Optimising Pump Operation Times for Water Distribution Networks

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AIMS - MISG

OUTLINE

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INTRODUCTION

Introduction

- Water transport and distribution accounts for 95% of the operational cost (i.e. pump operation)
- Water consumption varies throughout the day
- Energy prices to run pumps vary throughout the day

Problem: Optimise the pump operation schedule of the water distribution network such that operation costs are minimised whilst maintaining adequate water storage levels.

Assumptions

- The water consumption of all consumers throughout the day is known (t)
- The acceptable maximum and minimum water tank level is given h_L, h_U.
- Water flow is instantaneous
- All pumps operate with the same wattage P_{pump} and flow rate Q_{pump}
- All tanks have the same physical dimensions

SINGLE - TANK MODEL

Single -Tank Model

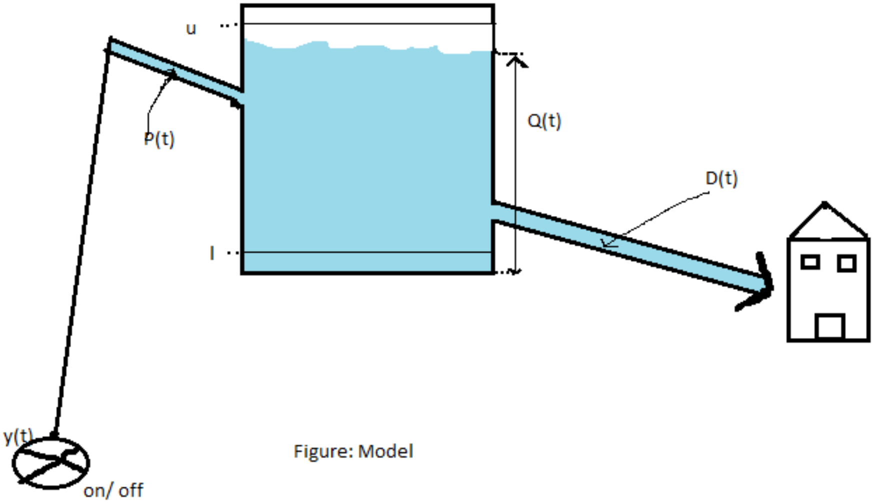


Figure: Model

Continuous Compartmental Model

Define the following variables:

- $Q(t)$ - Tank water level
- $y(t)$ - Pump scheduling indicator function

$$y(t) = \begin{cases} 1, & \text{pump is ON} \\ 0, & \text{pump is OFF} \end{cases} \tag{1}$$

- $\mu(t)$ - Water consumption rate
- q_{in}, q_{out} - Input/Output tank flow rate
- $c(t)$ - Cost price per energy unit
- $\mathcal{C}$ - Total daily cost

Continuous Compartmental Model

T

he amount of water in the the tank is : $Q(t) = \int (q_{in} - q_{out}) dt$

$$
\begin{aligned}
q_{in}(t) &= Q_{pump} p(t) \\
q_{out}(t) &= \mu(t) \\
\text{Then,} \qquad \dot{Q}(t) &= q_{in}(t) - q_{out}(t) \\
&= Q_{pump} p(t) - \mu(t)
\end{aligned}
$$

Tank Constraints

$$h_L \leq Q(t) \leq h_U, \quad \forall t \geq 0$$

Objective Function

$$\mathcal{C} = \int_0^{24} P_{pump} c(t) y(t) \, dt, \qquad \min_{y(t)} \mathcal{C}$$

Discrete Compartmental Model

Decisions

- When to turn on the pump
- When to turn it off
- the amount of water available in the tank

objective function

$minC = \sum_{t=0}^{T} C(t)y(t)$

Constraints

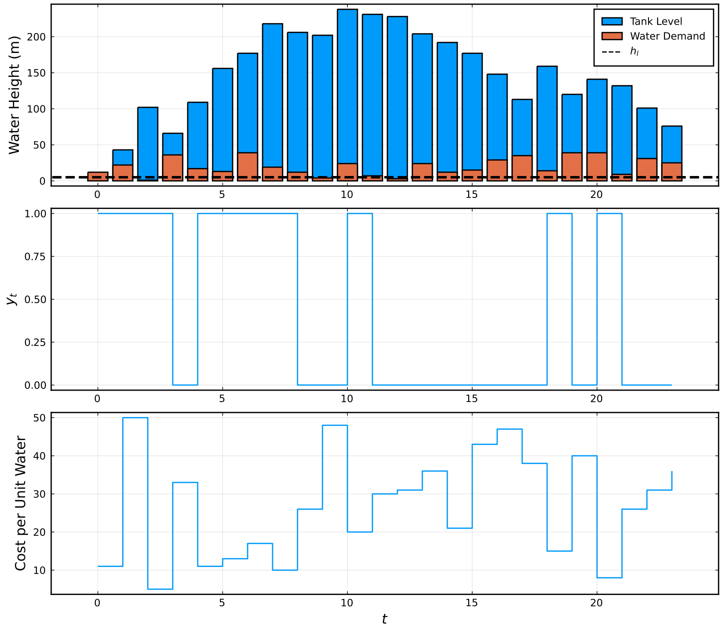
- $Q(t) = P(t)y(t) + Q(t-1) - D(t)$
- $h_L \leq P(t)y(t) + Q(t-1) - D(t) \leq h_U$

RESULTS

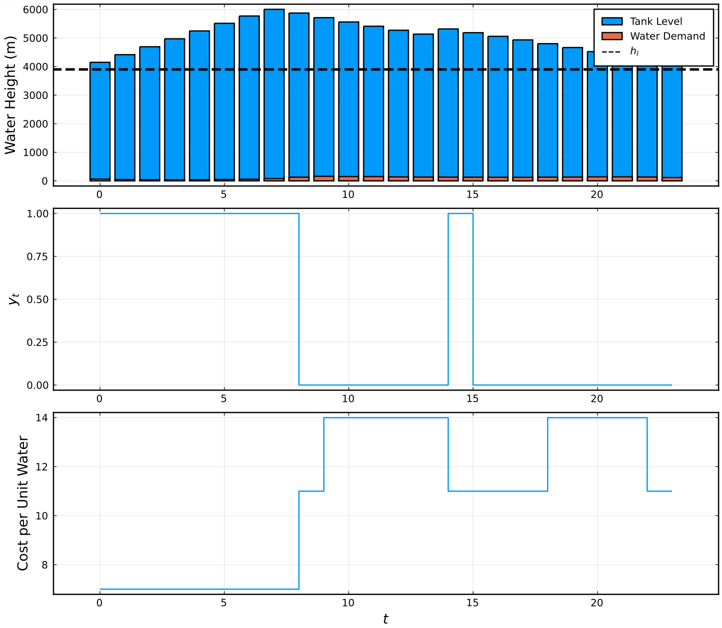
Data set

- We randomly generated a set of data to check and validate the effectiveness of our model
- 24 time periods
- The cost, the demand for each time period are random uniform integer numbers

Result from Random Data



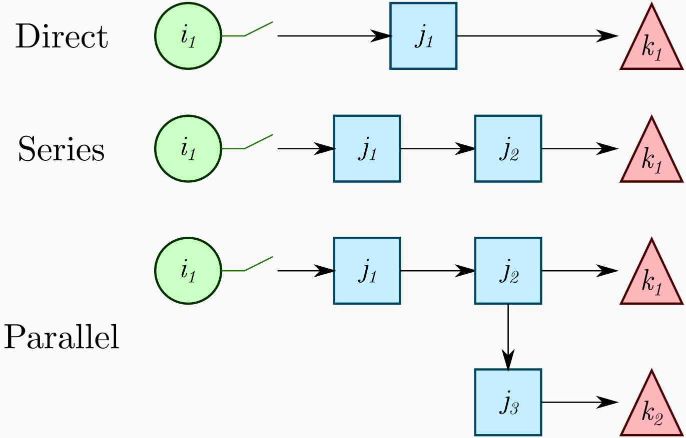
Result from Real Data



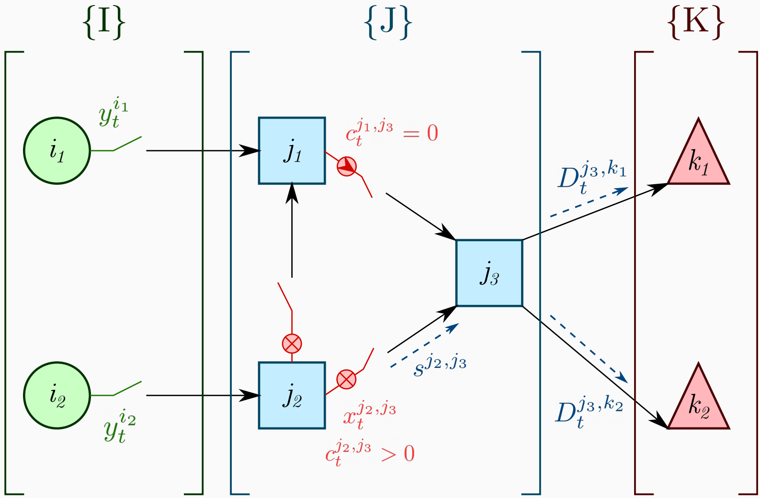
FULL NETWORK

Simple problem

- Cases Variability.



- All combined to form the full network.



Multi-tank Case

Define the following variables

- $y_t \rightarrow$ *Pump set of all pump scheduling indicator at time t*
- $x_t \rightarrow$ *Set of all switch scheduling indicator at time t*
- $y_t^i = \begin{cases} 1 & \textit{if the pump i is on at time t} \\ 0 & \textit{otherwise} \end{cases}$
- $x_t^{jj'} = \begin{cases} 1 & \textit{if the switch between tanks j and j' is on at time t} \\ 0 & \textit{otherwise} \end{cases}$
- $Q_t^j \rightarrow$ *level of water in the tank j at time t*
- $C_t^i \rightarrow$ *Cost (from the pump i at time t)*
- $C_t^{jj'} \rightarrow$ cost *(from the switch between tanks j and j′ at time t)*
- $P^{ij} \rightarrow$ *Amount of water pumped in tank j from pump i*
- $S^{jj'} \rightarrow$ *Amount of water pumbed from tank j to tank j′*
- $D_t^{jk} \rightarrow$*The amount of water from tank j to satisfy part of the demand at the demand point k during the time period t*

Multi-tank Case

The objective function is :

$$\min \qquad \sum_{i\in I}\sum_{t=1}^{T} C_t^i y_t^i + \sum_{j\in J}\sum_{j'\in J_+^j}\sum_{t=1}^{T} C_t^{jj'} x_t^{jj'}$$

Subjected to:

$$h_{L_j} \leqslant Q_t^j \leqslant h_{U_j} \qquad \forall j \in J, t = 1\ldots, T$$

$$Q_t^j = Q_{t-1}^j + P^{i_j j} y_t^{i_j} + \sum_{j'\in J_-^j} S^{jj'} x_t^{jj'} - \sum_{j'\in J_+^j} S^{jj'} x_t^{jj'} - D_t^{jk} \qquad \forall j \in J, t = 1\ldots, T$$

$$D_t^k = \sum_{j\in J^k} D_t^{jk} \quad \forall t = 1,\ldots,T, k \in K$$

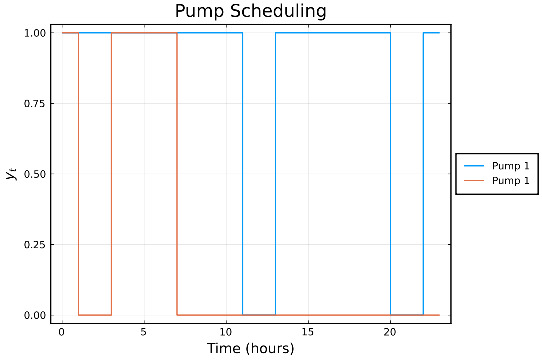
$$x, y \in \{0,1\}, \text{ and } Q \geq 0.$$

About the model

- The above model is a mixed integer linear problem (MILP)
- Small instances of this type of problem can be solved using MS Excel or the **optimization toolbox** of Matlab.
- But larger instances will require the use of more sophisticated optimization solvers (CPLEX, GUROBI, etc).

RESULTS

Result from Random Data



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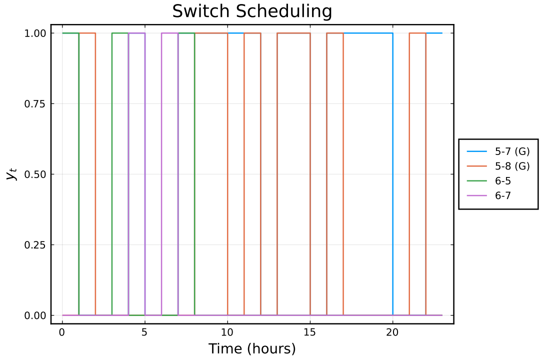
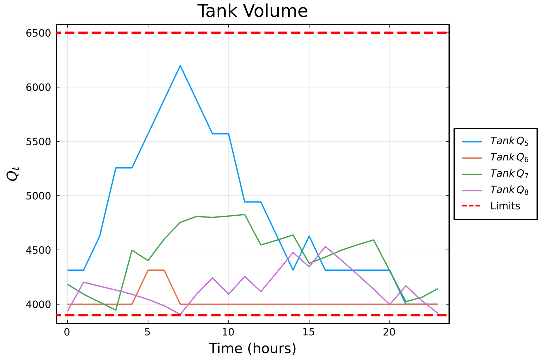
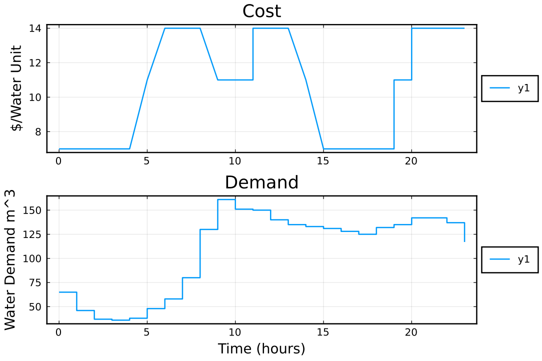


Result from Random Data



Result from Random Data



CONCLUSION