A General Algorithm for Rectangular Parking Optimization Design

Junhao Huang¹, Tianchi Liao², Haining Kang² and Jianjun Wang*²

¹College of Information Engineering, Sichuan Agricultural University, Ya'an City, Sichuan Province, 625000, China
²School of Science, Sichuan Agricultural University, Ya'an City, Sichuan Province, 625000, China

* Corresponding Author’s E-mail: jianjunw55@163.com

Abstract. The optimization design of parking is a comprehensive programming solution with a relatively large practical value. Determining the optimal design of the parking lot is the main goal of this paper. Before the algorithm design, this paper first deduces the calculation formula of the width of the lane in the parking lot; then refines the parking lot design problem into the choice of the layout of the double-side parking channel and the layout of the single-side parking channel, and the choice scheme is based on the greedy algorithm. On this basis, we establish a general optimization design algorithm for the rectangular parking lot, which is essentially a programming algorithm. Finally, this paper selects an example to solve the general algorithm by SA algorithm. It proves that the general algorithm meets the requirements and has practical value.

1. Introduction

With the development of global urbanization, global land resources become increasingly scarce. [1]. For any urban area in the world, the full use of land resources needs to be solved [2]. Parking is a common land-use facility that plays a very important role in urban areas. With the development of the economy, the number of cars has increased, and parking lots have gradually become a sought-after land resource [3]. As far as China is concerned, the average private car has only 0.398 parking spaces, parking problems have become particularly severe [4]. Therefore, in order to make better use of land resources and effectively solve the problem of imbalance between supply and demand of parking spaces, the management department needs to integrate various factors to design the parking lot to ensure that as many parking spaces as possible are planned under reasonable circumstances.

In real life, most parking lots can be classified as rectangular parking lots, and their structure is shown in Figure 1. At present, such parking lots lack a common and efficient design method [5]. In this paper, a general optimization design algorithm is proposed to make the rectangular parking lot designed by this algorithm have as many parking spaces as possible.
2. Derivation of formula for calculating the width of parking lot lane

The determination of the width of the lane is particularly significant when designing a parking lot. The width of the traffic lane width $G$ is mainly determined according to the path when the vehicle drives from the passage to the parking space. The movement process of the vehicle from the straight passage to the parking space is as follows:

$$G = R_1 - R_2 \cdot \cos(\theta_1) = R_1 - R_2 \cdot \cos(\theta_1)$$  \hspace{1cm} (1)

If the width $\omega$ of the traveling vehicle is known, the turning inner radius $R_2$ is $R_1 - \omega$. After a step-by-step derivation, the formula for calculating the width $G$ of the driving lane obtained in this paper is as follows:

$$G(\theta) = R_1 - (R_1 - \omega) \cdot \cos(\theta)$$  \hspace{1cm} (2)

The derivation of the calculation formula of the lane width plays an important role in establishing the optimization algorithm below. It is an important variable that affects the global design.

3. Two basic layouts for parking lot design

There are two basic layout units for parking lots: one is a double-sided parking channel layout, and the other is a single-sided parking channel layout. This paper will first analyse it separately, and then combine the subsystems to program the rectangular parking lot.

3.1 Research on the layout of double-sided parking channels

The layout of the double-side parking passage refers to a layout unit with available parking spaces on both sides of the traffic lane, and is also the most commonly used subsystem in the parking lot design [6]. The layout of the double-side parking channel is as follows:
Figure 3. Diagram of double-sided parking channel layout

In Figure 3, \( H_s \) represents the width occupied by the unit double-sided parking channel layout; \( L \) represents the length of the parking space, and \( W \) represents the width of the parking space.

For the two-sided basic layout shown in Figure 3, there are two key indicators affecting the parking system design, namely the width \( H_s \) of the basic layout and the number \( N_c \) of parking spaces that can be set in the basic layout.

In order to obtain the width \( H_s \) of the double-sided basic layout, we need to solve the \( h_1 \) and \( h_2 \) in Figure 3 respectively. The formula is:

\[
h_1 = L \cdot \sin(\theta), \quad h_2 = W \cdot \cos(\theta).
\]

From Figure 3, we can analyse the relationship between \( H_s \) and \( h_1 \) and \( h_2 \) as follows:

\[
H_s = G + 2 \cdot (h_1 + h_2)
\]

(3)

It can be seen from Figure 3 that \( l \) was wasted, \( L_r \) is the actual width of each parking space. In the case where the total length \( L_s \) is known, the formula for the number of parking spaces \( N_c \) that can be set for the double-sided basic layout is as follows:

\[
N_c = \frac{2 \cdot \left( L_s - l - \left( L_s - l \right) \% L_s \right)}{L_s}
\]

(4)

In this article, \% represents the modulo operator. The formula for obtaining \( l \) and \( L_r \) is as follows:

\[
\begin{align*}
l &= (L - L_s \cdot \cos(\theta)) \cdot \cos(\theta) \\
L_r &= \frac{W}{\sin(\theta)}
\end{align*}
\]

(5)

Bringing the formula (5) into the formula (4) gives the final expression of \( N_c \) as:

\[
N_c = 2 \cdot \left( L_s - \left( L - \frac{W \cdot \cos(\theta)}{\sin(\theta)} \right) \cdot \cos(\theta) - \left[ L_s - \left( L - \frac{W \cdot \cos(\theta)}{\sin(\theta)} \right) \cdot \cos(\theta) \right] \% \frac{W}{\sin(\theta)} \right)
\]

(6)

3.2 Research on the layout of single-sided parking channels

The layout of the single-side parking channel, that is, the parking lane has only one parking space on one side, and the parking space cannot be set on the other side due to insufficient space.

The layout of the single-sided parking channel is also one of the basic layouts of the parking lot. When the width of the layout of the double-sided parking lane is insufficient, the single-sided parking lane layout acts as a "patch", filling the remaining space so that the space can be fully utilized.

The diagram of the layout of the single-side parking channel is as follows:
As with the analysis of 3.1., the layout of the single-side parking channel also requires the width \( H_s' \) and the number of parking spaces \( N_c' \) that can be set in the basic layout. The formula for calculating \( H_s' \) is:

\[
H_s' = G + h_i + h_2
\]  

(7)

The formula for \( N_c' \) is:

\[
N_c' = \frac{W - \left( L - \frac{W \cdot \cos(\theta)}{\sin(\theta)} \right) \cdot \cos(\theta) - \left( L - \frac{W \cdot \cos(\theta)}{\sin(\theta)} \right) \cdot \cos(\theta) \% \frac{W}{\sin(\theta)}}{\sin(\theta)}
\]  

(8)

4. Optimal algorithm

Regardless of the complexity of the layout of a parking lot, the basic layout options available are only the above two. The specific impact of the two basic layouts on the optimization target can be specifically reflected by \( H_s \) and \( N_c, H_s' \) and \( N_c' \).

This paper firstly deals with the choice of basic layout based on greedy algorithm [7]. Then prioritizes the layout of double-sided parking channels. When the remaining width is not enough, consider the layout of single-side parking channels. Based on the greedy algorithm, the optimal \( \theta \) is determined using a single-objective nonlinear programming algorithm. The specific steps are as follows:

**Step1:** Calculate the number of parking spaces contributed by the layout of the double-sided parking channel based on the greedy algorithm \( N_{\text{double}} \):

\[
N_{\text{double}} = \frac{W_i - (W_i \% H_s)}{H_i} \cdot N_c
\]  

(9)

**Step2:** Calculate the number of parking spaces contributed by the layout of the single-sided parking channel \( N_{\text{one}} \):

\[
N_{\text{one}} = \frac{(W_i \% H_s) - (W_i \% H_s \% H_s')}{H_s'} \cdot N_c'
\]  

(10)

**Step3:** Optimization design of rectangular parking lot based on nonlinear programming algorithm:
The algorithm established by formula (11) is a general optimization design algorithm for rectangular parking lots. Solving the programming algorithm can obtain an optimal scheme close to the global optimal value.

5. Case Study

After establishing a general optimization design algorithm, this paper selects a design example to test the performance of the algorithm.

The rectangular parking lot selected in this paper meets the following conditions:

\[ L = 5.5 \text{m}, \quad W = 2.5 \text{m}, \quad R_1 = 5.5 \text{m}, \quad L_1 = 79 \text{m}, \quad W_1 = 26.5 \text{m}, \quad \omega = 1.8 \text{m} \]

In order to improve the efficiency of the algorithm, we choose the SA algorithm to solve the general algorithm (11) intelligently. SA is a stochastic optimization algorithm for solving combinatorial optimization problems. It takes the similarity between the solution of the optimization problem and the annealing process of the physical system as the starting point to achieve the goal of solving the global optimization problem [8].

For the conditions given in this example, our solution results are as follows:

(1) Best parking angle: 69.53°
(2) At the optimum angle, the width of the lane: 4.21m
(3) At the optimum angle, a row of vehicles can be placed: 29 cars
(4) At the optimum angle, A total of vehicles that can be placed in the parking lot: 87 cars

The final parking lot plan is drawn by the general optimization design algorithm:

![Figure 5. Graphic design of parking lot](image)

6. Conclusion

In this paper, a general rectangular parking lot optimization design algorithm is established. The algorithm performed well on the example with the high efficiency of the algorithm, which met the practical standards. The above results showed that our algorithm can be a potential choice for parking lot engineering designed.
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