

A Perspective on Reducing Uncertainties in Water Distribution Network Operation Using Clusters

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ABSTRACT

In water distribution system operation problems, a solution is often, if not always, valid for a small variety of forecasted scenarios. The number of unknown variables, such as consumer consumptions, pipe smoothness, leaks or infections makes the forecasting of the conditions in which the network operates almost impossible. On the other end, most of the solution procedures take use of deterministic models such as water and energy balance or demand patterns – and even stochastic models cannot predict the conditions for which the problem in hand is defined. This procedure of using exact solution models for inexact problems is reconsidered while a methodology of using clusters in water distribution systems is demonstrated on selected regions, utilizing simple examples as an effective tool for bridging the gap.

Keywords: water distribution systems, uncertainty, cluster

1 BACKGROUND

In water distribution system operation problems uncertainty is the "queen of battle" where a solution is often, if not always, valid for a very small variety of forecasted scenarios[1]. Deterministic equations, such as energy losses or water balance are used to solve the hydraulic state of a network for given set of initial conditions and topology but these conditions are often far from reality while the number of unknown variables, such as consumer consumptions, pipe smoothness, leaks or infections makes the forecasting of the conditions in which the network operates impossible. For example, a pipe flow can be calculated using an energy loss equation using its hydraulic parameters (diameter, length, friction coefficient etc.)[2] while the discharge in the pipe will be determined by the consumer end - depending if he chooses to consume water or not. One of the most used consumer consumption prediction methods, for example, is demand patterns. Such consumption assessments methods are used wildly to describe consumers demands using demand patterns or statistical analysis thus making the hydraulic solution dependent on the accuracy of the forecasted variables[3]. To tackle this problem, a grouping of the network elements – such as consumers or pipes – in the form of clusters is used to bridge the gap between the problem condition and solutions[4]. The main assumption used in this paper derives that variations from forecasted behaviours in large groups mean will be much smaller than in individual subjects. For example, the average height of students in class will circle around 160-170 cm, although an individual student may be as high as 210 cm. The assumption that student height is 165 cm is valid with a small area of mistake for a large group of students and can vary largely when tested

individually. The same methodology of applying assumptions on a group is used when network elements are gathered into clusters. The procedure of grouping elements in the network called cluster analysis in the goal of producing a simplified network[5], mimicking the original one, with fewer elements and where the predicted parameters of the clusters describes better the condition of the simplified network[6]. Sure, variations inside the clusters can be large, but the overall clustered network is much stable against uncertainty conditions. A better predicted network conditions may result in better network operation in a variety of fields such as pumping schedules, tank and storage management, pressure management, leakage control, contamination detection and prevention and much more[7]. This perspective paper reviews several possible cluster techniques and acknowledges its benefits in water distribution operation and design and sets objectives for further research in this field.

2 REVIEW

2.1 Clusters as concept

Dealing with a group of objects is more often easier than dealing with individuals and the examples are plenty: in fashion business – sizes of outfit products are separated to fit groups of customers, in advertisement – campaigns go for a group of interest based on managers assumptions based of individual similarity[8], even water products, such as water bottles do not address the individual customer need as they come in pre-defined volumes (i.e. 330ml, 0.5l, 1.5l). if the consumer need is less than the offered amount, he remains with excess, if it is more, he must acquire an additional pre-defined amount. All of the above are tools that uses a grouping of properties of the consumer in order to devise a global solution. Such grouping can be described as clusters of the consumer – groups of pre-determined properties and solutions. Clusters, therefore, can act as a management tool.

2.2 Clusters in water distribution systems

Separating the distribution network into zones is a long-used tool. Systems are separated into zones based on numerous properties such as pressure, demand or topology. Geographic spread is also a tool for managing large scale systems. The location of groups of nearby consumers (i.e. a city) is used to generate a self-managing water distribution zone. It is easier to control separated zones – a concept demonstrated, probably first, by the ancient Greeks with their motto of "divide et impera" (divide and rule)[9]. For leakage control – clusters act as a very effective methodology. Separating the system into District Metered Areas (DMAs) take use of the re-arrangement of looped networks into areas divided from each other with valves and meters to allow more accurate flow control[10]. For pressure control, location of water tanks to generate topographical pressure zones is used. The network is separated into zones based on the topographical properties of the consumers and each zone is governed by specific tanks. When forecasting of water demand patterns is needed, the forecasting models separate the population or consumers into groups based on similar properties such as the consumption type, the location within the network or even social properties[11][12]. This results with groups of consumers – clusters – for which a single model describes their water demand.

2.3 Hydraulic uncertainties

To draw the hydraulic condition of a network, most models use deterministic equations. These models require a complete determination of the hydraulic properties of the problem. Such properties include, for example, water demand, pipe geometry or topographical map of the system. As some of them can be determined with large accuracy (i.e. pipe length, consumer location) the rest are based

on a forecasted model (i.e. pipe condition, water demand). The conflict between exact solution and in-exact condition poses built-in inaccuracy in the solution models. This uncertainty must be taken to account when models are used[13]. Some methods for reducing uncertainty had been widely used and the results may improve significantly in terms of uncertainty reduction[14]. Demand uncertainty is probably the largest of them all. There is no accurate technique to determine when a consumer will open his tap. To attack this most models rely on external measurable parameters: climate, type affiliation, temperature, social behavior etc.

3 SUGGESTIONS

The benefits in applying various clustering techniques in water distribution system analysis is demonstrated in two conceptual areas:

3.1 Demand forecasting

As mentioned before, forecasting of demands relay on demand patterns. The patterns describe the change in demand of an individual consumer ad a function of time. The demand pattern is affiliated with a group of consumers with equivalent properties. But what happens if a single individual in the group deviates from the forecasted pattern - even scientifically. For example, a group of 100 consumers may include few consumers that deviate largely from the forecasted demand pattern (i.e. residential neighbourhood with households working nightshifts) but their influence on the overall average demand of the group will not be significant making the forecasted condition of the group more stable in a scene. This concept is demonstrated in Figure 1 showing 8 different demand patterns (black) and their average (dashed red)(a), when one of the patterns is varied largely (green) (b) the influence on the average pattern (dashed red) is not significant and the overall average of the group (consists of 8 patterns) remains roughly the same.

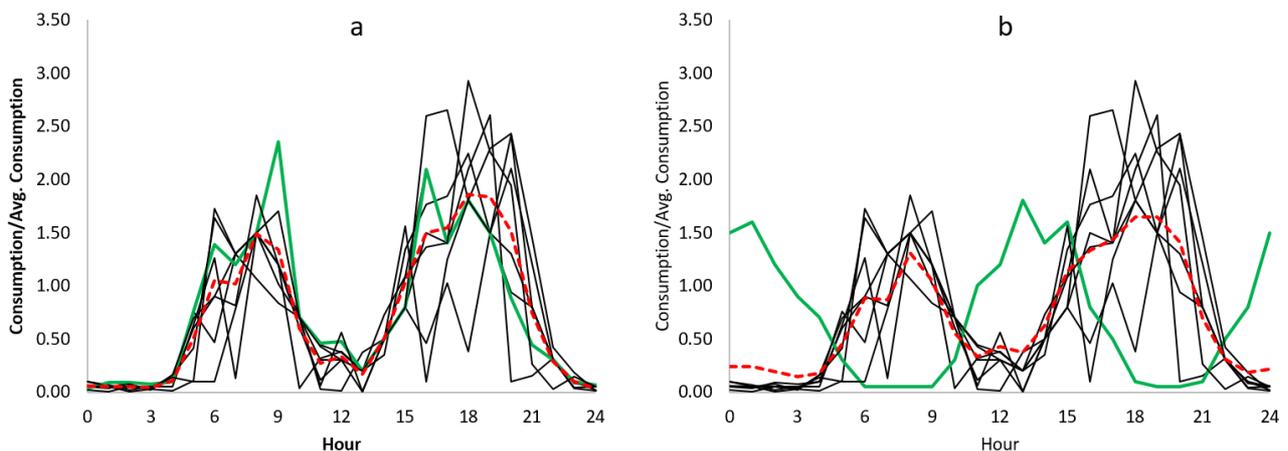


Figure 1. The influence of 1 demand pattern variation (green) over a group 8 patterns average (dashed red).

3.2 Contamination spread

Forecasting contamination event spread within network elements is a complex problem, mainly due to two reasons: 1. Demands of consumers, and therefor pipe flows, are inaccurate or unknown 2. In cases of contaminated water flow, consumers tend to change their consumption behaviour[15]. The combination of the above result with a complex problem for prediction of contamination spread during contamination events. A simplified, clustered, network can come to help here. Although

flows within clusters may be unknown, the flow between separated clusters is easier to predict – as demonstrated in Figure 2. The known flow between clusters 1 and 2 (C1, C2) or between 2 and 3 (C2, C3) are known and the direction is shown in bold arrows – it is easy to predict that a contamination in C3 will influence C4 while not C2 and C1. This is in oppose to the inside flows within the clusters that are unknown and the spread between the nodes inside each cluster is hard to predict.

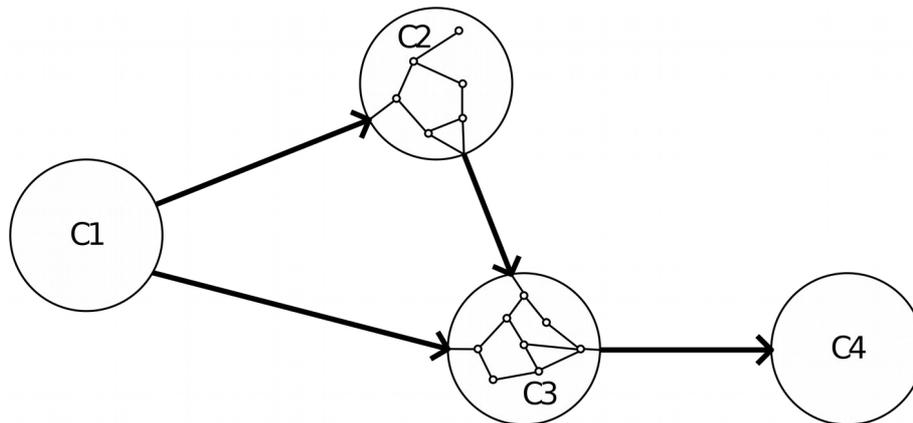


Figure 2. known flows between clusters (bold arrows) Vs. unknown flows within clusters.

This understanding can be critical for the general network manager to forecast and control contamination events. For the condition inside clusters we can suggest a "micro-management" concept (not yet determined): each cluster can be managed by automated tools based on general director instructions. Divide the overall network into sub-networks (clusters) that can be auto-managed by technological tools.

3.3 Data gathering

A new approach in water distribution systems managing calls the use of "data mining" and "big data" methodologies. Those techniques are using automated tools to gather large amounts of data, apply data analysis algorithms and conclude decisions. The emphasis here is on data collection. In basic, several measured parameters are selected and monitored while their relation to decisions is unclear. Patterns of correlation between data and decisions can be recognized and applied in future use[16][17]. For example, to predict peak consumptions in specific locations, data mining can follow social events nearby where large numbers of population attend[18]. Correlation between measured parameters and predictions are used for some time now, the advance is in the data processing capabilities. In the example described above, to predict a specific individual demand a data about the individual need to available. This is problematic, mainly for privacy reasons, thus making the data mining relevant for groups of population with similar properties – clusters within the population of the network.

4 CONCLUSIONS

In conclusion, this perspective reviewed the concept of clusters in water distribution systems and its correlation with uncertainty. Suggestions for the use of clusters to reduce uncertainty in selected areas were demonstrated through simple examples. There is still a gap between what can be possibly achieved using current technology advances and the methodologies available. Uncertainty poses a great challenge in system management and operation and tools are being developed

continuously. To take into consideration clustering when developing such tools may be affective and beneficial.

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