Hydraulic Capacity Recovery after Demand Expansion: Complex Network and Preference-Aided Multicriteria Analysis

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ABSTRACT

Given the growth of urban population, water distribution networks (WDNs) are stressed and may lose hydraulic performance while supplying citizens. WDNs should be modified by civil engineering interventions such as water network rehabilitation, aimed at recovering the originally designed hydraulic performance. In this work, a set of expansion scenarios are evaluated under hydraulic (resilience, pressure uniformity, and water quality) and complex network (centrality, average shortest path) indexes for better understanding the impacts of demand increasing in a water network. This first analysis allows to map the risk of demand increases at each district metered area, resulting in more suitable regions for demand expansion. In a second step, rehabilitation of water network based on changes of main pipes is proposed. Structural interventions from the civil engineering point of view are proposed. Since each intervention results in economical costs as well as in recovery performance, solutions are also evaluated under hydraulic indexes, whose degrees of importance may be established by means a preference-based approach and feedback exchanges with experts in the field. In this context, a multicriteria technique is applied for ranking solutions, leading to a map of expansion-solutions for WDN managers. The complex network and WDN hydraulic analyses have been performed in Phyton programming and, respectively, by means of the packages NetworkX 2.5 and WNTR 0.3.0. TOPSIS multicriteria analysis method is lastly used to classify the expansion solutions.

Keywords: Water distribution network, Demand expansion, Multicriteria Analysis.

1. INTRODUCTION, GOAL AND STRUCTURE

Considering the increase of the world population over the recent years and also expected trends of growht for the next few decades (Maja and Ayano 2020), expansion of water distribution networks (WDNs) remains an important issue for water utilities. According to the Progress on Household Drinking Water, Sanitation and Hygiene 2000-2020 report, from World Health Organization and United Nations Children's Fund (2021), one out of four people in the world did not have sufficient safe drinking water available at home in the year 2020. By the year 2030, it is estimated that even more people will continue to not have access to safe drinking water. As the population grows, urban areas take up more space and the water demand consequently increases. Due to this evidence, WDNs become overloaded, something that may likely lead to pressure drops in the network and limite the supply capacity of the system, making WDNs globally less efficient and more vulnerable to structural failure (Huzsvár et al. 2021). Water system analyses are then indispensable for an adequate planning of interventions contemplating the potential increase of consumption. Implementing a proper methodology can support to determine not only the main topological characteristics of networks, but also to provide the hydraulic behavior of WDNs for each expansion scenario.

In this context, water systems should be properly designed to suitably fulfill water needs of consumers, and itis well known as water system structures and connectivity likely affect such parameters as reliability, resilience and efficiency (Pagano et al. 2019). A potential way for analysing WDNs consists in modelling these structures based on the theory of complex networks. Complex networks theory is based on mathematical abstractions called graphs, which are constituted by a set of nodes connected by edges which can be weighted, directed and even dynamic over time (Boccaletti et al. 2006) according to the specific features of the network to be modeled. Just to mention an analogy with established mathematical-computational models of water supply systems, in the abstraction of complex networks theory the nodes represent reservoirs, tanks, demands and simple junctions, while the edges represent the pipes, valves and pumps (Castro-Gama et al. 2016). By assigning proper weights and directions, water networks can be easily characterised on the basis of a set of indexes and metrics related to connectivity, topology, redundancy and robustness (Simone et al. 2018, Meng et al. 2018). Other important aspects to verify the performance of water distribution networks are the hydraulic indexes. These indexes allow the characterization of the variations of hydraulic parameters over certain simulation periods, resulting particularly useful for decision-making that seeks to reduce risks of operational disturbances and system failures. Furthermore, a methodological analysis of such hydraulic indexes as resilence, pressure uniformity and water age can help to reduce social, economic and environmental burdens arising from network problems (Jeong and Kang 2020, Jalal 2008). All this considered, this research proposes an integrated methodology first based on water distribution network modeling in terms of complex network. The application of hydraulic indexes is also considered to identify such network features as robustness, alternative paths and hydraulic performance, for several scenarios of increasing demand.

In any case, the problem of WDNs capacity expansion aims to determine those best engineering interventions capable to effectively satisfy the new demand scenarios while minimizing cost (Sirsant and Reddy 2021). After implementing expansion scenarios and observing the hydraulic behavior of the network, pipe changes are strategically performed to adjust minimum pressures of the system. A multi-criteria analysis is lastly proposed for each expansion scenario, where a preference-aided approach supported by one or more decision-makers may be implemented for weighting all the hydraulic indexes of the network as well as the costs of the implemented engineering measure. From the results of the weightings of these criteria, the expansion scenarios are ranked to identify the most efficient and economically feasible scenarios.

2. METHODOLOGICAL APPROACH

The research methodology implements the following stages: water distribution network as directed and weighted graphs; complex network metrics; hydraulic criteria; multicriteria analysis; engineering measure.

3.1. Water distribution network as directed and weighted graph

At this stage, the water distribution network is incorporated as a graph of the Python programming language, using the packages: NetworkX 2.5, for the creation, manipulation and study of the structure, dynamics and functions of complex networks (Hagberg et al. 2008); and Water Network Tool for Resilience (WNTR), version 0.3.0, to interface water supply network data in EPANET 2.2 software with Python and analyze its hydraulic behavior after simulations (Rossman et al. 2020, Klise et al. 2018).

As mentioned by Giudicianni et al. (2018), the edges of WDNs' graphs can be weighted by hydraulic and topological characteristics of the system. To analyze and obtain more useful information about the hydraulic behavior of WDNs, the edges of the graph are directed according to the direction of flow in the pipes and are also weighted by flowrate and resistance coefficient (*RC*).

The weighting of the edges by the flowrate is done to obtain a mathematical analysis based on complex network theory taking into account the importance of each pipe on the water distribution process. The weights applied according to the resistance coefficients (RC) of the pipes are calculated by the following Hazen-Willians headloss equation:

$$RC = \frac{10.65 \times L}{C^{1.85} \times D^{4.87}} \tag{1}$$

where L and D, respectively, are the pipe length and diameter, and C is the Hazen-Williams roughness coefficient. The weighting of the edges of the graph of the water distribution network by the coefficient of resistance is applied in order to identify the paths in which the water flow generates higher hydraulic headloss.

3.2. Complex network metrics

In this section are presented the complex network metrics applied for analysis of the water distribution network graph. The first metric is normalised closeness centrality, $C_C(i)$. According to Alipour et al. (2013), the closeness centrality determines the interaction's speed among the nodes. So, the most central nodes are closest to all the others and usually require the shortest distances (total weighted edge length) for interactions with other central nodes. Therefore, the greater the closeness centrality, the faster the flow or transmission of information from one analysis node to all other reachable nodes in the network (McKnight 2014).

According to Freeman (1978), the closeness centrality is written as:

$$C_C(i) = \frac{n-1}{\sum_{j=1}^{n-1} d(j,i)} \tag{2}$$

where $d(j,i)$ is the shortest path distance between j and i, and n is the number of nodes that can reach i.

For directed graphs (e.g., water distribution systems modeled as graphs), the closeness centrality from the Freeman equation is related to the incoming closeness centrality (CC_{in}), where only the edges that reach or supply node i, or hydraulicly speaking, edges upstream to node i, are considered. To obtain the outcoming closeness centrality (CC_{out}), which refers to the edges that leave nodes (edges downstream to node i), the distance of the shortest paths from node i to j is considered, and n is the number of nodes that can reach j.

The second complex network metric used in this research is the average shortest path length (L_{avg}) between all pairs of nodes in the network, which is defined by the equation (Zhang et al. 2021):

$$L_{avg} = \frac{1}{n(n-1)} \times \sum_i \sum_{j \neq i} d_{ij} \tag{3}$$

where d_{ij} is the length of the shortest path directed from node i to node j.

The shortest path calculations are performed using the Floyd and Warshall Algorithm, usually applied to weighted graphs for solving problems such as the calculation of shortest path fast location networks in directed graphs (Sarwar and Shaheen 2021).

3.3. Hydraulic criteria

The hydraulic criteria are selected to characterize the efficiency and resilience of the water distribution network.

The first criterion presented is the pressure uniformity (PU), that measures the pressure distribution along the WDN. The main goal of PU is evaluating the difference between the pressures at the junction nodes and the average pressure of the system and also the minimum system pressures, for each time step.

According to Al-Hemairi and Shakir (2007), PU can be expressed by the equation:

$$PU = \sum_{t=1}^{M} \left[\frac{1}{N} \sum_{i=1}^{N} \left(\frac{P_{i,t} - P_{min}}{P_{min}} \right) + \frac{\sqrt{\frac{\sum_{i=1}^{N} \left(P_{i,t} - \bar{P}_t \right)^2}{N}}}{\bar{P}_t} \right] \tag{4}$$

where $P_{i,t}$ is the pressure at junction i at time step t; P_{min} is the minimum pressure required for network operation; and $\bar{P}_t$ is the average pressure in the network at time step t.

The second hydraulic criterion is the weighted average age of water over the limit set by the standard (WA), which according to Marchi et al. (2014) is defined by the equation:

$$WA = \frac{\sum_{i=1}^{N} \sum_{t=1}^{M} k_i^{(t)} q_i^{(t)} \cdot \left(WA_i^{(t)} - WA_{\lim} \right)}{\sum_{i=1}^{N} \sum_{t=1}^{M} q_i^{(t)}} \tag{5}$$

where $WA_i^{(t)}$ is the water age at junction i at time step t (except for tanks and reservoirs); $q_i^{(t)}$ is the demand at junction i at time step t; $WA_{\lim}$ is the water age limit (in hours) allowed by standard; and $k_i^{(t)}$ is a binary variable, set to 1 if the water age is greater than or equal to the limit, or 0 if it is less than the set limit. The WA is a hydraulic criterion that determines the age of the water in the supply system and can also evaluate how the expansion of the water distribution network interferes in the time required for the water to reach the consumption demand nodes and in the quality of the water to supply the system.

The last hydraulic criterion evaluated is the hydraulic resilience proposed by Todini (2000), which represents the network capacity to overcome failures and is defined by the equation:

$$R = \frac{\sum_{i=1}^{n_n} q_i(h_i - h_i^*)}{\sum_{R=1}^{n_r} Q_R H_R + \sum_{j=1}^{n_p} P_j/\gamma - \sum_{i=1}^{n_n} q_i h_i^*} \quad (6)$$

where n_n is the number of demand nodes; n_r is the number of reservoirs or tanks; n_p is the number of pumps of the network; q_i and h_i are the demand and hydraulic head of the demand node i; Q_R and H_R are, respectively, the flow and level of the reservoir or tanks; P_j is the power of the pump j in the system and γ is the specific weight of water; and h^* is the minimum hydraulic head the required for supply the system.

3.4. Multicriteria analysis

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a well-known Multi-Criteria Decision Making (MCDM) method, used to get a structured ranking of decision-making elements according to the weights previouslt attributed to criteria as relevant aspects of analysis. This can be done by collecting judgments of preference elicited by subjects with proven experience in the treated field. TOPSIS allows to deal with even huge sets of alternatives (Anchieta et al., 2021) and is based on the concept that the alternative representing the best trade-off in matching all the considered aspects should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. These solutions are calculated within the methodological framework according to the quantitative features of the problem under analysis. The technique can be developed as follows.

- Defining the input evaluation matrix by collecting quantitative assessments g_{ij} of alternative i under each criterion j.
- Calculating the normalised input matrix, where the generic element z_{ij} represents the normalised score of the generic solution i under criterion j:

$$z_{ij} = \frac{g_{ij}}{\sqrt{\sum_{i=1}^{n} g_{ij}^2}}. \quad (7)$$

- Calculating the weighted and normalised matrix, where the generic element u_{ij} is:

$$u_{ij} = w_j \times z_{ij}, \forall i \forall j, \quad (8)$$

w_j representing the weight of criterion j.

- Calculating the positive and negative ideal solutions, respectively identified as A^* and A^-, via the following equations:

$$A^* = (u_1^*, \dots, u_k^*) = \{(max_i u_{ij}^* | j \in I'), (min_i u_{ij}^* | j \in I'')\}, \quad (9)$$

$$A^- = (u_1^-, \dots, u_k^-) = \{(min_i u_{ij}^* | j \in I'), (max_i u_{ij}^* | j \in I'')\}, \quad (10)$$

I' and I''being the sets of criteria to be, respectively, maximised and minimised.

- Calculating S^* and S^-, respetively indicating the geometric distances from each alternative i to the postive ideal solution A^* and to the negative ideal solution A^-:

$$S^* = \sqrt{\sum_{j=1}^{k}(u_{ij} - u_{ij}^*)}, i = 1, \dots, n, \tag{11}$$

$$S^- = \sqrt{\sum_{j=1}^{k}(u_{ij} - u_{ij}^-)}, i = 1, \dots, n. \tag{12}$$

- Computing the closeness coefficient C_i^* for each alternative i, which indicates how alternative i performs with respect to the two ideal solutions:

$$C_i^* = \frac{S^-}{S^- + S^*}, 0 < C_i^* < 1, \forall i. \tag{13}$$

- Drawing up the final ranking of alternatives according to their decreasing values of closeness coefficients. For example, with relation to two generic alternatives i and z, if $C_i^* \geq C_z^*$ then solution i has to be preferred to solution z.

3.5. Engineering measure

In this step, to implement engineering interventions for improving the performance of the expansion scenarios, replacements of the original network pipes are made to larger diameter pipes (Bakri et al. 2015).

For pipe replacement, the unitiy headloss of pipes is analyzed. Then, while the minimum pressure of the analyzed water system is lower than the minimum required pressure, the pipe with the highest unit headloss is replaced by another pipe with an immediately larger diameter. This iterative process is repeated, for each expansion scenario, until the minimum pressure of the system is equal to or higher than the minimum required pressure. The pipe diameters considered for replacement in this work are: 0.015 m, 0.020 m, 0.025 m, 0.035 m, 0.040 m, 0.050 m, 0.065 m, 0.10 m, 0.20 m, 0.25 m, 0.30 m, 0.35 m, 0.40 m, and 0.50 m.

After observing the results of the expansion scenarios with the replacement of pipes, economic feasibility analyzes are carried out for each scenario, with the objective of proposing efficient and economically viable expansion projects. The prices of pipes are based on budgets updated by the Minas Gerais Sanitation Company – Companhia de Saneamento de Minas Gerais (COPASA) – and are calculated in Brazilian currency (real). Only PVC pipes are considered for replacement of original pipes in the network.

4. CASE STUDY

The water distribution network used in this research is the C-Town employed by Taormina et al. (2017), which has a minimum required pressure of 20m (Muranho et al. 2014). The model is built with 429 pipes, 388 nodes, 7 tanks, 1 reservoir, 11 pumps and 5 valves and divided into 5 DMAs.

The expansion scenarios are taking 30 nodes, selected from peripheral locations of the network. The main idea on this selection is to simulate city expansions and demand increase for water supply through population occupation of urban peripheries. In sequence, the C-Town network with its respective expansion nodes and DMAs are shown in Figure 1.

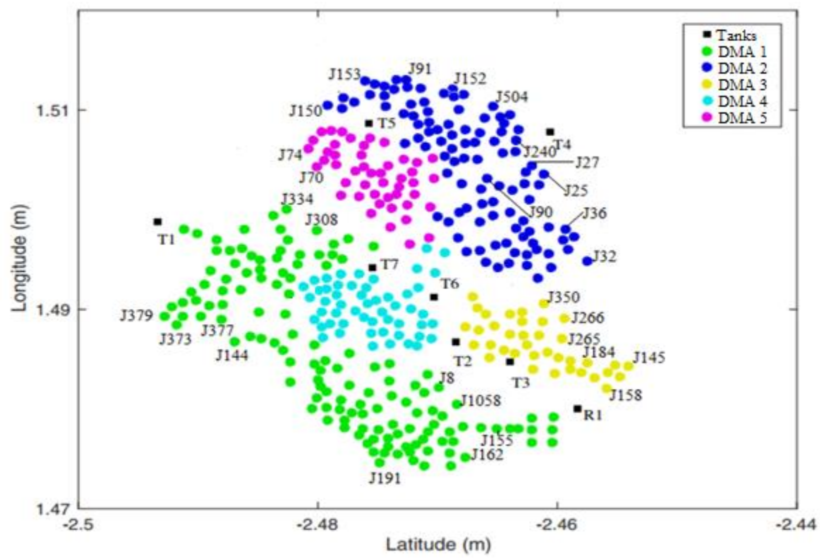

Figure 1. C-Town with its DMAs and expansion nodes identified.

In terms of demand increase, 0.5%, 1%, 2%, 5% and 10% of the total demand of the C-Town network without expansion (around 270 L/s) are simulated for each selected node.

5. RESULTS AND DISCUSSIONS

As results of the complex network metrics used in this research, considering a simulation time of 168 hours, Figure 2 presents the difference between the hourly average closeness centralities for the scenarios without and with increased demand of 2%, and with the flow weighted network edges. In sequence, Figure 3 presents the hourly averages of the network closeness centralities with flow weighted edges and demand increases of 0.1% and 10%.

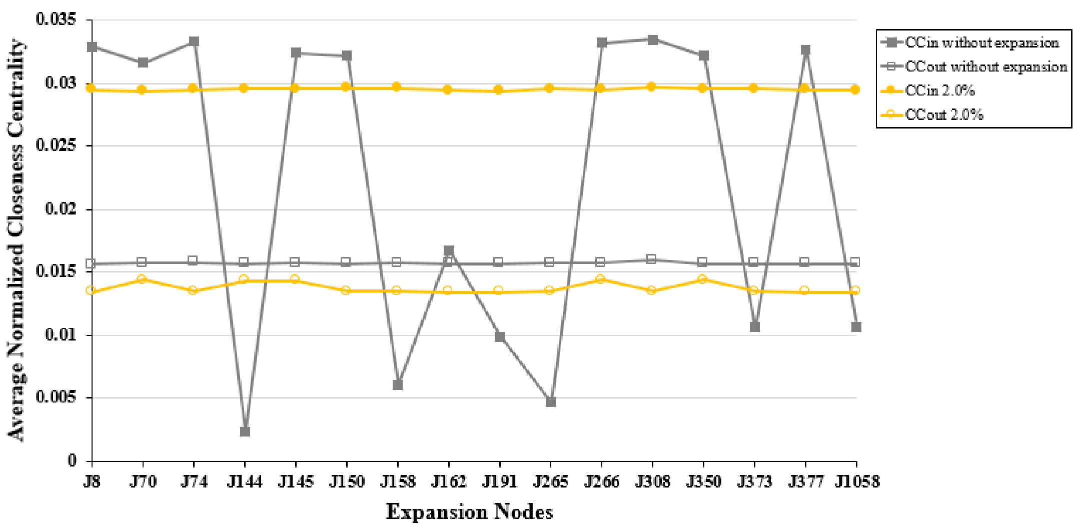

Figure 2. Average closeness centrality for some expansion nodes in scenarios without and with demand increase of 2% for edges weighted by the flow.

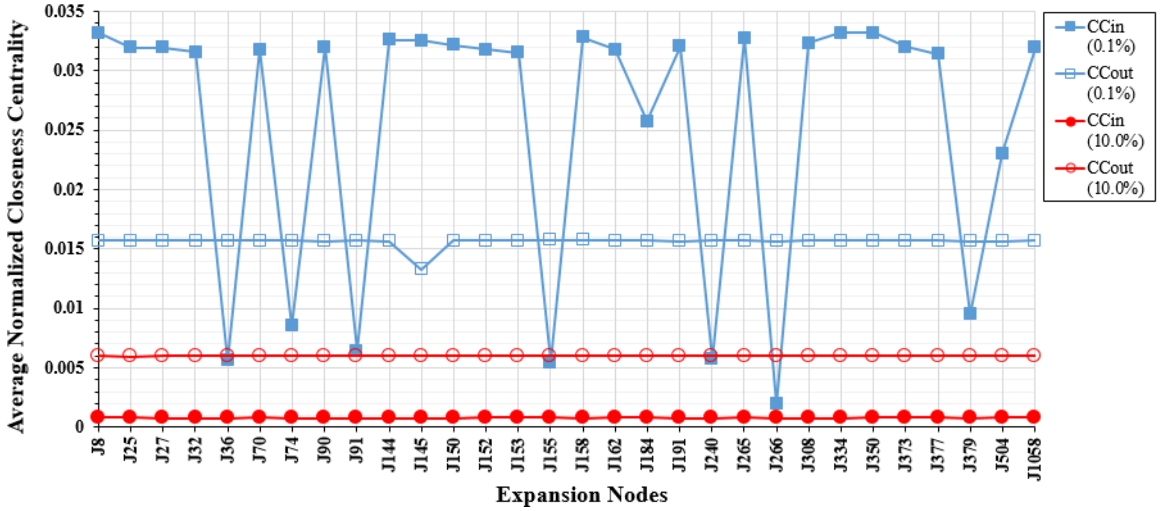

Figure 3. Average closeness centrality for expansion scenarios weighted by the flow and for demand increases of 0.1% and 10%.

At first, analysing the averages values of the normalised closeness centralities of Figures 2 and 3, it can be stated that the lengths of the shortest paths increase by increasing demand, while closeness centralities are reduced.

From Figure 2, it is also possible to observe that, by increasing the demand, the closeness centralities reduce the variation, if compared to expansion scenarios. This changes derive from the fact that, by increasing in demand, the pipes are filled by higher flows released by reservoir and tanks and thus the flow variation in the pipes is reduced.

Figures 2 and 3 also show that, in correspondence of smaller demand increases, CC_{in} is in general greater than CC_{out} due to the network nodes consuming the supplied water volume, which makes the edges or outcoming flows smaller than the incoming and often decreasing number of nodes that can be reached by water. CC_{in} and CC_{out} do not vary for the weighting of the edges by the resistance coefficient, being this parameter strictly topological, according to Equation (1).

Figures 4 presents the hourly averages for a simulation time of 168 hours, of the network average shortest paths lengths for the flow weighting.

For the weighting of edges by flow, higher average length of shorter paths means higher average flow for supplying demand nodes and, on the contrary, lower average flow distributed to nodes of the C-Town network. Then, observing Figure 4, it can first be stated that the higher the increase in demand, the higher the average length of the shortest paths. This fact comes from the increase in flowrate through the pipes to supply the higher demand for water consumption at the nodes.

Considering a hydraulic simulation time of 168 hours, results of the hydraulic criteria and pipes replacement prices were generated and the TOPSIS technique has been applied to get a final ranking of nodes under the four evaluation criteria (PU, WA, R, price for pipe replacement). Criteria are herein assumed as equivalently weighted for the sake of simplicity but, as already specified, considering different weights deriving from the integration of a preference-aided perspective is possible. In particular, six stages of TOPSIS application have been led, since the following six expansion scenarios were considered for the water network under analysis: 0.10%, 0.50%, 1.00%, 2.00%, 5.00% and 10.00%.

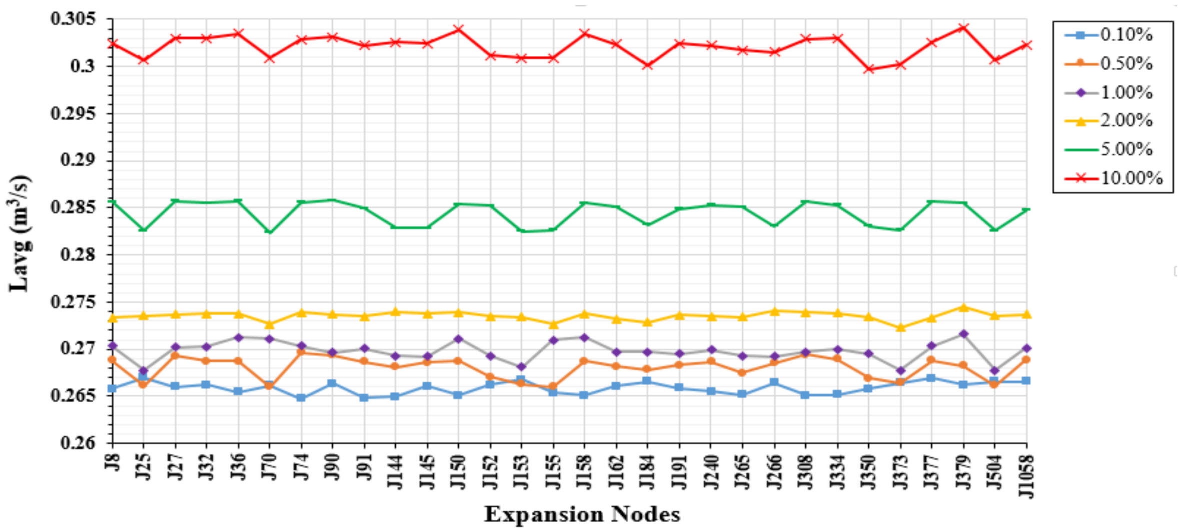

Figure 4. Average shortest paths lengths for each expansion scenario with edges weighted by flow.

Figure 5 shows the map of the C-Town network with the colored expansion nodes, according to the value of the closeness coefficient C_i^* calculated via TOPSIS, without changing pipes and considering 10% increase demand. In sequence, Table 1 and 2 report, respectively, the five best and worst scenarios of expansion without pipe replacement for maximum percent demand increase (10.00%), and the five best- and worst-case scenarios of expansion with pipe replacement for each percent demand increase.

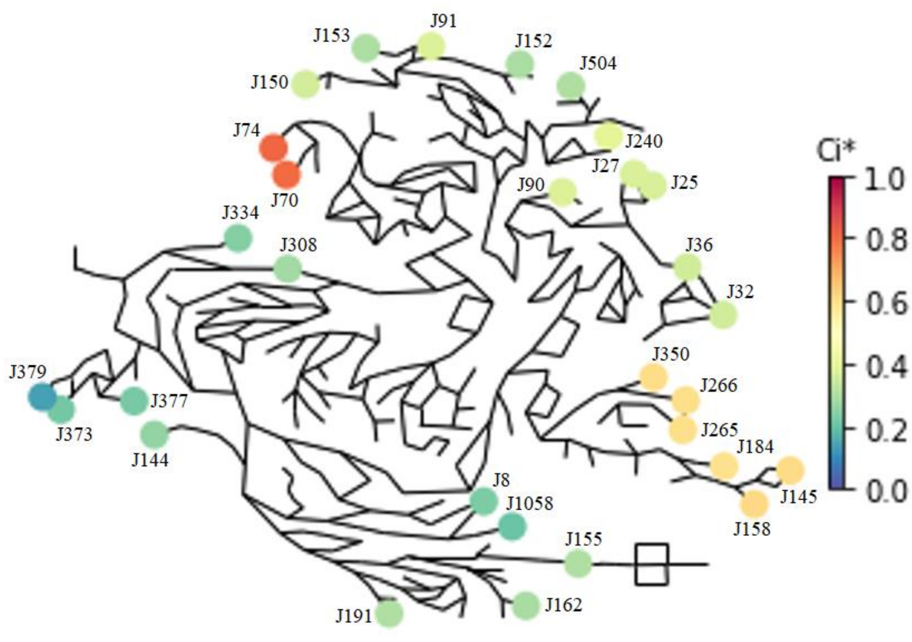

Figure 5. Map of the C-Town network with the colored expansion nodes according to C_i^* without changing pipes.

Table 1. Best and worst solutions for each expansion scenario with 10% increasing demand, without pipe replacement and according to values of C_i^*.

	Rank	Expansion Node	C_i^*
Best Solutions	**1st**	**J74**	0.809
	2nd	**J70**	0.801
	3rd	**J158**	0.610
	4th	**J145**	0.607
	5th	**J350**	0.602
Worst Solutions	**26th**	**J8**	0.236
	27th	**J377**	0.230
	28th	**J373**	0.225
	29th	**J1058**	0.208
	30th	**J379**	0.144

Table 2. Best and worst solutions for each expansion scenario without pipe replacement according to values of C_i^*.

	0.10%		0.50%		1.00%		2.00%		5.00%		10.00%	
	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*	Rank	C_i^*
Best Solutions	**J144**	0.965	**J144**	0.925	**J144**	0.939	**J350**	0.907	**J350**	0.949	**J350**	0.938
	J191	0.964	**J191**	0.924	**J191**	0.931	**J266**	0.907	**J266**	0.948	**J266**	0.936
	J308	0.963	**J308**	0.917	**J308**	0.928	**J265**	0.906	**J265**	0.946	**J265**	0.925
	J162	0.963	**J155**	0.917	**J373**	0.927	**J144**	0.893	**J144**	0.923	**J74**	0.841
	J373	0.963	**J162**	0.916	**J377**	0.927	**J373**	0.883	**J74**	0.876	**J377**	0.837
Worst Solutions	**J32**	0.549	**J145**	0.495	**J350**	0.567	**J91**	0.158	**J334**	0.325	**J504**	0.565
	J36	0.549	**J184**	0.495	**J266**	0.567	**J150**	0.156	**J91**	0.153	**J150**	0.305
	J350	0.043	**J265**	0.095	**J265**	0.566	**J152**	0.121	**J150**	0.143	**J91**	0.282
	J266	0.042	**J266**	0.095	**J152**	0.557	**J153**	0.083	**J153**	0.135	**J152**	0.174
	J265	0.042	**J350**	0.095	**J334**	0.043	**J334**	0.063	**J152**	0.106	**J153**	0.164

As it can be observed in Figure 5, before replacing pipes, the nodes J265, J266, J308, J191, J144 and J162 had worse hydraulic performance. Nonetheless, observing results reported in Tables 1 and 2, node J74 remains established as one of the best scenarios for a 10.0% increase demand, even by changing pipe diameters. The J350 node is the fifth best expansion scenario for maximum percentage increase demand without the application of pipe changes and it is also the best scenario for network expansion using pipe reinforcement for demand percentage increases of 2.0%, 5.0% and 10.0%. On the contrary, node J350 is one of the worst scenarios for expansions with 0.1%, 0.5% and 1.0% demand increases.

Analyzing Tables 1 and 2, it can be also noted as node J145 is one of the best scenarios for maximum network expansion without pipe replacements. However, by implementing the engineering measure considered in this research, node J145 is among the five worst scenarios for 0.5% increase demand. Furthermore, it is worth noticing that, after the pipe swap strategy, scenarios of expansion nodes J373 and J377, which were the worst for 10.0% increase demand, have upgraded. In this case, expansion node J373 is one of the best scenarios for 0.1%, 1.0% and 2.0% demand increase and node J377 is one of the best scenarios for 1.0% and 10.0% increase demand.

Next, for a better hydraulic evaluation of the results, PU (a), WA (b) and R (c) maps are presented in Figure 6, with the coloring of the expansion nodes according to the average of the differences exhibited in the results of the hydraulic criteria between the scenarios with pipe replacement and without pipe change, considering all the percentages of demand increase.

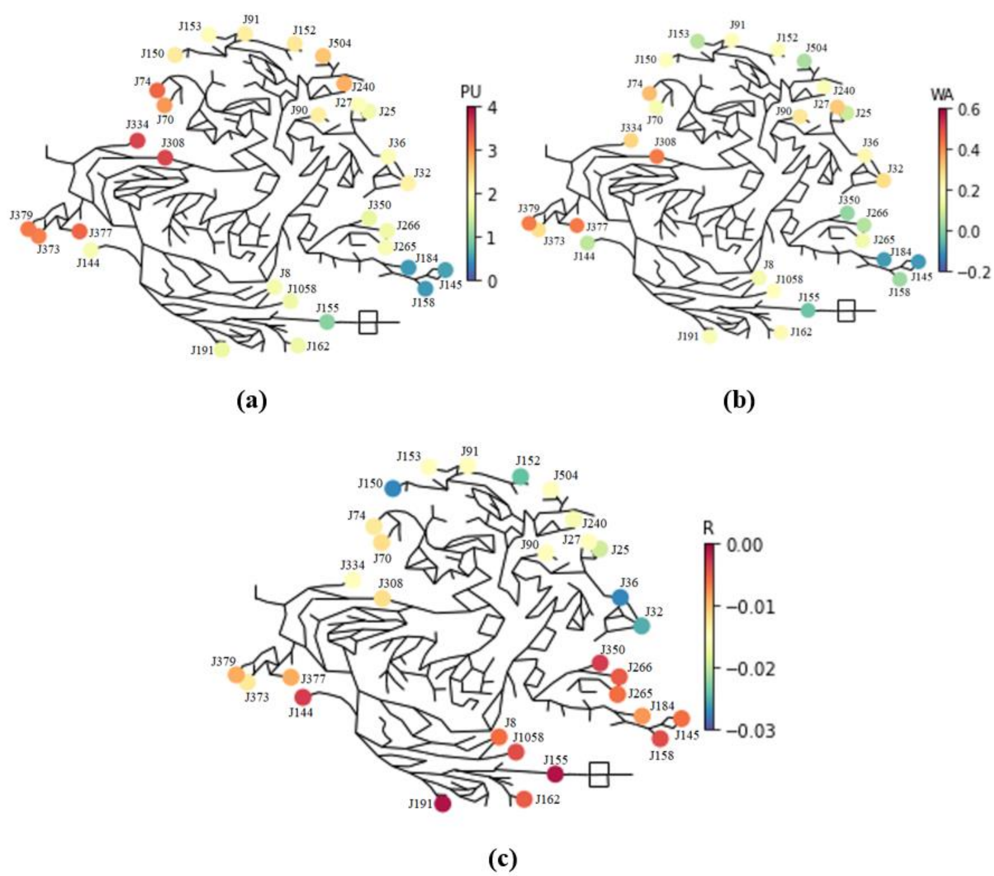

Figure 6. Maps of averages PU, WA e R differences between scenarios with and without pipe replacement.

From Figure 6 it can be seen that the highest ranked nodes in Table 2, in general, are the expansion nodes that made the C-Town network have smaller losses in hydraulic resilience, reduced or smaller increases in weighted average water age, and less marked increases in pressure uniformity. In contrast, the expansion nodes that were rated as worst solutions, according to Table 2, caused the C-Town network to have a greater loss of hydraulic resilience and increases in the weighted average water age and pressure uniformity. In addition, in general, it is also observed that the best sectors for implementing the expansion scenarios are the nodes that are located in DMA1 and DMA3 and the worst nodes for applying expansions are in DMA2.

These hydraulic results are consistent with the rankings in Table 2, as decreasing hydraulic resilience index values increase the vulnerability of the water distribution network to failure and increases in weighted average water age indices also increase the time it takes water to supply demand nodes, thus reducing the quality of water supply. In addition, increases in pressure uniformity index characterize higher system pressures related to average and minimum pressures and, consequently, lower water supply efficiency of the network. With relation to pipe replacement costs, as shown in Table 2, node J74 is among the best ranked for scenarios with demand increases of 5.00% and 10.00% due to its lower demand for pipe exchange and, consequently, a lower price for making DMAs 1 and 5 to reach the minimum operating pressure of the C-Town network. On the other hand, according to the rankings reported in Table 2, nodes J265 and J350 were among the worst solutions because they presented high cost of changing pipes to reach the minimum pressure of the C-Town network.

6. CONCLUSIONS

Water scarcity and growth of urban population require more and more accurated actions of future planning from water utilities. Joint mathematical and hydraulic analyses of expansion scenario of WDSs coupled to multicriteria analyses reveal to be a powerful tool to understand the impact of demand increases in water systems. Based on the results, the best expansion scenarios considering complex network metrics, the hydraulic criteria and the costs regarding pipe replacements for the different demand increases, are the following: 0. 1%: J191; 0.5%: J308, and J162; 1.0%: J308 and J377; 2.0%: J350 and J373; 5.0%: J350, J265 and J144; 10.0%: J350, J265 and J144; 10.0%: J266. The worst case scenarios are: 0.1%: J36 and J265; 0.5%: J265 and J350; 1.0%: J152; 2.0%: J91, J150 and J152; 5.0%: J153; 10.0%: J152 and J153.

From this study it is also possible to observe that, in general, such Civil Engineering interventions as the replacement of original pipelines of water distribution networks by pipes with a larger diameter, can be implemented to recover the supply capacity of the same network. The TOPSIS method also proved to be adequate to rank scenarios by considering indicators from different areas of knowledge. As the objective of this research was reached, it is concluded that hydraulic parameters can be involved with complex network metrics through weightings in order to obtain hydraulically efficient and economically viable scenarios for the expansion of water distribution networks.

Future works should analyse different Civil Engineering interventions, such as pump replacement or new tanks building, under the analysis of optimization process to achieve the best solution in terms of hydraulic analysis under minimal costs.

ACKNOWLEDGEMENTS

The research was financially supported by the Czech Science Foundation under Grant No. 19-06569S.

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