Using integer linear programming methods for optimizing the real-time pump scheduling

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Abstract The work presented in this talk deals with the management of a drinking water distribution network in terms of planning the use of different installations (treatment works, pumping stations, and valves) in order to convey water from sources (rivers, borings, springs,...) to supply areas.

More precisely we study the real-time pump scheduling problem. Being given a water distribution network and some previsions on the consumption at different nodes of the network during a considered time horizon, the main problem is to schedule water pump jobs under the constraint to satisfy water demands with the quality standards settled by French and European legislation, while minimizing the operating costs (treatment and electricity).

These operations should satisfy technical constraints as the respect of the minimum and maximum level of tanks, some contractual constraints as the respect of power levels defined by electricity supplier contracts, and last take some specific water distribution network constraints related to the impact of pressure in modeling or the need of the raw water flow to be as smooth as possible. The task is difficult because of the number and variety of operational constraints that exist in a water distribution system. Recently, this problem becomes more relevant because of the future liberalisation of the electric market that will make difficult the knowledge of the less expensive time slots.

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In this talk we will provide a study on the different constraints needed to be modelized and mathematical models for each of them. One of the main problems encountered in modelling is how to deal with hydraulic constraints in our network. This issue is of primary importance as it will lead the choice of the resolution tool to be used.

Keywords real-time · pump-scheduling · water distribution system · integer linear programming

1 Context

Different approaches exist in the literature to solve this problem: linear programming [1], non-linear programming [5], ant colony optimization [2] , genetic algorithm [4], etc.

Each method has advantages and drawbacks and a strategy could be more or less efficient depending on the characteristics of the studied network. In our case, we have to consider the following network characteristics:

– The considered networks are very large (about 100 pumps and 50 storages in our example);
– The allowed computation time to propose optimized solutions is relatively short (30 minutes maximum in the application in hand) due to the real-time scheduling constraint;
– The discrete behaviour of pump has to be expressed through the model. Indeed, the pumping stations work in some defined level of pumping depending on the type and the power of the station. Furthermore, the changes on pumping regime can be operated only periodically and not anytime.

Therefore, we chose to study linear programming, for its velocity in execution even with a lot of variables. With such an approach, the main difficulties are:

– Modelling through linear programming new constraints not expressed before;
– Express in a linear form the hydraulic constraints of the system;
– Ensuring limited CPU time while dealing with integer linear programming models of large size.

2 An integer linear programming model

Some previous search work [3] have already described some constraints with linear programming such as the respect of water demand, the respect of minimal and maximal level authorized for each storage, pumps that cannot work at the same time and pumps that have to work at the same time. In this talk, we show how to modelize new constraints:

– Respect the maximal number of switching on for some pumps;

– Ensure the required water quality level through mixing the water in some storage (for instance by guaranteeing a percentage of different water sources);
– Avoid stagnation in the storage to provide water quality;
– Include transfer delay when using very long pipe;
– Represent the hydraulic behaviour of the network.

If for the first four constraints one can employ some conventional tools to express them through linear equations, the last one is more difficult. Moreover, handling this is of particular importance as the hardness of linearising the hydraulic constraints is the first reason cited in literature to disqualify the use of linear programming for the pump-scheduling problem. It was therefore especially important for us to achieve considering it and showing that, at least for our case, these constraints can be written down through linear equations.

Let us first give an example where such constraints are encountered : when there are different gravitational pipes bringing water from different storages to the same consumption area, the quantity of water coming from each storage depends on the pressure in each pipe and storage. Then, the equations representing this phenomena are highly non linear.

Another problem with pressure was the existence of water exchanges between storages serving the same consumption area, because of the difference of pressure between them: they tend to balance their level of water. We solved the problem studying experimentally the behaviour between two storages, with and without consumption. We found that this behaviour can be linearised with coefficient that can be obtained experimentally.

There is therefore a preliminary work to do when implementing this method on a new network, to calculate the coefficients for each hydraulic problematic configuration. We will provide some experimental results and schemes illustrating this behaviour and justify our findings.

The model has been tested on a real network composed of more than 130 pumps and 30 storages, and several scenarios and hypothesis are already considered. We will report some numerical results in the conference and discuss issues on the efficiency and accuracy of using linear models for such problems.

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