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Optimizing Parcel Locker Locations in Minimarkets in Residential Areas Using the Incapacitated P-Median Model

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ABSTRACT;

The rapid growth of e-commerce in Indonesia has increased the complexity and cost of last-mile delivery. Parcel lockers offer a potential solution to reduce distribution inefficiencies, such as increased vehicle travel distance, congestion, and emissions associated with home delivery, while also improving service quality through flexible parcel collection. This study develops an optimization model for parcel locker placement in residential areas by utilizing minimarkets as potential facility locations, using an incapacitated p-median approach. The model aims to minimize the total system cost, consisting of distribution costs and user access costs, with service quality represented by access distance. The analysis is conducted using 210 demand points across seven subdistricts in Tebet District, South Jakarta, with 44 minimarkets as candidate locations. Two scenarios are compared: without and with administrative boundary constraints. The results indicate that the unrestricted scenario provides better service quality, reflected in shorter access distances, along with lower system costs. In contrast, the restricted scenario leads to longer access distances and higher system costs. Quantitatively, the implementation of parcel lockers reduces total distribution travel distance by up to 70% compared to home delivery. These findings demonstrate that optimizing parcel locker locations can improve logistics system efficiency and support sustainable urban transport planning.

Keywords: parcel locker; location optimization; p-median; facility location problem; incapacitated; city logistics.

INTRODUCTION

The development of e-commerce in Indonesia in recent years has prompted significant changes in the goods distribution system, especially at the last-mile delivery stage, which is the most crucial point in the logistics supply chain. The increasing transaction value indicates the high intensity of the movement of goods towards residential areas, which directly increases the pressure on urban distribution systems (Pahwa & Jaller, 2023).

The dominance of the home delivery model in package distribution poses various operational problems, such as increasing mileage of delivery vehicles, uncertainty in the time of receiving goods, and the high potential for delivery failure. This condition not only has an impact on the operational efficiency of logistics companies, but also causes negative externalities such as traffic congestion and increased emissions (Yang et al., 2020).

Alternatively, the parcel locker concept was introduced as an out-of-home-delivery-based solution that allows consumers to pick up packages independently at specific locations. This scheme offers an efficiency approach to solving last-mile challenges, especially obstacles in the delivery process (Moslem & Pilla, 2024). However, the success of parcel locker implementation is greatly influenced by the accuracy in the selection of facility locations. Placements that do not match demand distribution and user mobility patterns have the potential to reduce facility utilization rates (Sawik, Faulin, Serrano-Hernandez, & Ballano, 2022).

In this context, minimarkets have characteristics that support them as potential parcel locker locations, including a high level of accessibility, an even distribution in residential areas, and a high frequency of visits by the public. It is recorded in the databox data in 2025, the minimarket business in Indonesia in general tends to have a positive trend, with a growth rate of 1.73% in a span of 3 months, namely from December 2024 to March 2025.

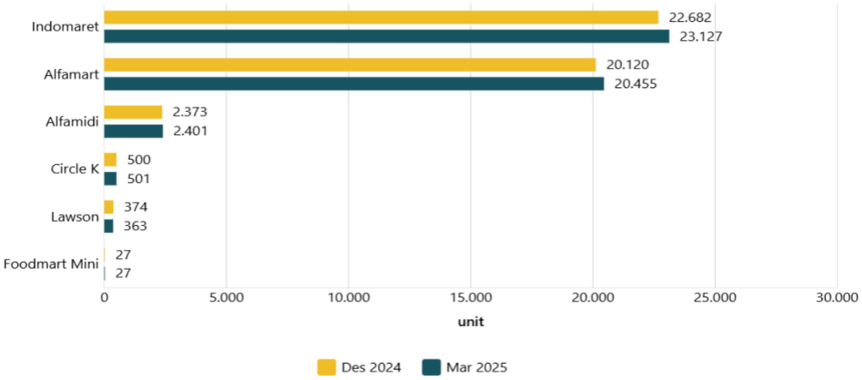

Figure 1. Number of Outlets of a Number of Minimarket Brands in Indonesia (Dec 2024 – March 2025)

Source: secondary data, 2025

The rapid growth of e-commerce in Indonesia increases the complexity of last-mile delivery, driving the need for efficient solutions such as parcel lockers. Minimarkets have ideal characteristics as potential locations due to their high accessibility and proximity to people's daily activities (Refaningati, Tangkudung, & Kusuma, 2020). Determining the right location is the key to the successful implementation of parcel lockers, so an analytical approach is needed that integrates spatial, demand, and operational efficiency aspects. This study fills the research gap from previous studies that are still limited to preference and macro-scale approaches, by proposing a p-median problem-based optimization model that minimizes the total distance between hubs, demand points, and facilities (Ranjbari, Diehl, Dalla Chiara, & Goodchild, 2023).

Therefore, an analytical approach is needed that is able to integrate spatial aspects, demand, and operational efficiency in determining the optimal location of parcel lockers.

This study aims to develop a model of optimization of parcel locker locations in residential areas by utilizing minimarkets as a candidate facility, using the p-median problem approach to minimize the total distance and cost of the system. This study departs from the assumption that the spatial distribution of minimarkets is related to demand patterns, so that it has the potential to become a strategic location in support of a more efficient last-mile distribution system. Therefore, this study explores how optimal location configuration can be generated by considering the interests of logistics operators and service users simultaneously.

In addition, this study aims to evaluate the impact of parcel locker implementation on the last-mile delivery system, especially in terms of changing movement patterns and reducing the total distribution mileage (Vehicle Kilometer Travelled/VKT) compared to the home delivery system. The model developed is also directed to produce a baseline solution through an incapacitated approach, which can be used as a reference in the development of advanced models with capacity limiters. The results of this study are expected to provide an analytical basis in efficient parcel locker location planning and support a sustainable urban transportation system. The benefits of this research include: (1) providing strategic recommendations for logistics operators in determining the optimal location of parcel lockers, (2) supporting policymakers in sustainable urban spatial planning and transportation through VKT and emission reductions, and (3) providing an adaptable analytical framework for the development of advanced models taking into account user capacity and behavior.

METHOD

This study was conducted in Tebet District, South Jakarta, involving 210 respondents spread across seven urban villages. The number of samples was determined using the Cochran formula at a confidence level of 95% (Z = 1.96) and the assumption of a population proportion of 0.5, which indicates a minimum need of around 196–204 respondents, so that the number of respondents used is statistically sufficient.

The data used includes the location of minimarkets as facility candidates, demand points, the number of daily packages, costs related to parcel lockers, and distribution hub locations, which are obtained from various sources such as official agencies, geospatial platforms, and field surveys. All data is then verified, including coordinate checks, and processed in the form of spatial layers to support analysis.

The core stage of the research lies in the development of optimization models. Models are built with conditions without capacity limitations in mind. Models with no capacity are used to obtain flexible initial configurations, while models with capacity are used to represent more realistic operational conditions.

Model solutions are obtained through optimization software that is run using Visual Studio Code (VS Code). Verification is carried out to ensure consistency between the model formulation and the optimization results, including checking the variable structure, constraints, and feasibility of the solution. If the model results do not meet the expected criteria, constraint adjustments and re-simulations are carried out until a valid solution is obtained. Furthermore, the model results are analyzed spatially and operationally.

The results analysis was carried out by identifying the location of the selected minimarket as the optimal location for parcel lockers, as well as evaluating the location determination process that had been carried out based on several scenarios. In addition, an impact analysis on the last-mile delivery system was carried out by comparing two scenarios, namely home delivery and locker delivery, to measure changes in mileage and distribution efficiency.

Furthermore, the results of the analysis of location effectiveness, service coverage, and distribution system efficiency were used to develop recommendations for parcel locker network development strategies and policy implications for stakeholders.

Structure Model

The model structure consists of 3 (three) interrelated minimization segmentations. The first segment, the optimization goal is to minimize the total weighted travel distance between the regional point of the hub and the facility, and the second segment discusses the minimization of distance between the demand point and the facility. In the third segment, the optimization is focused on minimizing the cost of providing parcel lockers at the candidate location. For ease of study, the minimum distance is converted into unit costs, namely the cost of distribution from the hub to the minimarket and the cost of customer access to parcel lockers.

This study was conducted by developing a model to minimize distance and cost in a last-mile delivery distribution system, taking into account a network design involving three main components, namely regional hubs as distribution origin points, customers as demand points, and minimarkets as potential locations for parcel locker placement.

Under existing conditions, distribution is carried out directly from the regional hub to the customer through the home delivery system. Meanwhile, in the scenario with parcel locker, the distribution flow changes from the regional hub to the minimarket (as the location of the parcel locker), then accessed by the customer independently. The following are the indices, sets, and variables used in the optimization model of this study.

Table 1. Index and Set

Index and set	Explanation
$\boldsymbol{h \in H}$	Hub regional coordinate index and set points
$\boldsymbol{i \in I}$	Index and set of customer coordinate points
$\boldsymbol{j \in J}$	Index and set of coordinate points of minimarket facilities

Source: Modified from Yang et al. (2020); Talitha (2021); Kompas.id (2022)

Table 2. Optimization Variables

Variable	Explanation
$\boldsymbol{d_{hj}^{HM}}$	Distance from hub *h* to minimarket *j* (meter)
$\boldsymbol{d_{ji}^{MC}}$	Distance from minimarket *j* to customer *i*
$\boldsymbol{c^{HM}}$	Transportation cost per unit distance from hub to convenience store
$\boldsymbol{c^{MC}}$	Travel cost per unit distance from convenience store to customer
$\boldsymbol{F_j}$	Cost of providing parcel locker at minimarket *j*

Source: Modified from Yang et al. (2020); Talitha (2021); Kompas.id (2022)

Table 3. Decision Variables

Decision Variables	Explanation
$\boldsymbol{y_j}$	1, if the locker is opened in the minimarket *j*
$\boldsymbol{x_{ji}}$	1, if the consumer *i* is allocated to the minimarket *j*
$\boldsymbol{z_{hj}}$	1, If minimarket *j* is served hub *h*

Source: p-median formulation (Hakimi, 1964); Peppel & Spinler (2021)

The objective functions used are as follows.

$$Minimize\ Z_1 = \sum_{h\in H}\sum_{j\in J} c^{HM} d_{hj}^{HM}\, z_{hj} + \sum_{j\in J}\sum_{i\in I} c^{MC} d_{ji}^{MC}\, x_{ji} + \sum_{j\in J} F_j\, y_j \qquad (1)$$

Subject to:

1. Each consumer *i* must be served by one *minimarket j*

$$\sum_{j\in J} x_{ji} = 1 \qquad , \forall i \in I \qquad (3)$$

2. Consumers may only be allocated to *open minimarkets*

$$x_{ji} \le y_j \qquad , \forall j \in J\ \forall i \in I \qquad (4)$$

3. Each *convenience store* that is opened must be served by one *hub*

$$\sum_{h\in H} z_{hj} = y_j \qquad , \forall j \in J \qquad (5)$$

4. The number of facilities opened is P.

$$\sum_{j\in J} y_j = P \qquad (6)$$

5. Consumers *i* may not be allocated to minimarket *j* if the two are in different villages

$$x_{ji} = 0 \qquad , \forall i,j\colon kel(j) \ne kel(i) \qquad (7)$$

The first segment is aimed at minimizing distribution costs from the hub to minimarkets, while the second segment focuses on minimizing consumer access costs to the location of parcel locker facilities. For the third segment, minimizing the cost of providing lockers by using the fj parameter.

Cost per Distance Conversion

a. Hub to Minimarket Fees

The amount of costs used for conversion uses logistics vehicle operational costs. Vehicle operational costs (BOK) are divided into two parts, namely vehicle fixed costs and vehicle non-fixed costs. The cost index used is IDR 2,265/km (Talitha, 2021).

b. Cost of Consumer Travel to Minimarket

The cost of consumer travel in this study was Rp1,070/km using the assumption of the sum of time costs, investment costs and gasoline:

1) Time fee based on the provincial minimum wage of the Special Region of Jakarta (IDR 5,729,876/month) and the use of a private motorized vehicle for each package pick-up assuming a trip of 4 minutes/km (speed 15km/h)
2) One month is equivalent to 43,800 minutes
3) The operational cost of private motorcycles (investment and gasoline) is IDR 546/km (Kompas, 2022).

Parcel Locker Supply Fee

The amount of the cost of providing parcel lockers for variable F in the objective function, is a combination of the cost of providing parcel lockers and land rental costs:

$$f_j = f^{rent} + f^{locker} \qquad (8)$$

Rental costs include land rental costs for the placement of lockers in convenience stores, and locker costs include maintenance, investment, and locker installation costs. The combination of these costs is expressed in daily value through an amortization approach and fixed cost adjustment as a daily equivalent cost. In addition, this calculation does not consider parcel locker capacity assuming that the entire provision of parcel lockers per minimarket only requires 1 set of lockers consisting of 4 locker columns.

Simulation of Movement Impact

This study uses 2 (two) scenarios to identify the impact of the optimization of parcel locker placement locations on existing conditions in the form of home delivery. The notation used is as follows.

Table 4. Movement Impact Simulation Variables

Variable	Explanation
$\boldsymbol{VKT_{home}}$	Total vehicle mileage in the *home delivery scenario*
$\boldsymbol{VKT_{locker}}$	Total vehicle mileage in parcel *locker scenario*
$\boldsymbol{d_{hub \to demand}}$	Distance between *the hub region* and the consumer point (*demand point*)
$\boldsymbol{d_{hub \to locker}}$	Distance between *the regional hub* and the *parcel locker location*
$\boldsymbol{Efisiensi_{VKT}}$	Percentage reduction in total vehicle mileage due to the implementation *of parcel locker* compared to *home delivery system*
$\boldsymbol{C}$	Total distribution costs calculated based on vehicle mileage
$\boldsymbol{C_{km}}$	Operating costs per kilometre
$\boldsymbol{C_{home}}$	Total distribution costs in the *home delivery scenario*.
$\boldsymbol{C_{locker}}$	Total distribution costs in the *parcel locker scenario*.
$\boldsymbol{Efisiensi_{biaya}}$	Cost of providing parcel locker at minimarket *j*

Source: VKT concept from Kahalimoghadam et al. (2024); Pinchasik et al. (2025)

1. *Scenario 1 – Home Delivery*

   Couriers deliver to all consumer points

   $$VKT_{home} = \sum d_{hub \to demand} \tag{9}$$

2. *Scenario 2 – Parcel Locker*

   The courier only delivers to *the optimal* locker

   $$VKT_{locker} = \sum d_{hub \to locker} \tag{10}$$

3. *Movement efficiency*

   $$Efisiensi_{VKT} = \frac{VKT_{home} - VKT_{locker}}{VKT_{home}} \times 100\% \tag{11}$$

   These results show the impact of the implementation of parcel lockers on courier routes.

4. *Cost Efficiency Analysis*

   Based on the results of VKT in the previous stage, the amount of costs can be obtained, namely:

   $$C = VKT \times C_{km} \tag{4}$$

   With cost savings:

$$Efisiensi_{biaya} = \frac{C_{home} - C_{locker}}{C_{home}} \times 100\% \tag{5}$$

RESULTS AND DISCUSSION

Identify Candidate Locations and Consumer Locations

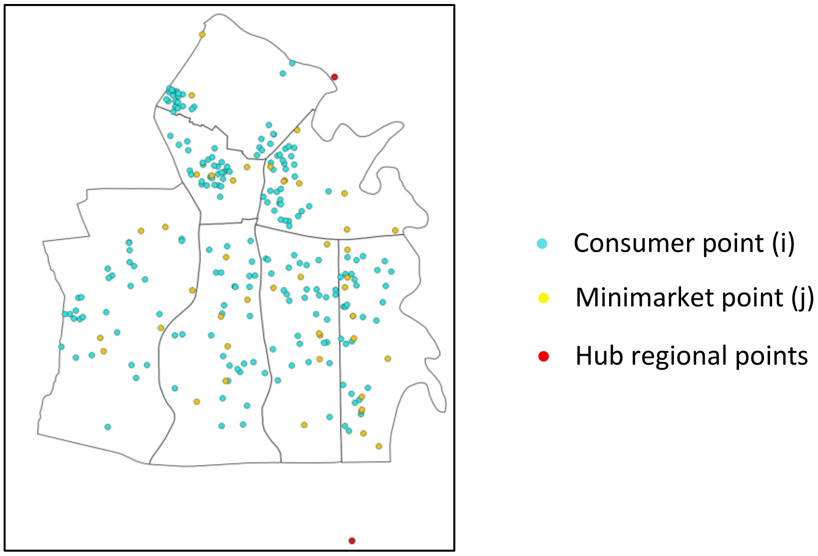

Figure 2. Consumer points, convenience stores, and regional hubs
Source: Primary Data, 2026

The coordinate data that has been obtained in the research data collection process is mapped in the QGIS application so that the following results are obtained (Pratama, 2019).

The Regional Hub that serves the study area, is divided into 2 (two) locations with different service areas. The division of service areas is as follows.

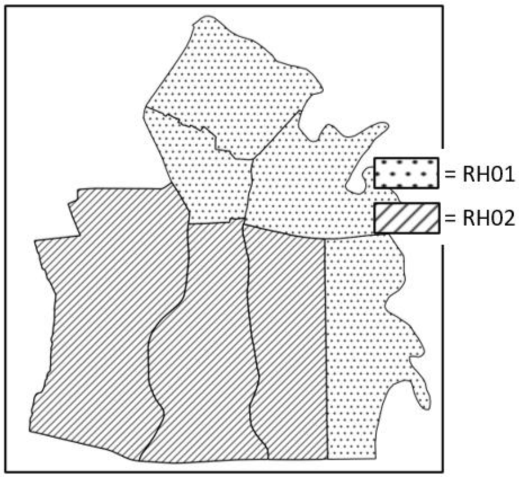

Figure 3. Regional Hub Service Area Distribution
Source: Primary Data, 2026

Regional Hub 1 (RH01) serves 4 villages, namely Bukit Duri, Kebon Baru, South Manggarai, and Manggarai Villages. Meanwhile, *Regional Hub* 2 (RH02) serves 3 villages, namely Menteng Dalam, West Tebet, and East Tebet Villages.

Identify the Cost of Providing *Parcel Lockers* at the Candidate's Location

The cost of providing *lockers* consists of a combination of *locker costs* and land rental at the candidate's location using units of money. The *cost of lockers* does not consider capacity assuming that the entire provision of *parcel lockers* per minimarket only requires 1 set of lockers consisting of 4 locker columns with. Meanwhile, the land rental fee is based on the results *of* a field survey that is in accordance with the dimensions of the *needs of the locker area* and the availability of land at the candidate's location (Pinchasik, Hovi, & Dong, 2025).

Model Optimization

The optimization process is balanced by the determination of thresholds of >300 meters (m) and >500 meters (m). This threshold is given for the identification of service quality in the form of evaluation of the number of consumers who have a distance of >300m and >500m to the location of the facility with the determination of the number of facilities P.

1. Scenario 1 – Consumer allocation is not bound by the sub-district area

This scenario is intended for location optimization with the condition that consumers can be allocated to minimarkets outside their villages so that they are more spatially flexible.

Table 5. Scenario Optimization Results 1

P	**Cost Component**						**∑Cost (Z)**	**Cust. dij >300m**		**Cust. dij >500m**	
	c^{HM}	%	c^{MC}	%	Fj	%		∑	%	∑	%
1	9,967	4	241,110	88	23,887	9	274,964	202	96	189	90
2	8,563	4	165,061	75	47,774	22	221,398	175	83	159	76
3	13,216	6	130,060	61	71,661	33	214,937	164	78	134	64
4	15,518	7	109,918	50	95,548	43	220,984	144	69	97	46
5	21,005	9	95,816	41	119,435	51	236,256	132	63	73	35
6	23,623	9	87,016	34	143,322	56	253,961	123	59	63	30
7	27,762	10	82,445	30	167,209	60	277,416	121	58	53	25
8	30,516	10	80,034	27	191,096	63	301,646	117	58	41	25
9	35,417	11	75,971	23	214,983	66	326,371	114	56	40	20
10	37,906	11	75,300	21	238,870	68	352,076	114	56	39	19
11	40,133	11	74,904	20	262,757	70	377,794	110	52	39	19
12	43,457	11	74,040	18	286,644	71	404,141	109	52	39	19

Source: Data Processing, 2026

At the P=1 condition, it was identified that the *objective value* was 274.964. The cost component consisted of c^{HM} 9.967 (4%), 241.110 (88%), and the facility cost $c^{MC} of\ Fj$ 23.887 (9%) of the total objective value. Furthermore, the distribution of distance between consumers and the location of minimarkets was evaluated to represent the quality of service where as many as 202 consumers (96% of the total 210 consumers) had a distance of more than 300 m, and 189 consumers (90%) had a distance of more than 500 m (Peppel & Spinler, 2021).

Furthermore, *a maximum distance restriction for* consumers to the facility location of 300m and 500m was applied, respectively. The optimization results showed *infeasible conditions* for the two *constraints*, in the number of facilities 1 to 44. This happened because there were consumers who were not within a radius of 300m and 500m from the facility location with 31 consumers and 3 consumers respectively.

2. Scenario 2 – Consumer allocation tied to the location of the village

This scenario seeks to obtain location optimization results by grouping consumers based on their urban area, so that it is more realistic administratively with a focus on localization of the service system.

Table 6. Scenario 2 Optimization Results

P	**Cost Component**						**∑Cost (Z)**	**Cust. dij >300m**		**Cust. dij >500m**	
	c^{HM}	%	c^{MC}	%	Fj	%		∑	%	∑	%
7	30,139	10	108,361	35	167,209	55	305,709	134	64	89	42
8	32,628	10	103,620	32	191,096	58	327,344	133	63	87	41
9	39,257	11	96,093	27	214,983	61	350,333	125	60	79	38
10	43,396	12	91,212	24	238,870	64	373,478	123	59	69	33
11	45,623	11	90,816	23	262,757	66	399,196	119	57	69	33
12	53,063	12	85,538	20	286,644	67	425,245	115	55	57	27
13	56,105	12	85,538	19	310,531	69	452,174	115	55	57	27
14	58,955	12	72,996	15	349,015	73	480,966	95	45	37	18
15	64,633	13	72,362	14	372,902	73	509,897	94	45	36	17
16	71,888	13	71,977	13	396,789	73	540,654	92	44	36	17
17	76,060	13	66,182	11	435,273	75	577,515	84	40	22	10
18	77,348	13	65,760	11	473,757	77	616,865	82	39	22	10
19	80,469	12	63,696	10	512,241	78	656,406	82	39	22	10
20	84,520	12	60,847	9	550,725	79	696,092	74	35	19	9
21	86,705	12	60,178	8	589,209	80	736,092	74	35	19	9
22	91,541	12	57,098	7	627,693	81	776,332	64	30	16	8
23	93,860	11	56,963	7	666,177	82	817,000	64	30	16	8
24	96,136	11	56,941	7	704,661	82	857,738	64	30	16	8
25	98,628	11	56,940	6	743,145	83	898,713	64	30	16	8
26	101,503	11	56,767	6	781,629	83	939,899	64	30	16	8
27	104,944	11	56,137	6	820,113	84	981,194	63	30	16	8

Source: Data Processing, 2026

At the P=7 condition, the objective function value was recorded at 305.709. The cost component consisted of 30.139 (10%), 108.361 (35%), and facility costs of 167.209 (55%) of the total objective value. Furthermore, the quality of service depicted in the$c^{HM}c^{MC}F_j$e-valuation of consumers' distance to the location of the minimarket showed that as many as 134 consumers (64% of the total 210 consumers) were at a distance of more than 300 m, while 89 consumers (42%) were at a distance of more than 500 m (Meliaresti, 2020).

Optimization begins with P=7, where the 7 facilities must be opened at the initial optimization to meet the criteria of consumer needs which requires demand allocation to be placed to 1 minimarket in the village. Furthermore, *the* maximum distance constraint of consumers to the location of the facility of 300m and 500m respectively is also applied to this scenario. The optimization results show *that the conditions are infeasible* for the two *constraints*, at the number of facilities 7 to 27. This occurs because there are consumers who are not in the radius of 300m and 500m with a total of 44 consumers and 11 consumers, respectively (Ma, Teo, & Wong, 2024).

The optimization results that have been carried out in two scenarios, namely (1) the scenario of consumer allocation not tied to the village and (2) the allocation of consumers tied to the village, show a significant difference. In the scenario without the village filter, the system is able to produce a better quality of service at the same number of facilities, as shown by the number of consumers with a lower access distance of more than 500 meters (Church & Murray, 2019). This happens because the system has the flexibility to allocate consumers to the nearest facility without being limited by administrative areas, so that the distribution is more efficient even though the cost from the hub to the facility location is higher than scenario 2.

Table 7. Comparison of Scenario Results with the same number of facilities opened

P=7	**Scenario 1** **(a)**	**Scenario 2** **(b)**	**Differences** **(a)–(b)**
c^{HM}	27,762	*30,139*	-2,377
c^{MC}	82,445	*108,361*	-25,916
Fj	167,209	167,209	0
∑Cost (Z)	277,416	305,709	-28,293
Cust. dij >300m	121	134	13
Cust. dij >500m	53	89	36

Source: Data Processing, 2026

Based on the comparison table above, it can be seen that the operator's distribution cost in scenario 1 is lower than in scenario 2, with a value of 27,762 compared to 30,139 (difference of 2,377) and of 82,445 compared to 108,361 (difference of 25,916). In contrast, the cost of facilities remains the same in both scenarios, which is 167,209. Overall, the value of objective functions in scenario 1 is lower, namely 277,416 compared to 305,709 in scenario 2, with a difference of 28,293.$\mathrm{c}^{\mathrm{HM}}\mathrm{c}^{\mathrm{MC}}\mathrm{F}_{\mathrm{j}}$

In terms of consumer access, the number of consumers with a distance of more than 300 m increased from 121 in scenario 1 to 134 in scenario 2 (difference of 13 consumers). The same thing can also be seen at the 500 m threshold, where the number of consumers increased from 53 to 89 (difference of 36 consumers).

These findings show that consumers' spatial attachment to their villages has an impact on increasing the distance of consumer access to facilities, which is reflected in the increase in the number of consumers with longer distances in scenario 2. On the other hand, this condition provides benefits for operators through reduced distribution costs. This is in line with better service performance in scenario 1, which is shown by the lower objective function value as a result of optimization.

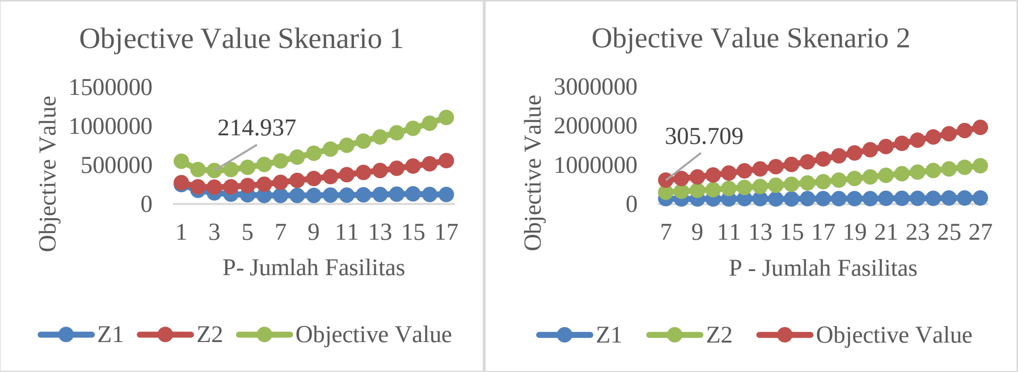

Figure 4. Optimization Results Graph 2 Scenarios
Source: Data Processing, 2026

Furthermore, the optimization results are depicted in the graph for both scenarios. In scenario 1, the open facilities of 1 show optimal optimization results, but the resulting objective value is greater than the optimization of the number of facilities P=3. Thus, it can be identified that the global optimum condition, with the most efficient balance point between service accessibility and facility investment costs for scenario 1 occurs when the number of facilities opened is 3, with an objective value of Rp214,937, -. This condition occurs because the decrease in distance costs at P=1 and P=2 is still greater than the cost of opening a new locker facility at P=3.

In contrast to the optimization results in scenario 2, the number of facilities P = 7 shows a minimum total cost of Rp.305,709, -. As the number of facilities increases, the objective value always increases so that the global optimum condition is at the number of facilities P = 7. Meanwhile, in terms of service, the quality of service is worse than scenario 1 where consumers who have to travel a distance of >300m are 13 consumers and 36 consumers for a distance of >500m (Khutsishvili & Kiknadze, n.d.).

Thus, the restriction of administrative areas in the placement of logistics facilities has the potential to reduce the efficiency of the distribution system, because it hinders the optimization of service distances globally. Therefore, it can be concluded that spatial flexibility is a key factor in achieving the efficiency of the last-mile delivery system.

Based on the results of the optimization, a simulation of the impact of movements due to the opening of facilities was carried out. Simulations were carried out on the two scenarios that had the lowest objective values, namely P=3 for the non-village-bound consumer allocation scenario and P=7 for the village-bound allocation scenario.

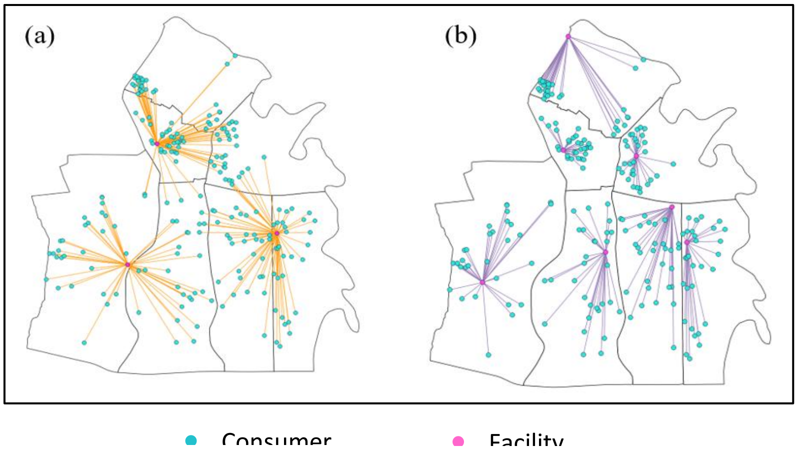

Figure 5. Consumers based on facilities opened, (a) Scenario 1 P=3; and (b) Scenario 2 P=7
Source: Data Processing, 2026

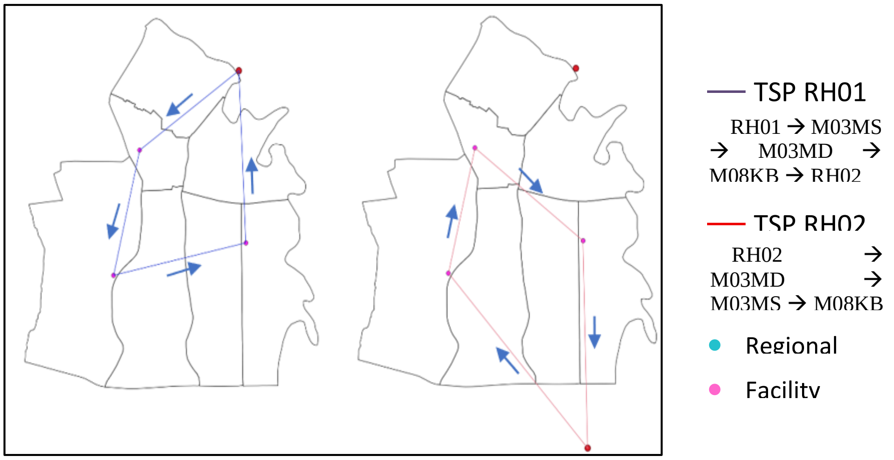

Figure 6. Route Assignment for (a) Scenario 1 P=3
Source: Data Processing, 2026

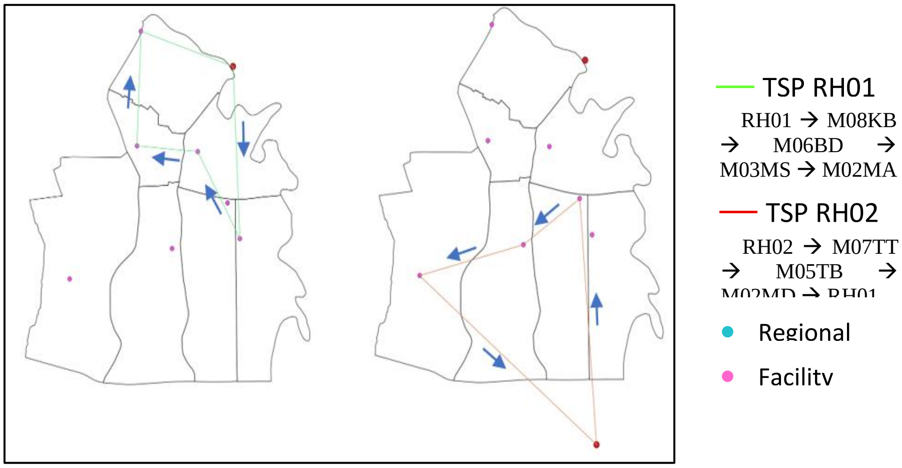

Figure 7. Route Assignment for (b) Scenario 2 P=7
Source: Data Processing, 2026

The results of the routing analysis using the TSP method were carried out in conditions before and after the implementation of parcel locker. The analysis was then used as VKT_{home} dan VKT_{locker}.

Table 8. VKT $Comparison_{home}$ dan VKT_{locker}

No	**Village**	**VKTHome**	**VKTLocker**	
			Scenario 1 (P=3)	Scenario 2 (P=7)
1	Menteng Dalam	11.21	6.35	7.63
2	West Tebet	8.28		
3	East Tebet	9.94		
4	Kebon Baru	7.38	7.74	6.13
5	Bukit Duri	3.86		
6	Manggarai Selatan	4.61		
7	Manggarai	4.50		
Total		49.79	14.09	13.76

Source: Data Processing, 2026

Table 9. Movement Efficiency of Using Parcel Lockers

Movement	**Home Delivery**	**S-1(a)**	**S-2(b)**
VKT	49.79	14.09	13.76
Efficiency VKT		71.70%	72.36%
Cost	112,774	31,914	31,167
Cost Efficiency		71.70%	72.36%

Source: Data Processing, 2026

Comparative analysis of VKT shows that the implementation *of parcel lockers* has a significant impact on movement efficiency in the *last-mile* distribution system. The total VKT in *the home delivery scenario* (conditions before the implementation *of parcel locker*) is 49.79km, while in the *parcel locker* scenario it is only in the range of 13 to 14 km. In addition, there is a cost efficiency impact, which is a decrease from IDR 112,774 to IDR 31,914 and IDR 31,167. Both efficiencies show that parcel lockers are able to reduce VKT and costs by around 70% (Fengrui & Guitang, 2019).

This decrease in VKT occurred due to the consolidation of delivery, where package delivery that was previously carried out directly to each consumer was diverted to a centralized point in the form of a parcel locker. This significantly reduced the number of distribution vehicle trips and the total mileage required (Dissauer, Einspieler, Krauser, Schartner, & Woschank, 2024).

The implementation *of parcel lockers* not only improves spatial efficiency in distribution systems, but also provides substantial economic benefits for logistics operators. Therefore, the use of *parcel lockers* can be an effective solution in supporting *a more efficient and sustainable* last-mile distribution system in urban areas.

CONCLUSION

This study demonstrates that the distribution of minimarkets in residential areas aligns with demand patterns, making them effective candidates for parcel locker locations, while the p-median optimization approach successfully integrates spatial aspects, costs, and service levels within a single analytical framework. A comparison of two scenarios reveals a trade-off between flexibility and service equity, where the scenario without administrative boundary restrictions produces shorter consumer access distances and smaller objective function values, whereas village-based restrictions increase both distance and system costs without yielding significant efficiency gains. From an operational standpoint, parcel locker implementation has proven to significantly reduce total distribution mileage (VKT) compared to home delivery systems through consolidation of deliveries to centralized facility points. Overall, the integration of spatial analysis and mathematical optimization yields a more cost- and service-efficient placement system, reinforcing that location planning should not be constrained by administrative boundaries but rather based on open service coverage to optimize distance and distribution costs. Collaboration between logistics operators and the retail sector in utilizing minimarkets as location candidates is strongly recommended, the number of facilities should be determined by balancing investment costs against operational benefits, and future research is encouraged to incorporate locker capacity, user pickup behaviour, and potential carry-over demand to more accurately represent real-world conditions.

REFERENCES

Church, R. L., & Murray, A. (2019). Location covering models: history, applications and advancements (Advances in Spatial Science). *International Journal of Geographical Information Science*, *33*(11). https://doi.org/10.1080/13658816.2019.1634271

Dissauer, M., Einspieler, B., Krauser, N., Schartner, S., & Woschank, M. (2024). *Parcel Lockers as a Logistic Concept: A Systematic Review of Implementation Strategies and Outcomes*. https://doi.org/10.46254/af05.20240238

Fengrui, C., & Guitang, L. (2019). *Global Value Chains and Production Networks*.

Khutsishvili, S., & Kiknadze, M. (n.d.). Methodology for Determining the Optimal Location of Transport Logistics Centres. *BRAIN. Broad Research in Artificial Intelligence and Neuroscience*, 68–73.

Ma, B., Teo, C. C., & Wong, Y. D. (2024). Location analysis of parcel locker Network: Effects of spatial characteristics on operational performance. *Transportation Research Part E: Logistics and Transportation Review*, *192*, 103776. https://doi.org/10.1016/j.tre.2024.103776

Meliaresti, M. I. A. (2020). *Analisis Efektivitas Sistem Pengiriman Parcel Locker pada Last Mile Delivery Berdasarkan Aspek Eksternalitas*.

Moslem, S., & Pilla, F. (2024). Planning location of parcel lockers using group Analytic Hierarchy Process in Spherical Fuzzy environment. *Transportation Research Interdisciplinary Perspectives*, *24*, 101024. https://doi.org/10.1016/J.TRIP.2024.101024

Pahwa, A., & Jaller, M. (2023). Assessing last-mile distribution resilience under demand disruptions. *Transportation Research Part E: Logistics and Transportation Review*, *172*. https://doi.org/10.1016/j.tre.2023.103066

Peppel, M., & Spinler, S. (2021). The impact of optimal parcel locker locations on costs and the environment. *International Journal of Physical Distribution & Logistics Management*, *52*(4), 324–350. https://doi.org/10.1108/IJPDLM-07-2021-0287

Pinchasik, D. R., Hovi, I. B., & Dong, B. (2025). Replacing home deliveries by deliveries to parcel lockers: cost, traffic, emissions, and societal cost effects of locker network expansions in greater Oslo. *International Journal of Logistics Research and Applications*, *28*(4), 401–426. https://doi.org/10.1080/13675567.2023.2286006

Pratama, H. S. (2019). *Analisis Efektivitas Sistem Parcel Locker di Jabodetabek (Sudut Pandang: Pelanggan)*.

Ranjbari, A., Diehl, C., Dalla Chiara, G., & Goodchild, A. (2023). Do parcel lockers reduce delivery times? Evidence from the field. *Transportation Research Part E: Logistics and Transportation Review*, *172*, 103070. https://doi.org/10.1016/j.tre.2023.103070

Refaningati, T., Tangkudung, E. S. W., & Kusuma, A. (2020). *Analysis of Characteristics and Efficiency of Smart Locker System (Case Study: Jabodetabek)*. *7*(1), 111–117.

Sawik, B., Faulin, J., Serrano-Hernandez, A., & Ballano, A. (2022). A Simulation-Optimization Model for Automated Parcel Lockers Network Design in Urban Scenarios in Pamplona (Spain), Zakopane, and Krakow (Poland). *Proceedings - Winter Simulation Conference*, 1648–1659. https://doi.org/10.1109/WSC57314.2022.10015458

Talitha. (2021). *Optimalisasi Sistem Distribusi Last Mile Delivery dengan Mempertimbangkan Biaya Eksternal*.

Yang, G., Huang, Y., Fu, Y., Huang, B., Sheng, S., Mao, L., Huang, S., Xu, Y., Le, J., Ouyang, Y., & Yin, Q. (2020). Parcel Locker Location Based on a Bilevel Programming Model. *Mathematical Problems in Engineering*, *2020*. https://doi.org/10.1155/2020/5263689