Sustainability improvements in semiconductor manufacturing using smart manufacturing technologies

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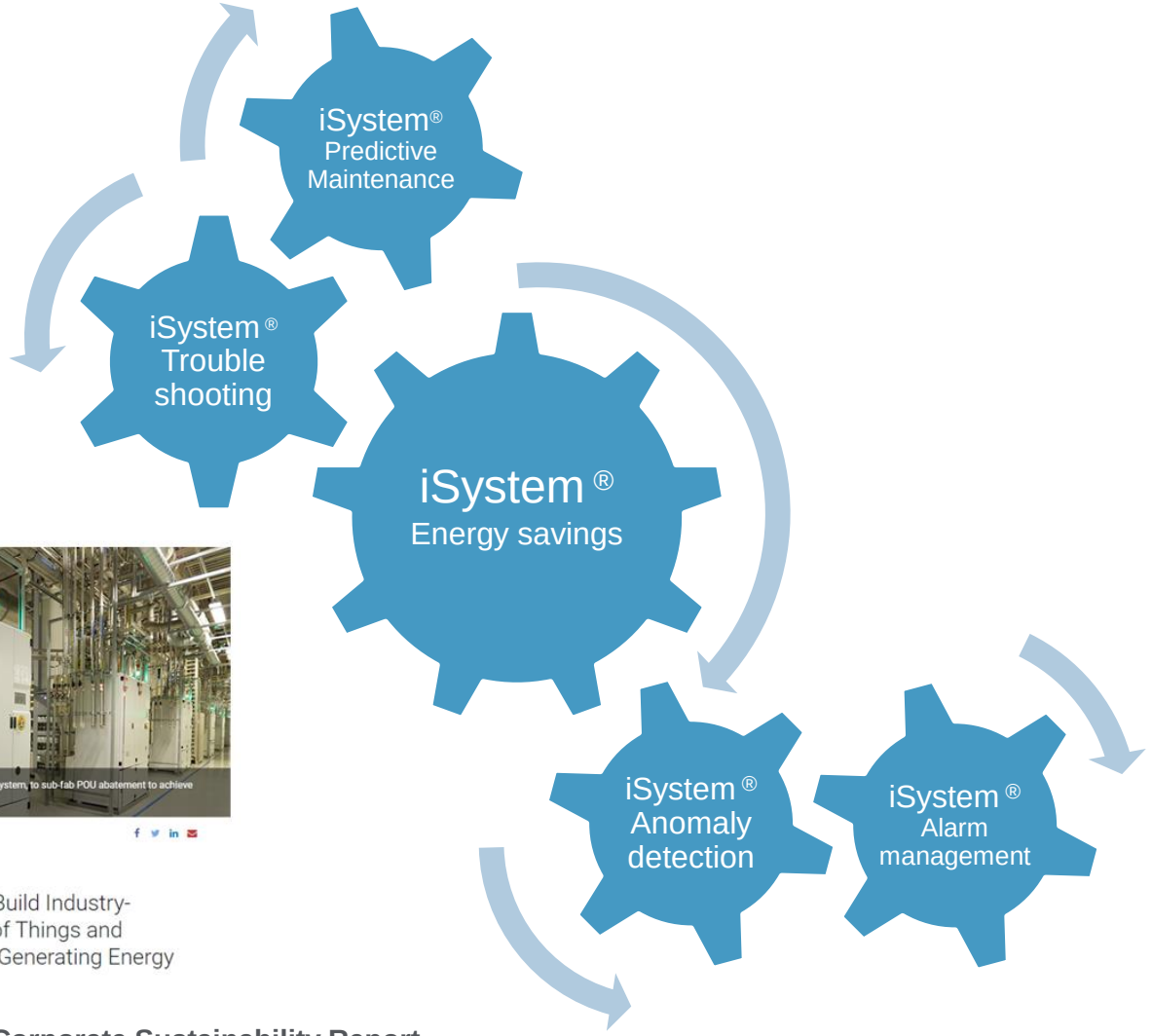
Sustainability and Smart Mfg Solution for Subfabs



TSMC Partners with Suppliers to Build Industry-pioneering iSystem™, an Internet of Things and Intelligent Energy Saving System, Generating Energy Saving Benefits of NT$85 Million

2021/05/13

Featured in TSMC 2021 Corporate Sustainability Report

Energy savings
- Idle and sleep mode
- Dry pumps & abatement incl. backup
- Continuous improvement

Reporting
- Authority reports, Subfab Equipment KPIs
- Energy and CO_2E
- Baseline and Savings Auto-calculation (ISO50001)

Anomaly detection
- Overlay of process and subfab information
- Integration of existing sensors
- Detection of trends

Alarm management
- Integration with SCADA or other systems

Troubleshooting
- Data analysis, Verification of changes
- Pressure cascade

Predictive maintenance
- Development of algorithms
- Continuous health monitoring

iSystem® enables Smart Manufacturing in Subfab, centered around Energy Savings

Maximizing the Value of Subfab Data

iSystem® prepares the data to work with customer databases.

iSystem® works with all major equipment suppliers to gather targeted subfab data into a single data stream

- Better utilizes existing sensors and data built into the devices
- **Provides a common communication protocol that simplifies customers IT efforts**
- Single point of connection
- Common time stamps
- Integration of stand-alone IOT and sensor data: power meters, vibration sensors, thermocouples, etc…
- Works with all tool OEMs

iSystem® provides a conduit for subfab data integration with tool and facilities data

- **Data streams can be connected to existing fab FDC, SCADA, and other customer databases**
- Enables advanced data analytics, including AI / Machine learning

And leverages the data analytics capability of complimentary Applied products.

Applied tools and sustainability solutions

- Energy and CO_2e reporting

Applied Global Services FSS Data Analytics for Applied tools with service contracts

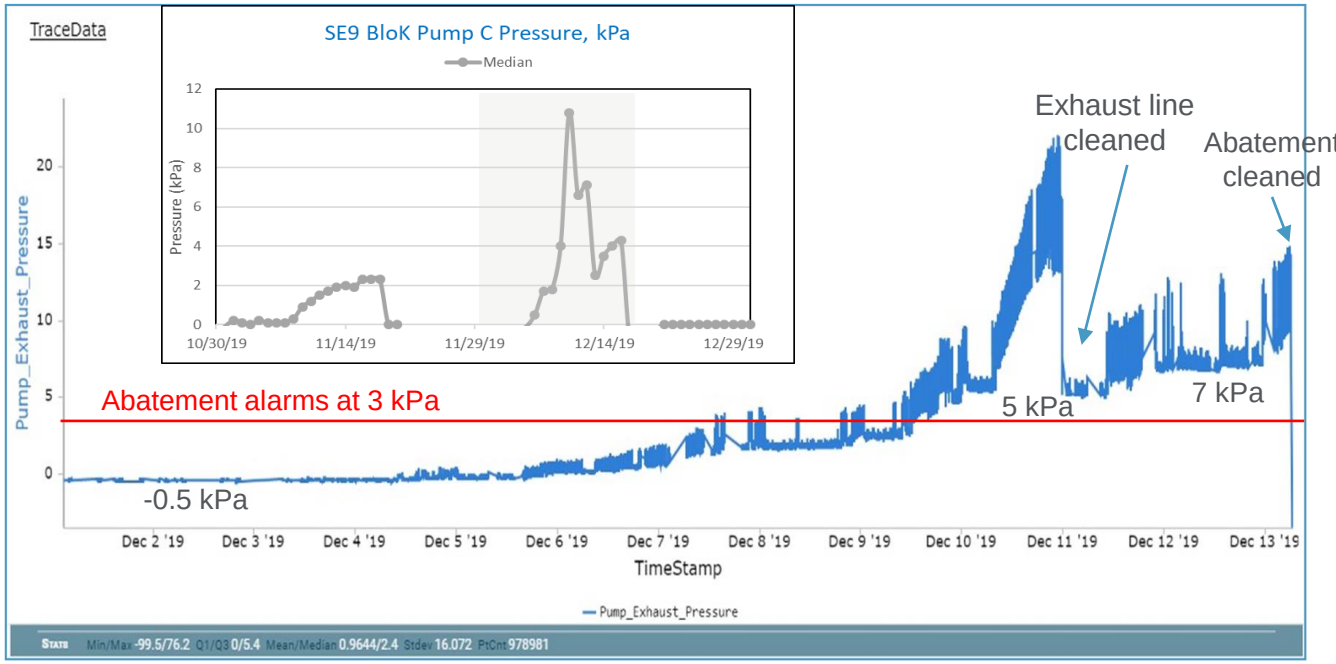
- **AI Anomaly Detection Ensemble**

Applied Automation Product Group

- **E3 FDC & Data Analytics**
  - Failure detection and logic setup within E3 Strategy Engine automatically takes action
  - Defined by customer based on classification (sends email, sets lot / wafer hold, inhibits tools, begins CMMS workflow)
- **Knowledge Advisor**
  - Electronic out-of-control action plans (OCAP) workflow for standardized and integrated dispositioning of OOC events
  - Further leverages the power of E3 platform and Strategy Engine

Exhaust Blockage Detection

- Pump exhaust pressure is used to detect exhaust clogging
- Pump backpressure gave an alarm, and operator called for exhaust line PM
  - First PM: Exhaust line was cleaned, but exhaust backpressure remained elevated
  - Second PM: Cleaning of abatement revealed inlet orifices were clogged



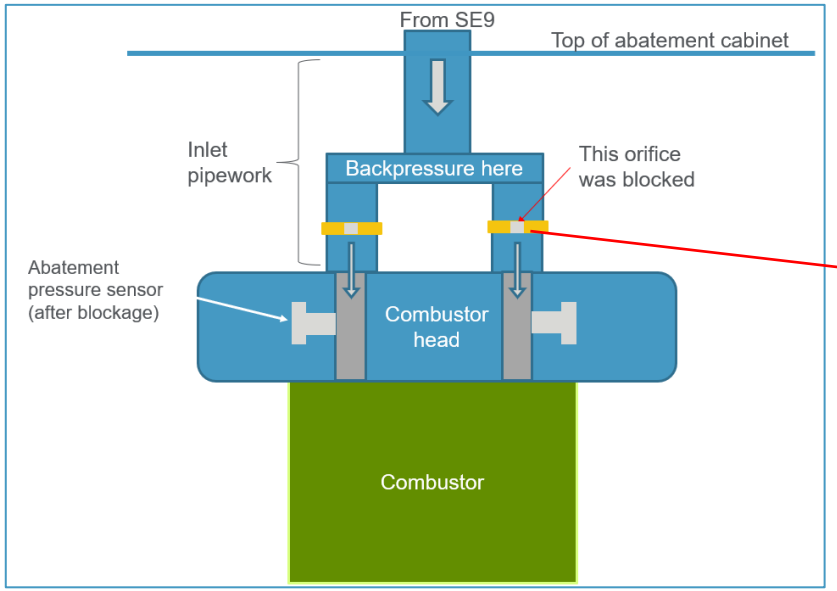
- Conclusions

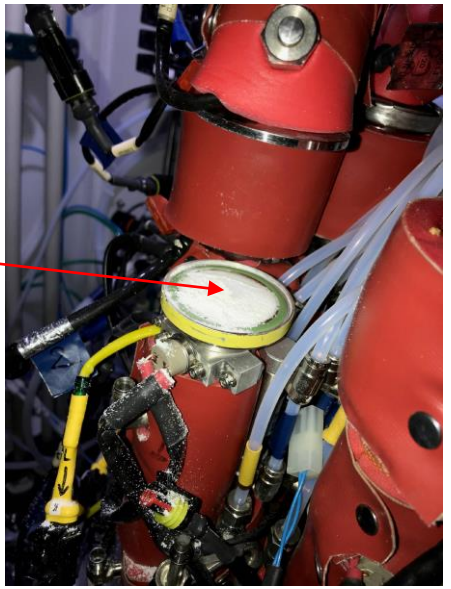
Parametric data from one piece of equipment can be used to detect problems on another.

Abatement equipment PdM model cannot catch this since the sensor is downstream.

With data readily available, the tech would have seen that the PM performed was not effective and avoided a 2nd PM.

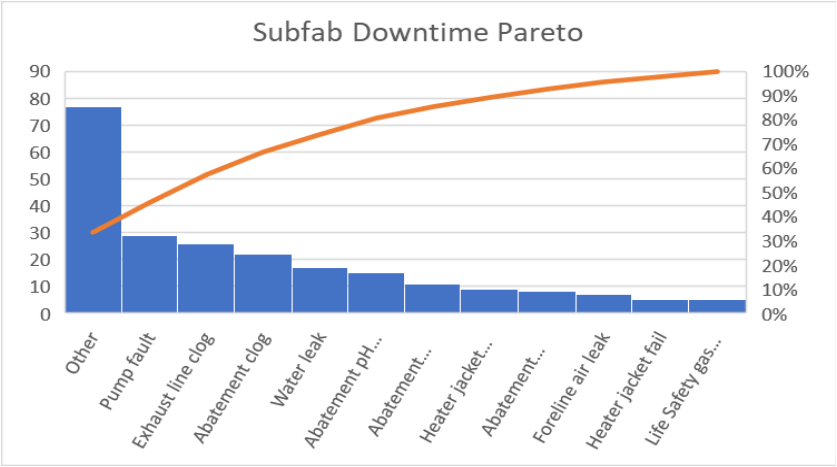
Future use of Applied Materials Knowledge Advisor (OCAP) will catch this.





Subfab Challenges for Smart Manufacturing

- Generally, not a single high value problem – instead multiple mid to low level problems that sum up to a higher value
  - High value problems have been addressed and new ones get addressed
    - Methods, people, and time are made available to do so
  - Total of subfab related downtime has high value
    - **Significant improvement requires addressing the problems on the long tail of the pareto**
    - Performing root cause analysis and corrective action for individual problems is too costly
    - Availability of subject matter expertise and data analytical skills is limited
    - Key contextual information is often missing – what was happening at the tool?



Illustrative Data

- **Therefore, traditional problem-solving methods need to change**
  - Humans are very good at single variable problems and not so great at multi-variate
  - More data and quick, easy sorting and display of that data enables faster analysis and on-the-spot troubleshooting
  - Differentiate between untrained / casual / infrequent users vs advanced data analysts

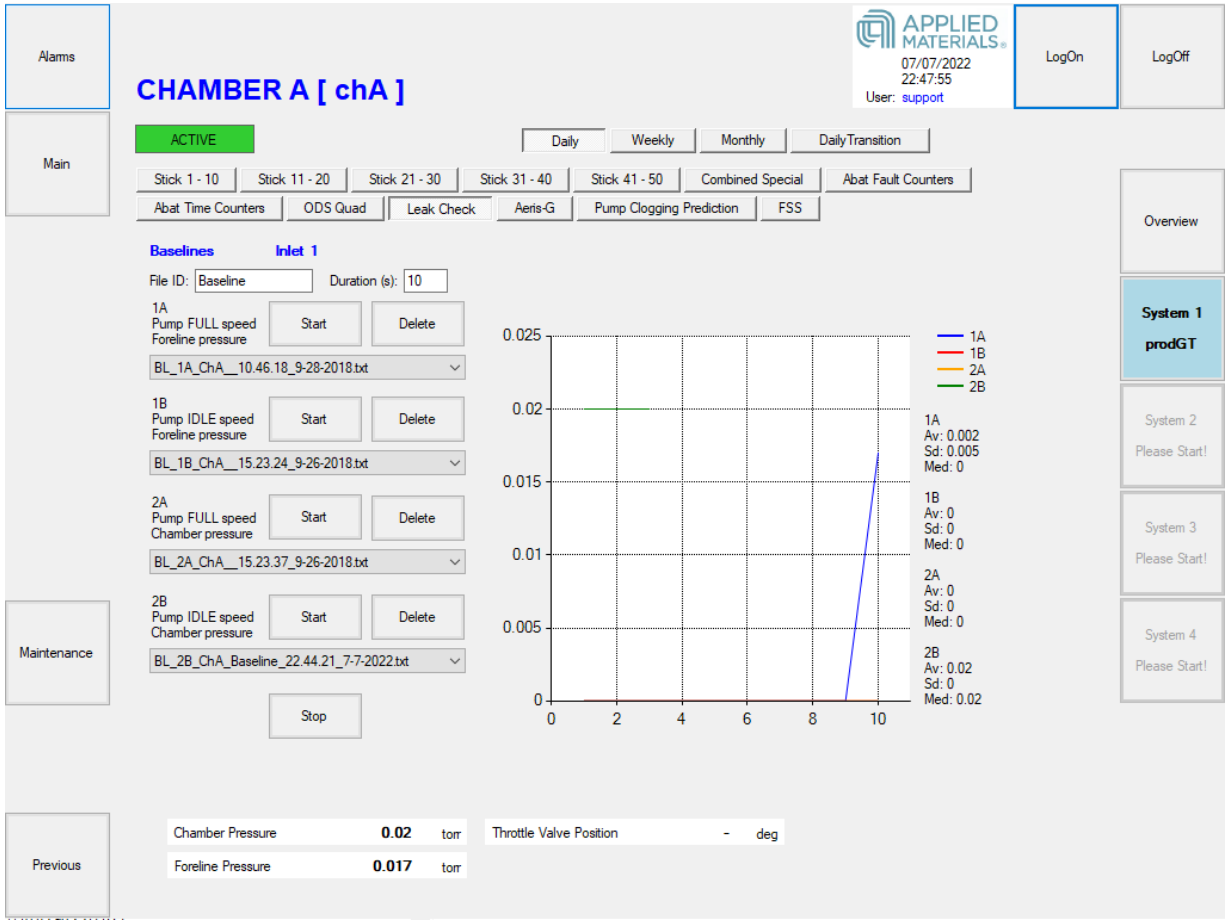
- Industry 4.0 / Smart Manufacturing methods provide a new path to better address these problems
  - Automate, automate, automate and predict

AI and automated functions must be leveraged to reduce time and expert man-power requirements.

Value Add ‘Smart’ Functions

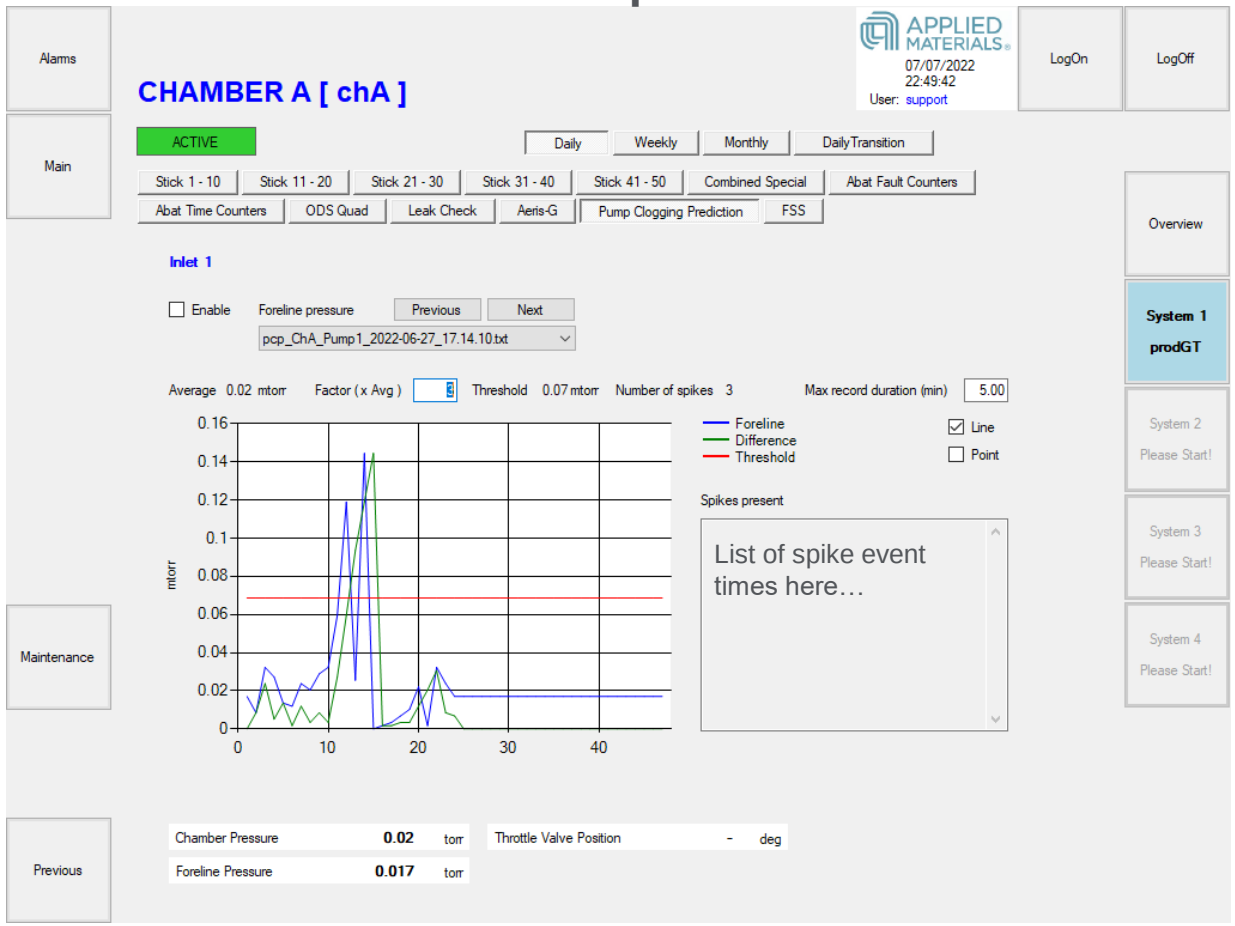
Two Examples of ‘Smart Mfg’ Functions

Foreline Leak Check Function



Procedure: Record baseline pumping performance baseline when system is new and known leak tight. Then compare against current performance.

Foreline Pressure Spike Detection

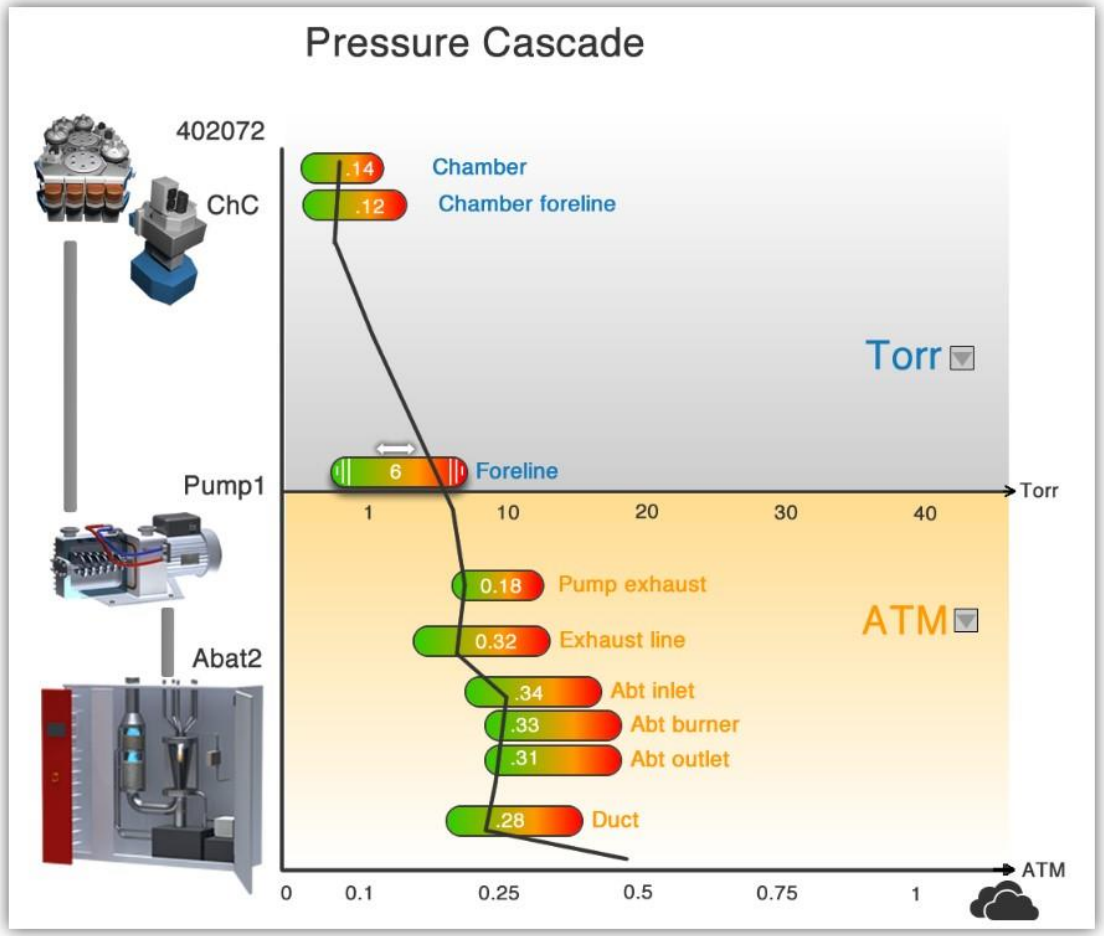


Spike Signal: Difference[i] = ABS(Foreline press [time i] – Foreline press [time i-1])
Threshold: User configurable factor x average pressure of all data points

Automated functions reduce manpower and expertise needed to identify problems.

Another Example of ‘Smart Mfg’ Function

- Pressure cascade presents the vacuum and exhaust as one continuous system
- Quickly visualize whether system pressures are within limits
- Send warnings and alarms when limits are exceeded



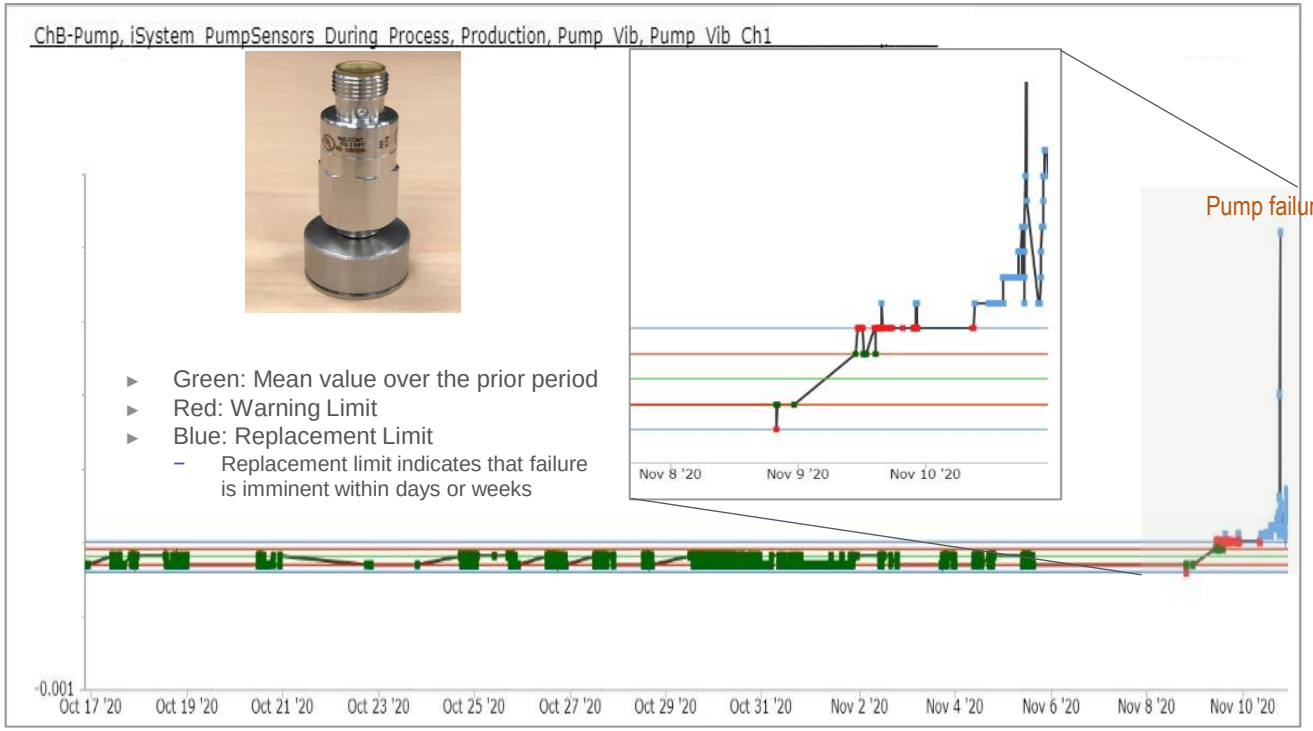
Under Development: Screen mock-up shown

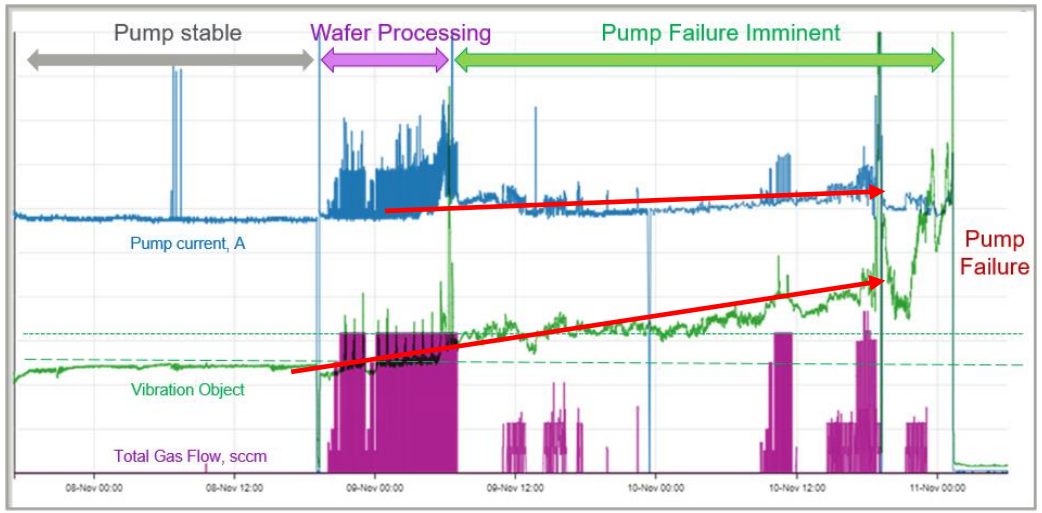
System level view significantly minimizes time and expertise necessary to identify problems.

Predictive Algorithms and AI / Machine Learning

Predictive Failure using Integrated Data

- Vacuum pump on CVD process in Applied Materials Lab
  - Pump failure on November 11, 2020
  - Observed vibration warning 2 days in advance
- Plot of selected pump vibration objects that indicate overall pump health
- Vibration sensor was located on foreline flange
  - Readily accessible, doesn't violate pump warranty
  - 5 Vibration objects used (V_rms, A_peak, etc…)
  - Optimally, pump manufacturers will provide vibration signals in the future…



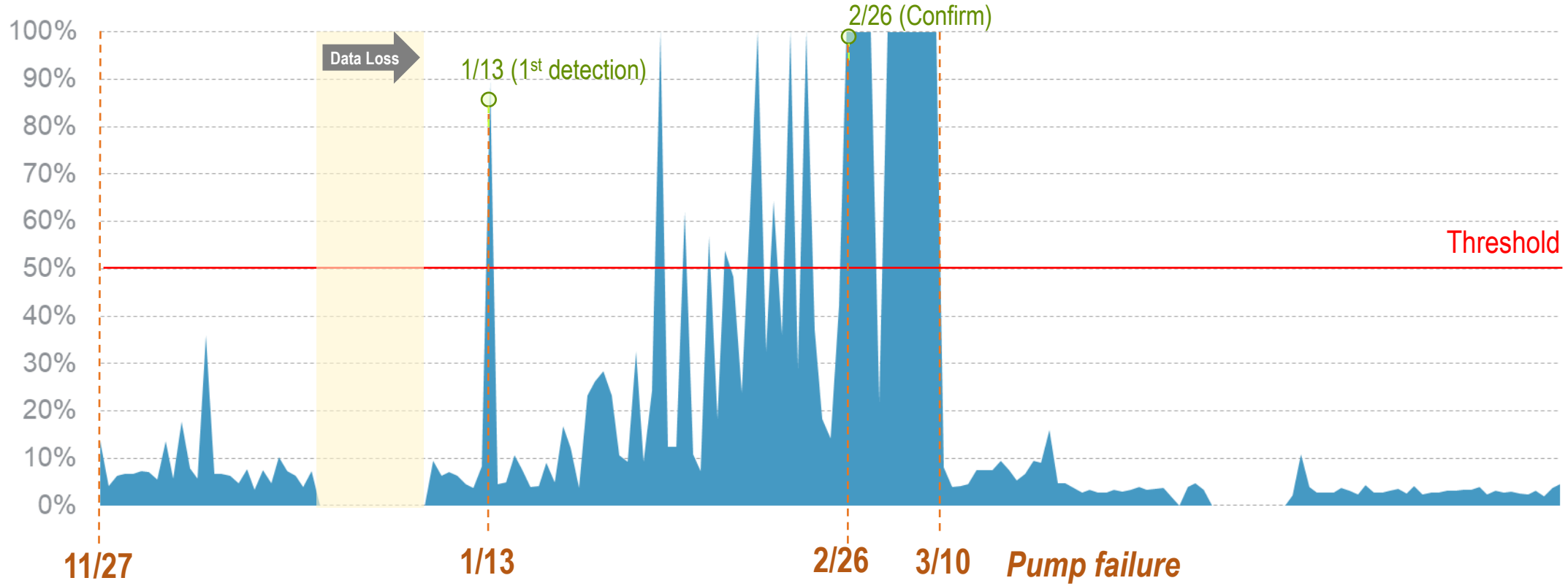


- iSystem® collects chamber gas flow, pump, and pump vibration data and sends to FDC system (i.e. AMAT E3 Strategy Engine)
- Combination of signals leads to further insights
- Pump current trend for the same event confirms the vibration response (although not as pronounced)

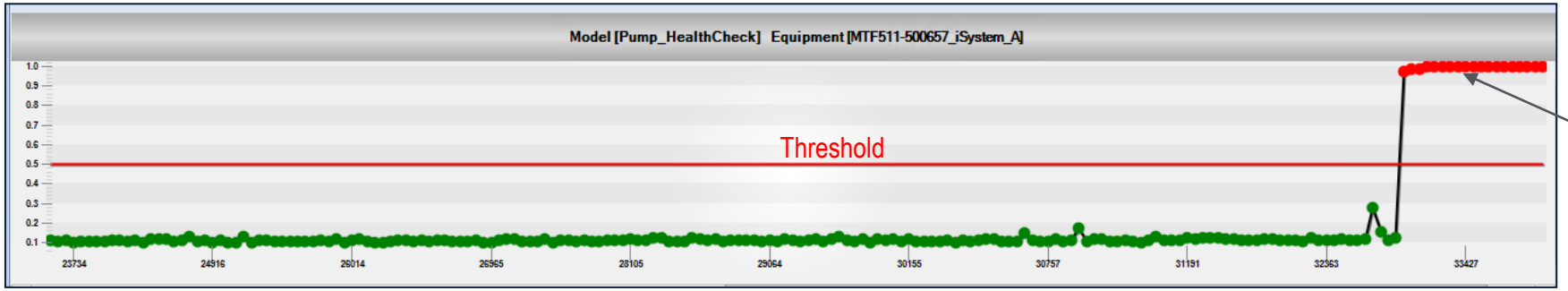
Predictive Pump Health Index Model

Utilize the pump and gas flow data via a proprietary Health Index model to predict pending failure.

Benefit: iSystem® + AMAT FDC provided a signal many days in advance for this application and failure mode



Pump Health Monitoring with AI Based Anomaly Detection



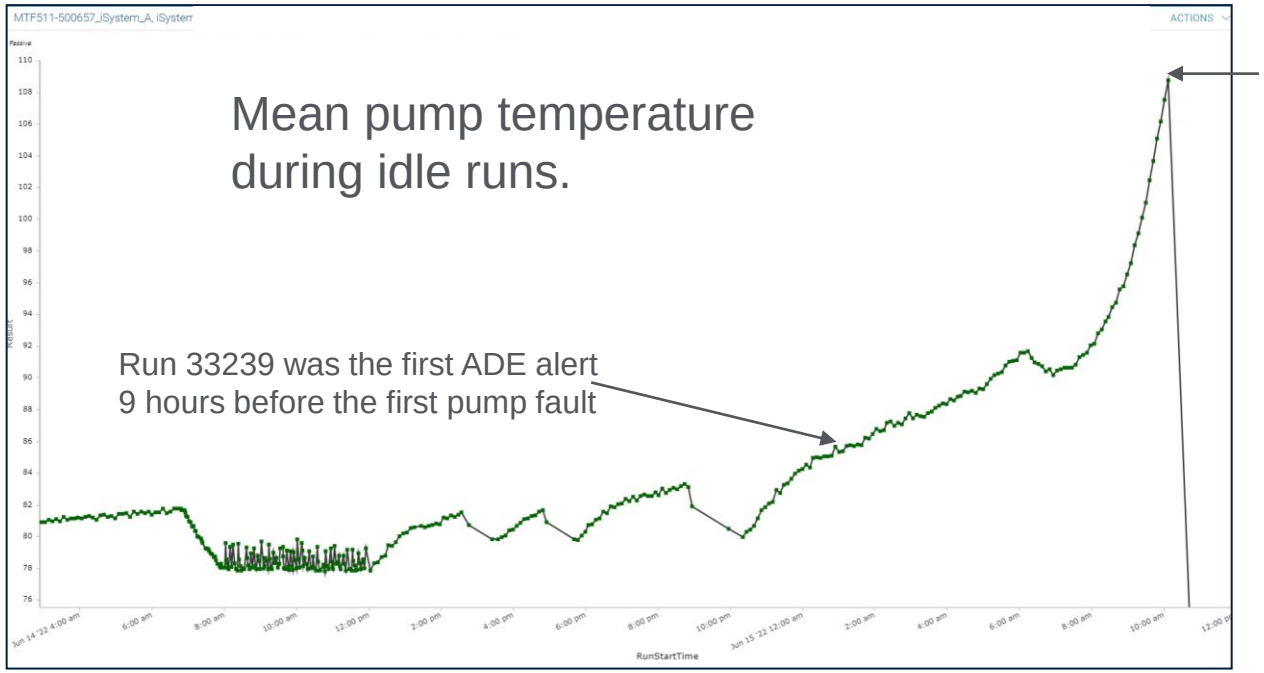
0 – 1 Health Index score provides a distinct signal to the user.

Example: Run 33239 was the first anomaly detected. ADE captured the issue 9 hours before the pump fault.

The Applied **Anomaly Detection Ensemble** function provides supervised and unsupervised machine learning models leveraging domain knowledge and virtual sensors.

Model inputs:

- Raw data of specific pump parameters and chamber gas load
- Statistics of parametric data
  - Mean, std dev, range, highs and lows, rates of change, etc…
- Uni and multi-variate threshold excursions
- Specific times of interest
  - Wafer runs vs idle time
  - Specified recipe steps
- Physics based ‘virtual’ sensor outputs



Post-event drill down into the data showed pump temperature was the main driver of this fault, which is valuable information for the root cause investigation.

Summary & Acknowledgements

- Semiconductor subfabs can and should be among the first to take advantage of the Big Data / AI / Smart Manufacturing era enabled by our industry's products!

- Thanks to Andreas Neuber, Shaun Crawford, Hemant Mungekar, Vaishnavi Chandershekar, Kashun Wong, John Albright, and Joe Van Gompel for their contributions to this presentation.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