

# A FAST METHOD TO IDENTIFY THE CRITICALITY OF INDIVIDUAL COMPONENTS IN WATER SUPPLY NETWORKS

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## ABSTRACT

*For the management of piped infrastructure (e.g. water supply networks, gas distribution systems) strategies are required to program the maintenance activities (e.g. repairs, replacement). In general, these activities are based on risk management that combines the probability and consequences of failure. In this paper a method is proposed to quickly identify the most critical elements in a network with respect to malfunctioning of a system as a whole. As opposed to methods applied so far, this method does not rely on iterative hydraulic calculations but takes the structure of the network as a starting point and is based on Graph theory.*

*First the theory of the method is presented, secondly the first results are presented based on a water supply network and the outcomes are compared with traditional methods applied so far. Finally, the results are discussed and conclusions are formulated.*

**Keywords:** Asset management, Criticality, Water supply networks

## 1 BACKGROUND

As generally acknowledged, infrastructure is becoming more and more important to keep cities functioning. For the human wellbeing water supply networks and sewer systems are two essential parts of the infrastructure. These networks are pivotal for the public health and preventing epidemics. In order to maintain the desired level of serviceability the infrastructure has to be properly maintained and rehabilitated [1], [2]. As in most western countries the infrastructure is ageing, the system managers have to decide how and when to maintain or rehabilitated which part of the network. Different methodologies have been proposed to optimize the maintenance of network systems [3], [4], [5].

Only little literature is available about the importance (or criticality) of the individual elements in piped networks (e.g. sewer systems, water supply networks) in relation to the performance of the system as a whole. The degree of criticality indicates the seriousness of failure of an element in a network. Arthur and Crow describe a methodology to identify so called “problem pipes” or critical assets [3], [6]. The described methodology is based on surcharged capacity and surcharged level and applicable for gravity systems only. Another method to determine the importance of a specific element for the functioning is to reduce the capacity of every pipe in a hydrodynamic model to (almost) zero and determine the consequences [5], [7]. However, this is a method that requires a large computational effort, certainly for large (looped) systems.

For water supply networks Halhal et al [8] give an overview of all kind of methods based on historical statistics and costs and algorithms for optimal rehabilitation decisions to prioritize maintenance and rehabilitation. Michaud and Apostolakis [9] present a methodology to rank elements of water supply networks. The methodology is based on multi-attribute utility theory and the Graph theory. For the so called high level network the Dijkstra algorithm [10] is used to define the supply coverage at a given sink defined as the ratio between the demand and the actual supply to this sink. The optimization of supply occurs for each sink sequentially. As a result the supply to sinks that are lower in the priority list becomes suboptimal in some cases. The method is based on a reduction of capacity of pipelines and not at leakage.

Failure of water supply networks has impact on the service level (supply of water) and may impact on several essential aspects of urban life (e.g. health risks, floods, blocked roads and material damage). When it is possible to determine, preferably with limited calculation effort only, the degree of criticality, managers get additional information to prioritize maintenance and rehabilitation actions. Combining the criticality of an element with the damage caused by failing of a (part of a) network can be an alternative way to prioritize the maintenance actions. The degree of criticality can therefore be used as a basis for risk based asset management. It also can be used to analyze the robustness of a network and to evaluate measures to increase the robustness.

This article presents a methodology to identify fast (with limited calculation effort, i.e. a factor 1000 less computation time) the criticality of individual components in water related network systems. The methodology is based on the Graph theory. Currently the method is tested on a water supply system. This article presents the first results.

## 2 METHODS

A methodology to determine the degree of criticality based on the graph theory is developed. Basically the methods exploit the fact that a network can be described as a Graph, by calculating the shortest path between ‘sources’ and ‘sinks’ in the network the ‘importance’ of an element in the network can be quantified. The information needed for this is a database containing the geometry of each element (and its hydraulic parameters), the structure of the network and information on the ‘source’ and ‘sinks’ in the system. With this methodology the degree of criticality can be determined with a fraction of the calculation effort that is needed for a hydraulic model. The methodology can be used for both looped and branched networks.

An analysis of the results of a hydraulic model shows that in case of a leakage the area of the pressure fall depends on location of the location of the break relative to the drinking water station and of the break location relative to the nodes of the network. During normal operation conditions water flows from a pumping station to the consumers with a connection to the system. For each node (source) a path can be determined to the drinking water station (target) of the system. Each path has its own length or “costs”. For each node the shortest or cheapest path to a target is determined based on the Dijkstra algorithm [10].

In case of a pipe break, a large amount of water will flow out of the system and the pressure will fall. A pipe break is simulated in the graph by adding a “break node” to the graph. This simulates a break on the intersection of end of a pipe.

The shortest paths during normal operation conditions are used to get a sub ranking for the position of the node relative to the drinking water station. The nodes are sorted based on the costs. The node

with the lowest costs get number 1 and is the most important node, the node with the highest costs is the less important node and get the highest rank.

The sub ranking of the location of the break relative to the network is based on the total costs of the graph. The total costs of a graph are determined by summing the costs of all nodes to a target. The target can be or the water pumping station or the break node. For every node the lowest cost of the path from the node to a target is used to determine the total costs of the graph. To minimize the calculation effort the calculations are not carried out from the source to the target node but from the target(s) to all nodes.

The rank of the node is based on the average of the two sub ranks. The process as shown in Figure is used to rank the nodes.

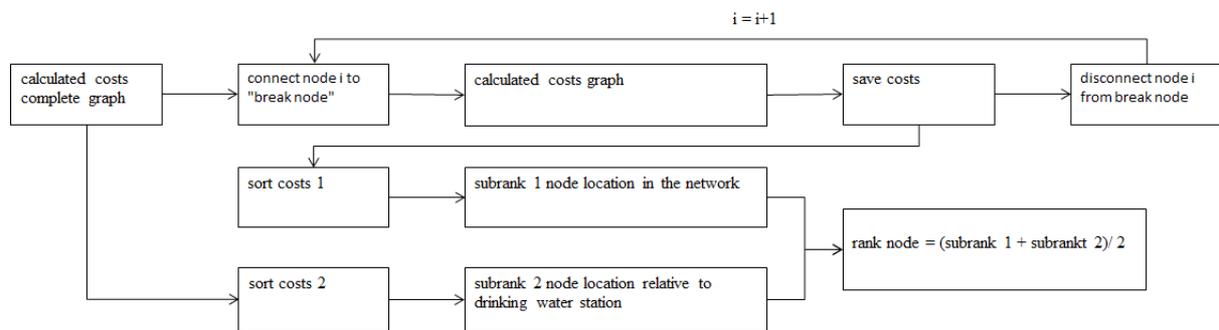


Figure . Process to determine degree of criticality with graph theory.

The links’ costs are derived of the head loss in a link. Energy is needed to let water flow from A to B. The amount of energy that is lost due to the resistance of water to flow between A and B is the dynamic head loss. The dynamic head loss depends on the characteristics of the liquid and the pipe.

### 3 FIRST RESULTS

For a water supply network the results of this methodology are compared with the outcomes of a hydrodynamic model. The Sobek software package has been used. The initial pressure in the water network is 3.000 kPa. The number of simulations is the same as the number of connections in the network. In each simulation a leak that causes a pressure fall of 200 kPa has been made at one of the connection points. The degrees of criticality based on both methods have a strong relationship with each other (see Figure 1).

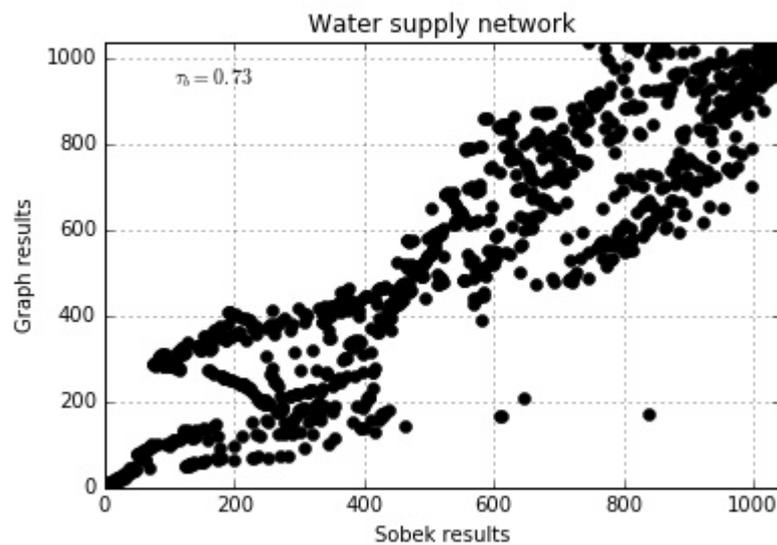


Figure 1. Comparison between the degree of criticality based on a hydrodynamic model and the graph methodology. The figure shows that there is a clear relation between the outcomes of both methods.

## 4 CONCLUSIONS

This abstract presents a methodology to determine the degree of criticality of pipelines based on the graph theory. The method requires little computational effort and is objective. The degree of criticality shows a clear relationship between the method based on the graph theory and the outcomes of a hydraulic model (Kendalls'  $\tau_b = 0.73$ ).

The required calculation effort of the new methodology makes it possible to rank elements in large networks based on criticality. This offers new possibilities for asset management and risk based management. It offers the possibility to prioritise maintenance and rehabilitation based on the importance of an element for the functioning of the system. This is useful input for risk based asset management.

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