The Efficient Allocation of Covid Testing Stations

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Abstract. Since the outbreak of the pandemic, the normalization of nucleic acid testing (NAT) has become a social phenomenon in China. According to the statement of the State Council of China in June 2022, the normalization of NAT will "help to identify potential risks earlier and implement prevention and control measures faster". In this case, the setting of COVID-19 test station has become one of the most critical stages. This paper will use linear planning and secondary planning, based on the current problems, Simulate the real distribution of population density in China's major cities (Shanghai) and reallocate test stations. The final data shows that the government can properly adjust the resource allocation and the density of test stations in various districts of Shanghai. This study can help us allocate resources more reasonably and make the society operate more efficiently.

Keywords: nucleic acid testing (NAT) · COVID-19 · Covid testing stations

1 Introduction

The regularization of nucleic acid testing (NAT) in China becomes a social-level phenomenon since the outburst of the pandemic, initiated in Jilin Province, in multiple central cities across the country. The high infectivity and immune escape nature of the omicron variant increase the difficulties for the government to achieve its previous goal of "ZERO-Covid" proposed by Jinping Xi in 2019's pandemic [1]. According to The State Council of China in June 2022 that the regularization of NAT will "facilitate earlier detection of potential risks and faster implementation of preventive and control measures." Whereas the regularization of NAT normalizes, routinizes, and long-term the acute nature of the pandemic influences people's social behavior and tightens local governments' financial budgets. Further confirmed by The National Health Commission of China in the early June of 2022 officially stated that the local government will be fully in charge of the regularization and all the costs produced [2].

Regularization of NAT implies the societal fact that every person who lives in the country is required to take and show the test result in order to enter public facilities and access different cities or provinces. The resulting surge in demand set a high standard for the government and the facilities to collect, process, and pose results of masses on a daily bases. Under such a challenge, the setting of Covid testing stations becomes one of

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the most crucial stages [3]. This is because these stations, on the one hand, distribute the capacity for testing in traditional settings like hospitals or community medical centers improving efficiency. On the other hand, the stations reduce the burden on hospitals and medical centers ensuring the functioning of the medical system. However, the limited financial budget, usable medical resources, and time posed constrains to the allocation [3, 4].

1.1 Limited Finance Budget

The limited budget that the local government can spend on the program director determines the number of stations that are enabled to build across the city. As mentioned above, the huge capacity that needs to be processed on a daily bases set a lower boundary for the number of stations that must be established. Therefore, the efficient allocation of these stations is needed to be planned and considered thoroughly.

1.2 Limited Usable Medical Resources

The medical resources that are needed for the functioning of the program include the constant supply of medical personnel, test tubes, protective clothing, vehicles for transport, instruments that can provide NAT, etc. While these resources can be increased through greater government or institutional investment, funding and labor supply are highly limited resources. Thus, the allocation of the stations reflects the effectiveness of the usage of these resources maximizing efficiency while minimizing the cost for the government and facilities.

1.3 Limited Time

Time is always a crucial factor. The people want to reduce the time of walking and waiting, the government wants to reduce the time of implementation, and the facilities want to reduce the time of receiving and processing samples. While some of the costs had to be paid, the expectations fell on the rest. The allocation of stations in this case affects the walking and waiting time of the people, the transportation time between the stations and the facilities, and the implementation time of the whole program opening to the public.

By evaluating under these constraints, the problems within the current situation are comparatively clear: 1) multiple testing stations in one area causing waste of resources 2) lack of testing stations in a high populated area (density) causing long waiting time 3) inefficient transportation of samples causing overloaded work for facilities.

This paper will use linear programming and quadratic programming to simulate a realistic distribution of population densities in major Chinese cities - Shanghai - based on the above constraints and current problems, and to reallocate test stations. This decision was made for the cities in China that currently have the highest volume of people and the most severe rates of confirmed outbreaks. The decision was also motivated by the urgency of the demand, the representational capacity, and the amount of data available. In order to make the model more informative and valuable for research, maximum reference will be made to real data and actual conditions, including population density, distance between facilities and sites, and real-time regulations. The survey hopes to maximize efficiency and reduce waste of resources (costs).

This study aims to maximize the efficiency of NAT during the COVID-19 pandemic through scientific data collection and analysis, while reducing the waste of personnel, medical and financial resources.

2 Literature Review

While the idea of regularization of Covid testing station is a relatively new concept, proposed by the Chinese government in 2022, there was not an abundance of references that directly discuss the topic. Though, the optimization of the placement of sharing facilities is considered by Zoran MILJANIC, Vladan RADULOVIC, and Budimir LUTOVAC (2018) [5]. They used integer linear programming to optimize the placement of electric vehicle charging stations, processing the input road network configuration data, calculating all combinations of shortest routes, and finding the optimal placement by calcite the connectivity matrix. The design of the total sharing system was investigated by Ma, Li, Zhou, and Hao in their article, specifically using the first horizontal model and multiple horizontal models. However, the varied constraints between electric vehicle stations and testing stations let the total setup required to be redetermined, which was discussed by Alan D. Kaye, Chikezie N. Okeagu, Alex D. Pham, Rayce A. Silva, Joshua J. Hurley, Brett L. Arron, Noreen Sarfraz, Hong N. Lee, G.E. Ghali, Jack W. Gamble, Henry Liu, Richard D. Urman, Elyse M. Cornett in their 2020's research4 [1]. Specifically, they highlighted the economic impact of Covid-19 in making policy decisions and the possible plan of allocating resources within the financial constraints. This discussion inspired the team in analyzing the financial constraints of China's situation. Taking into account the similarity between vaccine allocation and testing station distribution, the research paper written by Christian Alvin H. Buhat, Destiny S. M. Lutero, Yancee H. Olave, Kemuel M. Quindala, III, Mary Grace P. Recreo, Dylan Antonio S. J. Talabis, Monica C. Torres, Jerrold M. Tubay, and Jomar F. Rabajante regarding the constrained optimization for the allocation of COVID-19 vaccines in the Philippines is valuable to be referenced5 [2]. As they considered the prioritization of certain age groups and the costs, the programming model successfully minimized the death number of vaccinated Philippines. Noticing this paper got a different optimization goal, minimizing the number of testing stations, compared with the vaccination case, Erwin Kalvelagen's technical notes will be partially referenced6. Kalvelagen set the formulation using the second-order cone programming, minimizing the distances between facilities considering convex quadratic constraints [6–8].

3 Methodology

The linear model in this paper aims to s to calculate the potential positive population in each region while meeting the demand for nucleic acid testing stations and we set a specific city as i.

$$Ni - eff \times Si \tag{1}$$

To estimate the number of susceptible people in each locality after the test was extended.

Ni: The total population of city
Si: The number of people who receive test
Eff: The efficiency rate of receive a test. (the rate of tested positive)
Si = Hi + Li
Hi: The age beyond 14 and age higher than 60
Li: The age between 15–59
Hi ≥ 0
Li ≥ 0

$$1 - exp(-\frac{\delta i}{max[\delta i]}) \tag{2}$$

In China, because of the close distribution of population density, there is often a radioactive spread around the areas where symptoms of Covid-19 infection occur. The rational allocation of nucleic acid testing stations to result in minimizing the infection factor associated with the test is our main goal. Therefore, we must consider the population density of each region in this equation, and we set the population density in each district in Shanghai equal to δi, with i representing Shanghai. The max value of δi represents the total population density in Shanghai.

Due to the limited medical resources initially available in Shanghai, we distinguished two target groups based on the probability of post-nucleic acid positivity, one being those older than 60 years and those younger than 14 years, which are very susceptible to Covid-19 infection because of their weaker physical condition. The other pair of groups are those aged 15 to 59 years, which are less likely to be infected by Covid-19 or recover more quickly after infection because they are in relatively stronger physical condition than those older than 60 years and those younger than 14 years.

$$\sum_i (P \times Si + \frac{Si}{200}(150 + 233)) \leq A \tag{3}$$

$$A \leq The\ total\ budget\ for\ each\ region$$

Finally, we would consider the incorporating test costs for resource-limited countries, a key factor is the cost of nucleic acid testing. Some countries are interested in using multiple tests. In China, the national vaccine budget for nucleic acid is 1.3 billion, which will include the cost of testing props as well as the cost of training (150RMB) per nucleic acid testing and the cost of other peripheral equipment, such as Masks, masks, alcohol and cotton balls (233RMB), these two things are suitable for 200 people to use. The test assembly is defined as where P is the price per complete dose of the Nucleic acid testing equipment.

Minimize

$$\sum_i ((Ni - eff \times Si)(1 - exp(-\frac{\delta i}{max[\delta i]}))) \quad (4)$$

subject to

$$Ni - eff \times Si \geq 0 \quad (5)$$

$$Hi \geq 0, Li \geq 0 \quad (6)$$

$$\sum_i (P \times Si + \frac{Si}{200}(150 + 233)) \leq A \quad (7)$$

Δi is the population density in each district.

4 Analysis and Result

We collected data from the 2021 census to calculate this equation and chose Shanghai as our reference location. Table 1 shows the population distribution and area of each district in Shanghai, the age of the population, the flow of people at the test site, etc.

Table 2 show effectiveness because during the outbreak Shanghai, China set precautions between each area to avoid a person without any proof of vaccine or nucleic acid testing to reach another area. We can see in the results obtained that only the Jing'an, Qingpu and Chongming districts stand out as potentially positive populations, with all three of them carrying a value of 2 compared to the value of 1 in the other districts. Therefore, we decided to allocate more nucleic acid testing sites in these three districts.

From Fig. 1, we can see that the distribution of official nucleic acid testing stations in Shanghai is rather concentrated and not rationally distributed, and the purpose of our study is to distribute nucleic acid testing stations more efficiently. Based on the results of our data, we should reduce the number of testing stations around Jiading district and distribute them in chongming and qingpu districts.

Table 1. Data (self-painted)

		Number of test station	Area km^2	Regional population	Regional population age distribution %					
Area Name	Census 2020/11/1									Per of people test
					14-	15–59	60 +	14-&60 +	59-	
Huangpu	662030	17	20.49	32309 9072	0.086706949	0.647280967	0.266012085	0.352719033	0.733987915	662030
Xuhui	1113078	25	55.15	20179.079	0.097924715	0.614949241	0.287126044	0.385050759	0.712873956	1113078
Changning	693051	10	37.16	18650.4574	0.088876064	0.620112538	0.291011398	0.379887462	0.708988502	693051
Jingan	975707	36	36.77	26535.1093	0.093163082	0.591267808	0.3156708	0.108034683	0.68143169	975707
Putuo	1239800	12	55.16	22476.4321	0.093806111	0.600500081	0.305613809	0.399499919	0.694386191	1239800
Hongkou	757498	31	23.41	32357.8812	0.081848185	0.586006601	0.332145215	0.413993399	0.667854785	757498
Yangpu	1242548	17	60.55	20521.0239	0.088370221	0.593802817	0.317826962	0.406197183	0.682173038	1242548
Mingxin	2653489	80	373	7113.9115	0.108548954	0.68920294	0.202148106	0.31079706	0.797851894	2653489
Baoshan	2235218	115	314.9	7098.1835	0.100035791	0.67134932	0.228614889	0.32065068	0.771385111	2235218
Jiading	1834258	59	462.9	3962.5361	0.09907556	0.723382217	0.178487706	0.276563267	0.821457777	1834258
Pudong	5681512	400	1698	3346.0023	0.104831471	0.678870017	0.216298513	0.321129983	0.783701487	5681512
Jinshan	822776	87	667.8	1232.0694	0.092124453	0.672095284	0.235658726	0.327783179	0.764219737	822776
Songjiang	1909713	35	604.7	3158.1164	0.107137247	0.734984553	0.157878201	0.265015447	0.842121799	1909713
Qingpu	1271424	19	667.8	1903.8993	0.088642441	0.745005506	0.166430706	0.255073148	0.833647947	1271424

(continued)

Table 1. (*continued*)

		Number of test station	Area km^2	Regional population	Regional population age distribution %					
Area Name	Census 2020/11/1									Per of people test
Fengxian	1140872	100	805.4	1416.5284	0.092821457	0.713559471	0.193619073	0.286440529	0.806380927	1140872
Chongming	637921	67	1965	324.6417	0.066938392	0.536447719	0.396770654	0.463709045	0.603386111	637921
		1110								
Shanghai Regional population age	Positive test rate (%)									
14-	0.000286									
15–59	0.000444									
60 +	0.000275									
14-&60 +	0 000278247									

Table 2. Result (self-painted)

District	Result
	5.168852585
Huangpu	1
Xuhui	1
Changning	1
Jingan	2
Putuo	1
Hongkou	1
Yangpu	1
Mingxin	1
Baoshan	1
Jiading	1
Pudong	1
Jinshan	1
Songjiang	1
Qingpu	2
Fengxian	1
Chongming	2

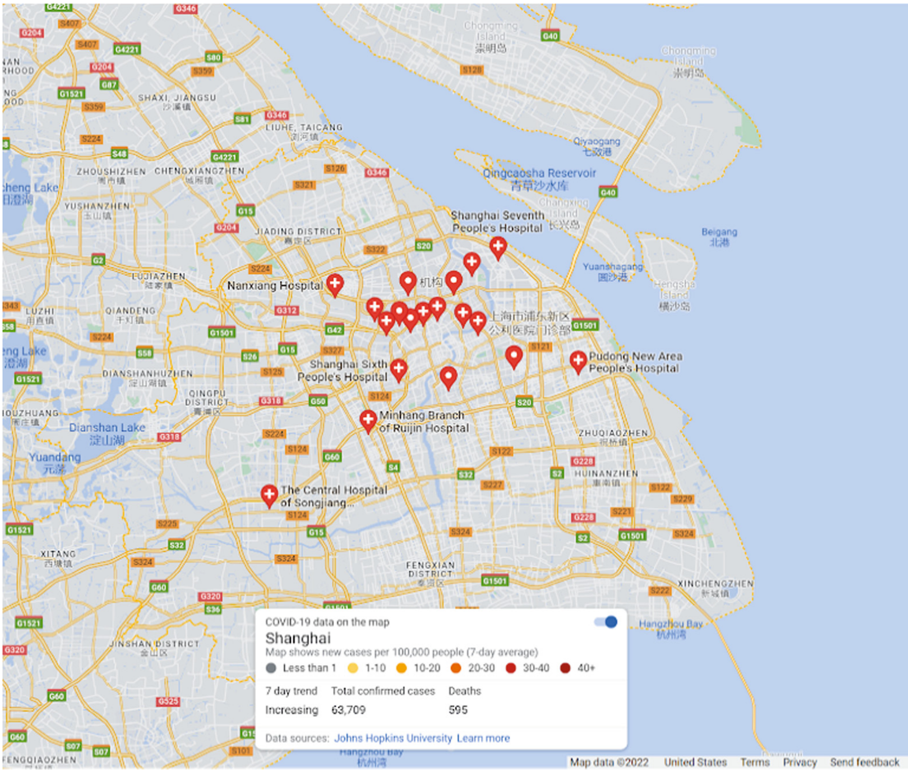

Fig. 1. Major Nucleic Acid Institutes and Covid Mortality in Shanghai [9]

5 Conclusion

The data derived from this paper suggest that, with government support, we can distribute the medical resources and social budget of the nucleic acid testing sites concentrated in Pudong New District to Jing'an, Qingpu and Chongming Districts. Subsequently, in order to reduce the queuing time, we should allocate a designated area for each district, establishing a major nucleic acid site with high traffic in the more densely populated cities, and presenting scattered nucleic acid sites in areas with relatively loose population distribution, so that resources can be utilized while allowing other areas to use them rationally. We will then make further studies on how to assign nucleic acid sites efficiently and the distribution of the number of nucleic acid sites.

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