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Mathematical modeling for selecting center locations for medical and health supplies reserve in Hainan Province

Xiao−Hua Hu[1], Chuan−Zhu Lu[2], Min Li[3], Cai−Hong Zhang[2], Hua Zhang[2*]

[1]No. 99 Longkun South Road, Hainan Normal University, Haikou, China
[2]Hainan Medical University, Haikou, China
[3]Hainan Provincial People's Hospital, Haikou, China

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ABSTRACT

Objective: To explore how to choose the center locations to build the medical and health supplies reserve among many island towns. **Methods:** The center locations were selected from 18 towns Hainan Province, it's maximum service range (distance) was required to reach the minimum, or to minimize. **Results:** Three scenarios were considered, the center locations included only one town, two towns, three towns. By the use of graph theory and MATLAB programming, a mathematical model was established to obtain the shortest distance and the shortest path between arbitrary two towns. **Conclusions:** We find out the center sites under certain conditions, and determine the specific service ranges of the center sites.

1. Introduction

With special geographical position and geological structure, Hainan province is regarded as an island area that the various natural disasters could occur frequently, such as typhoon, tsunami, earthquake, flood, fire *etc*. Hainan is located at the national border area and fortified with military base, currently facing Southeast Asia national complicated political, military and natural disaster environment. With the rapid development of Hainan Provincial economy, diversified culture in recent years, and the large chemical enterprises entering to Hainan island's western zone, we are also under the risk of non−natural disaster events, such as mass chemical poisoning, explosion, prevalence of the infectious disease, the sea and air transportation accidents, and the threat of terrorist attacks. Due to the establishment of Yangpu Economic Development Zone and Space city, it is imperative to build a relatively independent of disaster

medical rescue system[1−7] in Hannan island. In addition, Hannan province is blessed with the geographical features of island, it is connected with surrounding regions by two kinds of transportations, either by air, or by sea, but once the earthquake, typhoon, tsunami occur, none of traffic ways are often passable and readily reachable, so self−help and island's internal rescue capacity is even more important and effective than external assistance from other provinces and areas in China. On December 31, 2009, the State Council of China issued a white paper of "Recommendations on promoting the construction development of Hainan international tourism island"[8]. In it, the constructing Hainan as an international tourism became one of the national strategies. Thus, the construction of Hainan to be an international tourism island officially is well on track. As the China major strategic plan, Hainan Island will be built to be the world's top−class leisure resort in 2020, it will be made to be an open island, and a green island, a civilization and harmonious island, so, it is strategically important and significant to set up a medical and health supplies reserve, in quickly responding to the natural and non−natural risk or disasters.

2. Mathematical modeling and results

There were eighteen major towns in Hainan province. These towns were Lingao (1), Danzhou (2), Changjiang(3), Dongfang (4),Ledong (5), Sanya (6), Baoting (7), Lingshui (8), Wanning (9), Qionghai (10), Ding'an (11), Wenchang (12), Haikou (13), Chengmai (14), Tunchang (15),Baisha(16), Wuzhishan (17), Qiongzhong (18). For convenience of modeling, city's names were denoted by a number with in the parentheses 1,2,3,..., 18, respectively, First of all, an adjacent matrix was established[9] between two towns, the resultant matrix was as below

$$W= \begin{bmatrix} 0 & w_{1,2} & w_{1,3} & ... & w_{1,18} \\ w_{2,1} & 0 & w_{2,3} & ... & w_{2,18} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & & \cdot \\ w_{17,1} & w_{17,2} & ... & 0 & w_{17,18} \\ w_{18,1} & w_{18,2} & ... & w_{18,17} & 0 \end{bmatrix} \quad (1)$$

Where $w_{i,j}=w_{j,i}, i,j=1,2,...,18$, denotes the distance (km) between the town and the town . All the distance data of 18 Hainan towns[10] was shown in Table 1.

2.1. One center point (town) case

A center point (town) was selected from eighteen major towns in Hainan Province to build the medical and health supplies reserve. The maximum service range (distance) of the medical and health supplies was required to be the shortest distance to reach all towns of Hainan island[11–13]. First it was assumed that all towns have the required infrastructure and are eligible to be built such a reserve, and the roads connected arbitrary two towns are passable, and the length of path are known. By use of Floyd algorithm[14], the shortest distance matrix $D=(d_{ij}), i,j=1,1,...,18$, and the shortest path index matrix R could be found between any two points(towns), where d_{ij} denoted the shortest distance between arbitrary two towns. If the center point was taken to be the town , then the maximum service distance(range) of v_i was as below:

$$d_i=\max_{1\leqslant j\leqslant 18}(d_{ij}), i=1,2,...,18 \quad (2)$$

To search for an integer , such that:

$$d_k=\min_{1\leqslant j\leqslant 18}(d_i) \quad (3)$$

then the point v_k was the town to find. The maximum service distance (range) of v_k could reach the minimum. The specific process was as follow, by MATLAB programming[15], to obtain the maximum values of each line in the matrix $D=(d_{ij}), i,j=1,2,...,18$, the minimum value was taken out from these maximum values. The point corresponding to the minimum value was the target town. Calculating results showed that the minimum value was 219.9 km, and $v_k=18$, or Qiongzhong was the center town (point). Further more, the

shortest distance and the corresponding path to the rest of 17 towns from Qiongzhong could be determined and given as follows. The shortest distances from Qiongzhong(18) to Lingao (1), to Danzhou (2), to Ledong (5), to Sanya (6), to Baoting (7), to Lingshui (8), to Wanning (9), to Qionghai (10), Ding'an (11), to Haikou (13), to Chengmai (14), to Tunchang (15), to Baisha(16), to Wuzhishan (17) were 143.6 km, 86.2 km,101.3 km, 141.0 km, 108 km, 91.2 km, 82.3 km, 125.2 km, 125.9 km, 142.0 km, 105.2 km, 52.7 km, 70.9 km, 77.1 km, respectively. The corresponding path are direct (no middle point), but the shortest distance was 161.7 km from Qiongzhong (18) to Changjiang (3), the corresponding path was from Qiongzhong (18) to Danzhou (2) to Changjiang (3). The shortest distance was 219.9 km from Qiongzhong (18) to Dongfang (4), the corresponding path was Qiongzhong (18) to Danzhou (2) to Changjiang (3) to Dongfang (4). The shortest distance was 184 kilometers from Qiongzhong (18) to Wenchang (12). The corresponding path was Qiongzhong (18) to Qionghai (10) to Wenchang (12) (Figure 1).

Figure 1. One center point (town) case.

2.2. Two center points (towns) case

Two center points (towns) were selected as the medical and health supplies reserve from eighteen main towns in Hainan Province. The maximum service range (distance) of two center points was required to reach the minimum, or to minimize. The basic assumptions about the towns were the same as the previous case. It was assumed that two center points are located at the points v_i, v_j. Let d_{ij}^k denotes the shortest distance from the point v_k to two center points v_i, v_j.

$$d_{ij}^k =\min\{d_{ik},d_{jk}\}, k=1,2,...,18 \quad (4)$$

$$d(i,j)=\max_{1\leqslant j\leqslant 18}\{d_{ij}^k\}, i,j=1,2,...,18 \quad (5)$$

To search for two integers, such as that:

$$d(s,t)i=\min_{1\leqslant j\leqslant 18}\{d(i,j)\} \tag{6}$$

Then the point v_s, v_t were the places or twons. The maximum service distance (range) of v_s, v_t reached the minimum. By MATLAB programming, in order to obtain the matrix $D_{324\times18}=(d_{ij}^k)$, $d_{ij}^k=\min\{d_{ik},d_{jk}\}$, $i,j,k=1,2,...,18$, the maximum values of each line was taken in the matrix $D_{324\times18}$. Then, the minimum value from these maximum values was taken out. The points v_s, v_t which correspondwd to the minimum value, were the target town s and town t. Calculating results showed that the minimum value was 143.9 km:
(v_s,v_t)=(1,15),(2,15),(3,15),(4,15),(5,15),(11,15),(12,15),(13,15),(14,15),(15,16), (3,8),(4,8),(5,8),(6,8),(7,8)

   However, in the actual situation, the shortest distance between the point v_s and v_t was more than 143.9 km (otherwise, there was no point to choose two center points), and the point v_s and point v_t with the respective maximum service distance was at most 143.9km, the final result of calculation was (v_s,v_t)=(5,15) that was , Ledong (5) and Tunchang (15), the shortest distance between Ledong (5) and Tunchang (15)was 152.3 km . The service ranges of Tunchang (15) covered Lingao(1), Danzhou (2),Lingshui (8), Wanning (9), Qionghai (10), Ding′an (11), Wenchang (12), Haikou (13), Chengmai (14) and Tunchang (15); while the service ranges of Ledong (5) included Changjiang (3), Dongfang (4), Ledong (5), Sanya (6), Baoting (7), Baisha(16), Wuzhishan (17) and Qiongzhong (18).

2.3. Three center points (towns) case

   Now, three center points (towns) were selected to build the medical and health supplies reserve from eighteen major towns in Hainan Province. Similarly, the maximum service range (distance) of three center points was required to reach the minimum, or to minimize. It was assumed that three center points are located at the points v_i, v_j, v_k. d_{ijk}^l was used to denote the shortest distance from the point to three center points v_i, v_j, v_k.
$$d_{ijk}^l=\min\{d_{il}, d_{jl},d_{kl}\},1,2,...,18 \tag{7}$$

$$d(i,j,k)=\max_{1\leqslant j\leqslant 18}(d_{ijk}^l),i,j,k=1,2,...,18 \tag{8}$$

To identify three integer s, t, p, such that
$$d(s,t,p)=\min_{1\leqslant j\leqslant 18}\{d(i,j,k)\}$$
then the point v_s, v_t, v_p were the target places. The maximum service distance (range) of v_s, v_t, v_p reached the minimum. In the same approach of MATLAB programming, in order to obtain the matrix,
$D_{5832\times18}=(d_{ijk}^l)$, $d_{ijk}^l=\min\{d_{il},d_{jl},d_{kl}\}$, $i,j,k,l=1,2,...,18$, we take the maximum values of each line in the matrix $D_{5832\times18}$, and the minimum value was taken out from these maximum values. The points v_s, v_t, v_p corresponding to the minimum value were the town s, town t and town p. Calculating results showed that the minimum value was 105.2 km. However, a total of 446 groups met the requirement, there was three points in each group. However, Considering the actual situation, the shortest distances between the arbitrary pair of points v_s, v_t and v_p were more than 105.2 km (otherwise, there was no meaning to choose three center points), and the point v_s, v_t and point v_p with the respective maximum service distance was at most 105.2 km.The final result of calculation was (v_s,v_t,v_p)=(3,11,17) that is to say , Changjiang (3), Ding′an (11)

Table 1
Distance (km) between arbitrary two towns in Hainan provincial eighteen towns.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1		60.41	104.4	146.4	266.7	300	296.7	265	211.8	153.6	108.1	147.5	85	56.3	177.6	132.5	212.7	143.6
2	60.41		75.5	149.9	270.2	282	176.7	362.9	271	212.9	163.3	207	136	117.9	100.9	51.7	138.9	86.2
3	104.4	75.5		58.2	105.3	196	268.9	270.8	317.5	257.5	212	252.4	184	164.6	280.3	102.2	183.6	185.8
4	146.4	149.9	58.2		122	173	230.2	224.4	279	301.6	245.8	289.5	228	200.4	319.3	171.5	208.7	221.8
5	266.7	270.2	105.3	122		128	114.2	180.2	234.1	293.9	370.7	414.5	350	325.3	152.3	105.7	74.4	101.3
6	300	282	196	173	128		67	80	128	173	228.3	246	285	311	244.3	320.5	88	141
7	296.7	176.7	268.9	230.2	114.2	67		47.6	99.2	159	204.3	304.8	256	287	158.7	121.3	40.5	108.8
8	265	362.9	270.8	224.4	180.2	80	47.6		53.9	113.7	159	259.5	210	241.7	175	160.6	118.2	91.2
9	211.8	271	317.5	279	234.1	128	99.2	53.9		59.8	105.2	205.6	154	187.9	121.1	340.8	172.1	82.3
10	153.6	212.9	257.5	301.6	293.9	173	159	113.7	59.8		56.9	58.8	102	139.5	72.8	292.5	196.9	125.2
11	108.1	163.3	212	245.8	370.7	228.3	204.3	159	105.2	56.9		102.1	48.1	84.4	73.5	237.8	277.2	125.9
12	147.5	207	252.4	289.5	414.5	246	304.8	259.5	205.6	58.8	102.1		73	126.7	170.2	275.2	378.4	222.6
13	85	136	184	228	350	285	256	210	154	102	48.1	73		61	97	227	288	142
14	56.3	117.9	164.6	200.4	325.3	311	287	241.7	187.9	139.5	84.4	126.7	61		52.8	191.8	272.7	105.2
15	177.6	100.9	280.3	319.3	152.3	244.3	158.7	175	121.1	72.8	73.5	170.2	97	52.8		122	128.1	52.7
16	132.5	51.7	102.2	171.5	105.7	320.5	121.3	160.6	340.8	292.5	237.8	275.2	227	191.8	122		81.4	70.9
17	212.7	138.9	183.6	208.7	74.4	88	40.5	118.2	172.1	196.9	277.2	378.4	288	272.7	128.1	81.4		77.1
18	143.6	86.2	185.8	221.8	101.3	141	108	91.2	82.3	125.2	125.9	222.6	142	105.2	52.7	70.9	77.1	

Table 2
Site selection results in eighteen towns of Hainan Province.

Town	Lingao	Danzhou	Changjiang	Dongfang	Ledong	Sanya	Baoting	Lingshui	Wanning	Qionghai	Ding'an	Wenchang	Haikou	Chengmai	Tunchang	Baisha	Wuzhishan	Qiongzhong
Center point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
One																		18
Two					5										15			
Three		3									11						17	
Service area		1,2, 3,4			3,4, 5,6, 7,16, 17,18						9,10, 11,12, 13,14, 15,17				1,2, 8,9, 10,11, 12,13,	5,6,7, 8,15, 16,17		1——18

and Wuzhishan (17). Further more, the shortest distance between Changjiang (3) and Ding'an (11) was 212 km, the shortest distance between Ding'an (11) and Wuzhishan (17) was 201.6 km, the shortest distance between Ding'an (3) and Wuzhishan (17) was 179.7 km. As a result, the service ranges of Changjiang (3) included Lingao(1), Danzhou (2), Changjiang (3) and Dongfang (4), while the service ranges of Ding'an (11) were Wanning (9), Qionghai (10), Ding'an (11), Wenchang (12), Haikou (13), Chengmai (14) and Tunchang (15). Finally the service ranges of Wuzhishan (17) covered Ledong (5), Sanya (6), Baoting (7), Lingshui (8), Baisha(16), Wuzhishan (17) and Qiongzhong (18).

3. Analysis and model improvement

We represent the results from the previous section in Table 2 as below.

The above center points (despite case one, case two or case three) we have selected only consider "the equally important" for eighteen towns of Hainan province, or only consider the geographical position of these towns. We have not taken into consideration of the town's population, the size of area, and other factors. If each vertex (such as towns) of the graph are endowed with a respective weight (such as population number), and the weight condition of each vertex are taken into account, we may further consider of "weighted center" location problem[16].

In this article, we represented eighteen major towns in Hainan Province as eighteen points, by using the relevant knowledge in Graph theory, with the mathematical software MATLAB, the shortest distance and the shortest path between arbitrary two towns are determined. We respectively established mathematical models on condition of medical and health supplies reserve under one center point, two center points and three center points, through the program calculation the specific center locations of medical and health supplies reserve can be finally determined and the service range of the center points in three cases are also given respectively (Table 2).

Conflict of interest statement

We declare that we have no conflict of interest.

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