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Optimizing Waste Collection Routes in Purwokerto using the Dijkstra Algorithm

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Abstract

Waste is a complex problem that has the potential to cause environmental degradation if not handled properly. Waste management in Banyumas Regency, particularly in the Purwokerto area, encounters several fundamental limitations, including the limited capacity of the transportation fleet and the lack of an integrated route distribution system. Based on the documentation of the Banyumas Regency Environmental Service, of the total daily waste generation amounting to 600 tons, only 45% is transported to the Final Disposal Site (TPA), highlighting the urgent need for optimization in the waste management system. This study applies the Dijkstra Algorithm using the greedy principle, which weights the distances between points and calculates the minimum value to develop a simulation for determining the shortest route for transporting waste from the Temporary Shelter (TPS) to the TPA in Purwokerto. The results of the computational analysis indicate that the optimal route from the Environmental Service office to the TPA/PDU Tanjung is 10.553 kilometers long, involving eight stages of algorithmic iteration. This finding confirms the efficiency of the route compared to other alternatives, supporting the acceleration of waste reduction and handling targets in alignment with the Banyumas Regency's strategic policy directives.

1. Introduction

Daily human activities invariably produce residue in the form of waste, an unavoidable consequence of modern consumption patterns. Waste is a complex issue that can lead to environmental degradation if not managed properly [1]. Unwittingly, humans are waste producers, and if its management is neglected, waste can cause severe environmental pollution. The volume of waste production can increase due to factors within the community environment, as well as contributions from industrial sources and their associated waste. As a result, the volume of waste in Indonesia increases annually [2]. Therefore, the rate of waste accumulation must be monitored, and the quality of waste management must be improved to mitigate the negative impacts of waste.

Waste management remains a widespread issue in many areas, including Purwokerto City, Banyumas Regency. The Head of the Banyumas Regency Environmental Service reported that the daily waste production in Banyumas Regency amounts to 600 tons, based on the assumption that each resident generates 0.3 kg of waste per day, with a population of two million. Of this amount, only 45%, or approximately 270 tons of waste per day, is transported by the Environmental Service (DLH) for disposal at the TPA. According to the Banyumas Regency regional strategy policy on household and household-like waste outlined in the 2020 draft regional regulation, the waste reduction target is 30%, while the handling target is 70% by 2025 [3]. Another issue arises when waste accumulates in individual trash cans or during its transportation by officers. Waste collection in Purwokerto City is conducted using trucks, with different officers visiting each house, often without standardized guidance. As a result, the waste in trash cans becomes disorganized, leading to inefficient transportation.

To optimize waste management and reduction in Banyumas Regency, especially in Purwokerto City, this study offers a solution in the form of optimizing the waste transportation route from the Temporary Shelter (TPS) to the Final Processing Site (TPA). The optimization process is carried out by determining the shortest path, which is represented in the form of a graph. In the graph, the path is calculated based on the total weight connecting the nodes in the graph. In this context, the weight represents the distance between nodes, where each node represents a connected TPS [4]. The shortest path is determined using the Dijkstra Algorithm, a method widely applied in graph theory. This algorithm operates by comparing the smallest weights from the starting node to the destination node, enabling it to identify the most efficient path. The key advantage of this algorithm lies in its ability to handle positive-weight graphs and determine the optimal shortest path between points [5].

The Dijkstra Algorithm has been extensively applied to optimize various systems, particularly in the transportation sector. In this study, the algorithm was selected for its capability to determine the optimal route for transporting waste from TPS to TPA. This approach is expected to enhance the efficiency of waste transportation and support improved waste management targets [6]. Previous research by Gautama and Hermanto (2020) focused on optimizing school bus routes in Denpasar City using the Dijkstra Algorithm to determine the shortest distance traveled, directly influencing cost and time efficiency. The study found that the total route for the morning shift school bus covered 95.5 km. Using Pertadex fuel, priced at IDR 9,400 per liter with an efficiency of 12.8 km per liter, the fuel cost amounted to IDR 70,132. This study offers the Denpasar City Transportation Agency insights into how the Dijkstra Algorithm can be applied to optimize routes and reduce transportation operational costs [7].

This study seeks to develop a simulation using the Dijkstra Algorithm to identify the shortest waste transportation route from TPS to TPA in Purwokerto City, Banyumas Regency, addressing the previously described problems. This approach is expected to provide an optimal solution for supporting the waste reduction and handling targets established by the Banyumas Regency Environmental Service, aligning with the characteristics of existing waste management challenges.

2. Methodology

This study adopts a systematic methodological approach, focusing on a case study of waste transportation operations managed by the Banyumas Regency Environmental Service. The research methodology stages are comprehensively depicted in the procedural framework presented in Figure 1.

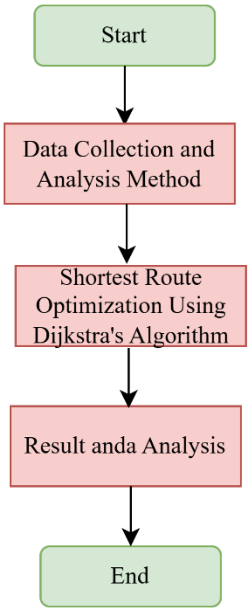

Fig 1. Research flow

2.1. Data Collection and Analysis Method

The data collection process involves gathering comprehensive information essential for supporting investigations and identifying problems based on the obtained data. This study focuses on a case study aimed at optimizing the shortest route for waste transport vehicles in Kedungwuluh Village, Banyumas

Regency, to determine the most efficient path. This study primarily relies on secondary data as the main source of information. The specific data includes measurements of the distance between Kedungwuluh Village and the Waste Recycling Center (PDU) in Banyumas Regency. All distance information is obtained using the Google Maps digital mapping service as a measurement tool.

2.2. Shortest Route Optimization using Dijkstra's Algorithm

Selecting the shortest route is an effective method to reduce the time required to complete a task [8]. For waste transportation by garbage trucks to the Final Disposal Site (TPA), selecting the shortest route is essential to prevent waste accumulation at the Temporary Waste Disposal Site (TPS). The use of the Dijkstra algorithm is taken based on the smallest value or weight on each vertex in a route. Each vertex that has a value will be analyzed, if there is a vertex with a small value, it means that the route direction will pass through that vertex. However, if there is another vertex with a value smaller than the previous vertex, the route will be changed through the vertex with the smallest value. Thus, this Dijkstra algorithm will go through routes where each vertex is represented by the smallest value. If all vertices have been passed, the use of the Dijkstra algorithm will stop [9]. From the steps above, after knowing the interconnected points on the graph and the weight of each node, the shortest weight of the target point expression can be calculated using the formula.

$$D(vi) = \min\ (D(vj), D(vi) + W(vi, vj)) \tag{1}$$

Where $D(vi)$ is the sum of the smallest weights from vi to vj while $W(vi, vj)$ is the node weight from vi to vj which will be calculated by calculating the minimum smallest weight from $D(vi)$to $D(vj)$ [10].

The sequence of steps for determining the shortest route for the garbage truck is outlined as follows:

1) Determine the base map location: Identify the base map that will serve as the foundation for defining the overall route path.
2) Assign values to nodes and establish connections: Assign values to each node and define the connections between nodes for each TPS (Temporary Waste Disposal Site) on the route. Label the nodes for clarity.
3) Measure the distance for each node: Perform distance calculations with the following steps:
   a. Assign a value of 0 to the initial node and an infinite value to all other nodes.
   b. Fix the value of the initial node as permanent, and assign temporary distance values to the remaining nodes.
   c. Set the initial node as the active node.
   d. Evaluate all neighboring nodes of the active node by adding the length of each edge to the node's value.
   e. If the resulting value is smaller than the current temporary value of a neighboring node, update its distance value.
   f. Select the node with the smallest distance value as the new active node and assign it a permanent value.
   g. Repeat steps (d) to (f) until no neighboring nodes with temporary distance values remain.
4) Analyze results: Upon completing the above process using the Dijkstra Algorithm, analyze the results at the research methodology stage. The outcome will provide the shortest path from the starting location to the destination PDU (Waste Recycling Center) or TPA (Final Disposal Site).

For a detailed visualization of the analysis process and the shortest path determination, refer to Figure 2.

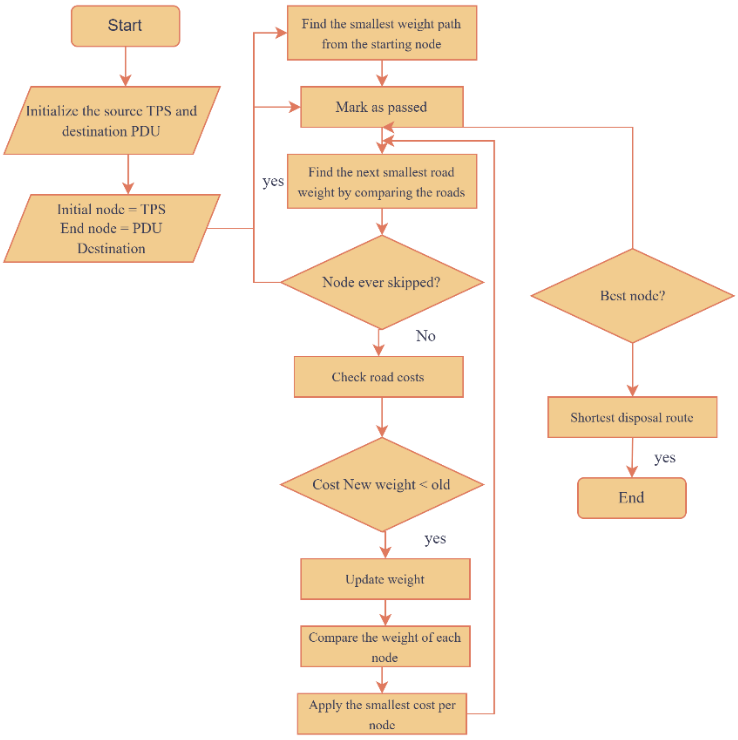

Fig 2. Shortest Path Determination Flow

3. Results and discussions

The domestic waste collection process in the Purwokerto area is operated using a garbage collection vehicle, with the starting point of operation being at the Banyumas Regency DLH office. The location of the final waste processing or TPA is in the PDU Tanjung area located in the South Purwokerto area, with the following details:

3.1. Route Optimization Steps

Steps to generate the optimal route for a garbage truck using Dijkstra's Algorithm:

1) Distance Table Creation:
   a. Prepare a table that includes the distance between connected points in the research area.
   b. Each point represents a specific location, such as TPS (Temporary Shelter) and PDU (Waste Recycling Center).
   c. The distance between points that do not have a direct connection is also calculated and entered into the table, including the distance from all points to the PDU.
2) Application of Dijkstra's Algorithm:
   a. Dijkstra's algorithm is used to determine the order of waste collection from each TPS.
   b. The transportation route is designed to cover these points before heading to the PDU, with priority on the shortest distance to increase efficiency.
3) Route Formation:

The results of data processing are in the form of the most optimal waste transportation route, covering all designated TPS to the PDU as the final destination.

3.2. Distance Determination and Tabulation

Determining the distance between points is by using the length of each road segment determined by looking at the map of Purwokerto City, Banyumas Regency using GoogleMaps. The distance of each known point is then placed in a distance table.

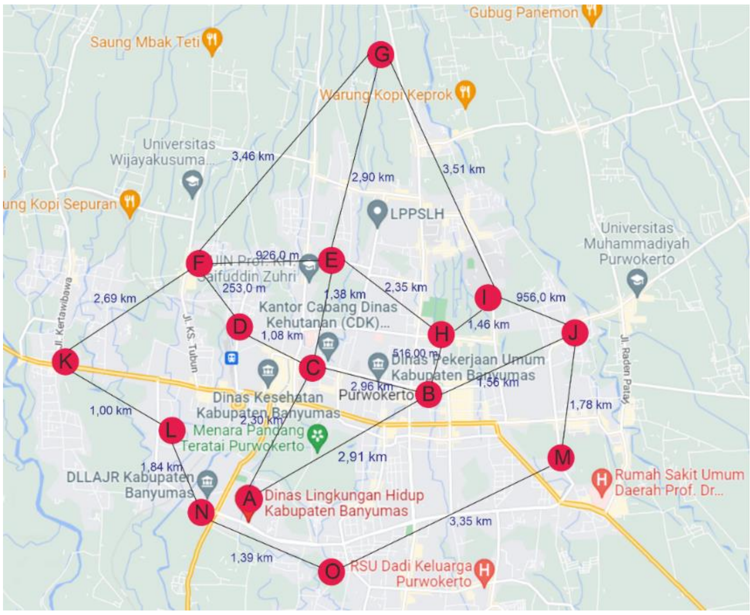

Fig 3. Sketch of a Map of Purwokerto City

Figure 3 shows a sketch of the Purwokerto city route. The line shows the road where the TPS is located, and the red node indicates its location.

Table 1. Distance from TPS to PDU

No	Node Location Name	Node	Point	Distance
1	Jl. Gerilya Barat (Dinas Lingkungan Hidup)	A	A to B A to C	2,91 km 2,30 km
2	Pasar Wage Purwokerto Wetan	B	B to C B to H B to J	2,96 km 516 m 1,56 km
3	Pasar Manis Purwokerto Barat	C	C to B C to D C to E	2,96 km 1,08 km 1,38 km
4	Kober Purwokerto Barat	D	D to C D to F	1,08 m 253 m
5	Pasar Ikan Purwanegara	E	E to C E to F E to H E to G	1,38 km 926 m 2,35 km 2,90 km
6	Bobosan Purwokerto Utara	F	F to D F to E F to G F to K	253 m 926 m 3,46 km 2,69 km
7	Red Chili Pabuaran	G	G to E G to F G to I	2,90 km 3,46 km 3,51 km
8	Dominic Hotel Purwokerto Lor	H	H to B H to E H to I	516 m 2,35 km 1,46 km
9	Gacoan Purwokerto Karangwangkal	I	I to G I to H I to J	3,51 km 1,46 km 956 m
10	SPBU Arcawinangun	J	J to B J to I	1,56 km 956 m

			J to M	1,78 km
11	Karanglewas Lor	K	K to F K to L	2,69 km 1,00 km
12	Pasir Kulon Purwokerto Selatan	L	L to K L to N	1,00 km 1,84 km
13	Berkoh Purwokerto Selatan	M	M to J M to O	1,78 km 3,35 km
14	Tanjung Purwokerto Selatan	N	N to L N to O	1,84 m 1,39 km
15	Pusat Daur Ulang Sampah Tanjung	O	O to N O to M	1,39 km 3,35 km

3.3. The Search for the Shortest Path

Table 2. Distance from TPS to PDU

Iteration	From A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
1	A	2,91 A	2,30 A	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
2	C	2,91 A	2,30 A	3,38 C	3,68 C	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
3	D	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	∞	∞	∞	∞	∞	∞	∞	∞	∞
4	F	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	7,093 F	∞	∞	∞	6,323 F	∞	∞	∞	∞
5	K	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	7,093 F	∞	∞	∞	6,323 F	7,323 K	∞	∞	∞
6	L	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	7,093 F	∞	∞	∞	6,323 F	7,323 K	∞	9,163 L	∞
7	N	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	7,093 F	∞	∞	∞	6,323 F	7,323 K	∞	9,163 L	10,553 N
8	O	2,91 A	2,30 A	3,38 C	3,68 C	3,633 D	7,093 F	∞	∞	∞	6,323 F	7,323 K	∞	9,163 L	10,553 N

Based on the distance of the interconnected points, it can be concluded that

a. The shortest distance from A to B is A-B with a length of 2.91 km
b. The shortest distance from A to C is A-C with a length of 2.30 km
c. The shortest distance from A to D is A-C-D with a length of 3.38 km
d. The shortest distance from A to E is A-C-E with a length of 3.68 km
e. The shortest distance from A to F is A-C-D-F with a length of 3.633 km
f. The shortest distance from A to G is A-C-D-F-G with a length of 7.093 km
g. The shortest distance from A to H
h. The shortest distance from A to I
i. The shortest distance from A to J
j. The shortest distance from A to K is A-C-D-F-K with a length of 6.323 km
k. The shortest distance from A to L is A-C-D-F-K-L with a length of 7.323 km

l. The shortest distance from A to M
m. The shortest distance from A to N is A-C-D-F-K-L-N with a length of 9.163 km
n. The shortest distance from A to O is A-C-D-F-K-L-N with a length of 10.553 km

The application of Dijkstra's Algorithm to determine the shortest path from point A to point O has been completed by adhering to procedural steps based on graph theory. In the initial stage, all successor points are assigned a value of ∞ (infinity) to indicate that no path has yet been identified. Meanwhile, the source point, point A, is assigned a value of 0, as it represents the starting point of the path. This approach ensures the clear initialization of values for all points to be evaluated. Subsequently, the algorithm begins by selecting point A as the starting point and evaluating all directly adjacent points, namely points B and C. At this stage, Dijkstra's Algorithm identifies the smallest value among the neighbors, selecting point C with a path weight of 2.30. The algorithm continuously selects the smallest value by updating the weight at each iteration until all paths are evaluated, and the shortest path is determined. Based on the Dijkstra Algorithm, the shortest path from point A to point O follows the route A-C-D-F-K-L-N, with a total path weight of 10.553 km, rounded up to 11 km. This calculation involves eight iterations, during which the trajectory is evaluated and updated at each step to achieve the final result.

The identified route covers several strategic locations in the Purwokerto area. It begins at Jl. Gerilya Barat, the site of the Environmental Service, and continues through Pasar Manis in Purwokerto Barat, the Kober Purwokerto Barat area, Bobosan in Purwokerto Utara, Karanglewas Lor, and Pasir Kulon in Purwokerto Selatan, before concluding at the Waste Recycling Center (PDU) in Tanjung, Purwokerto Selatan. This approach ensures the route is optimal in terms of distance and enhances efficiency in waste transportation distribution. Furthermore, this algorithmic process demonstrates how applied mathematics can effectively address logistical and transportation challenges.

4. Conclusion

The calculation results obtained using the Dijkstra Algorithm conclude that the shortest route for garbage trucks in Purwokerto City, Banyumas Regency, from the Environmental Service Office (DLH) to the TPA/Waste Recycling Center (PDU) in Tanjung, Purwokerto Selatan, covers a distance of 10.553 km, rounded up to 11 km. The algorithmic process involves eight iterations. The identified route passes through Jl. Gerilya Barat (Environmental Service), Pasar Manis in Purwokerto Barat, Kober in Purwokerto Barat, Bobosan in Purwokerto Utara, Karanglewas Lor, and Pasir Kulon in Purwokerto Selatan before reaching the Tanjung Waste Recycling Center. This distance represents the most optimal and efficient route compared to alternative paths. The Dijkstra Algorithm has proven highly effective for solving the shortest path problem due to its advantages, including efficient processing time (running time) and its ability to identify the path with the minimum distance. Furthermore, the results of this study demonstrate that mathematical and algorithmic approaches, such as Dijkstra's, can be applied not only to theoretical problems but also to practical challenges, such as waste transportation in urban areas. This research offers significant potential for further development. It is recommended to integrate additional coordinate points, including more starting points and destinations, to expand the coverage area and address more complex operational conditions. Such an approach could optimize waste transportation routes on a city-wide scale, rather than focusing on a single main route.

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