pIJmath

Pattimura International Journal of Mathematics (PIJMath)

Volume 03, issue 02, pages 069-076, Month Year
E-ISSN : 2830-6791

RESEARCH ARTICLE ◙ *OPEN ACCESS*

DOI: https://doi.org/10.51135/pijmathvol3iss2p69-76

Optimization Of The Water Distribution Network of Regional Water Utility Company (PDAM) Using Prim Algorithm

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ABSTRACT

Article History

Received: September, 20th 2024
Accepted: November, 3rd 2024
Published: November, 30th 2024

Keywords

Graph;
Prim Algorithm;
Distribution Network.

Graph Theory is an old part of mathematics but has many applications. Graphs are used to represent discrete objects and the relationships between them. One of its applications is in the field of network optimization to find the minimum total pipe length. This research will implement Prim algorithm in optimizing the water distribution network of PDAM Tirta Keumueneng Langsa City with the help of the MATLAB software program. The data used is in the form of secondary data, namely a map image of the water distribution network area and the length of the pipe used in PDAM Tirta Keumueng Langsa City. Based on this data, it can be represented as a graph, which can then be obtained a minimum spanning tree using Prim algorithm with the help of the MATLAB software program. The results showed that the minimum total length of pipe produced by Prim's algorithm was 105.080,8 meters. This means that it can be said that the application of the Prim algorithm provides an optimal total pipe length, thereby saving 10.113 meters of PDAM water distribution network pipes from the initial total length of 115.193,8 meters.

[1] ***How to cite this article:***
Nurviana, J. Harahap, F. Muliani, "OPTIMIZATION OF THE WATER DISTRIBUTION NETWORK OF REGIONAL WATER UTILITY COMPANY (PDAM) USING PRIM ALGORITHM", *Pattimura Int. J. Math. (PIJMATH).*, vol. 03, iss. 02, pp. 069-076, Nov. 2024.

1. Introduction

Water is an unlimited natural resource. However, its use must be limited so that it is maintained and can be used sustainably. More people are using water for their daily needs, causing a clean water crisis. In addition, many human activities that result in water pollution are also the cause of the reduced availability of clean water. For this reason, it is necessary to distribute clean water from clean water sources to places that require clean water. One of the efforts that can be taken is through the Regional Drinking Water Company (PDAM) [1].

PDAM was established based on *undang-undang* no. 5 of 1962 concerning regional companies. As a regional government-owned business entity that provides services and organizes public benefits in the drinking water sector. Many companies in Indonesia experience water distribution problems, one of which is the Tirta Keumueneng Regional Drinking Water Company (PDAM) in Langsa City. The problem in this PDAM water distribution is how to distribute water to all areas with optimal pipe lengths.

Data source: PDAM Tirta Keumueneng Langsa City

Figure 1. Langsa City PDAM Water Distribution Network Map

Figure 1 shows that there are many areas that are channeled by water from many pipelines due to the development of pipes in new consumer areas, which contain circuits so that there is an imbalance in the water distribution network from the PDAM. This shows that the PDAM water distribution network is not optimal. So, it is necessary to optimize the PDAM water distribution network so that it can be distributed effectively and efficiently [2]. Determining the right path will produce an efficient pat with minimum costs. The total length of the pipe effects the costs incurred by PDAM consumers [3] [4] [5]. The farther distance/length of the pipe, the more expensive the costs; on the other hand, if the distance traveled is minimum, the costs will be minimum [6].

In an effort to distribute clean water requires careful analysis to make decisions, so that a modeling is carried out in the formation of an optimal water distribution network, the model that will be developed is a model that can accommodate the relationship between the allocation of costs owned by the PDAM. The network model will be made according to the actual conditions in the field using a mathematical model, making it easier for the formation process [7]. One part of mathematics that can be used is graph theory.

Graph theory is an old subject but has many application until now [8]. Graphs are used in various fields of life and are useful for solving problems, especially in optimizing resource utilization. For example, in establishing an effective pipeline design with the least risk, the graph has an important role in its calculations [9].

The use of graphs will provide pipelines that have certain advantages, such as pipelines with the shortest distance, and pipelines with a high level of efficiency. So, the use of graphs in this research aims to obtain a water distribution network with a minimum distance weight so that it can save the pipes used and their operational costs.

There are two algorithms that can build a minimum spanning tree, namely Prim’s algorithm and Kruskal’s algorithm [10]. The algorithm that will be used in this research is Prim’s algorithm because the network modeling will be carried out from the starting points to the next points in stages and interconnected. Prim’s algorithm can be used to optimize routes or paths that are used and applied in everyday life. This algorithm has an important role in the advancement of science and technology [11]. The novelty of the method proposed in this study lies in the application of Prim's algorithm in the specific context of the water distribution network of PDAM Tirta Keumueneng Langsa City, using accurate secondary data to represent the real conditions in the field. This research not only calculates the minimum pipe length, but also emphasizes operational cost savings and more efficient use of resources. In addition, the use of MATLAB software for analysis and visualization provides a practical approach that can be adopted by other researchers and practitioners, making it relevant and applicable in water distribution management.

2. Research Methods

This research is an application of graph theory that utilizes Prim's algorithm. Prim's algorithm is an algorithm in graph theory that is used to find the minimum spanning tree for a weighted connected graph by taking the edge that has the smallest weight from the graph, where the line is side by side and does not form a circuit/cycle [12]. Suppose *T* is a spanning tree shoes edges are taken from graph G. Prim's algorithm forms a minimum spanning tree step by step [13]. In each step we take the edge *e* of the graph *G* which has the minimum weight and side by side with vertices *n* – 2 times [14]. The stages of data analysis carried out in this research are as follows:

1. Data collection; the data used in this research is secondary data in the form of a map of the PDAM water distribution network and the distance or length of the pipe used for water distribution in Langsa City, which was obtained from PDAM Tirta Keumueneng Langsa City.
2. Representing PDAM water distribution network data in the form of a graph.
3. Forming a minimum spanning tree using Prim's algorithm with the help of MATLAB software. MATLAB software is a program for numerical analysis and computation and is an advanced mathematical programming language that is formed using the premise of the nature and form of matrices [15].
4. Conclusion; represents the obtained graph model.

3. Results And Discussion

Data collection of PDAM water distribution network is obtained directly from PDAM Tirta Keumueneng Langsa City. The data used is an image of a map of the water distribution network area and the length of the pipe. In the data obtained, it is known that the points that make up the PDAM water distribution network are 323 and have 337 sides with a total pipe length of 115.193,8 meters.After getting the data, the next step is to form a minimum spanning tree by applying Prim's algorithm. Network modeling is made according to actual conditions in the field. It is assumed that $v_1, v_2, v_3, \dots, v_{323}$ are the meeting points (nodes) of two or more pipes, or end points of pipes that have pressure and flow (discharge). Meanwhile, $e_1, e_2, e_3, \dots, e_{337}$ are those connecting the meeting points with each other expressed by the sides and the distance from the meeting points of the pipes with one another expressed by weights. The formation of the minimum spanning tree from the starting point $v_1$to each point of the PDAM water distribution network in the graph formed by Prim's algorithm is as follows. By using Prim's algorithm, the first step chosen is to determine v_1 as the starting point. Next, select an edge of the graph with the smallest weight that is adjacent to v_1, namely the side (v_1, v_2) with a weight of 463 so that a graph show in Figure 2.

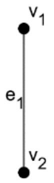

Figure 2. First Iteration Network Modeling

Then select again an edge with the smallest weight that is adjacent to one of the points v_1 and v_2, but does not form a circuit, namely the side (v_2, v_3) with a weight of 127 so that a graph like Figure 3 is obtained.

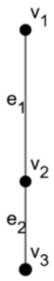

Figure 3. Second Iteration Network Modeling

Next, select an edge with the smallest weight that is side by side with one of the points v_1, v_2 and v_3, but does not form a circuit, namely the side (v_3, v_4) with a weight of 170 so that it is obtained as shown in Figure 4.

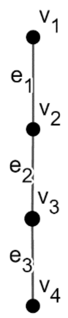

Figure 4. Third Iteration Network Modeling

Then re-select an edge with the smallest weight that is side by side with one of the points v_1, v_2, v_3 and v_4, namely the side (v_4, v_5) with a weight of 384, then we get a graph like **Figure 5**.

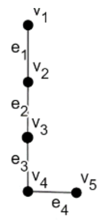

Figure 5. Fourth Iteration Network Modeling

And so on until all the points are connected and nothing forms a circuit. By using the MATLAB software program, the results of the last iteration are obtained which can be seen in the following minimum spanning tree image which is divided into 3 parts, namely **Figure 6 – Figure 8**.

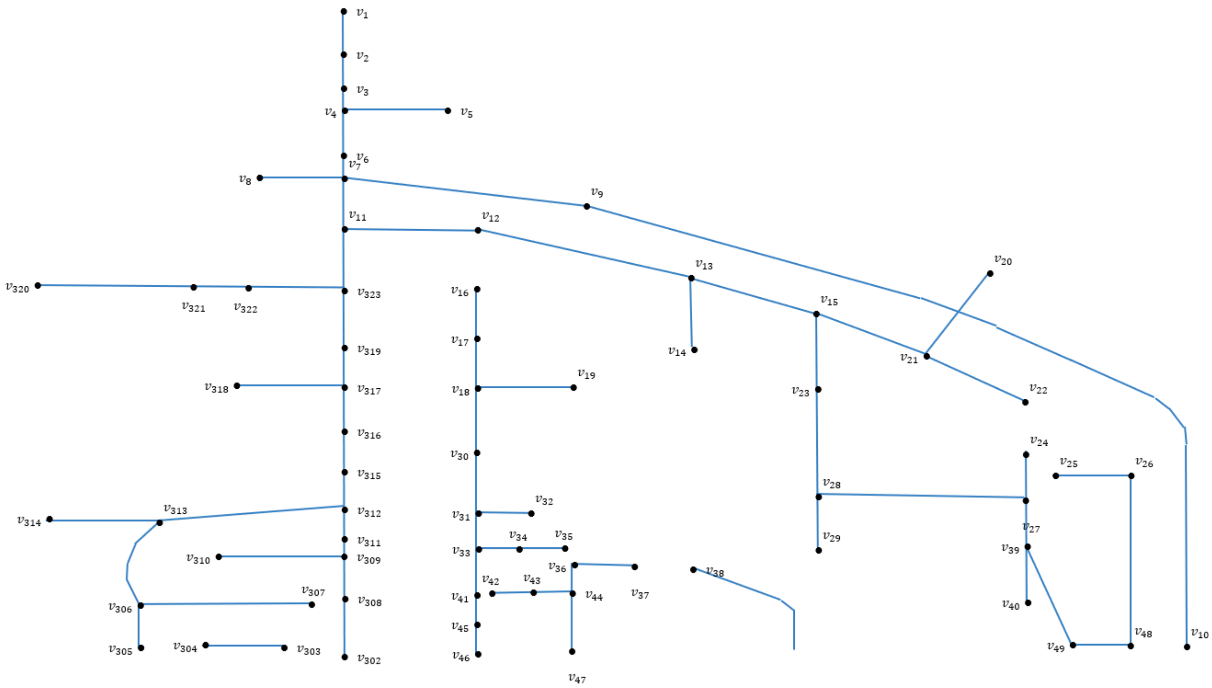

Figure 6. Minimum Spanning Tree Upside

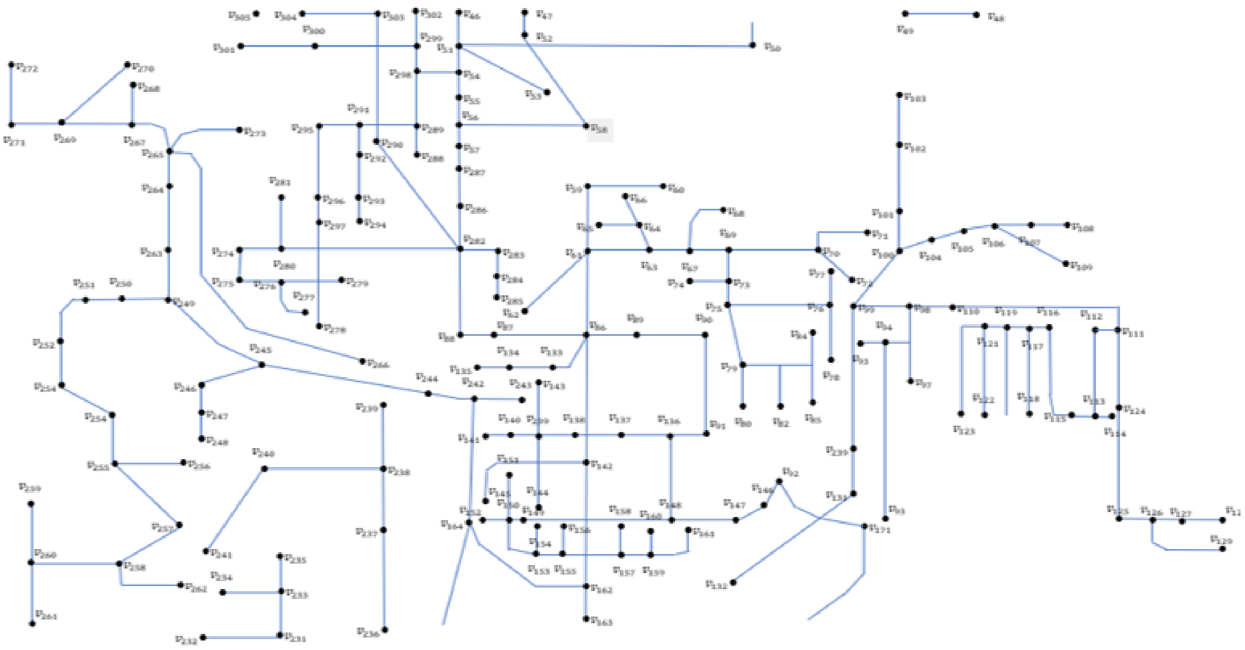

Figure 7. Minimum Spanning Tree Middle

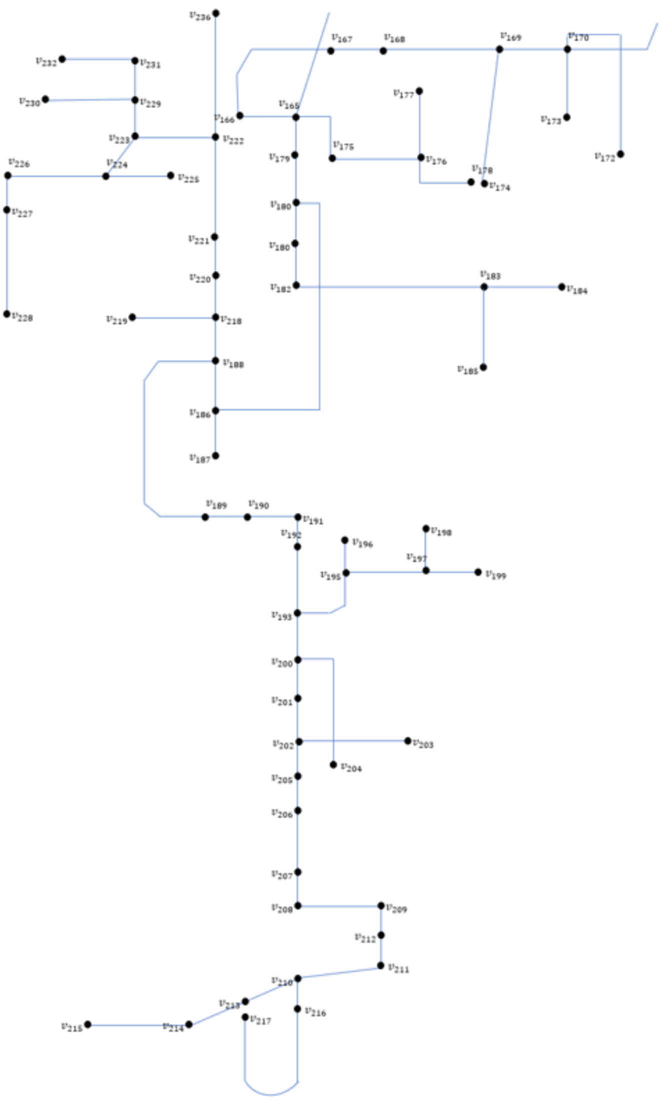

Figure 8. Minimum Spanning Tree downside

Based on **Figure 6 – Figure 8**, the results of applying Prim's algorithm to the water distribution network of PDAM Tirta Keumueneng Langsa City, are already connected and nothing forms a circuit, so the minimum spanning tree is obtained as follows in **Table 1**.

Table 1. PDAM Water Distribution Network Pipe Length Data After Optimization

Edge	Connected Vertex	Weight (in meters)
e_1	$v_1 - v_2$	463
e_2	$v_2 - v_3$	127
e_3	$v_3 - v_4$	170
e_4	$v_4 - v_5$	384
⋮	⋮	⋮
e_{334}	$v_{323} - v_{322}$	357
e_{335}	$v_{322} - v_{321}$	6,6
e_{336}	$v_{321} - v_{320}$	1074
e_{337}	$v_{323} - v_{11}$	482
	Total Length	**105.080,8**

Table 1 shows that the number of sides selected in the formation of the minimum spanning tree for the water distribution network of PDAM Tirta Keumueneng Langsa City is 322 sides with a total pipe length of 105.080,8 meters. The sides that are delected consist of $e_{15} = 643$ meters, $e_{19} = 571$ meters, $e_{26} = 440$ meters, $e_{29} = 595$ meters, $e_{43} = 1038$ meters, $e_{52} = 1220$ meters, $e_{63} = 509$ meters, $e_{90} = 1338$ meters, $e_{112} = 152$ meters, $e_{128} = 534$ meters, $e_{151} = 432$ meters, $e_{192} = 647$ meters, $e_{220} = 1001$ meters, $e_{284} = 820$ meters, dan $e_{302} = 173$ meters. From the results of the application of Prim's algorithm, it can be interpreted that this calculation has saved 10.113 meters of pipe from the initial total length of 115.193,8 meters.

4. Conclusions

Based on the results of research and discussion, it can be concluded that the minimum spanning tree from the water distribution network of PDAM Tirta Keumueneng Langsa City using Prim's algorithm has a total pipe length of 105.080,8 meters. The difference in pipe length between the minimum spanning tree and the initial pipe from the PDAM water distribution network is 10.113 meters. his study recorded pipe length savings of 10,113 meters compared to the initial total pipe length of 115,193.8 meters. This result confirms that Prim's algorithm not only provides an optimal solution in terms of pipe length, but also has the potential to reduce operational costs and improve efficiency in the management of water distribution networks. Thus, the application of this algorithm can be an effective model for a more sustainable and economical management of water resources.

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