Towards a benchmark simulation model for plant-wide control strategy performance evaluation of WWTPs

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Outline

• Introduction
• “Existing” benchmark models
• Motive for extension
• Benchmark Simulation Model no 2
• Conclusions
• Future perspectives
Introduction

Goal:
- a ‘realistic’ simulation benchmark for long-term, plant-wide control strategy evaluation – Benchmark Simulation Model no 2 (BSM2)
- combined with an influent wastewater generation model (Gernaey et al., 2005)
Benchmark Simulation Model no 1 (BSM1)

- Developed by IWA/COST task groups
- Model, control system, benchmark procedure and evaluation criteria
- Five-reactor biological plant (ASM1) with secondary clarification (Takacs 1-d, 10-layer model)
- Simulate 4 weeks with influent data defined by files
- Performance of the last week evaluated (defined criteria)
- Sensor classes defined, ideal actuators
- Available in SIMBA, GPS-X, WEST, Matlab, Aquasim
On-going extension: BSM1 Long-Term (BSM1_LT)

The original BSM1 configuration with:
• One year evaluation period
• Influent characteristics model
• Time (temperature) varying parameters
• Sensor and actuator failures
• Process faults
• Additional actuators with long-term effects
• Focus on monitoring

(see Rosen et al., 2004, AutMoNet’2004)
Motive for extension

- BSM1 and BSM1_LT allow only for local control (monitoring) of AS systems
- Need for plant-wide (“within-fence”) evaluation
- Importance of the sludge train
- Allow for supervisory long-term strategies
- Include full plant process interactions
- Avoid sub-optimisation
- Seasonal effects (also in BSM1_LT)
- Generalisation of influent generation (also in BSM1_LT)
Benchmark Simulation Model no 2

- ‘Within-fence’ WWT plant description (primary, activated sludge, sludge treatment) + sensors and actuators
- General plant layout not defined by any single national design standards
- Main processes found in most industrialised countries
- Evaluation based on one-year fully dynamic control strategy performance
- Too extensive simulation effort?
Influent wastewater generation

Dynamic model-based approach:

- Dry weather with diurnal, weekend, seasonal and holiday effects (household and industrial)
- Rain and storm water generation including first-flush effects in sewers
- More sewer network effects
- Simple drainage, soil and infiltration models
- Batch-type solid waste input (e.g. septic waste)
- Stand-alone model for BSM2 (and BSM1_LT) but also for other applications
Benchmark Simulation Model no 2

Primary clarifier
\[ V = 900 \text{ m}^3 \]

TSS \( \approx 3\% \)

Activated sludge reactors

Secondary clarifier

Bypass

Influent wastewater

Effluent water

Thickener

TSS \( 7\% \)

Anaerobic digester
\[ \Theta_H \approx 20\text{d} \]

Dewatering

Sludge removal

Controllable flow rate

Valve

ASM/ADM interfaces

ADM/ASM interface

Additional loads

Gas

Effluent water
Primary clarifier

- Otterpohl approach (1994)
- Empirical model based on hydraulic retention time and particulate to total COD ratio
- Does not affect soluble components
- No biological transformations (same as in secondary clarifier)
- Simple model → ‘fast’ simulation
  - 1.5 years of closed-loop dynamics including noise
  - input wastewater changing every 15 min
Benchmark Simulation Model no 2

Influent wastewater → Primary clarifier V = 900 m³ → Activated sludge reactors → Secondary clarifier → Effluent water

Primary clarifier TSS ≈ 3%

Activated sludge reactors

Secondary clarifier

Thickener TSS 7%

Anaerobic digester Θ_H ≈ 20d

Dewatering Sludge removal TSS 28%

Additional loads

Controllable flow rate Valve

AUXILIARIES

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Thickener and dewatering units

- Ideal models
- Sludge flow TSS 7% and 28%, respectively
- 98% of particulate material removed
- Does not affect soluble components
- No biological transformations
- No local control capability
- Simple models → ‘fast’ simulation
Benchmark Simulation Model no 2

Influent wastewater → Primary clarifier $V = 900 \text{ m}^3$

TSS $\approx 3\%$

→ Activated sludge reactors

→ Secondary clarifier

Bypass

Effluent water

Thickener

TSS $7\%$

→ Anaerobic digester $\Theta_H \approx 20\text{d}$

Gas

Dewatering

Sludge removal

Gas

Controllable flow rate

Valve

Additional loads

Controllable flow rate

Valve

ASM/ADM interfaces

ADM/ASM interface

Controllable flow rate

Valve

TSS $28\%$

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Anaerobic digester

- IWA Anaerobic Digestion Model no 1 (ADM1) with minor modifications
- Biological transformations, liquid-gas interactions, gas production
- Mesophilic system (35°C)
- Retention time about 20 days (constant volume)
- Slow and fast dynamics
- Essential for overall plant performance
- Complex model → slow simulation
Benchmark Simulation Model no 2

- **Influent wastewater**
  - Primary clarifier: $V = 900 \text{ m}^3$
  - TSS $\approx 3\%$
  - Additional loads

- **Activated sludge reactors**
  - TSS $\approx 7\%$

- **Secondary clarifier**
  - Dewatering
  - Gas
  - Effluent water

- **Thickener**
  - TSS $\approx 3\%$
  - ASM/ADM interfaces

- **Anaerobic digester**
  - $\Theta_H \approx 20\text{d}$
  - ADM/ASM interface
  - Dewatering
  - TSS $\approx 28\%$

- **Sludge removal**

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Model interfaces

• Necessary for combining ASM and ADM
• 13 vs 24 state variables
• COD fractions vs protein, lipids, carbohydrates
• Rudimentary proposal in ADM1 report
• AD disintegration process part of interface
• Primary and secondary sludge different therefore two ASM/ADM interfaces (same principle)
• Always maintain mass balances
• Two alternatives: Copp et al., 2003 (WEFTEC) and Vanrolleghem et al., 2004 (AD10)
Benchmark Simulation Model no 2

Influent wastewater → Primary clarifier $V = 900 \text{ m}^3$ → Activated sludge reactors → Secondary clarifier → Effluent water

Bypass

Primary clarifier $TSS \approx 3\%$

Secondary clarifier $TSS \approx 3\%$

Primary clarifier $TSS \approx 28\%$

Secondary clarifier $TSS \approx 7\%$

Thickener $TSS \approx 7\%$

Gas

Anaerobic digester $\Theta_H \approx 20\text{d}$

Dewatering Sludge removal

Controllable flow rate

Additional loads

Valve

ASM/ADM interfaces

ADM/ASM interface

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Control capabilities

• Pumps and valves for most plant-wide flows including by-passing
• Full control of AS system (BSM1):
  – Step-feed, all types of internal recirculation flows
  – Oxygen, carbon source, anoxic/aerobic volume fraction
• Add equalisation basin and storage tank
• AD control? Chemical additions?
• Time for batch waste influent load?
• Ideal actuators?
• More than 50 control handles in total
Sensor availability

- Based on Rieger et al., 2003 (Wat. Sci. Tech.)
- All realistic sensors possible
- Defined by classes related to:
  - Noise level
  - Drift
  - Time response and delay
  - Calibration and maintenance requirements
  - Lower & upper limits
  - Measuring interval
- Also allows measurements from lab analyses
BSM performance evaluation

• Based on plant performance and controller performance

• BSM1 plant: effluent quality, energy, operational cost, sludge production, effluent violations

• Extended by, for example:
  – Energy usage in all new units
  – Sludge disposal costs
  – Gas production
  – Use of chemicals

• ‘Simpler is better’, i.e. penalty for sensors, extra control handles
Conclusions

- BSM2 allows for plant-wide benchmarking and development of control strategies
- Plant layout and models proposed
- Not yet fully defined – inputs are welcome
- One year evaluation period for long-term strategies
- Synergies with BSM1_LT (and BSM1)
- Stand-alone influent wastewater model with diurnal, seasonal, holiday effects, etc.
Future perspectives 1(2)

• BSM1_LT + BSM2 + more = BSM3
• Plant-wide monitoring and control
• Allow for ASM1, ASM2d, ASM3, ASM4
• Reactive settlers, sludge characteristics, etc.
• Extend ADM1 with phosphorus
• Special phenomena, e.g. bulking sludge, filamentous organisms, coagulants, polymers, toxicity
• Xenobiotics?
Future perspectives 2(2)

COST benchmark simulation model

- Simulation tool
- Assessment tool
- Database
- Evaluation tool

Sensor signals → Actuator signals

User-defined control strategy

' Benchmark tool

IWA Task Group on Benchmarking?
Thank You for Your Attention!

Questions and comments?