Determination of a Depot Location in Northern Sumatra Using the P-Median Approach

Gisti Ayu Pratiwi[1], Femi Yulianti[2]
[1,2]Telkom University, Department of Industrial and System Engineering, Bandung
Email: [1]gistiayupratiwi@telkomuniversity.ac.id, [2]femiyulianti@telkomuniversity.ac.id

Received: 2026-08-21 Received in revised from 2026-08-28 Accepted: 2026-09-30

Abstract

Timely spare parts delivery is essential in automotive after-sales services, as delays in obtaining the required parts can extend vehicle downtime and affect service performance. In PT XYZ, spare parts for Northern Sumatra are still largely supplied from the Bekasi Part Center, resulting in delivery times of approximately five to nine days. The existing Palembang Depot has limited capability to accommodate the variety of spare parts required across the region. To improve delivery responsiveness, the company plans to establish one additional depot with a target of reducing delivery time by at least 30%. This study determines the optimal location for the proposed depot using a demand-weighted P-Median model. Fourteen dealers are considered both demand points and candidate locations, with the number of depots fixed at one ((p=1)). Dealer demand and inter-dealer travel time are incorporated to minimize the overall demand-weighted travel time. The solution is further verified through complete enumeration and examined through sensitivity analysis. The results identify Dealer C in Medan as the optimal location, producing an objective value of 97,312,319 minute-units. The demand-weighted average travel time decreases from 2,173.86 to 318.70 minutes per unit, equivalent to an 85.34% reduction. Even when Dealer C is excluded, the reduction remains 68.10%. These findings indicate that locating the depot in Medan can substantially improve distribution responsiveness and demonstrate how P-Median provides a practical, demand-based approach to support depot location decisions.

Keywords: *Demand-weighted travel time; Depot location; Facility location; P-Median; Pare parts distribution*

1. Introduction

Spare parts availability is essential to automotive after-sales service, as delays in obtaining required parts can extend maintenance time and vehicle downtime. Managing spare parts is particularly challenging due to the large variety of items with different demand patterns, values, and levels of criticality [1]. Therefore, the design of the distribution network, particularly the location of inventory facilities, plays an important role in ensuring responsive spare parts delivery. PT XYZ distributes automotive spare parts through a central Part Center (PC) in Bekasi and several regional facilities. However, Northern Sumatra, covering Aceh, Medan, Padang, Pekanbaru, Rokan Hulu, and Batam, still relies largely on direct shipments from Bekasi, with delivery times of approximately five to nine days. The existing Palembang Depot can accommodate around 1,044 SKU variations, while the region requires approximately 1,800 SKU variations. As a result, a substantial portion of demand continues to be fulfilled directly from Bekasi.

To improve distribution responsiveness, PT XYZ plans to establish one additional Depot in Northern Sumatra, with a KPI of achieving at least a 30% reduction in travel time. Since the company plans to open only one facility, selecting its location becomes an important network decision. The location should not only be geographically accessible but should also reflect differences in demand across dealers, as facility location can directly influence transportation and service performance [2]. The P-Median model is suitable for this problem because it locates a predefined number of facilities by minimizing the total demand-weighted distance or travel time between facilities and demand points [3], [4]. By incorporating demand as a weight, higher-demand locations have a greater influence on the location decision [3], [5]. In this study, P = 1 reflects the company's policy to establish only one additional Depot rather than an assumption made by the researchers. Therefore, the model addresses a

specific decision: given that only one Depot can be opened, where should it be located to minimize total demand-weighted travel time?

Previous studies have widely applied the P-Median model to determine facility locations by considering demand and travel distance or time [3]–[6]. However, practical applications may involve additional company-specific conditions that need to be considered in the location decision. In this case, PT XYZ has already decided to establish only one additional Depot, while demand varies considerably among the 14 dealers. The selected location is also expected to support the company's target of reducing travel time by at least 30%. Therefore, this study focuses on applying the P-Median model to determine the most suitable location under these specific operational conditions and to evaluate whether the proposed location can meet the company's performance target. The analysis considers 14 dealers as both demand points and candidate Depot locations. Dealer demand and inter-dealer travel time are incorporated into the model. The optimal solution is verified through complete candidate enumeration, while sensitivity analysis is used to examine the stability of the selected location under changes in the dominant dealer's demand.

2. Method

This study used a quantitative optimization approach to determine the location of one additional Depot for PT XYZ's spare parts distribution network in Northern Sumatra. The location problem was formulated using a demand-weighted P-Median model. The P-Median model is commonly used to locate a predetermined number of facilities by minimizing the total weighted distance or travel time between facilities and the demand points they serve [3]–[5].

2.1. Study Area and Data

Each dealer serves two roles in the model: as a demand point and as a candidate location for the proposed Depot. This node-based structure is consistent with the classical P-Median problem, where facilities are selected from a predefined set of candidate nodes and demand points are allocated to the selected facilities [3], [4], [6]. Total observed demand across the network is 305,344 units. Since demand varies considerably among dealers, the actual demand of each dealer was retained as a weight in the optimization model. Demand weighting is a fundamental feature of the P-Median problem because the objective represents the aggregate service burden by combining the magnitude of demand with the distance or travel time required to serve it [3], [5], [7].

Two types of travel-time data were used in this study. The baseline travel time from the Bekasi Part Center to each dealer was obtained from PT XYZ's company data and represents the existing distribution condition. Meanwhile, the inter-dealer travel times used as input for the P-Median model were obtained from Google Maps and compiled into a 14 × 14 origin-destination matrix. The company data were used to represent the actual baseline condition, while Google Maps travel times provided a consistent estimate across all candidate-to-dealer pairs required by the P-Median model. Travel time was used instead of straight-line distance because the company's performance target is expressed in terms of travel-time reduction.

P-Median formulations can use either distance or travel time as the impedance measure between demand points and candidate facilities [5], [6], [8]. The p-median objective covers the downstream depot to dealer leg only, the PC to selected depot replenishment leg is intentionally excluded from the objective and from the before-after comparison. For the selected location C, the PC to depot travel time is 2,400 minutes and should be considered separately when designing replenishment operations.

Table 1. Dealer demand and baseline/selected-depot travel time

Dealer	City	Demand	Share (%)	PC→Dealer (min)	C→Dealer (min)
A	Medan	3,962	1.30	2,400	13
B	Pekanbaru	2,524	0.83	1,620	813
C	Medan	149,468	48.95	2,400	0
D	Padang	16,395	5.37	1,680	1,022
E	Pekanbaru	49,933	16.35	1,620	823

F	Batam	6,513	2.13	2,160	2,220
G	Medan	44,265	14.50	2,400	13
H	Pekanbaru	19,817	6.49	1,620	813
I	Rokan Hulu	1,598	0.52	1,920	691
J	Medan	4,393	1.44	2,400	37
K	Aceh	621	0.20	3,000	710
L	Aceh	4,059	1.33	3,000	705
M	Pekanbaru	941	0.31	1,620	817
N	Padang	855	0.28	1,680	1,023

2.2. P-Median Formulation

The P-Median problem seeks to locate a predetermined number of facilities while minimizing the total weighted distance between demand points and their assigned facilities [3], [4]. In this study, distance is represented by travel time because the company's performance target is specifically related to travel time reduction.

I = set of dealer demand points, i = 1, ……, 14
J = set of candidate Depot locations, j = 1, ……, 14
d_i *= spare-parts demand at dealer i*
t_{ij} *= travel time from candidate location j to dealer i*
p *= number of depot to be established, where p=1*

The binary facility-location variable is defined as:
$y_j = \{1, if\ a\ sub-warehouse\ is\ opened\ at\ location\ j; 0, otherwise\}$

while the allocation variable is:
$x_{ij} = \{1, if\ dealer\ i\ is\ assigned\ to\ facility\ j; 0, otherwise\}$

Following the classical P-Median formulation [3], [4], the objective function minimizes total demand-weighted travel time:

$$Min\ Z = \sum_{i\in I}\sum_{j\in J} D_i t_{ij} x_{ij} \quad (1)$$

Equation (1) minimizes the aggregate demand-weighted travel time across all dealer demand points [3]–[6]. A candidate location becomes more attractive when it provides shorter travel times to dealers with relatively high demand [3]–[6]. Thus, the model prioritizes overall network accessibility according to the distribution of demand rather than treating all dealer locations equally. This structure distinguishes the P-Median objective from location models such as the P-Center, which focus on minimizing the maximum service distance rather than aggregate weighted travel [5], [10].

Each dealer must be assigned to exactly one selected facility:

$$\sum_{j\in J} x_{ij} = 1,\ \forall i \in I. \quad (2)$$

A dealer can only be assigned to a candidate location when that facility is selected:

$$x_{ij} \le y_j, \forall i \in I, j \in J \quad (3)$$

The number of selected facilities is restricted by:

$$\sum_{j\in J} y_j = p \quad (4)$$

For the case investigated in this study $p = 1$
The value $p = 1$ represents the company's actual expansion constraint, as PT XYZ plans to establish only one additional Depot in Northern Sumatra. Therefore, the model searches for the single candidate that minimizes the overall demand-weighted travel time.
Finally:

$$x_{ij}, y_j \in \{0, 1\} \quad (5)$$

This formulation follows the basic discrete facility-location structure introduced in the classical median location literature [3], [4] and commonly used in network location analysis [5].

2.3. Model Solution and Verification

The model evaluates each candidate based on the interaction between dealer demand and travel time. Consequently, locations with high demand have a greater influence on the objective function than locations with relatively low demand. This is consistent with the P-Median principle, where demand weights are used to represent the relative importance of individual demand points [3], [5]. Because the problem contains only 14 candidate locations and the number of facilities is fixed at one, the optimization result was independently checked using complete candidate enumeration. For each candidate j, the total demand-weighted travel time was calculated as:

$$Z_j = \sum_{i \in I} D_i t_{ij} \tag{6}$$

The optimal candidate is therefore:

$$j^* = arg^{min}_{j \in J} Z_j \tag{7}$$

Enumeration is computationally practical for this case because only 14 single facility configurations need to be evaluated. The procedure is used as an independent verification of the mathematical model rather than as an alternative formulation. Exact and approximate solution procedures have been widely developed for larger P-Median instances, where complete enumeration becomes computationally impractical [6], [9].

2.4. Travel Time Performance Evaluation

After the optimal Depot was identified, the proposed network was compared with the existing distribution structure. The evaluation was designed around PT XYZ's KPI of achieving at least a 30% reduction in travel time. Because demand varies considerably among dealers, network performance was evaluated using demand-weighted average travel time rather than a simple arithmetic average. The baseline performance was calculated as:

$$T_{before} = \frac{\sum_{i \in I} D_i T_i^{PC}}{\sum_{i \in I} D_i} \tag{8}$$

Where T_i^{PC} represents the existing travel time from the Bekasi Part Center to dealer.

The proposed network performance was calculated as:

$$T_{after} = \frac{\sum_{i \in I} D_i t_{ij*}}{\sum_{i \in I} D_i} \tag{9}$$

where j^* represents the selected Depot.

Travel time improvement was then calculated as:

Because dealer demand varies substantially, network performance was evaluated using demand-weighted average travel time rather than a simple arithmetic average. This measure is consistent with the minisum objective of the P-Median model, in which travel burden is evaluated relative to the amount of demand associated with each node [5]–[7].

$$Travel\ Time\ Reduction = \frac{T_{before} - T_{after}}{T_{before}}\ x\ 100\% \tag{10}$$

The proposed network was considered to satisfy the company's KPI when $Travel\ Time\ Reduction \geq 30\%$.

In addition to the aggregate measure, changes in travel time were evaluated for each dealer. This dealer-level evaluation was used to identify whether the proposed Depot improved accessibility across the network or created a trade-off for locations.

2.5. Sensitivity Analysis

Facility-location solutions can be influenced by changes in demand because demand weights directly affect the P-Median objective function [5]. A sensitivity analysis was therefore performed to evaluate the stability of the selected Depot location. The analysis focused on Dealer C, which has the largest baseline demand. Dealer C's demand was reduced while the demand of all other dealers and the travel-time matrix were kept unchanged. Six representative scenarios were first evaluated, corresponding to 100%, 70%, 50%, 35%, 25%, and 15% of Dealer C's baseline demand. To identify the transition points more precisely, an additional grid analysis was performed from 5% to 100% of the baseline demand in 0.5-percentage-point increments, resulting in 191 scenarios. For each scenario, the objective value of all candidate locations was recalculated, and the location with the minimum demand-weighted travel time was identified.

The analysis was used to determine whether the baseline location remained optimal as Dealer C's demand changed and to identify the point at which another candidate became preferable. This provides additional information about the robustness of the location decision, particularly because demand is highly concentrated at several dealers. Previous P-Median studies have shown that changes in demand distribution and demand weights can influence facility-location solutions [7], [10].

3. Results and Discussion

3.1. Optimal Depot Location and Candidate Ranking

The demand-weighted P-Median model identified Dealer C in Medan as the optimal location for the proposed Depot under the company's requirement to establish only one additional facility ($p = 1$). The optimal solution produced an objective value of 97,312,319-minute units, equivalent to a demand-weighted downstream travel time of 318.70 minutes per unit. The same selected location and objective value were obtained through complete enumeration of all 14 candidate locations, confirming the consistency of the optimization result.

The selection of Dealer C is closely related to the spatial distribution of demand. Dealer C accounts for 149,468 units, or 48.95% of total demand, making it the largest demand point in the network. Several other high-demand dealers are also located in Medan, particularly Dealer G, which represents 14.50% of total demand. This concentration means that locating the Depot at Dealer C substantially reduces the weighted travel burden associated with the largest share of spare-parts flow.

Dealer C is nevertheless not an isolated optimum. Dealer G ranks second with an objective value of 98,206,800 minute-units, only 0.92% above the optimum, while Dealer A is 1.06% above C. Dealer J follows with a gap of 7.11%. All four leading candidates are in Medan. This indicates that the optimization provides strong evidence for Medan as the preferred service cluster, while the exact site within Medan remains relatively competitive among the top candidates.

Table 2. Leading P-Median candidate ranking

Rank	Candidate	City	Z (minute-unit)	Gap to optimum (%)
1	C	Medan	97,312,319	0.00
2	G	Medan	98,206,800	0.92
3	A	Medan	98,339,760	1.06
4	J	Medan	104,227,231	7.11
5	B/H	Pekanbaru	196,679,073	102.11

The concentration of the leading candidates in Medan is consistent with the fundamental behavior of weighted facility location models, in which demand distribution strongly influences the location of the median facility [3], [5]. Gwalani et al. [10] similarly showed that the spatial distribution of demand can materially affect P-Median solutions. In the present case, this effect is particularly visible because Dealer C alone represents 48.95% of total demand, while another 14.50% is associated with Dealer G in the same city. However, the small objective gaps among Dealers C, G, and A suggest that the managerial implication extends beyond the selection of a single dealer site: Medan itself represents a relatively stable location cluster under the observed demand structure.

Figure 1 shows how the network structure changes once Dealer C is selected. Before facility selection, the model considers the full 14 × 14 inter-dealer travel-time matrix. Under the p = 1 solution, only the travel time relationship between Dealer C and the remaining dealer nodes determines the downstream allocation structure, producing a star-shaped network centered on Dealer C.

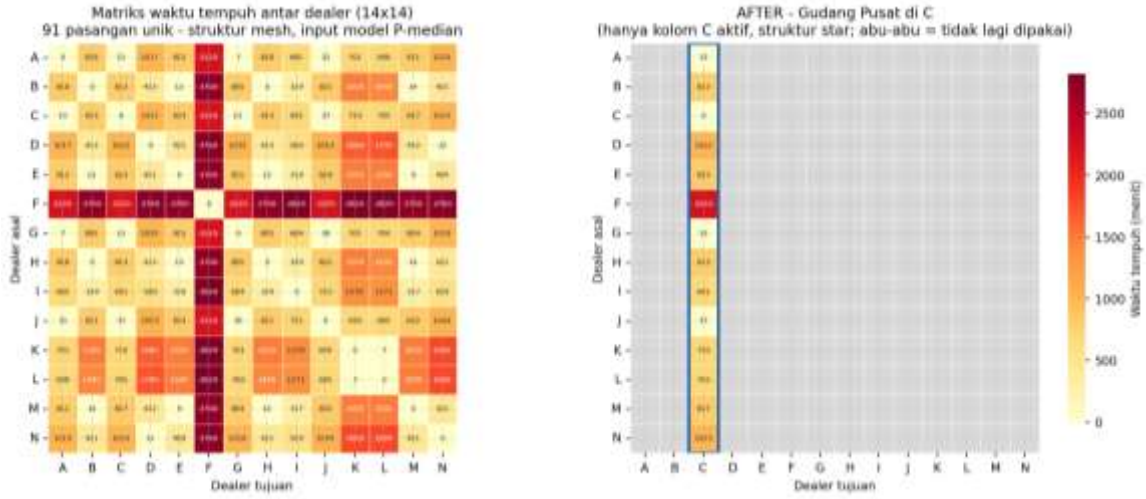


Figure 1. Travel-time matrix before and after selecting Dealer C as the single Depot.

3.2. Travel Time Improvement and KPI Achievement

The operational effect of the selected location was evaluated by comparing the existing PC-to-dealer travel times with downstream travel times from Dealer C to each dealer. Under the existing distribution structure, the demand-weighted average travel time is 2,173.86 minutes per unit. After the proposed Depot is located at Dealer C, the corresponding downstream weighted average decreases to 318.70 minutes per unit. This represents an 85.34% reduction. This reduction is substantially higher than PT XYZ's KPI of achieving at least a 30% reduction in travel time. Based on the demand-weighted downstream indicator, the proposed location exceeds the target by 55.34 percentage points. The KPI is used here as a performance benchmark rather than as a constraint in the P-Median objective.

The magnitude of the improvement requires careful interpretation because Dealer C itself represents almost half of total demand and receives a downstream travel time of zero after colocation. To assess whether this structural effect dominates the result, the reduction was recalculated after excluding Dealer C. The resulting improvement remains 68.10%, which is still well above the company's 30% target. Therefore, the network improvement is not solely caused by the zero-travel time assigned to the selected location.

Table 3. Before-after performance and KPI achievement

Indicator	Result
Total demand	305,344 units
Selected Depot	Dealer C, Medan
Z*	97,312,319 minute-units
Weighted travel time - before	2,173.86 min/unit
Weighted downstream travel time - after	318.70 min/unit
Travel-time reduction	85.34%
Reduction excluding Dealer C	68.10%
Company KPI	>= 30%
KPI status	Achieved
Dealers experiencing deterioration	1 of 14 (Dealer F)

The improvement is uneven across individual dealers. The strongest reductions occur among Medan dealers A, C, G, and J, whose travel times become 13, 0, 13, and 37 minutes, respectively. Aceh dealers K and L decreased from 3,000 minutes to 710 and 705 minutes. The Pekanbaru dealers decrease from 1,620 minutes to approximately 813-823 minutes, while Dealer I in Rokan Hulu decreases from 1,920 to 691 minutes. Dealer F in Batam is the only exception. Its travel time increases from 2,160 to 2,220 minutes, equivalent to a 2.78% deterioration. Since Dealer F represents only 2.13% of total demand, the P-Median objective accepts this local deterioration in exchange for considerably larger reductions at higher-demand nodes. This result reflects the aggregate demand-weighted objective of the P-Median model: a small deterioration at a relatively low demand dealer may be accepted when it is offset by substantially larger improvements at higher-demand locations.

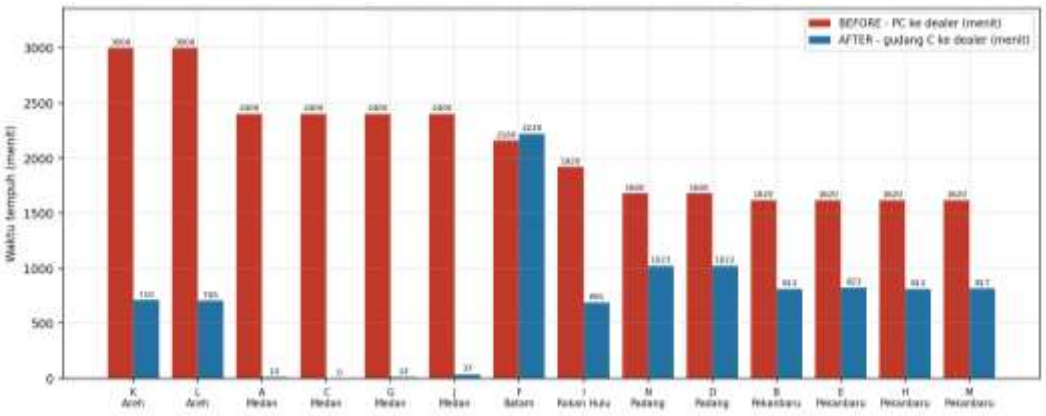


Figure 2. Dealer-level travel time before and after selecting Dealer C.

3.3. Spatial Change in the Distribution Structure

Under the existing system, spare parts are shipped directly from the Bekasi Part Center to all 14 dealers in Northern Sumatra. Baseline PC-to-dealer travel time ranges from approximately 1,620 to 3,000 minutes. With Dealer C selected as the regional Depot, the downstream structure becomes centered on Medan. Dealers located within Medan can be served within minutes, while dealers in Aceh, Pekanbaru, Padang, and Rokan Hulu experience substantially shorter regional travel times compared with direct shipment from Bekasi.

The spatial comparison should not be interpreted as a complete end-to-end redesign of the supply chain. The P-Median model evaluates only the downstream Depot-to-dealer leg. The replenishment movement from the Bekasi Part Center to Dealer C remains outside the objective function. The PC-to-C replenishment travel time is approximately 2,400 minutes and should therefore be considered separately when determining replenishment frequency, inventory policy, and shipment consolidation.

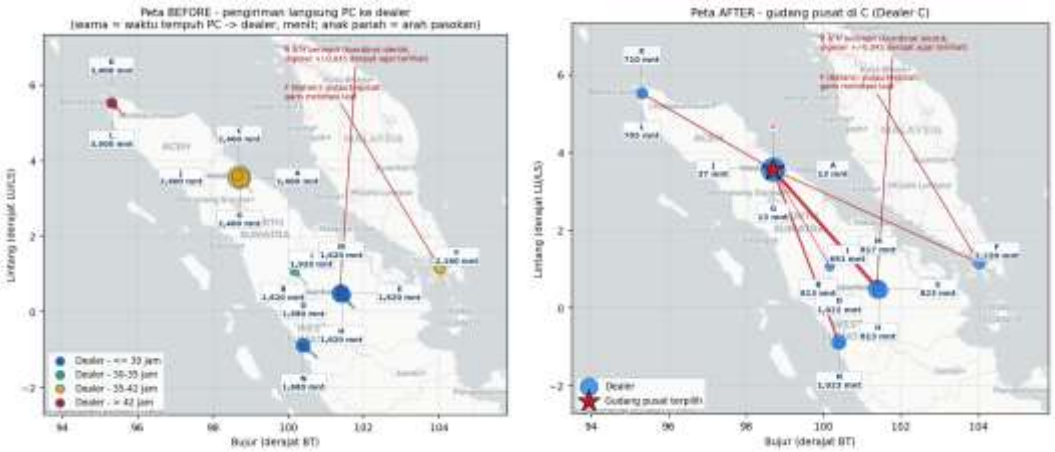


Figure 3. Spatial structure of the existing direct PC-to-dealer network and the proposed downstream network centered on Dealer C.

3.4. Travel Time Matrix Evaluation

Because the P-Median model relies on the inter-dealer travel-time matrix, the travel-time data were evaluated by comparing them with straight-line Haversine distances for 91 unique dealer pairs. As shown in Figure 4, the complete network shows a positive relationship between distance and travel time, with a Pearson correlation of 0.6799 and a Spearman correlation of 0.8455. However, several Batam-related pairs deviate from the general pattern. When these pairs are excluded, the Pearson correlation increases to 0.9902, showing a strong relationship between distance and travel time among land-connected dealers.

Figure 4 also shows that Batam-related pairs generally have longer travel times than land-connected pairs at comparable Haversine distances. This difference is reasonable because Batam is an island and has different transport connectivity from the other dealer locations in Sumatra. This finding shows that straight-line distance does not always represent actual accessibility, particularly when locations have different transport networks [5], [6], [8]. Therefore, travel time is considered a more suitable measure for the P-Median model in this case.

Overall, Figure 4 shows that the travel-time pattern is geographically reasonable, while the deviation associated with Batam can be explained by its different network connectivity. These results support the use of the Google Maps-based travel-time matrix in the location analysis.

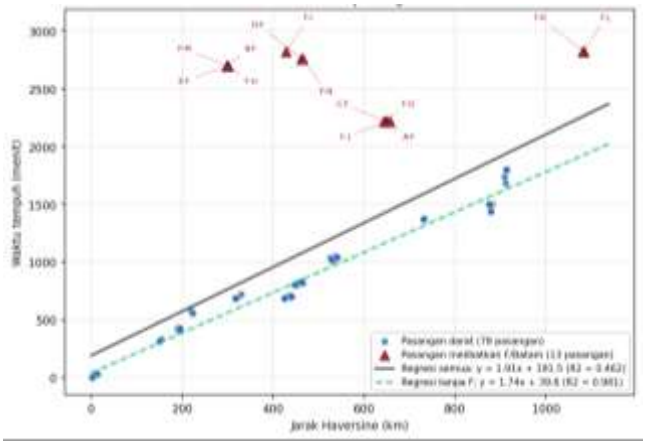


Figure 4. Relationship between Haversine distance and inter-dealer travel time.

3.5. Sensitivity of the Selected Location to Demand Changes

Dealer C accounts for 48.95% of the total baseline demand, making its demand an important factor in the location decision. As shown in Figure 5, Dealer C remains in the optimal location when approximately 54% or more of its baseline demand is retained. Below this level, the optimal location shifts to Dealer G, which is also located in Medan. When Dealer C's demand decreases to approximately 18% of its baseline value, the optimal location shifts again to Pekanbaru candidate B.

Figure 5 also shows that the objective values of the leading Medan candidates remain relatively close, particularly around the transition point between Dealer C and Dealer G. This indicates that although the exact dealer location is sensitive to changes in Dealer C's demand, Medan remains a relatively robust location cluster under substantial demand changes. This finding is consistent with previous P-Median studies showing that changes in demand weights and spatial demand distribution can influence facility-location decisions [7], [10].

The sensitivity results should also be considered together with the baseline candidate ranking. Dealer G is only 0.92% above Dealer C, while Dealer A is 1.06% above the optimum. Therefore, Dealer C provides the minimum demand-weighted travel time under the current demand structure, but the overall results provide stronger support for Medan as the preferred Depot location cluster rather than for a single dealer site under all demand conditions.

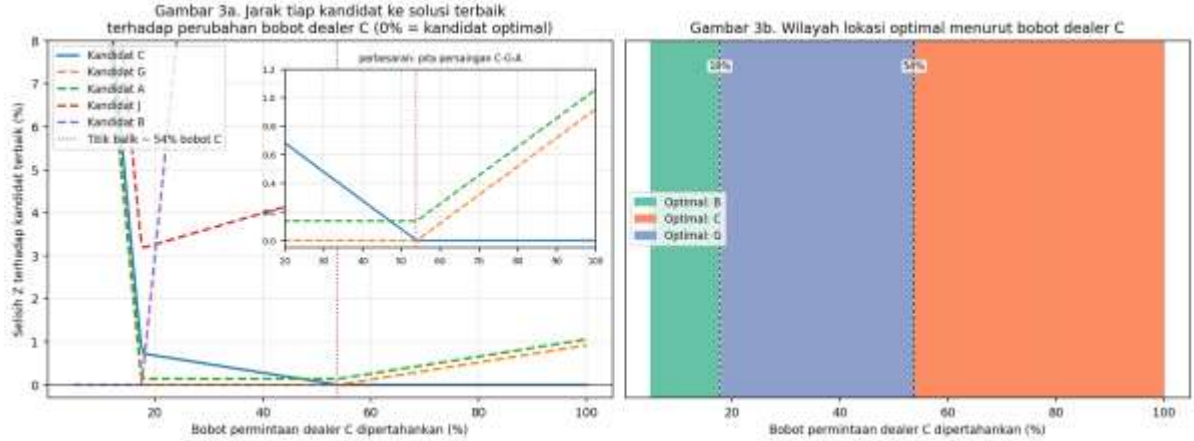


Figure 5. Sensitivity of the optimal P-Median location to changes in Dealer C demand.

3.6. Managerial Implications and Model Boundaries

Overall, the results provide quantitative support for locating PT XYZ's single planned Depot in Medan, specifically at Dealer C under the current demand structure. The proposed configuration reduces demand-weighted downstream travel time by 85.34%, substantially exceeding the company's 30% travel-time reduction KPI. Even after removing the structural advantage associated with Dealer C's zero local travel time, the reduction remains 68.10%.

However, the result should be interpreted within the boundaries of the P-Median formulation. The model optimizes service location rather than the entire logistics cost structure. Depot capacity, inventory holding, handling time, PC to depot replenishment, shipment frequency, and transport cost are outside the current objective. Dealer C should therefore be interpreted as the best location from a demand-weighted downstream travel-time perspective, rather than automatically as the lowest-cost location for the entire supply chain.

The Batam result also highlights an important service trade off. Although the network level KPI is comfortably achieved, Dealer F experiences a slight deterioration. If the company requires a minimum improvement for every dealer, a future extension could incorporate a maximum travel-time or service-level constraint alongside the P-Median objective. Such an extension would prevent a low demand but

geographically isolated dealer from being disadvantaged solely because its contribution to the weighted objective is small.

4. Conclusion

This study used a demand-weighted P-Median model to determine the location of one additional Depot for PT XYZ in Northern Sumatra. The number of facilities was fixed at p = 1, following the company's plan to open only one new Depot. Based on the demand and travel-time data of 14 dealers, Dealer C in Medan was identified as the optimal location, with a demand-weighted downstream travel time of 318.70 minutes per unit.

Compared with the existing distribution from the Bekasi Part Center, the proposed location reduces the demand-weighted travel time from 2,173.86 to 318.70 minutes per unit, or 85.34%. This improvement is well above the company's KPI of at least a 30% travel-time reduction. Even when Dealer C is excluded from the calculation, the reduction remains 68.10%. The sensitivity analysis also shows that Dealer C remains the preferred location under moderate demand changes, while the overall results consistently point to Medan as the strongest location cluster.

These findings show that P-Median can provide a practical basis for selecting a Depot location by considering both dealer demand and travel time. However, the current model focuses on the downstream Depot to dealer network. Future research could extend the analysis by including facility capacity, inventory, replenishment from the Part Center, and transportation cost to provide a more complete distribution network decision.

Acknowledgments

The authors gratefully acknowledge **PT XYZ** for providing the data and operational insights that supported this study.

Reference

[1] J. Huiskonen, "Maintenance spare parts logistics: Special characteristics and strategic choices," *International Journal of Production Economics*, vol. 71, no. 1–3, pp. 125–133, 2001.

[2] M. T. Melo, S. Nickel, and F. Saldanha-da-Gama, "Facility location and supply chain management – A review," *European Journal of Operational Research*, vol. 196, no. 2, pp. 401–412, 2009.

[3] S. L. Hakimi, "Optimum locations of switching centers and the absolute centers and medians of a graph," *Operations Research*, vol. 12, no. 3, pp. 450–459, 1964.

[4] C. S. ReVelle and R. W. Swain, "Central facilities location," *Geographical Analysis*, vol. 2, no. 1, pp. 30–42, 1970.

[5] M. S. Daskin, *Network and Discrete Location: Models, Algorithms, and Applications*, 2nd ed. Hoboken, NJ: Wiley, 2013.

[6] R. L. Church, "BEAMR: An exact and approximate model for the p-median problem," *Computers & Operations Research*, vol. 35, no. 2, pp. 417–426, 2008, doi: 10.1016/j.cor.2006.03.006.

[7] O. Berman and D. Krass, "The network p-median problem with discrete probabilistic demand weights," *Computers & Operations Research*, vol. 37, no. 8, pp. 1455–1463, 2010, doi: 10.1016/j.cor.2009.10.007.

[8] Y. Liu, Y. Yuan, J. Shen, and W. Gao, "Emergency response facility location in transportation networks: A literature review," Journal of Traffic and Transportation Engineering (English Edition), vol. 8, no. 2, pp. 153–169, 2021, doi: 10.1016/j.jtte.2021.03.001.

[9] J. E. Beasley, "Lagrangean heuristics for location problems," *European Journal of Operational Research*, vol. 65, no. 3, pp. 383–399, 1993, doi: 10.1016/0377-2217(93)90118-7.

[10] H. Gwalani, C. Tiwari, and A. R. Mikler, "Evaluation of heuristics for the p-median problem: Scale and spatial demand distribution," Computers, Environment and Urban Systems, vol. 88, Art. no. 101656, 2021, doi: 10.1016/j.compenvurbsys.2021.101656.