Optimal Placement of Valves in a Water Distribution Network

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A water supply system is a complex system that brings the water from one or more sources to the users. The water distribution network can be thought of as a labelled graph, in which pipes are represented as undirected edges. In the network, there is at least one special node that is the source of the water (node 0 in Figure 1); users are then connected to the edges of the water distribution network. Each edge of the graph is labelled with the total demand of the users linked to it. E.g., in Figure 1, the edge $e_{2,5}$, connecting nodes 2 and 5, has a demand of $15l/s$.

In case a pipe has to be repaired (e.g., because of a break), a part of the network has to be disconnected from the rest of the network, in order to allow workers to fix the broken pipe. The isolation system consists of a set of *isolation valves*, that are placed in the pipes of the network. Once closed, the isolation valve blocks the flow of water through the valve itself.

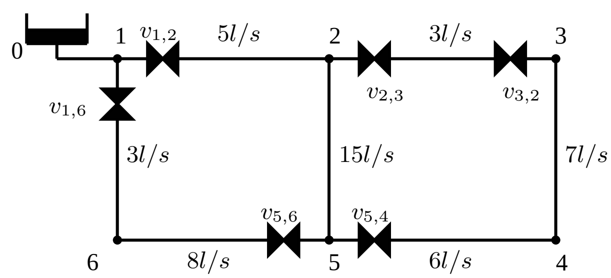

Fig. 1. A schematic water distribution system with valves

Each valve has a cost, that is not only due to the manufacturing and physical placing of the valve, but also to the fact that the pipe is more fragile and deteriorates more quickly near valves. So, placing many valves means more frequent damage, leakage, and possibly water loss. On the other hand, placing few valves means that large parts of the network should be disconnected in case of pipe substitution, which means that many users will remain without service during repair works.

The design of the isolation system consists of placing in the distribution network a given number of valves such that, in case of damage, the disruption is "minimal".

In the hydraulic literature, Giustolisi and Savić [6] address the problem as a two-objective problem: one objective is minimizing the number of valves, and the other is the minimization of the (maximum) undelivered demand. They adopt a genetic algorithm that is able to provide near-Pareto-optimal solutions.

We believe that a complete search algorithm could provide better solutions, although at the cost of a higher computation time. Since the problem should be solved during the design of the valve system, there is no need to have a solution in real-time, and an algorithm providing a provably Pareto-optimal solution may be preferable with respect to incomplete algorithms, even with higher computation times.

We propose several formulations of the same problem studied by Giustolisi and Savić with complete algorithms.

In [2], we address the two-objective problem as a sequence of single-objective ones. Given the number of valves, we model the design of the isolation valve system as a two-player game, and solve it with a minimax approach. As the game has an exponential number of moves, we reduce the search space by pruning redundant branches of the search tree, implementing the minimax algorithm in Constraint Logic Programming on Finite Domains (CLP(FD)), in particular we used the open source solver ECL^{i}PS^e [1]. Our algorithm is complete, so it is able to find the optimal solutions and prove optimality; we show improvements on the best solutions known in the literature, up to 10% of the objective function value [2]. The source package is available online and it contains both the program and the instance [3].

We are currently studying an implementation based on Answer Set Programming [4]; several ASP encodings have been implemented and tested, by exploiting the solver *Clingo* [5] provided by the Potassco team. Such programs consist of few rules, about 25, and are a quite different; above all, sectors may be explicitly defined by the program, or else the concept of sector may be kept implicit.

We are also studying a Bilevel (Mixed Integer) Linear Programming implementation [7], where a Maximum Flow model and a Graph Partitioning one are nested together to achieve an opportune formalization of the problem.

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