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Determining Optimal New Waste Disposal Facilities Location by Using Set Covering Problem Algorithm

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ABSTRACT
The inadequacy of an appropriate location and quantity of Temporary Disposal Facility or TPS in Subulussalam city has caused the municipal waste to be disposed in an arbitrary disposal site that mostly lacks the appropriate norm. In response to the necessity to improve waste management issues in the city of Subulussalam, this paper presents a model for determining the TPS location in the Subulussalam city Aceh, Indonesia. This study aims to determine the optimal location and quantity of the TPS by using the Set Covering Problem (SCP) algorithm. Data processing in this study was carried out by using Lingo software version 17.0. The data processing resulted in 23 optimal TPS waste locations with a 5-minute travel time between the TPS location to the waste source. The expected output of this study is to develop a recommendation that can be used to determine the optimum number and location of the temporary municipal waste disposal shelter in the city of Subulusalam.

Keywords: *SCP Algorithm, TPS, Municipal Waste, Optimal TPS Location*

1. INTRODUCTION

Waste management still presents a huge challenge to be solved, especially in developing countries. In the last few decades, the growth of population has contributed exponentially to the increase of the quantity and complexity of the generated wastes produced from household, commercial and industrial entities, especially in developing countries[1]. Population growth in line with the increase of human necessities does not balance with a proper and healthy municipal waste service.

The city of Subulussalam is one of the cities in Aceh, Indonesia, that still require immediate attention regarding waste disposal facilities and location. Data from the Health and Environmental Service (DLHK) of Subulusalam city estimated that the city population grows at an annual rate of 2.7% with a total land area of 1,391,100 km2 while the waste piles generated from the city reached 99,07 m3 per day in 2019[2]. The lack of proper waste disposal facilities in the area causes solid waste to be disposed of and dumped in arbitrary dump sites that mostly lack the appropriate norms. These practices have negative environmental consequences ranging from the pollution of natural resources and ecosystems to the emergence of health issues that could lead to long-term public health issues [3]. Furthermore, the city's geographic location in a highland area may lead to landslide disasters that will eventually cause a deeper impact on the city. This indicates that immediate planning is required before the number of municipal wastes reached the maximum capacity and causes more significant problems to the area.

In the process of waste handling, determining the location of the Temporary Waste Disposal Facility (TPS) is one of the vital parameters to be considered. TPS is a place before the waste is transported to the Final Disposal Site (TPA). In general, TPS are placed based on the locations that have the potential to generate large volumes of waste. The type of TPS that is often used as a public waste disposal site in most rural cities in Indonesia is in the form of detachable and non-permanent truck containers[4],[5]. In determining the location of temporary waste disposal sites, several aspects were evaluated, such as the distance of the polling station to the main road, the distance to the surrounding river, the distance to residents' wells, and buffering around the temporary garbage collection[6],[7].

However, it seems that these criteria are not appropriately implemented in Subulusalam city. Evidence suggests that an uneven accumulation of waste occurs in several locations in the city, where the volume of garbage collected at several TPS exceeds the maximum capacity of a waste container, while several other containers are mostly empty [2]. The uneven accumulation of waste is caused by the incorrect placement of TPS in the area, which is difficult to reach in a short time and far from the source of waste. Therefore, this study aims to optimize the number and location of TPS facilities in the city of Subulusalam. In this study, Set Covering Problem (SCP) algorithm is used as a numerical method to allocate the number of facilities needed to cover the most optimum location. SCP is often used to provide a solution in determining the minimum number of facilities and determining the location of facilities to meet the existing demand by at least one facility[8],[9].

This paper is organized as follows: the first stage is to determine the candidate location of the potential TPS within the city. The candidate location was determined by allocating the maximum distance to the demand point while also considering the associated government requirements for TPS facilities location in Indonesia. The second stage is the developed mathematical model to optimize the number of TPS locations in the city of Subulusalam. The optimization process is generated by using Lingo 17.0 software. In this context, the optimization process can lead to creating a new location or eliminating existing facilities. The expected output of this study is to develop a recommendation that can be used to determine the optimum number and location of temporary municipal waste disposal shelters in the city of Subulusalam.

1.1 Preliminary Data

1.1.1 Demand Point

The demand point in this study is classified as a potential location with high volume of waste produce in one day. The demand point in this study is gathered from the data of Subulusalam city environmental service and direct observation in 2020. Location such as education institution, markets, public transportation terminal and community establishment are considered as potential demand point within the city. Thus, the demand point of municipal solid waste in Subulusalam city in organized in Table 1.

Table 1. Demand point of waste of Subulusalaam city (m3/day).

No	Location	Volume
1	Terminal	13.26
2	Cut Nyak Dien	10.22
3	Malikulsaleh	11.04
4	Pasar Baru	18.44
5	SMP Muhammadiayah	8.87
6	Teuku Umar	8.14
7	SMAN 1 Simpang Kiri	7.63
8	Abadi	7.13
9	SDN 1 Subulussalam	8.24
10	Pertemuan	4.86
11	Pardosi	3.00
12	Pegayo	4.27
13	Meukem	5.18
14	MAN 1 Simpang Kiri	2.66
15	Chitditiro	4.23
16	Terang Bulan	5.00
17	Panglima Polen	2.00
18	Siti Ambia	3.72
19	Suci Lestari	1.32
20	Nyak Adam Kamil	1.10
21	Cepu Indah	8.12
22	Istiqomah Cepu	7.05
23	SDN 3 Subulussalam	4.00
24	Raja Asal	3.33
25	Bilal Santoso	2.12
26	Belegen	5.21
27	Lae Oram	4.68
28	Tangga Besi	5.52
29	S Barat	8.24
30	Dusun Rahmah	6.13
31	Suka Makmur	4.72
32	Kuta Cepu	4.12
33	Makmur Jaya	5.04
34	Mukti Makmur	4.75
35	Buluh Dori	4.25
36	Pasar Panjang	3.18
37	Sikalonandg A	3.17
38	Sikalonandg B	3.00
39	Penanggalan	7.17

Table 1. Demand point of waste of Subulusalaam city (m3/day).

No	Location	Volume
40	Pemancar	2.26
41	Dusun Sila	2.16
42	Lae Bersih	2.10
43	Penuntungan	2.00
44	Jontor	3.12
45	Cepu	2.52
46	Sekelang	2.14
47	Lae Motong	3.00
48	Kampung Baru	1.56
49	Kuta Tengah	1.89
50	Lae Ikan	2.58
51	Belukur Makmur	2.19
52	Binanga	2.76
53	Dah	1.88
54	Geruguh	2.00
55	Harapan Baru	2.17
56	Kampong Badar	3.09
57	Kuala Kepeng	2.22
58	Kuta Beringin	2.19
59	Lae Pemualen	2.11
60	Lae Mate	2.00
61	Mandilam	1.86
62	Muara Batu Batu	2.29
63	Oboh	3.00
64	Panglima S	2.16
65	Pasar Runding	10.13
66	Suak Jampak	1.73
67	Sepaand	2.04
68	Sibuasan	2.00
69	Seperkas	3.10
70	Sibungke	2.18
71	Tanah Tumbuh	2.16
72	Telaand Baru	2.00
73	Tualang	1.87

1.1.2 Waste Disposal Facilities Criteria

According to National standard agency of Indonesia (SNI) number SNI 19-2454-2013, the criteria that needed to be considered for determining waste disposal facilities includes [10].

- Waste facilities need to be located within a place that has the potential to accommodate a large volume of waste
- Candidate TPS location with minimum space requirement of 200 m^2
- TPS must be located in an accessible area.
- TPS must not contaminate or pollute the surrounding area.
- TPS has minimal disruption to the aesthetic side of the city.

2. METHOD

This study was conducted in the city of Subulusalam which located in the southern part of the province of Aceh, Indonesia. The approach model used in this study is Minimal Covering Location Problem model, this model aims to determine the adequacy and quantity of TPS location by maximizing the amount of waste source that can be served at minimum distance from the potential waste source. The candidate location of TPS was determined by considering the SNI 10-2454-2013 requirement and the distance from the TPS candidate location to the demand point. The selection of the optimum number and location of the TPS is conducted by using Lingo 17.0 software.

3. RESULT AND DISCUSSION

3.1. TPS Location Candidates

The location candidate is evaluated based on the maximum distance to the demand point. This study assumes that the garbage *disposal* facility is a stationary container system in the form of a permanent building consisting of several types of facilities in accordance with the volume of capacity.

Table 2. TPS candidate location.

No	Location	Symbol
1	Terminal	x_1
2	Cepu Indah	x_2
3	Pasar Baru	x_3
4	Abadi	x_4
5	Pegayo	x_5
6	Terang Bulan	x_6
7	Raja Asal	x_7
8	Lae Oram	x_8
9	Dusun Rahmah	x_9
10	Suka Makmur	x_{10}
11	Makmur Jaya	x_{11}

Table 2. TPS candidate location.

No	Location	Symbol
12	Mukti Makmur	x_{12}
13	Pasar Panjang	x_{13}
14	Sikalonandg Atas	x_{14}
15	Lae Bersih	x_{15}
16	Cepu	x_{16}
17	Jontor	x_{17}
18	Lae Motong	x_{18}
19	Kuta Tengah	x_{19}
20	Kampung Baru	x_{20}
21	Sikelang	x_{21}
22	Lae Ikan	x_{22}
23	Tanah Tumbuh	x_{23}
24	Belukur Makmur	x_{24}
25	Lae Mate	x_{25}
26	Mandilam	x_{26}
27	Muara Batu Batu	x_{27}
28	Oboh	x_{28}
29	Panglima Sahman	x_{29}
30	Telaand Baru	x_{30}
31	Kampung Badar	x_{31}
32	Kuala Kepeng	x_{32}
33	Pasar Runding	x_{33}
34	Suak Jampak	x_{34}
35	Kuta Beringin	x_{35}
36	Dah	x_{36}
37	Sepadan	x_{37}
38	Sibuasan	x_{38}

The specified TPS candidate is expected to cover maximum volume of waste given at the demand point, each TPS candidate is symbolize by X_J, J = 1,2,3… 28. The selected TPS candidate is presented in Table 2.

3.1.1 Mathematical models

In this study, the mathematical model in the set covering problem is presented with one objective function and two constraint functions, where the objective function was developed to identify the minimal number of TPS facilities needed with the emphasis to maximize the coverage of service distance from the facility to the demand point. In addition, the constraint function set ensure that every demand node is covered by at least one facility. Several literatures have formulated the formula for set covering problem in the following way [11], [12]:

Objective Function:

$$Min\ Z = \sum_{j\epsilon J} x_j \quad (1)$$

Constraint Function:

$$\sum_{J\epsilon N} x_{j \geq 1} \forall_i \epsilon_I \quad (2)$$

$$x_j \epsilon_{\{0,1\}} \forall_j \epsilon_J \quad (3)$$

Where:

Z : Objective Function
I : Set of demand point type I with the index i
J : Set of candidate facility location point with the index j
Y_{ij} : The distance between demand point i with candidate location j
Y_c : *Distance Coverage*
N_i : $\{j \mid D_{ij} \leq D_c\}$ = set of all facilities j which cover location i
X_j : Binary value (1 if the facilities with index j is able to cover demand with, 0 if the *opposite)*

Based on the minimal covering problem model, the syntax used in Lingo 17.0 processing software is written as follow:

```
Min=@sum (SET_j ( j ) : x ( j ) ) ;
```

Sets listed as x (j) is regarded as the selected candidate for the TPS location, if x (j) is indexed with the value of 1 then the location is selected and if the x (j) is valued as 0 then the location is not selected. Furthermore, in the constraint function, the determination of the optimum TPS facilities is carried out with two main constraints. To determine the suitable value for optimization result, we may need to consider various factors as constraint point. This study assumes 38 candidate locations and 73 waste sources as the constraint point. Based on the measurement of travel time between demand points and constraint points, the location of demand points 1, 8, 10 and 11 can be met by several candidate points, demand points 1, 8, 10 and 11 are noted as x1 + x2 + x3 + x4 + x5 + x6 + x7 1, this indicate that the demand points at 1, 8, 10 and 11 can be covered by 7 candidate points with a maximum distance of 5 minutes. The following model for the constraint function is written as follow:

Constrains 1,8,10,&11: $x_1+x_2+x_3+x_4+x_5+x_6+x_7 \geq 1$ (1)

Constrains 2,3,4,5,&24: $x_1+x_2+x_3+x_4+x_6+x_7 \geq 1$ (2)

Constrains 6: $x_2 + x_3 + x_4 \geq 1$ (3)

Constrains 7: $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_9 \geq 1$ (4)

Constrains 9: $x_1 + x_3 + x_4 + x_5 + x_6 + x_7 + x_9 \geq 1$ (5)

Constrains 12: $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \geq 1$ (6)

Constrains 13: $x_1 + x_3 + x_4 + x_5 + x_6 \geq 1$ (7)

Constrains 14: $x_3 + x_4 + x_5 + x_6 + x_7 + x_9 \geq 1$ (8)

Constrains 15, 18, 20: $x_1 + x_2 + x_3 + x_5 + x_6 + x_7 \geq 1$ (9)

Constrains 16, and 17: $x_1 + x_2 + x_3 + x_6 + x_7 \geq 1$ (10)

Constrains 19: $x_1 + x_2 + x_3 + x_6 \geq 1$ (11)

Constrains 21 and 22: $x_1 + x_2 + x_3 + x_4 + x_7 \geq 1$ (12)

Constrains 23: $x_1 + x_2 + x_3 + x_4 + x_6 + x_7 + x_9 \geq 1$ (13)

Constrains 25: $x_1 + x_3 + x_4 + x_7 \geq 1$ (14)

Constrains 26: $x_2 + x_4 + x_6 + x_7 \geq 1$ (15)

Constrains 27 and 31: $x_8 + x_{10} \geq 1$ (16)

Constrains 28: $x_1 + x_2 + x_4 + x_6 + x_7 \geq 1$ (17)

Constrains 29 and 30: $x_4 + x_9 + x_{14} \geq 1$ (18)

Constrains 32: $x_1 + x_2 + x_4 \geq 1$ (19)

Constrains 33: $x_{11} \geq 1$ (20)

Constrains 34: $x_{12} \geq 1$ (21)

Constrains 35: $x_{14} + x_{31} \geq 1$ (22)

Constrains 36: $x_{13} \geq 1$ (23)

Constrains 37 and 38: $x_9 + x_{14} \geq 1$ (24)

Constrains 39: $x_{17} \geq 1$ (25)

Constrains 40, 41, 42 and 43: $x_{15} \geq 1$ (26)

Constrains 44: $x_{17} \geq 1$ (27)

Constrains 45 and 49: $x_{16} + x_{19} \geq 1$ (28)

Constrains 46 and 48: $x_{20} + x_{21} \geq 1$ (29)

Constrains 47: $x_{18} \geq 1$ (30)

Constrains 50: $x_{22} \geq 1$ (31)

Constrains 51 and 52: $x_{24} + x_{33} \geq 1$ (32)

Constrains 53: $x_{25} + x_{36} \geq 1$ (33)

Constrains 54: $x_{19} \geq 1$ (34)

Constrains 55: $x_{23} \geq 1$ (35)

Constrains 56: $x_{14} + x_{31} \geq 1$ (36)

Constrains 57: $x_{23} + x_{24} \geq 1$ (37)

Constrains 58: $x_{35} \geq 1$ (38)

Constrains 59: $x_{20} \geq 1$ (39)

Constrains 60: $x_{21} + x_{27} \geq 1$ (40)

Constrains 61: $x_{26} \geq 1$ (41)

Constrains 62 and 64: $x_{27} + x_{29} \geq 1$ (42)

Constrains 63: $x_{28} \geq 1$ (43)

Constrains 65: $x_{24} + x_{33} \geq 1$ (44)

Constrains 66: $x_{34} \geq 1$ (45)

Constrains 67 and 70: $x_{37} \geq 1$ (46)

Constrains 68: $x_{18} + x_{36} + x_{38} \geq 1$ (47)

Constrains 69: $x_{35} \geq 1$ (48)

Constrains 71: $x_{23} + x_{32} \geq 1$ (49)

Constrains 72: $x_{30} \geq 1$ (50)

Constrains 73: $x_{32} \geq 1$ (51)

Based on the constraint function with the emphasis that every TPS candidates is expected to cover at least 1 demand point is written as follow:

```
@for(SET_i(i):@sum(SET_j(j):x(j)*Y(i,j))>
=1);
```

The syntax used in Lingo 17.0 to determine the sensitivity analysis of the model is written as follow:

```
@for(SET_j(j):@bin(x(j)));
```

3.2. Optimization Result And Analysis

Based on the calculation generated from Lingo 17.0 software, the selected TPS location to cover the demand point in the city of Subulusalam is presented in Table 3. The result obtained in this study is generated based on the optimal distance from the TPS to the demand point which resulted to the discovery of a 19 new location together with additional 4 existing locations. The selected of the TPS location points are expected to reach 73 existing demand points with a maximum distance of 5 minutes. Furthermore, the result assumes that each demand point is covered by not only one TPS but also can be reached by a nearby TPS. Therefore, each facility covers a percentage of waste demand.

Table 3. Selected TPS.

No	Existing TPS	New TPS location	District
1	Pasar Baru	Pasar Baru	Simpang Kiri
2	Terminal	Lae Oram	
3	Suka Makmur	Dusun Rahmah	
4		Makmur Jaya	
5		Mukti Makmur	

6		Pasar Panjang	
7	Penanggalan	Lae Bersih	Pe-nangga-lan
8	Cepu	Cepu	
9		Jontor	
10		Lae Motong	
11		Kampung Baru	
12		Lae Ikan	
13	Pasar Runding	Tanah Tumbuh	Runding
14	Kampung Ba-dar	Belukur Makmur	
15	Oboh	Mandilam	
16		Muara Batu-Batu	
17		Oboh	
18		Teladan Baru	
19		Kampung Badar	
20		Suak Jampak	
21		Kuta Beringin	
22		Sepadan	
23		Sibuasan	

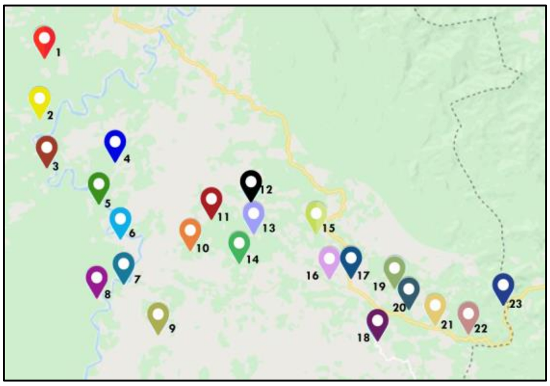

Figure. 1 Selected TPS location.

Information:

1. Suak Jampak
2. Tanah Tumbuh
3. Mandilam
4. Sepadan
5. Sibuasan
6. Muara Batu-batu
7. Belukur Makmur
8. Oboh
9. Kuta Beringin
10. Teladan Baru
11. Mukti Makmur
12. Pasar Panjang
13. Makmur Jaya
14. Kampung Badar
15. Lae Oram
16. Dusun Rahmah
17. Pasar Baru
18. Lae Motong
19. Lae Bersih
20. Cepu
21. Kampung Baru
22. Jontor
23. Lae Ikan

The increase in the TPS stations number generated from the Lingo software may be driven by the growth of the population in the Subulussalam City. The total population of the Subulussalam city in 2017 is estimated at 78.059 people with total production of 93.93 m3 of waste per day, in contrast the number of populations in 2020 has increased to 90.751 people with a total waste of 99.07 m3 per day[13]. This indicates that the city requires more TPS facilities to accommodate the increase of wastes from 8 TPS in 2017 to 23 TPS in 2020. Thus, the geographical location of the selected TPS location in the city of Subulussalam is visualized in Fig.1.

4. CONCLUSION

The problem associated with waste management has been one of the major problems requiring constant attention in all major cities worldwide. The growth of population alongside the increase in municipal solid waste produced per day is not coped with adequate TPS facilities in the area. This study utilized a set covering problem method together with Lingo 17.0 to determine a new TPS facilities location in Subulussalam city. Result found that from 8 existing TPS facilities in the city, the model suggests a total of 23 new facilities within the city. The suggested model is based on the distance between the source of waste or demand point to the candidate TPS location. The expected output of this study is to develop a recommendation that can be used to determine the optimum number and location of temporary municipal waste disposal shelters in the city of Subulusalam.

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