Multi-objective Optimisation of the Pump Scheduling Problem using SPEA2

M. López-Ibáñez
School of the Built Environment
m.lopez-ibanez@napier.ac.uk

T. Devi Prasad
School of the Built Environment
p.tumula@napier.ac.uk

Ben Paechter
School of Computing
b.paechter@napier.ac.uk

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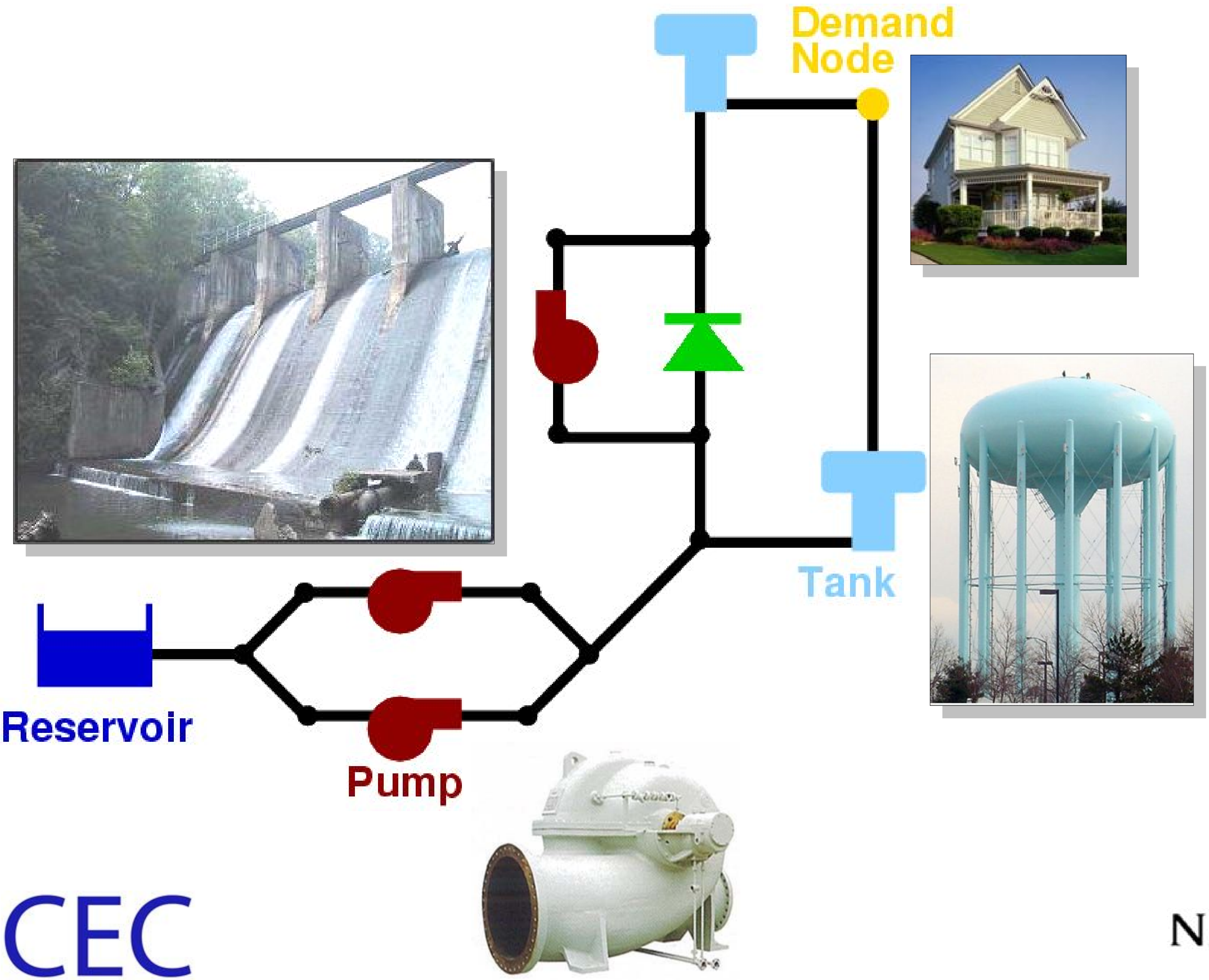
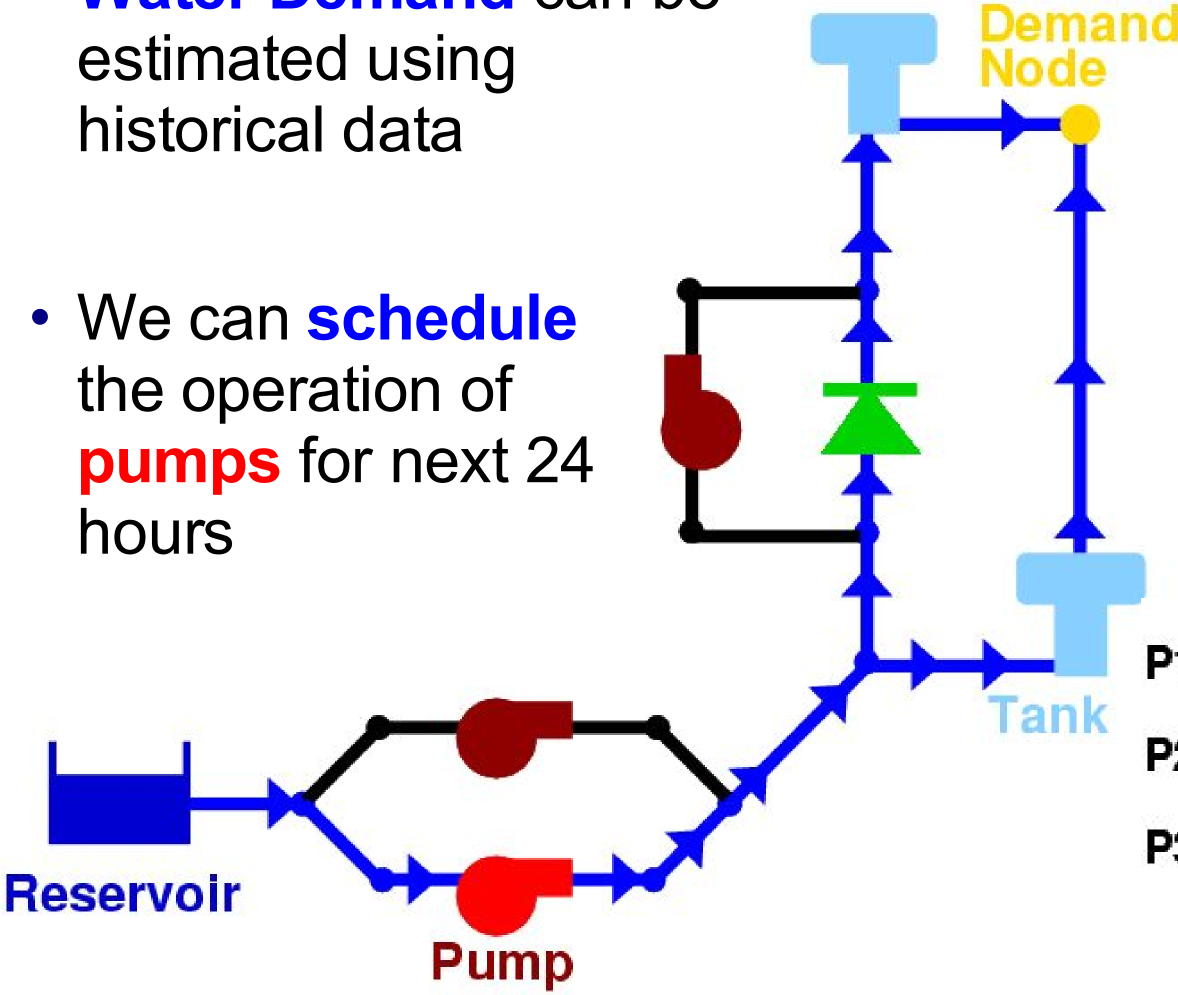
Elements of a (complex) Water Distribution Network

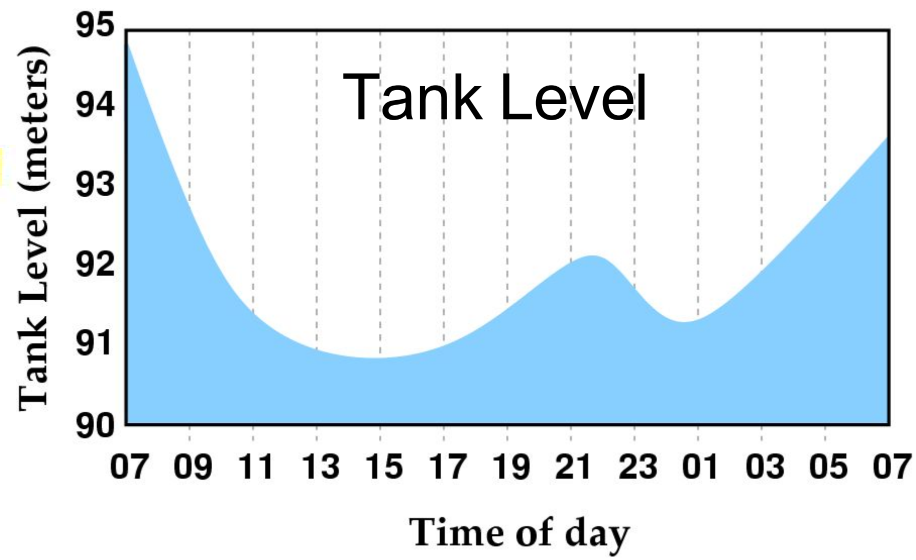


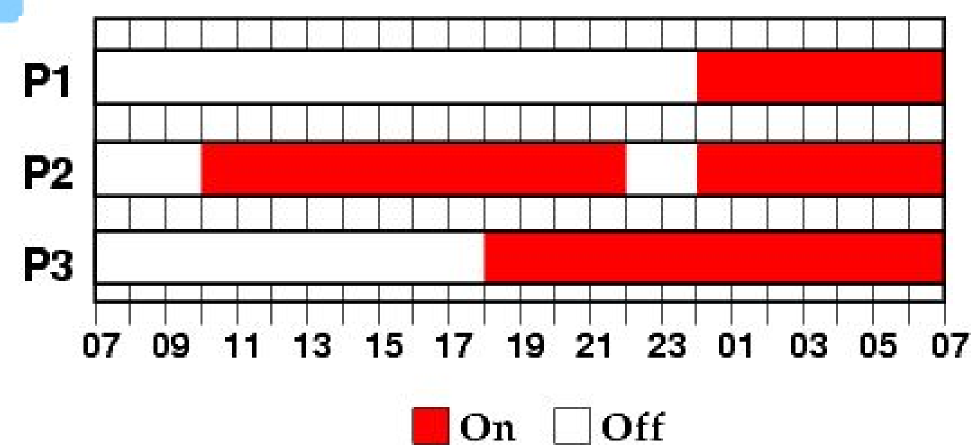
- Pipes
- Nodes/Junctions
- Demand Nodes
- Tanks
- Reservoirs
- Pumps
- Other elements: check valves, pressure control valves, …

Operation of Water Distribution Networks

- **Water Demand** can be estimated using historical data
- We can **schedule** the operation of **pumps** for next 24 hours







The Pump Scheduling Problem: (1) Objectives

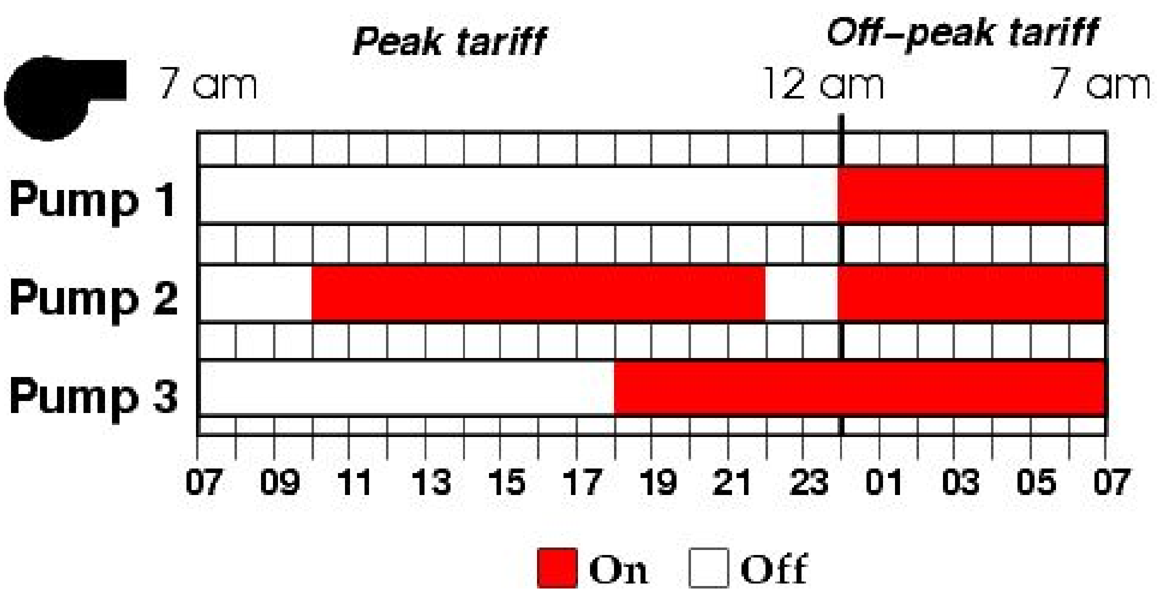
The goal is to minimise the cost of supplying water,
while keeping constraints within limits

Electrical costs (£/day)

- Pumping to higher elevation requires more energy
- Different billing periods: peak and off-peak tariffs.
- Demand charge: peak energy consumed
- Flow of water (litre/s) affects performance of the pump

Maintenance costs

- Cannot be exactly measured
- Pump Switch: from OFF to ON
- Minimisation of **Pump Switches**



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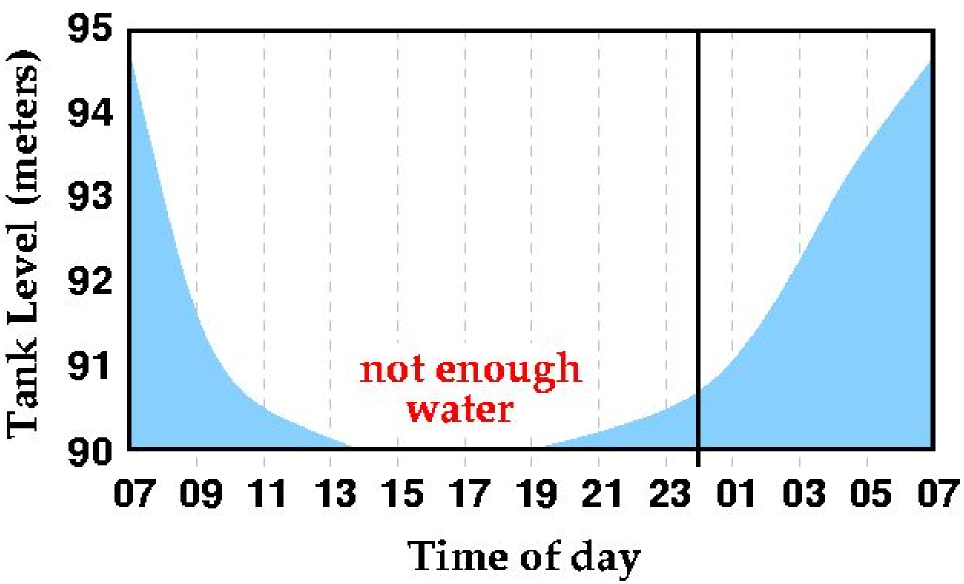
The Pump Scheduling Problem: (2) Constraints

The goal is to minimise the cost of supplying water,
while keeping constraints within limits

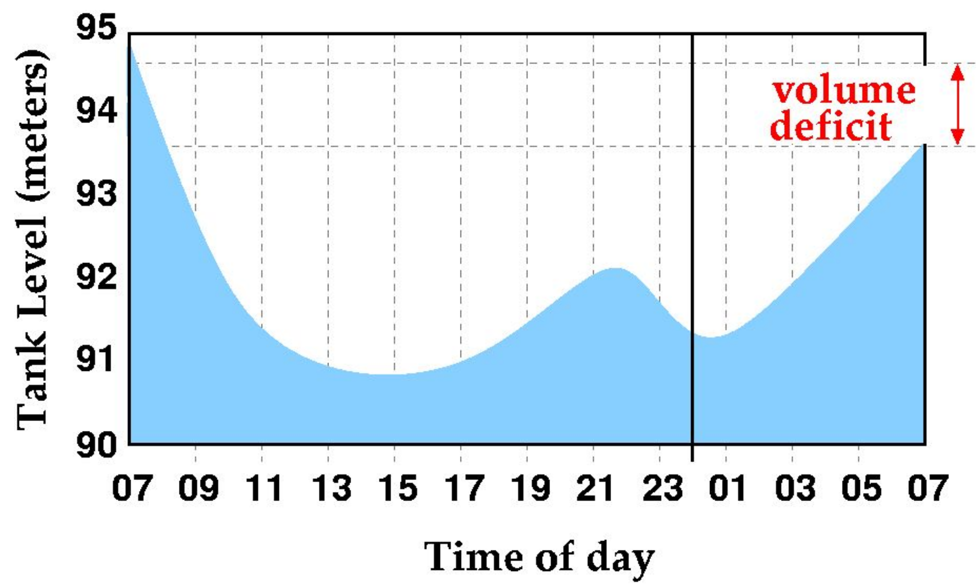
- Physical constraints (conservation of mass and energy...)
- **Operational constraints:**

Achieve Water Demand



✗ Negative Pressures

Periodicity



✗ Deficit of Volume (%)

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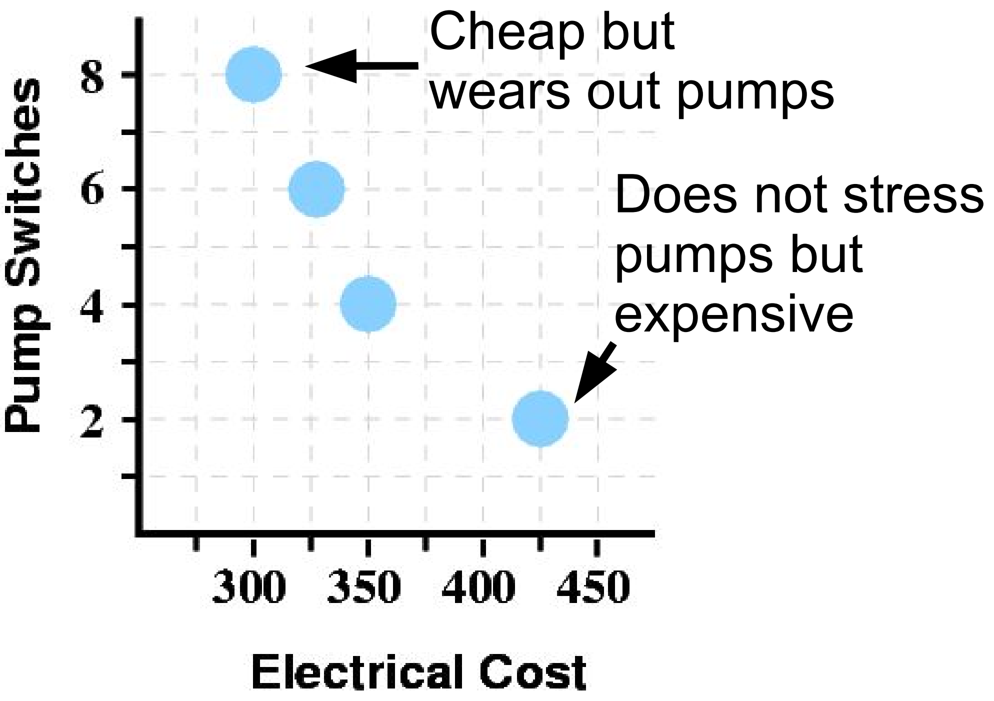
Single Objective versus Multi-Objective Approaches

Single objective

- Objective function is electrical cost
- Number of pump switches is another constraint
- Violation of constraints: penalise objective function / reject solution
- One output solution: trade-off between electrical cost and maintenance cost depends on penalties

Multi-objective

- Minimise both electrical cost and number of pump switches
- Output is a Pareto set:



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Solution Methodology

Hydraulic Simulator (**EPANET**) ⟷ Multi-Objective Optimiser (**SPEA2**)

Hydraulic Simulator (EPANET)

- Handles physical constraints and minimum and maximum tank levels
- Models complex networks
- It is a black box
- Performing a simulation is expensive
- Evaluation time is not constant: Number of Evaluations

Multi-Objective Optimiser (SPEA2)

- Binary representation 24×1h
- Recombination
  - Uniform
  - One-point
- Initial Population
  - Random
  - From empty solution
  - From complete solution
  - From feasible solution
- No Mutation (fast convergence)
- Handling of operational constraints

Constraints Handling

Dominance criteria takes into account feasibility
[Deb & Jain, 2002]

A solution **dominates** another if:

➊ Lower number of **pressure violations**

➋ Lower total **volume deficit**

➌ Normal dominance criteria:

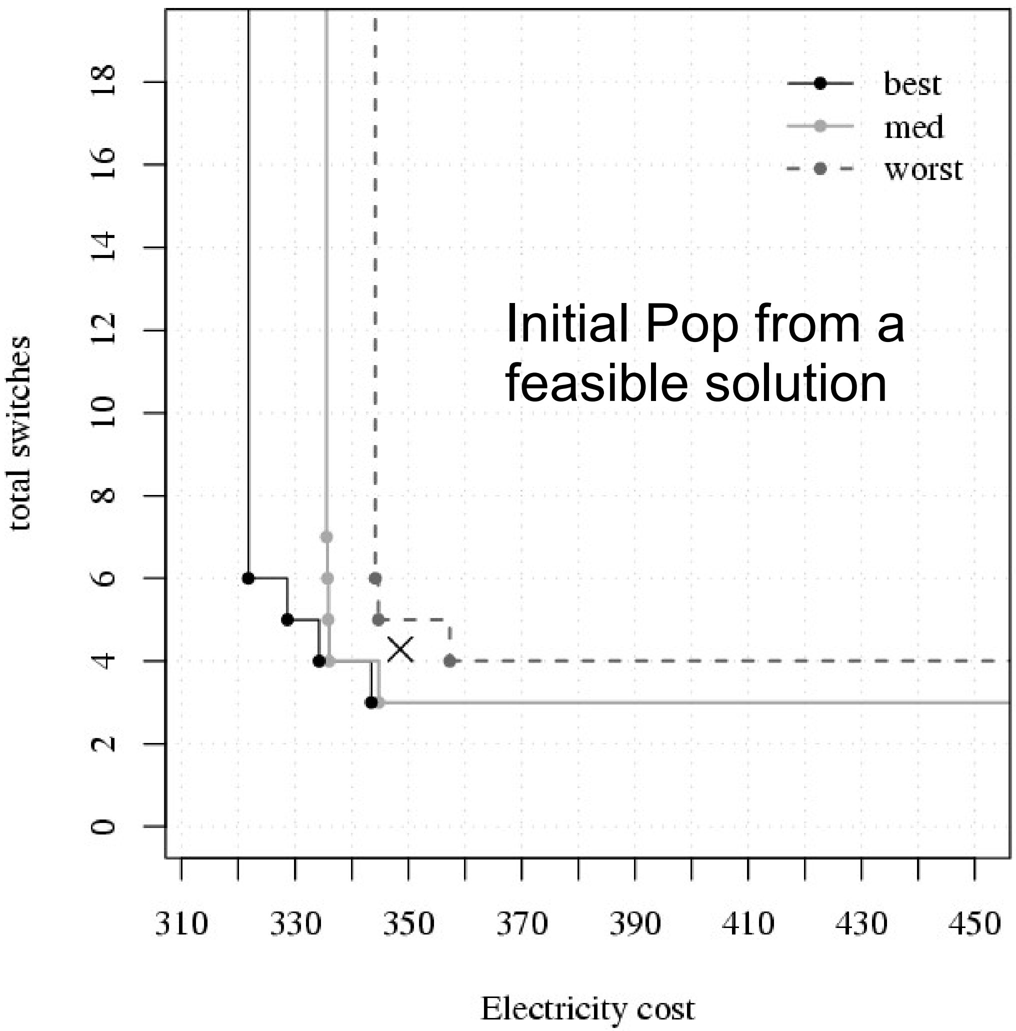
the **electricity cost** and the **number of pump switches** are not higher and at least one of them is actually lower

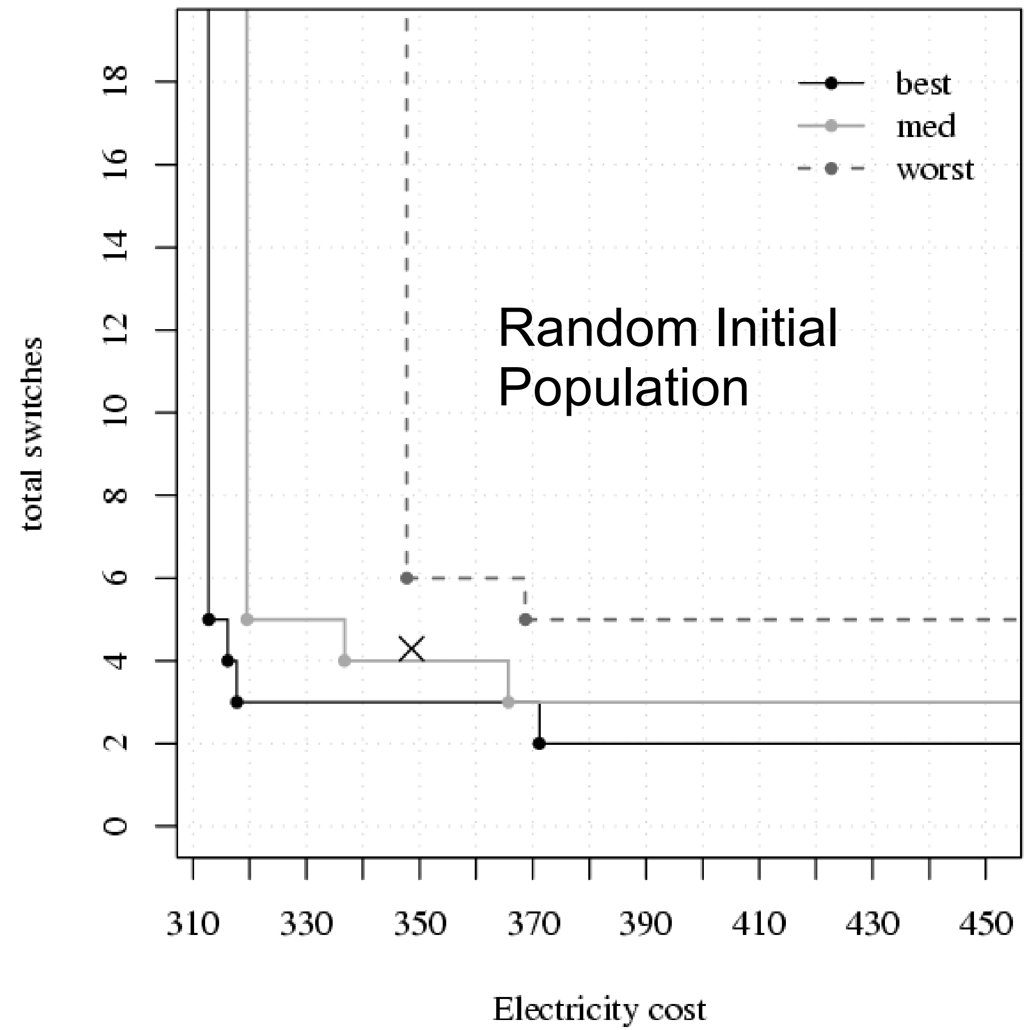
Feasible solutions
(no pressure violations and zero volume deficit)
always dominate infeasible ones

Results

- Uniform Crossover
- 6,000 Evaluations

× average solution of single-objective Hybrid GA [Van Zyl et al., 2004]





Conclusions

- Multi-objective approach is viable
- EPANET + SPEA2 + Uniform crossover + Random Initial Population
- Equal solution quality (even best-known) within same number of evaluations
- Flexibility to trade-off energy costs for maintenance costs
- Generates a Pareto set of feasible solutions which can be examined with respect to more subjective operational considerations

Future Work

- Alternative representations to the binary string
- Different (and larger) network instances
- Hybridisation
- Other MOEAs (NSGA-II, ...)
- Additional objectives: stop time, leakage, water quality, ...

EPANET library and network instance available at

http://sbe.napier.ac.uk/~manuel/