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Application of dijkstra algorithm to optimize waste transportation distribution routes in Tegal Regency

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ABSTRACT

Efficient waste management is essential for sustainable urban development, especially in densely populated areas such as Tegal Regency. The study addresses inefficiencies in current waste hauling routes that contribute to increased operational costs and environmental impacts due to long transit times and increased emissions. By applying the Dijkstra Algorithm, this study aims to optimize waste transportation routes to reduce these inefficiencies. This approach involves collecting primary and secondary data on the waste management system in Tegal, which is then analyzed using the *dijkstra* algorithm to determine the most efficient transport route. The findings show that route optimization can significantly reduce operational costs and carbon emissions, contributing to more sustainable waste management practices in the Tegal District. This study not only improves theoretical understanding of route optimization but also provides practical solutions to real problems in waste management systems.

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1. INTRODUCTION

Facing global challenges related to environmental management, waste management is one of the main issues that require serious attention, especially in urban areas and districts such as Tegal (Supriyanto, 2022), (Hidayat et al., 2023). Waste, as a byproduct of human activities, if not managed properly, can cause a variety of environmental, economic, and social problems. In Tegal Regency, the waste transportation system faces various obstacles, including route inefficiencies that lead to increased transportation times, operational costs, and negative environmental impacts (Shah et al., 2021). This study identifies several factors that cause inefficiencies in the waste transportation system in Tegal Regency. First, suboptimal routes and scheduling lead to longer and inefficient trips, increasing operational costs. Second, variations in waste volumes at different locations make it difficult to plan effective routes. Third, poor road infrastructure conditions slow down vehicles and increase maintenance costs. Fourth, ineffective fleet management, such as inappropriate vehicle allocation and lack of maintenance, increases downtime and reduces efficiency. Lastly, the lack of use of data and modern technology makes route management unresponsive to changes in actual conditions on the ground.

This problem becomes significant because such inefficiencies not only affect environmental sustainability but also people's quality of life (Severo et al., 2021). Increased greenhouse gas emissions from inefficient garbage transport vehicles are contributing to global climate change (Shen et al., 2020). Therefore, this research was conducted to find solutions to these problems, focusing on optimizing waste transportation routes using algorithms *Dijkstra* (Hidayatulloh et al., 2023), (Manoharam et al., 2021).

This research is important because it aims to solve the problem of route inefficiencies in waste transportation systems, which in turn can reduce operational costs, transport time, and carbon emissions. This study also seeks to fill gaps in the academic literature regarding the application of route optimization techniques in the context of waste management in areas such as Tegal Regency.

To solve this problem, this study used an algorithm *dijkstra*, known for its ability to find the shortest route between two points in a graph (Wayahdi et al., 2021), (Salem et al., 2022). This study adapts the algorithm for the context of waste transportation, taking into account specific variables such as road type, waste volume, and haulage time (Yazdani et al., 2021), (Mojtahedi et al., 2021).

In this study, the methods used include primary and secondary data collection related to the waste transportation system in the Tegal Regency, data analysis using algorithms *dijkstra*, and simulations to determine optimal waste transport routes. The state of the art of the study lies in the practical application of algorithms *dijkstra* in a specific and innovative context, namely optimization of waste transportation distribution routes (Shahrier & Hasnat, 2021), (Yazdani et al., 2021).

The innovation proposed through this research is the adaptation and modification of the algorithm *dijkstra* to consider specific factors of garbage transport, such as vehicle capacity, road type, and transport time restrictions (Ragavan et al., 2021), (Pourhejazy et al., 2021). It is hoped that this research will produce a route optimization model that can be implemented by the Tegal Regency government to improve the efficiency of waste transportation. The Dijkstra algorithm was chosen because of its several advantages in route optimization. These algorithms are able to quickly find the shortest routes in complex networks, which is crucial for operational efficiency in waste transportation. Its ability to manage many points and variables makes it suitable for the conditions of Tegal, which has many waste collection locations and diverse road infrastructure. Its simplicity of implementation and adaptability to local conditions make it a stable and reliable solution compared to other methods.

This research not only contributes to science through the development of new theories and methods in route optimization but also provides practical solutions to waste management problems in the Tegal District. The results of this study are expected to help local governments in planning and implementing a more efficient, sustainable, and environmentally friendly waste transportation system. This research is expected to have a significant positive impact on the quality of life for the residents of Tegal Regency. Optimizing waste transportation routes will reduce travel time and operational costs, allowing resources to be redirected to other urgent needs. Shorter travel times will also decrease carbon emissions and pollution, leading to improved air quality.

Research on Dijkstra's algorithm has seen significant advancements and varied applications across different domains. Recent studies have focused on optimizing the classical algorithm to enhance its efficiency and adaptability. An investigation (Buzachis et al., 2021) introduced a hybrid approach combining dijkstra algorithm with A* for improved performance in dynamic routing scenarios. Similarly, (Alghamdi et al., 2023) developed a parallelized version of *dijkstra* algorithm that leverages GPU acceleration, demonstrating substantial reductions in computational time for large-scale networks. Another study by (Liu et al., 2020) explored the integration of machine learning techniques to predict optimal paths, thereby reducing the algorithm's dependency on real-time computations. In the realm of robotics, (Dirik & KOCAMAZ, 2020) applied a modified dijkstra's algorithm to enhance pathfinding efficiency in autonomous navigation systems. Finally, a comprehensive review by (Boubedra et al., 2023) evaluated the algorithm's application in smart city planning, highlighting its role in optimizing urban traffic flows and infrastructure management. These studies collectively underscore the ongoing evolution and broad applicability of Dijkstra's algorithm in addressing contemporary computational challenges.

This study identified several gaps in the literature related to waste management and route optimization. There are limited applications of advanced algorithms in waste management. Although various algorithms already exist for route optimization, their application in specific contexts such as Tegal Regency is still poorly explored. Many studies apply optimization techniques in general but often ignore local specificities or fail to adapt algorithms to the unique challenges of waste management systems in smaller or under-studied areas. Environmental management is a critical global challenge, with waste management being a significant issue, especially in urban areas like the Tegal Regency. Inefficient waste transportation systems contribute to environmental, economic, and social problems. Waste management faces numerous obstacles, including inefficient transportation routes that increase operational costs, transportation times, and negative environmental impacts. This research focuses on optimizing waste transportation routes using Dijkstra's algorithm to address inefficiencies and their impacts.

2. RESEARCH METHOD

This method section provides a clear and systematic framework for conducting researching on the optimization of waste transportation distribution routes in the Tegal Regency. The quantitative approach with a combination design of experimental methods, quantitative analysis, and model validation ensures that this research can produce valid, accurate, and applicable solutions.

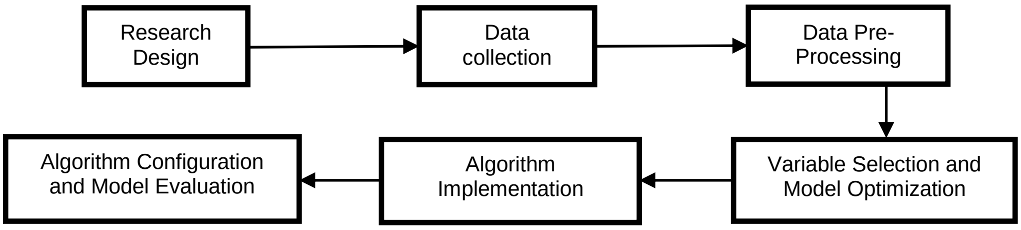

Figure 1. Method Flow

Figure 1 describes a process that begins with the determination of research objectives, followed by a research design that integrates experimental methods, quantitative analysis, and model validation. After that, data collection and data pre-processing are carried out to prepare for analysis. The next step is variable selection and model optimization to develop optimal solutions, which are then applied in the implementation of the algorithm. The process ends with the configuration of the algorithm and the evaluation of the model to validate the effectiveness and applicability of the research results.

Research Design

This study used a combinative research design involving experimental methods, quantitative analysis, and model validation. An experimental approach was used to test the effectiveness of *the Dijkstra Algorithm* in the optimization of waste transport routes. Quantitative analysis is performed to evaluate the efficiency improvements generated by the algorithm. Model validation is performed to ensure the accuracy and reliability of the proposed solution.

Data Collection

The data used in this study included information on the road network in Tegal Regency, and the location of landfills. This data is obtained from the Google Maps https://www.google.co.id/maps to ensure the accuracy and completeness of the required data.

Table 1. Distance of the location of the temporary dump to the final dump

No	Temporary dump location	Distance (m)
1	Landfill Ceplik, Kesuben	18000
2	Landfill Trayeman, Slawi Market	11000
3	Landfill Sidul Merekah, Lebaksiu Kidul	14000

Data Pre-processing

The collected data then undergoes a pre-processing process, which includes data cleansing, normalization, and data transformation. The purpose of pre-processing is to ensure that the data used in the study is accurate, complete, and ready for analysis.

Variable Selection and Model Optimization

The variables chosen for model optimization include distance, transport time, and operational costs. Model optimization is carried out with the aim of finding the most effective algorithm configuration to reduce these variables. This process involves adjusting algorithm parameters and testing various transport scenarios.

Algorithm Implementation

Algoritma *dijkstra* was implemented to determine the shortest route from the waste collection point to the landfill site (Mananoma et al., 2021), (Wirastuti et al., 2023). The implementation of the algorithm is done using the appropriate programming language and is run on a pre-processed dataset (Sharma et al., 2020).

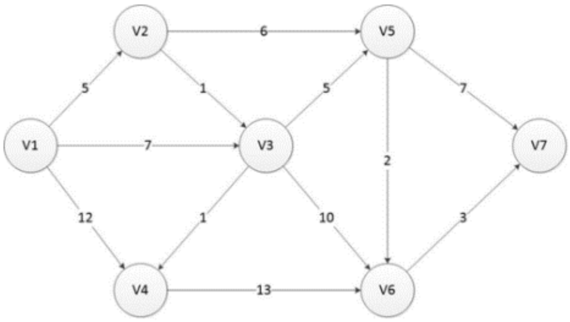

Figure 2. *Dijkstra* algorithm flow

Figure 2 shows a graph for finding the shortest route from V1 to V7, having multiple route points with weights, with each node connecting each point (Sipayung et al., 2023), (Sun et al., 2021). The following are the steps to calculate the shortest route using the algorithm *dijkstra*. First, determine the start and end points for the shortest distance calculation. Then, initialize the distance of all nodes except the initial node as infinity, while the initial node is initialized with zero spacing. The next step is to identify the nearest unvisited node from the original node. This node will be used as the current node. For each neighbour of the current node, calculate the total distance from the original node to that neighbour and update the distance if the new total distance is smaller. After that, mark the current node as visited. Repeat the process of identifying nearby nodes, calculating distances, and marking nodes as visited until all nodes have been visited or end nodes found. If the end node is successfully found, then the shortest distance is the distance from the initial node to the end node, otherwise it means that there is no path available from the initial node to the end node.

From the above step, after knowing the interconnected points on the graph and the weight of each node, we can calculate the shortest weight of the target point expression with formulas.

$$D(vi) = min\big(D(vj), D(vi) + W(vi, vj)\big) \quad (1)$$

Where D(vi) is the smallest amount of weight 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) (Addanki et al., 2020).

Algorithm Configuration and Model Evaluation

Algorithm configuration involves tuning algorithm parameters to achieve the best route optimization. Model evaluation is performed to ensure that the routes generated by the algorithm are optimal. Evaluation metrics include a comparison of transport time, operational costs, and carbon emissions before and after algorithm implementation. External validation is carried out through field simulations and feedback from relevant stakeholders.

3. RESULTS AND DISCUSSION

The research on optimizing waste transportation routes in Tegal Regency through the application of Dijkstra's algorithm employs a comparative approach to understand and integrate best practices from other countries. Specifically, the study compares waste management systems and optimization techniques from Indonesia with those used in countries like Singapore and Sweden. These countries are chosen based on their exemplary performance in waste management and their diverse approaches to handling waste transportation efficiently. The comparative analysis also highlights gaps in the current system and suggests potential areas for development based on successful practices from other countries. This approach ensures that the recommendations are grounded in proven methodologies and tailored to the specific needs and capabilities of Tegal Regency, ultimately aiming to enhance the efficiency and sustainability of its waste management system.

Base Map

This research case study was conducted in Tegal Regency, Central Java. The data used were roads from three samples of Landfills in Tegal Regency, namely Landfill Ceplik Kesuben, Landfill Trayeman Slawi Market, Landfill Sidul Merekah Lebaksiu Kidul with the aim of Landfill Penujah Village, Kedungbanteng District, Tegal Regency. In this study using the base map of Tegal Regency from https://www.google. co.id/maps. To calculate the distance between one node and another. To initialize nodes and calculate the distance between nodes using Google Maps.

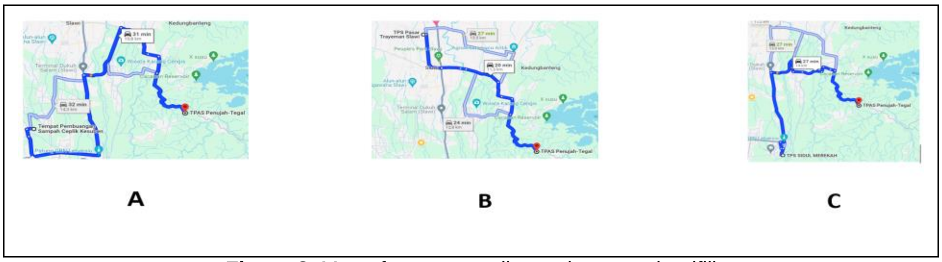

Figure 3. Map of temporary disposal route to landfill

Figure 3 shows a map of the route from the three Temporary Dumping Sites to the Landfill, figure A is the route from the Ceplik Kesuben Temporary Dumping Site, Picture B, is the route from the Trayeman Slawi Market Temporary Dumping Site, and Figure C is the route from the Sidul Merekah Temporary Dumping Site, Lebaksiu Kidul.

Node Identification Process

Based on the base map of Tegal Regency taken from https://www.google.co.id/maps, the size of each side is calculated using Google Maps. The identification process from three Temporary Dumping Sites in Tegal Regency to the Penujah Village Landfill in Tegal Regency resulted in 29 nodes. The process of identifying nodes / points in this study can be illustrated as follows.

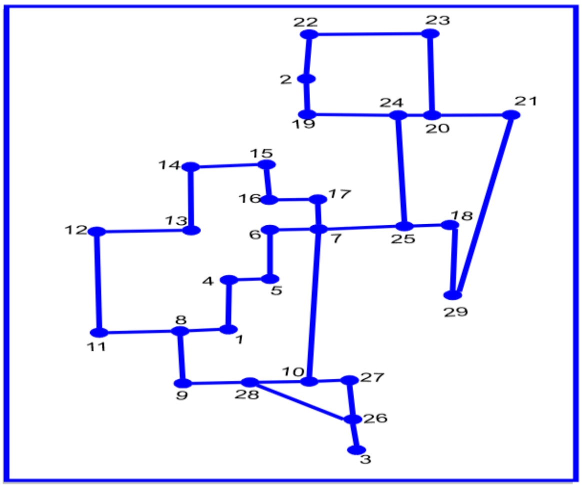

Figure 4. Nodes/point identification

Table 2. Node description

No. Node	Information
1	Landfill Ceplik, Kesuben
2	Landfill Trayeman Slawi Market
3	Landfill Sidul Merekah, Lebaksiu Kidul
4	Sidomakmur Sreet
5	Brug Duwur Lebakowah Market
6	Jomblang Jaya Building Shops
7	Lingkar Slawi Street
8	Perempatan Ceplik, Kesuben
9	Tegal - Purwokerto Highway
10	Patung GBN Lebaksiu
11	Balaradin Street
12	Kambangan Green Open Space
13	Tegalandong Highway
14	R.A Kartini Street
15	W.R Supratman Street
16	Cipto Mangunkusumo Street
17	Dukuhsalam Street
18	Dukuhjati Kidul Village Hall
19	Tugu Nol Kilometer Slawi II
20	SPBU Pertamina Pangkah
21	Dukuhjati Kidul Highway
22	Flores Baru Street
23	Among Djiwo Street
24	Slawi Pangkah Highway
25	Penusupan Village Hall
26	SDN Lebaksiu 1 Street
27	Bukit Sitanjung Street
28	Gerbang Desa Lebaksiu Kidul
29	Landfills Penujah - Tegal

Process of measuring the distance between nodes

The distance measurement of each node is carried out using Google Maps https://www.google.co.id/maps so as to obtain node distance information as follows.

Table 3. Distance data between nodes

Node		Initialization Between Nodes	Distance (m)
A	B		
1	8	J1	750
1	4	J2	1000
4	5	J3	850
5	6	J4	2300
6	7	J5	5600
8	9	J6	1200
8	11	J7	1200
9	28	J8	2800
11	12	J9	3400
12	13	J10	2200
13	14	J11	1400
14	15	J12	1000
15	16	J13	2000
16	17	J14	650
17	7	J15	4500
28	10	J16	200
10	27	J17	110
26	27	J18	600
26	28	J19	300
3	26	J20	700
2	19	J21	2400
19	24	J22	2500
24	25	J23	2900
7	25	J24	3000
25	18	J25	2500
18	29	J26	3500
2	22	J27	750

Node		Initialization Between Nodes	Distance (m)
A	B		
22	23	J28	4000
23	20	J29	1100
20	24	J30	300
20	21	J31	2600
21	29	J32	3900

Dijkstra Algorithm Testing

The *dijkstra* algorithm test step took three samples of Landfill, namely Landfill Ceplik Kesuben, Landfill Trayeman Market Slawi, Landfills Sidul Merekah Lebaksiu Kidul with the aim of Landfill Penujah Village, Kedungbanteng District, Tegal Regency using calculations in Microsoft *Excel.*

1. Testing from landfills Ceplik, Kesuben

Table 4. Data input between nodes passed from the ceplik temporary to the penujah landfill

Node Start	Node End	Traversed Nodes	Distance (m)
1	8	J1	750
8	9	J1, J6	1950
9	28	J1, J6, J8	4750
28	10	J1, J6, J8, J16	4950
10	7	J1, J6, J8, J16, J18	13250
7	25	J1, J6, J8, J16, J18, J25	1200
25	18	J1, J6, J8, J16, J18, J25, 26	18750
18	29	J1, J6, J8, J16, J18, J25, J26, J27	22250
1	4	J2	1000
4	5	J2, J3	1850
5	6	J2, J3, J4	4150
6	7	J2, J3, J4, J5	9750
7	25	J2, J3, J4, J5, J25	12750
25	18	J2, J3, J4, J5, J25, J26	15250
18	29	J2, J3, J4, J5, J25, J26, J27	18750

Table 5. *Dijkstra* algorithm calculation shortest distance from node 1

Node	Shortest Distance	Previous Node	Value
1			
4	1	J2	1950
5	4	J2, J3	1850
6	5	J2, J3, J4	4150
7	6	J2, J3, J4, J5	9750
8	1	J1	750
18	25	J2, J3, J4, J5, J25, J26	15250
25	7	J1, J6, J8, J16, J18, J25	1200
29	18	J2, J3, J4, J5, J25, J26, J27	18750

Table 4 is the data input process between nodes passed from the Ceplik Temporary Landfill to the Colonizer Landfill, table 5 is the shortest route calculation generated based on the data from table 4. The shortest route resulting from the Ceplik Temporary Landfill to the Penujah Landfill is 18750 meters.

2. Testing from landfills Trayeman Slawi Market

Table 6. Data input between nodes passed from the Trayeman Slawi Market Landfill to the Penujah Landfill

Node Start	Node End	Traversed Nodes	Distance (m)
2	19	J22	2400
2	22	J28	750
19	24	J22, J23	4900
24	20	J22, J23, J32	7500
24	25	J22, J23, J24	7800
25	18	J22, J23, J24, J26	10300
18	29	J22, J23, J24, J26, J27	13800
20	21	J22, J23, J31, J32	7800

21	29	J22, J23, J31, J32, J33	11700
22	23	J28, J29	4750
23	20	J28, J29, J30	5850
20	21	J28, J29, J30, J32	8450
21	29	J28, J29, J30, J32, J33	12350

Table 7. *Dijkstra* algorithm calculation shortest distance from node 2

Node	Shortest Distance	Previous Node	Value
2			
19	2	J22	2400
22	2	J28	750
24	19	J22, J23	4900
23	22	J28, J29	4750
20	24	J22, J23, J32	7500
29	21	J22, J23, J31, J32, J33	11700

Table 6 is the data input process between nodes passed from the Trayeman Slawi Market Temporary Dump to the Colonizer Landfill, table 7 is the shortest route calculation generated based on the data from table 6. The shortest route resulting from the Trayeman Slawi Market Landfill to the Penujah Landfill is 11700 meters.

3. Testing from landfill Sidul Merekah, Lebaksiu Kidul

Table 8. Data input between nodes passed from the Sidul Merekah, Lebaksiu Kidul Landfill to the Penujah Landfill

Node Start	Node End	Traversed Nodes	Distance (m)
3	26	J21	700
26	27	J21, J20	1300
26	28	J21, J19	1000
27	10	J21, J20, J17	1410
10	7	J21, J20, J17, J18	9710
7	25	J21, J20, J17, J18, J25	12710
25	18	J21, J20, J17, J18, J25, J26	15210
18	29	J21, J20, J17, J18, J25, J26, J27	18710
28	10	J21, J19, J16	1200
10	7	J21, J20, J16, J18	9500
7	25	J21, J20, J16, J18, J25	12500
25	18	J21, J20, J16, J18, J25, J26	15000
18	29	J21, J20, J16, J18, J25, J26, J27	18710

Table 9. *Dijkstra* algorithm calculation shortest distance from node 3

Node	Shortest Distance	Previous Node	Value
3			
26	3	J21	700
27	26	J21, J20	1300
10	28	J21, J19, J16	1200
7	10	J21, J19, J16, J18	9500
25	7	J21, J20, J16, J18, J25	12500
18	25	J21, J20, J16, J18, J25, J26	15000
29	18	J21, J20, J16, J18, J25, J26, J27	18500

Table 8 is the process of data input between nodes passed from the Sidul Merekah Temporary Landfill, Lebaksiu Kidul to the Penujah Landfill, table 9 is the shortest route calculation generated based on data from table 6. The shortest route resulting from the Sidul Merekah Temporary Landfill to the Penujah Landfill is 18500 meters.

4. CONCLUSION

The *dijkstra* Algorithm was tested at three waste collection points, demonstrating its efficiency in finding the shortest routes to the Penujah landfill. From landfill Ceplik Kesuben, the shortest path measured 18.750 meters, from landfill ground Trayeman Slawi Market, it was 11.700 meters, and from landfill Sidul Merekah Lebaksiu Kidul, 18.500 meters. Each location utilized detailed input tables to calculate paths based on node data and distances traveled. These results showcase the *Dijkstra* Algorithm's precision in optimizing waste transport routes, enhancing the operational efficiency of waste management facilities and helping to plan infrastructures that reduce transport times and costs effectively. The research on optimizing waste transportation routes in Tegal Regency using Dijkstra's algorithm has limitations. It relies on Google Maps data, which may not reflect real-time road conditions, and focuses mainly on distance without considering traffic, road quality, or environmental impacts. The model also lacks adaptability to dynamic changes in waste patterns and road conditions. Future research should integrate real-time traffic data, environmental assessments, and machine learning to enhance robustness and applicability. Field validation and stakeholder feedback are essential for practical feasibility and continuous improvement. Improving waste transportation efficiency significantly impacts climate change and reduces greenhouse gas emissions by cutting fuel consumption, minimizing travel distances, and decreasing traffic congestion. This leads to lower carbon dioxide emissions and overall atmospheric pollution, promoting sustainable waste management and environmental innovations.

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