Optimization Supply Chain Network Design for Bioreactor: A Case Study in Jakenan Pati

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Abstract

The potential for waste that appears every time must be managed optimally. Waste management sites that are far away and have high costs are one of the problems that must be solved. Jakenan District is located ± 23 Km from the center of the Landfill (TPA). This study aims to create a Kapal Selam Bioreactor (BKS) waste supply chain network located in Jakenan District. To produce a more optimal waste network and high economic benefits. In determining the initial 7 locations using Mixed Integer Linear Programming (MILP). Mixed Integer Linear Programming (MILP) is used to formulate the location of the capacity allocation that is applied to solve the problem. Furthermore, ILOG Cplex is used to complete the mathematical formulation in this model. There are seven locations opened to cover waste in Jakenan District, namely Jakenan, Dukuhmulyo, Sidomulyo, Sembaturagung, Kalimulyo, Sonorejo, and Sendangsoko.

Keywords
Jakenan , Kapal Selam Bioreactor, Location Allocation , MILP, Supply Chain Network Design.

1. Introduction
Garbage is an item that results from the behavior and activities of living things. According to data disclosed by the Ministry of Environment and Forestry, Indonesia's waste stockpile in 2020 is estimated at 67.8 million tons. And this is indicated to continue to grow along with population growth and the improving level of welfare.

From the estimated amount of waste, the handling of the presence of the waste has been carried out. According to data from the National Waste Management Information System (SIPN) regarding the achievement of waste processing performance in 2020 consisting of 291 regencies/cities throughout Indonesia, they are as follows: the total waste is 36.9 million tons/year, 15.88% waste reduction, or 5.8 million tons/year. year), Waste Management

37.09% or 13.7 million tons/year, Managed Waste 52.97% or 19.5 million tons/year), Unmanaged Waste 47.03% or 17.3 million tons/year.
The amount of waste, it can be divided according to its composition, namely waste by type of waste consisting of food waste 30.8%, wood/twigs/leaves 12%, paper/cardboard 11.2%, plastic 18.5%, rubber/leather 3.5%, cloth 4.9 %, glass 2.8%, metal 3.6%, others 12.8%. Meanwhile, the composition of waste based on the source of waste is 32.4% households, 9.9% offices, 21.7% traditional markets, 13.9% commercial centers, 11% public facilities, 6.1% areas, 5% others.

The Jakenan area of Pati district is one of the areas to the south and east of the city of Pati. So far, the process of processing waste from the Jakenan sub-district is carried out at the Final Disposal Site (TPA) located in Sukoharjo Pati. The distance between the Jakenan sub-district and the TPA is ± 23 KM. The long transportation distance results in a very large amount of vehicle fuel being released. This causes high carbon emissions. The transport sector currently produces about a quarter of global anthropogenic CO2, the transition from petroleum-based fuels will be a key part of efforts to achieve net-zero emissions targets(Comello & Glenk, 2020)

In the process of processing waste at the TPA, apart from the very large processing capacity, the costs required to build it are also very large, but by using BKS, the waste can be processed into something of value and can generate income. With the Kapal Selam Bioreactor (BKS), waste can be processed at a location closer to the source of the waste so that less vehicle fuel is released and fewer carbon emissions are released. To further optimize the development of BKS facilities in Jakenan District, it is very necessary to design a supply chain network.

Supply Chain Network Design (SCND) is a problem whose decisions include “the role of the facility, the location of the facilities associated with manufacturing, storage, or transportation, and the allocation of capacity and markets for each facility” (Chopra & Meindl, 2013). The supply chain network is the result of several strategic decisions, one of which is a decision about the location of production facilities and decisions about purchasing raw materials(Wahyudin et al., 2015). The SCND BKS in Jakenan District consists of four entities, namely domestic household waste and market waste as suppliers, kapal selam bioreactors as manufacturers, distribution centers for solid and liquid organic fertilizers, and consumers as users of electrical and gas energy.

This research is expected to produce an SCND development model for the construction of the Kapal Selam Bioreactor (BKS) facility, namely by determining the number of bioreactors built, the location of the BKS, and which BKS serves any area.

2. Literature Review

Several articles discuss supply chain design related to allocation locations. Here are some articles that have been compiled (Table 1).

Table 1. Mapping of Past Research

Publication	Parameter								
	Facility Opening		Allocation Location		Garbage Coverage		Sustainability		
	TPF	DPF	D	UD	TC	DC	AE	US	AL
Balaman et al. (2014)		v	v			v	v		v
Mohammadi et al. (2019)		v		v		v	v	v	v
Bijarchiyan et al. (2020)		v	v			v		v	v
Habibie et al. (2021)		v		v		v	v	v	v
Kwon. et al (2022)		v		v	v				

Publication	Parameter								
	Facility Opening		Allocation Location		Garbage Coverage		Sustainability		
	TPF	DPF	D	UD	TC	DC	AE	US	AL
This research		v	v			v	v	v	v

Note: TPF = without opening of facilities, DPF = opening of facilities, D = dedicated, UD = undedicated, TC = without coverage, DC = with coverage, AE = economic aspects, AS = social aspects, AL = environmental aspects

The research roadmap shows the novelty of the research by comparing similar studies that have been done previously. The table 1 shows the research position. Several research models have been developed by previous researchers. (Page S & Selim H, 2014) has developed a supply chain (SC) method by considering the selection of facilities, the location of dedicated allocations, waste coverage, and environmental economic aspects. (Mohammadi et al., 2019) and (Habibie et al., 2021) both consider the selection of facilities, the location of the allocation of undedicated, with waste coverage, and all aspects of sustainability (economic, social, and environmental). (Bijarchiyan et al., 2020)considering the selection of facilities, dedicated allocation locations, with waste coverage and sustainability aspects only from the social and environmental fields. Whereas(Kwon et al., 2022) only consider the selection of location facilities for undedicated allocation and without waste coverage. In this study, we will consider and integrate the supply chain network design model, environmental issues and determine the location - allocation of kapal selam bioreactor facilities.

3. Methods

The problem raised in this research is determining the location of the BKS facility by considering the potential allocation of domestic waste and market waste. and maximize costs by considering revenue, capacity, investment, and transportation costs. In this research method, a description of the problem will be described as the basis for designing a supply chain network, along with its mathematical model. By adopting the concept of a node model where nodes represent facilities at potential locations. Thus, the Jakenan sub-district area is divided into several centers consisting of several villages to determine the ideal location of the BKS facility (Figure 1).

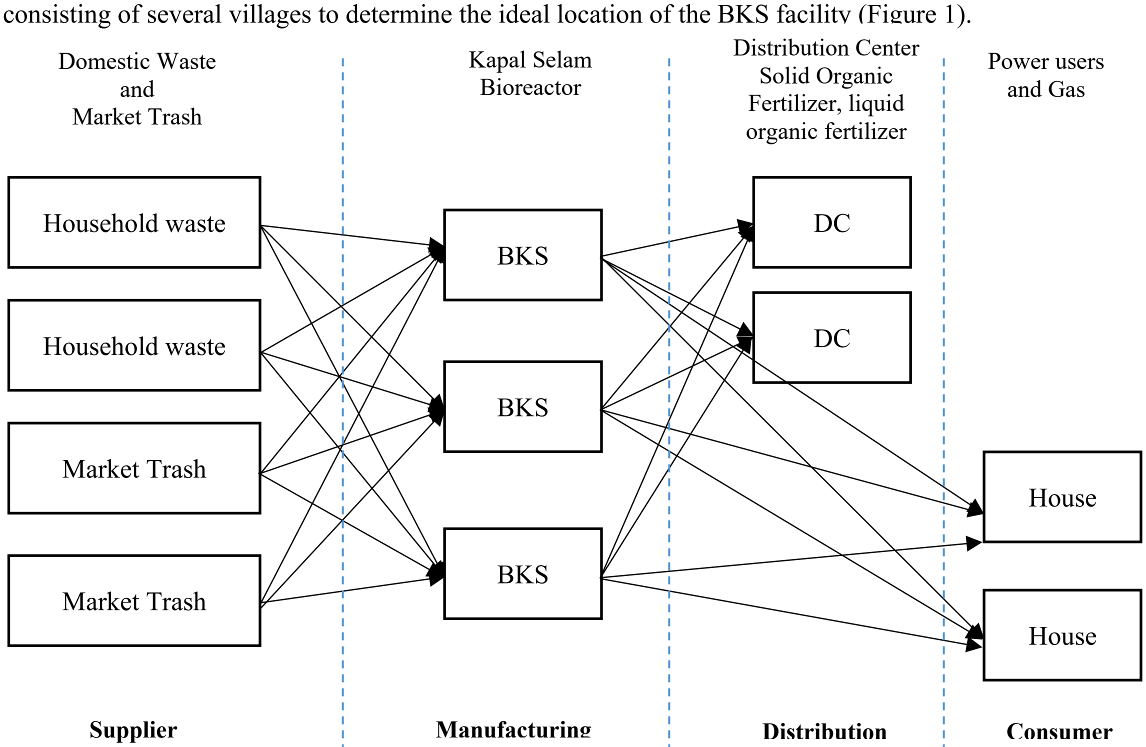

Figure 1. Framework for Supply Chain Network Design

In the supply chain network, the suppliers consist of domestic household waste and market waste. In Jakenan District, the population in 2020 consists of 47,568 people. It consists of 23 villages which are divided into 58 Rukun Warga (RW) and 341 Rukun Tetangga (RT). There are 4 markets, namely Jakenan Market, Sematuragung Market, Addmulyo Market, and Glonggong Market. Its manufacture is in the form of a kapal selam bioreactor. Distribution Center (DC) is a solid organic fertilizer and liquid organic fertilizer. Consumers consist of direct users of electricity and gas.

The movement of waste from household waste and market waste is then transported to a kapal selam bioreactor for processing. After undergoing the fermentation process, it will produce organic fertilizer, gas, and decomposers. Organic fertilizers are in the form of liquid and solid organic fertilizers, while gas can be in the form of gas energy and converted to electricity. Products in the form of solid and liquid organic fertilizers are then sent to the distribution center, while gas and electricity products are directly distributed to consumers in the homes of each resident.

In the article (Page S & Selim H, 2014)in solving SCND problems using mixed-integer linear programming (MILP) which has been widely used to design and operate bioenergy supply chains. The purpose of the SCND design is to maximize the benefits of the entire supply chain. Some of the supply chain decisions made in the model are the location of locations for biomass crops and storage, capacity levels for mills and storage, the amount of biomass to be transported from the supplier area to storage, and from storage to the mill, the amount of fertilizer to be transported from the plant to the supplier area. , as well as the volume of biogas production and electricity generation.

In this article, we will describe the optimization of the supply chain network design for BKS facilities using the MILP model to determine the optimal capacity and location of facilities. So with the BKS needs to be opened and closed to minimize supply chain costs. Mixed Integer Linear Programming (MILP) is used to formulate the capacity location-allocation that is applied to solve the problem. Furthermore, ILOG Cplex is used to complete the mathematical formulation in this model. The functions that exist in the ILOG CPLEX are basic functions that can be used to solve simple to quite complex problems(Sutopo et al., 2016). To determine the initial location of the BKS facility and its number, the load distance method is used.

in the book(Watson, 2013)explained that the load distance method is a way of choosing the optimal location by considering the distance. The smallest load value will be chosen as the location for the BKS facility so that waste delivery is more efficient.

$$LD = \sum_{i}^{n} l_i d_i$$

$$\text{in} = \sqrt{(\mathbf{x_i} - \mathbf{x})^2 + (\mathbf{y_i} - \mathbf{y})^2}$$

where,
LD = Load value – distance
l_i = Expressed as weight load, number of trips, or units shipped from the same location proposed to location i.
in = Distance between proposed and site location i.
(x,y) = Proposed site coordinates
(xi,yi) = Coordinates available for facilitation

3.1 Influence Diagram

Figure 2 describes the influence diagram of this model. From this diagram, it can be seen that the goal is cost maximization. 3 costs need to be considered, namely total income, total investment costs, total operational costs, total costs for water needs, and total transportation costs. There are 12 parameters, namely gas prices, electricity prices, liquid fertilizer prices, solid fertilizer prices, investment costs, investment recovery factors, operational costs, operational recovery factors, water costs, transportation costs from suppliers to BKS, and transportation costs from BKS to DC. In addition, there are 10 decision variables considered in this model, namely the amount of gas, the amount of electricity, the amount of liquid fertilizer, the amount of solid fertilizer, the amount of BKS, the amount of water needed, the amount of waste brought from the supplier to the BKS, the amount of solid fertilizer brought from the BKS. to the distribution center, and the amount of liquid fertilizer brought from BKS to the distribution center. The optimal solution will be calculated by MILP.

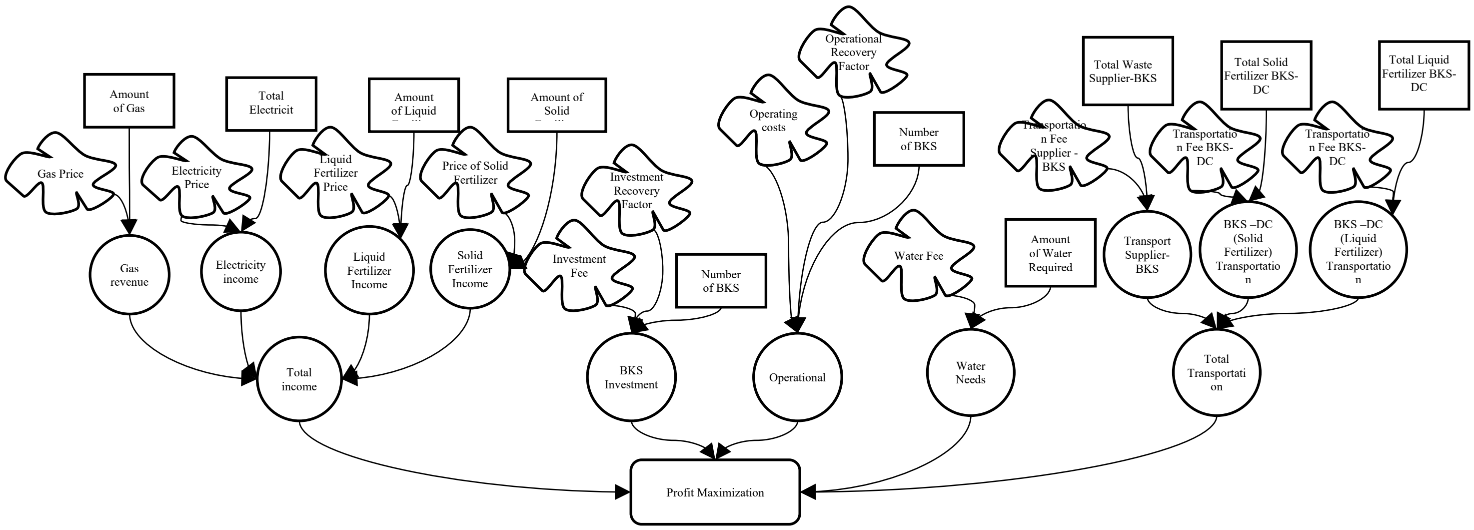

Figure 2. Influence Diagram

3.2 Mathematical Model

Since the early 1950s, Hard Operations Research researchers have developed many objective models, such as linear programming and its various extensions, network models, such as critical path scheduling, and waiting line models, and so on. They have a well-defined mathematical structure and associated solution methods, usually in the form of an algorithm(McNickle, 2005). Furthermore, the objective function of this paper is to maximize the profit of opening BKS facilities. Parameter notation, decision variables, objective functions used for this model are

Index

r : supply area index (houses and markets)
p : BKS index
c : Fertilizer Distribution Center index

Parameter

SP	:	price of solid fertilizer (Rp/m3)
LP	:	price of liquid fertilizer (Rp/Lt)
EP	:	electricity price (Rp/KWh)
GP	:	gas price (Rp/m3)
Invp	:	BKS location investment cost p (Rp)
Opp	:	annual operating costs at BKS locations p (Rp)
CR1	:	capital recovery factor for investment cost
CR2	:	capital recovery factor for operating costs
QWr	:	amount of waste available in the supply area r (m3)
QSp	:	the amount of solid organic fertilizer s produced at the BKS location p (m3)
QLp	:	the amount of solid organic fertilizer s produced at the BKS location p (m3)
WP	:	water price (Rp/m3)
Tranrpw	:	waste transportation cost w from supply area r to BKS location p (Rp/m3)

Tranpcs : transportation cost of solid organic fertilizer s from BKS location p to distribution center (DC) c (Rp/kg)
Tranpcl : transportation costs of liquid organic fertilizer l from BKS location p to distribution center (DC) c (Rp/lt)
Capp BKS Capacity (m3)

Decision Variable
Outsolp : The amount of solid fertilizer produced at the BKS location p (m3)
Outliqp : Amount of liquid fertilizer produced at the BKS location p (Lt)
Outelcp : The amount of electricity generated at the BKS location p (kW)
Outgp : Amount of gas produced at BKS location p (m3)
Wp : amount of water use at BKS location p (lt)
Qp : Number of installations built at BKS location p
Qrpw : the amount of waste w transported from the supply area r to the BKS location p (m3)
Qpcs : amount of solid organic fertilizer s transported from BKS location p to distribution center (DC) c (kg)
Qpcl : amount of liquid organic fertilizer l transported from BKS location p to distribution center (DC) c (lt)

Objective Function:
Maximization of $Z = \left(SP * \sum_p Outsol_p\right) + \left(LP * \sum_p Outliq_p\right) + \left(EP * \sum_p Outelc_p\right) + \left(GP * \sum_p Outg_p\right)\Big) - \Big(\left(\sum_p Inv_p * Q_p\right) * CR_1 + \left(\sum Op_p * Q_p\right) * CR_2 + \left(WP * W_p\right)\Big) + \left(\sum_r \sum_p \sum_w Tran_{rpw} * Q_{rpw}\right) + \left(\sum_p \sum_c \sum_s Tran_{pcs} * Q_{pcs}\right) + \left(\sum_p \sum_c \sum_l Tran_{pcl} * Q_{pcl}\right)$ (1)

Function Constraint
$\sum_r Q_{rpw} \leq QW_r$: the amount of waste w transported from the supply area r to the BKS location p must be less than or equal to the amount of waste available in the supply area r (2)
$\sum_r Q_{rpw} \leq Cap_p$: the amount of waste w transported from the supply area r to the BKS location p must be less than or equal to the capacity of BKS (3)
$\sum_p Q_{pcs} \leq QS_p$: the amount of solid organic fertilizer s transported from the BKS location p to the distribution center must be less than or equal to the amount of solid organic fertilizer s produced at the BKS location p (4)
$\sum_p Q_{pcl} \leq QL_p$: the amount of liquid organic fertilizer l transported from the BKS location p to the distribution center must be less than or equal to the amount of solid organic fertilizer s produced at the BKS location p (5)

4. Data Collection

As in the table 2 it is explained that in this study, data collection was carried out directly and via the internet. Data on specifications, capacity, investment, and BKS operations are obtained directly at the BKS location. Data on the number of residents and the number of markets in Jakenan District were obtained from the internet. The village and market location coordinates are sourced from a google earth search. For transportation costs between entities sourced from processed products which are influenced by diesel price data sourced from the Internet.

Table 2. Types and Sources of Data

Data Type	Source	Type
BKS Specifications	BKS	Primary
BKS Capacity	BKS	Primary
Operational and investment costs	BKS	Primary

Data Type	Source	Type
Total Population of Jakenan Districts	Internet	Secondary
Total Market Jakenan District	Internet	Secondary
Supplier location coordinates	Google Earth	Secondary
Transportation costs between entities	Researcher Process	Secondary
Solar Price	Internet	Secondary

In table 3 is data on the specifications of the Kapal Selam Bioreactor which consists of a production capacity of 100 m3, a total investment of ± Rp. 700,000,000 for a minimum of 43 m2

Table 3. Kapal Selam Bioreactor Specifications

Capacity	100 m3
BKS investment fee	Rp. 693,975,690 (rounded up to Rp. 700,000,000)
Land requirements	Min. 43 m2
DC current booster circuit	12V/35A
No. IPR Registration	IDM000619429

Based on table 4, it is known that the total potential for waste from 23 villages and 4 markets in Jakenan District is 34.79 m3/day and according to the capacity of BKS, seven (7) BKS facilities must be established throughout Jakenan District.

Table 4. Village Data, Market and Waste Potential

No	village	X	Y	Number of Citizens	Potential (m3)
1	Plosojenar	519510.67	9253781.08	1.585	1.11
2	Jakenan	518214.92	9252538.94	3,410	2.39
3	Tanjungsari	518013.26	9251946.4	2,126	1.49
4	Jakenan Market	518223.21	9252596.41	-	0.06
5	Dukuhmulyo	516614.17	9253562.7	3,209	2.25
6	Middle Tens	516759.18	9252675.37	1,859	1.30
7	Tondokerto	514846.27	9251610.52	1,697	1.19
8	Middle Manting	516049	9250982.09	2,074	1.45
9	Karangrejo Lor	517448.98	9250095.91	1.160	0.81
10	Jatisari	517894.3	9249559.05	993	0.70
11	Sidomulyo	518066.05	9250418.32	3,464	2.42
12	Bungasrejo	514267.25	9254303.04	2.073	1.45
13	Glonggong	513738.18	9253203.36	2,266	1.59
14	Sembaturagung	515000.29	9252973.78	3,275	2.29
15	Sematuragung Market	515084.38	9252930.12	-	0.20
16	Glonggong Market	513605.57	9253216.33	-	0.07
17	Kalimulyo	513029.06	9253465.71	2,331	1.63
18	Karangrowo	509640.73	9254282.69	788	0.55
19	Sidoarum	511685.61	9253258.54	1,682	1.18
20	Tondomulyo	512614.81	9254744.41	2,186	1.53

No	village	X	Y	Number of Citizens	Potential (m3)
21	Ngastorejo	509043.97	9253084.58	971	0.68
22	Tlogorejo	511333.49	9252360.51	1.081	0.76
23	Sonorejo	510494.15	9252177.68	1,591	1.11
24	Kedungmulyo	508553.52	9251640.07	1,633	1.14
25	Sendangsoko	510902.49	9251108.29	1,873	1.31
26	Addmulyo	511918.26	9251516.21	5,393	3.78
27	Banglean Market	511689.45	9250917.53	-	0.36
Total Potential					**34.79**

Figure 3 describes data processing. That is, starting from calculating the potential for existing waste and estimating the need for a bioreactor based on the engine capacity. After that, a model based on the location of the allocation was developed. Then the calculation is carried out with the application after running optimally, the model can be determined.

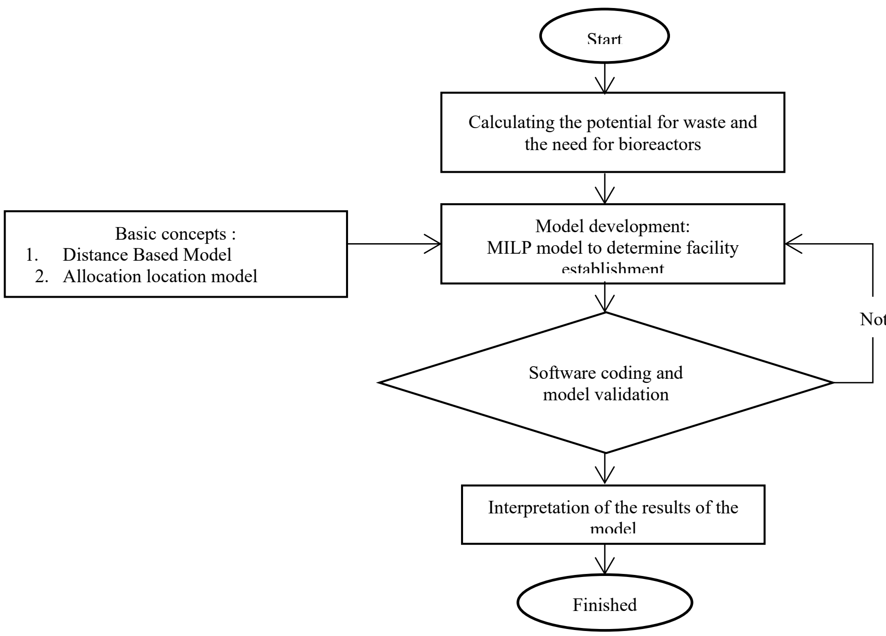

Figure 3. Data Processing

5. Results and Discussion

Judging from the potential and capacity of BKS found in the village and market, there are 7 potential locations for BKS facilities to be built. The first thing to do is make a grouping based on the distance of the closest village and the amount of potential waste in as many as 7 (seven) groups. From the existing groups, the location was chosen using the load distance method (Table 5).

Table 5. Location BKS 1

BKS Potential	X	Y
Plosojenar	519510.7	9253781
Jakenan	518214.9	9252539
Tanjungsari	518013.3	9251946
Jakenan Market	518223.2	9252596

supplier	X	Y	Waste Potential (m3)
Plosojenar	519510.7	9253781	1.1
Jakenan	518214.9	9252539	2.4
Tanjungsari	518013.3	9251946	1.5
Jakenan Market	518223.2	9252596	0.1

LD Plosojenar = 7908
LD Jakenan = 2926
LD Tanjungsari = 4160
LD Jakenan Market = 3096

Jakenan village was chosen because it has the smallest distance load value, which is 2926 (table 6)

Table 6. Location BKS 2

BKS Potential	X	Y
Dukuhmulyo	516614.2	9253563
Middle Tens	516759.2	9252675
Tondokerto	514846.3	9251611

supplier	X	Y	Waste Potential (m3)
Dukuhmulyo	516614.2	9253563	2.2
Middle Tens	516759.2	9252675	1.3
Tondokerto	514846.3	9251611	1.2

LD Dukuhmulyo = 4299
LD Middle Tens = 4620
LD Tondokerto = 8765
Dukuhmulyo village was chosen because it has the smallest distance load value, which is 4299 (Table 7)

Table 7. Location of BKS 3

BKS Potential	X	Y
Middle Manting	516049	9250982
Karangrejo Lor	517449	9250096
Jatisari	517894.3	9249559
Sidomulyo	518066.1	9250418

supplier	X	Y	Waste Potential (m3)
Middle Manting	516049	9250982	1.5
Karangrejo Lor	517449	9250096	0.8
Jatisari	517894.3	9249559	0.7
Sidomulyo	518066.1	9250418	2.4

LD Mantingan Middle = 8044
LD Karangrejo Lor = 4579
LD Jatisari = 6074
LD Sidomulyo = 4215
Sidomulyo village was chosen because it has the smallest distance load value, namely **4215** (Table 8)

Table 8. Location of BKS 4

BKS Potential	X	Y
Bungasrejo	514267.3	9254303
Glonggong	513738.2	9253203
Sembaturagung	515000.3	9252974
Sematuragung Market	515084.4	9252930
Glonggong Market	513605.6	9253216

supplier	X	Y	Waste Potential (m3)
Bungasrejo	514267.3	9254303	1.5
Glonggong	513738.2	9253203	1.6
Sembaturagung	515000.3	9252974	2.3
Sematuragung Market	515084.4	9252930	0.2
Glonggong Market	513605.6	9253216	0.1

LD Bungasrejo = 5821
LD Glonggong = 4993
Sembaturagung LD = 4355
Sembaturagun Market LD = 4820
Glonggong Market LD = 5601

Sematuragung village was chosen because it has the smallest distance load value, namely 4355 (Table 9)

Table 9. Location of BKS 5

BKS Potential	X	Y
Kalimulyo	513029.1	9253466
Karangrowo	509640.7	9254283
Sidoarum	511685.6	9253259
Tondomulyo	512614.8	9254744

supplier	X	Y	Waste Potential (m3)
Kalimulyo	513029.1	9253466	1.6
Karangrowo	509640.7	9254283	0.6
Sidoarum	511685.6	9253259	1.2
Tondomulyo	512614.8	9254744	1.5

LD Kalimulyo = 5580	LD Sidoarum = 6161
LD Karangrowo = 12985	LD Tondomulyo = 5917

Kalimulyo village was chosen because it has the smallest distance load value (Table 10), namely **5580**

Table 10. Location BKS 6

BKS Potential	X	Y
Ngastorejo	509044	9253085
Tlogorejo	511333.5	9252361
Sonorejo	510494.2	9252178
Kedungmulyo	508553.5	9251640

supplier	X	Y	Waste Potential (m3)
Ngastorejo	509044	9253085	0.7
Tlogorejo	511333.5	9252361	0.8
Sonorejo	510494.2	9252178	1.1
Kedungmulyo	508553.5	9251640	1.1

LD Ngastorejo = 5466
LD Tlogorejo = 5872
LD Sonorejo = 4114
LD Kedungmulyo = 5453
Sonorejo village was chosen because it has the smallest distance load value, namely **4114**

Table 11. Location BKS 7

BKS Potential	X	Y
Sendangsoko	510902.5	9251108
Addmulyo	511918.3	9251516
Banglean Market	511689.5	9250918

supplier	X	Y	Waste Potential (m3)
Sendangsoko	510902.5	9251108	2.2
Addmulyo	511918.3	9251516	1.3
Banglean Market	511689.5	9250918	1.2

LD Sendangsoko = 2386
LD Addmulyo = 3220
Banglean Market LD = 2653
Sendangsoko village was chosen because it has the smallest distance load value (Table 11), namely **2386**

Figure 4. BKS Location Map in Jakenan District

Figure 4 is a map of the location of BKS in Jakenan District which covers the surrounding villages. In detail, the locations of BKS and villages covered are as shown in table 12.

Table 12. BKS Location Data and Covered Villages

No	Location	Covered village	Rated Load Distance
1	Jakenan	Plosojenar Jakenan tanjungsari jakenan market	2926
2	Dukuhmulyo	dukuhmulyo middle tens tondokerto	4299
3	Sidomulyo	middle hand Karangrejo lor Jatisari Sidomulyo	4215
4	Sembaturagung	bungasrejo barking sembaturagung sembaturagung market glonggong market	4355
5	Kalimulyo	kalimulyo Karangrowo sidoarum tondomulyo	5580
6	Sonorejo	ngastorejo tlogorejo sonorejo kedungmulyo	4114
7	Sendangsoko	sendangsoko addedmulyo banglean market	2653

For the location of the distribution center for solid and liquid organic fertilizers, the villages of Tanjungsari and Kalimulyo were chosen because they are located in the middle of other villages. So it can be more efficient transportation.

By analyzing the load distance model (Table 12), seven locations of BKS facilities were found that could cover the potential for waste in Jakenan District. The determination of seven locations has the smallest load distance value so that SCND waste handling with BKS facilities will be more efficient.

The determination of the seven locations was based on the value of the waste load from each village and market as well as the distance between villages/markets. So to achieve a more optimal SCND value, it must be calculated using a mathematical model function and can use the Ilog CPlex program.

6. Conclusion

The results of the analysis using the load distance method show that to process waste from households and markets in Jakenan District, seven Kapal Selam Bioreactor facilities must be built. The seven locations are Jakenan, Dukuhmulyo, Sidomulyo, Sembaturagung, Kalimulyo, Sonorejo, and Sendangsoko. This location is the location chosen based on the load value of the smallest distance from the surrounding villages that are covered. So that the waste processing process in Jakenan District is more efficient. Further research can be studied about the SCND optimization step, namely by applying the mathematical model function using the Ilog CPlex program.

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