Resilience Analysis of Water Distribution Network

SC435: Introduction to Complex Networks

202103017 - Dhruv Shah
202103022 - Vatsal Shah
202103040 - Pranav Patel
202103052 - Vraj Thakkar

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Introduction and Objectives

- Crucial to ensure efficient water delivery, detect potential vulnerabilities, **optimize resource management** and ensure the **robustness** of the network.
- **Objectives:**
  - Identifying potential reservoirs in the network.
  - Contamination spread in the water distribution network.

The dataset represents the water pipeline distribution network of the **US state Colorado.**

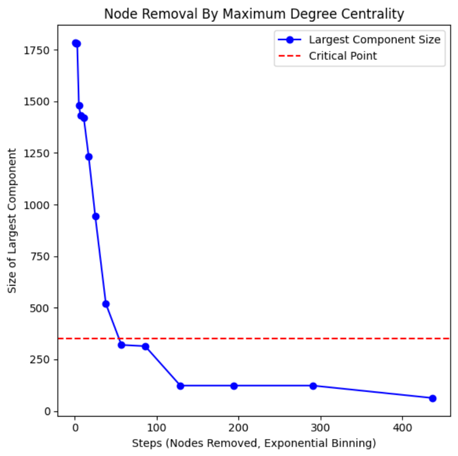
	Node	xcord	ycord
0	3001	3220655	1419888
1	6006	3222695	1416954
2	1003	3219027	1415374
3	6005	3221926	1417827
4	6011	3220433	1415395

Figure 1: Node ID along with their corresponding spatial coordinates **(1786 nodes)**.

	Node 1	Node 2	Diameter [inch]
0	12112	11200	8.0
1	12314	1172	8.0
2	12243	11206	8.0
3	1171	9022	24.0
4	1023	11097	8.0

Figure 2: Presence edges between nodes and the diameter of the pipes connecting them **(1995 edges)**.

- First, we remove node with highest **centrality measure** and note the size of the largest component that remains.
- Threshold **80-20 rule:** Network is disrupted when 80% of the original nodes get removed or the largest component has size of 20% of the network.



Centrality Type	Nodes Removed
Degree	49
Current Flow Betweenness	91
Betweenness	119
Closeness	575

Figure 4: Nodes removed for each centrality measure.

Obejctive 1 : Identifying the Resorvoirs in the Network

- **Method 1 :** Pick nodes with **highest closeness centralities** and look at their structural equivalance (r-ring neighborhood).
- The reservoirs should be placed such that they are as close as possible to the homes to which they provide water.
- Set of nodes to which they supply water should be disjoint or at least different up to some percentage.
- This measure of disjoint will also capture the resilience of network and we can decrease to make the nodes in each reservoir set similar to make the network more robust to reservoir failure.

Obejctive 1 : Identifying the Resorvoirs in the Network

- **Method 2 :** Iteratively removing edges with high betweenness centrality, helps in identifying the clusters that can function independently (using Girvan Newman's Algorithm).
- Among those clusters, we select the nodes with highest closeness centrality as the reservoirs.

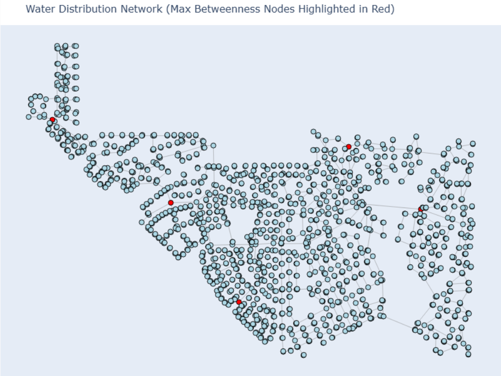


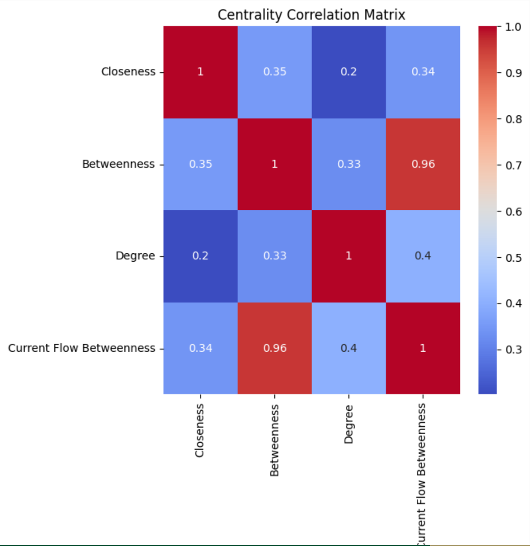
Figure 5: Identification of Reservoirs(red colored nodes).

Contamination problem & Current Flow Betweenness centrality

- Nodes with high betweenness centrality are essential for the flow across the network, identifying the bottlenecks.
- Standard betweenness centrality, ignore the flow in the pipes from non-geodesic paths.
- Newman gave **Current Flow betweenness** or **Random Walk betweenness centrality.**
- A linear flow network, i.e. the flow over an edge depends linearly on the gradient of a potential function across the edge.

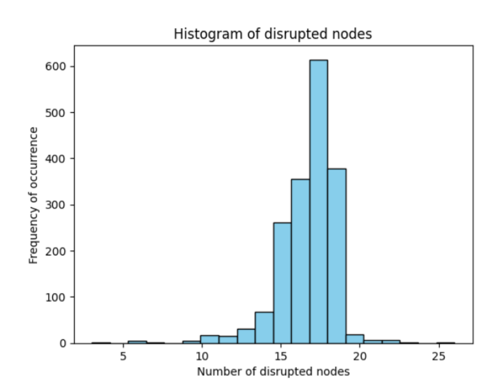
Contamination problem & Current Flow Betweenness centrality

- **RESULTS:** Current flow betweenness centrality **correlates** well with both betweenness**(0.96)** and degree centrality**(0.4).**



Flow Simulation in the network

- Analogous with the flow of current in a circuit. We apply Ohm's law and Kirchoff's law.
- Iteratively stop each node and note the change in flow in the entire system.
- We assume that the net flow reaching each node should be greater than some threshold.
- Goal is to see that removing which nodes cause the maximum node failures.



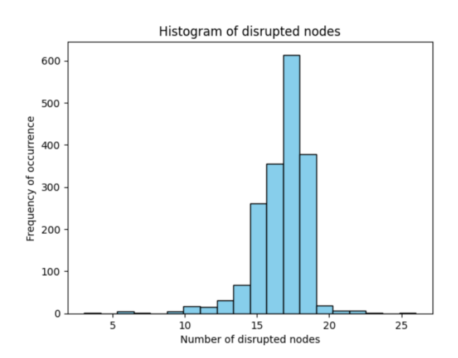


Figure 8: Threshold of flow for failed node was assumed to be 0.0001(in appropriate dimensions)

Centrality Type	Correlation with Node Failure
Degree	-0.17
Current Flow Betweenness	-0.32
Betweenness	-0.41
Closeness	-0.24

Figure 9: Correlation between the importance of nodes obtained by flow simulation and centrality

References

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THANK YOU!

We are open for Questions.