Scheduling and disturbance control of a water distribution network

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Outline:
• OPUS project
• MDP +/-
• Sopron-case

• Simulations
• Discussion, Conclusions, Future
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:
\[
J = \sum_{t=1...24} \sum_{j=1,2} T_s P_j (t) C (t)
\]

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

Enso Ikonen
SYTE 2011
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 $\pi(x)$ 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 $\pi(\mathbf{x})$: 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
Conclusions & Future work

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THANK YOU