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Robust-Set Covering Problem and Sensitivity Analysis to Determine The Location of Temporary Waste Disposal Sites

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Abstract
The increasing population has resulted in a significant increase in the amount of waste. One effort that can be made to overcome the waste problem is to provide a Temporary Waste Disposal Site (TWDS). This research aims to optimize the TWDS in the Bukit Kecil sub-district, Palembang city, by formulating a Robust-Set Covering Problem (Robust-SCP) model and solving the model with the software. Sensitivity analysis is used to analyze the optimal solution. Bukit Kecil sub-district is the sub-district that has the highest number of TWDS in Palembang city. The robust-SCP model obtained 10 optimal TWDS. Therefore, this research recommends the Robust-SCP model as the optimal solution for the determination of TWDS in the Bukit Kecil sub-district, namely TWDS Kartini Street, TWDS front of Starbucks KI Street, TWDS Merdeka Street, TWDS Illegal at 26 Ilir Market, TWDS Flat Block 35, TWDS Flat Block 49, TWDS Merdeka Women's Prison, TWDS Musi Riverbank Park, TWDS Monpera, and TWDS Cinde Market, with the addition of TWDS Mayor's Office in 22 Ilir village and TWDS Flat Block 01 in 23 Ilir village. The sensitivity analysis results in this study show that the solution remains optimal if the coefficient change is within the coefficient interval value.

Keywords
Temporary Waste Disposal Sites, Set Covering Problem, Robust-Set Covering Problem, Sensitivity Analysis

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1. INTRODUCTION

Solid waste disposal is crucial for large cities such as Palembang city. The city, which covers an area of 400.61 km^2 with a population of 1,754,437 in 2022, is Indonesia's oldest city and the second-largest city on Sumatra island after Medan. Data from the Central Statistics Agency (CSA) in Palembang city shows an increase of 68,364 individuals in the population of Palembang city since 2021. This surge in population has led to a substantial rise in annual waste production. The trend is primarily a result of population growth and the consumption patterns of its residents (Karimi et al., 2019). By 2022, the director of the Environment and Hygiene Department (EHD) in Palembang city predicts that the city will produce 1,180 metric tonnes of waste daily. Waste leads to multiple rubbish dumps, causing significant hygiene and health concerns (Ramadhani, 2022). Improper waste management practices can result in environmental deterioration of soil, water, and air quality.

The government and EHD Palembang city address waste challenges by establishing Temporary Waste Disposal Sites (TWDS) at different location (Bangun et al., 2022). Each locality must have its waste management facilities. The TWDS is an intermediate waste-handling facility before waste is redirected to recyclers or integrated waste management. TWDS units mainly comprise containers such as steel litter bins or concrete containers. TWDS is crucial in mitigating the waste problem by linking waste from the source to the Final Disposal Site (FDS). The distance between the TWDS and local communities' settlements further hinders resolving the waste issue. The TWDS is situated in a remote location, leading locals to prefer waste collection at the nearby TWDS. The volume of waste generated is directly proportional to the increase in population, and solid waste reduction has dramatically influenced the community's active role as a producer of garbage (Putri et al., 2019). Proper management of accumulated waste eases the creation of a hygienic environment (Bangun et al., 2022). The maximum distance between TWDS is regulated at 500 m, as stipulated in Regulation No. 3 of the Minister of Public Works of the Republic of Indonesia on implementing Waste Infrastructure and Facilities in Handling Household Waste and Waste Similar to Household Waste, Article 32c.

This study aims to analyze the best location for TWDS to be located in Bukit Kecil, a sub-district located in Palembang City, which is one of 18 sub-districts within the city. Bukit Kecil sub-district comprises six urban villages with a population density of

5,022.48 individuals per km^2. This sub-district, which resulted from the expansion of the Ilir Barat I sub-district, is situated in the downtown area on the Musi Riverbank in Palembang city. Given its prime location, the Bukit Kecil sub-district has trade, service, and tourism potential. Most of Palembang's famous tourist attractions are in the Bukit Kecil sub-district, such as Kuto Besak Fort, Kambang Iwak Park, Belido Fish Monument, Sekanak River, and Sultan Mahmud Badaruddin II Museum. According to data from EHD Palembang city in 2021, the Bukit Kecil sub-district has the most significant number of TWDS in Palembang city, namely 44. However, many TWDS do not guarantee that the Bukit Kecil sub-district has no waste problems.

Finding the optimum location is part of the optimization problem. The Set Covering Problem (SCP) is one of the optimization models that can be used. SCP is part of integer linear programming related to optimization and concerns the problem of set covering to minimize factors that affect the constraints in the model (Sitepu et al., 2019). The set-covering model is designed to reduce the number of facilities with at least one facility location to serve all needs (Daskin and Maass, 2019). SCP models are often used in everyday life to select fire station locations, determine bus stop locations, distribute goods, health facility locations, and so on (Chauhan et al., 2019; Fischetti et al., 2017; Hashim et al., 2021; Javid et al., 2017; Karatas and Yakıcı, 2018; Kwon et al., 2020; Octarina et al., 2022a; Tao et al., 2018). According to Octarina et al. (2022a), the SCP model consists of the Set Covering Location Problem (SCLP), the Maximal Covering Location Problem (MCLP), the p-Median Location Problem, and the p-Centre Location Problem. The four models are related. However, they have different objective functions. The SCLP is a coverage-based model that aims to satisfy all demand points with the optimal number of facilities (Octarina et al., 2022b). MCLP is a coverage-based model that maximizes the number of demand points with a certain number of facility locations in standard time (Javid et al., 2017). The p-Median Location Problem is a model to minimize the average distance between facility locations and demand points. The p-Centre Location Problem aims to minimize the distance connecting facility locations with demand points.

An evolution of the SCP is the robust model. Robust optimization is an optimization model that uses linear programming to find the correct solution and is affected by uncertain parameters. Robust optimization is usually used in developing the fields of transportation, economics, logistics, and the environment (Choi et al., 2017; Hakli and Ortacay, 2019; Hartono et al., 2018; Jenkins et al., 2020; Makui et al., 2016; Manisri et al., 2011; Martins et al., 2018; Puspita et al., 2021; Rahmaniani et al., 2013; Solano-Charris et al., 2015; Sun et al., 2015; Yuliza et al., 2020). Robust optimization used to determine probabilistic variants is called the Uncertain Set Covering Problem (USCP) (Lutter et al., 2017). Besides determining the optimal location solution, it is also important to analyze the optimal model used to observe the changes that occur (Amarilies et al., 2020). One of the analyses that can be used is sensitivity analysis. Sensitivity analysis aims to determine the effects when objective function parameters and model constraints change (Mohajan and Mohajan, 2023; Tham, 2019).

A study has determined the ideal location for TWDS within the Bukit Kecil sub-district. This study differs from previous research regarding updating the TWDS quantity and the model used. Bangun et al. (2022) and Octarina et al. (2022a) found the optimal TWDS in Palembang city and proposed the result of the research to EHD Palembang city. The government of Palembang city has applied the results of this research to determine the TWDS and waste collection route, but not for the unofficial TWDS, due to the constantly changing number of unofficial TWDS. Additionally, various researchers have examined waste management using the robust model. Hartono et al. (2018) studied waste management issues in the Ilir Timur II sub-district and the Alang-Alang Lebar sub-district using the Robust Counterpart Open Capacitated Vehicle Routing Problem (RC-OCVRP) model. Sitepu et al. (2022) studied the optimal dynamic location of emergency services in Palembang city using TOPSIS and used the Robust-SCP to determine the optimal location of emergency services in the city. In addition, Du et al. (2020) and Du and Zhou (2018) proposed robust optimization for p-centre allocation in the facility location problem.

The novelty of this research is developing the SCP model into a Robust-SCP model to determine the optimal TWDS and analyze the feasibility of changing the optimal solution using sensitivity analysis. This study aims to identify the optimal locations for TWDS in the Bukit Kecil sub-district. Several objective models of SCP, such as SCLP, MCLP, p-Centre Location Problem, and Robust-SCP are employed in this study. Each model is solved using the software, followed by sensitivity analysis for the Robust-SCP model.

2. EXPERIMENTAL SECTION

2.1 Methods

We discussed the method used in this research in this section. The study consisted of two primary stages. Initially, the researchers conducted direct observations in the field to obtain data about the TWDS in the Bukit Kecil sub-district of Palembang city. The obtained data, which included the name, number, and coordinates of the TWDS, was presented in a tabular format. Subsequently, the collected data was analyzed to identify any recurring patterns or trends. Measuring TWDS distances in the Bukit Kecil sub-district was accomplished using Google Maps. The results are presented in tabular format.

This study outlines the variables and parameters of SCLP, MCLP, p-Centre Location Problem, and Robust-SCP models for the Bukit Kecil sub-district. The SCLP, MCLP, and p-Centre Location Problem models are formulated for the SCP and solved using the software. Formulate the Robust-SCP model, then solve the robust model formulation also using the software. Analyze the outcomes of the SCLP, MCLP, p-Centre Location Problem, and Robust-SCP models, and finally, draw a conclusion based on the findings attained. Perform a sensitivity analysis to determine the feasibility interval for changes so that the solution remains optimal.

3. RESULTS AND DISCUSSION

This section presents research data to determine the optimal number and location of TWDS in the Bukit Kecil sub-district, Palembang city. The formulations for the SCLP, MCLP, p-Center Location Problem, and Robust-SCP models are discussed. The provided data comprises a list of villages in the Bukit Kecil sub-district. EHD Palembang city's 2022 data, the sub-district includes 47 TWDS scattered throughout these six villages. The definitions of the village and TWDS variables in the Bukit Kecil sub-district are shown in Table 1 and Table 2. The village name variable is represented by b_i, where $i = 1, 2, ..., 6$ while the TWDS variable is represented by h_j, where $j = 1, 2, 3, ..., 47$.

Table 1. Variable Definition of Villages in the Bukit Kecil Sub-District

Variable	List of Villages
b_1	Talang Semut Village
b_2	26 Ilir Village
b_3	22 Ilir Village
b_4	19 Ilir Village
b_5	24 Ilir Village
b_6	23 Ilir Village

Based on Table 3, the parameters for village's name in Bukit Kecil sub-district are denotated by m_k whereas $k = 1, 2, ..., 6$. m_1 defines Talang Semut village with parameter value is 4, which means there are 4 TWDS in Talang Semut village. m_2 has 3 of parameter value which means there are 3 TWDS in 26 Ilir Village, and so on to m_6 Distance data for TWDS in the Bukit Kecil sub-district was collected through field surveys on July 5-6, 2023, using Google Maps.

3.1 Formulation of The Set Covering Problem Model

This section discussed the formulation of the SCLP, MCLP, and p-Center Location Problem model. The SCLP model for the TWDS in the Bukit Kecil sub-district is formulated as follows:
Minimize,

$$Z_{SCLP} = \sum_{j=1}^{47} h_j \tag{1}$$

Subject to

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{20} h_j + h_{24} \geq 1 \tag{2}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_{24} \geq 1 \tag{3}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_8 + h_{24} \geq 1 \tag{4}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=8}^{9} h_j + \sum_{j=18}^{21} h_j \geq 1 \tag{5}$$

$$\sum_{j=18}^{21} h_j + h_7 + h_9 + h_{24} \geq 1 \tag{6}$$

$$\sum_{j=4}^{6} h_j + \sum_{j=8}^{14} h_j + h_{18} + h_{21} + h_{24} \geq 1 \tag{7}$$

$$\sum_{j=6}^{13} h_j + h_{21} + h_{24} \geq 1 \tag{8}$$

$$\sum_{j=8}^{17} h_j + h_{21} \geq 1 \tag{9}$$

$$\sum_{j=10}^{18} h_j + h_8 + h_{21} \geq 1 \tag{10}$$

$$\sum_{j=10}^{17} h_j \geq 1 \tag{11}$$

$$\sum_{j=1}^{8} h_j + \sum_{j=18}^{21} h_j + h_{14} + h_{24} \geq 1 \tag{12}$$

$$\sum_{j=1}^{7} h_j + \sum_{j=18}^{21} h_j \geq 1 \tag{13}$$

$$\sum_{j=3}^{14} h_j + \sum_{j=18}^{21} h_j \geq 1 \tag{14}$$

$$\sum_{j=1}^{5} h_j + \sum_{j=7}^{9} h_j + h_{18} + h_{24} + h_{25} \geq 1 \tag{15}$$

$$h_{22} + h_{28} \geq 1 \tag{16}$$

$$h_{23} \geq 1 \tag{17}$$

$$h_{24} + h_{25} + h_{27} + h_{38} + h_{39} \geq 1 \tag{18}$$

$$h_{26} + h_{27} + h_{39} \geq 1 \tag{19}$$

$$\sum_{j=25}^{27} h_j + \sum_{j=40}^{47} h_j \geq 1 \tag{20}$$

Table 2. Variable Definition of TWDS in the Bukit Kecil Sub-District

Variable	Name of TWDS	Variable	Name of TWDS	Variable	Name of TWDS
h_1	TWDS front of Sushi Thei	h_{17}	TWDS Hang Jebat Street	h_{33}	TWDS front of GH BKB
h_2	TWDS Kramajaya Street	h_{18}	TWDS Below Bamboo KI	h_{34}	TWDS BKB Night Park
h_3	TWDS Mayor's Official Residence	h_{19}	TWDS front of PMKRI	h_{35}	TWDS Musi Riverbank Park
h_4	TWDS Thamrin Street	h_{20}	TWDS front of Starbucks KI	h_{36}	TWDS Monpera
h_5	TWDS Gubah Market	h_{21}	TWDS Hotel Swarna Dwipa	h_{37}	TWDS Cinde Market
h_6	TWDS Sutomo Street	h_{22}	TWDS Merdeka Street	h_{38}	TWDS Ilir Barat Permai
h_7	TWDS Wahidin Street	h_{23}	TWDS Illegal at 26 Ilir Market	h_{39}	TWDS Radial Street
h_8	TWDS front of Kanwil DJP from 26 Ilir Market Square to. TL Kedaung Four Square	h_{24}	TWDS A. Dahlan Street	h_{40}	TWDS Flat Block 06
h_9	TWDS Diponegoro Street	h_{25}	TWDS Flat Block 35	h_{41}	TWDS Flat Block 14
h_{10}	TWDS Pangeran Ario Kesuma Street	h_{26}	TWDS Flat Block 46	h_{42}	TWDS Flat Block 12
h_{11}	TWDS Kartini Street	h_{27}	TWDS Flat Block 49	h_{43}	TWDS Flat Block 17
h_{12}	TWDS Infront of LRT Sumsel Divre III Palembang Office	h_{28}	TWDS Mayor's Office	h_{44}	TWDS Flat Block 28
h_{13}	TWDS front of Mediska PTKAI Clinict	h_{29}	TWDS Kesdam	h_{45}	TWDS Flat Block 30
h_{14}	TWDS front of PMI	h_{30}	TWDS Sultan Mahmud Badarudin Street	h_{46}	TWDS Flat Block 01
h_{15}	TWDS Hang Tuah Street	h_{31}	TWDS Merdeka Women's Prison	h_{47}	TWDS Flat Block 02
h_{16}	TWDS Hang Suro Street	h_{32}	TWDS BKB		

Table 3. Parameter and Parameter Value for SCP Model

Parameter	Village's Name	Parameter Value
m_1	Talang Semut Village	4
m_2	26 Ilir Village	3
m_3	22 Ilir Village	2
m_4	19 Ilir Village	7
m_5	24 Ilir Village	9
m_6	23 Ilir Village	2

$$\sum_{j=32}^{35} h_j + +h_{29} + h_{30} \geq 1 \tag{21}$$

$$h_{31} \geq 1 \tag{22}$$

$$h_{36} \geq 1 \tag{23}$$

$$h_{37} \geq 1 \tag{24}$$

$$h_{25} + h_{38} + h_{39} \geq 1 \tag{25}$$

$$h_{25} + h_{26} + h_{38} + h_{39} \geq 1 \tag{26}$$

$$\sum_{j=40}^{47} h_j + h_{27} \geq 1 \tag{27}$$

$$h_j \in \{0, 1\}, j = 1, 2, ..., 47 \tag{28}$$

Based on the formulation of the SCLP model in Equation (1) and Constraints (2) to (28), it is clarified that:

1. The Equation (1) describes the minimum number of candidates required for TWDS in the Bukit Kecil sub-district
2. Constraints (2)-(27) apply to demand points in the Bukit Kecil sub-district, where at least 1 TWDS available at each demand point.
3. Constraint (28) specifies that the variables in the SCLP model take on a binary value of either 0 or 1.

The optimal solution for the SCLP model of the Bukit Kecil sub-district was obtained and displayed in Table 4.

Based on Table 4, the solver status for the class model is determined using PILP (Pure Integer Linear Programming), which means that the decision variable is an integer value. In this case, the value of the variable is 0 or 1. The "state" indicates that the resulting solution is globally optimal with an objective value of 10. The infeasibility is 0, which means that the infeasibility value of the variable is 0; in other words, the SCLP model produces a feasible solution, and the iteration is 0. The "branch and bound" method is used in the extended solver state. The SCLP model has identified ten TWDS, resulting in an objective value of 10. The model requires 38K memory allocation, as the Generated Memory Used (GMU) metric indicates. Additionally, the model was resolved in 1 second, as shown by the Elapsed Runtime (ER) metric.

Table 4. Optimal Solution of the SCLP Model

Solver Status	
Model Class	PILP
State	Global Optimal
Objective	10
Infeasibility	0
Iteration	0
Extended Solver Status	
Solver Type	Branch and Bound
Best Objective	10
Objective Bound	10
Steps	0
Active	0
Update Interval	2
GMU (K)	38
ER (sec)	1

The optimal solutions of the SCLP model are $h_{11} = h_{20} = h_{23} = h_{25} = h_{27} = h_{28} = h_{31} = h_{35} = h_{36} = h_{37} = 1$ which means that the optimal location of TWDS in the Bukit Kecil sub-district should be in 10 locations, as follows:

1. TWDS Kartini Street
2. TWDS front of Starbucks KI
3. TWDS Illegal at 26 Ilir Market
4. TWDS Flat Block 35
5. TWDS Flat Block 49
6. TWDS Mayor's Office
7. TWDS Merdeka Women's Prison
8. TWDS Musi Riverbank Park
9. TWDS Monpera
10. TWDS Cinde Market

The objective of the MCLP model is to maximize the number of demand points within a predetermined location distance. Each demand point variable is denoted by s_i where $i = 1, 2, ..., 47$. Table 5 defines the variables of demand points in the Bukit Kecil sub-district.

The formulation of the MCLP model is

Minimize,

$$Z_{MLCP} = \sum_{i=1}^{47} S_i \tag{29}$$

Subject to

$$\sum_{j=1}^{47} h_j = 10 \tag{30}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{20} h_j + h_{24} \geq S_1 \tag{31}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{20} h_j + h_{24} \geq S_2 \tag{32}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_{24} \geq S_3 \tag{33}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_{24} \geq S_4 \tag{34}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_{24} \geq S_5 \tag{35}$$

$$\sum_{j=1}^{6} h_j + \sum_{j=18}^{21} h_j + h_8 + h_9 \geq S_6 \tag{36}$$

$$\sum_{j=18}^{21} h_j + h_7 + h_9 + h_{24} \geq S_7 \tag{37}$$

$$\sum_{j=4}^{6} h_j + \sum_{j=8}^{14} h_j + h_{18} + h_{21} + h_{24} \geq S_8 \tag{38}$$

$$\sum_{j=6}^{13} h_j + h_{21} + h_{24} \geq S_9 \tag{39}$$

$$\sum_{j=8}^{17} h_j + h_{21} \geq S_{10} \tag{40}$$

$$\sum_{j=8}^{17} h_j + h_{21} \geq S_{11} \tag{41}$$

$$\sum_{j=8}^{17} h_j + h_{21} \geq S_{12} \tag{42}$$

$$\sum_{j=8}^{17} h_j + h_{21} \geq S_{13} \tag{43}$$

$$\sum_{j=10}^{18} h_j + h_8 + h_{21} \geq S_{14} \tag{44}$$

$$\sum_{j=10}^{17} h_j \geq S_{15} \tag{45}$$

$$\sum_{j=10}^{17} h_j \geq S_{16} \tag{46}$$

Table 5. Variable Definition of Demand Points in the Bukit Kecil Sub-District

Variable	Name of Demand Points	Variable	Name of Demand Points
S_1	Front of Sushi Thei	S_{25}	Flat Block 35
S_2	Kramajaya Street	S_{26}	Flat Block 46
S_3	Mayor's Official Residence	S_{27}	Flat Block 49
S_4	Thamrin Street	S_{28}	Mayor's Office
S_5	Gubah Market	S_{29}	Kesdam
S_6	Sutomo Street	S_{30}	Sultan Mahmud Badarudin Street
S_7	Wahidin Street	S_{31}	Merdeka Women's Prison
S_8	Front of Kanwil DJP	S_{32}	BKB
S_9	Diponegoro Street	S_{33}	Front of GH BKB
S_{10}	Pangeran Ario Kesuma Street	S_{34}	BKB Night Park
S_{11}	Kartini Street	S_{35}	Musi Riverbank Park
S_{12}	Front of LRT Sumsel Divre III Palembang Office	S_{36}	Monpera
S_{13}	Front of Mediska PTKAI Clinic	S_{37}	Cinde Market
S_{14}	Front of PMI	S_{38}	Ilir Barat Permai
S_{15}	Hang Tuah Street	S_{39}	Radial Street
S_{16}	Hang Suro Street	S_{40}	Flat Block 06
S_{17}	Hang Jebat Street	S_{41}	Flat Block 14
S_{18}	Below Bambu KI	S_{42}	Flat Block 12
S_{19}	Front of PMKRI	S_{43}	Flat Block 17
S_{20}	Front of Starbucks KI	S_{44}	Flat Block 28
S_{21}	Hotel Swarna Dwipa	S_{45}	Flat Block 30
S_{22}	Merdeka Street	S_{46}	Flat Block 01
S_{23}	Illegal at 26 Ilir Market	S_{47}	Flat Block 02
S_{24}	A. Dahlan from 26 Ilir Market Square s.d. TL Kedaung Four Square		

$$\sum_{j=10}^{17} h_j \geq S_{17} \tag{47}$$

$$\sum_{j=1}^{8} h_j + \sum_{18}^{21} h_j + h_{14} + h_{24} \geq S_{18} \tag{48}$$

$$\sum_{j=1}^{7} h_j + \sum_{18}^{21} h_j \geq S_{19} \tag{49}$$

$$\sum_{j=1}^{7} h_j + \sum_{18}^{21} h_j \geq S_{20} \tag{50}$$

$$\sum_{j=3}^{14} h_j + \sum_{18}^{21} h_j \geq S_{21} \tag{51}$$

$$h_{22} + h_{28} \geq S_{22} \tag{52}$$

$$h_{23} \geq S_{23} \tag{53}$$

$$\sum_{j=1}^{9} h_j + h_{18} + h_{24} + h_{25} \geq S_{24} \tag{54}$$

$$h_{24} + h_{25} + h_{27} + h_{38} + h_{29} \geq S_{25} \tag{55}$$

$$h_{26} + h_{27} + h_{39} \geq S_{26} \tag{56}$$

$$\sum_{j=25}^{27} h_j + \sum_{40}^{47} h_j \geq S_{27} \tag{57}$$

$$h_{22} + h_{28} \geq S_{28} \tag{58}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{29} \tag{59}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{30} \tag{60}$$

$$h_{31} \geq S_{31} \tag{61}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{32} \tag{62}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{33} \tag{63}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{34} \tag{64}$$

$$\sum_{j=32}^{35} h_j + h_{29} + h_{30} \geq S_{35} \tag{65}$$

$$h_{36} \geq S_{36} \tag{66}$$

$$h_{37} \geq S_{37} \quad (67)$$
$$h_{25} + h_{38} + h_{39} \geq S_{38} \quad (68)$$
$$h_{25} + h_{26} + h_{38} + h_{39} \geq S_{39} \quad (69)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{40} \quad (70)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{41} \quad (71)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{42} \quad (72)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{43} \quad (73)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{44} \quad (74)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{45} \quad (75)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{46} \quad (76)$$
$$\sum_{j=40}^{47} h_j + h_{27} \geq S_{47} \quad (77)$$
$$h_j \in \{0, 1\}, j = 1, 2, ..., 47 \quad (78)$$
$$S_i \in \{0, 1\}, j = 1, 2, ..., 47 \quad (79)$$

Based on the MCLP model formulation in Equation 29 and Constraints 30 to 79, it is explained that:

1. Equation 29 is the objective function to maximize the demand for each TWDS in the Bukit Kecil sub-district.
2. Constraint 30 states that 10 facility locations will be placed.
3. Constraints 31 to 77 are constraints that state for the location demand points to .
4. Constraints 78 and 79 state that each variable in the MCLP model is binary, namely 0 and 1.

The optimal solution of the MCLP model is shown in Table 6.

The value of $S_1 = S_2 = ... = S_{47}$ and $h_{10} = h_{19} = h_{22} = h_{23} = h_{25} = h_{27} = h_{29} = h_{31} = h_{36} = h_{37} = 1$which means that all demand points are covered and the optimal TWDS in the Bukit Kecil sub-district should be in 10 locations, as follows:

1. TWDS Pangeran Ario Kesuma Street
2. TWDS front of PMKRI
3. TWDS Merdeka Street
4. TWDS Illegal at 26 Ilir Market
5. TWDS Flat Block 35
6. TWDS Flat Block 49
7. TWDS Kesdam
8. TWDS Merdeka Women's Prison
9. TWDS Monpera
10. TWDS Cinde Market

The objective of the p-Centre Location Problem model formulation is to minimize the maximum distance between the TWDS and demand points. Table 7 displays the chosen TWDS variables in the Bukit Kecil sub-district identified as S_k whereas $k = 10, 19, 22, 23, 25, 27, 29, 31, 36$, and 37.

Table 6. Optimal Solution of the MLCLP Model

Solver Status	
Model Class	PILP
State	Global Optimal
Objective	47
Infeasibility	0
Iteration	27
Extended Solver Status	
Solver Type	Branch and Bound
Best Objective	47
Objective Bound	47
Steps	0
Active	0
Update Interval	2
GMU (K)	58
ER (sec)	0

Table 7. Location of Optimal TWDS in the Bukit Kecil Sub-District

Variable	Location
S_{10}	TWDS Pangeran Ario Kesuma Street
S_{19}	TWDS Front of PMKRI
S_{22}	TWDS Merdeka Street
S_{23}	TWDS Illegal at 26 Ilir Market
S_{25}	TWDS Flat Block 35
S_{27}	TWDS Flat Block 49
S_{29}	TWDS Kesdam
S_{31}	TWDS Merdeka Women's Prison
S_{36}	TWDS Monpera
S_{37}	TWDS Cinde Market

The optimal TWDS in the Bukit Kecil sub-district is measured for each demand point using the village data in Table 3 and the corresponding travel distance as shown in Table 8.

Table 8 states that $d_{i,j}$ is the distance from Talang Semut village S_{10} to TWDS Pangeran Ario Kesuma Street (b_1) is 500 m, (b_1) is the distance from Talang Semut village to TWDS Front of PMKRI S_{19} is 650 m, and so on. The formulation of p-Center Location Problem is

Minimize,

Table 8. The Distance between the Village and the Optimal TWDS in the Bukit Kecil Sub-District (in meter)

$d_{i,j}$	10	19	22	23	25	27	29	31	36	37
1	500	650	800	850	900	1100	1500	1400	3300	2200
2	1100	500	1400	1200	400	850	2100	2000	3100	1100
3	950	1400	1100	800	1300	850	400	300	2900	1800
4	1900	2300	2000	1600	2200	1700	1400	1400	1300	2100
5	1200	1100	1200	900	550	550	1700	1600	2500	1200
6	1100	1000	750	400	700	260	1200	1100	2600	1400

$$Z_{p-center} = L \quad (80)$$

Subject to

$$b_{1,10} + b_{1,19} + b_{1,22} + b_{1,23} + b_{1,25} + b_{1,27} + b_{1,29} + b_{1,31} + b_{1,36} + b_{1,37} = 1 \quad (81)$$

$$b_{2,10} + b_{2,19} + b_{2,22} + b_{2,23} + b_{2,25} + b_{2,27} + b_{2,29} + b_{2,31} + b_{2,36} + b_{2,37} = 1 \quad (82)$$

$$b_{3,10} + b_{3,19} + b_{3,22} + b_{3,23} + b_{3,25} + b_{3,27} + b_{3,29} + b_{3,31} + b_{3,36} + b_{3,37} = 1 \quad (83)$$

$$b_{4,10} + b_{4,19} + b_{4,22} + b_{4,23} + b_{4,25} + b_{4,27} + b_{4,29} + b_{4,31} + b_{4,36} + b_{4,37} = 1 \quad (84)$$

$$b_{5,10} + b_{5,19} + b_{5,22} + b_{5,23} + b_{5,25} + b_{5,27} + b_{5,29} + b_{5,31} + b_{5,36} + b_{5,37} = 1 \quad (85)$$

$$b_{6,10} + b_{6,19} + b_{6,22} + b_{6,23} + b_{6,25} + b_{6,27} + b_{6,29} + b_{6,31} + b_{6,36} + b_{6,37} = 1 \quad (86)$$

$$S_{10} + S_{19} + S_{23} + S_{25} + S_{27} + S_{29} + S_{31} + S_{36} + S_{37} = 10 \quad (87)$$

$$500b_{1,10} + 650b_{1,19} + 800b_{1,22} + 850b_{1,23} + 900b_{1,25} + 1100b_{1,27} + 1500b_{1,29} + 1400b_{1,31} + 3300b_{1,36} + 200b_{1,37} \leq L \quad (88)$$

$$1100b_{2,10} + 500b_{2,19} + 1400b_{2,22} + 1200b_{2,23} + 400b_{2,25} + 850b_{2,27} + 2100b_{2,29} + 2000_{2,31} + 3100b_{2,36} + 1100b_{2,37} \leq L \quad (89)$$

$$950b_{3,10} + 1400b_{3,19} + 1100b_{3,22} + 800b_{3,23} + 1300b_{3,25} + 850b_{3,27} + 400b_{3,29} + 300b_{3,31} + 2900b_{3,36} + 1800b_{3,37} \leq L \quad (90)$$

$$1900b_{4,10} + 2300b_{4,19} + 2000b_{4,22} + 1600b_{4,23} + 2200b_{4,25} + 1700b_{4,27} + 1400b_{4,29} + 1400b_{4,31} + 1300b_{4,36} + 2100b_{4,37} = 1 \quad (91)$$

$$1200b_{5,10} + 1100b_{5,19} + 1200b_{5,22} + 900b_{5,23} + 550b_{5,25} + 550b_{5,27} + 1700b_{5,29} + 1600b_{5,31} + 2500b_{5,36} + 1200b_{5,37} \leq L \quad (92)$$

$$1100b_{6,10} + 1000b_{6,19} + 750b_{6,22} + 400b_{6,23} + 700_{6,25} + 260b_{6,27} + 1200b_{6,29} + 1100b_{6,31} + 2600b_{6,36} + 1400b_{6,37} \leq L \quad (93)$$

$$b_{1,10}, b_{2,10}, b_{3,10}, b_{4,10}, b_{5,10}, b_{6,10} \leq S_{10} \quad (94)$$

$$b_{1,19}, b_{2,19}, b_{3,19}, b_{4,19}, b_{5,19}, b_{6,19} \leq S_{19} \quad (95)$$

$$b_{1,22}, b_{2,22}, b_{3,22}, b_{4,22}, b_{5,22}, b_{6,22} \leq S_{22} \quad (96)$$

$$b_{1,23}, b_{2,23}, b_{3,23}, b_{4,23}, b_{5,23}, b_{6,23} \leq S_{23} \quad (97)$$

$$b_{1,25}, b_{2,25}, b_{3,25}, b_{4,25}, b_{5,25}, b_{6,25} \leq S_{25} \quad (98)$$

$$b_{1,27}, b_{2,27}, b_{3,27}, b_{4,27}, b_{5,27}, b_{6,27} \leq S_{27} \quad (99)$$

$$b_{1,29}, b_{2,29}, b_{3,29}, b_{4,29}, b_{5,29}, b_{6,29} \leq S_{29} \quad (100)$$

$$b_{1,31}, b_{2,31}, b_{3,31}, b_{4,31}, b_{5,31}, b_{6,31} \leq S_{31} \quad (101)$$

$$b_{1,36}, b_{2,36}, b_{3,36}, b_{4,36}, b_{5,36}, b_{6,36} \leq S_{36} \quad (102)$$

$$b_{1,37}, b_{2,37}, b_{3,37}, b_{4,37}, b_{5,37}, b_{6,37} \leq S_{37} \quad (103)$$

$$b_{i,j} \in \{0, 1\}, i = 1, 2, \ldots, 6 \text{ and } j = 10, 19, 22, 23, 25, 27, 29, 31, 36, 37 \quad (104)$$

$$S_{10}, S_{19}, S_{22}, S_{23}, S_{25}, S_{27}, S_{29}, S_{31}, S_{36}, S_{37} \in \{0, 1\} \quad (105)$$

$$L \geq 0 \quad (106)$$

Based on the p-Centre Location Problem model formulation in Equation (80) and Constraints (81) to (106), it is explained that:

1. Equation (80) is the objective function to minimize the maximum distance between the demand point and the TWDS in the Bukit Kecil sub-district.
2. Constraints (81) to (81) are restrictions that state for the demand points at locations b_1 to b_6.
3. Constraint (87) is a constraint that states the number of TWDS.
4. Constraints (88) to (93) are constraints that determine the maximum distance from the demand point. The coefficients in the equations are got from the distance between the village and the optimal TWDS from MCLP model.
5. Constraints (94) to (103) are constraints that state the demand point by the optimal location of the MCLP model waste stations.
6. Constraints (104) and (105) state that each variable in the p-Centre Location Problem model is binary, namely 0 and 1.

7. Constraint (106) states that the value of the objective function is non-negative.

The optimal solution of the p-Center Location Problem model can be seen in Table 9. The optimal solution of the p-Center Location Problem is $b_{1,10} = b_{2,25} = b_{3,31} = b_{4,36} = b_{5,35} = b_{6,27} = 1$, which means

1. The demand in Talang Semut village (b_1) will be located at TWDS Pangeran Ario Kesuma Street (S_{10}).
2. The demand in 26 Ilir village (b_2) will be located at TWDS Flat Block 35 (S_{35}).
3. The demand in 22 Ilir village (b_3) will be located at TWDS Merdeka Women's Prison (S_{31}).
4. The demand in 19 Ilir village (b_4) will be located at TWDS Monpera (S_{36}).
5. The demand in 24 Ilir village (b_5) will be located at TWDS Flat Block 35 (S_{35}).
6. The demand in 23 Ilir village (b_6) will be located at TWDS Flat Block 49 (S_{37}).

Table 9. Optimal Solution of the p-Center Location Problem Model

Solver Status	
Model Class	MILP
State	Global Optimal
Objective	1300
Infeasibility	0
Iteration	0
Extended Solver Status	
Solver Type	Branch and Bound
Best Objective	1300
Objective Bound	1300
Steps	0
Active	0
Update Interval	2
GMU (K)	37
ER (sec)	0

3.2 Formulation of The Robust-Set Covering Problem Model

The Robust-SCP model formulation aims to attain solutions with probabilistic variations based on parameters that have uncertainty. The Robust-SCP model data employs the SCLP model data to determine the location of TWDS in the Bukit Kecil sub-district. The formulation of the Robust-SCP model in the Bukit Kecil sub-district is outlined below. Minimize

$$Z_{SRCP} = L \tag{107}$$

subject to

$$\sum_{j=1}^{47} h_j \le L \tag{108}$$

Table 10. Optimal Solution of the Robust-SCP Model

Solver Status	
Model Class	MILP
State	Global Optimal
Objective	10
Infeasibility	0
Iteration	0
Extended Solver Status	
Solver Type	Branch and Bound
Best Objective	10
Objective Bound	10
Steps	0
Active	0
Update Interval	2
GMU (K)	38
ER (sec)	0

Constraints (2)-(28)

$$L \ge 0 \tag{109}$$

Based on the formulation of the Robust-SCP model in Constraints (2-28) and Model (107-109), it is explained as follows:

a Equation (107) is the objective function to minimize the maximum distance between the demand point and the TWDS in the Bukit Kecil sub-district.

b The Constraint (108) is a constraint that determines the maximum distance from each demand point.

c Constraints (2) to (28) are constraints on demand points.

d The Constraint (109) states that the value of the objective function is non-negative.

The Robust-SCP model in the Bukit Kecil sub-district was solved using the software, resulting the optimal solution shown in Table 10.

The optimal solutions of the Robust-SCP are $h_{11} = h_{20} = h_{22} = h_{23} = h_{25} = h_{27} = h_{31} = h_{35} = h_{36} = h_{37} = 1$ which means the optimal TWDS, are as follows:

1. TWDS Kartini Street
2. TWDS Infront of Starbucks KI
3. TWDS Merdeka Street
4. TWDS Illegal at 26 Ilir Market
5. TWDS Flat Block 35
6. TWDS Flat Block 49
7. TWDS Merdeka Women's Prison
8. TWDS Musi Riverbank Park
9. TWDS Monpera
10. TWDS Cinde Market

Sensitivity analysis of the Robust-SCP model aims to determine the interval of the objective function coefficients and model constraints that can change without affecting the optimal obtained. The interval value of each coefficient can be

Table 11. The Result of Sensitivity Analysis of the Robust-SCP Model

Variabel	Current Coefficient	Allowable Increase	Allowable Decrease	Interval
L	10	Infinity	1	$9 \leq L \leq \infty$
h_1	0	0	1	$-1 \leq h_1 \leq 0$
h_2	0	Infinity	0	$0 \leq h_2 \leq \infty$
h_3	0	Infinity	0	$0 \leq h_3 \leq \infty$
h_4	0	Infinity	0	$0 \leq h_4 \leq \infty$
h_5	0	Infinity	0	$0 \leq h_5 \leq \infty$
h_6	0	Infinity	0	$0 \leq h_6 \leq \infty$
h_7	0	Infinity	1	$-1 \leq h_7 \leq \infty$
h_8	0	Infinity	1	$-1 \leq h_8 \leq \infty$
h_9	0	Infinity	1	$-1 \leq h_9 \leq \infty$
h_{10}	0	Infinity	0	$0 \leq h_{10} \leq \infty$
h_{11}	1	Infinity	0	$1 \leq h_{11} \leq \infty$
h_{12}	0	Infinity	0	$0 \leq h_{12} \leq \infty$
h_{13}	0	0	1	$-1 \leq h_{13} \leq \infty$
h_{14}	0	Infinity	0	$0 \leq h_{14} \leq \infty$
h_{15}	0	Infinity	0	$0 \leq h_{15} \leq \infty$
h_{16}	0	Infinity	0	$0 \leq h_{16} \leq \infty$
h_{17}	0	Infinity	0	$0 \leq h_{17} \leq \infty$
h_{18}	0	0	0	$h_{18} = 0$
h_{19}	0	Infinity	0	$0 \leq h_{19} \leq \infty$
h_{20}	1	Infinity	0	$1 \leq h_{20} \leq \infty$
h_{21}	0	1	0	$0 \leq h_{21} \leq 1$
h_{22}	1	Infinity	0	$1 \leq h_{22} \leq \infty$
h_{23}	1	Infinity	1	$0 \leq h_{23} \leq \infty$
h_{24}	0	Infinity	0	$0 \leq h_{24} \leq \infty$
h_{25}	1	1	0	$1 \leq h_{25} \leq 2$
h_{26}	0	Infinity	1	$-1 \leq h_{26} \leq \infty$
h_{27}	1	0	1	$1 \leq h_{27} \leq 1$
h_{28}	0	0	1	$-1 \leq h_{28} \leq 0$
h_{29}	0	Infinity	0	$0 \leq h_{29} \leq \infty$
h_{30}	0	Infinity	0	$0 \leq h_{30} \leq \infty$
h_{31}	1	Infinity	1	$0 \leq h_{31} \leq \infty$
h_{32}	0	Infinity	0	$0 \leq h_{32} \leq \infty$
h_{33}	0	Infinity	0	$0 \leq h_{33} \leq \infty$
h_{34}	0	Infinity	0	$0 \leq h_{34} \leq \infty$
h_{35}	1	0	1	$0 \leq h_{35} \leq 1$
h_{36}	1	Infinity	1	$0 \leq h_{36} \leq \infty$
h_{37}	1	Infinity	1	$0 \leq h_{37} \leq \infty$
h_{38}	0	0	0.5	$0.5 \leq h_{38} \leq 0$
h_{39}	0	1	0	$0 \leq h_{39} \leq 1$
h_{40}	0	Infinity	0	$0 \leq h_{40} \leq \infty$
h_{41}	0	Infinity	0	$0 \leq h_{41} \leq \infty$
h_{42}	0	Infinity	0	$0 \leq h_{42} \leq \infty$
h_{43}	0	Infinity	0	$0 \leq h_{43} \leq \infty$
h_{44}	0	Infinity	0	$0 \leq h_{44} \leq \infty$
h_{45}	0	Infinity	0	$0 \leq h_{45} \leq \infty$
h_{46}	0	Infinity	0	$0 \leq h_{46} \leq \infty$
h_{47}	0	Infinity	0	$0 \leq h_{47} \leq \infty$

calculated using the following equation: For the left side of the interval

$$b_{i,j} = \text{current coeficient}_{i,j} - \text{allowable decrease}_{i,j} \quad (110)$$

Table 12. Optimal TWDS of the SCP Model

Name of Village	Optimal TWDS
Talang Semut Village	TWDS Pangeran Ario Kesuma Street
26 Ilir Village	TWDS Flat Block 35
22 Ilir Village	TWDS Merdeka Women's Prison
19 Ilir Village	TWDS Monpera
24 Ilir Village	TWDS Flat Block 35
23 Ilir Village	TWDS Flat Block 49

Table 13. Optimal TWDS of the Robust-SCP Model

Name of Village	Optimal TWDS
Talang Semut Village	TWDS Kartini Street
	TWDS front of Starbucks KI
	TWDS Merdeka Street
	TWDS Illegal at 26 Ilir Marke
26 Ilir Village	TWDS Flat Block 35
	TWDS Flat Block 49
19 Ilir Village	TWDS Merdeka Women's Prison
	TWDS Musi Riverbank Park
	TWDS Monpera
24 Ilir Village	TWDS Cinde Market

For the right side of the interval

$$b_{i,j} = \text{current coeficient}_{i,j} + \text{allowable decrease}_{i,j} \quad (111)$$

Based on Equations (110) and (111), the result of sensitivity analysis of the Robust-SCP model can be seen in Table 11.

From Table 11, the interval value of h_1 is $-1 \leq h_1 \leq 0$. This means that as long as the changes that occur within the interval value $-1 \leq h_1 \leq 0$, the solution will remain optimal, and vice versa if the changes that occur within the interval value $h_1 < -1$ or $h_1 > 0$ then the solution is no longer optimal, and so on until the interval value of the variable h_{47}.

3.3 Analysis of The SCP and Robust-SCP Model Results

The SCP and Robust-SCP models generated numerous ideal TWDS within the Bukit Kecil sub-district. However, the quantity and whereabouts of optimal TWDS vary between the SCP and Robust-SCP models. Tables 12 and 13 display the optimal TWDS based on the SCP and the Robust-SCP model results.

According to Table 12, there are six villages in the Bukit Kecil sub-district. Each village has one optimal TWDS. However, some optimal TWDS based on the results of the p-Centre Location Problem model do not match the village.

Table 13 shows the optimal TWDS of the Robust-SCP model in the Bukit Kecil sub-district. Talang Semut village has 4 optimal TWDS, 26 Ilir village has 2 optimal TWDS, 19 Ilir village has 3 optimal TWDS, and 24 Ilir village has only 1 optimal TWDS. Two villages that do not have optimal TWDS, namely 22 Ilir and 23 Ilir village. Therefore, this study recommends a solution from the Robust-SCP model, with the addition of the TWDS Mayor's Office in 22 Ilir village and TWDS Flat Block 01 in 23 Ilir village. The optimal TWDS is shown in Figure 1.

Figure 1. Optimal TWDS in the Bukit Kecil Sub-District, Palembang City

Description:

: Talang Semut Village

: 26 Ilir Village

: 22 Ilir Village

: 19 Ilir Village

: 24 Ilir Village

: 23 Ilir Village

The optimal solution from this research can be used as a consideration for EHD Palembang City to determine the optimal location of TWDS in the Bukit Kecil sub-district and organize waste transportation routes from TWDS to final disposal sites.

4. CONCLUSION

Based on the results and discussion of determining the optimal TWDS in the Bukit Kecil sub-district by formulating the SCP and Robust-SCP models, it can be concluded as follows: the SCP model formulation results in each demand point having at least 1 optimal TWDS, namely Talang Semut village with TWDS Pangeran Ario Kesuma Street, 26 Ilir village with TWDS Flat Block 35, 22 Ilir village with TWDS Merdeka Women's Prison, 19 Ilir village with TWDS Monpera, 24 Ilir village with TWDS Flat Block 35, and 23 Ilir village with

TWDS Flat Block 49. The Robust-SCP model formulation resulted in 10 optimal TWDS in Bukit Kecil sub-district, namely TWDS Kartini Street, TWDS front of Starbucks KI, TWDS Merdeka Street, TWDS Illegal at 26 Ilir Market, TWDS Flat Block 35, TWDS Flat Block 49, TWDS Merdeka Women's Prison, TWDS Musi Riverbank Park, TWDS Monpera, and TWDS Cinde Market.

Based on the sensitivity analysis results, the solution remains optimal if the coefficient change is within the interval value. This study recommends the SCP model as the optimal solution for determining the location of TWDS because it can fulfill all demand points in the Bukit Kecil sub-district.

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