Data-driven Process Control in Wastewater Treatment Facilities: Simple Statistical Models

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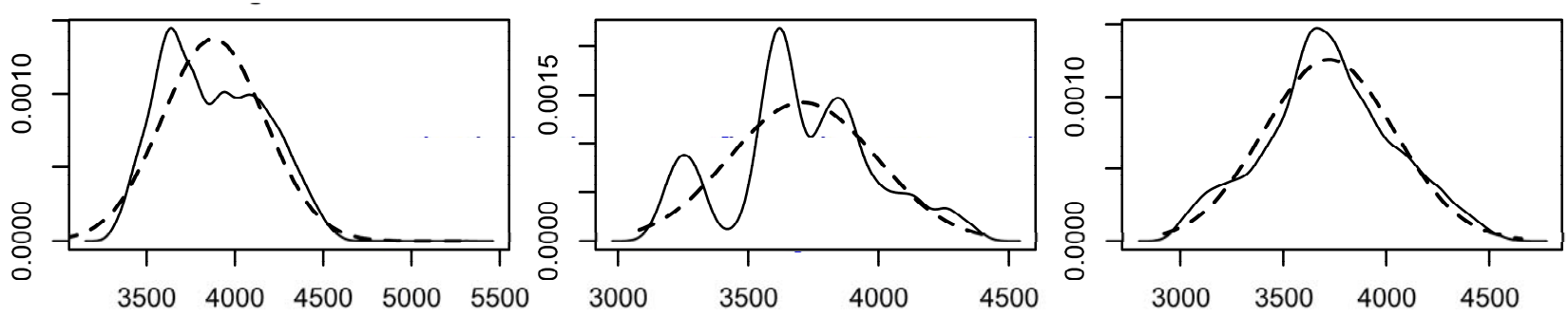
Why do we need to improve process control in wastewater treatment?

- Fault detection
  - **Single variable** monitoring, upper and lower limits
    - High false alarm rates and low true detection rates
  - **Multivariate** monitoring
    - Data violates assumptions of standard statistical methods
    - Not well developed or tested



Why do we need to improve process control in wastewater treatment?

- Process control
  - **Feedback** control is dominant scheme
    - Straightforward to troubleshoot, difficult to optimize
  - **Feedforward** control
    - Requires accurate model of treatment and control action

No model

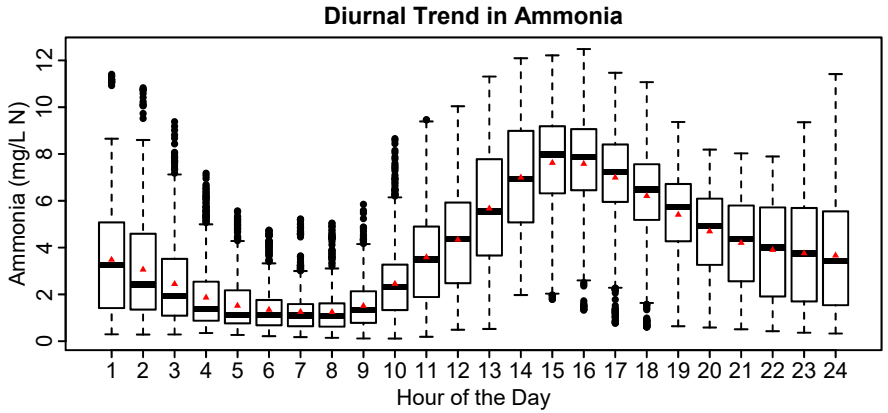
Only one scenario

Not accurate enough

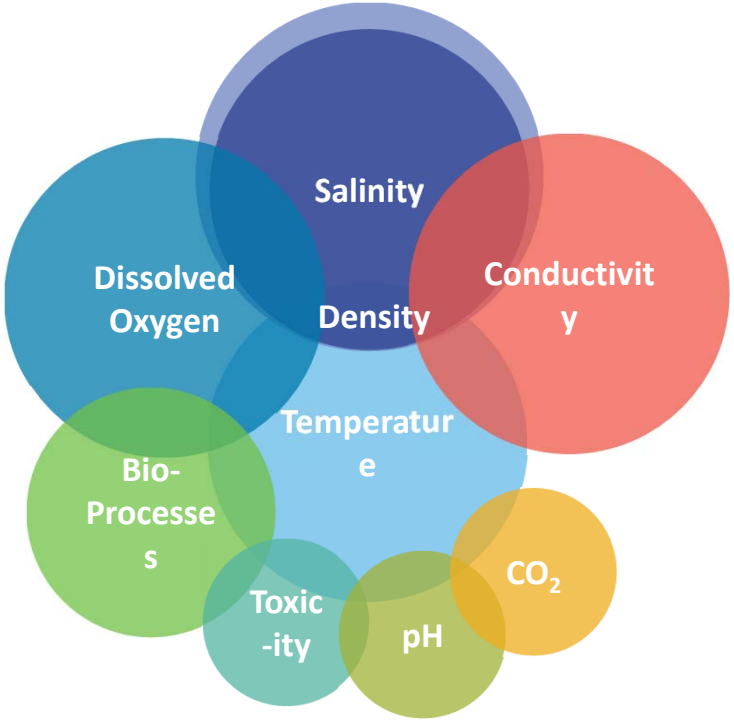
Impact of variable interactions

Relationship to conditions

- Combinations of *physical*, *chemical*, and *biological* processes which are affected by a wide-range of *environmental and operating* conditions



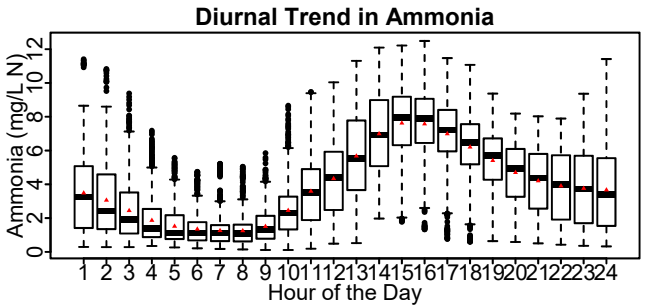
Relationship to time

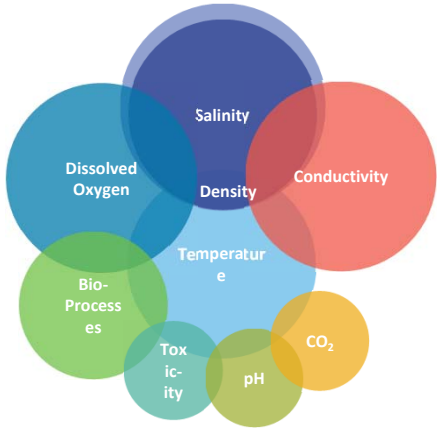


Relationship to other variables

Account for variable interactions

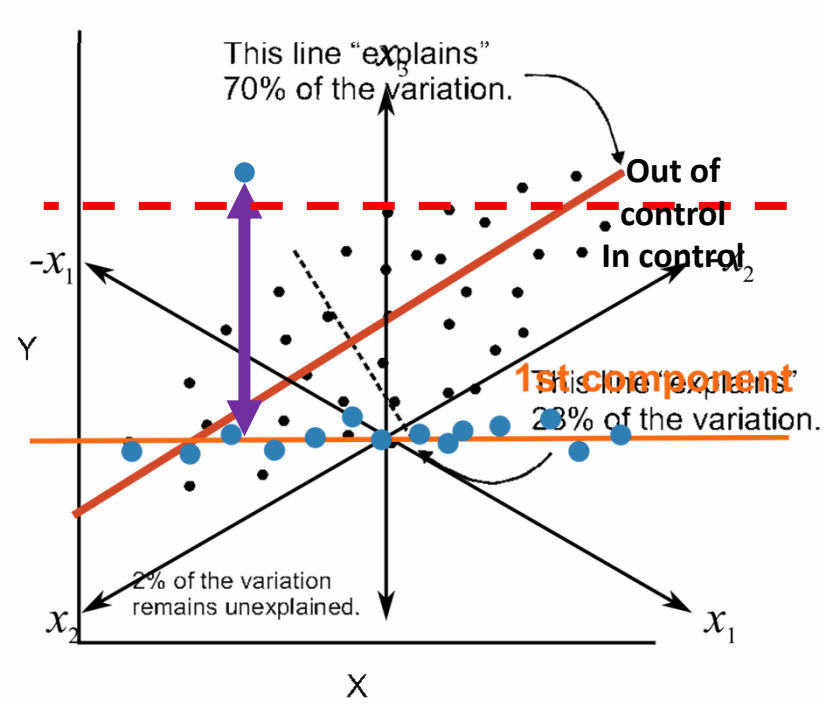
- Autocorrelated / time dependence:
  - Consider previous timestamp in calculation
  - Build diurnal model
- Non-stationarity / changing averages:
  - Moving window of time
- Co-correlation / multivariate dependence:
  - Dimension reduction methods and metrics



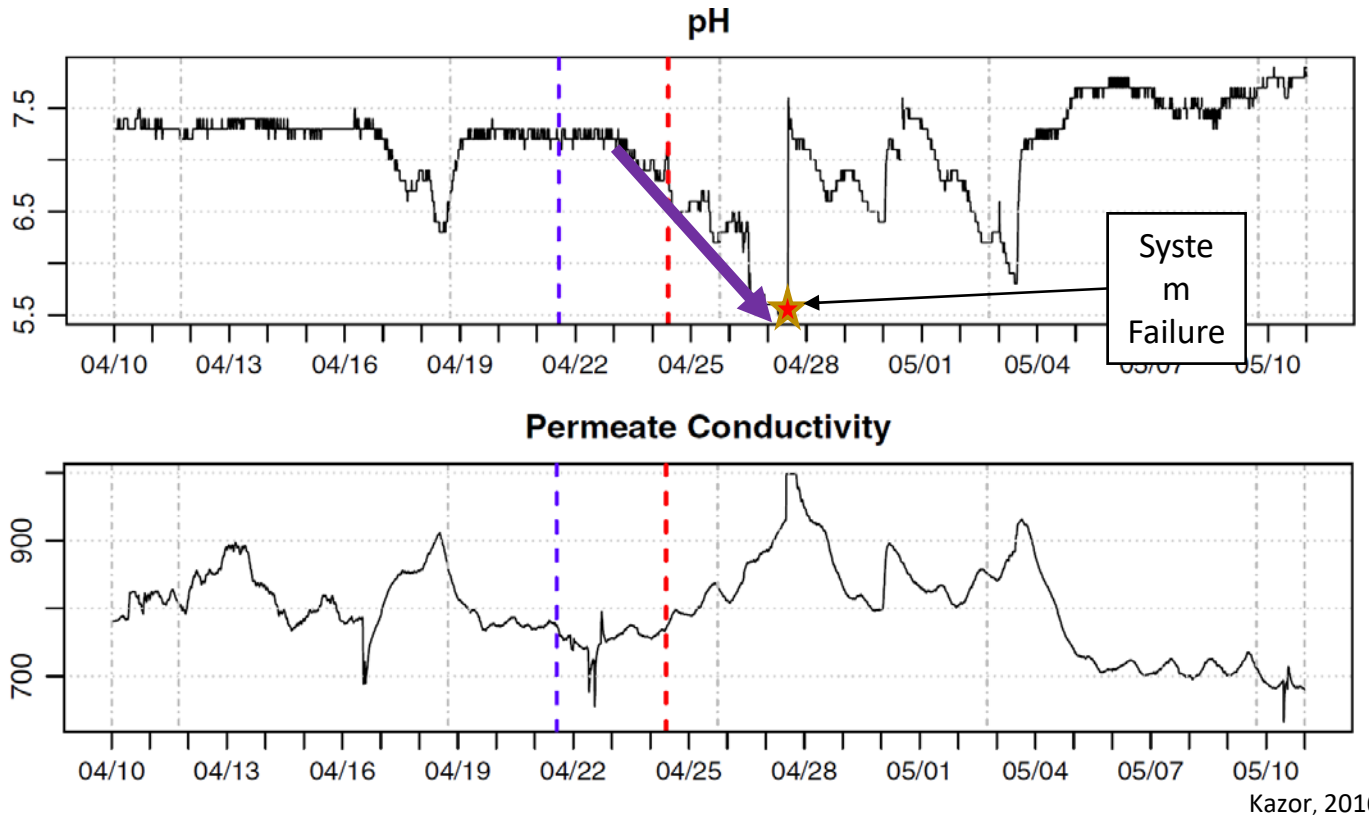


Principal Component Analysis (PCA)

- Data reduction technique
- Linear combinations of data to simplify variation
  - Principal components
  - 1st component
    = maximum variance
    = maximum variability
- We modify it for wastewater by…
  - Adaptive = rolling window
  - Dynamic = last timestamp



Fault detection using AD-PCA



Kazor, 2016

Fault detection using AD-PCA

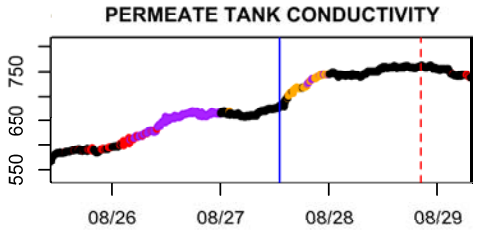
- PCA-based process control has been used in manufacturing/chemical engineering.. Let's bring it into wastewater!
- Simple, holistic process monitoring method, tailored for wastewater treatment data

Pump failure

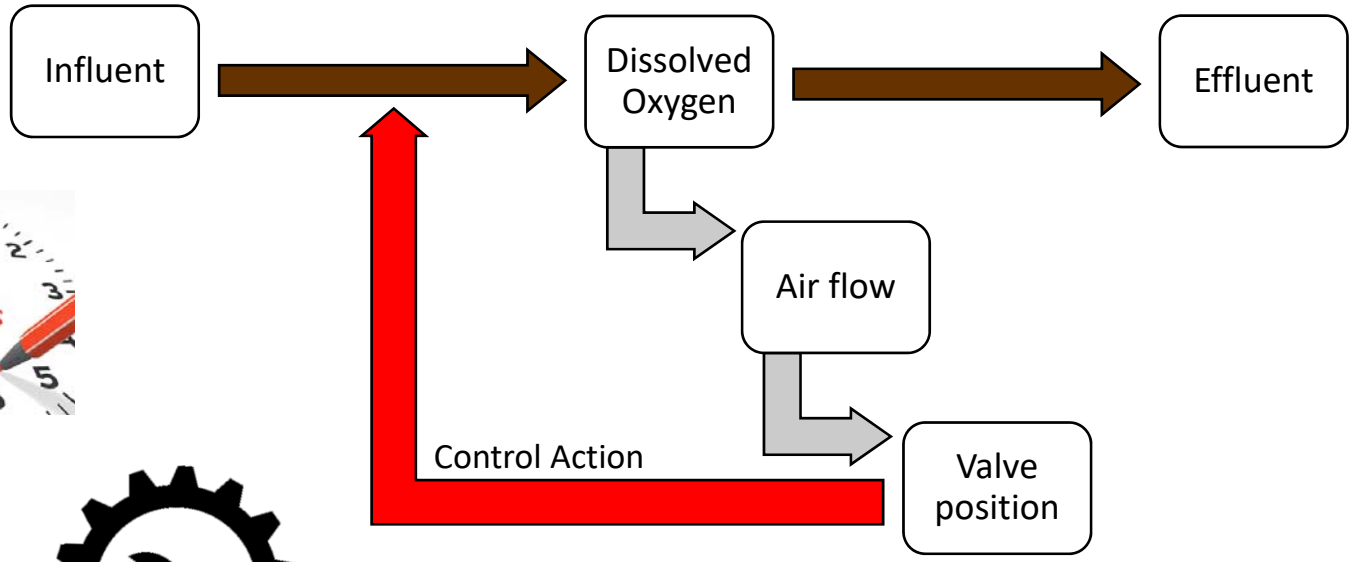
Membrane failure

Microbiological-shift

Water quality changes

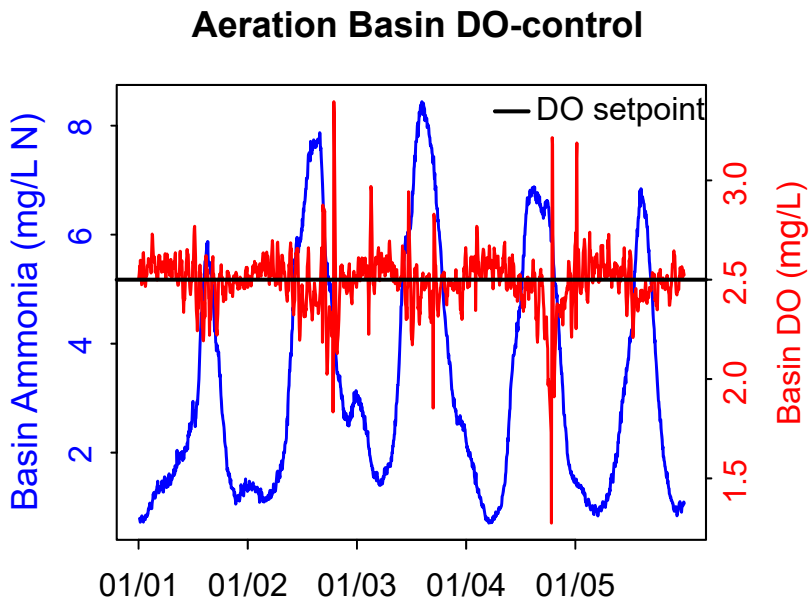


Challenges with traditional feedback / cascade control



Challenges with dissolved oxygen (DO) cascade control

- BWRRF DO-based control concerns:
  - Difficult to optimize using manual adjustments
  - Disregards real-time conditions
- Consequences:
  - Over-aeration → Excessive energy demand
  - Imprecise → No direct control of effluent ammonia



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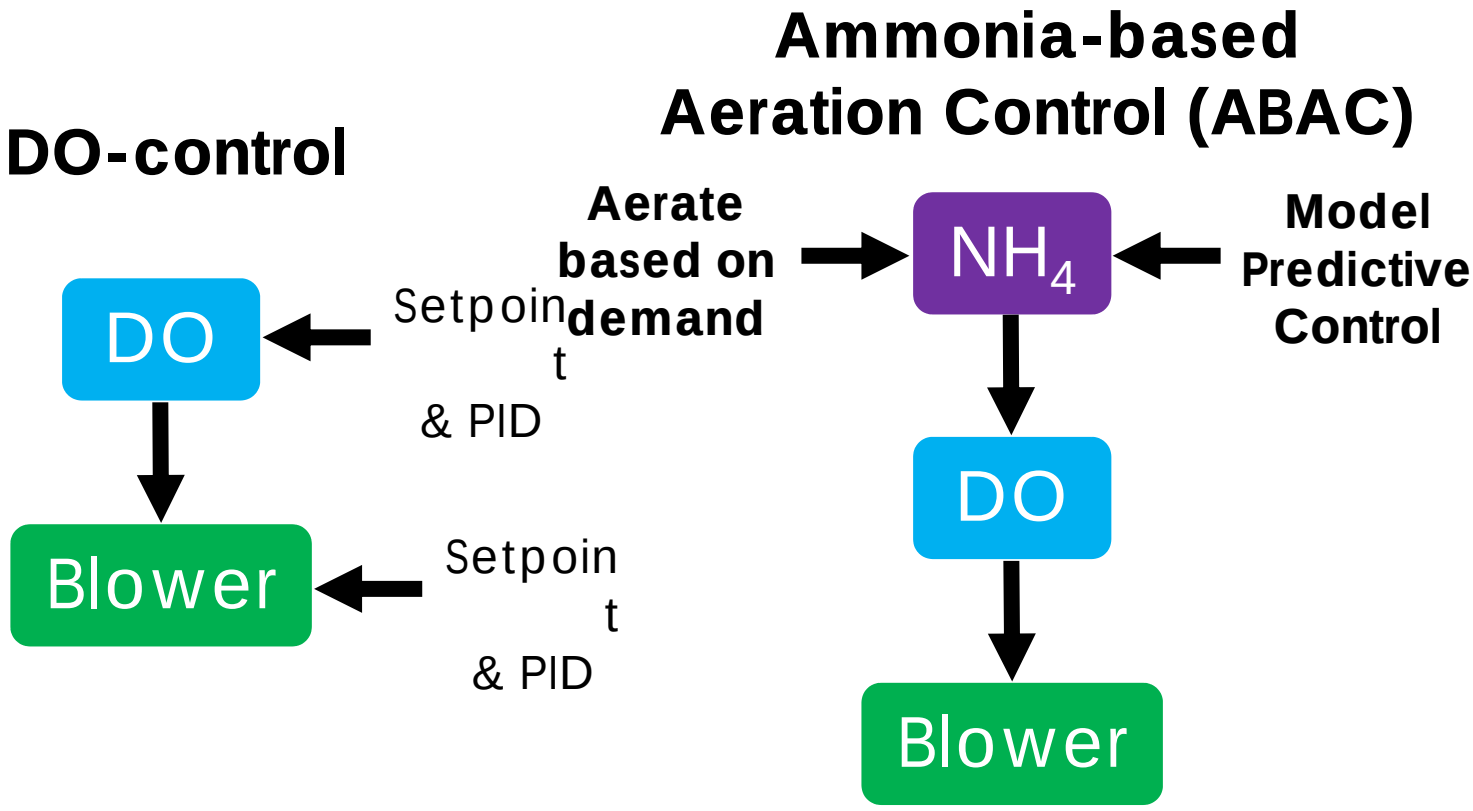
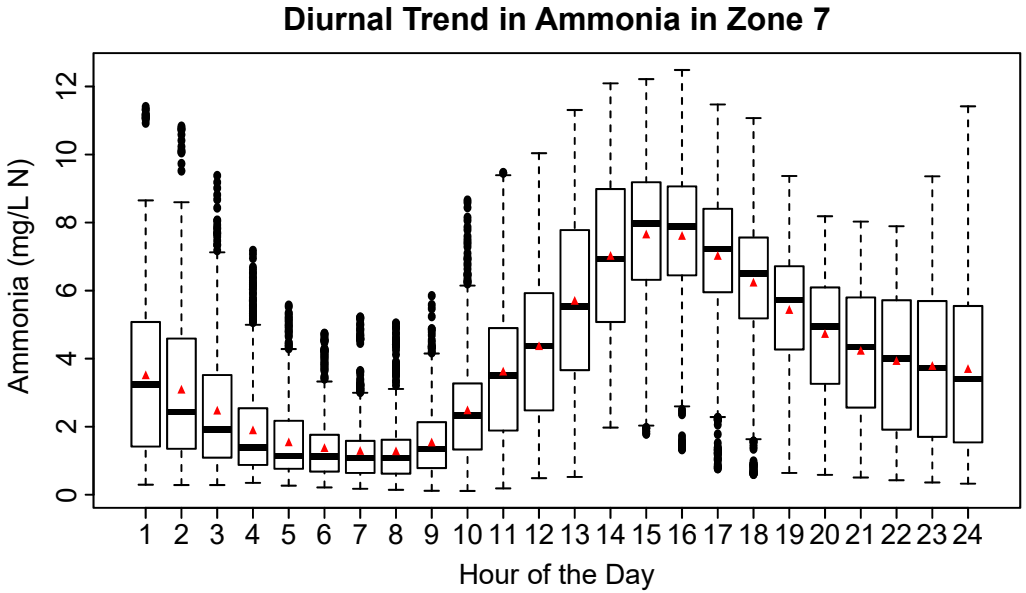
Alternative aeration control strategy

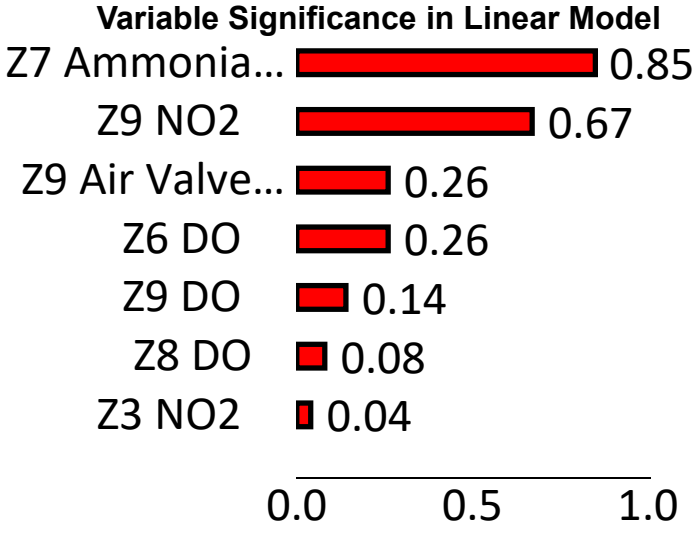


City of Boulder, CO
Water Resource Recovery Facility

- 25 MGD design, 12 MGD average
- Daily ammonia limits as low as 1.9 mg/L
  - High DO operation is trusted control strategy
- Carbon addition for N removal
  - Monthly acetic acid consumption > 6,000 gal
- SCADA has multiple aeration control modes
  - Airflow
  - Dissolved oxygen (DO)
  - Ammonia-based aeration control (ABAC)

Diurnal + Linear model





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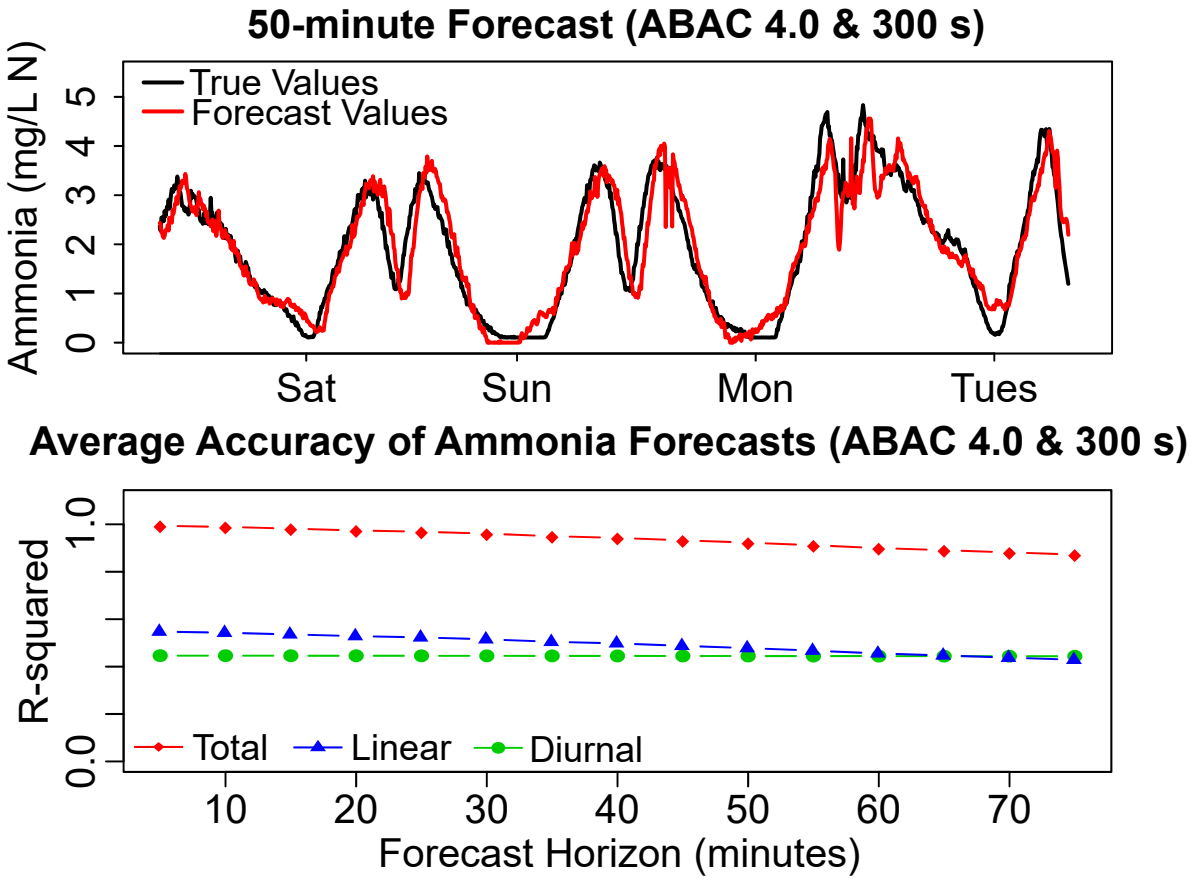
Optimize forecasting model



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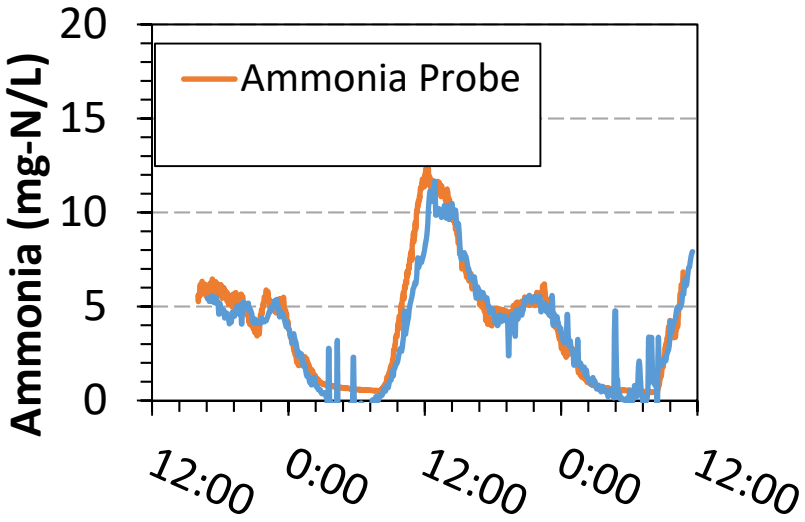
Full-scale implementation

- Programmed statistical analysis to communicate with SCADA
- Able to predict the diurnal trend and fluctuations in real-time
- Performance comparison between traditional and forecasted PID control

Prediction Performance

Forecast Horizon	*Sensor (RMSE)*	*Forecast (RMSE)*	*Improvement (%)*
5 min	0.105	0.111	-5.7
25 min	0.286	0.250	12.7
50 min	**0.530**	**0.470**	**11.4**
75 min	0.757	0.684	10.0



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Impact of collaboration

City of Boulder

- Operators value and make use of data for predictive control
- Adopted a novel data-driven control scheme
- Solution reduced aeration and energy consumption

Relevance to Industry

- Open-source software solution for variable forecasting
- Simple, straightforward approach that can be used in other unit processes controlled by PID

Acknowledgements

Contact: Kate Newhart, kbnewhart@mines.edu