot problems in limited space. Based on this study, the Pizza/KFC outlet at Seremban 2 needs to expand the parking area to provide more parking lots by following the standard measurement.

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7. Conflict of Interest

The authors have no conflicts of interest to declare.

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