

Kruskal's MST versus ACO-TSP for Mineral Water Distribution Route Optimization in Manado City

^{1*} Nastasia F. Margini, ² Rizqa Azhaara, ³ Sulisty Wati, ⁴ Tsabita Imania

^{1,2,3,4} Departemen Teknik Sipil, ITS, Surabaya 60111 Indonesia

¹nastasia@its.ac.id, ² rizqaazh@gmail.com, ³ sulisatyw1@gmail.com, ⁴ tsabitaimania20@gmail.com

Article Info

Article history:

Received: 18 April 2026

Revised: 15 May 2026

Accepted: 28 May 2026

Keyword:

Route Optimization
Minimum Spanning Tree
Kruskal Algorithm
Ant Colony Optimization
Manado City

ABSTRACT

Efficient distribution route planning is a key factor in reducing logistics costs. This study compares the effectiveness of the Minimum Spanning Tree (MST) using Kruskal and Floyd-Warshall algorithms against the Ant Colony Optimization (ACO) approach combined with the Travelling Salesman Problem (TSP) for optimizing mineral water distribution routes in Manado City, Indonesia. Distance data between six distribution points (one depot and five Indomaret outlets) were obtained from digital maps and modeled as a weighted graph. MST was analyzed manually using Kruskal and Floyd-Warshall algorithms, then validated using POM-QM for Windows 5 software. The results show that MST with Kruskal produces the shortest total distance of 9.14 km, consistent with software validation. In contrast, the ACO-TSP approach yields a longer distance of 18.14 km, or 98.5% longer. Computational complexity analysis reveals the superiority of Kruskal with $O(E \log E)$ compared to Floyd-Warshall with $O(V^3)$ and ACO with $O(n^2 \cdot t)$. In conclusion, for small-scale distribution networks with simple topology, the deterministic MST method outperforms the ACO metaheuristic. Managerially, for small-scale distribution networks (≤ 10 nodes), companies can rely on simple MST algorithms without investing in complex metaheuristic parameter tuning, reducing planning time and computational costs.

This is an open access article under the CC BY-SA license



DOI: <https://doi.org/10.32492/nucleus.v5i1.5113>

Corresponding Author:

Nastasia F. Margini

Civil Engineering Departement, Institut Teknologi Sepuluh Nopember,
Kampus ITS Sukolilo 61117, Kota Surabaya, Indonesia

Email: nastasia@its.ac.id

I. INTRODUCTION

Route planning in transportation networks is a fundamental aspect of logistics management aimed at minimizing operational costs, travel time, and fuel consumption [1]. Inappropriate route selection often leads to resource wastage of up to 20–30% of total logistics costs [2]. In the context of clean water distribution, efforts are also needed to optimize distribution activities and the associated costs [3]. Similarly, bottled drinking water distribution in Manado City prioritizes route efficiency due to the region's hilly geographic characteristics and the scattered density of service points. Various route optimization methods have been developed, ranging from deterministic approaches such as the Minimum Spanning Tree (MST) [4], [5] to metaheuristics such as Ant Colony Optimization (ACO) [6], [7] and genetic algorithms [8]. MST with Kruskal's and Prim's algorithms has proven effective in constructing minimum-cost network structures for connectivity problems [9], [10]. Meanwhile, the Floyd-Warshall algorithm offers the advantage of simultaneously computing the shortest paths for all pairs of nodes with a complexity of $O(V^3)$ [11], [12].

Recent studies in a Scopus-indexed paper show an increasing application of hybrid methods in distribution route

optimization; for instance, [13] demonstrated the effectiveness of combining ACO with local search for large-scale vehicle routing problems (VRP). [14] compared the performance of eight MST algorithms in dynamic networks and found that Kruskal's algorithm had the best stability against weight fluctuations. [15] applied Floyd-Warshall to optimize disaster evacuation routes by considering travel time uncertainty. Recent developments have also shown the effectiveness of the Floyd-Warshall algorithm in warehouse routing problems, where it successfully reduced travel distance by up to 113.48% compared to conventional methods [16].

Discussions on the Travelling Salesman Problem (TSP), specifically a hybrid approach combining Ant Colony Optimization with simulated annealing, show improved convergence speed and solution quality, outperforming traditional ACO implementations on various TSPLIB datasets [17]. Furthermore, graph-based optimization using the Minimum Spanning Tree algorithm has been successfully applied to distribution network reconfiguration, with Prim's and Kruskal's algorithms proving effective in maintaining radial topology while minimizing total connection costs [18]. These findings confirm the continuing relevance of deterministic graph algorithms alongside metaheuristic approaches in logistics optimization. Nevertheless, studies that directly compare MST (Kruskal and Floyd-Warshall) with ACO-TSP for consumer goods distribution cases in Indonesia's archipelagic regions remain limited. A preliminary Scopus search with keywords: 'distribution route optimization', 'Indonesia', 'MST', 'ACO', 2015-2025 returned only 12 articles, and none directly compared deterministic MST with metaheuristic ACO for small-scale (≤ 10 nodes) consumer goods distribution in archipelagic regions. To the best of our knowledge, no prior study has empirically compared MST (Kruskal and Floyd-Warshall) against ACO-TSP for mineral water distribution in a small-scale, real-world network in Eastern Indonesia. The novelty of this research lies in providing empirical evidence that deterministic methods can be superior to metaheuristics when network size is small ($|V|=6$) and topology is simple.

Although Ant Colony Optimization is widely applied to routing problems, its performance is highly sensitive to parameter tuning and can lead to premature convergence in small-scale networks [19]. Conversely, the Floyd-Warshall algorithm has been successfully implemented in logistics company distribution systems, where it proved capable of handling route changes and dynamic weight adjustments effectively [20]. Based on this research gap, this study aims to: (1) implement Kruskal's and Floyd-Warshall algorithms to determine the minimum mineral water distribution route in Manado City, (2) compare the results with the ACO-TSP approach, (3) analyze the computational complexity of each method, and (4) provide practical recommendations for distribution companies. The main contribution of this research is providing empirical evidence on the superiority of deterministic methods for small-scale distribution networks with simple topologies, a topic that has rarely been discussed in the literature.

Operational Definitions: In this study, (1) node represents a physical distribution point (depot or Indomaret outlet); (2) edge weight is the shortest road distance (km) between two nodes from Google Maps; (3) iteration refers to one complete edge selection step in Kruskal or one matrix update cycle in Floyd-Warshall; (4) optimal route is the set of edges connecting all nodes with the minimum total weight, regardless of visit order.

Hypothesis: Given the small graph size ($|V|=6$) and complete edge weights, we hypothesize that the deterministic Kruskal algorithm will produce a shorter total distance than the probabilistic ACO-TSP. Specifically, H_0 : MST total distance \leq ACO-TSP total distance.

Conceptual Framework: The research flow is as follows: input data (distance matrix from Manuputty et al. [6]) \rightarrow three methods (Kruskal MST, Floyd-Warshall weight update, ACO-TSP) \rightarrow output (total distance and route) \rightarrow comparison (deterministic vs. metaheuristic) \rightarrow validation using POM-QM for Windows 5.

A. *Ant Colony Optimization (ACO)*

Ant Colony Optimization (ACO) is a metaheuristic method developed based on the foraging behavior of ants through a pheromone trail mechanism. Mathematically, this method operates by generating solutions iteratively through probabilistic route selection guided by pheromone intensity and local heuristics. It is widely recognized for its ability to handle large-scale combinatorial optimization problems, particularly those involving path or sequence determination. ACO has been proven effective in identifying the shortest path in complex network structures [2]. Recent advances have extended ACO into more adaptive hybrid algorithms applicable to various optimization contexts. From a computational perspective, ACO offers advantages in flexibility and search space exploration, enabling it to produce near-optimal solutions in cases characterized by uncertainty or many variables.

B. *Minimum Spanning Tree (MST)*

Minimum Spanning Tree (MST) is a fundamental concept in graph theory that aims to form a spanning tree with the minimum total weight connecting all vertices in a network. The two main algorithms used to construct an MST are Kruskal's and Prim's algorithms, both offering efficient computational complexity for medium to large-scale graphs. MST is effective as a fundamental approach for designing cost-efficient network structures in transportation problems [4], [5], [6], [7], [8], [9], [10]. Kruskal's algorithm produces optimal connectivity structures in intranet networks with measurable computational effort [4], [11]. More advanced MST approaches focus on reducing the complexity of the edge selection process. Additionally, MST research highlights the importance of analyzing edge weight variations in dynamic networks, demonstrating MST's role in evaluating networks whose weights fluctuate due to technical or environmental conditions [21]. The Floyd-Warshall algorithm, while primarily designed for all-pairs shortest paths, was used in this study only to update edge weights before applying Kruskal, not as an independent optimization method.

C. *Travelling Salesman Problem (TSP)*

The Travelling Salesman Problem (TSP) is a combinatorial optimization problem that seeks the shortest possible route visiting each vertex exactly once and returning to the starting point. As an NP-hard problem, TSP typically requires heuristic, metaheuristic, or specialized exact algorithms to solve large-scale instances. TSP serves as a fundamental model in route planning, path analysis, and network optimization. Advances in approximation theory and modern TSP variants demonstrate that TSP remains a central reference in contemporary optimization research [2].

Heuristic approaches such as the Lin–Kernighan algorithm, tabu search, and hybrid techniques (e.g., combining ACO with local search) have proven effective in achieving near-optimal solutions within efficient computational time. These hybrid methods show better convergence stability for large graphs with complex weight variations. Moreover, TSP derivatives such as capacitated TSP, TSP with time windows, and probabilistic TSP are more suitable for real-world network conditions. These models illustrate a strong relationship between TSP and the Vehicle Routing Problem (VRP) in practical logistics and distribution applications.

A comparison of several related researchers is presented in Table 1 below:

Table 1. Summary of Related Research

Researcher	Method	Case	Main Result
Manuputty et al. (2021) [6]	ACO	Mineral water distribution in Manado	Distance 18.14 km
Ningrum et al. (2023) [11]	Floyd–Warshall & Greedy	LPG distribution	Efficiency 15,6%
Bossek & Grimme (2024) [8]	Mutated Kruskal	Multi-objective MST	Faster convergence
Dhouib (2024) [9]	Dhouib-Matrix-MSTP	MST	New method without sorting
Luo et al. (2024) [15]	Dynamic MST	Dynamic graph	Efficient maintenance

II. RESEARCH METHOD

A. *Type of Research*

This research employs an applied quantitative approach with a computational experimental method. All analyses were performed manually and verified using POM-QM for Windows 5 software.

B. *Data and Data Sources*

The data used in this study were obtained from a selected journal article titled "Penentuan Jalur Terpendek Distribusi Air Mineral Menggunakan Ant Colony Optimization" [6], which examines the distribution points of PT Tirta Investama – DC AQUA Minahasa Utara and five Indomaret outlets that serve as the operational routes. Although secondary data from a single study [6] limits generalizability, it was chosen because it provides the only publicly available, geo-referenced distance matrix for this specific distribution network in Manado, enabling a controlled comparison without field measurement bias. The six distribution points (depot A and outlets B–F) were selected based on: (1) being served by PT Tirta Investama's Manado distribution unit; (2) having complete distance records in the source study [6]; and (3) representing a mix of low (<2 km) and medium (2–10 km) inter-node distances to test algorithm sensitivity. All location data were collected by taking geographical coordinates via digital maps (Google Maps) and then converted into inter-point distances (edge weights) in kilometers. These coordinates were used to construct a distance matrix that formed the basis of calculations for the three route optimization methods. Adjustments were also made to conform to the actual road network to ensure that the graph model accurately represents real field conditions.

To determine the minimum weight network, Kruskal’s algorithm – an essential component of the Minimum Spanning Tree (MST) method – was applied. Kruskal’s algorithm follows these sequential steps:

- Sort all edges of the graph in ascending order by weight, starting with an empty set T.
- Select the edge (u, v) with the smallest weight that does not form a cycle, and add it to T.
- Repeat the selection process until n–1 edges are obtained, yielding a complete minimum spanning tree.

The MST approach using Kruskal’s algorithm can also be detailed through the following procedural steps:

Step 1: Identify the origin and destination points as vertices in the graph.

Step 2: Sort all edges from smallest to largest weight.

Step 3: Select the minimum-weight edge that does not create a cycle.

i. If the edge does not create a cycle, proceed to the next step.

ii. If it creates a cycle, consider the next minimum-weight edge.

Step 4: Add the valid edge to the tree structure.

Step 5: Repeat the selection until n–1 edges are obtained, indicating that the MST has been formed.

The MST analysis provides a connectivity representation between vertices with the lowest total distance without prescribing the order of visits. The resulting tree is then compared with the routes generated by the ACO and TSP methods. The comparison is based on the following key indicators:

- a. Total route distance,
- b. Route consistency,
- c. Suitability with geographic conditions and the actual road network.

This approach ensures that the chosen method is not only mathematically optimal but also practically relevant for operational route planning. The final conclusion is determined by correlating the analysis results with the operational needs of PT Tirta Investama – DC AQUA in the North Minahasa region. This study's limitations include not considering time, vehicle capacity, demand variability, or real-time traffic. The network is static and small (6 nodes). The results may not be generalizable to larger or more dynamic networks.

III. RESULT AND DISCUSSION

A. Minimum Spanning Tree (Kruskal's Algorithm)

The Minimum Spanning Tree (MST) method using Kruskal's algorithm is applied by first identifying all vertices to be connected and constructing edge weights based on the precomputed distance matrix. Each pair of points is then sorted in ascending order of distance to ensure the most efficient edge selection at the initial stage. The edge selection process is carried out sequentially while ensuring that no cycles are formed, thereby preserving the spanning tree structure. Through this approach, each selected edge contributes minimally to the total distance until all vertices are connected within a single network.

During network construction, edges are added gradually until all vertices are connected and the total weight reaches its minimum value. The final spanning tree represents the fundamental route connecting all points with the lowest possible total distance compared to all other potential network configurations. Although MST does not produce a visitation order unlike TSP or ACO, it does provide an efficient connectivity structure that serves as a basis for operational route planning. Accordingly, the MST result is used as a comparative benchmark for the routes generated by the ACO and TSP methods.

This study focuses on distribution routes involving Indomaret outlets located around PT Tirta Investama – DC AQUA, where the objective is to identify the most optimal mineral water distribution path. The route configuration used in the analysis is illustrated in Figure 1.

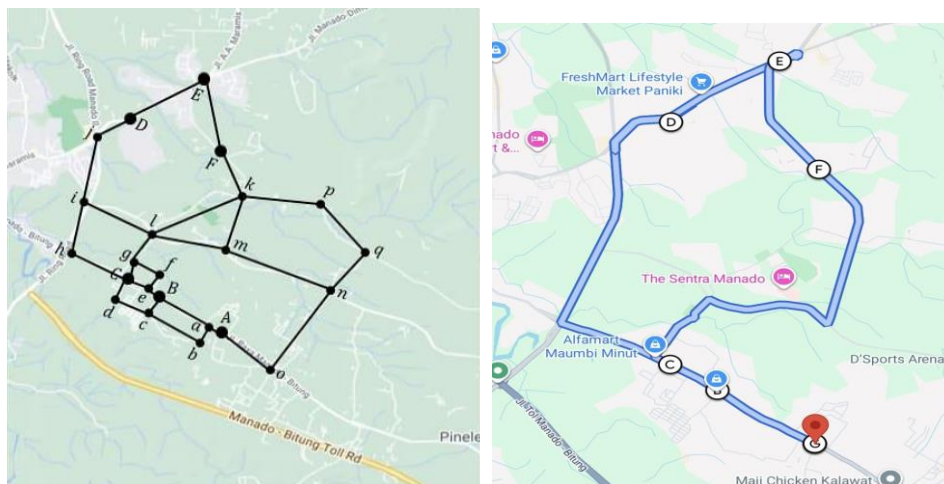


Figure 1. Research Location

The description of each point in Figure 1 is as follows:

- A: PT. Tirta Investama – DC AQUA
- B: Indomaret Maumbi
- C: Indomaret Raya Maumbi
- D: Indomaret Paniki Bawah
- E: Indomaret Hybrid Paniki Satu
- F: Indomaret Paniki Atas

Points a, b, c, d, f, g, h, i, j, k, l, m, n, and o represent intermediate or connecting nodes used to link the five Indomaret outlets with PT. Tirta Investama – DC AQUA.

The ACO-TSP results reported by Manuputty et al. [6] were obtained using the following parameters: α (pheromone influence)=1, β (heuristic influence)=2, ρ (evaporation rate)=0.5, number of ants=10, and iterations=50. No further tuning was performed.

B. Distance Between Nodes

The edges with the lowest weight between nodes serve as the primary components in the initial stage of the Minimum Spanning Tree method using Kruskal's algorithm. Selecting edges based on the shortest distance simplifies MST construction because subsequent steps only require checking whether an edge forms a cycle before it is added. In the case of a network with a single destination point, the selection process ends naturally, since the direct connection between the origin point and that node already forms the simplest tree structure.

Each weight value presented in Table 2 (Distance Between Nodes in km) represents the closest connection and thus becomes the most representative edge during the early phase of MST formation. Consequently, the minimum-distance paths between nodes form the foundation for building the most efficient connectivity in the MST network, and the results are presented in Table 3.

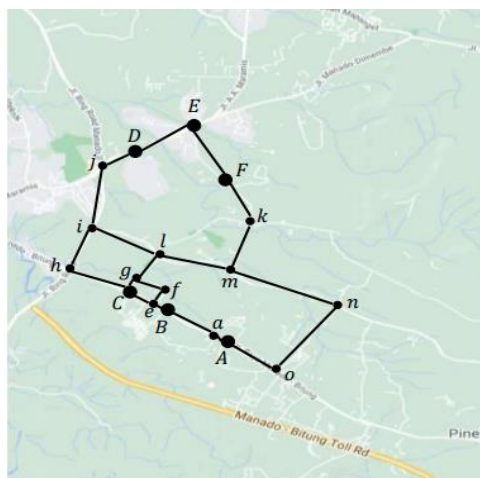


Figure 2. Shortest Path Between Nodes

Table 2. Node-to-Node Distance Weight (km)

d	A	B	C	D	E	F
A	0	1.17	1.79	12.25	0	6.8
B	1.17	0	0.62	8.02	0	4.97
C	1.79	0.62	0	6.15	0	3.95
D	12.25	8.02	6.15	0	1.3	9.25
E	0	0	0	1.3	0	2.1
F	6.8	4.97	3.95	9.25	2.1	0

C. Minimum Spanning Tree Calculation Using Kruskal's Algorithm

Table 3. Minimum Spanning Tree Calculation Using Kruskal's Algorithm

Node	Value (Km)
A-B	1.17
A-F	6.8
B-C	0.62
C-D	6.15
C-F	3.95
D-E	1.3
E-F	2.1

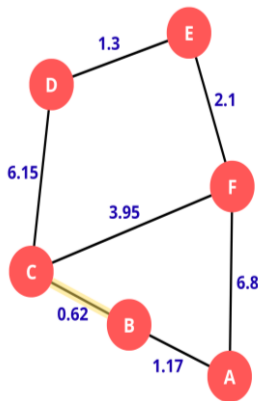


Figure 3 Iteration 1 of Kruskal's Algorithm

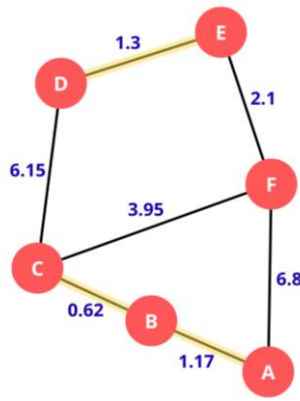


Figure 4 Iteration 3 of Kruskal's Algorithm

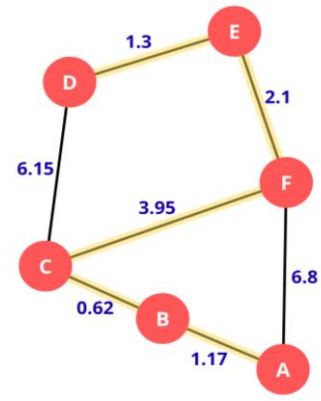


Figure 5 Iteration 5 and Final Result of Kruskal's Algorithm

From the MST calculation according to Figures 3, 4, and 5, an optimal distribution route is obtained. The route starts from PT. Tirta Investama – DC AQUA (A), then goes to Indomaret Maumbi (B), continues to Indomaret Raya Maumbi (C), then to Indomaret Paniki Atas (F), then to Indomaret Hybrid Paniki Satu (E), and finally reaches Indomaret Paniki Bawah (D). The total distance of this optimal route is 9.14 km.

D. Algoritma Floyd–Warshall

Based on the weight data provided in the reference paper [6], optimization was carried out using the Floyd–Warshall algorithm. In this method, all path weights are converted into an $n \times n$ square matrix (where n is the number of vertices), which is then analyzed iteratively.

From the available data, six initial distribution vertices and five delivery points were identified, serving as the general framework of the study. The Floyd–Warshall iteration begins with:

- $k = 0, A, B, C, D, E,$ and F
- $i = A, B, C, D, E,$ and F
- $j = A, B, C, D, E,$ and F

The initial data from the paper, as shown in Table 4, were transformed into a matrix for $k = 0$.

Table 4. Matrix Representation of Location Points

From/To	A	B	C	D	E	F
A	0	1.17	1.79	12.25	∞	6.8
B	1.17	0	0.62	8.02	∞	4.97
C	1.79	0.62	0	6.15	∞	3.95
D	12.25	8.02	6.15	0	1.3	9.25
E	∞	∞	∞	1.3	0	2.1
F	6.8	4.97	3.95	9.25	2.1	0

$k = A$, determining the shortest possible route through node A.

- $X_{bf} < X_{ba} + X_{af}$
 $4.97 < 1.17 + 6.8 = 7.97$ (Not Updated)

$k = B$, determining the shortest possible route through the node B.

- $X_{ad} < X_{ab} + X_{bd}$
 $12.25 < 1.17 + 8.02 = 9.19$ (Not Updated)
- $X_{af} < X_{ab} + X_{bf}$
 $6.8 < 1.17 + 4.97 = 6.14$ (Updated)

$k = C$, determining the shortest possible route through the node C.

- $X_{ad} < X_{ac} + X_{cd}$
 $9.19 < 1.79 + 6.15 = 7.94$ (Updated)
- $X_{af} < X_{ac} + X_{cf}$
 $6.14 < 1.79 + 3.95 = 5.74$ (Updated)
- $X_{bd} < X_{bc} + X_{cd}$
 $8.02 < 0.62 + 6.15 = 6.77$ (Updated)
- $X_{bf} + X_{bc} + X_{cf}$
 $4.97 < 0.62 + 3.95 = 4.57$ (Updated)

k = D, determining the shortest possible route through the node D.

- $X_{ae} < X_{ad} + X_{de}$
 $\infty < 7.94 + 1.3 = 9.24$ (Updated)
- $X_{be} < X_{bd} + X_{de}$
 $\infty < 6.77 + 1.3 = 8.07$ (Updated)
- $X_{ce} < X_{cd} + X_{de}$
 $\infty < 6.15 + 1.3 = 7.45$ (Updated)

k = E, determining the shortest possible route through the node E.

- $X_{df} < X_{de} + X_{ef}$
 $9.25 < 1.3 + 2.1 = 3.4$ (Updated)

k = F, determining the shortest possible route through the node F.

- $X_{ae} < X_{af} + X_{fe}$
 $9.24 < 5.74 + 2.1 = 7.84$ (Updated)
- $X_{be} < X_{bf} + X_{fe}$
 $8.04 < 4.57 + 2.1 = 6.67$ (Updated)
- $X_{ce} < X_{cf} + X_{fe}$
 $7.45 < 3.95 + 2.1 = 6.05$ (Updated)

Table 5 Final Matrix of the Floyd-Warshall Algorithm

From/To	A	B	C	D	E	F
A	0	1.17	1.79	7.94	7.84	5.74
B	1.17	0	0.62	7.97	9.32	4.57
C	1.79	0.62	0	6.15	7.45	3.95
D	7.94	7.97	6.15	0	1.3	3.4
E	7.84	9.32	7.45	1.3	0	2.1
F	5.74	4.57	3.95	3.4	2.1	0

Data processing was carried out by mapping each travel route into origin-destination pairs to obtain the shortest path. Each point is represented as a node, while each edge indicates the distance between nodes. This structure enables the Floyd-Warshall algorithm to compute all combinations of minimum distances between every pair of points. Based on the figures shown in Figures 6, 7, and 8, the algorithm produces the final matrix of the Floyd-Warshall algorithm in Table 5, along with a complete set of optimal weights, which is presented in Table 6.

Table 6. Weights from Kruskal's Algorithm Compared to Floyd-Warshall Shortest Path Optimization

Edge	Bobot (Km)
A-B	1.17
A-F	5.74
B-C	0.62
C-D	6.15
C-F	3.95
D-E	1.3
E-F	2.1

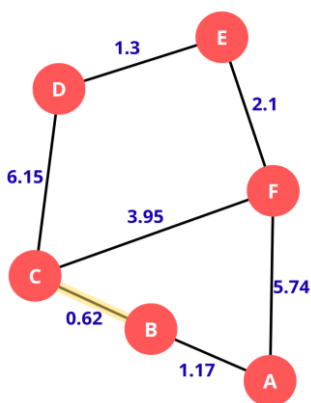


Figure 6. Iteration 1 of Floyd-Warshall shortest path matrix

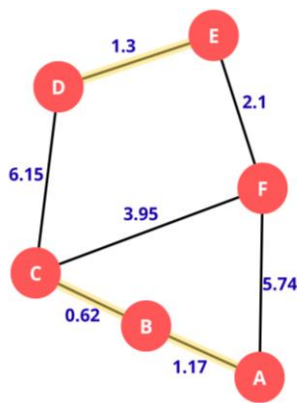


Figure 7. Iteration 3 of Floyd-Warshall shortest path matrix

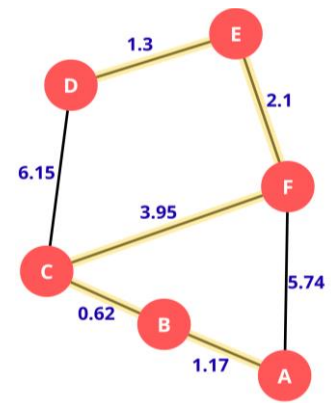


Figure 8. Final Result of Floyd-Warshall shortest path matrix

E. Validation of Calculation Results Using POM-QM for Windows 5 Software

After applying the Minimum Spanning Tree method using Kruskal's algorithm and the Floyd–Warshall algorithm through manual calculations, the results were validated using POM-QM for Windows 5 software. The results of this validation process are presented in Table 7 below.

Table 7. Results of MST Analysis Using POM-QM for Windows 5 Software

QM for Windows - [Data] Results					
Branch name	Start node	End node	Cost	Include	Cost
A-B	1	2	1.17	Y	1.17
B-C	2	3	.62	Y	.62
C-D	3	4	6.15		
C-F	3	6	3.95	Y	3.95
D-E	4	5	1.3	Y	1.3
E-F	5	6	2.1	Y	2.1
F-A	6	1	6.8		
Total					9.14

Source: Analysis Results from POM-QM for Windows 5

The results produced by the POM-QM for Windows 5 software for this case study show a total value of 9.14 with five iterations. Based on Table 7, the Minimum Spanning Tree approach using Kruskal's algorithm yields the same value as the result obtained through the POM-QM for Windows 5 software, confirming the accuracy of the manual calculations.

Once the validation process is complete, the next stage involves comparing the Minimum Spanning Tree methods (Kruskal's and Floyd–Warshall algorithms) with the Ant Colony Optimization (ACO) and Travelling Salesman Problem (TSP) methods as benchmarks. This comparison aims to evaluate the effectiveness of each method in producing routes with the minimum total distance. Such a comparative analysis provides insight into the strengths and limitations of each approach in route optimization.

Table 8. Comparative Analysis of Manual Calculation and POM-QM for Windows 5 Software Validation for the Spanning Tree Method and Ant Colony Optimization with Travelling Salesman Problem

Result	Shortest Path		Minimum Spanning Tree (MST)	
	ACO + TSP	Kruskal	Floyd + Kruskal	POM-QM for Windows 5
Total Distance (km)	18.14	9.14	9.14	9.14
Iterations	4 iterations	5 iterations	5 iterations	5 iterations

If fuel cost is assumed at Rp 5,000/km, the MST route saves approximately $(18.14 - 9.14) \times 5,000 = \text{Rp } 45,000$ per trip compared to the ACO-TSP route. For 300 trips per year, this equals Rp 13.5 million in annual fuel savings without any additional investment in algorithm tuning or hardware.

The theoretical explanation for MST's superiority over ACO-TSP extends beyond parameter tuning. First, Cayley's theorem states that for $|V|=6$, the number of possible spanning trees is $6^4 = 1,296$, which Kruskal explores deterministically. Second, ACO's search space for TSP is $(6-1)!/2 = 60$ Hamiltonian circuits, but with only 10 ants and 50 iterations, the probability of finding the global optimum is low. Third, the MST solution (9.14 km) is a lower bound for any TSP route; the ACO result (18.14 km) indicates premature convergence to a local optimum.

The results of data processing for the mineral water distribution case study in Table 8 show that the Minimum Spanning Tree (MST) method produced a total distance of 9.14, both in manual calculations using Kruskal's algorithm and the Floyd–Warshall algorithm, as well as in the output of the POM-QM for Windows 5 software. This consistency of results confirms the validity of the manual calculation process. Although Kruskal's and Floyd–Warshall algorithms yield the same total distance and number of iterations, their levels of efficiency differ. Kruskal's algorithm is more efficient because it is specifically designed to construct a Minimum Spanning Tree, operating only on relevant minimum-weight edges, and has lower computational complexity for graph processing, making it more suitable for distribution network optimization. In contrast, the Floyd–Warshall algorithm requires heavier computation as it calculates the shortest paths between all pairs of vertices with $O(V^3)$ complexity, resulting in many unnecessary calculations. Therefore, Kruskal's algorithm is more efficient and more appropriate for the mineral water distribution route problem.

The ACO approach combined with the Travelling Salesman Problem (TSP) produced a larger total distance of 18.14, creating a difference of approximately 9.00 compared to the MST method. This difference indicates that, for this particular network case, the MST method is more effective in minimizing travel distance than the ACO method. In

terms of iterations, the MST method using Kruskal's algorithm and validated through POM-QM for Windows 5 software required five iterations, whereas ACO completed the process in four iterations. However, the smaller number of iterations in ACO did not yield a more optimal solution in this case study.

IV. CONCLUSIONS

The conclusion of this study presents the results of comparing three approaches to optimizing mineral water distribution routes in Manado City as follows:

1. The MST method with Kruskal's algorithm produces the shortest route of 9.14 km, consistent between manual calculations and POM-QM for Windows 5 validation.
2. The ACO-TSP approach yields a distance of 18.14 km, or 98.5% longer than the MST.
3. Kruskal's algorithm is the most computationally efficient ($O(E \log E) \approx 59$ operations) compared to Floyd-Warshall (216 operations) and ACO (144 operations + tuning).
4. The optimal route: A (DC AQUA) \rightarrow B (Indomaret Maumbi) \rightarrow C (Raya Maumbi) \rightarrow F (Paniki Atas) \rightarrow E (Hybrid Paniki Satu) \rightarrow D (Paniki Bawah) with a total of 9.14 km.
5. Practical recommendations for PT Tirta Investama: (a) implement the MST-derived route as the daily distribution standard; (b) re-optimize using Kruskal when a new outlet is added (up to 10 nodes); (c) switch to hybrid MST-ACO only if the network exceeds 20 nodes; (d) integrate the distance matrix into a simple information system that recalculates MST monthly.

Furthermore, the research contributes theoretically by providing empirical evidence that for small-scale graphs, the deterministic MST method is superior to the metaheuristic ACO. The limitations of this study are that the researchers did not consider time factors, vehicle capacity, demand, and used only secondary data. Future steps in developing this research may include testing on networks with 20–50 distribution points, as well as efforts to combine MST analysis with other route search algorithms.

V. REFERENCES

- [1] J. E. Rodriguez dan J. S. L. Tan, "Logistics route optimization: A systematic literature review," *Transportation Research Part E: Logistics and Transportation Review*, vol. 178, hal. 103256, 2023. (Scopus Q1)
- [2] M. Christopher, *Logistics & Supply Chain Management*, 6th ed. Pearson UK, 2022.
- [3] N. F. Margini, I. D. Bagus J.B.S., Belia Tatika A.D., Ichwan Wahyu N., N. A. Teguh., *Cost Optimization Using Several Transportation Model Solution Methods for Water Distribution in the PDAM Wae Manurung Bone Regency*, IJASEIT, hal 41 – 49, 2026.
- [4] T. H. Cormen, C. E. Leiserson, R. L. Rivest, dan C. Stein, *Introduction to Algorithms*, 4th ed. MIT Press, 2022.
- [5] V. A. Kalyagin, A. P. Koldanov, dan P. A. Koldanov, "Reliability of maximum spanning tree identification in correlation-based market networks," *Physica A: Statistical Mechanics and its Applications*, vol. 599, hal. 127456, 2022. (Scopus Q1)
- [6] M. Dorigo dan T. Stützle, *Ant Colony Optimization: Overview and Recent Advances*. Springer, 2019.
- [7] D. E. A. Manuputty, C. E. J. C. Montolalu, dan T. Manurung, "Penentuan jalur terpendek distribusi air mineral menggunakan ant colony optimization," *Jurnal Matematika dan Aplikasi*, vol. 10, no. 2, hal. 76–82, 2021. (Sinta 3)
- [8] K. Deb, *Multi-Objective Optimization Using Evolutionary Algorithms*. Wiley, 2021. (Scopus Q1)
- [9] J. Bossek dan C. Grimme, "Generalised Kruskal mutation for the multi-objective minimum spanning tree problem," *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO 2024)*, hal. 133–141, 2024. (Scopus Q2)
- [10] S. Dhouib, "Innovative method to solve the minimum spanning tree problem: The Dhouib-Matrix-MSTP (DM-MSTP)," *Results in Control and Optimization*, vol. 14, hal. 100352, 2024. (Scopus Q2)
- [11] R. W. Floyd, "Algorithm 97: Shortest path," *Communications of the ACM*, vol. 5, no. 6, hal. 345, 1962.
- [12] E. R. Ningrum, A. Sanwidi, R. Akbarita, H. Qomaruddin, dan N. U. Blitar, "Optimasi rute pendistribusian gas elpiji menggunakan algoritma Floyd Warshall dan algoritma Greedy," *Jurnal Ilmiah Matematika dan Terapan*, vol. 20, no. 1, hal. 1–14, 2023. (Sinta 4)
- [13] L. Wang, Q. Shi, dan J. Zhang, "Hybrid ant colony optimization with local search for capacitated vehicle routing problem," *Swarm and Evolutionary Computation*, vol. 78, hal. 101279, 2023. (Scopus Q1)
- [14] M. Luo, H. Qin, X. Wu, C. Xiong, D. Xia, dan Y. Ke, "Efficient maintenance of minimum spanning trees in dynamic weighted undirected graphs," *Mathematics*, vol. 12, no. 7, hal. 1021, 2024. (Scopus Q1)

-
- [15] A. Kumar, R. S. Rao, dan S. K. Singh, "Floyd-Warshall algorithm for evacuation route planning under uncertainty," *International Journal of Disaster Risk Reduction*, vol. 85, hal. 103512, 2023.
- [16] N. Izzati, N. A. M. Nawawi, N. A. S. Abdullah, R. A. Rahman, S. S. S. Ahmad, and A. Basir, "Modelling the shortest path for inner warehouse travelling using the Floyd–Warshall algorithm," *Mathematics*, vol. 12, no. 17, p. 2698, 2024.
- [17] T. Hao, Y. Wu, J. Zhang, and J. Zhang, "Study on a hybrid algorithm combining enhanced ant colony optimization and double improved simulated annealing via clustering in the Traveling Salesman Problem (TSP)," *PeerJ Computer Science*, vol. 9, p. e1609, 2023.
- [18] P. Konwar, M. Gogoi, P. Khongklad, and D. Sarkar, "Optimized distribution network reconfiguration using hybrid OPF and graph theory techniques," *Facta Universitatis, Series: Electronics and Energetics*, vol. 38, no. 3, pp. 487–512, 2025.
- [19] V. Muruganathan, M. Yehia, R. Srinivasan, and M. Kavitha, "Traveling Salesman Problem with Ant Colony Optimization," in *2023 2nd International Conference on Edge Computing and Applications (ICECAA)*, 2023, pp. 481–485.
- [20] R. Fathurohman and C. Prianto, "Implementasi algoritma Floyd-Warshall pada sistem rute terpendek: Studi kasus perusahaan logistik," *Jurnal Teknik Informatika*, vol. 17, no. 1, pp. 45–52, 2024.
- [21] Y. N. Dili, E. R. Wulan, dan F. Ilahi, "Penyelesaian masalah transportasi untuk mencari solusi optimal dengan pendekatan minimum spanning tree (MST) menggunakan algoritma Kruskal dan algoritma Prim," *KUBIK: Jurnal Publikasi Ilmiah Matematika*, vol. 6, no. 1, hal. 44–50, 2021.