Optimal Patients and Material Distribution to Combat COVID in Wuhan based on Nonlinear Programming

Haochen Wang
Xi'an Gaoxin No.1 High School, AP2, 710075, China

Abstract: COVID-19 broke out in Wuhan, China, in January 2020. The COVID-19 virus is highly contagious and has a long incubation period, which led to the closure of Wuhan city by the Chinese government on January 23 after the outbreak was announced on January 22. In the following 10 days, Wuhan experienced an explosive increase in confirmed cases. Although the state deployed a large number of personnel and material resources to support Wuhan's fight against the epidemic, the outbreak was so fierce that Wuhan's medical system experienced huge challenges in terms of epidemic prevention and control, material supply and treatment capacity. During this period, there were constant news reports that due to the rapid emergence of COVID-19 infection symptoms in all parts of Wuhan, the response of the patient placement and material distribution system was slow and the management was chaotic. In order to cope with the situation in Wuhan during the epidemic, this paper selected five hospitals in Wuhan that were the first batch of patients designated by the government to receive COVID-19 patients, and explored the allocation scheme over 10 days of patients and medical supplies with the goal of minimizing the cost by using nonlinear optimization. The paper studied respectively different ways of considering total cost when the unsatisfactory cost of denying admission to each COVID-19/ general inpatient was considered/disregarded and the practical problem was transformed into a standard nonlinear programming problem, demonstrating the optimal cost and optimal allocation of patients and medical resources in both cases. When cross-infection in hospital is taken into account, it is believed that the greater the number of patients relative to the capacity of the hospital, the greater the frequency of contact between non-infected people in the hospital and infected people, and the higher the risk of cross-infection. The cross-infection rate of COVID-19 in hospital is in direct proportion to the density of patients.

Keywords: Nonlinear programming, COVID-19, Wuhan, Distribution, Recieve and cure patients

1. Introduction

The first coVID-19 outbreak in China was reported in Wuhan in January 2020, and the Chinese government blocked all external traffic in Wuhan on January 23, as the city was already seriously affected by the epidemic. Despite the implementation of strict control measures on crowd activities within Wuhan and the emergency deployment of personnel and material resources by the central government to Wuhan in the following month or so, the number of COVID-19 infections was still far beyond the capacity of local hospitals. Hospitals did not have sufficient screening capacity to quickly screen large numbers of patients for infection, leading to poor isolation of COVID-19 patients and cross-infection within hospitals. When the hospital beds were saturated, the hospital had to refuse new inpatients admission, incurring significant social cost. In the absence of medical resources, the local government of Wuhan needed a quantitative allocation plan for medical supplies and patients. This paper aims to use nonlinear programming to provide a model that minimizes the cost of treatment for COVID-19 patients and the sum of the monetary cost of admission for ordinary /COVID-19 patients and the cost of medical supplies consumption due to insufficient beds under the assumption that the actual coVID-19 patients and the number of hospital visits are basically determined. In this paper, the authors hope to provide a plan for minimizing the cost of medical resources and patient allocation in the context of the coVID-19 outbreak, which is an emergent and highly contagious epidemic, with the primary consideration being the limited availability of medical supplies and hospital beds, and the psychosocial costs of refusing to admit patients.

On January 22, 2020, the epidemic was publicized in Wuhan. After the closure of the city on January 23, a large number of Wuhan residents flocked to hospitals from their homes to test for the virus. Under such circumstances, wuhan hospital, as the most important line of defense against the epidemic, faces two serious problems: severe cross-infection in hospitals and shortage of medical supplies. The two go hand in hand. (b) The shortage of medical supplies led to more frequent and closer contact of medical personnel and uninfected patients with injected patients, increasing cross-infection rates; The more cross-infection, the higher the number of COVID-19 patients in the hospital, the more protective materials were needed to avoid cross-infection. The effect of epidemic prevention in hospitals is influenced by many factors, such as whether the government's response to changes in the demand for protective materials in hospitals is timely, etc. This paper mainly considers the influence of the density of coVID-19 patients received from outside on the epidemic prevention in hospitals.

2. Description of Subscripts, Variables and Constants

2.1. Subscript

The subscript J will be adopted in this paper, and its meaning and value are shown in the table:

Table 1. Meaning of the subscripts

Subscript	Meaning	Value	Description
j	The 5 hospitals in wuhan selected by central government to be the first batch of hospitals to receiveCOVID-19 Patients And Their number of sickbeds	1	Tongji Hospital affiliated to Huazhong University of Science and Technology
		2	HubeiProvincial People's Hospital (Wuhan University People's Hospital
		3	Union Hospital affiliated to Huazhong University of Science and Technology
		4	Wuhan Central Hospital
		5	Central South Hospital affiliated to Wuhan University

2.2. Variables

According to the National Health Commission of China, the average hospitalization fee and total ordinary inpatients in China from January to March 2019 is about 13,820.5 yuan. 17.209 million. Wuhan has a population of 10379114 people. With these data we can calculate the approximate number of ordinary inpatients PN in wuhan within 10 days to be 14176 hospitalized. The proportion of these ordinary inpatients who would choose to go to J =1-5 hospitals equals the ratio of the total number of sickbeds in 5 hospitals to the total number of sickbeds in Wuhan General Hospital. According to the notifications for epidemic by wuhan, hubei Wei Jian Wei, from 2020 February 1 to February 10 hubei COVID - 19 infections experienced an increase of 15240 people. This is the time interval when wuhan epidemic is at its peak, so choose the number within 10 days as the estimate of the wuhan infections. With regard to the transmission capacity of COVID-19 under travel restrictions, Andrew Atkeson's "What WILL BE THE ECONOMIC IMPACT OF COVID-19 IN THE US? ROUGH ESTIMATES OF diseases SCENARIOS" says, Rt is the ratio of the rate at which coVID-19 patients come into contact with normal people and spread the virus to the rate at which they are discharged and die. The value of Rt decreases with the tightening of social travel restrictions. Due to the strict quarantine policy implemented by the Chinese government and the cooperation of wuhan residents, I take the lower limit of the Rt value range of Atkeson, which is 1.6. The value of γ mentioned in the paper is 1/18. According to the model β=Rt*γ in this paper, therefore, over 10 days, the rate of virus transmission of each unadmitted COVID-19 patient is Sp 1.6*1/18=4/45. In 10 days, the total transmission add up to 40/45 person per COVID-19 patient. The total cost of rejecting each COVID-19 patient is the sum of the medical expenses of the individual and those he or she will infect.

Table 2. Meaning and value of the variables

Variables	Meaning	Unit
X_j	Number of coVID-19 patients admitted to Hospital J	person
M_j	Number of masks supplied to Hospital J	person
P_j	Quantity of protective clothing supplied to Hospital J.	set
Do_j	The number of doctors needed in Hospital J	person
Nu_j	The number of nurses needed at Hospital J	person
Pn_j	Number of non-COVID-19 inpatients from Community I to hospital J	person

Table 3. Meaning and value of the constants

Constants	Meaning	Value	Unit
SB_1	Tongji Hospital affiliated to Huazhong University of Science and Technology offers beds.	6000	Zhang
SB_2	Number of beds in Hubei Provincial People's Hospital (Wuhan University People's Hospital)	5200	Zhang
SB_3	Number of beds in Union Hospital affiliated to Huazhong University of Science and Technology.	5000	Zhang

SB_4	Number of beds available in Wuhan Central Hospital.	3381	Zhang
SB_5	Number of beds in Central South Hospital affiliated to Wuhan University.	3300	Zhang
P_m	Average price per medical mask or N95/KN95 mask	8	RMB
P_p	The price of each piece of medical protective clothing	89	RMB
H_c	The average cost of curing a coVID-19 patient is [17000RMB], according to an interview by Guangming Daily.	17000	RMB
C_I	the highest cross-infection rate when Covid-19 patients have the highest density, the greatest shortage of medical supplies	41%	Beds/
P_N	Total ordinary inpatients who should visit 5 hospitals within 10 days in Wuhan.	7797	person
P_C	Change in number of COVID-19 patients in Wuhan within 10 days.	15240	person
C_n	Average hospitalization expenses for non-COVID-19 patients	13820.5	RMB/ person
S_p	The rate at which coVID-19 is transmitted by untreated coVID-19 patients	4/45	person / day
D_n	The economic value of dissatisfaction in the denial of each ordinary inpatient	0/13820.5	RMB/ person
D_c	The economic value of dissatisfaction in denial of each COVID-19 inpatient	0/17000	RMB/ person

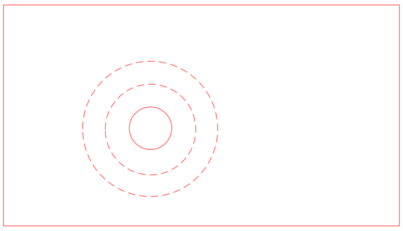
3. Model: Nonlinear Programming

3.1. Objective function

The objective function to minimize is divided into three parts: the cost of treatment for hospitalized and other coVID-19 patients who are cross-infected in the hospital, the monetary cost of denying admission to ordinary/COVID-19 patients due to insufficient beds, and the cost of medical supplies.

A) Part One:

According to Wuhan university Zhongnan hospital Zhiyong peng team report, 41 percent of the 138 coVID-19 patients diagnosed between January 1 and January 28, 2020 were expected to be cross-infected. For most of those 28 days, the nature of human-to-human transmission had not been determined, and health care workers had not taken the additional precautions required for common pneumonia (i.e. changing a mask a day and not wearing protective clothing and goggles). Since the protection conditions were very poor, I assume that the cross infection rate at this time is the maximum cross infection rate, CI, which equals 41%. The cross-infection rate is mainly determined by the frequency of contact between uninfected and infected persons. As shown in Figure 3-1, the relationship between cross-infection rate and the number of initial infected persons can be understood. The rectangle in the figure shows the range of activity of all people in all hospitals. The solid circle represents the initial coVID-19 patient population in a hospital. The area S represents the number of people, and the perimeter C represents the contact opportunity of uninfected people with COVID-19 patients. According to the area and circumference formula of the circle, C=√S*2√. It can be seen that the cross infection rate increases with the increase of the number of infected persons. At the same time, it can also be seen from the figure that the greater the range of activities of uninfected persons, the lower the chances of contact between infected persons and them. Therefore, the cross-infection rate is in direct proportion to the density of COVID-19 patients in the hospital.



Then, the first part of the objective function can be established, as shown in Equation (1).

$$J_1 = Hc \times \Sigma_j \left[CI \times \left(X_j / SB_j \right) \times \left(Do_j + Nu_j + P_j \right) + X_j \right] \quad (1)$$

B) Part II:

The second part is the total cost of masks and protective clothing delivered to hospitals. Pm, Pp are the prices of individual masks and protective clothing, see the footnote above. Then, the second part of the objective function can be established, as shown in Equation (2).

$$J_2 = \Sigma_j \left(M_j \times P_m + P_j \times P_p \right) \quad (2)$$

C) Part III:

The third part calculates the cost of denying ordinary and COVID-19 patients. PN-∑jPj for the number of ordinary patients not admitted, PC- ∑jXj for the number of COVID-19 patients not admitted. By the end of the 10 days, the number of coVID-19 patients out of hospital had increased (1+Sp*10) as unadmitted COVID-19 patients continued to move and infect others. (In the real 10 days, patients are only admitted after successive diagnosis, rather than all at once; So there will always be infectious COVID-19 patients who will be admitted within 10 days but are still active. Here to ignore this, makes the calculated for 10 days at the end of the hospital infection is slightly lower than the number of actual value) The reason that the healing cost of refused COVID - 19 patients is counted but not the refused ordinary patients is that the Chinese government agreed to undertake COVID free - 19 patients during the outbreak of all treatment costs, but not the ordinary patients. Therefore, for ordinary patients, only the economic value of their dissatisfaction with rejection is considered, while for COVID-19 patients, both treatment cost and dissatisfaction are considered. Because the economic value of dissatisfaction is difficult to determine, and is likely to have a large numerical value and influence, this paper will try different dissatisfaction costs of being refused admission in the calculation part, to observe its impact on the minimum cost and optimal allocation scheme. Then, the third part of the objective function can be established, as shown in Equation (3).

$$J_3 = Dn \times \left(PN - \Sigma_j P_j\right) + Hc \times \left(PC - \Sigma_j X_j\right) *(1 + Sp * 10) + Dc \times \left(PC - \Sigma_j X_j\right) \quad (3)$$

3.2. Constraints

In the study of Peng Zhiyong's team, 138 COVID-19 patients were admitted to hospitals with protective measures (138 patients were successively admitted from 2020.1 to 2020.28, among which the characteristics of person-to-person transmission of COVID-19 were not clear from 1 to 22 days). As mentioned above, they were considered as the minimum protective measures. According to the interviews with the frontline medical staff in Wuhan hospital, medical staff who have frequent contact with COVID-19 patients need 4 masks a day. Because of the shortage of medical resources, the condition of zero coVID-19 patient density is set as the condition that medical staff only need 1 mask per day to cope with outpatient visits, while when the hospital density of COVID-19 patient is 100%, medical staff need 4 masks per day. In general, hospitalized patients have less exposure to COVID-19 patients, and even if placed in the same hospital, there are quarantine measures, so their mask requirements are set as. In addition, patients with coronavirus wear masks in hospitals because they are already threatened with asphyxiation: non-medical personnel or patients are ignored because the Numbers are small. Therefore, the constraint conditions can be established as shown in Equation (4).

$$g_1 = M_j \geq 10 \times \left[1 \times \left(Nu_j + Do_j + 1/3 \times Pn_j\right) \times \left(1 + 3 \times X_j / SB_j\right)\right] ? \quad j = 1, 2, \ldots, 5 \quad (4)$$

At least one protective clothing medical worker per day. The results were due to the fact that the medical protective clothing could not be eaten or excreted, so it was assumed that one person had at least one a day to use. It should be noted that it is not believed that the number of COVID-19 patients admitted to a hospital will affect the demand for protective clothing. The reason is that the respirator is in direct contact with the respiratory system, the protective ability is low, and the insecurity will increase rapidly in an environment with high virus exposure rate. And the permeability of protective clothing, compared with the mask, even more frequent contact with patients, hardly affected the protective clothing's ability to block the virus. Therefore, the constraint conditions can be established as shown in Equation (5).

$$g_2 = P_j \geq 10 \times \left[1 \times \left(Nu_j + Do_j\right)\right] ? \quad j = 1, 2, \ldots, 5 \quad (5)$$

The total number of beds in the five hospitals is about 22,880, and the total number of beds in all hospitals in Wuhan is about 41,600. The number of beds in the five selected hospitals accounted for the majority of all government-designated hospitals during the epidemic, so it is considered that the five hospitals should receive all COVID-19 patients in Wuhan. For ordinary inpatients, these five hospitals should receive 10 days of the total number of ordinary patients in Wuhan, which is equivalent to the ratio of total beds in Wuhan. Therefore, the constraint conditions can be established as shown in Equation (6).

$$g_3 = X_j + Pn_j \leq SB_j ? \quad j = 1, 2, \ldots, 5 \quad (6)$$

according to China's national health select committee report [http://www.nhc.gov.cn/jkj/s3578/202002/87fd92510d094e4b9bad597608f5cc2c.shtml] on February 29th, about 6.1% of China's COVID - 19 cases are critical cases, need to receiving treatment in ICU. According to the network times an interview of China [https://www.chinatimes.net.cn/article/94870.html], each need at least 2.5 nurses of ICU patients, each common ward patients need at least 0.4 nurses care. Therefore, the constraint conditions can be established as shown in Equation (7).

$$g_4 = Nu_j \geq X_j \times \left(93.9\% \times 0.4 + 6.1\% \times 2.5\right) + Pn_j \times 0.4 ? \quad j = 1, 2, \ldots, 5 \quad (7)$$

According to the requirements of the Chinese government on the number of medical personnel in grade Iii and Grade A hospitals, each patient should be equipped with at least 1.03 health technicians and 0.4 nurses. Health technicians mainly include doctors, nurses, nutritionists and other personnel whose duties are directly related to the health of patients. Only these three types are considered here. Therefore, the constraint conditions can be established as shown in Equation (8).

$$g5 = Do_j \geq Nu_j \times \left(1.03 - 0.4 - 1/150\right) / 0.4 ? \quad j = 1, 2, \ldots, 5 \quad (8)$$

The total number of COVID-19 patients admitted to 5 hospitals is less than or equal to the total number of CO-

VID-19 patients. Therefore, the constraint conditions can be established as shown in Equation (9).

$$g6 = \sum_j X_j \le 15240 \quad j = 1,2,\ldots,5 \quad j = 1, 2, \ldots, 5 \tag{9}$$

The sum of ordinary patients admitted to 5 hospitals is less than or equal to the total number of ordinary patients to be admitted. Therefore, the constraint conditions can be established as shown in Equation (10).

$$g7 = \sum_j Pn_j \le 7797 \quad j = 1, 2, \ldots, 5 \tag{10}$$

3.3. Conversion to standard form of nonlinear programming

The reason why this optimization problem is nonlinear programming is that there is quadratic term in G1 (x).The standard form of nonlinear programming is shown in Equation (11).

$$\min J(x) \quad s.t.\ gi(x) \le 0?\ \ i = 1, 2, \ldots, \quad mhj(x) = 0?\ \ j = 1, 2, \ldots, p \tag{11}$$

Where x=(x1... , xn) is the variable vector; Min J(x) denotes the minimization objective function J(x), and the symbol S.T. denotes "constrained by". There is at least one nonlinear function in GI (x) and Hj (x).

According to the previous description, the variable vector x is:

$$x = [X_1, X_2, X_3, X_4, X_5, Pn_1, Pn_2, Pn_3, Pn_4, Pn_5, M_1, M_2, M_3, M_4, M_5, P_1, P_2, P_3, P_4, P_5, Nu_1, Nu_2, Nu_3, Nu_4, Nu_5, Do_1, Do_2, Do_3, Do_4, Do_5] \tag{12}$$

Objective function:

$$J(x) = Hc \times \sum_j \left[CI \times (X_j / SB_j) \times (Do_j + Nu_j + P_j) + X_j \right] + \sum_j (M_j \times Pm + P_j \times Pp) + Dn \times (PN - \sum_j P_j) + Hc \times (PC - \sum_j X_j) \times (1 + Sp \times 10) + Dc \times (PC - \sum_j X_j) \tag{13}$$

The restriction inequalities are:

$$\begin{aligned}
& g1(x) = 10 \times \left[1 \times (Nu_j + Do_j + 1/3 * Pn_j) * (1 + 3 * X_j / SB_j) \right] - M_j \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g2(x) = 10 \times 1 \times (Nu_j + Do_j) - P_j \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g3(x) = X_j + Pn_j - SB_j \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g4(x) = X_j * (93.9\% * 0.4 + 6.1\% * 2.5) + Pn_j * 0.4 - Nu_j \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g5(x) = Nu_j * (1.03 - 0.4 - 1/150) / 0.4 - Do_j \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g6(x) = \sum_j X_j - 15240 \le 0 \\
& j = 1, 2, \ldots, 5 \\
& g7(x) = \sum_j Pn_j - 7797 \le 0 \\
& j = 1, 2, \ldots, 5
\end{aligned} \tag{14}$$

This nonlinear programming problem has no equality constraint.

4. Calculation Results and Conclusions

The author used Optimization Toolbox in Matlab to solve the above nonlinear programming problem.

4.1. Convergence of the nonlinear program

The algorithm used is IPM (Interior-point-method) for nonlinear programming. At present, there is no algorithm to solve general nonlinear programming problems which can guarantee to find the global maximum point of objective function. The result of the calculation is affected by the uncertainty of the input "initial conjecture" -- an arbitrary set of solutions that requires input. To determine the global optimal solution, 100 sets of random "initial conjectures" were tried to run solvers with and without considering the social cost of denial of admission, until a stable, minimum value was obtained. The random "initial guess" is generated by the Python random integer generation function.

4.1.1. No unsatisfactory cost of refusing patients

The final optimal value and optimal solution of 100 sets of different initial conjectures are all equal. However, there are generally two changes in the function value during the calculation process, as shown in the more representative figure 1 and 2. A smaller optimal value of 42467.8 million yuan with its optimal solution is selected. The optimal solution is shown in the next section.

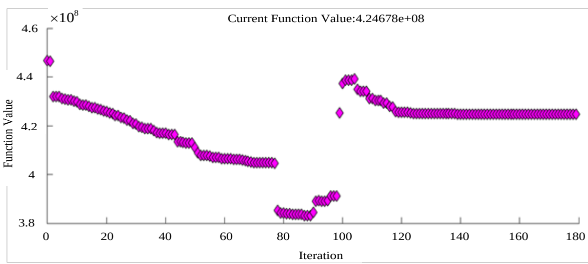


Figure 1. Calculation process and results without considering the cost of denying patients situation 1

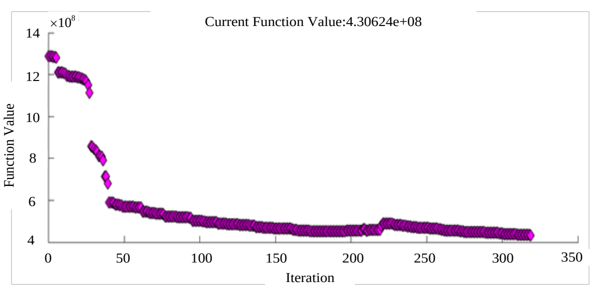


Figure 2. Calculation process and results without considering the cost of denying patients situation 2

4.1.2. The denial of admission costs were Dn=13820.5RMB/ person and Dc=17000RMB/ person respectively

In 100 runs, the results were basically similar to the following two. The optimal value is close to 444 million. The value of the optimal variable is also close. Here, a smaller value of 44402.9 million yuan is selected as the optimal case. The optimal solution is explained in the next section.

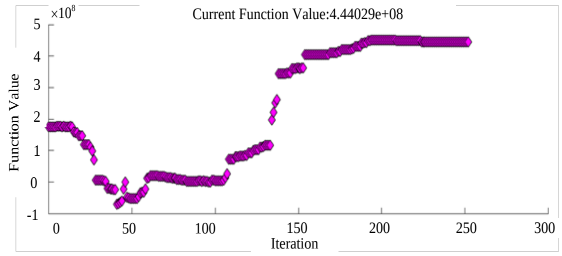


Figure 3. Calculation process and results when Dn=13820.5 Dc=17000 situation1.

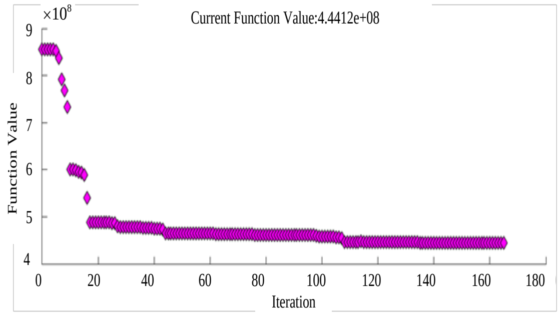


Figure 4. Calculation process and results when Dn=13820.5 Dc=17000 situation2

4.2. Display of results

The optimal plan without considering the social cost of refusing to accept patients

Table 4 The optimal scheme without considering the social cost of denying admission to patients

	Name	Initialguess	Lowerbound	Upperbound	Optimal Value
1	X_1	4000	0	15240	2441
2	X_2	3000	0	15240	2088
3	X_3	2500	0	15240	2055
4	X_4	2000	0	15240	1423
5	X_5	1800	0	15240	1370
6	Pn_1	0	0	7797	0
7	Pn_2	0	0	7797	0
8	Pn_3	0	0	7797	0
9	Pn_4	2345	0	7797	0
10	Pn_5	3456	0	7797	0
11	M_1	40000	0	∞	73288
12	M_2	50000	0	∞	62216
13	M_3	60000	0	∞	62038
14	M_4	80000	0	∞	43514
15	M_5	70000	0	∞	41576
16	P_1	10000	0	∞	33004
17	P_2	20000	0	∞	28223
18	P_3	24000	0	∞	27782
19	P_4	30000	0	∞	19234
20	P_5	20000	0	∞	18518
21	Nu_1	2345	0	∞	1289
22	Nu_2	2345	0	∞	1102
23	Nu_3	2345	0	∞	1085
24	Nu_4	2345	0	∞	751

25	Nu_5	2345	0	∞	723
26	Do_1	3456	0	∞	2011
27	Do_2	3456	0	∞	1720
28	Do_3	3456	0	∞	1693
29	Do_4	3456	0	∞	1172
30	Do_5	3456	0	∞	1128

Table 5 The denial of admission costs are Dn=13820.5RMB/ person and Dc=17000RMB/ person respectively

	Name	Initialguess	Lowerbound	Upperbound	Optimal Value
1	X_1	4000	0	15240	5610
2	X_2	3000	0	15240	4818
3	X_3	2500	0	15240	4812
4	X_4	2000	0	15240	0
5	X_5	1800	0	15240	0
6	Pn_1	0	0	7797	0
7	Pn_2	0	0	7797	0
8	Pn_3	0	0	7797	0
9	Pn_4	2345	0	7797	3381
10	Pn_5	3456	0	7797	3300
11	M_1	40000	0	∞	290418
12	M_2	50000	0	∞	247063
13	M_3	60000	0	∞	253770
14	M_4	80000	0	∞	34621
15	M_5	70000	0	∞	33792
16	P_1	10000	0	∞	76120
17	P_2	20000	0	∞	65269
18	P_3	24000	0	∞	65186
19	P_4	30000	0	∞	34621
20	P_5	20000	0	∞	33792
21	Nu_1	2345	0	∞	2973
22	Nu_2	2345	0	∞	2549
23	Nu_3	2345	0	∞	2546
24	Nu_4	2345	0	∞	1352
25	Nu_5	2345	0	∞	1320
26	Do_1	3456	0	∞	4638
27	Do_2	3456	0	∞	3977
28	Do_3	3456	0	∞	3972
29	Do_4	3456	0	∞	2110
30	Do_5	3456	0	∞	2059

4.3. Result analysis

4.3.1. Analysis of optimal scheme for patient allocation

A) Without considering the cost of refusing a patient admission:

As shown in the variables Xj and Pnj in Table 4-2-1, only COVID-19 patients were admitted to 5 hospitals. Refusing a coVID-19 patient because there is no cost to admitting a normal patient to a hospital will cause him to be out in the field and continue the infection, so the five hospitals should treat only COVID-19 patients. However, only 2441+2088+2055+1423+1370=9377 patients were admitted out of 15,240 coVID-19 patients, because the high density of COVID-19 patients in hospitals would result in a large number of patients with cross-infection. Thus, even if as many as 15,240-9,377 = 5,863 COVID-19 patients are denied admission to hospitals, they will continue to act as a source of infection. Under the threat of high cross-infection rate caused by the high density of COVID-19 patients in hospitals, and with the help of the government's strong personnel movement control, it is a better choice than admission to hospitals. A better solution would be to open multiple makeshift hospitals to treat patients, especially those with mild COVID-19 who are highly active and infectious and have low medical requirements. It can also be seen that the distribution of COVID-19 patients in the five hospitals is basically weighted average. This equalization also prevents a high rate of cross-infection, mainly among health care workers, resulting from a high density of patients in a hospital.

B) Consider the cost of denying admission for ordinary patients, Dn=13820.5RMB/ person, Dc=17000RMB/ person for COVID-19 patients:

As shown in the variable Xj and Pnj in Table 4-2-2, the optimal solution was to distribute all 15,240 COVID-19 patients in the hospitals with J =1-3 in a weighted average according to the number of beds, and all the beds in the hospitals with J =4-5 were used for the admission of ordinary patients. Most of the 7797 ordinary patients receivable were admitted, 3381+3300=6681. The number of coVID-19 patients is much higher than that of the general population because this distribution of COVID-19 patients demonstrates the importance of isolation to avoid more cross-infection and minimize the cost of treating common and COVID-19 patients in the same place, in addition to being evenly distributed. Nevertheless, considering the cost of denying patients admission, hospitals basically treat patients within their admission capacity, leading to a large number of cross-infections.

Regardless of the psychological cost caused by refusal of admission, the optimal allocation of patients is the minimum point of balance between cross-infection caused by admission and infection caused by continuing activities of patients caused by non-admission. When considering the psychological cost of denial of admission, hospitals need to treat a large number of COVID-19 patients in limited bed space, which results in a large number of in-hospital cross-infections, but at the same time, the out-of-hospital infection is significantly reduced, and only a small amount of psychological cost of denial of admission is generated. The optimal value of the objective function in the two cases was 42467.8 million and 444.12 million respectively, with a small gap, indicating that under the strict control of personnel gathering activities implemented by the government, the cost gap caused by adjusting the number of patients admitted within a certain range was not large. However, the out-of-hospital social infection caused by a small number of patients is obviously more unpredictable and uncontrollable than the cross-infection in the hospital. In addition, if fewer patients are selected to reduce cross-infection, it is necessary to implement the control of crowd activity for a long time to prevent the worsening of out-of-hospital infection, which will bring great economic losses. Therefore, the government as a whole should choose to receive and treat more and try to avoid the external source of infection. In addition, a number of makeshift hospitals with sufficient space for the treatment of COVID-19 patients can not only accommodate a large number of patients, but also significantly reduce the cross-infection rate in each hospital, especially for patients with mild COVID-19 who are highly active and infectious but do not have high requirements for medical conditions.

4.3.2. Analysis of the optimal plan for medical material distribution

As can be seen in tables 4-2-1 and 4-2-2, the high number of COVID-19 patients admitted has doubled the demand for medical supplies. In Table 4-2-1, although the number of patients in the three hospitals receiving COVID-19 patients is 1-2 times that in the two hospitals receiving ordinary patients j=9 and 10, the demand for masks is about 11 times higher than that in the two hospitals. Items in the SARS virus in the environment of survival and the research of the resistance, the viability of SARS virus in dry and humid environment was studied. COVID - 19 viruses and the SARS virus has a high similarity, and while a mask is water absorption material, wear in the nose and mouth but make it in the wet state, often made users' frequent contacts masks a decision on when the patient and by rapid increase the risk of respiratory infections, so need to contact with COVID - 19 patients with frequency change mask replacement frequency. Although the surface of protective clothing does not absorb water, the virus can remain on its surface for a long time, but it has a strong anti-permeability, protective ability is not easily affected by the degree of virus exposure. Therefore, the demand for masks in hospitals is greatly affected by the density of COVID-19 patients, while the demand for protective clothing is basically proportional to the total number of patients and has nothing to do with COVID-19 or ordinary patients.

It is mentioned in 4.3.1 that the cost caused by rejecting patients is taken into account in choosing to admit a large number of COVID-19 patients. The biggest problem in choosing to admit a large number of COVID-19 patients to hospital is the shortage of protective materials. As shown in Table 4-2-2, when 5610,4818,4812 COVID-19 patients were treated in J =1-3 hospitals, the demand for masks reached 791,249 and the demand for protective clothing reached 206,665 in 10 days according to the standard.

4.3.3. Analysis of the optimal plan for medical staff allocation

The number of optimal medical staff is maintained at the lowest level of national standards, which is basically proportional to the number of hospital patients. This will not only reduce the number of cross-infections, but also save much-needed medical supplies.

5. Summary

If we don't consider the cost of refusing patients that are supposed to be hospitalized, the optimal solution of distributing patients and medical supplies with the goal of minimizing total cost will distribute the COVID-19 patients almost averagely in the 5 hospitals, while not receiving a single ordinary inpatient; if other conditions does not change ,and we consider the cost of refusing a COVID-19 patient and a ordinary patient to be their respective treatment cost, the optimal solution would receive majority of both kinds of patients to the capacities of the hospitals. However, the cost of the latter strategy was only higher than that of the first for 4.5%. In this situation, choose to treat as many patients as possible can also improve the controllability of the social infection situation, as well as the benefits of slowing down the policy of control of agglomeration activities and restoring the economy as early as possible. But admitting large Numbers of COVID-19 patients also poses a major challenge to the availability of medical supplies. In terms of nosocomial cross-infection, treating COVID-19 patients separately from other patients, as well as building multiple hospitals with large space and strong reception capacity and distributing patients in each hospital will significantly reduce the cross-infection rate. In terms of its economic impact, the epidemic cost at least 400 million yuan in treatment and supplies in just 10 days, causing huge economic losses. The government can fully mobilize the production of medical supplies, build a makeshift hospital, and treat patients as soon as possible with the overall strategy of minimizing the cost of patients and the distribution of medical supplies, so as to eliminate the uncertainty of the risk caused by infectious sources outside the hospital.

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