Determining the Best Location for COVID-19 Vaccine Distribution in Palembang Using the Set Covering Problem Model and Greedy Heuristic Algorithm

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Abstract

Optimizing the location of public health facilities is crucial to ensure public accessibility. Palembang City uses public health facilities for COVID-19 vaccine distribution and administration. This study identified the best location for COVID-19 vaccine distribution in Palembang City by implementing the Set Covering Problem (SCP) model and solving it with the Greedy Heuristic Algorithm. The SCP model consists of the Set Covering Location Problem (SCLP) model and the p-Centre Location Problem (p-CLP) and considers the separating distance between vaccine distribution sites located in each sub-district of Palembang City. The p-CLP model was formulated, and the Greedy Heuristic Algorithm was executed to determine the optimal distribution location for COVID-19 vaccines. The SCLP model successfully identified 27 optimal COVID-19 vaccine locations in Palembang City. These locations were subsequently used to formulate the p-CLP model. The p-CLP model's solution and the application of the Greedy Heuristic Algorithm yielded 27 optimal vaccine sites, which include Ariodillah Health Centre, Naga Swidak Health Centre, Sako Health Centre, Bukitsangkal Health Centre, Sei Lincah Health Centre, Kenten Health Centre, Kalidoni Health Centre, Pakjo Health Centre, Sei Baung Health Centre, Merdeka Health Centre, OPI Health Centre, Sosial Health Centre, Talang Betutu Health Centre, Myria Hospital, Sukarami Health Centre, Keramasan Health Centre, Karya Jaya Health Centre, 7 Ulu Health Centre, Sabokingking Health Centre, Charitas Hospital, Dr. Mohammad Hasan Hospital, Siti Khadijah Hospital, Bunda Hospital, Bunda Noni Hospital, Pelabuhan Kelas II Palembang Health Office, Tiara Fatrin Hospital, and Alang-Alang Lebar Health Centre.

Keywords: *Location, Vaccine, Set Covering Problem, Set Covering Location Problem, p-Center Location Problem, Greedy Heuristic Algorithm.*

A. INTRODUCTION

Coronavirus disease 2019, commonly known as COVID-19, is an infectious disease caused by the SARS-CoV-2 virus. The first cases were reported in China in December 2019. Amidst its highly contagious nature, the disease has affected 6,045,043 people across 34 provinces and 510 districts and cities as of 2021 (Chung et al., 2021). This paper aims to identify the most suitable location for distributing COVID-19 vaccines in Palembang, the capital of South Sumatra Province.

Palembang is divided into 18 administrative sub-districts and 107 urban settlements, encompassing a total area of 400.61 km^2. It shares borders with Banyuasin Regency to the north, east, and west, and Muara Enim Regency to the south. Demographic changes and population growth influence the development of

Palembang City. Fast, transparent, effective, and accountable public services are critical for the city's growth and progress (Antoni et al., 2021). Compared to other cities and districts in South Sumatra Province, Palembang City has the highest population density (Devi et al., 2016). The government of Palembang City is taking measures to prevent the spread of COVID-19, such as conducting campaigns to promote healthy living, participating in the vaccination movement, and identifying the most suitable locations for administering COVID-19 vaccines.

Vaccination is intended to establish herd immunity, ensuring that individuals can maintain their productivity in performing daily activities. The vaccination process consists of four stages: dose 1, dose 2, booster 1, and booster 2. Various vaccines are available, such as Sinovac, AstraZeneca, Moderna, Pfizer, and Sinopharm. Vaccination sites in Palembang are in central and auxiliary health centres, government or private clinics, government or private hospitals, health service units, and malls. There are 43 vaccination locations located in Palembang and spread out throughout 14 sub-districts (Dewi & Bustan, 2021).

Optimization problems related to location and allocation involve the Set Covering Problem (SCP) model (Octarina et al., 2022). The application of the SCP model can be observed in tackling real-world issues, such as determining the optimal route for garbage collection vehicles to the collection point, distributing machines for designated tasks, and allocating job roles to individuals (Brimkov et al., 2019; Daskin & Maass, 2019; Kwon et al., 2020; Octarina et al., 2022; Octarina et al., 2022; Xu & Li, 2018). The SCP model maximizes the number of facility locations that can efficiently cater to all requirements. The SCP model comprises diverse model groups, specifically the Set Covering Location Problem (SCLP), Maximum Covering Location Problem (MCLP), p-Centre Location Problem (p-CLP), and p-Median Problem that interrelate (Javid et al., 2017). SCLP optimizes facility placements to serve all demand points in a distribution system issue model (Octarina et al., 2022). MCLP is designed to identify the most significant demand coverage within a standard time frame using a specified number of p facilities. According to Syakina & Nurdiati (2021), the objective function of MCLP is to maximize the number of facilities acquired within a specific period.

One algorithm for solving the SCP is the Greedy Heuristic Algorithm. It determines the best facility to construct at each step (Bangun et al., 2022). As per Amarilies et al. (2020), the Greedy Heuristic Algorithm is the most suitable method to acquire solutions for the SCLP model and the p-CLP issue. The Greedy Heuristic Algorithm can be implemented in a sequence of steps, first identifying high-demand candidates and then identifying facilities capable of providing the required replacements, with the caveat that more than one facility is allocated (Katayama, 2019). This algorithm selects the optimal replacement option after the best possible swap. Additionally, it considers the removal of each selected candidate and substitution with unselected substitutes (Bangun et al., 2023).

Previous research on location determination using SCP has advanced significantly. Sitepu et al. (2022) proposed an optimization solution for the covering-based model in emergency room (ER) settings. The study identified five emergency

room locations: Alang-Alang Lebar, Gandus, Ilir Barat I, Ilir Barat II, and Kertapati sub-districts. Sitepu et al. (2019) optimized the locations ER in Palembang City using the SCP model, resulting in six ER serving eight sub-districts. The ER are in Ilir Timur II, Kalidoni, Sako, Seberang Ulu II, Sematang Borang, and Sukarami sub-districts. According to Bangun et al. (2022), the Greedy Heuristic Algorithm is valuable for finding optimal solutions to large-scale problems. This study examines the SCP modelling of COVID-19 vaccine distribution locations. Subsequently, it implements the greedy heuristic algorithm to determine the optimum COVID-19 vaccine location in Palembang City.

B. METHODS

The stages carried out in this research are:

1. Measure the distance of each COVID-19 vaccine location in Palembang using Google Maps and present it as a data table.
2. Defining variables and parameters for the SCLP model and p-CLP for determining the location of the COVID-19 vaccine in Palembang City.
3. Formulate the SCP model, including the SCLP model and the p-CLP.
4. Determine the solution of the two SCP models with the help of LINGO 13.0 software.
5. Solving SCP with the Greedy Heuristic Algorithm.
6. Analyze the results of the SCP model with LINGO 13.0 and the Greedy Heuristic Algorithm.

C. RESULTS AND DISCUSSION

This section examines the research data, determining the quantity and whereabouts of COVID-19 vaccine distribution in Palembang City, formulating the SCLP model and the p-CLP as the SCP model, and implementing the Greedy Heuristic Algorithm to solve the SCP. The dataset comprises a roster of sub-districts, the names of the COVID-19 vaccine dispensary outlets in Palembang City, and the intervening distance separating each depot. Information on the COVID-19 vaccine distribution sites was procured from the Palembang City Health Office, which surveyed and collated the data based on location points in each sub-district of Palembang City. Table 1 displays the classification of COVID-19 vaccine distribution sites by sub-district.

In the Ilir Timur 1 sub-district, for instance, there are three health centres, specifically Ariodillah Health Centre, Dempo Health Centre, and Talang Ratu Health Centre, as well as three hospitals: Charitas Hospital, YK Madira Hospital, and Sriwijaya Hospital. The number of vaccine distribution locations decreases here, with the Alang-Alang Lebar sub-district having only one COVID-19 vaccine distribution location, namely the Alang-Alang Lebar Health Centre.

Table 1. List of COVID-19 Vaccine Distribution Sites in Palembang City

No	Sub-District	COVID-19 Vaccine Distribution Sites
1	Ilir Timur I	Ariodillah Health Centre
		Charitas Hospital
		Dempo Health Centre
		Talang Ratu Health Centre
		YK Madira Hospital
		Sriwijaya Hospital
2	Plaju	Naga Swidak Hospital
3	Sako	Sako Health Centre
		Multiwahana Health Centre
4	Kalidoni	Bukitsangkal Health Centre
		Sei Lincah Health Centre
		Kenten Health Centre
		Kalidoni Health Centre
5	Kemuning	Dr. Mohammad Hasan Hospital
		Bhayangkara Hasan Hospital
6	Ilir Barat I	Kampus Health Centre
		Pakjo Health Centre
		Siti Khadijah Health Centre
		Bunda Hospital
		Graha Mandiri Hospital
		MMC Hospital
		Bunda Noni Hospital
		Padang Selasa Health Centre
		Sei Baung Health Centre
7	Bukit Kecil	Merdeka Health Centre
8	Jakabaring	OPI Health Centre
9	Sukarami	Sosial Health Centre
		Talang Betutu Health Centre
		Myria Health Centre
		Pelabuhan Kelas II Palembang Health Office
		Sukarami Health Centre
		Ar Rasyid Hospital
10	Kertapati	Keramasan Health Centre
		Karya Jaya Health Centre
11	Seberang Ulu II	Taman Bacaan Health Centre
12	Seberang Ulu I	7 Ulu Health Centre
		Bari Hospital
13	Ilir Timur II	Boom Baru Health Centre
		Sabokingking Health Centre
		11 Ilir Health Centre

		5 Ilir Health Centre Tiara Fatrin Hospital
14	Alang-Alang Lebar	Alang-Alang Lebar Health Centre

The variable definitions of the name of the COVID-19 vaccine distribution location and the variable names of sub-districts in Palembang City can be seen in Table 2-Table 4, respectively.

Table 2. Variable Definition for COVID-19 Vaccination Distribution Locations in Palembang City

Variable	Location	Variable	Location
y_1	Ariodillah Health Centre	y_{23}	Padang Selasa Health Centre
y_2	Charitas Hospital	y_{24}	Sei Baung Health Centre
y_3	Dempo Health Centre	y_{25}	Merdeka Health Centre
y_4	Talang Ratu Health Centre	y_{26}	OPI Health Centre
y_5	YK Madira Hospital	y_{27}	Sosial Health Centre
y_6	Sriwijaya Hospital	y_{28}	Talang Betutu Health Centre
y_7	Naga Swidak Health Centre	y_{29}	Myria Hospital
y_8	Sako Health Centre	y_{30}	Pelabuhan Kelas II Palembang Health Office
y_9	Multiwahana Health Centre	y_{31}	Sukarami Health Centre
y_{10}	Bukitsangkal Health Centre	y_{32}	Ar Rasyid Hospital
y_{11}	Sei Lincah Health Centre	y_{33}	Kramasan Health Centre
y_{12}	Kenten Health Centre	y_{34}	Karya Jaya Health Centre
y_{13}	Kalidoni Health Centre	y_{35}	Taman Bacaan Health Centre
y_{14}	Dr. Mohammad Hoesin Health Centre	y_{36}	7 Ulu Health Centre
y_{15}	Bhayangkara Hasan Hospital	y_{37}	Bari Hospital
y_{16}	Kampus Health Centre	y_{38}	Boom Baru Health Centre
y_{17}	Pakjo Health Centre	y_{39}	Sabongkingking Health Centre
y_{18}	Siti Khadijah Health Centre	y_{40}	11 Ilir Health Centre
y_{19}	Bunda Hospital	y_{41}	5 Ilir Health Centre
y_{20}	Graha Mandiri Hospital	y_{42}	Tiara Fatrin Hospital
y_{21}	MMC Hospital	y_{43}	Alang-Alang Lebar Hospital
y_{22}	Bunda Noni Hospital		

Table 3. Variable Definition of Sub-District in Palembang

Variable	Sub-District
z_1	Ilir Timur I Sub-District
z_2	Plaju Sub-District
z_3	Sako Sub-District
z_4	Kalidoni Sub-District
z_5	Kemuning Sub-District
z_6	Ilir Barat I Sub-District
z_7	Bukit Kecil Sub-District
z_8	Jakabaring Sub-District
z_9	Sukarami Sub-District
z_{10}	Kertapati Sub-District
z_{11}	Seberang Ulu II Sub-District
z_{12}	Seberang Ulu I Sub-District
z_{13}	Ilir Timur II Sub-District
z_{14}	Alang-Alang Lebar Sub-District

Table 2 explains that y_1 represents Ariodillah Health Centre, y_2 represents Charitas Hospital, y_3 represents Dempo Health Centre, until y_{43} represents Alang-Alang Lebar Health Centre. Table 3 states that z_1 represents Ilir Timur I Sub-District, z_2 represents Plaju Sub-District, and so on until z_{15} represents Alang-Alang Lebar Sub-District.

Table 4. Parameter and The Value of Parameter

Parameter	Name of Sub-District	The Value of Parameter
p_1	Ilir Timur I Sub-District	6
p_2	Plaju Sub-District	1
p_3	Sako Sub-District	2
p_4	Kalidoni Sub-District	4
p_5	Kemuning Sub-District	2
p_6	Ilir Barat I Sub-District	9
p_7	Bukit Kecil Sub-District	1
p_8	Jakabaring Sub-District	1
p_9	Sukarami Sub-District	6
p_{10}	Kertapati Sub-District	2
p_{11}	Seberang Ulu II Sub-District	1
p_{12}	Seberang Ulu I Sub-District	2
p_{13}	Ilir Timur II Sub-District	5
p_{14}	Alang-Alang Lebar Sub-District	1

Table 4 describes the parameters and parameter values used in the model. p_1 defines Ilir Timur I Sub-District with a value of 6, which means that there are 3 Health Centres and 3 Hospitals located in Ilir Timur I Sub-District, p_2 defines Plaju Sub-District with a value of 1, which means that there is only 1 Healh Centre located in Plaju Sub-District, until p_{14} defines Alang-Alang Lebar Sub-District with a value of 1,

which means that there is 1 Health Centre located in Alang-Alang Lebar Sub-District.

Data on the distance between COVID-19 vaccine distribution sites in Palembang City was obtained by directly measuring the site on January 15, 2022, using Google Maps. According to Article 18 of the Law on the Implementation of COVID-19 Vaccination, the Regency/City Health Office and the Provincial Health Office shall gradually collect data and determine the implementing health service facilities, as well as determine the distribution of COVID-19 vaccines, supporting equipment, and logistical tools that can be used to implement COVID-19 vaccination. Permenpera/No.32/Permen/M/2006 states that the ideal distance standard for health service facilities of community health centres is 2 km.

The SCLP Model Formulation

The SCLP model formulation for COVID-19 Vaccine Distribution Locations in Palembang City is in the form of:

Minimize $Z_{SCLP} = \sum_{j=1}^{43} y_j$ (1.1)

Subject to

$y_1 + y_2 + y_4 + y_5 + y_6 + y_{14} + y_{15} + y_{17} + y_{18} + y_{19} \geq 1$ (1.2)

$y_1 + y_2 + y_3 + y_5 + y_{14} + y_{16} + y_{24} + y_{26} + y_{42} \geq 1$ (1.3)

$y_2 + y_3 + y_{40} \geq 1$ (1.4)

$y_1 + y_4 + y_{17} \geq 1$ (1.5)

$y_1 + y_2 + y_5 + y_{24} + y_{42} \geq 1$ (1.6)

$y_1 + y_6 + y_{15} + y_{17} \geq 1$ (1.7)

$y_7 + y_{35} \geq 1$ (1.8)

$y_8 \geq 1$ (1.9)

$y_9 + y_{10} \geq 1$ (1.10)

$y_9 + y_{10} + y_{38} + y_{40} + y_{41} \geq 1$ (1.11)

$y_{11} \geq 1$ (1.12)

$y_{12} \geq 1$ (1.13)

$y_{13} \geq 1$ (1.14)

$y_1 + y_2 + y_{14} + y_{15} + y_{17} + y_{24} \geq 1$ (1.15)

$y_1 + y_6 + y_{14} + y_{15} + y_{17} + y_{18} + y_{19} \geq 1$ (1.16)

$y_2 + y_{16} + y_{18} + y_{19} + y_{24} \geq 1$ (1.17)

$y_1 + y_4 + y_6 + y_{14} + y_{15} + y_{17} + y_{18} + y_{19} + y_{20} \geq 1$ (1.18)

$y_1 + y_{15} + y_{16} + y_{17} + y_{18} + y_{19} + y_{20} + y_{24} \geq 1$ (1.19)

$y_{17} + y_{18} + y_{19} + y_{20} \geq 1$ (1.20)

$y_{21} + y_{27} \geq 1$ (1.21)

$y_{22} + y_{23} \geq 1$ (1.22)

$y_2 + y_5 + y_{14} + y_{16} + y_{18} + y_{19} + y_{24} \geq 1$ (1.23)

$y_{25} \geq 1$ (1.24)

$y_{26} \geq 1$ (1.25)

$y_{21} + y_{27} \geq 1$ (1.26)

$y_{28} \geq 1$ (1.27)

$y_{30} \geq 1$ (1.28)

$y_{31} \geq 1$ (1.29)
$y_{29} + y_{32} \geq 1$ (1.30)
$y_{33} \geq 1$ (1.31)
$y_{34} \geq 1$ (1.32)
$y_{36} \geq 1$ (1.33)
$y_{27} + y_{37} \geq 1$ (1.34)
$y_{10} + y_{38} + y_{40} \geq 1$ (1.35)
$y_{39} \geq 1$ (1.36)
$y_3 + y_{10} + y_{38} + y_{40} + y_{42} \geq 1$ (1.37)
$y_{10} + y_{41} + y_{42} \geq 1$ (1.38)
$y_2 + y_5 + y_{40} + y_{41} + y_{42} \geq 1$ (1.39)
$y_{43} \geq 1$ (1.40)
$y_1, y_2, y_3, \dots, y_{43} \in \{0,1\}$ (1.41)

Model (1.1) aims to minimize the number of COVID-19 vaccine distribution locations in Palembang City while meeting all demand points. Constraints (1.2) to (1.40) outline the requirements for each COVID-19 vaccine distribution location in Palembang City, with at least one demand needing to be fulfilled. Constraint (1.41) specifies that variables y_1 to y_{43} are binary. The SCLP model was implemented using LINGO software, and the results are presented in Table 5.

Table 5. Optimal Solution of SCLP Model

Solver Status	
Model Class	PILP
State	*Global Optimal*
Objective	21
Infeasibility	0
Iterations	0
Extended Solver Status	
Solver Type	*Branch and Bound*
Best Objective	21
Objective Bound	21
Steps	0
Active	0
Update Interval	2
GMU (K)	34
ER (sec)	1

The variable value from solving the SCLP model using LINGO 13.0 is either 0 or 1. A value of 0 indicates that no facilities are located at the given location, while a value of 1 indicates that facilities are present. There are 21 variables worth 1, namely hospitals and health centres with variables $y_2, y_8, y_{10}, y_{11}, y_{12}, y_{13}, y_{17}, y_{23}, y_{26}, y_{27}, y_{28}, y_{30}, y_{31}, y_{32}, y_{33}, y_{34}, y_{35}, y_{36}, y_{39}$, and y_{43}. This indicates the candidate locations for the facilities are:

1. Charitas Hospital

2. Sako Health Centre
3. Bukitsangkal Health Centre
4. Sei Lincah Health Centre
5. Kenten Health Centre
6. Kalidoni Health Centre
7. Pakjo Health Centre
8. Padang Selasa Health Centre
9. Merdeka Health Centre
10. OPI Health Centre
11. Sosial Health Centre
12. Talang Betutu Health Centre
13. Pelabuhan Kelas II Palembang Health Centre
14. Sukarami Health Centre
15. Ar Rasyid Health Centre
16. Kramasan Health Centre
17. Karya Jaya Health Centre
18. Taman Bacaan Health Centre
19. 7 Ulu Health Centre
20. Sabongkingking Health Centre
21. Alang-Alang Lebar Health Centre

The p-CLP Model Formulation

The p-CLP model is formulated using the selected candidates from solving the SCLP model. The objective of this model is to identify a strategic location for COVID-19 vaccine distribution in Palembang City that can meet the demand of all points. Table 6 shows the variable definitions of the selected COVID-19 vaccine distribution locations in Palembang City.

Table 6. Candidate Locations of Selected Hospitals and Health Centres

Variable	Candidate Location	Variable	Candidate Location
y_2	Charitas Hospital	y_{28}	Talang Betutu Health Centre
y_8	Sako Health Centre	y_{30}	Pelabuhan Kelas II Health Office
y_{10}	Bukitsangkal Health Centre	y_{31}	Sukarami Health Centre
y_{11}	Sei Lincah Health Centre	y_{32}	Ar Rasyid Hospital
y_{12}	Kenten Health Centre	y_{33}	Kramasan Health Centre
y_{13}	Kalidoni Health Centre	y_{34}	Karya Jaya Health Centre
y_{17}	Pakjo Health Centre	y_{35}	Taman Bacaan Health Centre
y_{23}	Padang Selasa Health Centre	y_{36}	7 Ulu Health Centre
y_{25}	Merdeka Health Centre	y_{39}	Sabokingking Health Centre
y_{26}	OPI Health Centre	y_{43}	Alang-Alang Lebar Health Centre
y_{27}	Sosial Health Centre		

The p-CLP model is as follows:

$$Z_{p-Center} = \min L \quad (2.1)$$

Subject to

$$\sum_{j\in J} z_{ij} = 1, i \in \{1,2,\dots,14\} \text{ and } j \in \{2,8,10,11,12,13,17,23,25,26,27,28,30,31,32,33,34,35,36,39,43\} \quad (2.2)$$

$$\sum_{j\in J} y_j = 21, \ j \in \{2,8,10,11,12,13,17,23,25,26,27,28,30,31,32,33,34,35,36,39,43\} \quad (2.3)$$

$$1900z_{1,2} + 11000z_{1,8} + 7900z_{1,10} + 12000z_{1,11} + 6200z_{1,12} + 9300z_{1,13} + 2800z_{1,17} + 3800z_{1,23} + 3700z_{1,25} + 12000z_{1,26} + 4000z_{1,27} + 14000z_{1,28} + 11000z_{1,30} + 8000z_{1,31} + 5900z_{1,32} + 9200z_{1,33} + 12000z_{1,34} + 6500z_{1,35} + 5700z_{1,36} + 6700z_{1,39} + 10000z_{1,43} \le L \quad (2.4)$$

$$6800z_{2,2} + 13000z_{2,8} + 11000z_{2,10} + 10000z_{2,11} + 9900z_{2,12} + 8000z_{2,13} + 10000z_{2,17} + 8100z_{2,23} + 5700z_{2,25} + 9800z_{2,26} + 12000z_{2,27} + 22000z_{2,28} + 19000z_{2,30} + 16000z_{2,31} + 13000z_{2,32} + 7500z_{2,33} + 12000z_{2,34} + 1600z_{2,35} + 4200z_{2,36} + 6400z_{2,39} + 18000z_{2,43} \le L \quad (2.5)$$

$$9200z_{3,2} + 2300z_{3,8} + 1300z_{3,10} + 7700z_{3,11} + 2300z_{3,12} + 4900z_{3,13} + 9600z_{3,17} + 13000z_{3,23} + 11000z_{3,25} + 19000z_{3,26} + 6300z_{3,27} + 14000z_{3,28} + 8800z_{3,30} + 11000z_{3,31} + 13000z_{3,32} + 15000z_{3,33} + 18000z_{3,34} + 9900z_{3,35} + 11000z_{3,36} + 6500z_{3,39} + 15000z_{3,43} \le L \quad (2.6)$$

$$6900z_{4,2} + 6600z_{4,8} + 4400z_{4,10} + 4200z_{4,11} + 5200z_{4,12} + 60z_{4,13} + 8900z_{4,17} + 9600z_{4,23} + 7600z_{4,25} + 15000z_{4,26} + 9300z_{4,27} + 19000z_{4,28} + 14000z_{4,30} + 15000z_{4,31} + 12000z_{4,32} + 13000z_{4,33} + 16000z_{4,34} + 6400z_{4,35} + 7300z_{4,36} + 3000z_{4,39} + 16000z_{4,43} \le L \quad (2.7)$$

$$6300z_{5,2} + 6300z_{5,8} + 3600z_{5,10} + 9800z_{5,11} + 1800z_{5,12} + 7100z_{5,13} + 4800z_{5,17} + 8600z_{5,23} + 8600z_{5,25} + 15000z_{5,26} + 1800z_{5,27} + 13000z_{5,28} + 7700z_{5,30} + 6400z_{5,31} + 6000z_{5,32} + 12000z_{5,33} + 14000z_{5,34} + 8100z_{5,35} + 8900z_{5,36} + 7900z_{5,39} + 11000z_{5,43} \le L \quad (2.8)$$

$$4800z_{6,2} + 14000z_{6,8} + 12000z_{6,10} + 16000z_{6,11} + 9800z_{6,12} + 13000z_{6,13} + 5100z_{6,17} + 1800z_{6,23} + 3900z_{6,25} + 14000z_{6,26} + 7600z_{6,27} + 18000z_{6,28} + 15000z_{6,30} + 12000z_{6,31} + 9500z_{6,32} + 12000z_{6,33} + 7700z_{6,34} + 9400z_{6,35} + 6700z_{6,36} + 9700z_{6,39} + 11000z_{6,43} \le L \quad (2.9)$$

$$2700z_{7,2} + 12000z_{7,8} + 11000z_{7,10} + 11000z_{7,11} + 9500z_{7,12} + 9200z_{7,13} + 4700z_{7,17} + 1600z_{7,23} + 1600z_{7,25} + 11000z_{7,26} + 7200z_{7,27} + 17000z_{7,28} + 14000z_{7,30} + 11000z_{7,31} + 9100z_{7,32} + 8900z_{7,33} + 9300z_{7,34} + 7100z_{7,35} + 5400z_{7,36} + 7700z_{7,39} + 12000z_{7,43} \le L \quad (2.10)$$

$$31000z_{8,2} + 41000z_{8,8} + 38000z_{8,10} + 33000z_{8,11} + 36000z_{8,12} + 31000z_{8,13} + 35000z_{8,17} + 32000z_{8,23} + 30000z_{8,25} + 24000z_{8,26} + 36000z_{8,27} + 51000z_{8,28} + 48000z_{8,30} + 45000z_{8,31} + 38000z_{8,32} + 30000z_{8,33} + 29000z_{8,34} + 25000z_{8,35} + 29000z_{8,36} + 29000z_{8,39} + 44000z_{8,43} \le L \quad (2.11)$$

$$8500z_{9,2} + 11000z_{9,8} + 11000z_{9,10} + 16000z_{9,11} + 10000z_{9,12} + 13000z_{9,13} + 6900z_{9,17} + 11000z_{9,23} + 11000z_{9,25} + 18000z_{9,26} + 6100z_{9,27} + 8800z_{9,28} + 3400z_{9,30} + 230z_{9,31} + 2500z_{9,32} + 21000z_{9,33} + 17000z_{9,34} + 14000z_{9,35} + 12000z_{9,36} + 15000z_{9,39} + 5100z_{9,43} \le L \quad (2.12)$$

$$16000z_{10,2} + 27000z_{10,8} + 24000z_{10,10} + 22000z_{10,11} + 23000z_{10,12} + 20000z_{10,13} + 18000z_{10,17} + 16000z_{10,23} + 15000z_{10,25} + 13000z_{10,26} + 21000z_{10,27} + 30000z_{10,28} + 26000z_{10,30} + 24000z_{10,31} + 25000z_{10,32} + 8600z_{10,33} + 7700z_{10,34} + 15000z_{10,35} + 12000z_{10,36} + 18000z_{10,39} + 22000z_{10,43} \le L \quad (2.13)$$

$$5300z_{11,2} + 11000z_{11,8} + 9100z_{11,10} + 8500z_{11,11} + 8300z_{11,12} + 6500z_{11,13} + 10000z_{11,17} + 7600z_{11,23} + 5300z_{11,25} + 9400z_{11,26} + 10000z_{11,27} + 22000z_{11,28} + 19000z_{11,30} + 16000z_{11,31} + 13000z_{11,32} + 7500z_{11,33} + 12000z_{11,34} + 1600z_{11,35} + 4200z_{11,36} + 6400z_{11,39} + 19000z_{11,43} \le L \quad (2.14)$$

$$5000z_{12,2} + 14000z_{12,8} + 12000z_{12,10} + 12000z_{12,11} + 9900z_{12,12} + 9600z_{12,13} + 8600z_{12,17} + 6300z_{12,23} + 3900z_{12,25} + 8200z_{12,26} + 9800z_{12,27} + 20000z_{12,28} + 17000z_{12,30} + 14000z_{12,31} + 12000z_{12,32} + 4700z_{12,33} + 8900z_{12,34} + 4000z_{12,35} + 1500z_{12,36} + 7500z_{12,39} + 15000z_{12,43} \le L \quad (2.15)$$

$$4000z_{13,2} + 7700z_{13,8} + 5600z_{13,10} + 5000z_{13,11} + 4900z_{13,12} + 2900z_{13,13} + 7700z_{13,17} + 6800z_{13,23} + 4800z_{13,25} + 12000z_{13,26} + 8000z_{13,27} + 19000z_{13,28} + 14000z_{13,30} + 15000z_{13,31} + 11000z_{13,32} + 9300z_{13,33} + 14000z_{13,34} + 3600z_{13,35} + 4400z_{13,36} + 2000z_{13,39} + 15000z_{13,43} \le L \quad (2.16)$$

$$11000z_{14,2} + 15000z_{14,8} + 15000z_{14,10} + 19000z_{14,11} + 14000z_{14,12} + 16000z_{14,13} + 8200z_{14,17} + 10000z_{14,23} + 12000z_{14,25} + 21000z_{14,26} + 9000z_{14,27} + 9100z_{14,28} + 7300z_{14,30} + 4400z_{14,31} + 5400z_{14,32} + 19000z_{14,33} + 15000z_{14,34} + 16000z_{14,35} + 15000z_{14,36} + 16000z_{14,39} + 30z_{14,43} \le L \quad (2.17)$$

$$z_{ij} \le y_j, i \in \{1,2,\dots,14\} \text{ and } j \in \{2,8,10,11,12,13,17,23,25,26,27,28,30,31,32,33,34,35,36,39,43\} \quad (2.18)$$

$$z_{ij} \in \{0,1\}, \ i \in \{1,2,\dots,14\} \text{ and } j \in \{2,8,10,11,12,13,17,23,25,26,27,28,30,31,32,33,34,35,36,39,43\} \quad (2.19)$$

$y_j \in \{0,1\}\, j \in \{2,8,10,11,12,13,17,23,25,26,27,28,30,31,32,33,34,35,36,39,43\}$ (2.20)

$L \geq 0$ (2.21)

The objective function (2.1) minimize the distance between the demand point and the allocated facility. Constraint (2.2) specifies that each demand point can only be covered by one facility. The constraint (2.3) specifies the number of facilities to be built. Constraints (2.4-2.17) specify the maximum demand distance. Constraint (2.18) indicates that demand points are only covered by open facilities. Constraints (2.19)-(2.21) define the constraint domain. Table 7 shows the LINGO 13.0 optimum solution of the p-CLP model is 24,000 with a GMU of 101K and an ER of 0 second. The minimum distance between requests in Palembang City sub-districts to hospitals and health centres is 24,000 metres.

Table 7. Optimal Solution of p-CLP Model

Solver Status	
Model Class	*MILP*
State	*Global Optimal*
Objective	24000
Infeasibility	0
Iterations	0
Extented Solver Status	
Solver Type	*Branch and Bound*
Best Objective	24000
Objective Bound	24000
Steps	0
Active	0
Update Internal	2
GMU (K)	101
ER (sec)	0

Based on Table 7, the optimum distance of COVID-19 vaccine distribution locations in Palembang City is 24,000 meter with optimal solutions $z_{1,2} = z_{2,35} = z_{3,10} = z_{4,13} = z_{5,27} = z_{6,23} = z_{7,23} = z_{8,26} = z_{9,31} = z_{10,34} = z_{11,35} = z_{12,36} = z_{13,39} = z_{14,43} = 1$ which mean:

1. The demand in the Ilir Timur I Sub-District (z_1) will be located at Charitas Hospital (y_2)
2. The demand in the Plaju Sub-District (z_2) will be located at Taman Bacaan Health Centre (y_{35})
3. The demand in the Sako Sub-District (z_3) will be located at Bukitsangkal Health Centre (y_{10})
4. The demand in the Kalidoni Sub-District (z_4) will be located at Kalidoni Health Centre (y_{13})
5. The demand in the Kemuning Sub-District (z_5) will be located at Sosial Health Centre (y_{27})
6. The demand in the Ilir Barat I Sub-District (z_6) will be located at Padang Selasa Health Centre (y_{23})

7. The demand in the Bukit Kecil Sub-District (z_7) will be located at Padang Selasa Health Centre (y_{23})
8. The demand in the Jakabaring Sub-District (z_8) will be located at OPI Health Centre (y_{26})
9. The demand in the Sukarami Sub-District (z_9) will be located at Sukarami Health Centre (y_{31})
10. The demand in the Kertapati Sub-District (z_{10}) will be located at Karya Jaya Health Centre (y_{34})
11. The demand in the Seberang Ulu II Sub-District (z_{11}) will be located at Taman Bacaan Health Centre (y_{35})
12. The demand in the Seberang Ulu I Sub-District (z_{12}) will be located at 7 Ulu Health Centre (y_{36})
13. The demand in the Ilir Timur II Sub-District (z_{13}) will be located at Sabokingking Health Centre (y_{39})
14. The demand in the Alang-Alang Lebar Sub-District (z_{14}) will be located at Alang-Alang Lebar Health Centre (y_{43})

Implementation of The Greedy Heuristic Algorithm in Solving SCLP

The distribution of COVID-19 vaccines in Palembang City is addressed through the Greedy Heuristic Algorithm, which utilizes distance data initialized to 0 or 1. This information is presented in Table 8. The coefficient constraint value of 1 indicates that COVID-19 vaccine distribution locations in Palembang City are less than 2,000 meters apart, while 0 shows more than 2,000 meters apart.

Table 8. Objective Function of The SCLP Model

Location	1	2	3	4	5	6	7	8	9	10	11
Parameter q_i	1	1	1	1	1	1	1	1	1	1	1
Location	12	13	14	15	16	17	18	19	20	21	22
Parameter q_i	1	1	1	1	1	1	1	1	1	1	1

The orange row states the location of the COVID-19 vaccine distribution in Palembang City. The blue row states the parameter q_i, where $q_i$is the objective function coefficient at each i = 1, 2, 3, ..., 43, which are all worth 1.

Iteration 1

Step 1

In step 1 if $q_i = 0, \forall i, y_i = 1$, where q_i is the objective function coefficient, i = 1, 2, 3,…, 43. Next eliminate all constraints where y_i has a coefficient of 1. In that step it does not apply because all values of q_i in the objective function are greater than 0.

Step 2

In step 2 if $q_i > 0, \forall i$ and y_i does not have a coefficient of 1 on any of the remaining constraints then $x_i = 0$. In this step first calculate d_i, where d_i is the number of constraints y_i with coefficient 1.

If there is no constraint y_i = 0, so this step is also not applicable.

Step 3

On the remaining variables, then calculate $\frac{q_i}{d_i}$ where d_i is the number of constraints y_i with coefficient 1. Select the minimum $\frac{q_i}{d_i}$ variable and the set y_i has coefficient 1.

Step 4

If there are no more constraints, all remaining sets of variables 0 are stopped, otherwise repeat Step (1).

The calculation process continues until the 27th iteration. The optimal solution from the Greedy Heuristic algorithm is yaitu $y_1 = y_2 = y_7 = y_8 = y_{10} = y_{11} = y_{12} = y_{13} = y_{14} = y_{17} = y_{18} = y_{19} = y_{22} = y_{24} = y_{25} = y_{26} = y_{27} = y_{28} = y_{29} = y_{30} = y_{31} = y_{33} = y_{34} = y_{36} = y_{39} = y_{42} = y_{43} = 1$ which means that the optimal COVID-19 vaccine distribution location can be seen in Table 9.

Table 9. Optimal Location of The Greedy Heuristic Algorithm

No	Optimal Result of Greedy Heuristic Algorithm
1.	Ariodillah Health Centre
2.	Charitas Hospital
3.	Naga Swidak Health Centre
4.	Sako Health Centre
5.	Bukitsangkal Health Centre
6.	Sei Lincah Health Centre
7.	Kenten Health Centre
8.	Kalidoni Health Centre
9.	Dr. Mohammad Hoesin Hospital
10.	Pakjo Health Centre
11.	Siti Khadijah Hospital
12.	Bunda Hospital
13.	Bunda Noni Hospital
14.	Sei Baung Helath Centre
15.	Merdeka Health Centre
16.	OPI Health Centre
17.	Sosial Health Centre
18.	Talang Betutu Health Centre
19.	Myria Hospital
20.	Pelabuhan Kelas II Health Office
21.	Sukarami Health Centre
22.	Kramasan Health Centre
23.	Karya Jaya Health Centre
24.	7 Ulu Health Centre
25.	Sabongkingking Health Centre
26.	Tiara Fatrin Hospital
27.	Alang-Alang Lebar Health Centre

The completion of the SCP model and the Greedy Heuristic Algorithm obtained the optimal distribution location of the COVID-19 vaccine in the sub-districts of Ilir Timur I, Plaju, Sako, Kalidoni, Kemuning, Ilir Barat I, Bukit Kecil, Jakabaring,

Sukarami, Kertapati, Seberang Ulu I, Ilir Timur II, and Alang-Alang Lebar, so it is necessary to recommend the distribution location of the COVID-19 vaccine in other sub-districts in Palembang City.

D. CONCLUSIONS

From the discussion and results of determining the optimal location for COVID-19 vaccine distribution in Palembang City, it can be concluded that the SCLP model and the p-CLP model both produce 27 optimal vaccine distribution locations. However, there are differences in locations in several sub-districts. The study recommends the Greedy Heuristic Algorithm as the optimal solution for locating COVID-19 vaccine distribution locations in Palembang City.

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REFERENCES

1. Amarilies, H. S., Redi, A. A. N. P., Mufidah, I., & Nadlifatin, R. (2020). Greedy heuristics for the maximum covering location problem: a case study of optimal trashcan location in Kampung Cipare-Tenjo-West Java. *IOP Conference Series: Materials Science and Engineering*, *847*(1), 1–8.
2. Antoni, D., Herdianyah, M. I., Akbar, M., & Sumitro, A. (2021). Pengembangan infrastruktur jaringan untuk meningkatkan pelayanan publik di Kota Palembang. *Available Online at Https://Ejurnal.Stmik-Budidarma.Ac.Id/Index.Php/Mib*, *5*, 1652–1659.
3. Bangun, P. B. J., Octarina, S., Afrilia, R., Puspita, F. M., Supadi, S. S., & Hanum, L. (2023). The genetic algorithm approach in solving set covering model to determine the temporary waste disposal sites in Kemuning Sub-District Palembang ◎. *AIP Conference Proceedings*, 1–11.
4. Bangun, P. B. J., Octarina, S., Aniza, R., Hanum, L., Puspita, F. M., & Supadi, S. S. (2022). Set covering model using greedy heuristic algorithm to determine the temporary waste disposal sites in Palembang. *Science and Technology Indonesia*, *7*(1), 98–105.
5. Brimkov, B., Fast, C. C., & Hicks, I. V. (2019). Computational approaches for zero forcing and related problems. *European Journal of Operational Research*, *273*(3), 889–903.
6. Chung, J. Y., Thone, M. N., & Kwon, Y. J. (2021). COVID-19 vaccines: The status and perspectives in delivery points of view. *Advanced Drug Delivery Reviews*, *170*, 1–25.
7. Daskin, M. S., & Maass, K. L. (2019). Location analysis and network design. In *Lecture Notes in Logistics*. Springer International Publishing.

8. Devi, S., Fatchiya, A., & Susanto, D. (2016). *Jurnal Penyuluhan, September 2016 Vol. 12 No. 2 Kapasitas Kader dalam Penyuluhan Keluarga Berencana di Kota Palembang, Provinsi Sumatera Selatan Family Planning Volunteers Capacity in Extension in Palembang City, South Sumatera Province*. *12*(2).
9. Dewi, A., & Bustan, R. (2021). Sosialisasi Vaksinasi Covid-19 Dan Protokol Kesehatan 7 M Sebagai Upaya Pencegahan Penyebaran Virus Covid-19. *SNPPM-3 (Seminar Nasional Penelitian Dan Pengabdian Kepada Masyarakat)*, *3*, 197–209.
10. Javid, A. A., Seyedi, P., & Syam, S. S. (2017). A survey of healthcare facility location. *Computers and Operation Research*, *79*(3), 223–263.
11. Katayama, N. (2019). A combined fast greedy heuristic for the capacitated multicommodity network design problem. *Journal of the Operational Research Society*, *70*(11), 1983–1996.
12. Kwon, Y. S., Lee, B. K., & Sohn, S. Y. (2020). Optimal location-allocation model for the installation of rooftop sports facilities in metropolitan areas. *European Sport Management Quarterly*, *20*(2), 189–204.
13. Octarina, S., Puspita, F. M., & Supadi, S. S. (2022). Models and heuristic algorithms for solving discrete location problems of temporary disposal places in Palembang City. *IAENG International Journal of Applied Mathematics*, *52*(2), 1–11.
14. Octarina, S., Puspita, F. M., Supadi, S. S., Afrilia, R., & Yuliza, E. (2022). Set covering location problem and p-median problem model in determining the optimal temporary waste disposal sites location in Seberang Ulu I sub-district Palembang. *AIP Conference Proceedings*, 1–10.
15. Octarina, S., Puspita, F. M., Supadi, S. S., & Eliza, N. A. (2022). Greedy reduction algorithm as the heuristic approach in determining the temporary waste disposal sites in Sukarami Sub-District, Palembang, Indonesia. *Science and Technology Indonesia*, *7*(4), 469–480.
16. Sitepu, R., Puspita, F. M., Lestari, I., Yuliza, E., & Octarina, S. (2022). Facility location problem of dynamic optimal location of hospital emergency department in Palembang. *Science and Technology Indonesia*, *7*(2), 251–256.
17. Sitepu, R., Puspita, F. M., Romelda, S., Fikri, A., Susanto, B., & Kaban, H. (2019). Set covering models in optimizing the emergency unit location of health facility in Palembang. *Journal of Physics: Conference Series*, *1282*(1).
18. Syakina, L., & Nurdiati, S. (2021). Studi literatur: Analisis distribusi masalah lokasi fasilitas untuk logistik bantuan kemanusiaan. *Jurnal Pijar Mipa*, *16*(2), 207–214.
19. Xu, F., & Li, J. (2018). A hybrid encoded memetic algorithm for set covering problem. *Proceedings-2018 10th International Conference on Advanced Computational Intelligence, ICACI 2018*, 552–557.