Summer 5-28-2021

Research on the Location of Nucleic Acid Detection Institutions Based on Coverage Model

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Short Research Papers

Research on the Location of Nucleic Acid Detection Institutions Based on Coverage Model

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Abstract: We should optimize the location of nucleic acid testing institutions, consider the actual situation, and carry out differentiated management for high-risk and low-risk nucleic acid testing according to the needs of epidemic prevention and control. Based on the coverage model, the optimization model of nucleic acid detection and location of nucleic acid collection points is established with the objective of minimizing the social cost of emergency, and lingo and CPLEX tools are used to optimize the solution. The feasibility of the model is verified by an example.

Keywords: Location optimization; Coverage model; Emergency facilities; Lingo

1. INTRODUCTION

The sudden epidemic broke the original peaceful life and caused great economic losses. Sudden major emergencies, the emergency medical system is a huge test. Major emergencies are defined as events with low frequency and great impact. Once they happen, they need a lot of first-time emergency rescue and assistance from local governments and (or) countries, such as natural disasters, public health events, major production safety accidents and terrorist attacks. When COVID-19 occurs, once a city has a case, it will often carry out nationwide nucleic acid detection. How to quickly carry out the layout of emergency medical facilities is particularly important. It requires not only the maximum coverage in a short time, but also the minimum social cost. Once the emergency medical facilities are established, they will operate for a long time. It not only affects the direct cost of operation, but also has a great impact on the coverage, work efficiency and management level., It is very important to choose the right deployment location in order to reduce social costs and improve work efficiency.

2. LITERATURE REVIEW

The location problem is to use a series of methods to find the optimal location of the target facilities, so that the target facilities can meet the demand, cost, policy, environment and other requirements. The location of emergency facilities can be divided into many types according to different standards [1]. Permanent emergency facilities refer to the long-term existence of emergency facilities in a fixed place; temporary emergency facilities refer to the short-term existence in a fixed place, which is used to deal with the deployment of emergency facilities for large-scale emergencies. Emergency facilities can be divided into emergency medical facilities, emergency logistics facilities and disaster prevention and mitigation facilities in the view of usage. Disaster prevention and mitigation facilities refer to the disaster reduction and avoidance places that need to be

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established when major disasters occur. Today, the research of emergency facility location model mainly includes basic location problem, dynamic location problem, stochastic location problem, robust optimization location problem and other location problems. The basic location problem is mainly studied from the coverage model, p-median model and p-center model; the dynamic location model considers the time parameters, usually considering different locations in different time periods; the stochastic location problem considers the location problem when the parameters obey the probability distribution; the robust optimization location problem considers the location problem when the parameter distribution is uncertain location, through robust optimization model, to find the optimal results under random fluctuations; The model considered in this paper is a deterministic mixed integer programming location problem. Many scholars at home and abroad have proposed a variety of models and algorithms in the corresponding fields: Yu Dongmei et al.[2] considered the location problem of emergency facilities in the situation of facility interruption, proposed to establish an optimization model of reliability emergency facility selection with sharing uncertain demand and limited service capacity by extending MCLP model, and improved Gray Wolf algorithm to solve the model; Based on the theory of bounded rationality, Chen Gang et al.[3] consider the individual behavior of the affected residents in the perspective of survival probability of the wounded. This paper proposes the maximum robust location model for the survival probability of the wounded under uncertain demand from the tactical level; Sun huali[4] and others propose the minimum delivery time and material delivery time model in the perspective of material delivery time, and verify the effectiveness of the model with several examples; Sun jianping and others[5] study the location problem of high-speed rail emergency resources. This paper establishes the location optimization model of high-speed railway emergency resource reserve point, and uses the sequential selection genetic algorithm to solve the model, and obtains a good optimization result. Chen zhizong and others[6] consider the fairness and efficiency of emergency rescue facilities, integrate the maximum coverage model, p-center model and p-median model, and put forward a multi-objective location model, which is proved to be effective by an example.

In the above studies, the main focus is on the location of earthquake, anti-terrorism, shelters and so on. There are few studies on the location of epidemic situation, and most of the studies on the location of emergency facilities do not consider the capacity constraints and economic issues. In the epidemic situation, nucleic acid testing for the whole people should not only consider the full coverage, but also the risk of epidemic transmission caused by large-scale population flow. It is particularly important to quickly allocate the population for orderly testing and consider the social cost in the optimal solution. In this paper, based on the coverage model, an optimization model of emergency facility location with limited service capacity is established to reduce potential risks and provide scientific and reasonable decision-making basis for emergency management departments in the perspective of residents and society.

3. PROBLEM DESCRIPTION AND MODEL CONSTRUCTION

3.1 Problem description

Based on the mathematical programming method, the location of nucleic acid detection points and nucleic acid collection points in key areas, the number of detection reagents provided to them and the population they should serve are determined. Area network graph can be represented by directed graph G=(V, A), where V is a group of nodes and A is a group of arcs. The set V can be divided into $\{V_0, V_1, V_2, V_3\}$, where V_0 is the distribution center set, v_0 is the location of the supply point, and $v_0 \in V_0$ is the set of population gathering points, V_2 is the set of detection points to be selected, and V_3 is the set of collection points to be selected. The number of population at the node $v_i \in V_1$ is q_i, W_i is defined as the set of detection points to be selected within the coverage radius r_1 km of $v_i \in V_1$, $W_i \in V_2$, L_i is defined as the set of detection points at the node v_i . The collection of points to be selected within the coverage radius r_2 km of $v_i \in V_1$, $L_i \in V_3$. The route of transport vehicle from v_0 to $v_j \in V_2$ is represented by arc (v_0, v_j), the route of crowd v_i from $v_i \in V_1$ to $v_j \in V_2$ is represented by arc (v_i, v_j), the route of collection point v_k from $v_k \in V_3$ to $v_j \in V_2$ is represented by arc (v_k, v_j), and the route of crowd v_i from $v_i \in V_1$ to $v_k \in V_3$ is represented by arc (v_i, v_k).

For the convenience of analysis, assumptions are made in the following:

1) It is assumed that the test is carried out in the way of one person and one reagent;

2) Suppose that the samples collected from the collection point are sent to the nearest detection point for detection according to the shortest distance principle;

3) One person only tested once;

4) Assume that all nucleic acids are detected in the region;

5) It is assumed that the sample detection in severe epidemic areas is provided with additional detection capability, that is, the samples sent to the corresponding detection points are processed separately and are not constrained by the original detection capability.

3.2 Model building

3.2.1 Symbol description

1) Decision variables

x_{ij}: The proportion of v_j people going to v_j for testing;

x_{ik}: $v_i$the proportion of people who need to go to the collection point to receive nucleic acid collection;

y_j: 0-1 variable, when j detection point is selected, v_j = 1, otherwise v_j = 0;

g_k: 0-1 variable, when k detection point is selected, v_k = 1, otherwise v_k = 0。

2) Parameters

q_i: The number of population at node $v_i \in V_1$;

α_{ij}: Time cost and transportation cost of unit citizen inspection;

ξ_{ik}: Time cost and transportation cost of unit citizens going to collection points;

β_j: From the distribution center to each testing point j, the unit cost of testing supplies;

η_k: The transportation cost of transporting the collected samples from the collection point K to the nearest detection point for testing;

θ_k: From the distribution center to each collection point K, the cost of sample processing per unit of reagent collection;

γ_j: The fixed cost of testing point includes the salary of testing personnel and the cost of setting up testing point;

σ_k: The fixed cost of collection point includes the salary of collection personnel and the cost of setting collection point;

d^*_{ij}: Distance of residents from community v_i to detection point v_j;

v: Average travel speed of residents;

t_1: Average time spent collecting nucleic acid;

c_1: Unit travel cost of users;

c_2: Unit time cost lost by users going to test;

c_3: Unit transportation cost from reagent production site v_0 to detection site v_j;

c_4: Unit transportation cost from v_k to v_j;

c_5: Unit collection cost of v_k;

c_6: Fixed cost of v_j;

c_7: Daily salary of the inspector at v_j;

c_8: Construction cost of acquisition point v_k;

c_9: Daily salary of collector in v_k collection point;

C_{10}: Unit cost of testing supplies;

C_{11}: Unit cost of sampling supplies;

d^r_{oj}: Distance between reagent distribution center and v_j;

d^r_{ok}: Distance between distribution center v_0 and detection point v_k;

z_j: The number of testing personnel needed for v_j of each testing point;

r_k: *The number of acquisition personnel required for* v_k *acquisition point*;

n_1: Single person daily testing ability of testing personnel;

n_2: Single person daily collection capacity of collection point;

d_{kj}^{g}: Distance between v_k acquisition point and v_j detection point;

M: Infinity;

F_j: Maximum detection capability of v_j of detection point;

F_k : Maximum acquisition capacity of acquisition point v_k.

3.2.2 Modeling

(1) Objective function

Considering the complexity and particularity of nucleic acid detection location in reality, this paper takes minimizing the total social cost in the distribution process as the optimization objective to measure the economic benefits of the model. The total social cost includes two aspects: the user perspective cost and the government public cost. User cost mainly considers user time cost and transportation cost $\sum_{i\in V_1}\sum_{j\in w_i}\alpha_{ij}q_i x_{ij}$ and $\sum_{i\in V_1}\sum_{k\in L_i}\xi_{ik}x_{ik}q_i$; government public cost includes: reagent transportation cost $\sum_{i\in V_1}\sum_{j\in w_i}\beta_j q_i x_{ij}$, collection point transportation cost $\sum_{i\in V_1}\sum_{k\in L_i}\eta_k q_i x_{ik}$, collection reagent transportation cost $\sum_{i\in V_1}\sum_{k\in L_i}\theta_k q_i x_{ik}$, detection point investment cost $\sum_{j\in V_2}\gamma_j y_j$, collection point investment cost $\sum_{k\in L_i}\sigma_k g_k$. As for the user's time cost, because time and economy are two different concepts and cannot be calculated directly, it is necessary to convert the time cost into the value cost that the user can create in that period of time. Income method and production method are used for conversion for different types of users,.

The income method is used for conversion for those who do not have regular work. The conversion formula is as follows: the cost of income reduction due to nucleic acid detection is reduced for those who do not have regular work. The production method is adopted for conversion for the personnel with fixed work, and the loss that caused by the personnel can not create greater value due to the loss of this period of time. The conversion formula is as follows:

$$TC_1=\frac{IC}{WC}\qquad TC_2=\frac{GDP}{WN*WT}$$

Where, TC_1 is the unit time cost converted by income method, where IC is the annual per capita income and WT is the average annual working hours. Where, TC_2 is the unit time cost converted by production method, where GDP is GDP and WN is the annual fixed number of workers.

Assuming that the proportion of people without fixed jobs in a region is ε, then the proportion of people with fixed jobs is 1 - ε, then the average unit time cost of the region is$C_2=\varepsilon TC_1+(1-\varepsilon)TC_2$.

To sum up, the final objective function is as follows:

$$\min\sum_{i\in V_1}\sum_{j\in w_i}\alpha_{ij}q_i x_{ij}+\sum_{i\in V_1}\sum_{k\in L_i}\xi_{ik}x_{ik}q_i+\sum_{i\in V_1}\sum_{j\in w_i}\beta_j q_i x_{ij}+\sum_{i\in V_1}\sum_{k\in L_i}\eta_k q_i x_{ik}+\sum_{i\in V_1}\sum_{k\in L_i}\theta_k q_i x_{ik}+\sum_{j\in V_2}\gamma_j y_j+\sum_{k\in L_i}\sigma_k g_k$$

Among them, the travel cost per unit citizen is composed of transportation cost and the time cost of participating in the detection $\alpha_{ij}=2*d_{ij}^{*}C_1+\left(\frac{2*d_{ij}^{*}}{v}+t_1\right)C_2$, the cost of nucleic acid Collection $\xi_{ik}=\left(\frac{2*d_{ik}^{*}}{v}+t_1\right)C_2$, the cost of testing supplies per unit $\beta_j=C_3 d_{oj}^{r}$, the cost of transporting samples nearby per unit $\eta_k=C_4\min_j\left[(1-y_j)M+d_{kj}^{g}\right]$, the cost of sampling supplies per unit $\theta_k=C_5 d_{ok}^{r}$, the investment cost of testing points $\gamma_j=C_6+z_j C_7$, and the investment cost of sampling points $\sigma_k=C_8+r_k C_9$.

(2) Constraints

All people will be detected for constraints.

$$\sum_{j\in w_i} x_{ij} + \sum_{k\in L_i} x_{ik} = 1, \quad i \in V_i$$

Ensure that only the selected checkpoint is open for detection.

$$x_{ij} \le y_j, \quad i \in V_1, j \in W_i$$

Ensure that only the selected detection points are open for collection.

$$x_{ik} \le G_k, \quad i \in V_1, k \in L_i$$

Detection capability constraints of checkpoints.

$$\sum_{i\in V_i} q_i x_{ij} \le F_j, j \in W_i$$

Acquisition capacity constraints of acquisition points.

$$\sum_{i\in V_i} q_i x_{ik} \le F_k, k \in L_i$$

Calculation formula of detection capability.

$$F_j = z_j * n_1$$

Calculation formula of acquisition capacity.

$$F_K = z_K * n_2$$

Variable nonnegative constraint

$$x_{ij}, x_{ik} \ge 0,$$

0-1 constraint, when j detection point is selected, y_j is 1, otherwise it is 0; when k acquisition point is selected, g_k is 1, otherwise it is 0.

$$y_j \in \{0,1\}, g_k \in \{0,1\}$$

4. EXAMPLE TEST

4.1 Parameter setting

It is modified in order to verify the effectiveness of the model based on the medium-sized random example designed in literature. Suppose that 30 cells are randomly distributed in a 70km × 80km area, one cell is randomly selected as the high-risk area (the cell No. 25 is selected in this paper), and 10 test points are randomly distributed. Four sampling points are generated within 3km around the high-risk cell 25, and the reagent distribution center is at (60, 10), as shown in the Figure 1. It is required to complete the full detection within three days. In this example, Euclidean distance is used to calculate the distance between points. The coordinates and population of the plot are shown in the Table 1, and the coordinates and detection capacity of the selected points of the detection point are shown in the Table 2. The detection point within 25km from the cell can be used as the alternative detection point of the cell. In addition, t_1 takes 30 minutes, c_1 takes 1.5 yuan / km, c_2 takes 0.2 yuan / km, c_3 takes 0.2 yuan / km, c_4 takes 0.2 yuan / km, c_5 takes 2 yuan / person, c_7 takes 200 yuan / person, c_9 takes 200 yuan / person, c_{10} takes 50 yuan / piece, c_{11} takes 10 yuan / piece.

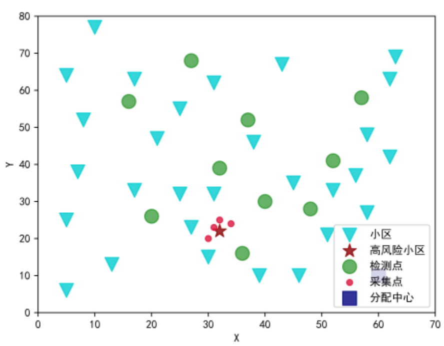

Figure 1 Distribution of residential area, detection point and acquisition point

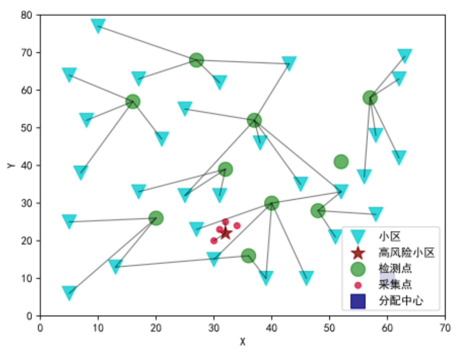

Figure 2 Site selection results

Table 1. Parameters of crowd gathering point

District number	coordinate /KM	population /10000 people	District number	coordinate /KM	population /10000 people
1	(31,32)	1.4	16	(52,33)	0.4
2	(38,46)	1.1	17	(58,27)	1.3
3	(31,62)	1.7	18	(5,6)	0.7
4	(25,55)	0.7	19	(13,13)	1.2
5	(17,63)	0.6	20	(62,42)	0.3
6	(25,32)	1.2	21	(63,69)	1.4
7	(5,64)	0.3	22	(21,47)	1.0
8	(8,52)	1.3	23	(17,33)	0.4
9	(5,25)	0.6	24	(7,38)	1.3
10	(10,77)	0.5	25	(32,22)	0.7
11	(45,35)	0.8	26	(58,48)	0.4
12	(27,23)	0.7	27	(51,21)	1.1
13	(56,37)	0.3	28	(62,63)	0.4
14	(39,10)	1.5	29	(30,15)	1.2
15	(46,10)	0.2	30	(43,67)	0.5

Table 2. Parameters of alternative test points

number	coordinate /KM	Daily detection capability	Three day detection capability	Construction cost / 10000 yuan	Number of personnel
1	(16,57)	1.3	3.9	130	13
2	(20,26)	0.6	1.8	60	6
3	(27,68)	1.2	3.6	120	12
4	(32,39)	0.9	2.7	90	9
5	(36,16)	0.4	1.2	40	4
6	(40,30)	1.1	3.3	110	11
7	(37,52)	1.1	3.3	110	11
8	(48,28)	0.8	2.4	80	8
9	(52,41)	1.5	4.5	150	15
10	(57,58)	1.1	3.3	110	11

Table 3. Parameters of alternative sampling points

number	coordinate /KM	Daily detection capability	Number of personnel	Construction cost / 10000 yuan
1	(32,25)	4200	6	2.1
2	(34,24)	3800	5	1.9
3	(30,20)	3600	5	1.8
4	(31,23)	2000	4	1.0

4.2 Result analysis

Through lingo programming, this kind of problem is mixed integer programming, and the minimum social cost is 3.970685 × 10 ^ 7 yuan. The results showed that the alternative test point 9 was not selected, and the other points were selected to open. Table 4 shows the results of population proportion from each population gathering point to each open test point and from high-risk areas to each open collection point. Table 5 shows the unit transportation cost between the acquisition point and the nearest open detection point. It can be seen from Table 4 that the selected candidate can make the demand of each small area covered and met, and there is a small amount of excess detection capacity in No. 3 and No. 10 detection points, which can be arranged as the emergency response capacity to deal with emergencies, and the overall utilization rate of the candidate points is 97.25%; acquisition points 1 and 3 are selected and open, and point 1 operates at full load, and point 3 has a surplus of 800 person times The utilization rate was 77.8%. It can be seen from Table 5 that the samples collected from collection point 1 are sent to the sixth detection point for nucleic acid detection, while the samples collected from collection point 3 are sent to detection point 5 for nucleic acid detection. From Figure 2, we can see the corresponding cell situation of each detection point.

Table 4. The results of the ratio of alternative test points to population

number	Inspection point									Collection point	
	1	2	3	4	5	6	7	8	10	1	3
1				1.00							
2							1.00				
3			1.00								
4							1.00				
5			1.00								
6				0.71			0.29				
7	1.00										
8	1.00										
9		1.00									
10			1.00								
11							1.00				
12						1.00					
13									1.00		
14					0.31	0.69					
15						1.00					
16						0.60	0.33	0.07			
17								1.00			
18		1.00									
19		0.39			0.61						
20									1.00		
21									1.00		
22	1.00										
23				1.00							
24	1.00										
25										0.6	0.4
26									1.00		
27								1.00			
28									1.00		
29						1.00					
30			0.39				0.61				
Total	3.9	1.8	3.6	2.7	1.2	3.3	3.3	2.4	3.3	0.42	0.28
Surplus	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0	0.08

Table 5. Unit cost of transportation near the collection point and results of corresponding detection point

η_k	1	2	3	4
Unit freight	1.88	1.64	1.44	1.72
Corresponding detection point	6	5	5	5

5. CONCLUSIONS

Aiming at the location problem of nucleic acid detection institutions in emergency management of sudden epidemic situation, differentiated management is carried out for high-risk and medium low-risk areas combined with practical problems. In this paper, a distribution model based on coverage model is constructed with the goal of comprehensive coverage of residential areas and minimum social cost. A specific example is taken to optimize the solution. The commercial solution software lingo and CPLEX are used to solve the problem. Don't solve, get the final optimization result. Thus, the feasibility of the model is verified, which provides ideas and methods for the planning and layout of nucleic acid testing institutions of urban emergency management departments, and provides reference for the decision-making of relevant departments to deal with the epidemic situation.

ACKNOWLEDGEMENT

This research was supported by Guangdong Tobacco Monopoly Bureau (Company) science and technology projects (Contract No.201944000200036).

REFERENCES

[1] Toregas C.ReVelle C. (1972). Optimal location under time or distance constraints. Papers of the Regional Science Association, 28:133-143.

[2] Yu Dongmei, Gao Leifu, Zhao Shijie. (2020). Research on reliability location model considering interruption risk and defense of emergency facilities. Operations research and management, 29 (9): 53-61.

[3] Chen Gang, Fu Jiangyue, he Meiling.(2019). Study on the location of emergency shelters considering residents' choice behavior. Operations research and management, 28 (9): 6-14.

[4] Sun Huali, Xiang Meikang, Xue Yaofeng. (2019). Robust optimization of emergency facility location and path under uncertain information [J]. Journal of systems management, 28 (6): 1126-1133.

[5] Sun Jianping, Gong Suping, Tang Zhaoping, Liu Huan. (2019). Site selection optimization of high-speed rail emergency resource reserve based on set coverage model. China Science and technology paper, 12 (19): 2213-2218.

[6] Chen zhizong, you Jianxin. (2006). Multi objective decision making model for site selection of emergency rescue facilities for major emergencies. Management science, 52(4): 10-14.