How to detect as many leaks as possible with as few flow meters as possible

Karel van Laarhoven
(KWR Watercycle Research Institute)

Dennis Gardien
(Dunea Duin & Water)

It is becoming increasingly important for water companies to have an accurate overview of the water flows through the water distribution grid and to be able to quickly identify disruptions in the water supply. Dunea and KWR are working together on one of the possible strategies for achieving this: by dividing the water supply grid into District Metered Areas.

District Metered Areas (DMAs) are subsections of a water supply grid of which all inlet and outlet pipes are fitted with a volume flow meter. This enables the water balance of these areas to be measured. The water balance provides insight into water flows and consumption patterns and reveals deviations from regular consumption.

With the latter, DMAs also offer the possibility of detecting and locating (latent) leaks in real time, even before a small leak can develop into a pipe burst. In countries with bigger altitude differences and greater water losses, DMAs have been playing a crucial role in pressure control and leakage reduction for years.

Installing flow meters and adjusting the water supply grid configuration is a challenging task. In urban areas such as The Hague, room to manoeuvre in the underground is typically scarce. Moreover, many vital functions are present above ground, making it difficult to obtain permits to carry out the work. In addition, modifying the transport grid poses challenges due to the importance and depth of the pipes.

In the end, it takes at least a week to install one flow meter. For this reason, it is essential to install as many DMAs as possible with as few volume flow meters as possible. This is a complex task, as the Dutch water supply grids generally are highly looped, allowing for countless different DMA configurations.

Within the joint research of the dune water companies, KWR has added functionality to the Gondwana software tool to support the design of DMAs with evolutionary optimization methods. Here we answer the question of how Dunea, supported by this tool, can divide its most complex grid, The Hague, into optimal DMAs.

Optimization

In close cooperation with a team of experts from Dunea's distribution department, items were described such as: the annual budget available to Dunea for installing water meters, a representative model of the water supply grid and an overview of the pipes that were eligible to serve as a DMA boundary. By digitizing such expert knowledge, the optimization tool can be provided with input that describes practice as accurately as possible. This is crucial to obtain realistic results that are valuable for the water company.

Gondwana uses an evolutionary algorithm, an optimization algorithm inspired by concepts from genetics. The general principle behind this type of algorithm is shown schematically by the blue boxes in figure 1. First, a collection of possible solutions is created (a population of individuals). The solutions are tested for their performance according to the user criteria. The least successful solutions are discarded (natural selection) and the collection is supplemented with new solutions. The new solutions are generated by creating small variations in well-performing solutions (mutation) or by combining elements from two well-performing solutions (reproduction). The process is then repeated several times, gradually improving the quality of solutions (evolution).

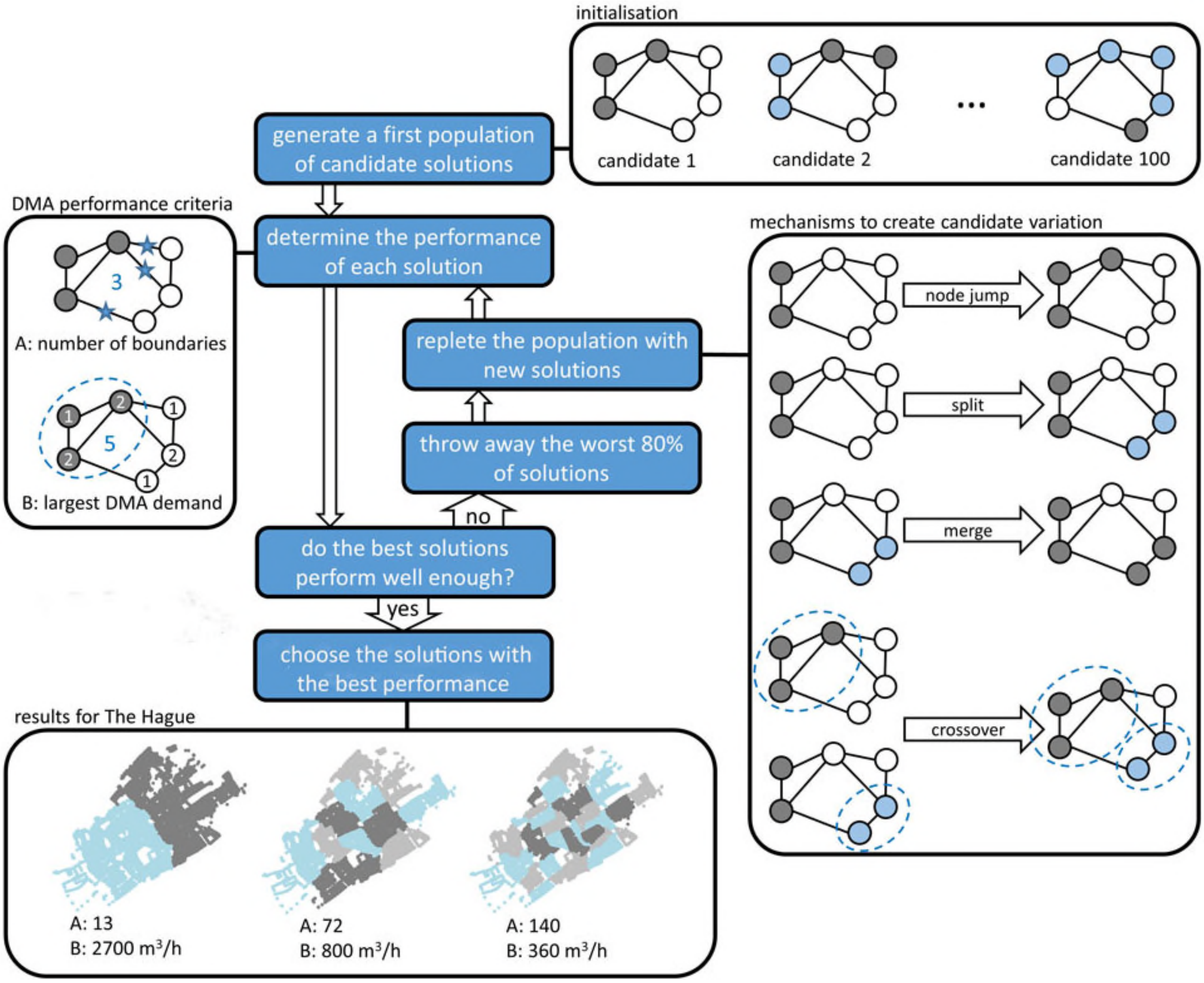

Figure 1. Schematic representation of the evolutionary optimization algorithm used. The blue boxes summarize the general operation of the algorithm. The white boxes illustrate the specific implementation of the algorithm used to optimize a DMA configuration.

The white boxes in figure 1 show the way in which the algorithm was specifically applied to optimize a DMA configuration. A single configuration is defined as a water supply grid in which each node is assigned to a specific DMA. During reproduction, mutations in the offspring are made by: exchanging nodes between DMAs, merging adjacent DMAs, splitting single DMAs and constructing a new configuration with DMAs from two different “parents”. The performance of a potential DMA configuration is determined on the basis of two aspects. Firstly, the number of boundaries between DMAs should be as low as possible so that it takes as little effort as possible to achieve the configuration. Secondly, the total water consumption within a DMA should be as low as possible so that any deviation from regular water consumption is as obvious as possible.

An optimal DMA blueprint

The two performance targets are opposites: more volume flow meters are required in order to make smaller, more accurate DMAs. Therefore, the first result of optimization is a collection of possible DMA configurations with differing, optimal combinations of the number of boundaries and the maximum consumption (see figure 1, "Results for The Hague"). This provides insight in Dunea's leeway to balance sensitivity against costs in their DMA configuration for The Hague. Based on this, a choice was made for the configuration shown in figure 2.

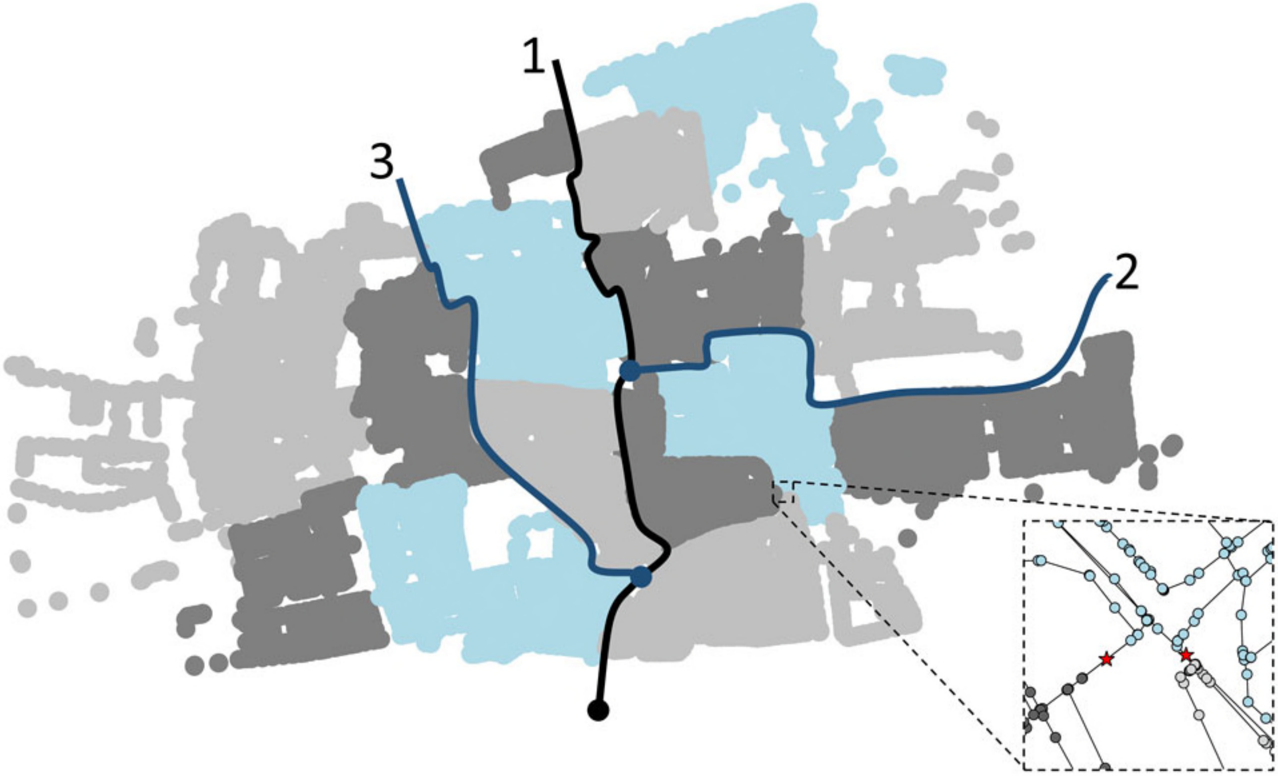

Figure 2. The selected DMA configuration for The Hague. The different coloured boxes represent different DMAs. The three numbered lines represent the first three of eight steps that comprise the optimal transition to this configuration. The magnified part of the water supply grid shows several boundaries between DMAs, marked with a star.

The DMA configuration in figure 2 creates 15 DMAs with 92 boundaries. These are too many boundaries to realize in a short time. Therefore, an optimal transition was determined, a sequence in which The Hague can be evenly divided into increasingly smaller DMAs through the yearly realization of a limited number of the remaining boundaries. In figure 2, the first three steps of this transition are shown by the numbered lines. Five more similar steps are to follow before the 15 DMAs are completed.

Completion

With the resulting DMA configuration, Dunea will set to work in drawing up a concrete implementation plan. Given the looped nature of the water supply grid, it would be inefficient to maintain all existing DMA boundaries as pipelines equipped with a volume flow meter. The final plan will therefore include the creation of a security of supply analysis to be made

for the entire region of The Hague. The analysis examines the importance of each DMA boundary (marked as stars in the magnified supply grid in figure 2) for the water supply, with the following options:
- indispensable boundaries will be fitted with a flow meter (most large supply pipelines will remain in operation, as, ultrasonic sensors will be used and placed on the outside of the pipeline whenever possible);
- boundaries required in the event of an emergency are closed using an existing valve;
- boundaries that have become superfluous will be permanently removed, a guiding principle being to avoid the creation of dead end pipes with little or no consumption.

This analysis determines what work will need to be done and enables an estimation of the necessary costs to be made. This forms the basis of a planning for the coming years. At the beginning of 2019, a start was made with the first “cut”, dividing the region of The Hague into two balance areas according to line 1 in figure 2. These areas will then be further subdivided, until the configuration in figure 2 is achieved.

Outlook

The results of the optimization provide Dunea with a concrete and substantiated starting point for a DMA configuration. For Gondwana, this is an important proof-of-principle that shows the added value of implementing numerical optimization techniques within the design process of a water company.

We would like to emphasize the importance of interaction between the expert and the optimizations. On the one hand, the results of an optimization depend on the question and knowledge entered by the expert. On the other hand, the results provide the expert with an understanding of the various possible optimal solutions, which creates a new perspective on the problem so that the question and input can be further detailed. Based on the understanding acquired in this project, the security of supply analysis mentioned above will be included in the performance criteria of future optimizations.

By dividing the water supply grid into DMAs, Dunea will gain more insight into what is happening in the water supply grid. Dunea expects to use the final DMA configuration in order to:

- monitor and control water flows through the grid;
- validate the consumption models used in business operations with the actual consumption measured in DMAs;
- measure and then reduce the water losses per DMA in The Hague.

Active leak detection and leak localization will also be used with DMAs. Small leaks can be detected and repaired before they develop into a burst pipe. On the one hand, this will reduce public inconvenience (as a pipe burst can cause considerable damage). On the other hand, leakages are detected more quickly so that customers are inconvenienced less by supply interruptions. It will also be possible to detect and trace latent leaks that are not visible at ground level, reducing water losses.

Dunea also expects there to be long-term advantages in its approach of not equipping all boundaries with volume flow meters but to also close pipes where possible. This constitutes a redesign of the water supply grid to better meet the requirements for water quality and security of supply:

- the amount of sections in the water supply grid with long retention times of potable water is reduced;
- the larger pipes better fulfil their role as transmission lines;
- chances of sediment settling are reduced, which ultimately leads to fewer brown water complaints.

In this way, the transport grid in The Hague is more effectively used to provide potable water to the hinterland of the supply area, while the main distribution grid is better used for its intended purpose to provide potable water at the district level.

All in all, the results of this project provide a first outline of the water supply grid of the future, designed and monitored using modern techniques. The opportunities offered by the Internet of Things with respect to sensors fit this concept well. Ultimately, this will make high quality potable water coming from the tap become a matter of course even more!

Karel van Laarhoven
(KWR Watercycle Research Institute)
Dennis Gardien
(Dunea Duin & Water)

Summary

DMAs enable water companies to better monitor the water flows through the water supply grid and to identify and detect leakages more quickly. However, achieving a complete DMA configuration requires a large number of costly interventions in the drinking water distribution network. Dunea and KWR are working together to use evolutionary algorithms to optimize a configuration to require as few interventions as possible. The result is a target configuration that Dunea will gradually be completing in the coming years.