MONITORING-BASED COMMISSIONING USING AUTOMATED FAULT DETECTION AND DATA ANALYTICS

EXPERIENCES WITH PROCUREMENT AND IMPLEMENTATION

Gerry Sapienza – Sr. Principal Engineer
Abbott Laboratories, Corp Engineering Strategic Programs

Larry Lister - Project Executive/Senior Mechanical Engineer
Facility Dynamics Engineering Corp

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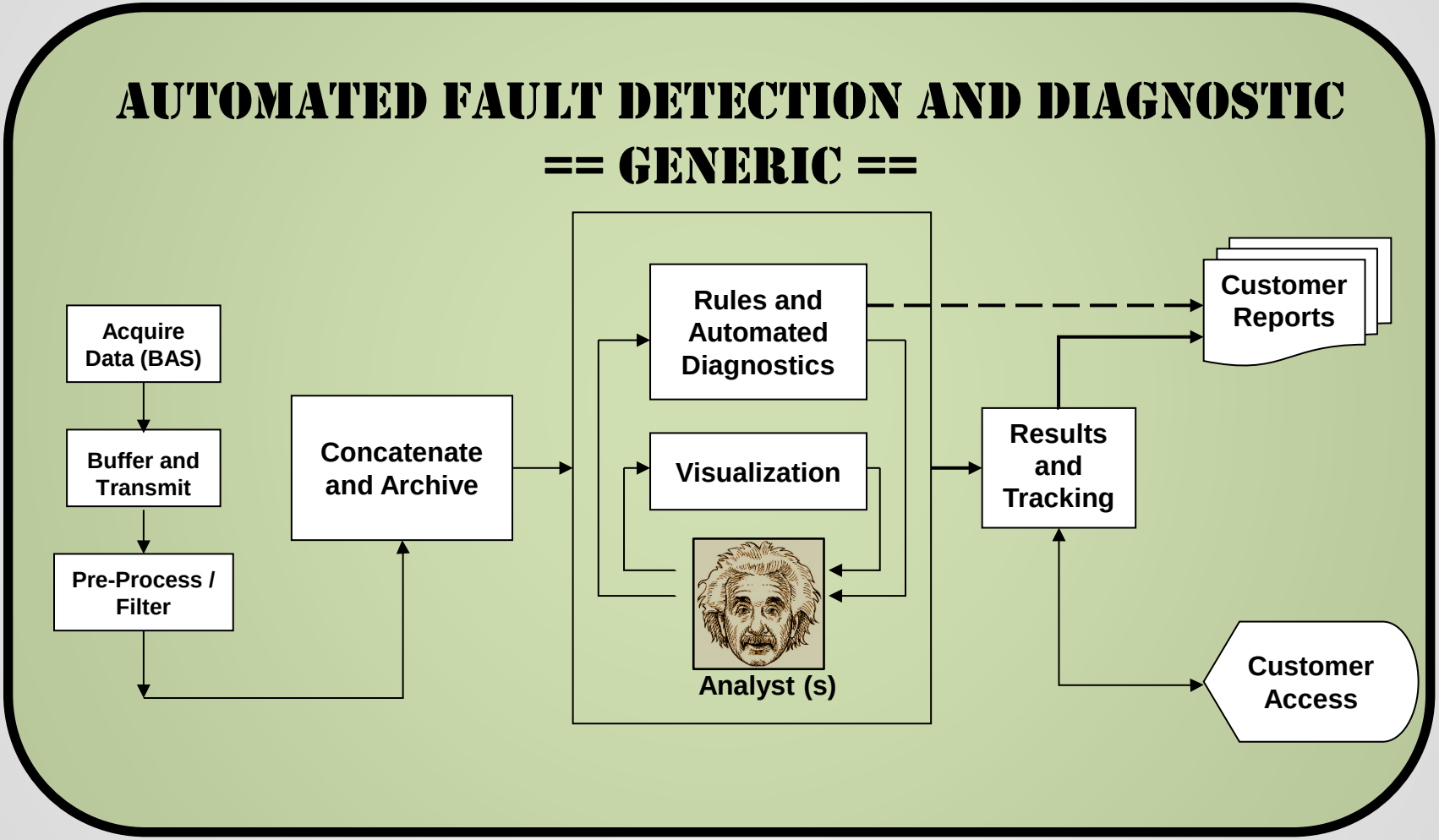
Agenda

- Introduction to Fault Detection and Diagnostics (FDD)
- Value Proposition
- Project: Intent , Scope, Vendor Selection
- Project: Technology
- Progress and Findings to Date
- Current Status
- Q&A

Introduction to Fault Detection



"FDD" TERMINOLOGY - NO STANDARDS

- "Analysis": Of what, exactly? 'If > Else' logic or actual embedded engineering?
- "Detection": Identify that there is a problem and provide some characterization
- "Diagnostics": Identify the probable /likely/possible CAUSE of that problem
- "Automated" : Often misused over the years
  - Should NOT mean: "Data comes from an automated system…"
  - Should mean: Detection & diagnoses are automated with no human in the loop
    - Benefit: accuracy and consistency over time
- "Visualization": Presenting raw data to the User in useful ways
  - Present data in useful formats to assist in analysis and presentation
  - Can be very powerful: Dashboards, benchmarking…
  - Generally require user to be analyst
  - Caution: Visualization is not equivalent to Diagnostics
- FDD State-of-the-Shelf: "Caveat emptor…" (Let the buyer beware…)

Value Proposition

Investment and Cultural Change

Up-front cost and resource commitment
- Cost of software and configuration
- Installation / Startup requires focused effort of higher skilled techs and/or engineer
- Foundational remediations will be needed
  - Demand WOs to restore / repair / replace
  - Engineering / programming changes
  - Capital project upgrades or remediations
- New processes to review/ prioritize diagnostics for action

Strategic View / Paradigm Change
- Long-term shift in the balance of O&M Talent:
  - Net reduction in personnel
  - Ratio of High Skill / Standard Skill Increases

Maintenance of the FDD Tool
- Annual software maint license and as-builts for FDD software/service

Problems more visible (“Ignorance is not bliss")

Energy savings are typical and likely but not guaranteed

What This Means to Me:

Sustainability: Building Operations, Comfort, and Energy Waste Identification
- Identifies energy reductions (improper operation, energy saving measures)
- Switch from Reactive to Proactive Maintenance
- Identifies shifts in building usage that affect energy and comfort

Reductions / Displacement of PMs
- Eliminate unneeded tasks remaining PMs (Focus on more important / less routine)
- Problems caused by unnecessary adjustment, replacements, and overrides

Increase O&M staff effectiveness
- Reduce Unplanned Maintenance and Comfort Calls
- Fosters expertise, engagement, empowerment, and experiential learning
- Fewer "Rote” repetitive tasks / more "Root Cause"

Sustainable energy savings 5-30%
More persistent remediation and fixes

Project Intent

Project Objectives

Implement a pilot project utilizing fault dete

- ❑ Identify and direct correction / improven
- ❑ Reduce building energy consumption
- ❑ Ensure proper operation of multiple indiv pumping stations to improve central chill
- ❑ Identify opportunities to increase the effe mitigate the increasing scarcity of skilled t foster engagement, empowerment, and experiential le
- ❑ Achieve total project cost reduction ($100 - 130M)
- ❑ Trial of fault detection for Continuous Commissioning

Continuous Commissioning is a continuous process of collecting and analyzing building data from existing BAS and/or standalone metering equipment, and making the necessary operational changes or repairs/replacement to sustain building systems operation at a high level of performance

Strategic Opportunities

Strategic Programs Group providing project engineering, technical direction, and KPIs to implement pilot project. Findings and data will be utilized by Global Strategic Programs to *Evaluate and Launch FDD as a scalable predictive maintenance solution*.

Project Vendor Selection

FDD Provider - Selection Considerations

- Overall quality and depth of detection and diagnostics
- Minimize dependency on vendor for compiling reports
  - Desire to directly interpret and apply reports after training
  - Control extent to which analyst is used
- History / Commitment / Experience in Market
- Minimize IT and BAS complications
  - Minimize permission, Corporate firewall penetration, IT involvement
  - BAS network traffic and conflicts
- Vendor development and implementation team should have direct experience and expertise in HVAC/controls
- Response to RFP
- Analysis Configuration
  - Owner vs FDD vendor vs System Integrator/Consultant
- First- and Multiyear- Costs
- Interviews with FDD installations (multiple Vendors)
- Direct experience from previous intermittent limited trials (1999-2005, 2010-11)

Project Scope

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- 360,00 sf Laboratory/Office Building
  - ❑ HVAC systems (16)
  - ❑ Hydronic heating and chilled water pumping systems (8)
  - ❑ Offices, common areas, and ”simple” laboratory tracking zones (120)
  - ❑ Excluded from this phase: 250 Laboratory Room Controllers
- Site-wide building chilled water “Decoupling” pump stations (14)

Project Funding

- Funded by Site Operations (Facilities Management)
  - ➢ Capital: Anticipated capital improvements
  - ➢ Expense:
    - ❑ Software Licenses and data storage for project + 2 years
    - ❑ Configuration and additional consultation services

Fault Detection and Diagnostics for Pilot Project

Project employs engineering and cloud-based fault detection software developed by external engineering firm. (Facility Dynamics Engineering, "*PACRAT™*")

Uses native trending and reporting functionality of BAS to collect data.

- CSV report files sent to vendor weekly via file transfer protocol.

Vendor performs one-time mapping of BAS points and data to be used by the mechanical and control system FDD/analysis engine.

- Configured and/or customized to match our systems.

Historical trend data is stored in vendor database and analyzed for faults and anomalies:

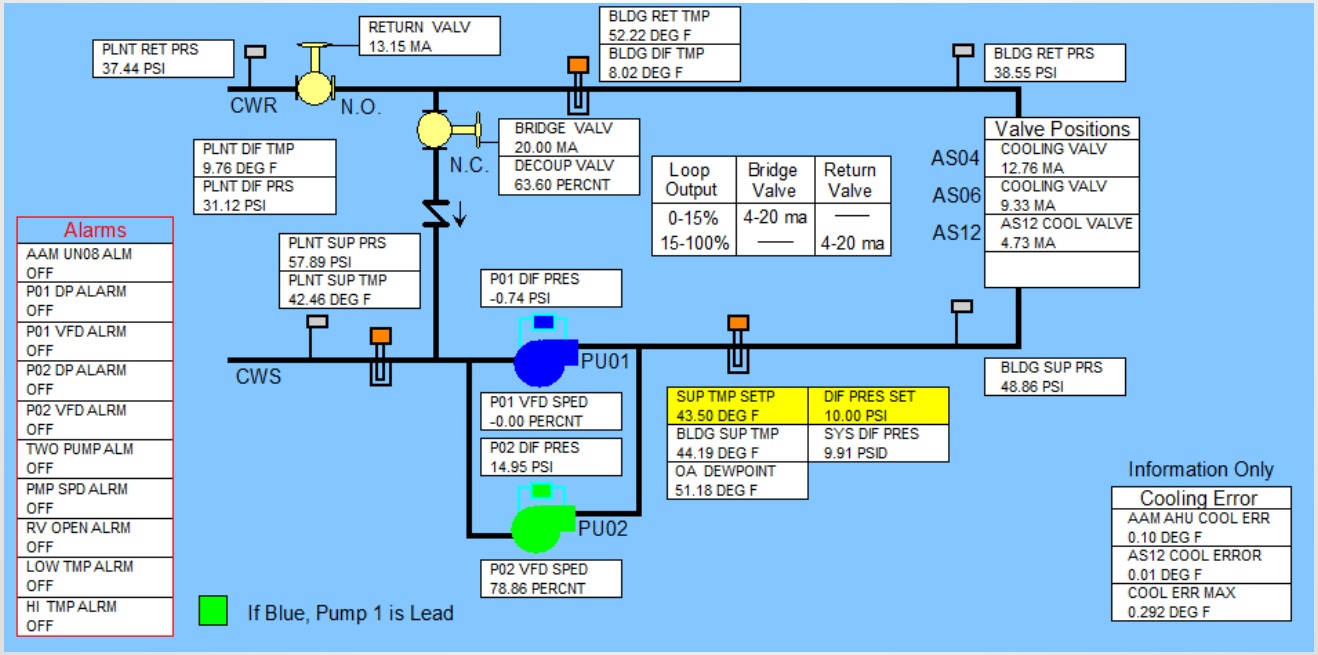
- Diagnostic reports
- Abbott users access information via an interactive web-based interface.
  - View periodic reports (Monthly for HVAC, Weekly for chilled water)
  - View historical data stored in Vendor database
  - Collaborative incident tracking

AHU and Terminal Diagnostics Include…

- ✓ 'Failed' or 'Suspect' sensors
- ✓ Miscalibrated/Uncoordinated sensors
- ✓ Out-of-sequence coil operation (and associated wasted cost and false load)
- ✓ Lack of economizer/missed free cooling opportunities (and associated wasted cost)
- ✓ Fighting coils (and associated wasted cost and false load)
- ✓ Leaking valves (and associated wasted cost and false load)
- ✓ Struggling system capacities
- ✓ Unoccupied period operation (fan and ventilation) and associated wasted cost
- ✓ Unstable and oscillating control
- ✓ Deviation from setpoint
- ✓ 'Custom' deviation anomaly
- ✓ Inadequate or over-ventilation rates (along with the associated parameter statistics)
- ✓ Failed outputs or those with a poor performance characteristic

Hydronic and Pumping Station Diagnostics Include…

- ✓ Sensor Coordination
- ✓ Plant Sensor/Meter Calibrations
- ✓ Struggling Loops
- ✓ Reverse Bridge Flow
- ✓ Primary/Secondary Load Match
- ✓ Low/Degrading Plant ΔT



ALARMS vs. ANOMALIES

DIAGNOSTICS ARE NOT REAL-TIME ALARMS

- Alarms (Acute): Real-time, BAS-initiated events
- Anomalies (Chronic): Based on historical data, requiring analyses over a variety of conditions to identify incorrect or inefficient operation
- FDD attacks Chronic (as opposed to Acute) problems
- Anomalies are often the underlying problem causing Alarms
- Most Anomalies:
  - Go undetected
  - Waste money
  - Waste system capacities and capabilities
  - Degrade personnel productivity
  - Depend on individual initiative and preventative maintenance to detect and correct

Technology

Detailed, Actionable Diagnostic Results: PACRAT results tell the User what went wrong, when, and by how much. Includes statistics and cost analyses where applicable.

- Anomaly Title & Detailed Description: What was detected, statistics, and detailed description of the problem
- Start/End Date: When the anomaly was first (and last) detected
- Cost Waste: If applicable, the calculated energy cost waste (uses detailed utility rate schedule)
- Priority: Customized capability to develop a prioritization value to help manage anomaly remediation
- Visualization Link: Opens data plots at start of anomaly period
- Sensors/Data Involved
- Analysis Period: The historical period over which the analysis was evaluated (monthly)
- Causes/Resolutions: An reference list of the potential causes for the anomaly and what the technician should look for to correct it.

Example: Air Handler Diagnostic

AS06-100% OA (Corridor Lab Makeup) **$416.35**

> Coils fight due to valve leaking or miscalibrated actuator (Valve Leak-Fighting)

**PHV_O--Coil 1/16/2016 8/1/2015 - 12/31/2015 Energy Waste $414.73*

Sequenced coils were both adding and removing heat due to PHV_O leaking an average of 3.3°F. This imposed an average of 2 tons of false load.

Anomaly Date Range: 8/17/2015 12:00:00 AM - 12/14/2015 6:20:00 AM

Example: VAV Box Diagnostic

Zone_L179_AS09 (TEC - VAV w/ Reheat) **$0.00**

> Controlled variable deviates from setpoint (Setpoint Deviation)

**SUP_CFM 7/8/2016 6/1/2016 - 6/30/2016 Poor Control $0.00*

The SUP_CFM input value deviated from its setpoint for 42.35% of the time in the analysis period. The setpoint value is 500 CFM and the allowable tolerance is + 50 to -50 CFM. The error below setpoint occurred 21.62% of the time across the analysis period, while the error above the setpoint occurred 20.73% of the time. The range of values for the SUP_CFM input was 52 CFM to 812 CFM with an average value of 522.41 CFM.

Anomaly Date Range: 6/5/2016 4:20:00 AM - 6/30/2016 10:50:00 PM

Anomalies - Causes and Resolutions

Example Anomaly: Unstable control loop (control loop exhibits erratic, unpredictable, or highly oscillating behavior)

Anomaly Code	Possible Cause	Anomaly Resolution
Unstable Control	Gain settings are set too high on the control Loop.	Reduce the gain (Proportional Band on a PID loop). Loops tuned under high load (low system gain periods) may become unstable under low load (high system gain periods). Check control loop tuning under low load conditions as well.
Unstable Control	Control valves and/or systems are significantly oversized for the current duty.	Configure the systems to sizes/capacities more appropriate for the systems current duty. For instance install smaller control valves, use less sections of the damper, blank off and isolate flow to some of the coils, etc.
Unstable Control	Input sensor is fluctuating due to poor location or malfunction.	Check sensor location for unwanted physical influences and check calibration for acuracy.
Unstable Control	Output device is poorly sized or malfunctioning.	Check valve or damper for proper operation across range.

Boy there's a lot of stuff in this Building

"Help! I'm trying to drink from a fire hose !"

"Hey, this stuff might really work…"

Stage 1 Initial Install 10/15 - 2/16

- Info transfer: Funct Specs, P&IDs, Equip Schedules, BAS Pts and Graphics
- Data transfer – Trend setup, IT agents or portals
- Configuration (Central and Room systems)
- Customization (Rules)
- Initial field and BAS verification of diagnostics
- Filling gaps in data

Stage 2 Learning And Tuning 2/16 - 5/16

- Further customization
- De-sensitizing Rules
- Further data gap filling
- Correcting BAS and instrument errors
- Reporting Schedule
- Some ineffective first reactions
- Identify initial savings opportunities
- Identify performance issues
- Understanding more complex anomalies
- Develop processes to review and react

Stage 3 Foundational Remediation 3/16-7/16…

- Field calibrations and repairs
- Minor capital improvements
- Update as-built Docs and Drawings
- Decreasing anomalies
- Additional tuning
- Engineering / Funct Specs / Programming (Actual or Plan)
- Quantify estimated ongoing effort
- Realize energy savings

Stage 4 FDD Incorporated as PdM 5/16…

- Remediations identified, implemented, planned
- Ongoing Diagnostics: Manageable quantities, Regularly reviewed, More directly actionable
- FDD Software and Configuration Maintenance Agreement/Contract
- FDD actively displaces a number of PMs
- O&M Staff reallocated - More data & diagnostic driven / Less reactive and routine / More experiential learning
- Sustainability, persistence, and cost avoidance vs. new savings
- Contributes to Facility O&M KPIs
- **Projects**: FDD a deliverable and used for commissioning

Concentrated Team Effort

CHOKE POINT!

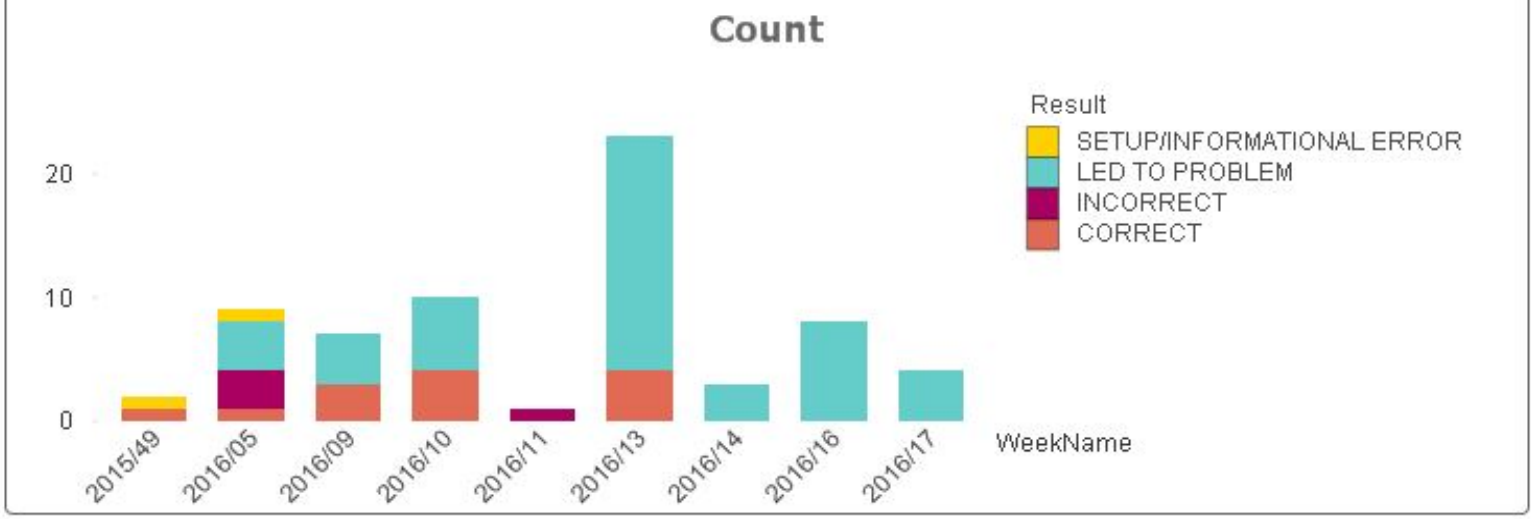
Findings and Results to Date

Accuracy of Diagnostics (Efficacy Based on first 5 months)

Summary

Task ID	Task Description	LSCO Maintenance	Technical Group	Total	Percent
20	CORRECT - FDD REPORT SPOT ON WITH REPORTED PROBLEM	7	6	13	19%
30	LED TO PROBLEM - FDD REPORT NOT SPOT ON, LED TO SOLUTION	8	40	48	72%
40	INCORRECT - FDD REPORT WAS MISLEADING, OR NO PROBLEM FO...	4	0	4	6%
50	SETUP/INFORMATIONAL ERROR - FDD CONFIGURATION ERROR	2	0	2	3%
		21	**46**	**67**	**100%**

Summary



Note: Ratings of diagnostics resulting in direct action or investigation after review. Total Number of anomalies much greater.

Findings and Results to Date

Energy Savings ($125,000 – $180,000)

(Savings estimates vary in certainty, stated estimates "aggressively conservative")

[D] = Direct Impact from FDD [I] = Indirect Impact

- [D] Scheduling ($10K)
- [D] Multiple terminal unit / terminal box overflowing ($26K)
- [D] Duct humidifier failure, leakage, collar heating ($30-$50K)
- [D] Box temperature control / reheat leakage ($10-$25K)
- [I] Reduced excess make-up air ($21-$35K)
- [D] Hot water reheat system setpoint reset ($20-$30K ; in progress)
- [D] AHU valve leakages and simultaneous heating/cooling (in progress)
- [I] Excess OA on RA units (under investigation)
- [D] Reduced return duct static pressure (reduction and failed fan control devices)
- [D] Missed free cooling opportunities
- [I] Flow station setup / training
- [I] Over-pressurization of ductwork
- [D] Non-optimal AHU damper/coil sequencing

Findings and Results to Date

- **Potential for Displacement of PMs**
  (FDD is a condition-based / predictive maintenance program)
  - Total HVAC PMs $80k/yr
  - Apparent opportunities present but not yet quantified
    - AHU temperature and static pressure sensor calibration
    - Control valve and damper calibration
    - Sequence verification
    - Others

- **ComEd MBCx Incentive and Rebate Program**
  - $25,000 for operational installation
  - $0.07/kWh for fully documented electricity and chilled water savings
    - First Submission: $22,400
    - Very likely, likely, potential: $40,000 - $70,000

Findings and Results To Date

More Early Learned or Confirmed Lessons:

- Importance of having experienced mechanical/controls engineering embedded within the programming as well as during initial configuration/set-up. Details matter greatly!
- Importance of site engineering/controls/programming team members (not just field techs)
- Some effort will be needed to understand more complex anomalies. The existence of multiple interrelated problems in the field may require "peeling-the-onion".
- Importance of sufficient data and instrumentation to accommodate accurate analysis. 'Diagnostic points' can pay off. (e.g., Temperature sensors after each coil and humidifier)
- The **configuration process is extremely valuable** in understanding systems and revealing shortcomings. Configuring and exercising rules enforces a discipline that surveys cannot.
- **"Indirect" finds are invaluable** : Force understanding and change
- Expect and be sensitive to some defensive reaction to FDD findings:
  - ➢ "I could'a told you that", "I could'a found that", "We've known that for 10 years" ...
  - ❑ Yes... We could'a found and fixed these, but we haven't (Usually with for very good reason)
  - ❑ FDD helps us by keeping these items in the forefront over time
  - ❑ We can choose to ignore or defer anomalies to match our capacity and funding to address, but "FDD doesn't forget"

Current Status and Next Steps

Status and Next Steps: Pilot is still in progress…

- Organizational Acceptance:
  - ❑ FDD recognized by Operations as:
    - ➢ A viable and scalable technical success.
    - ➢ The basic value propositions are achievable, in exchange for the cost of FDD and the commitment to initial remediations and shifting personnel to ongoing use of FDD.
    - ➢ Accepted as a Condition-based / Predictive Maintenance (PdM) tool.
  - ❑ Operations is incorporating current scope as a quarterly PdM.
  - ❑ ECM / Utility MBx Rebate activities and remediations continue to be directed by project in partnership with O&M
  - ❑ Full commitment is not yet a reality due to:
    - –Pending stabilization of O&M organization, processes, and focus stemming from partial outsourcing of maintenance functions

Current Status and Next Steps

Status and Next Steps: Pilot is still in progress…

- Next steps
  - ❑ Current project results have led to a limited expansion of the program:
    - ➢ Additional zones in current laboratory building
    - ➢ Application to executive office building controls upgrade for central systems and VAV zones
    - ➢ Includes evaluation of FDD for new project commissioning.
      - ❖ QA to reduce re-work / Assess readiness to transition from startup to final commissioning
      - ❖ Travel reduction
  - ❑ Key Performance Indicators (KPIs) : Develop or incorporate FDD into Operations and Maintenance metrics

Discussion

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