# Depth First Search Algorithm for Optimizing Gravity Pipe Networks Layout

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# 1 Introduction

Well-designed Layout of pipelines is very important for efficient and effective infrastructure systems. These networks play a fundamental role in transporting water, fluids, and sewage. Designing the Layout of gravity pipelines is among the trickiest gravity pipe network design problems. Often the design of the layout is not cheap since several points should be taken into consideration. Any network system requires a good design of the street layout, hills, mountains, cavities, and other factors should be taken into consideration. In addition to that, the implementation of Gravity pipe networks is so expensive regarding hydraulic infrastructure tasks. As stated by Diogo and Graveto [1]in addition to the computational elements regarding the complexity of the enhancements. Such a gravity pipe network design could look like this: The optimal configuration consisting of directed tree forests that can be obtained by starting with an undirected graph and placing some solutions. Numerous directed trees, indicated by nodes and pipes, exist in every network. Based on Mai and Evans [2] larger networks have an enormous number of alternative paths, which makes optimizing the enumeration of network branches more difficult. There were many enhancement techniques that were proposed to enhance the layouts, Liebman [3] used (NLP) Non-Linear programming. After that both Dajani [4] and Velon [4] used (LP) Linear Programming. Brown and Walsh [5] using the concepts that Haith [6] has offered, developed a Dynamic programming (DP) model that gives more precise cost functions. Mays and Yen [7] evolved 2 computational models to enhance water collection network systems using (DDDP) Discrete Differential Dynamic Programming

# 2 Methodology

The hypothesis of graph theory is a part of mathematics that focuses on the relationship among entities through graphs, that includes vertices and edges. Entities are vertices and edges are the connection between vertices.

## 2.1 Depth First Search concept

As mentioned by Cormen et al. [8] Search Algorithms carry out a process in the graph to discover all edges and vertices. There are many ways where Search Algorthims work, the one that will be used in this paper is (DFS) Depth-First-Search where it works as Stack (LIFO), it goes to all child nodes first and then it backtracks to the top.

## 2.2 Tools

C# programming language was used since it is easy to understand, clear, and it's compatibility with windows operating system. Visual studio code was the IDE used to program. The computer used for the designing and modeling had the following specs: Intel Core i7-5500u, 4MB cache, 2.40GHz, 2 cores, 4 processors, and 8GB RAM .

## 2.3 Model Development

Before starting, the Slope should be calculated to know in what way the water will be moving. Gravity has a huge impact on that since it controls the motion of the water, it causes water to flow from higher elevations to lower elevations. By calculating the slope, engineers can make sure that water flows in the desired direction preventing inefficient flow patterns. Slope is calculated using the following formula:

$$S = (NEi\text{-}NEi + 1)/L$$

S: Ground Slope.
NEi: Upstream node elevation.
NEi+1: Downstream node elevation.
L: The length of the pipe

3 conditions to be evaluated regrading the pipe layout slope gradient in gravity network.

1. Positive slope ($S > 0$) which is a preferable slope where the downstream is less than upstream ground level node (Rising ground).
2. Zero Slope ($S = 0$) which is when the downstream node is equal to the upstream one,(Flat ground).
3. Negative slope ($S < 0$) Which is an unfavorable slope where the ground of the downstream node is bigger than the upstream one (Descending Slope).

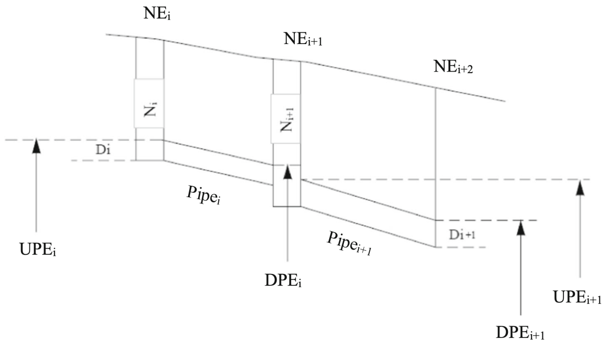


Figure 1: Geometry of 2 pipes in Gravity network.[9]

Pipes with NULL or NEGATIVE slopes are the target. To calculate the weight of edges of the weighted directed graph we use the following equation:

$$A = (NE_i - NE_{i+1})|L$$

The value of the equation is 0 if the slope is null, and negative otherwise.

We use the following function to decrease the sum of the unprefrable areas of the pipes:

$$\text{Minimize } A_{\text{total}} = \sum_{i=i}^{\text{SP}} A$$

$A_{\text{total}}$ : Sum of Unpreferable areas
A: Unpreferable area
SP: The amount of Pipes lining up to the terminating point.

1. Reading the data and Initial network parameter verification.
   (a) The model starts searching for the complete network and reads the data of the pipes and nodes. Outlet nodes are excluded from the network.
   (b) Water flow by the cause of the ground's natural slope is inspected throughout the entire network.
   (c) The outflow and inflow stream pipes of every node are determined.
   (d) Looking for nodes that only have one inflow stream pipe without any outflow stream pipes. These pipes will have the opposite flow direction.

(e) By following the instructions given above, it might occur that there is one node or more that has multiple inflow streams without an outflow stream pipes. This is an obstruction in the hydraulics of networks since there would be no downstream flow from the node. This node is called the (Confluent Node) shown in Figure 2.

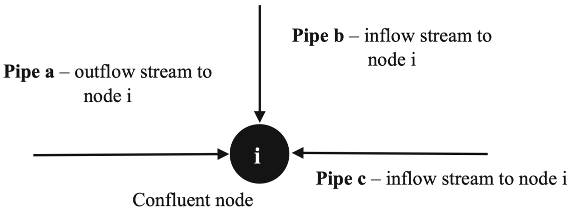


Figure 2: Confluent Node [10]

2. Depth First Search Methodology.

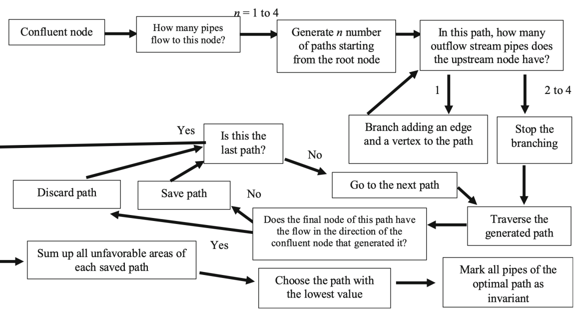


Figure 3: Second phase flowchart [10]

Searching starts, the standards for terminating the search is when branch reaches to a node that has two or more outflow pipes or two inflow pipes demonstrated in Figure 4, node **a** represents the termination point. Search Algorithm starts from the root, and checks all possible paths of the generated graph by calculating the unpreferable area. This calculation is equal to the weight of every edge. Then all areas are added starting from the root until point **a** using (Minimization formula). All paths will have an unpreferable area accumulated value, Figure 5 is an example, there are 3 paths each has its weight, hence the weight of 0-3 is the highest, the higher the accumulated unfavorable value the more expensive and the greater the adverse topography that we will need to cross. A loop must be avoided, an example in the figure 6 shows a loop, in a point like 5 the water can't leave the circle which leads to other problems such that the water can't move outside of the loop since there is no Flow outlet. To solve this problem there was a condition added to the protection that from happening, the outlet node of each path cannot return to itself

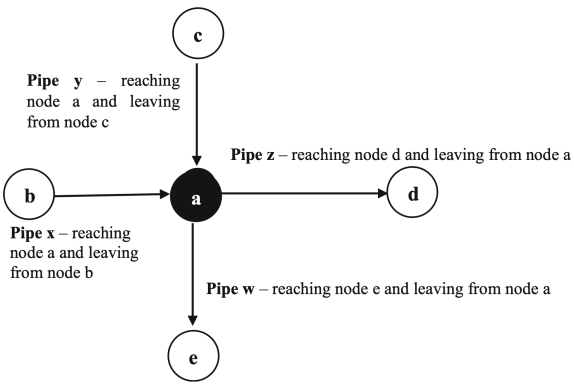


Figure 4: Branch terminating point[10]

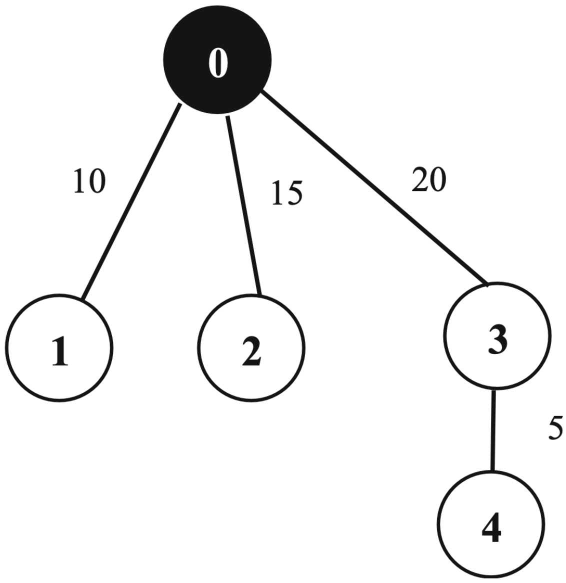


Figure 5: Weighted directed graph[10]

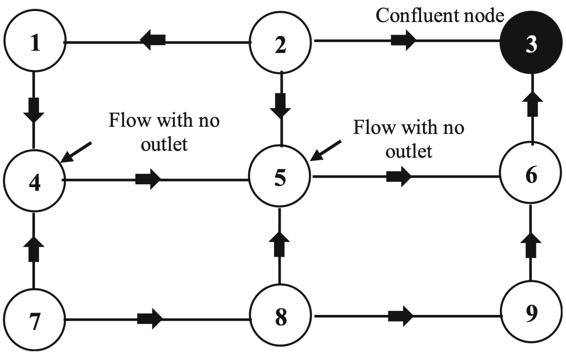


Figure 6: Flow with no outlet [11]

# 3 Experiments and Findings

A real network was used to make sure that this method is going to work, 7, the graph is taken from a network in São Paulo/Brazil. The network had 125 sections and 74 nodes. Many pipes have been designed opposing the natural slope of the ground for the water to reach Node 51. Four confluent nodes were occurred in the network after the execution: 15, 41, 70, and 72. For the flow to reach node 51 some of the four pipe nodes must have an opposite flow direction. Figure 8 shows the confluent nodes with the respective adopted possible paths. The algorithm analyses and determines which path for every confluent node will lead to the smallest sum of null or unpreferable slopes.

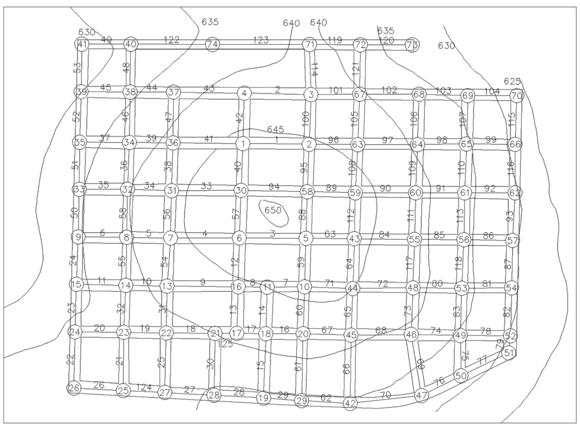

Figure 7: Real Network of the case study[10]

| Confluent node | Possible path number | Number of not feasible paths due to loop formation | Number of feasible paths | Pipe(s) of the feasible path(s) | Sum of the feasible path weight(s) |
|---|---|---|---|---|---|
| 15 | 6 | 2 | 4 | 11 and 10 | 471.496 |
| | | | | 24 | 41.910 |
| | | | | 11 and 55 | 407.694 |
| | | | | 23 and 22 | 391.286 |
| 41 | 6 | 5 | 1 | 49, 122 and 123 | 1772.191 |
| 70 | 6 | 4 | 2 | 104, 103 and 102 | 950.912 |
| | | | | 115, 116 and 93 | 291.386 |
| 72 | 2 | 1 | 1 | 121 | 209.287 |

Figure 8: Real Network table [10]

# 4 Discussion

The reason behind this paper and model is to effectively improve the layout of the sewer and to make it cheaper and more effective. As shown by the results taken from the experiment it did the job well, by solving some problems that would have taken a long time from the designers to fix.

# 5 Conclusion and Future Work

An innovative (DFS) algorithm was presented to optimize the gravity pipe network layout. One of the key points in using (DFS) is that it goes to the depth of the nodes first which helps with unpreferable or flat grounds. This helped in decreasing the time needed to enhance the gravity pipe layout and help designers solve problems like loops or confluent nodes, it also helped reduce the price of the layout while also making it environmentally friendly. In the experiment, the model found all possible solutions and managed to enhance the layout and solve the problems.

For the up coming work, there are many other Algorithms that can be tested in order to find one that can be more efficient and faster, also this method can be tested more to prove efficiency.

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