Research on the Optimal Spacing of Urban Environmental Sanitation Facilities: Smoke-extinguishing Pillar as an Example

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Abstract: Since the spacing of urban environmental sanitation facilities is not reasonable enough, customers and service desks in the queuing theory were used to simulate the environmental sanitation facilities and pedestrians in daily life, and the established queuing system was then optimized based on the purpose of minimum costs. This optimization model was used to determine the optimal spacing of the sanitation facilities for street-like linear sites, and quantify the positive and negative utility of whether garbage is thrown into the sanitation facilities. Moreover, the optimal spacing of the sanitation facilities on street-like linear places was calculated according to the coefficient "k" and the maximum tolerable distance "s" of pedestrians holding a piece of garbage. Moreover, an algorithm for park-like flat sites was provided by establishing a set covering model. Then the maximum tolerable distance of pedestrians holding a piece of garbage was obtained through field research, which was then used in practical calculation. Finally, conclusions and suggestions were given correspondingly.

1. Introduction
With the rapid development of national economy and the continuous improvement of people's living standards, the awareness of environmental protection has gradually increased. Civilized smoking facilities in urban areas play an indispensable role in protecting the city environment and maintaining the cleanliness of streets and public places. Under the limitation of hardware resources, city planners can improve the utilization of hardware resources by reasonably planning the location and spacing of the civilized smoking facilities, thus achieving the purpose of saving resources. This move also actively answers the important proposal of "accelerating the construction of a resource-saving and environment-friendly society" clearly put forward in the "Twelfth Five-Year Plan". Taking the smoke-extinguishing pillar as an example, this paper studied the optimal spacing of the smoke-extinguishing pillar on the street-like linear sites. Without any clear standard for the setting distance between two smoke-extinguishing pillars, relevant departments only arrange them based on past experience and pedestrian volume. However, as a kind of intensive device highly needed in each city, the smoke-extinguishing pillar is an important facility for the construction of a civilized smoking environment. Once the spacing of the smoke-extinguishing pillar is too narrow, a huge waste of resources may be caused, while the original goal of setting the pillar may not be achieved in the case
of too large spacing. Therefore, it is extremely valuable to explore a setting standard for the smoke-extinguishing pillar that can be used as a reference for different cities.

2. Model Assumptions and Establishment

2.1. Model Assumptions
After conducting a behavioral study on smokers, it can be concluded that the process of smoking cigarettes can be divided into two parts, with the smoking of a cigarette being the first part, while the looking for a smoke-extinguishing pillar for a cigarette butt in hand being the second part. From the research of the above-mentioned behaviors, it can be found that there is a certain relationship between the distance that the smokers can tolerate a cigarette butt in their hands and the distance between two pillars. In order to obtain the optimal spacing between two pillars, it is important to figure out the relationship between the distance of smokers tolerating a cigarette butt in their hands and the optimal spacing between two pillars. To better facilitate the study of this problem, following two assumptions are made before giving the model:

a. Assuming that every smoker has a maximum distance for tolerating the holding of a cigarette butt;

b. Assuming that the studied street is a straight street, and the influence of the width of the street and other things on the placement of the smoke-extinguisher pillar can be ignored.

2.2. Model of Queuing Theory
Queuing theory, an important mathematical research method in operation, is often used to study stochastic service systems. Though people will encounter all kinds of queuing problems in their daily life, the basic problem studied by queuing theory is the problem of system optimization, and its main purpose is to make the system stay at the optimal or most reasonable state. In daily life, because the smoke-extinguish pillar is a fixed body, it is the smokers who move themselves to find a pillar. In this study, in order to use the queuing theory to figure out the optimal spacing between two pillars, people were regarded as a fixed body, while the pillars as mobile ones. In other words, people were the service desk in the queuing theory, while pillars were the ones who queued to receive the cigarette butts in the hands of the smokers, namely the customers in the queuing system. The average distance between two pillars was set as $c$, then the average arrival rate of one certain pillar was $\lambda = \frac{1}{c}$.

Moreover, the maximum distance of smokers tolerating the holding of a cigarette butt was $s$, which was corresponding to the service distance of the service desk in the queuing theory. If no pillar was found beyond the distance $s$, the cigarette butt would be thrown out of the pillar, which in return means the pillar failed to enjoy its service, and the average service rate of the service desk was $u = \frac{1}{s}$.

There are idle periods and busy periods in the queuing theory.

Busy period: It refers to the period from the time the customer arriving at the available service organization to the service organization becoming vacant again, namely the time that the service organization is in its continuous busy time.

Idle period: It refers to a time opposite to the busy period, namely, a time which the service organization remains idle. The idle period and busy period always appear alternately in the queuing system.

In balanced states, the busy period $B$ and the idle period $I$ are generally random variables, so it may be rather troublesome to find their distribution. Therefore, it is suggested to find the average busy period $\overline{B}$ as well as the average idle period $\overline{I}$. Due to the fact that the probability of the busy period and the idle period is $\rho$ and $1-\rho$, respectively, ($\rho = \frac{\lambda}{\mu}$, and $\rho$ is the service intensity of the
queuing system), the ratio of the length for the busy period and the idle period in this duration can be considered as \( \rho : (1 - \rho) \). What's more, the ratio of the average length for the busy period \( \bar{B} \) and the idle period \( \bar{I} \) should be \( \rho : (1 - \rho) \) as well, namely \( \frac{\bar{B}}{\bar{I}} = \frac{\rho}{1 - \rho} \). The interval of the idle time enjoyed by the organization still obeys the negative exponential distribution of parameter \( \lambda \). Therefore, the average idle period is \( \frac{1}{\lambda} \), consequently, the average busy period is

\[
\bar{B} = \frac{\rho}{1 - \rho} \cdot \frac{1}{\lambda} = \frac{1}{\mu - \lambda}.
\]

2.3. Indexation and Quantification of Utility
The concept of utility was first proposed by Daniel Bernoulli in the explanation of the St. Petersburg Paradox, with the purpose of challenging the standard of decision-making with the expected value of money. Later it was widely used in economics as one of the most commonly used concepts in economics. With the increasing integration of various disciplines, the term utility is not only used in economics, but also widely used in other disciplines. For example, utility theory in sociology is used as a measure of happiness and satisfaction, with positive utility representing happiness, and negative utility representing pain.

2.3.1. Construction of Indicators
Utility was used to measure the consequences of whether the cigarette butts are thrown into the smoke-extinguishing pillars or not. The positive utility will be brought by throwing the cigarette butts into the pillar, while the negative utility will be brought by throwing the cigarette butts outside the pillar.

After considering the scientificity, comparability, quantifiability and availability of the indicators, the indicator system constructed in this paper is shown in Table 1. The indicator system included two first-level indicators, which represent the positive utility and the negative utility, respectively. Following is main content included:

The positive utility was composed of three secondary indicators: reduced workload of sanitation workers, enhanced city image and improved living conditions of residents.

The negative utility was composed of three secondary indicators: increased smoke-extinguishing pillars, increased shame among consumers and damage of fire caused by cigarette butts.

| Table 1 Indicators of positive and negative utility |
|-----------------------------------------------|
| Dimension | Indicators |
|-----------------------------|-----------------------------|
| Positive utility | Reduced workload of sanitation workers |
| | Enhanced city image |
| | Improved living conditions of residents |
| Negative utility | Increased smoke-extinguishing pillars |
| | Increased shame among consumers |
| | Damage of fire caused by cigarette butts |

2.3.2. Explanation of Indicators
1. Reduced workload of sanitation workers: Cigarette butts, as a relatively small type of garbage, are extremely troublesome to be cleaned up. Some cigarette butts will get stuck in various brick slots and gaps, therefore, it will make sanitation workers spend a lot of energy and time cleaning up cigarette butts. However, if the smoker throws cigarette butts into the smoke-extinguishing pillar, the sanitation workers only need to clean the pillar regularly, which, in the end, can save a lot of time for other work. Reducing the workload of sanitation workers, through setting indexes from a quantitative perspective,
can guarantee more work within prescribed working hours. In this way, the number of sanitation workers can be decreased from the perspective of cost, and the wages of sanitation workers are reduced from the perspective of marginal cost. Though it is distinct in different provinces and cities, the wages of sanitation workers are close to the minimum wage standard. Therefore, the minimum wage standard in each province was used in this paper to measure the reduction in the workload of sanitation workers. Moreover, the minimum wage standards in the provinces in China were divided into five levels from high to low. With the application of grading system, provinces in the first level were scored five points, while those in the fifth level were rated one point.

2. Enhanced city image: While enjoying rapid economic growth, different provinces and cities gradually shift their focus on environmental protection. Regarding "No Cigarette Butts On The Ground" as their publicity slogan, it is undoubted that clean and tidy streets can be conducive to the presenting of a beautiful image for different cities. Moreover, the enhancement of the city image is beneficial for the attraction of a large number of tourists, and the vigorous development of local tourism. Therefore, tourism income was selected to measure the image of a place in this paper. Provinces in China were divided into five levels from high to low according to its tourism income. With the application of grading system, provinces in the first level were scored five points, while those in the fifth level were rated one point.

3. Improved living environment of residents: National sanitary city means that the sanitary environment of a city has reached a nationally recognized standard, and the living environment of residents is at a high level. Therefore, the number of how many cities in a province selected as national sanitary cities is used in this article to measure the residential living environment of a province. According to its number of the national sanitary cities, provinces in China were divided into five levels from high to low. With the application of grading system, provinces in the first level were scored five points, while those in the fifth level were rated one point.

4. Increased smoke-extinguishing pillars: The main reason why smokers do not throw cigarette butts into the smoke-extinguishing pillars is that the distance between the two is too large, making the smokers fail to find the smoke-extinguishing pillars accurately within limited time. Therefore, it is necessary to increase the number of smoke-extinguishing pillars for the realization of "No Cigarette Butts On The Ground". The number of increase depends on how much the city attaches importance to this aspect, and the item "No Cigarette Butts On The Ground" is included in the evaluation standard of national civilized cities. Regarding the number of national civilized cities as an indicator of the number of the smoke-extinguishing pillar, it can be showed that the more national civilized cities a province has, the more attention this province is paid to the goal of "No Cigarette Butts On The Ground". When smokers are found to throw cigarette butts on the ground, this province will intensify its efforts to increase the smoke-extinguishing pillars, thus increasing the cost and bringing negative utility. According to the number of national civilized cities in each province, provinces were divided into five levels from high to low. The provinces in the first level were scored five points, while those in the fifth level were rated one point.

5. Increased shame among smokers: When smokers throw cigarette butts on the ground, they will have a sense of shame. The intensity of such shame is generally related to their level of education. The level of education was selected in this paper to measure the level of shame among smokers. According to the proportion of the population with a college degree or above in the total population in each province, provinces in China were divided into five levels from high to low, and the grading system was used, with provinces in the first level scored five points, while those in the fifth level scored one point.

6. Damage of fire caused by cigarette butts: Cigarette butts thrown away by smokers contain sparks prone to fire. China suffers heavy losses due to fires caused by cigarette butts every year. According to the annual damage of fire caused by the random discard of cigarette butts, provinces in China were divided into five levels from high to low, and the grading system was used, with provinces in the first level scored five points, while those in the fifth level scored one point.

Supposing the utility brought by smokers throwing cigarette butts out of the smoke-extinguishing
pillar is $p$, while the utility brought by smokers throwing cigarette butts in the smoke-extinguishing pillar is $q$, then the utility coefficient is:

$$k = \frac{q}{p} = \frac{1}{3} \frac{x_1 + x_2 + x_3}{y_1 + y_2 + y_3}$$

(1)

$x_1, x_2$ and $x_3$ are the scores of reduced workload of sanitation workers, enhanced city image and improved living conditions of residents respectively. $y_1, y_2$ and $y_3$ are the scores of increased smoke-extinguishing pillars, increased shame among smokers and damage of fire caused by cigarette butts.

2.4. Street-like linear sites

The established queuing system was optimized to determine the optimal spacing, and the realization of minimizing the cost was regarded as the optimization objective when building an optimization model. The idle period means that the service organization is idle and the cigarette butts have not been thrown into the pillar, indicating that the smoke-extinguishing pillar does not receive service. The busy period means that service organization is working and the cigarette butts have been thrown into the pillar. The waiting cost of the smoke-extinguishing pillar is expressed by the loss caused by the unsuccessful throwing of the cigarette butt into the pillar, that is, the cost of the idle period. When the smoke-extinguishing pillar is served, the service desk also has its service costs. The purpose of this paper is to optimize these two parts, making the sum cost the smallest. The cost of the idle period is the cost brought by the landing of cigarette butts, that is $p$, while the service cost may be difficult to be calculated or estimated, so it was converted in this paper. The service desk in service means the cigarette butt has not fallen on the ground, which will bring positive utility $q$. Hence, utility $q$ is used as service cost. The relationship between service level and cost is shown in Figure 1 below.

\[
\begin{align*}
\min Z &= \frac{1}{\mu - \lambda} \cdot q + \frac{1}{\lambda} \cdot p \\
\text{While} & \quad \mu = \frac{1}{s} \\
& \quad \lambda = \frac{1}{c}
\end{align*}
\]
\[ \rho = \frac{\lambda}{\mu} \]  

(5)

Substitute formula (3), formula (4), and formula (5) into formula (2) to get

\[ \min Z = \frac{q_{sc} c - s}{c - s} + cp \]  

(6)

Take the derivative of \( c \) from formula (6)

\[ \text{Supposing } \frac{dz}{dc} = \frac{q_{sc}(c - s) - q_{sc} c}{(c - s)^2} + p = 0 \]  

(7)

Simplify and solve formula (7)

\[ c = s\left(\frac{q}{p} + 1\right) \]  

(8)

Find the second derivative of formula (6)

\[ \frac{d^2z}{dc^2} = \frac{2qs^2(c - s)}{(c - s)^4} \]  

(9)

Substitute formula (8) into formula (9), the result of formula (9) is greater than 0, that is, the minimum value is obtained by \( \min Z \) when \( c = s\left(\frac{q}{p} + 1\right) \).

2.5. Park-like Flat Sites - Set Covering Model

In real life, smoke-extinguishing pillars exist not only in linear locations such as streets, but also in various public places, which are different from linear places, for they contain many types of shapes, including circular, rectangular, and irregular shapes. The placement of the smoke-extinguishing pillars must be calculated according to their coverage area, hence the queuing theory is not applicable here. The set covering model was adopted in public places by this article.

The set covering model \(^4\) is a common model in the discrete location model, which can be used to study the problem of the minimum number of facilities or the minimum cost under the premise of covering all demand points of customers. Through the establishment of the corresponding objective function and constraint conditions, operations research related knowledge and computers have been used to solve the function \(^5-7\). In this paper, integer programming in operations research was used to establish the objective function and constraint conditions, and the lingo software in the computer was used to solve the problem.

In order to transform practical problems into mathematical models, following assumptions are made in this paper:

(1) The Euclidean distance calculation formula was used to calculate the distance between two points. With the coordinates of \( i \) being \((x_i, y_i)\), and the coordinates of \( j \) being \((x_j, y_j)\), it can be known that the distance between \( i \) and \( j \) is \( d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \). Additionally, \( N_i = \{j \mid d_{ij} \leq S\} \) is followed \(^8-9\).

(2) The locations of demand points and facilities in this paper were represented by grid type. The mathematical model established is as follows:

\[ \min \sum_j X_j \]  

(10)

\[ st. \sum_{j \in N_i} X_j \geq 1 \quad \forall i \in I \]  

(11)
\[ x_j = \{0, 1\} \quad \forall j \in J \]  

(12)

Where

- \( I \): A collection of demand points, \( \{i \in I\}, i = 1, 2, 3, ..., n \)
- \( J \): A collection of candidate facilities, \( \{j \in J\}, j = 1, 2, 3, ..., m \)
- \( d_{ij} \): The distance between two points.
- \( S \): The covering radius of each smoke-extinguishing pillar.
- \( N_i = \{j \mid d_{ij} \leq S\} \): A collection of candidate facilities that can cover demand point \( i \) and conform to \( d_{ij} \leq S \).

\[ x_j = \begin{cases} 1 & \text{Candidate facility } J \text{ has been chosen.} \\ 0 & \text{Candidate facility } J \text{ has not been chosen.} \end{cases} \]

3. Empirical Results and Analysis

3.1. Empirical Results

Field survey was used to collect data for the indicator of the maximum distance that a smoker can hold cigarette butts. Paper questionnaires were distributed in some streets and public places in Chang'an and Yanta Districts of Xi'an. A total of 1,200 copies were issued, and 1,000 valid questionnaires were actually collected. The statistical distribution is as follows.

| Maximum distance/m | Number/r |
|--------------------|----------|
| <20                | 10       |
| 20-40              | 90       |
| 41-60              | 230      |
| 61-80              | 560      |
| 81-100             | 80       |
| >100               | 30       |
3.2. Street-like Linear Sites

It can be seen from Table 2 that the maximum distance that a smoker can hold cigarette butts is concentrated in 60-80 m, and the optimal spacing under different conditions can be solved by MATLAB.

| $s/m$ | 20   | 40   | 60   | 80   | 100  | 120  |
|-------|------|------|------|------|------|------|
| $k$   | 0.2  | 28.944 | 57.889 | 86.833 | 115.777 | 144.721 | 173.666 |
|       | 0.4  | 32.649 | 65.298 | 97.947 | 130.596 | 163.246 | 195.895 |
|       | 0.6  | 35.492 | 70.984 | 106.476 | 141.968 | 177.560 | 212.952 |
|       | 0.8  | 37.889 | 75.777 | 113.666 | 151.554 | 189.443 | 227.331 |
|       | 1.0  | 40.000 | 80.000 | 120.000 | 160.000 | 200.000 | 240.000 |
|       | 1.2  | 41.909 | 83.818 | 125.727 | 167.636 | 209.544 | 251.453 |
|       | 1.4  | 43.664 | 87.329 | 130.993 | 174.657 | 218.322 | 261.956 |
|       | 1.6  | 45.298 | 90.596 | 135.895 | 181.193 | 226.491 | 271.789 |
|       | 1.8  | 46.833 | 93.666 | 140.498 | 187.331 | 234.164 | 280.997 |
|       | 2.0  | 48.284 | 96.568 | 144.853 | 193.137 | 241.421 | 289.706 |

Note: $K$ is the utility coefficient of the positive and negative effects of smoking consumers throwing cigarette butts into the pillar.

3.3. Park-like Flat Sites

From the above statistical data, it can be seen that the maximum distance that a smoker hold cigarette butts is concentrated in 60-80 m. The following analysis of examples was calculated with taking 60 m as an example. The maximum distance that a smoker can hold a cigarette butt is 60 m, which is equivalent to the maximum covering radius of a smoke-extinguishing pillar being 60 m. A public place is divided into 15 demand areas. Assuming that these 15 demand areas all meet the criteria for candidate smoke-extinguishing pillars, the purpose of analyzing the calculation example is to select a number of pillars from the 15 candidate smoking-extinguishing pillars (in demand areas), thus satisfying all the 15 demand areas. Without losing its generality, 15 demand areas (after centralization) are randomly generated in an area of 100 m×100 m, whose specific locations are as shown in the
Since the coordinates of each point have already been known, the distance between any two of these 15 points could be calculated below. The specific distance is as follows:

Table 4 Distance between any two points

|   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 0   | 41.2| 66.0| 25.1| 53.0| 70.7| 87.7| 81.9| 100.6| 77.6| 111.7| 86.4| 111.5| 93.2| 97.1|
| 2 | 41.2| 0   | 25.1| 24.5| 64.4| 62.6| 78.1| 75.3| 87.7| 86.4| 99.7| 89.6| 102.2| 94.5| 103.2|
| 3 | 66.0| 25.1| 0   | 37.2| 53.0| 70.7| 87.7| 81.9| 100.6| 77.6| 111.7| 86.4| 111.5| 93.2| 97.1|
| 4 | 41.2| 24.5| 37.2| 0   | 50.0| 38.1| 53.9| 50.8| 64.6| 68.0| 76.3| 67.7| 78.0| 71.6| 82.3|
| 5 | 91.0| 64.4| 53.0| 50.0| 0   | 49.5| 63.2| 52.9| 80.4| 25.0| 87.3| 38.5| 81.6| 47.2| 45.4|
| 6 | 63.1| 62.6| 70.7| 38.1| 49.5| 0   | 17.0| 13.0| 32.2| 52.2| 41.8| 41.1| 40.8| 40.8| 57.4|
| 7 | 71.8| 78.1| 87.7| 53.9| 63.2| 17.0| 0   | 11.0| 17.3| 60.2| 25.0| 44.3| 24.2| 40.3| 59.5|
| 8 | 75.0| 75.3| 81.9| 50.8| 52.9| 13.0| 11.0| 0   | 28.2| 49.3| 34.4| 34.0| 30.4| 31.2| 49.7|
| 9 | 73.0| 87.7| 100.6| 64.6| 80.4| 32.2| 17.3| 28.2| 0   | 77.0| 12.4| 60.0| 20.2| 54.7| 74.3|
| 10| 106.8| 86.4| 77.6| 68.0| 25.0| 52.2| 60.2| 49.3| 77.0| 0   | 80.6| 20.1| 72.0| 29.2| 20.9|
| 11| 85.1| 99.7| 111.7| 76.3| 87.3| 41.8| 25.0| 34.4| 12.4| 80.6| 0   | 62.0| 12.2| 55.2| 74.7|
| 12| 102.1| 89.6| 86.4| 67.7| 38.5| 41.1| 44.3| 34.0| 60.0| 20.1| 62.0| 0   | 52.6| 9.2| 16.3|
| 13| 92.2| 102.2| 111.5| 78.0| 81.6| 40.8| 24.2| 30.4| 20.2| 72.0| 12.2| 52.6| 0   | 45.0| 64.1|
| 14| 103.4| 94.5| 93.2| 71.6| 47.2| 40.8| 40.3| 31.2| 54.7| 29.2| 55.5| 9.2| 45.0| 0   | 19.6|
| 15| 118.0| 103.2| 97.1| 82.3| 45.4| 57.4| 59.5| 49.7| 74.3| 20.9| 74.7| 16.3| 64.1| 19.6| 0   |

Using the above data to establish the model:
\[
\begin{align*}
\min & \sum_{j=1}^{15} X_j \\
\text{st.} & x_1 + x_2 + x_4 \geq 1 \\
& x_2 + x_3 + x_4 + x_6 + x_7 + x_9 + x_{10} + x_{12} + x_{14} + x_{15} \geq 1 \\
& x_3 + x_4 + x_5 + x_6 + x_8 + x_9 + x_{10} + x_{11} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_6 + x_7 + x_8 + x_9 + x_{10} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_7 + x_8 + x_9 + x_{10} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_8 + x_9 + x_{10} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_9 + x_{10} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_{10} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_{11} + x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_{12} + x_{13} + x_{14} + x_{15} \geq 1 \\
& x_{13} + x_{14} + x_{15} \geq 1 \\
& x_{14} + x_{15} \geq 1 \\
& x_{15} \geq 1 \\
& x_j \in (0,1) \quad x_j = 1, 2, 3, \ldots, 15
\end{align*}
\]

After solving the above 0-1 planning model using Lingo11.0, \( x_2 = x_6 = 1 \) could be got finally, namely, when the covering radius of the smoke-extinguishing pillar is 60 m, the smoke-extinguishing pillars should be set up at the second and sixth candidate points.

4. Conclusion

Based on the above results of empirical analysis, the following conclusions can be drawn:

(1) It can be seen that as the value of \( k \) increases, the value of \( c \) will gradually increase. That is to say, the greater the positive utility brought by the successful throwing of cigarette butts into the smoke-extinguishing pillars, the larger the distance between the smoke-extinguishing pillars can be set, and the greater the social resources can be saved.

(2) Making full use of the environmental protection slogan on the smoke-extinguishing pillars for guidance can increase the maximum endurance distance \( s \), thereby increasing the value of \( c \), which can save urban public resources.

(3) In general, the spacing of the smoke-extinguishing pillars on street-like linear sites can be 90-190 m. It is recommended to arrange the smoke-extinguishing pillars on both sides of traffic arterial roads and general streets with large traffic with an interval of 90 m. In short, the minimum distance should not be less than 30 m, and the maximum distance should not be larger than 190 m, which will not waste resources but will help effectively collect cigarette butts.

(4) The optimal spacing of the smoke-extinguishing pillars in park-like flat places should be determined according to the size of the place and the maximum tolerable distance of smokers. The entire area of the place can be calculated with the least smoke-extinguishing pillars via the set covering model, thus saving resources.

(5) Other urban sanitation facilities can also be calculated with reference to this method, such as garbage bins and public toilets.
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