Scheduling and disturbance control of a water distribution network

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Outline:

- OPUS project
- MDP +/–
- Sopron-case
- Simulations
- Discussion, Conclusions, Future

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The OPUS Project

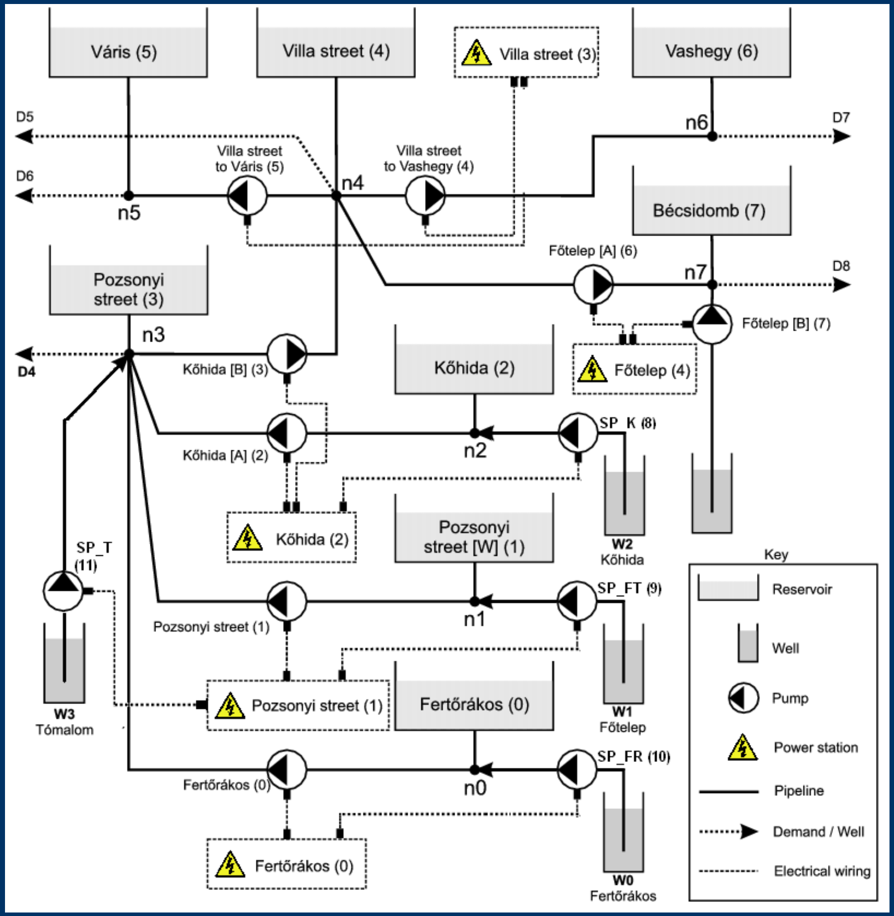
Optimization of Pump Scheduling with Dynamic Probabilistic Methods (SA #138349, CIMO TM-10-6890)

- 2011-2014
  - Academy of Finland (80%)
  - Univ. Oulu (20%)
- SYTE/Oulu
  - in cooperation with Dept. Hydrodynamic Systems/ Budapest
- Background
  - PhD on neutral GA (I. Selek)
  - preliminary studies with CFMC [incl. this paper]
- Methods
  - dynamic & stochastic models
  - random search & population based approaches
  - problem formulation
- Water distribution networks
  - stochastic problems
  - medium-to-large problems
  - on-line optimization

Pump Scheduling Problem

The full Sopron problem

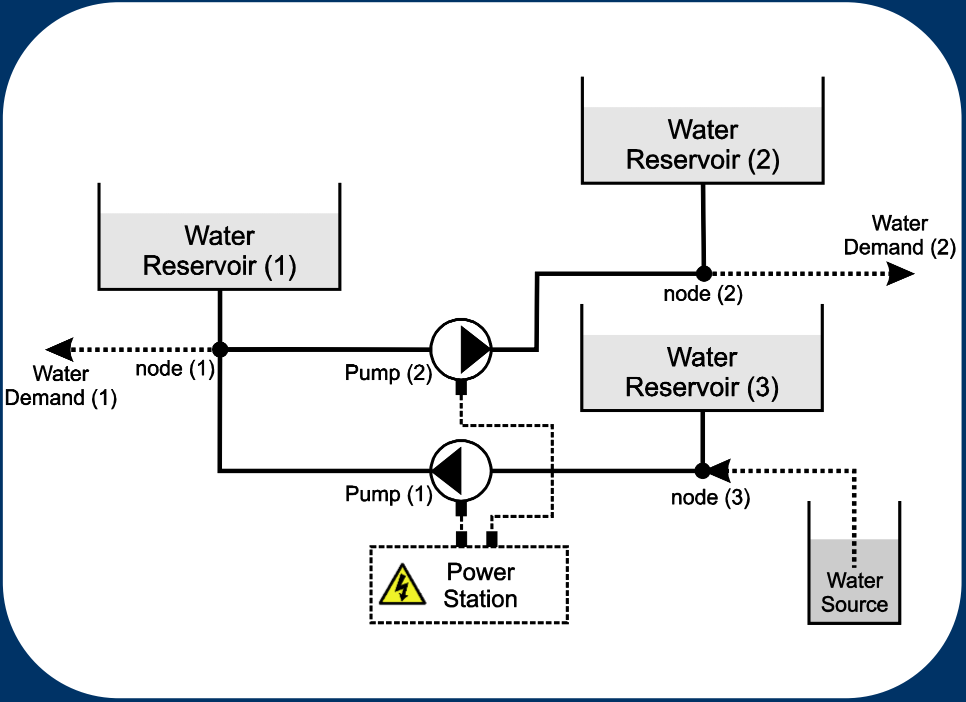
- Primary objective for control: satisfy water demands of the residential and industrial consumers
- Building elements:
  - wells (scenarios), W
  - pump groups (n-ary pump groups), Q
  - power stations (a hourly changing energy price, total power limit)
  - reservoirs (storage limits), R
  - water demands (scenarios), D



Pump Scheduling Problem

Simplified Sopron case

- Regional water network
  - sub-problem of full Sopron:
    - 3 water reservoirs
    - 2 pump groups:
      - {off, small pump on, large pump on}
      - one common power station
    - well flow and demands from a prob. scenario
  - optimization of next 24h



mass balance equations:

$$R_1(t+1) = R_1(t) + T_s[Q_1(t) - Q_2(t) - D_1(t)]$$
$$R_2(t+1) = R_2(t) + T_s[Q_2(t) - D_2(t)]$$
$$R_3(t+1) = R_3(t) + T_s[W(t) - Q_1(t)]$$

costs of operation:

$$J = \Sigma_{t=1\ldots24}\Sigma_{j=1,2}\, T_s P_j(t) C(t)$$

where P_j = power consumed by pump group j
C = hourly price of electricity

Markov Decision Processes

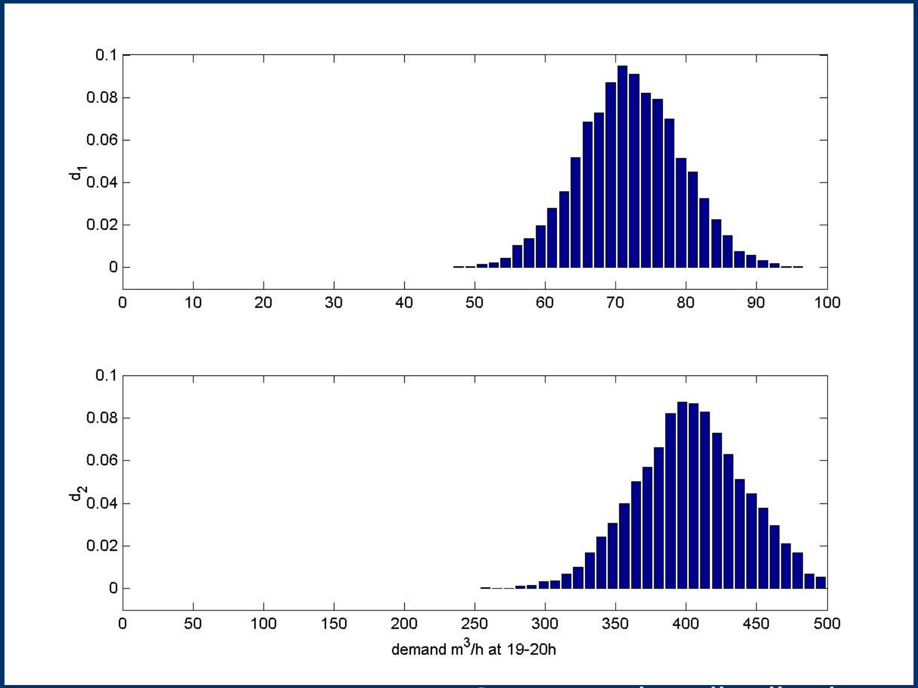
CFMC + DP

- System propagation modelled as markovian transitions
- State-space formulation
  - reservoir volumes
  - time of day (demands & el.price)
- Discretization of states & controls
  - 4D grid (resolution vs comp/memory)
  - on/off pumps (groups)
- Target
  - minimize short term costs due to energy consumption
    - with a given hourly price & demands
    - under constraints (reservoir levels, pump station limits, initial/final state)

- MDP pros/cons
  - \+ suitable for uncertain, nonlinear, discont., dynamic systems
  - \+ straightforward modeling
  - \+ systems analysis
  - \+ 'optimal' control
  - – Curses of dimensionality/ modelling
    - poor scalability
  - – What is sufficient resolution? Accumulation of errors in prediction

Simulations with Stochastic Consumer Demands

- Discretization into 19 reservoir volumes, 30min time step
  - ~330 000 cells
  - 9 actions
- Mass balance with stochastic realizations was used when building the plant model
- Truncated Gaussians
  - mean from scenario
  - variance 10% from mean
    - real data ~10%
- Inf. horizon controller
  - DP, value iteration



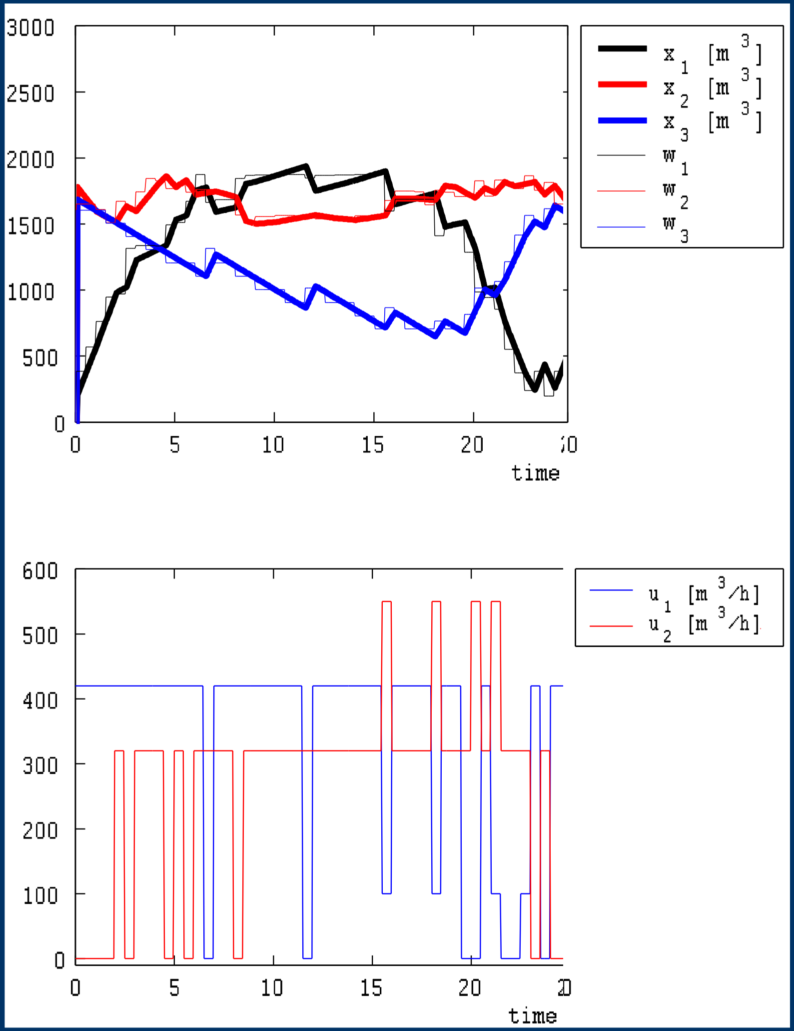
Consumption distribution at 19-20h

1-day simulation

MDP with stochastic models

Main observations

- (i) Controllers designed for a particular noise scenario provided the most robust controller
- (ii) Quality of solution improved with denser resolution
- (iii-1) Controllers designed under milder noise assumptions performed poorly with higher noises.
- (iii-2) Converse was not true (robustness), however the economical performance deteriorated.

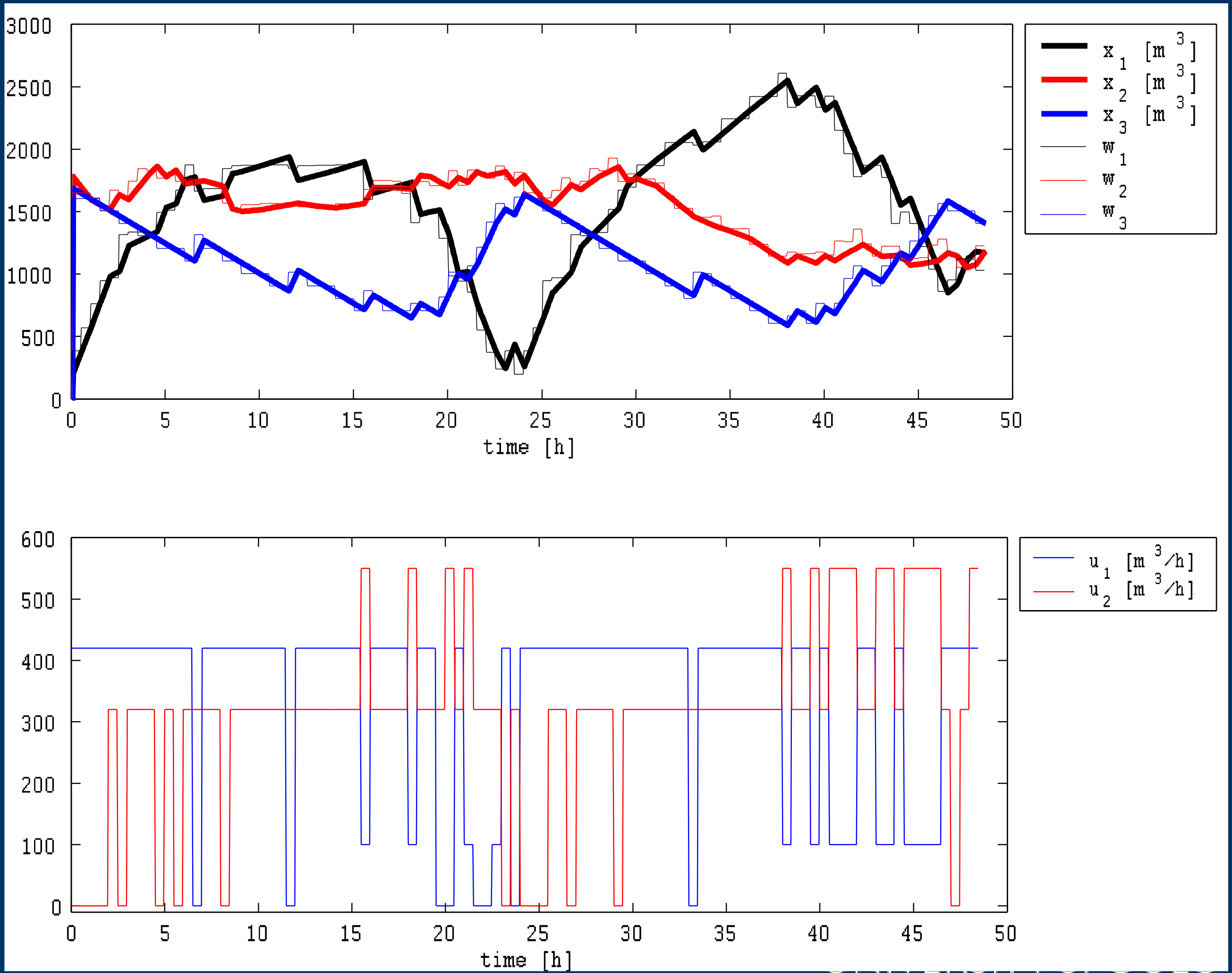


2-day simulations

25% decrease in pump-2 efficiency at 24h

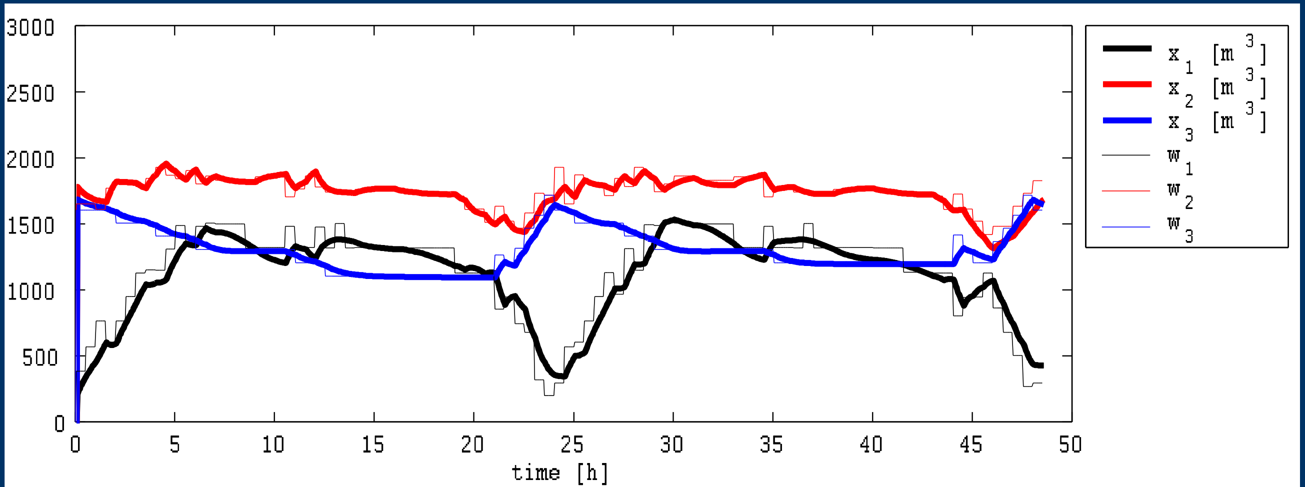
A complete control policy π(**x**) exists, no re-computing needed

However, since model is incorrect (25% decrease) the result is far from ok.

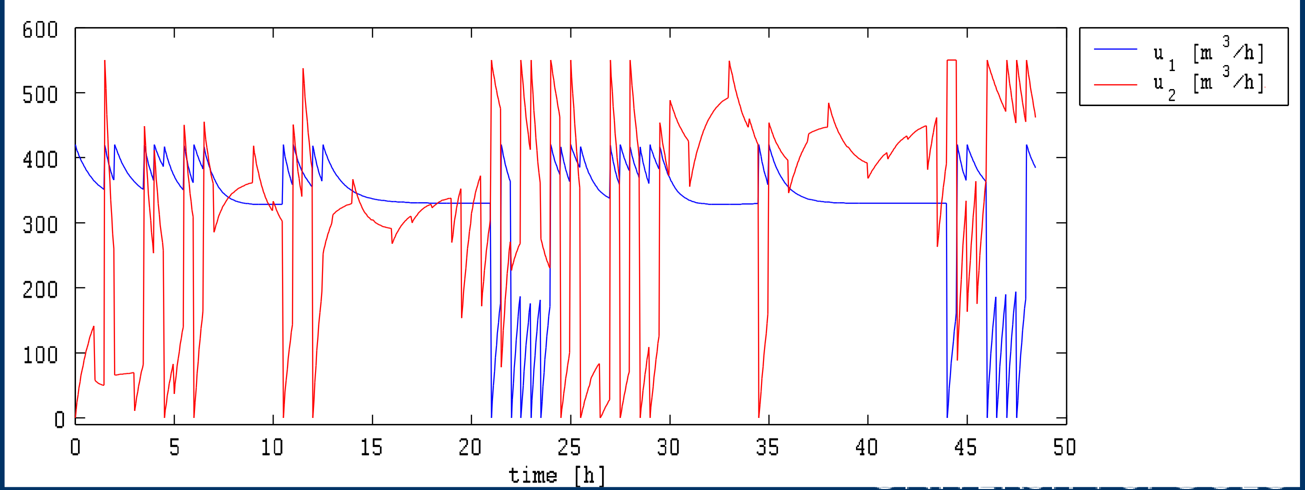


2-day simulation

25% decrease in pump-2 efficiency – setpoints for local PI



Alternative to recomputing π(**x**): Convert optimal actions to set points, using plant model.

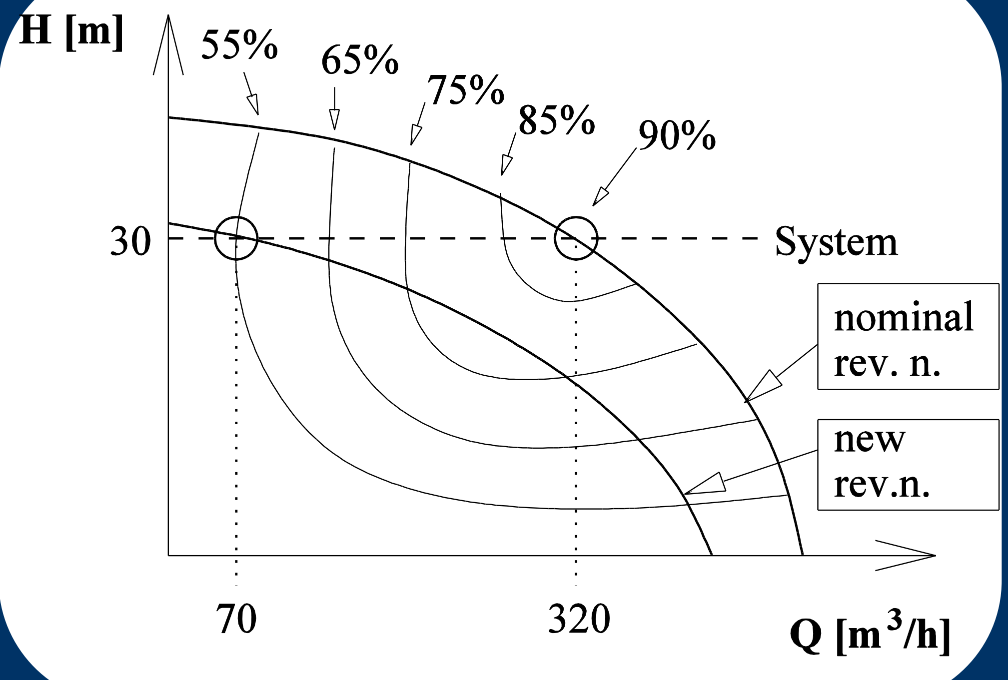


Use local controllers to keep set points

- PI-implementation requires variable speed pumps..
- Other local solutions(?)

Discussion

- hydraulic considerations
- strong effect on efficiency
  - variable speed pumps
  - to be included in optimization



Conclusions & Future work

- Conclusions
  - MDP ok for small Sopron
  - MDP needs problem specific tuning for full Sopron problems
    - computation speed
    - accuracy
  - specialized approaches
- Comments/suggestions?
  - lessons to be learned from multireservoir optimization (hydropower etc.)

- OPUS
  - 2011: Deterministic problems
    - using DP, ADP, discretization, problem re-formulation...
    - feasible, efficient techniques
  - 2012: Stochastic problems
    - stochastic demands
    - deterministic tech. + MC
    - probabilistic set-ups
  - 2013-: Control strategies
    - practical experiences

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THANK YOU

http://cc.oulu.fi/~posyswww/