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# Design of Open Parking Lot Based on Grid-Segmentation and Greedy-Algorithm

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## Abstract

**In order to further improve the people's livelihood problems in urban parking difficulties, make full use of limited land resources, make reasonable and effective planning of existing parking lots, and accommodate as many parking spaces as possible while meeting fire safety and other factors. This paper uses greedy algorithm to optimize the parking space of open parking lot. The irregularly shaped parking lot is solved by mesh segmentation and greedy algorithm. For the rectangular parking lot, we define the mathematical expressions of the parameters such as the angle of the parking space and the width of the channel through the plane geometric relationship, and use the greedy algorithm to obtain the optimal solution of the number of parking spaces. For the shopping mall parking lot, taking into account the fire safety and other factors, and in order to make the number of parking spaces in the parking lot as large as possible, it is assumed that the lanes in the parking lot are all single lanes, in order to avoid the accident caused by the car in the parking lot due to an emergency. The incident occurred, and the exit and entrance locations were divided into northwest and northeast to ensure the consistency of the direction of travel of the vehicles in the parking lot. Since the parking lot of large shopping malls is irregular, we use the mesh segmentation method and the greedy algorithm to solve. Through calculation, the arrangement of parking areas in the north-south direction is obtained.**

## Keywords

**Open Parking Lot; Parking Space Design; Grid Segmentation; Greedy Algorithm.**

## 1. INTRODUCTION

With the rapid development of the urban economy, the number of household cars in China has shown a “spurt-type” growth, and the parking space gap is huge. According to the data provided by the National Development and Reform Commission, the ratio of cars to parking spaces in large cities in China is 1:0.8, and that in small and medium-sized cities is 1:0.5. The parking problem has gradually become an urgent problem for people's livelihood in major cities. Parking spaces are limited due to the size of the venue. How to ensure that vehicles are free to enter and exit, as far as possible to allocate parking spaces for the existing parking lot is an important research topic.

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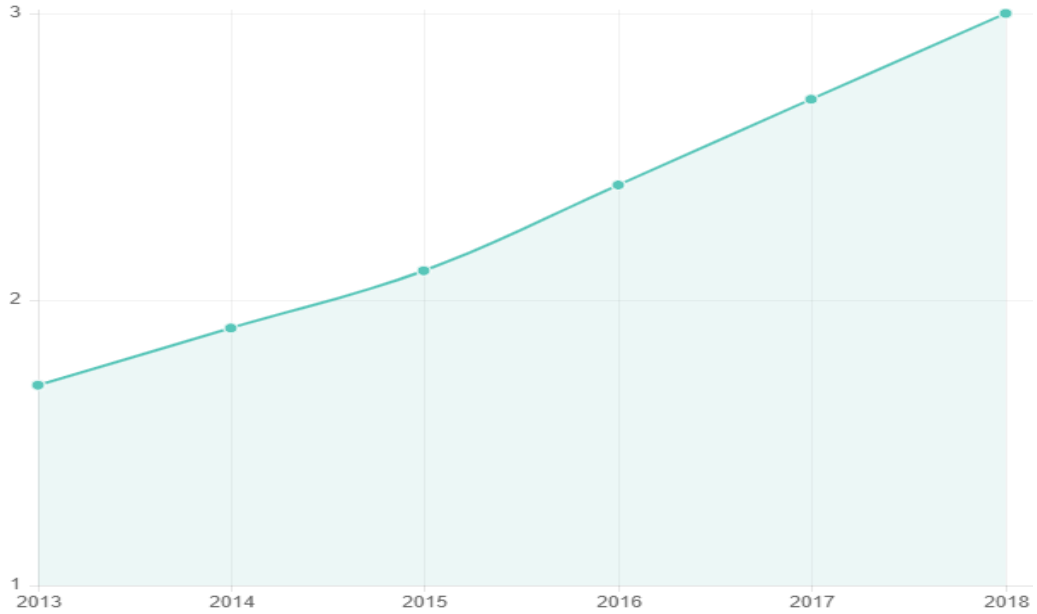
**Tab 1.** China's parking space demand between 2013 and 2018 (unit: 100 million)




The parking space should be designed to meet the driver's sufficient space when parking, and the passage is too wide to ensure that the parking is reduced while the number of parking spaces is reduced, while the narrow passage is not conducive to parking. Therefore, the arrangement of the parking spaces can be set to parallel, diagonal, vertical, and the like. Considering that the common car has a turning radius of 5.5 meters, it requires a length of 5.5 meters and a width of 2.5 meters for vertical parking.This paper optimizes the design of parking spaces for two different types of open parking lots. One design for rectangular parking lot with a length of 79 meters and a width of 26.5 meters, as shown in Figure 1. Another design for the parking lot of a large shopping mall, as shown in Figure 2.

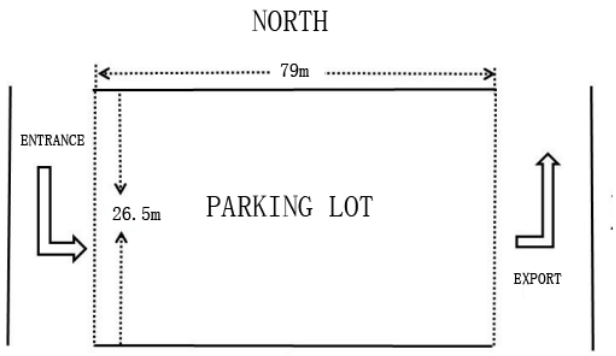



**Fig 1.** Rectangular parking lot

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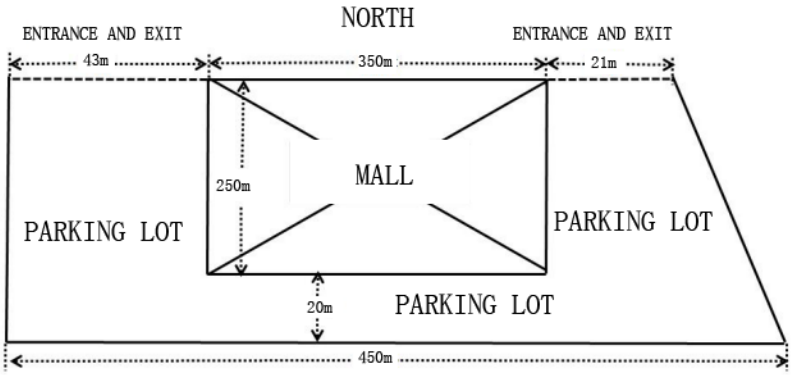


**Fig 2.** Mall parking lot

## 2. PROPERTIES

For the rectangular parking lot, when studying the car alignment problem, it is assumed that the car is traveling circumferentially on a circle with a radius of 5.5 m, and then enters the parking space at an angle of θ, as shown in Figure 3.

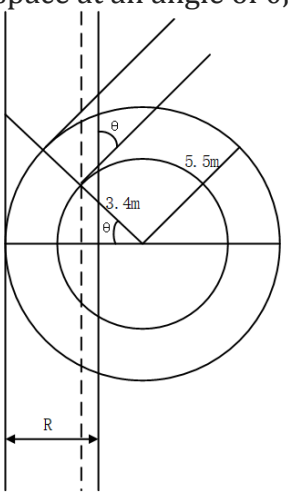


**Fig 3**

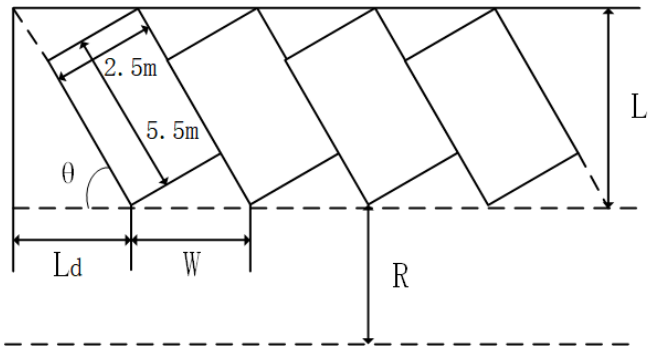


**Fig.4**

It can be seen from the figure that the channel width is:

$$R = 5.5 - 3.4\cos\theta \tag{1}$$

Because each car is parked at the same angle, as shown in Figure 4, the width of the parking space is $W$, the length is L, and the distance at the end of the parking space is Ld. The setting parameters satisfy the following relationship:

$$W = 2.5/\sin\theta \tag{2}$$

$$L = 5.5\sin\theta + 2.5\cos\theta \tag{3}$$

$$\mathrm{L}_d = 5.5 - 2.5\cot\theta\cos\theta \tag{4}$$

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When designing the parking space of the parking lot, in order to ensure the maximum number of parking spaces, the north-south road is no longer arranged in the middle of the parking lot. The entrance and exit of the parking lot is east-west. The vehicle distribution is arranged according to the east-west direction, without considering the arrangement of the vehicles, parking the distribution of parking spaces is roughly as shown in Figure 5.

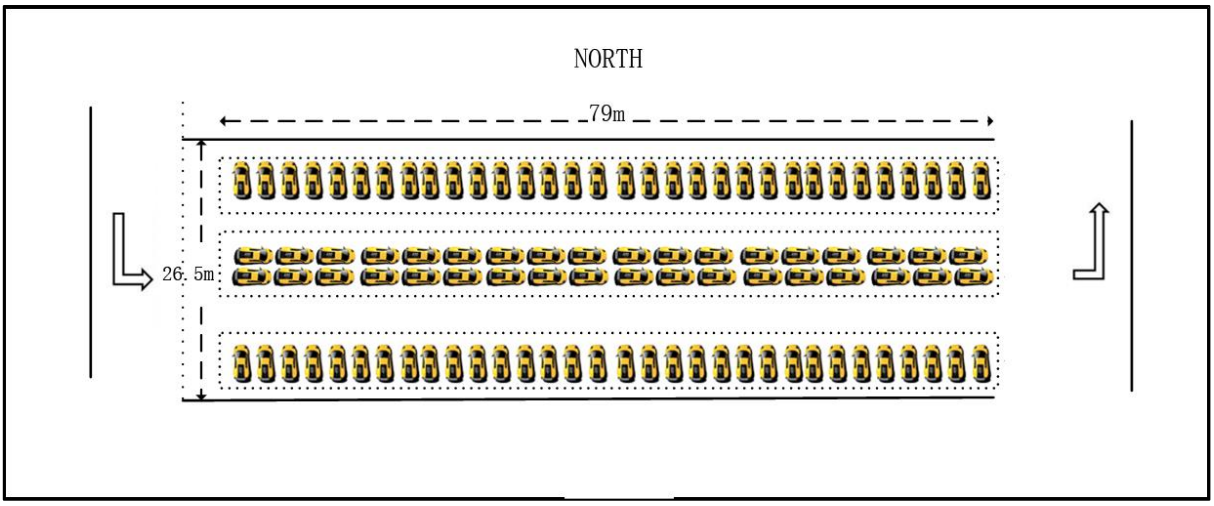


**Fig 5.** The distribution of parking spaces

Let xi be the number of parking spaces that can be accommodated in the ith parking area. Under the premise of satisfying the design conditions in the title, allocate parking spaces as much as possible, then the objective function is

$$Max \sum_{i=1}^{3} x_i \tag{5}$$

The following constraints are met:

$$4L+2R=26.5 \tag{6}$$

$$x_1 = x_3 = (79\text{-}L_d)/W \tag{7}$$

$$x_2 = 2 \times (79 - L_d)/W \tag{8}$$

$$x_i > 0 (i \in \{1,2,3\}) \tag{9}$$

In order to ensure the connectivity of the parking lot passage network for the shopping mall parking lot, this paper divides the parking area according to the shape of the area inside the parking lot. The division steps are as follows:

Step 1: Determining whether the parking space is arranged around the parking area geometry. If the parking space is allocated, determine the position of the parking space and the corresponding channel to ensure the feasibility of the parking space design calculation. The edge area of the parking space is not arranged, and it can be designed as a fire pedestrian passage if it does not meet the minimum turning radius of the vehicle.

Step 2: Dividing the remaining designable parking areas in step 1 to obtain 8 minimum cells, as shown in Figure 6.

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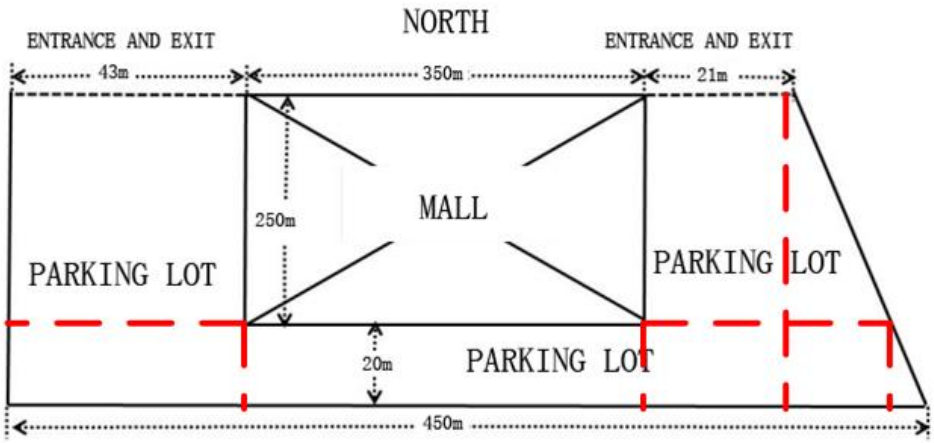


**Fig 6.** Eight minimum cells

Step 3: Combine the smallest units, and arrange the parking spaces in each area after the merger to ensure the consistency of the parking direction in the combined area, and obtain the final design plan. After combining in step 3, two areas are obtained, such as Figure 7.

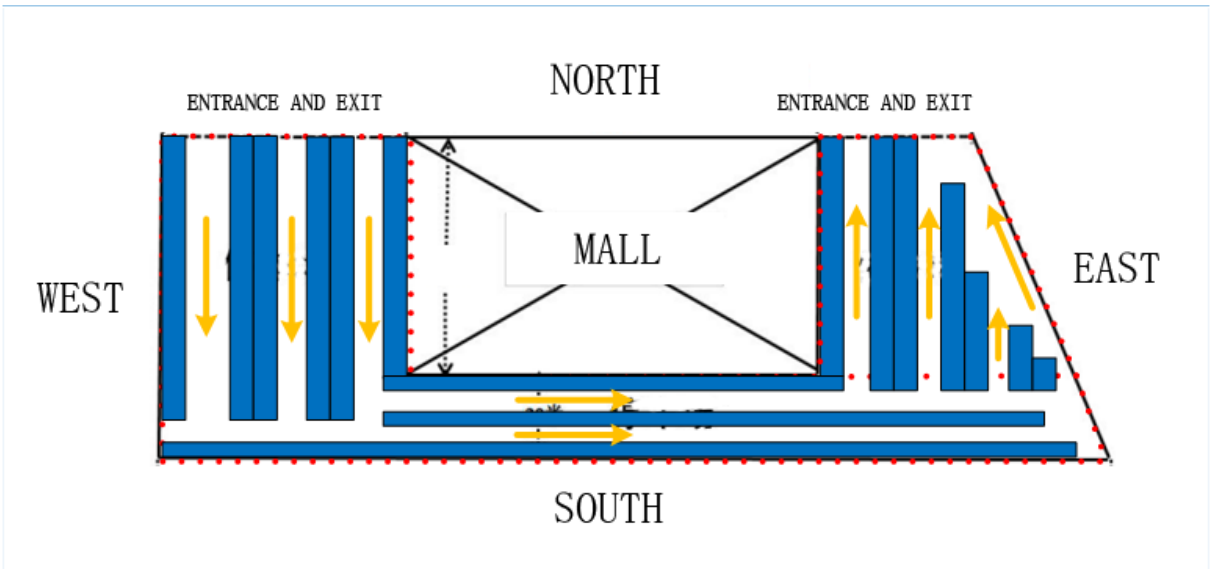


**Fig 7.** Final design

In Fig. 7, the red dotted frame indicates the merged area, the blue bar is the parking area, the yellow arrow is the vehicle traveling direction, the northwest side vehicle entrance and exit position is provided with three entrances, and the northeast side vehicle entrance and exit position is provided with three exits. In the model, the northwest side is the entrance, the northeast side is the exit, and all the lanes are single lanes, ensuring that the vehicles in the parking lot are coherent, avoiding congestion and car situations in an emergency, and effectively carrying out the vehicle and Evacuation of personnel.

The parking space arrangement is determined by step 1 to determine the area to be divided, and steps 2 and 3 determine the parking area division scheme. Step 1 is divided according to the boundary of the parking lot geometry, the divided area is taken as input, the objective function is set to be the largest total number of vehicles, and the minimum unit division and merging is performed on the area, and step 3 is used as an output result.

Set the vertex $v \in V$ of the parking area division area, the dividing line $k \in K$ in the grid, and the rectangle or triangle obtained by the area mesh division is $u_i \in U$. As shown in Figure

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6, after dividing by the mesh, k=22 is obtained. After the segmentation grid is determined, the segmentation line k is converted into a minimum grid cell. The minimum grid unit conversion steps are as follows:

Step 1: The dividing line k in the set K is divided into two categories and assigned. The dividing line of the edge contour of the parking lot is assigned a value of 1, and the remaining internal dividing lines are assigned a value of 2. A dividing line having a value of 1 is referred to as a set K1, and a dividing line having a value of 2 is referred to as a set K2.

Step 2: Take a dividing line k1 from the set K1 and rotate it around one end of K1 until it finds the dividing line k' where K intersects with K1 and the angle is less than 90°, and rotate with another disjoint vertex of k' as the center, repeat the above steps to find another dividing line until the closed geometry is formed, which is the smallest grid unit u. When $K_1 = \emptyset$, the algorithm ends and returns the minimum grid cell set U.

Step 3: Perform an assignment update operation on the parting line constituting the minimum grid unit u, update all the values of the dividing line with a value of 2 to 1, and update the value of the dividing line with a value of 1 to 0. Update the split line set K.

After determining the minimum grid unit, cluster it to get the final parking space layout design.

Let $\lambda_{ij} \in \Lambda(i = 1,2, \dots I, j = 1,2, \dots J)$ be the 0-1 variable in ui in the merged region gj, where I is the minimum number of grid cells, J is the number of regions in the parking space arrangement, satisfying I>J, when ui<gi, $\lambda_{i,j} = 1$, Otherwise 0.

Let $\sigma\ (g_i)$be the maximum number of parking spaces in $g_i$, then the objective function is defined as

$$max \sum_{j=1}^{J} \sigma\ (g_i) \tag{10}$$

Meet the following constraints

$$g_i = \sum_{i=1}^{I} \lambda_{ij} u_i, \quad \forall j \tag{11}$$

$$\sum_{j=1}^{J} \lambda_{ij} = 1, \quad \forall i \tag{12}$$

Constraint (11) specifies the constituent units of gi, and constraint (12) ensures that there is one and only one of each minimum grid unit in set G.

## 3. DESIGN SCHEME BASED ON GREEDY-ALGORITHM

For the rectangular parking lot, in order to obtain the optimal solution of the objective function, this section uses the greedy algorithm to solve. Considering that the length of the parking lot is 79 meters, it can be known that the vertical arrangement can be used to place up to 31 parking spaces per row. The horizontal arrangement can be used, and at least 14 parking spaces can be placed in each row. From the formula (2), the width of the parking space is clamped. The effect of the angle. The relationship between the angle and the number of parking spaces calculated by Matlab is shown in Figure 8.

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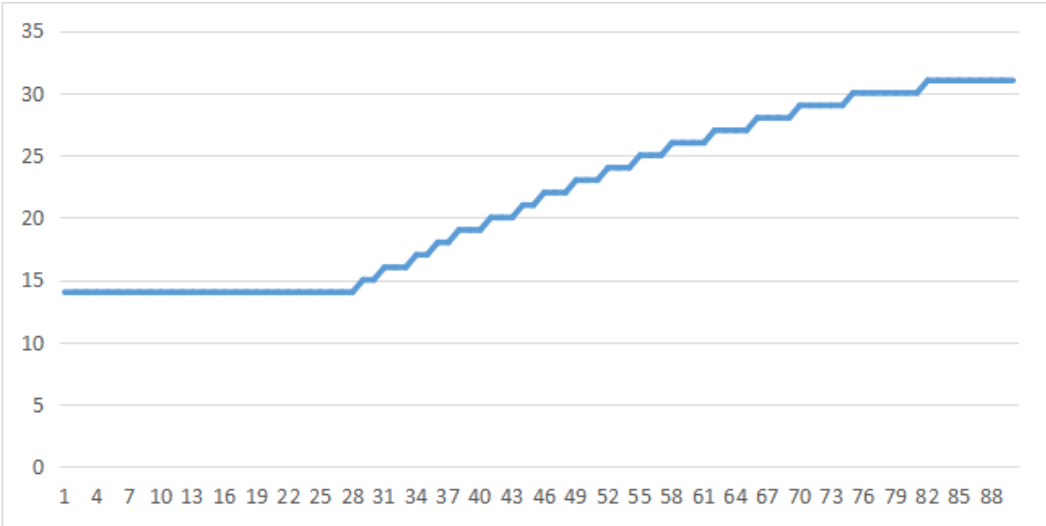


**Fig 8.** Relationship between the angle of the car and the number of parking spaces

Since the parking spaces are arranged in parallel when $\theta = 0°$, W=5.5m, the relationship between the angle $\theta$ and each parameter can be obtained by calculation as shown in Table 2.

**Tab 2.** The relationship between the angle and the number of parameters

| 角度 | … | 27 | 29 | 31 | 34 | 36 | 38 | 41 | 44 | 46 | 49 | 52 | 55 | 58 | 62 | 66 | 70 | 75 | 82 | … |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26.5/Width | … | 4.7 | 4.9 | 5.0 | 5.1 | 5.3 | 5.4 | 5.5 | 5.6 | 5.7 | 5.8 | 5.9 | 5.9 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 5.8 | … |
| Channel Width | … | 2.5 | 2.5 | 2.6 | 2.7 | 2.7 | 2.8 | 2.9 | 3.1 | 3.1 | 3.3 | 3.4 | 3.5 | 3.7 | 3.9 | 4.1 | 4.3 | 4.6 | 5.0 | … |
| Max Parking Spaces | … | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | … |

Consider the first and third zones of the model as a whole. According to the principle of greedy algorithm, the maximum number of parking spaces xi that can be accommodated in one zone and three zones is preferentially placed in the parking lot. The channel width setting needs to meet the maximum turning radius of the car. It can be seen from equation (1) that different angles $\theta$ correspond to different channel widths. The relationship between the angle $\theta$ and the length L of the parking space is calculated as shown in Fig. 9.

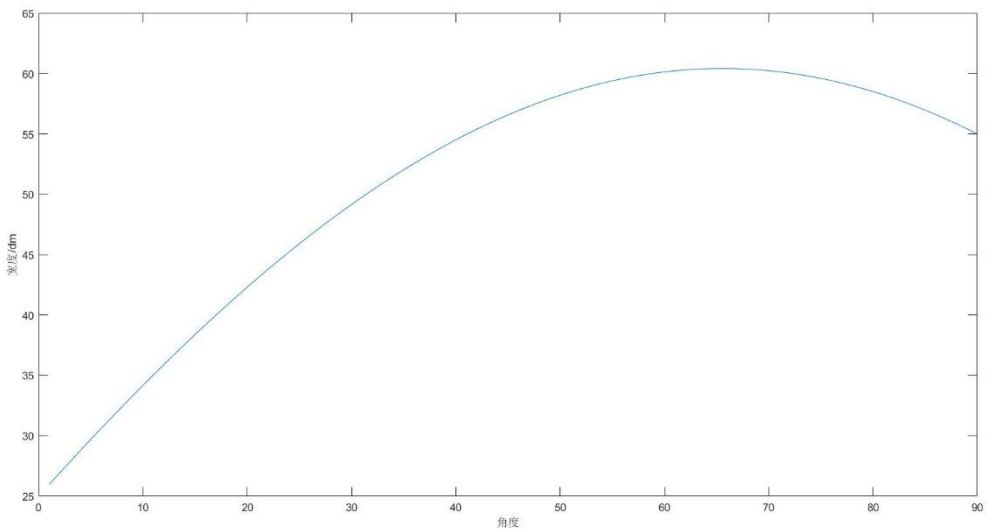


**Fig 9.** Correspondence diagram between angle and parking length

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It can be seen from the figure that $\theta = 66°$ at that time is the peak value of the occupied length of the parking space. When the angle is $0° \leq \theta < 66°$, L increases with the increase of the angle; $66° < \theta \leq 90°$, L decreases at that time. According to the relationship between the angle of the combination and the width R of the channel, as shown in Fig.10, the width distance occupied by different design angles of each parking space can be obtained, and the local optimal solution can be obtained by using the greedy algorithm, and the local maximum solution can be obtained by enumerating the different angles. Excellent solution, get the global optimal solution.

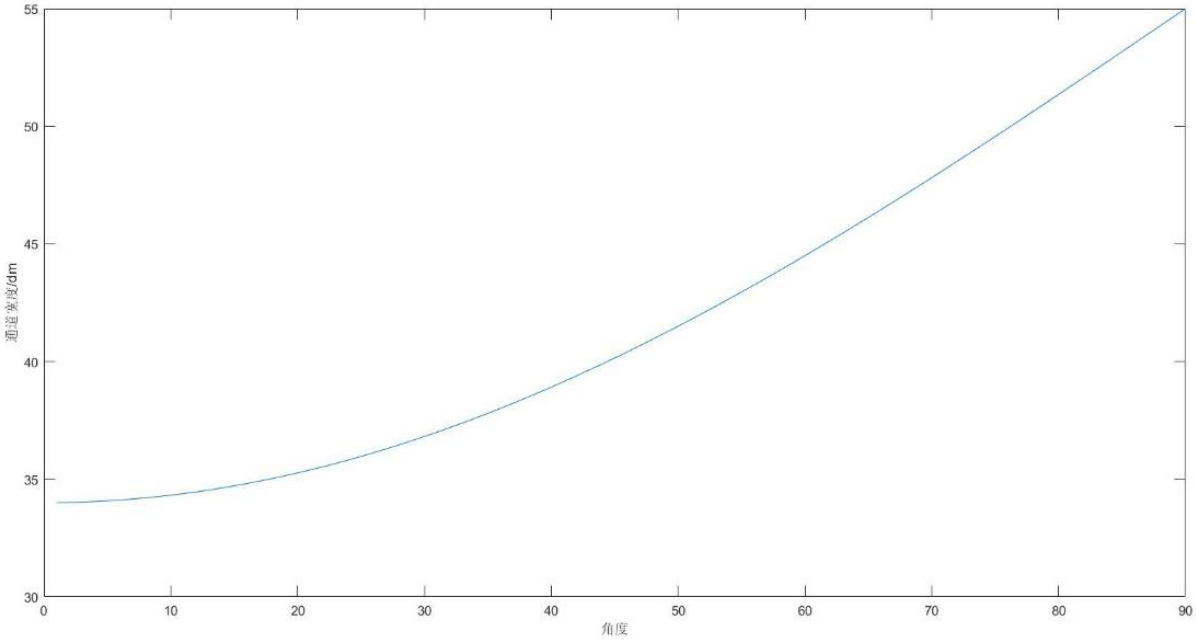


**Fig 10.** Angle and channel width diagram

According to the calculation, when the parking spaces in Zone 1, Zone 3 and Zone 2 are parked at 28.67°and 81.93°respectively, the parking lot can accommodate the largest number of parking spaces, with 92 parking spaces. When the parking space is parked at 28.67°, it can accommodate 15 parking spaces in the east-west direction; when the parking space is parked at 81.93°, it can accommodate 31 parking spaces in the east-west direction. The parking lot plan is shown in Figure 11.

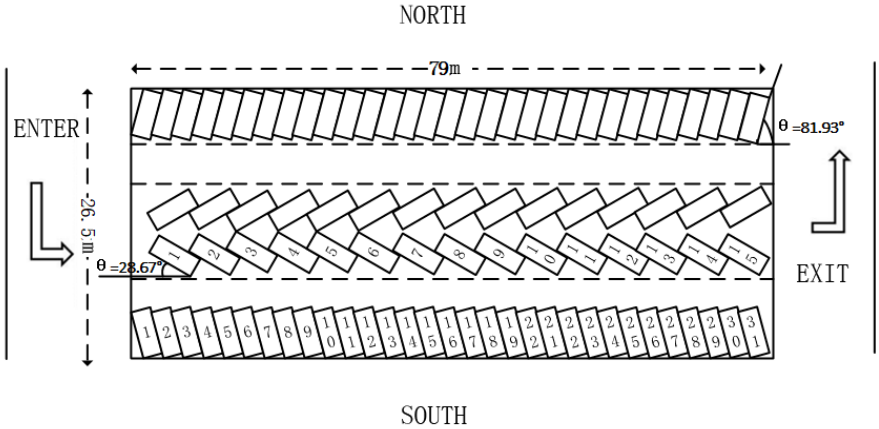


**Fig 11.** Rectangular parking lot design

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## 4. DESIGN SCHEME BASED ON GRID-SEGMENTATION

In this section, we use the greedy algorithm to solve the problem of merging the smallest grid unit in the shopping mall parking lot, and add the smallest grid unit to the merged parking area area arrangement. Each time a new ui is added, P is reserved as the maximum value. When the same maximum value occurs, one of the schemes is randomly reserved until all the merges are completed. The greedy algorithm used in this paper has a complexity of $O(KI^2)$.

Programming through Matlab, the greedy algorithm solves the running time as shown in Figure 12. When the greedy algorithm retention scheme number P is a fixed value, as the minimum number of grid cells I increases, the time taken for the minimum grid unit to merge is approximately equal to the polynomial time curve. As P increases, the time-consuming curve approximates a linear curve.

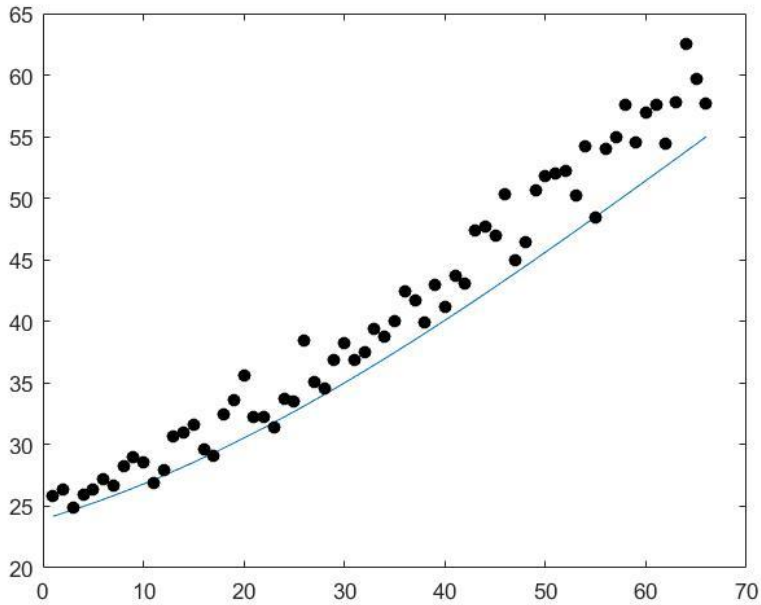


**Fig 12.** Greedy algorithm running time

Solving the final parking lot arrangement as shown in Figure 13.

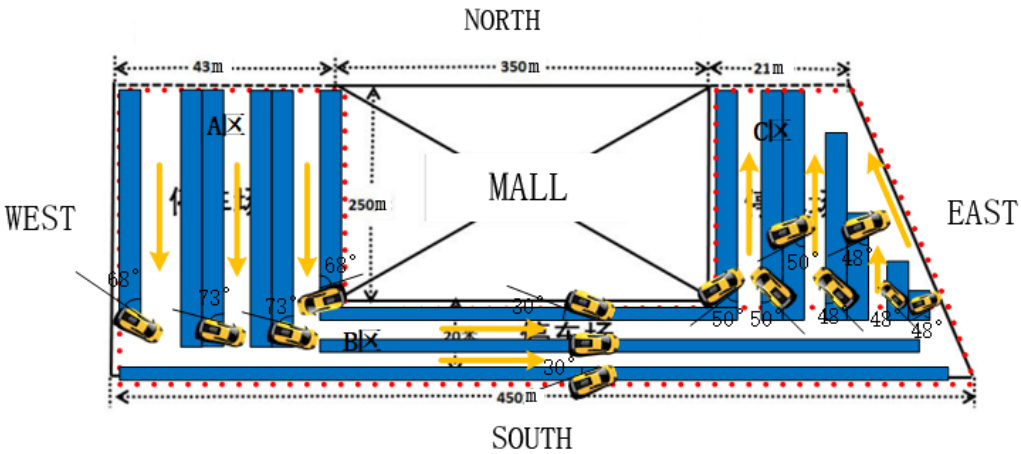


**Fig 13.** Plan view of shopping mall parking lot

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For the convenience of description, we divide the parking lot into three areas, namely, A, B, and C.

In Area A, there are four parking areas. The angle between the left and right parking spaces is 68°, and the angle between the parking spaces in the middle two parking areas is 73°. It is calculated that the number of parking spaces in The parking area in the A area from the westernmost parking area is 66, the number of parking spaces in the east is 50. The number of two trains in the middle is 140.

The angles of the three parking areas in Area B are both 30°, and the number of parking spaces is 64, 70, and 87 from north to south.

The parking spaces in the three parking areas in the west of Area C are all 50°, and the parking spaces in the four parking areas in the east are 48°. From west to east, the number of parking spaces in the parking area is 75, 150, 48, 36 respectively.

According to the calculation, the maximum number of parking spaces in the mall parking lot is 926.

## 5. CONCLUSION

In the rectangular parking lot, the entrance and exit are specified from west to east, so the basic prototype of the parking space is designed as the parking space from south to north. According to the design of the length and width of the parking lot, the diagonal arrangement between the horizontal arrangement and the vertical arrangement calculates the width of the parking belt. A combined calculation using a greedy algorithm. Since the greedy algorithm can only guarantee local optimization during the solution process, global optimization cannot be guaranteed. Therefore, other algorithms can be considered for solving the objective function of the model.

In the mall parking lot, the basic position of the entrance and exit is specified. Since the available parking area is an irregular polygon, the parking area is divided into basic cells by using the grid division method, and the method in the rectangular parking lot problem is used for each unit. The distribution of the optimal parking spaces is assigned, and the optimal solution is obtained by combining the intervals. The grid segmentation method based on greedy algorithm can effectively reduce the calculation time while improving the parking space capacity in the parking area, which is beneficial to improve the accuracy of the parking space design of the irregular parking lot.

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