Informatics Driven
Central Plant Optimization

Presented by: Alex Huang, Kayvan Torkashvan, Don Guan

Division of Technical Resources
National Institutes of Health
NIH and What We Do

A federal government agency
Annual research funding ~ $37 billion
27 biomedical research institutes
75 buildings over 300 acres
Total building area~12 million sqft
Houses world-class 240-bed research hospital
NIH Central Utility Plant (CUP) Overview

One of the largest CUPs under one roof in the USA

Provides campus with chilled water, steam, electricity, and compressed air

CUP Components

Twelve 5,000 Ton capacity chillers
7.75 million gal CHW thermal storage tank
5 million gal Industrial Water System
Five gas/ diesel dual fuel fired boilers
800 KPPH, 980 KPPH with Cogen
Cogeneration Power Plant

One of the largest US government Cogen plants
One of the cleanest Cogen plants in the world
23 MW, 180KPPH steam (40% of campus demand)

TES and chiller controls upgrade project presentation will be 3:00 PM today
Data Platform - Heart of Actionable Operational Intelligence

- 2014: 633,000 data points recorded automatically per day.
- 2015: 5 million data points recorded automatically per day through a historian data platform, critical for plant operation, management, and funding application.
- 2016: 12 million data points recorded automatically per day through historian data platform, critical for plant operations; advanced calculations used for optimization.
- 2017: 20.6 million data points recorded automatically through historian data platform, critical for plant operations; advanced calculations used for optimization.
- 2018: 34.6 million data points recorded automatically through historian data platform, critical for plant operations; advanced calculations used for optimization.

**Reads per day by system type (2018):**
- Over 1,000,000 advanced calculations conducted per day from over 5,000 continuously running analyses.
- Campus Load Monitoring: 250,000
- Electrical Monitoring: 5,150,000
- Water Treatment: 4,500,000
- Cogen: 1,500,000
- Boiler Plant: 8,150,000
- Chiller Plant: 15,000,000

Total: 34,550,000
Enterprise-level Cross Platform Data Integration

Collection, Communication Layers  
- Chiller Controls  
- Electrical SCADA  
- Building automation system  
- Boiler controller network  
- Existing Chiller control system  
- Cogen  
- Water treatment system  
- Weather and PJM  
- Web Service Data  
- Continuous Emission Monitoring  
- Oil Tank Leak Monitoring System  
- Future Systems  
  - Refrigerant Scale Info  
  - Refrigerant Monitoring System  
  - Vibration Monitoring System  
  - Campus Electrical SCADA

Storage, Analysis Layers  
- Asset management  
- OSI PI Historian  
- Energy Accounting Database

Presentation Layer  
- Client End Users  
  - Managers  
  - PI Developers  
  - PI Users  
    (Engineers and Operators)  
  - Data Reviewers
Web-based Executive Level Summaries and Reporting

Executive daily performance and operation data accessible with 1 click:

(Not the actual data)
Dynamic CUP Dashboard
Data Platform Powering the CUP Control Room

The real-time, actionable data drives operations from reactive to proactive.
Actionable Operational Intelligence & Fault Detection

Data Platform provides operators **actionable** intelligence, in-time RCA, and helps review operators’ performance.
Alarm Notification and Mobility
# Digitization Plant Operations - Round Data Entry Website

## Water Chemistry Data Entry

**Boiler:**
- Select Data

**Conductivity:**
- (μS/cm)
  - 200 - 600

### City Water

**Conductivity**

<table>
<thead>
<tr>
<th>User</th>
<th>Submitted at</th>
<th>Value</th>
<th>Value timestamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIHJohnho</td>
<td>1/19/2019 10:59:40 AM</td>
<td>345</td>
<td>1/19/2019 10:59:40 AM</td>
</tr>
<tr>
<td>NIHJohnho</td>
<td>1/20/2019 11:08:41 AM</td>
<td>456</td>
<td>1/20/2019 11:08:41 AM</td>
</tr>
<tr>
<td>NIHJohnho</td>
<td>1/21/2019 11:05:29 AM</td>
<td>567</td>
<td>1/21/2019 11:05:29 AM</td>
</tr>
<tr>
<td>NIHJohnho</td>
<td>1/22/2019 12:00:41 PM</td>
<td>678</td>
<td>1/22/2019 12:00:41 PM</td>
</tr>
</tbody>
</table>

**Hardness**
- (ppm)

**Total Alkalinity**
- (ppm)

(Not the actual data)
### Risk Management - Weekly Boiler Plant Chemical Dashboard

#### Boiler Feed Water Round
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity Daily Rounds</td>
<td>μS/cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH Daily Rounds</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>O2 Concentration Daily Rounds</td>
<td>ppm</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Hardness Daily Rounds</td>
<td>ppm</td>
<td></td>
<td>90</td>
</tr>
</tbody>
</table>

#### Steam Condensate Return Round
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRC Amine Daily Rounds</td>
<td>ppm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Soft Water Round
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness Daily Rounds</td>
<td>ppm</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

#### RO 1 Round
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Hardness Daily Rounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet ORP Daily Rounds</td>
<td>mV</td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>RO Filter pressure drop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outlet Conductivity Daily Rounds</td>
<td>μS/cm</td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>Outlet pH Daily Rounds</td>
<td></td>
<td>ppm</td>
<td>100</td>
</tr>
<tr>
<td>Inlet pH Daily Rounds</td>
<td></td>
<td>ppm</td>
<td>90</td>
</tr>
</tbody>
</table>

#### RO 2 Round
<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Units</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Hardness Daily Rounds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inlet ORP Daily Rounds</td>
<td>mV</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>RO Filter pressure drop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outlet Conductivity Daily Rounds</td>
<td>μS/cm</td>
<td></td>
<td>96</td>
</tr>
<tr>
<td>Outlet pH Daily Rounds</td>
<td></td>
<td>ppm</td>
<td>100</td>
</tr>
<tr>
<td>Inlet pH Daily Rounds</td>
<td></td>
<td>ppm</td>
<td>92</td>
</tr>
</tbody>
</table>

#### Boiler Round Data

#### Boiler 1-6 Conductivity Live
<table>
<thead>
<tr>
<th>Description</th>
<th>μS/cm</th>
<th>% compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler 1 Conductivity</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Boiler 2 Conductivity</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Boiler 3 Conductivity</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Boiler 4 Conductivity</td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Boiler 5 Conductivity</td>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

#### Boiler 3 Rounds

#### Boiler 4 Rounds

#### Boiler 5 Rounds

(Not the actual data)
Ongoing Project - Rapid ATP-2G Detection Technology

ATP, DipSlides, Petrifilm correlations
Digitization Plant Operations - Operator Shift Turn Over Website

Asset status, work orders closed and submitted, alarms, misc. events, live log, message to the next shift
**Steam Turbine Start up Preliminary Checklist**

**Chiller 22/23**

Operator

Ensure that the three condenser and surface condenser isolation valves are **properly lined up**

The surface condenser water inlet valve (SCIV-22) and the surface condenser outlet valve (SCOV-22) should be **Open**, and the condenser outlet valve (COV-22) from the chiller condenser should be **Closed**.

Operator

Ensure that the chiller and condenser barrels have been **properly vented**.

Operator

Ensure that the emergency stop button is **pulled out**.
### Machine Learning / Statistical Modeling Methods

<table>
<thead>
<tr>
<th>Supervised Learning</th>
<th>Unsupervised Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discrete</strong></td>
<td><strong>Continuous</strong></td>
</tr>
<tr>
<td>Classification or Categorization</td>
<td>Clustering</td>
</tr>
<tr>
<td>Regression</td>
<td>Dimensionality Reduction</td>
</tr>
</tbody>
</table>
ANN based Load Forecaster and Online Error Analysis
Streaming Machine Learning Calculations Architect

ML Analytics Development and Packaging (Local PC)

Compiler

Package

Code / test

Integration with real-time database

Real-time Computational Engine

Data sources / applications

Worker processes

Request Broker

Production Server

Access

Enterprise Application

Mobile / Web Application

3rd party dashboard

https
Real-Time Machine Learning Integration: Simulated Compressor Performance

Compressor 26

Compressor 27

Steam-driven Compressor 23

Steam-driven Compressor 22
Ongoing Project – Operator Simulator Project

Operator training on normal and emergency scenarios, situation playback, evaluate innovative control strategy and optimize the process
Chiller Plant Optimization

Objective function: Minimize (the total equivalent cost in next 48 hrs)

The individual component models are from machine learning models

The Constraints:
• Chiller run time and availability
• Electrical feeder load balance
• Limits of the individual chiller /free cooling capacity, flow, temp, etc.
• TES tank status and capacity
• Load Forecasting and Energy Balance
• Future PJM Electricity Price

The Decision Variables:
• The chiller condenser evaporator flow, temp
• The load distribution among the chillers
• Free cooling flow, number of heat exchangers
• TES charge / discharge dispatch decision and flow
**Optimization Results and Recommendations**

**Typical Suggestions:**
Run minimum number of chillers, shift more load to free cooling, the more efficient chillers or the steam turbine chiller, run more cooling tower cells to reduce the tower return temp, or increase the chilled water supply temp.
Data Quality Life Cycle Management

Data Generation

- Completeness
- Consistency
- Accuracy
- Integrity
- Non-duplicate
- Timeliness

Calibrate and maintain the sensors
Fix the data / interface communication errors
Online statistic scan
Identify the incorrect and missing data
Clean and smooth the data
Error propagation and metrological standards

Data Utilization

Calculation Handbook and Change Management SOP
Daily / Monthly Dashboard Review SOP
Machine baseline and health check
Energy / mass/ cost balance and cross disciplinary check
Auto Fault Detection, text message & emails notifications
Goal:
• Obtain reliable post-processed data
• Actionable plans based on more reliable and trusted data without too much need for post processing.

Results:
• Saved hours of time spent on post processing the noise.
• Less space used on server
• Less load on server
• Cost savings for plant operation due to better data for forecasting and optimization modeling.
Real-time Data Quality Dashboard
Tangible Results – Financial

Millions of dollars saved despite increased utility costs & demand!

Bethesda Campus Energy & Water Billing

\[
\mu + \frac{\mu_T}{\sigma_\varepsilon} \frac{\partial \varepsilon}{\partial x_i} + C_I \frac{\varepsilon}{k} (P + C_3 G) - C_2 \rho \frac{\varepsilon}{l}
\]
Thank You

Many thanks to NIH Office of Research Facilities Director Mr. Dan Wheeland, Division of Technical Resources (DTR) Director Dr. Farhad Memarzadeh, Deputy Director Mrs. Alamelu Ramesh, and colleagues in DTR team to make all of these happen!
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Data Generation

Energy Balance

\[
\text{Energy In} = \text{Energy Out}
\]
\[
Q_{\text{In}} + W_{\text{in}} = Q_{\text{out}}
\]
\[
T_{\text{ons}_\text{Evap}} + kW = T_{\text{ons}_\text{Cond}}
\]
\[
\text{Percent} = \frac{T_{\text{ons}_\text{Evap}} \times \text{Conversion} + kW}{T_{\text{ons}_\text{Cond}} \times \text{Conversion}} \times 100
\]

Error Propagation

\[
kW = \sqrt[3]{V \times I \times PF}
\]
\[
\frac{\partial kW}{\partial V} = \sqrt[3]{I \times PF}
\]
\[
\frac{\partial kW}{\partial I} = \sqrt[3]{V \times PF}
\]
\[
\frac{\partial kW}{\partial PF} = \sqrt[3]{V \times I}
\]
\[
W = \dot{m}(h_i - h_e) \times \text{Conversion}
\]

\[h_i = \text{enthalpy at Steam Turbine Inlet at Saturation}\]
\[h_e = \text{enthalpy at Surface Condenser Vacuum Pressure}\]
Machine Learning Models Learning

- Model learned cooling load vs. ambient lead/lag effect
- Learned using data with no explicit context
- Took several years worth of data to recognize pattern
- Data provided insight on system dynamics with respect to weekend/weekday, time lag between ambient heat and cooling load, increase in demand for steam on weekdays around 8am and 5pm