

AI/ML Innovation for Condition-Based Maintenance (CBM+) to address the DoD mandate

Glenn Reis, *Federal Aerospace & Defense Lead*

Richard Resseguie, *AI Solutions Product Manager*

DAFITC 2023
August 28-30th

Agenda

Introductions

Impetus for This Session

CBM Maturity Journey

Operationalizing and Scaling CBM+ across the enterprise

AI/ML Innovation for CBM+

Use Cases

Session Takeaways

Q & A

Presenters



Glenn Reis

Senior Manager FA&D Lead

Glenn Reis is a seasoned business and technical consultant with 30 years of experience in Digital Transformation and implementing advanced technologies in the Federal Aerospace and Defense sector. Reis specializes in complex implementations that scale global enterprises and guides numerous FA&D clients through Organizational Change Management. Reis has organized, vetted and managed global delivery teams for major FA&D programs that required Model-Based Systems Engineering (MBSE) and integrated Digital Thread capabilities across complex lifecycles and enterprises.



Richard Resseguie

AI Solutions Product Manager

Richard Resseguie is managing a portfolio of AI applications focused on asset optimization and predictive maintenance use cases. His current focus is on providing easy to use no code machine learning tailored to controls engineers to help model their asset's behavior and drive business outcome.



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**LIFECYCLE IQ
Services**

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Rockwell Automation

Our strategy is to bring The Connected Enterprise to life.

We integrate control and information across the enterprise to help industrial companies and their people be more productive and sustainable.

\$6.3B

FISCAL 2020 SALES

23,500

EMPLOYEES

100+

COUNTRIES

ABOVE-MARKET GROWTH | PRODUCTIVITY | INTELLECTUAL CAPITAL >>> VALUE CREATION



**Rockwell
Automation**

KALYPSO

Kalypso delivers digital transformation for Rockwell Automation.

We help our clients discover, create, make and sell better products with digital.

Established in 2004

Rockwell Automation's
Digital Services arm
since 2020

Recognized Digital Leader



INDUSTRY FOCUS



Life
Sciences



Consumer



Industrial
High Tech

COMPREHENSIVE CAPABILITIES

Consulting

Digital Thread Strategy
Product & Portfolio Management (PPM)
Operations Performance Improvement
Supply Chain Optimization
Sustainability
Organizational Change Management

Data Science & AI

Product Lifecycle Intelligence
Autonomous Manufacturing
Model Predictive Control
Predictive Service & Maintenance

Technology

Digital Twin
Product & Data Lifecycle Management
Supply Chain Management (SCM)
Enterprise Resource Planning (ERP)
Internet of Things (IoT)
Extended Reality (AR/VR/MR)

Managed Services

Application Management
Continuous Improvement
Cloud Infrastructure & Hosting
Solution Services

Impetus for this session



DoD INSTRUCTION 4151.22

CONDITION-BASED MAINTENANCE PLUS FOR MATERIEL MAINTENANCE

Originating Component:	Office of the Under Secretary of Defense for Acquisition and Sustainment
Effective:	August 14, 2020
Releasability:	Cleared for public release. Available on the Directives Division Website at https://www.esd.whs.mil/DD/ .
Reissues and Cancels:	DoD Instruction 4151.22, "Condition Based Maintenance (CBM ⁺) for Materiel Maintenance," October 16, 2012
Approved by:	Ellen M. Lord, Under Secretary of Defense for Acquisition and Sustainment

Key Elements of the Mandate

4.1. CBM+ DURING THE ACQUISITION PHASE

(a) **Include CBM+** in the development of mandatory sustainment key performance parameters and supporting key system attributes **required for Acquisition Category I & II programs.**

(g) Establish a CBM+ approach that **integrates** condition-based maintenance and predictive maintenance and that optimizes material availability, minimizes unscheduled repairs, eliminates unnecessary maintenance, and employs the most **cost-effective system health management processes** based on DoD 4151.22-M compliant RCM principles and reliability analyses

4.2 CBM+ FOR LEGACY SYSTEMS

Improve materiel readiness and affordability for legacy systems, the Military Services and lifecycle managers will consider implementing and executing CBM+.

(f) **Comply with cybersecurity requirements** in accordance with DoDI 8500.01, SIM in accordance with DoDI 4151.19, and IUID in accordance with DoDI 8320.04

Our Understanding

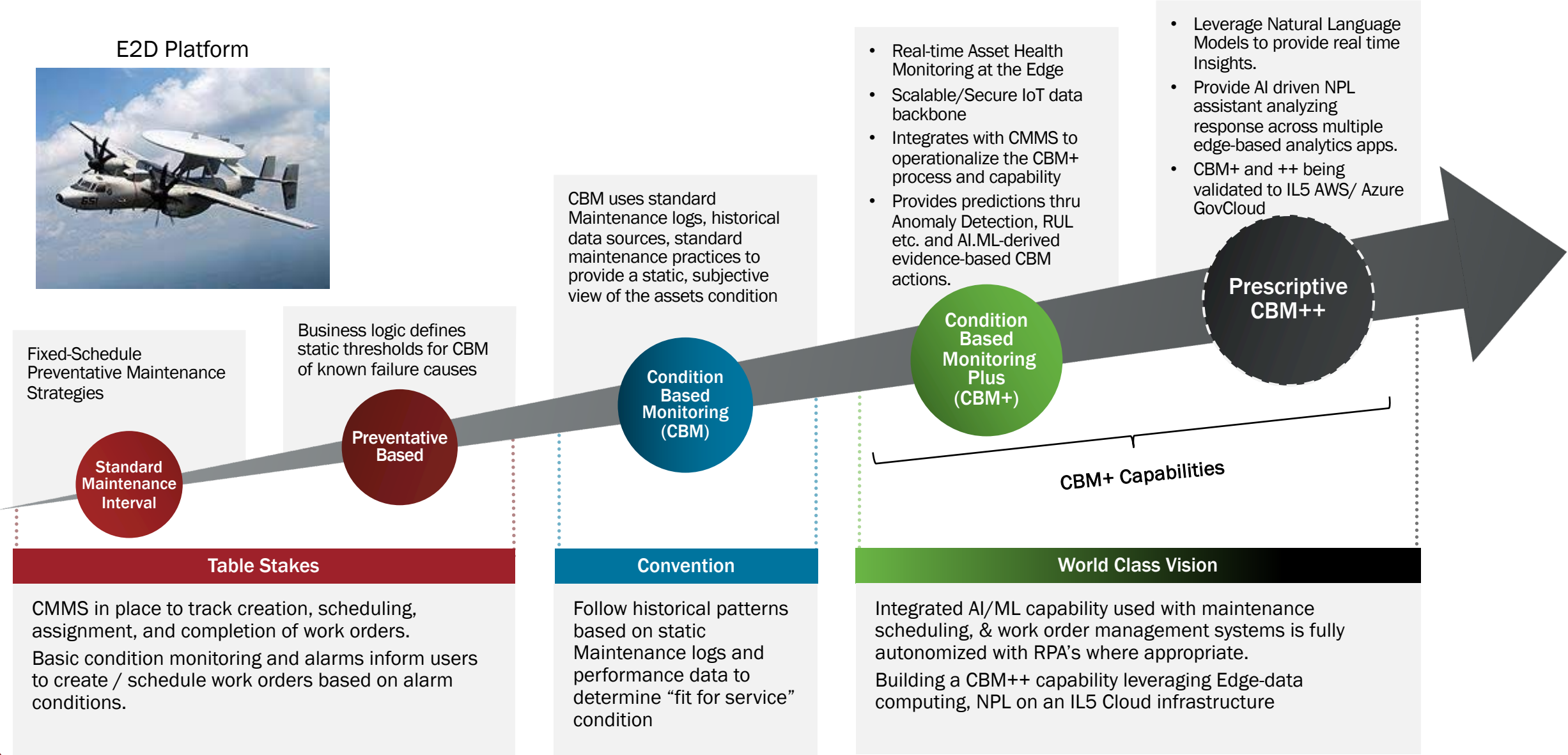
The Department of the Air Force has designated the Rapid Sustainment Office's Predictive Analytics and Decision Assistant (PANDA) program is an integrated artificial intelligence and machine learning tool for predictive maintenance that has been designated as a system of record by the Department of the Air Force.

C3 ai is an enterprise artificial intelligence software company that partnered with the Rapid Sustainment Office (RSO) to support the development of the Predictive Analytics and Decision Assistant (PANDA) program.

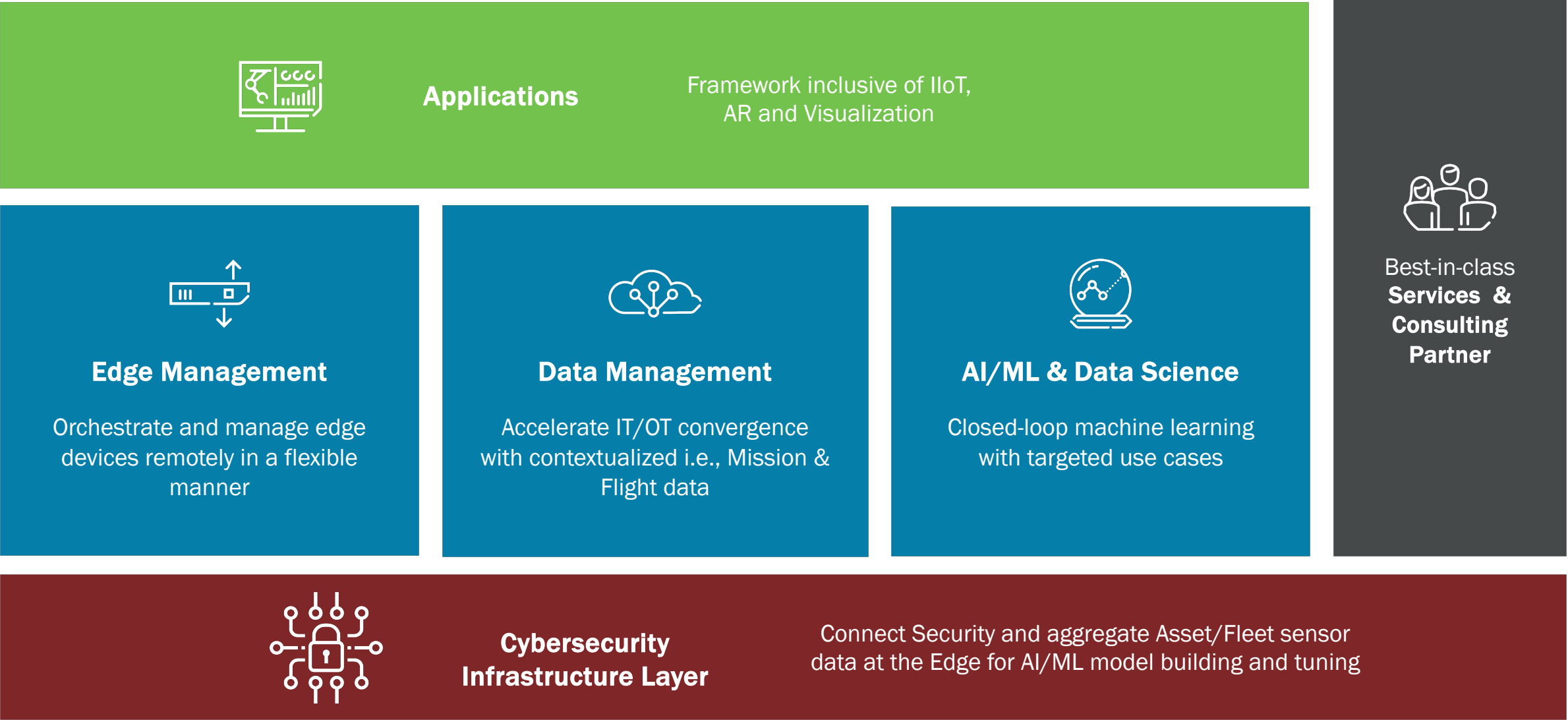
What you will hear today is how Rockwell/Kalypso is evolving CBM+ capability through

1. Leveraging Edge computing paradigm to advance AI/ML processing capability of the solution
2. How to scale CBM+ capability across the enterprise in context with the digital thread
3. Show how we envision the CBM+ enterprise operating model
4. Our Multi-industry and application innovation

Our CBM⁺⁺ Maturity Vision



Foundational Framework for Scaling CBM+



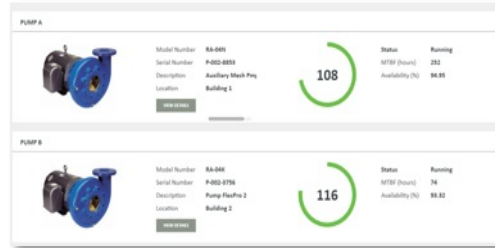
CBM+ Capabilities for the Enterprise

1. Standard Asset Data Models



Templates that standardize what variables are being monitored for a given asset. Enables rapid scaling to additional assets or fleets.

2. Asset Profile Pages



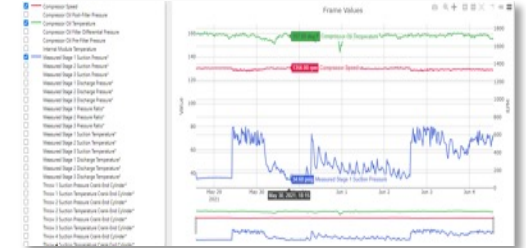
Dashboard that displays real-time status of all assets, including tail number, location, status and availability, etc..

3. Real-time Sensor Streaming and Analytics



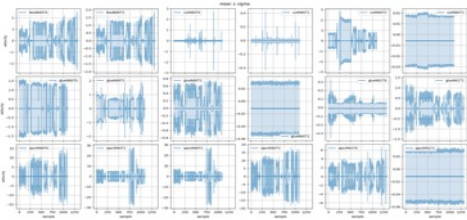
Dashboard that displays real-time sensor data with key metrics and analytics defined by Command Ops.

4. Condition Based Maintenance



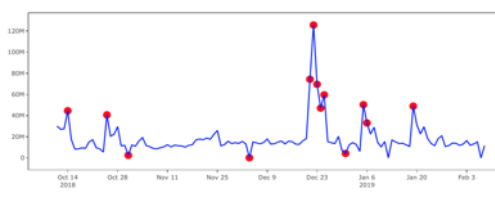
List of rules monitoring a parameter or condition that identifies a significant change indicative of a developing fault

5. Condition Monitoring



Engineering techniques for advance detection of asset faults and failures (e.g., vibration, motor circuit analysis, oil analysis, thermography, ultrasonic).

6. Anomaly Detection



A predictive model that provides early identification of probable faults when there is limited or no historical data. This is the first step in the Predictive Journey.

7. Complex Data Orchestration



Contextualization of maintenance event data, process data, and CAD assets and P&ID documents from disparate sources for full asset lifecycle analysis.

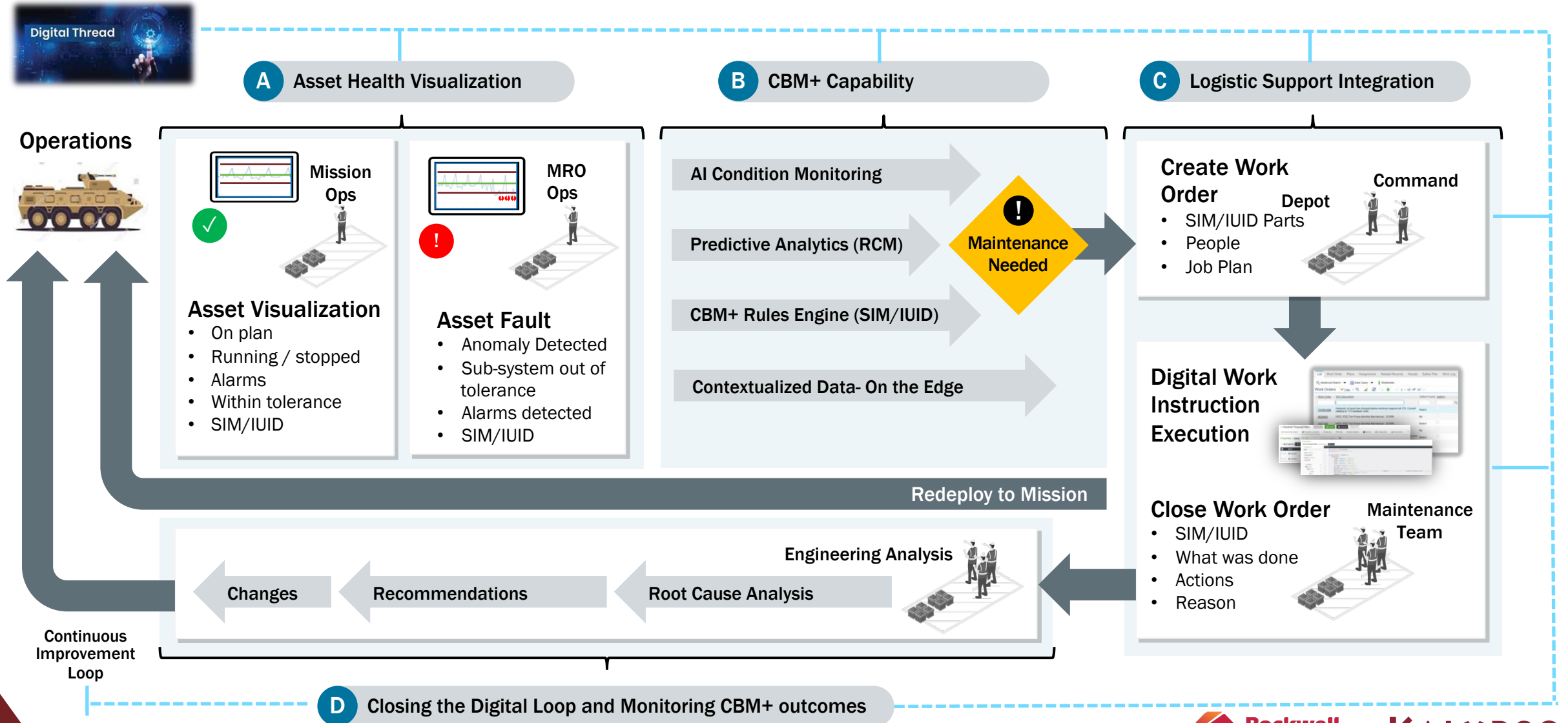
8. Integration to CMMS/EAM for Automated Work Order Creation



API integration with CMMS/EAM to set the foundation for advanced work order automation and streamlining the process.

North Star Objective: CBM+ Data-Driven Maintenance Operations

Enabling the Digital Thread across **Closed-Loop Operating Model** for CBM+ **Maintenance Operations**



AI/ML Innovation for CBM+

Richard Resseguie, *AI Solutions Product Manager*



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Edge vs Cloud Computing

- Edge computing is designed for applications that require **low latency, high bandwidth, and real-time data processing**, such as autonomous vehicles, industrial automation, and Heavy Equipment etc.
- Edge computing focuses on pushing more of a device's **computation to locations closer to its users**.
- By contrast, cloud computing takes processing tasks away from individual devices and distributes them across multiple servers at remote data centers.
- Edge computing is used to **process time-sensitive data**, while cloud computing is used to process data that is not time-driven.





Four Trends Shaping the Future of Cloud, Data Center and Edge Infrastructure

Trend 2:

New Application Architectures Will Demand New Kinds of Infrastructure

I&O teams are continually challenged to meet new and growing demands with new types of infrastructure — including edge infrastructure for data-intensive use cases, serverless edge architectures, and 5G mobile service.

Gartner predicts **15%** of on-premises production workloads will run in containers by 2026, up from less than **5%** in 2022.



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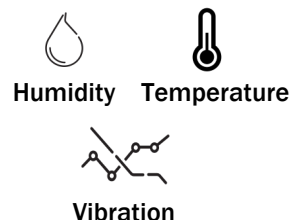
The State of Condition-Based Monitoring

Current state

Maintenance Log Review



Manual Recording of Parameters



Scheduled Maintenance Planning



Challenging to get real-time insight

- High-degree of manual processes
- Low integration with other systems
- Point and siloed applications and data sources
- Static data archives

Future state- NOW

Real Time Sensor Data (High Frequency)



Analyze Data at the Edge



Live Monitoring of Degradation



Leverage Maintenance Expertise



Train Machine Learning Models to Understand Failure Modes

Optimize Maintenance Based on Remaining Useful Life



Real-time insight of asset state

- Data captured and processed at the Edge.
- Optimal for processing and training AI/ML based predictive models
- API Integration and automation opportunities cost-effective.

GuardianAI Application Workflow for CBM+

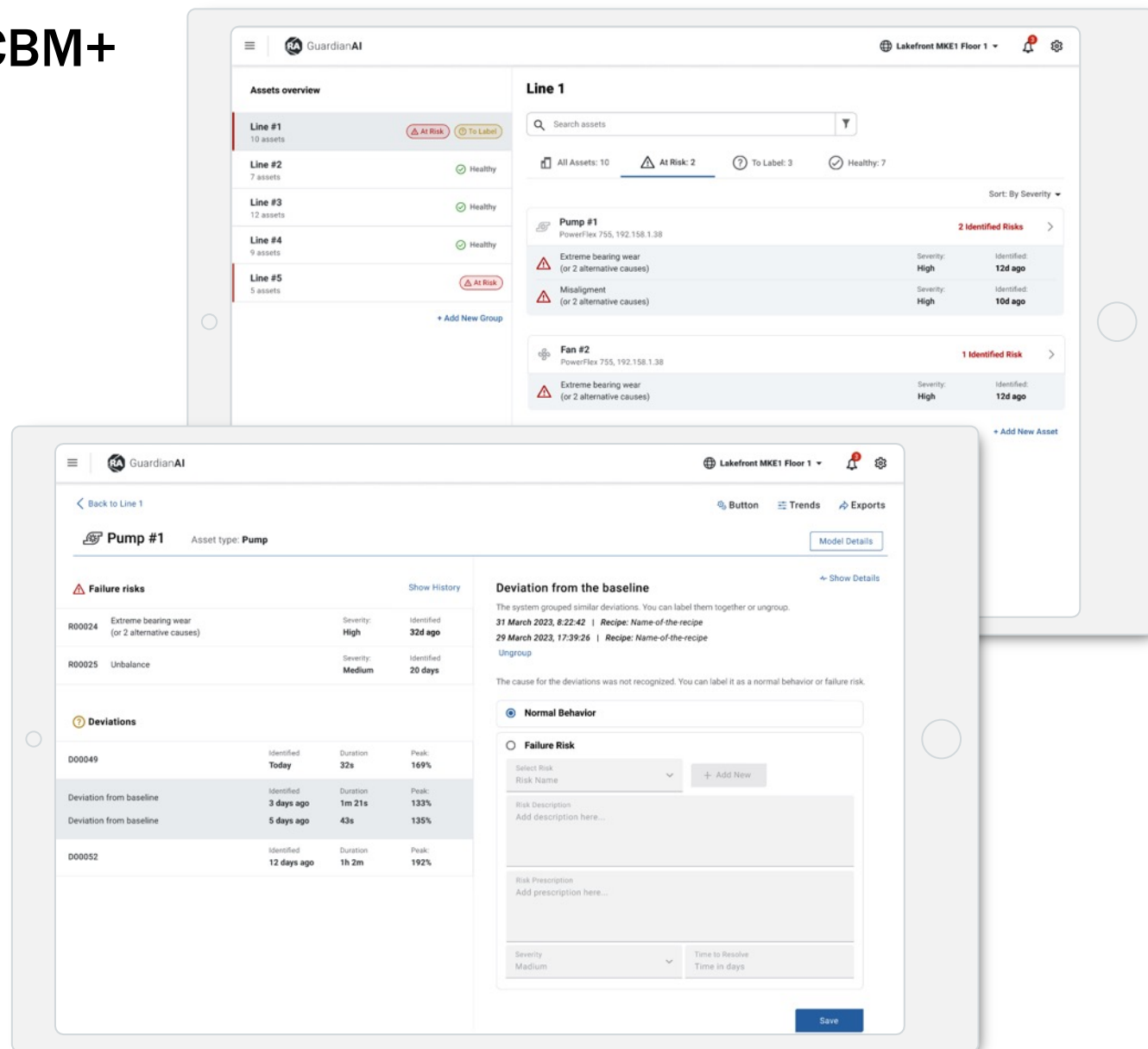


- 1 Establish baseline asset behavior under normal conditions

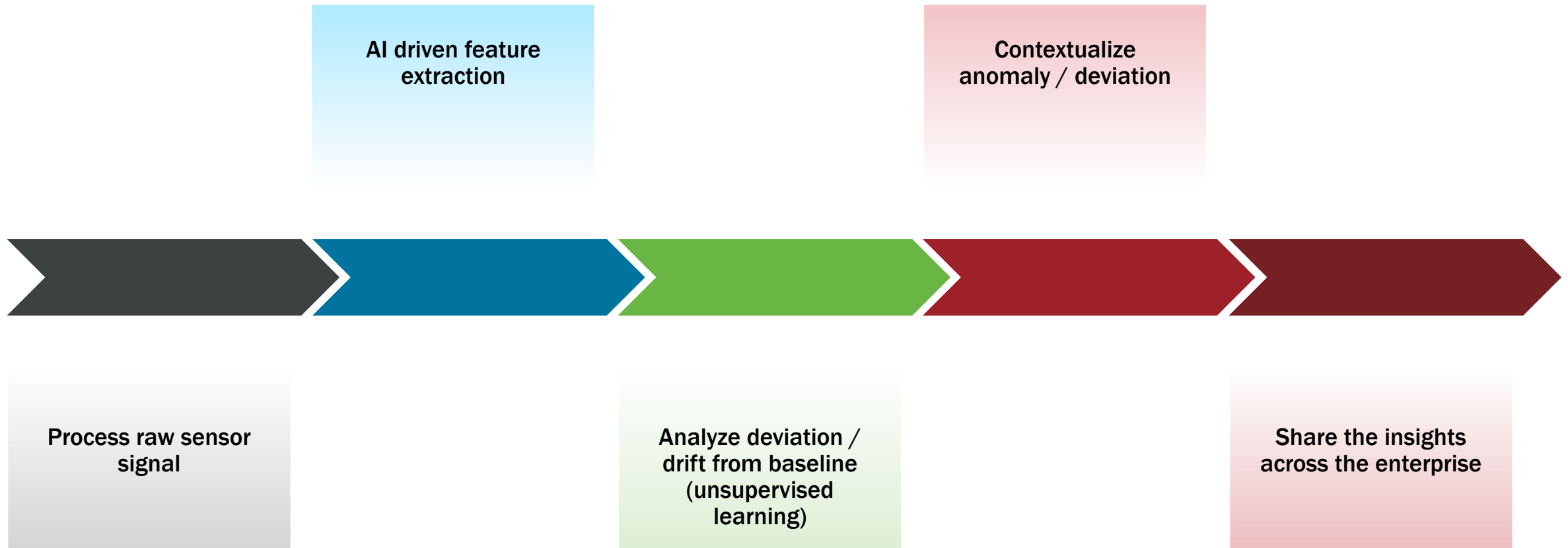
- 2 AI automatically monitors deviation from baseline behavior

- 3 Flag and notify user when an anomaly is detected

- 4 Leverage embedded expertise or label the detected anomaly



AI Driven Methodology for CBM+ High Frequency Data Analysis



Guardian^{AI} for Electrical Signals

Offers AI as electrical expert (First Principles)

Electrical
Signal
Expertise

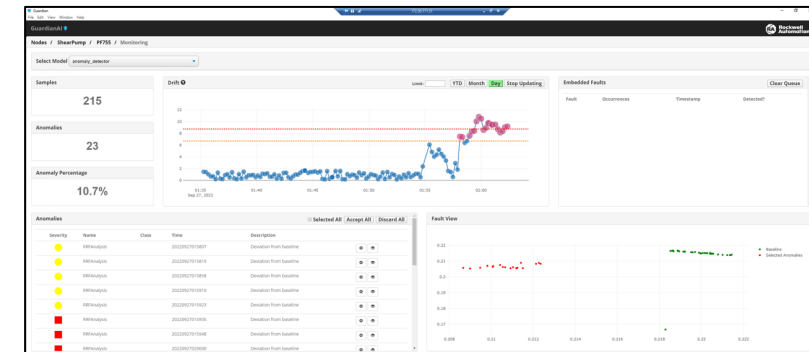


AI Enabled



Scalable
Integration

- ☐ **Analyzes data from motor electrical signal**
 - Data fidelity is enhanced algorithmically
 - Acquires buffered drive signals via trend object (1024 @ 128μs)
 - Time/Frequency domain model for bearings, gearboxes, pumps, conveyors, fans, compressors and more
 - Useful in detecting bearing fault, stator fault, broken-bar, misalignment as well as application related faults
- ☐ **Uses AI to offer additional layer of protection**
 - **Anomaly Detection:** AI engine learns a baseline then detects deviation
 - **Continuous Learning:** AI engine absorbs expert feedback in the form of labels for identified operation states
- ☐ **Integrates with automation & enterprise software**
 - Simplifies scalable deployment
 - Minimizes infrastructure and maintenance costs



GuardianAI for Vibration Signals

Offers AI as Vibration Expert

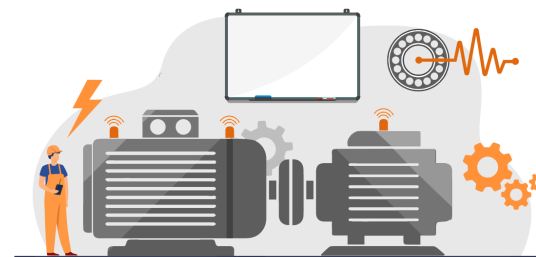
Vibration Expertise

AI Enabled

Scalable Integration

❑ Analyzes vibration data from Dynamix + IoT sensors

- ISO standards or first principal rules coupled with machine learning provides immediate value
- Time/Frequency domain model for bearings, gearboxes, pumps, conveyors, fans, compressors and more

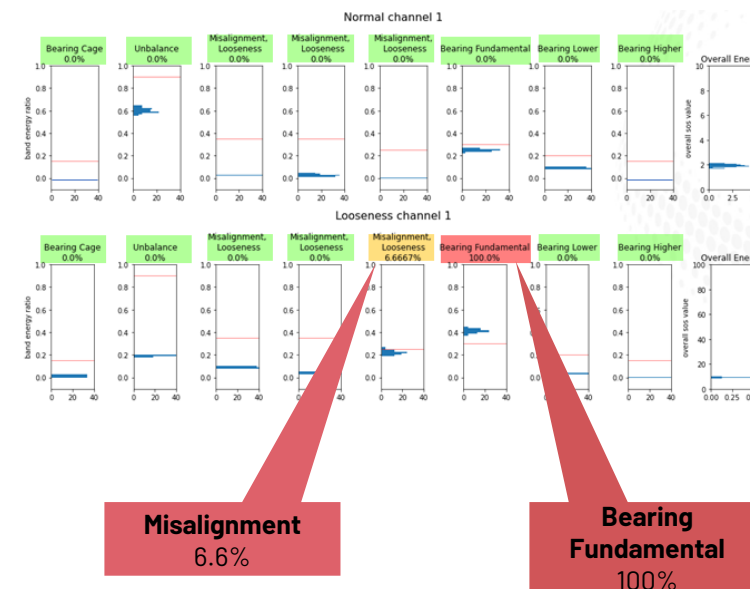


❑ Uses AI to offer additional layer of protection

- **Anomaly Detection:** AI engine learns a baseline then detects deviation
- **Continuous Learning:** AI engine absorbs expert feedback as labels for identified operation states

❑ Integrates with automation & enterprise software

- Simplifies scalable deployment
- Minimizes infrastructure and maintenance costs



GuardianAI for Process Data

Offers AI as process expert

Process
Expertise



AI Enabled



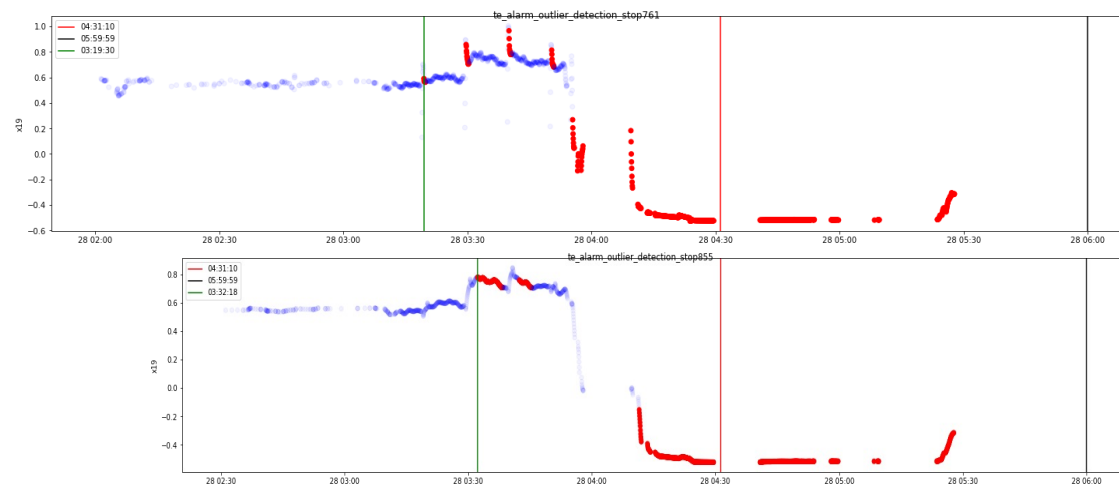
Scalable
Integration

- ❑ **Embedded domain expertise**
 - Process know-how is used to apply the right first-principles
 - Domain expertise labels identified process signatures



- ❑ **AI for multi-variate process analysis**

- Robust nonlinear feature extraction
- Automated anomaly detection
- Assist for root-cause analysis



- ❑ **Integration with automation & enterprise software:**

- Simplifies scalable deployment
- Minimizes infrastructure and maintenance costs

Leverage Natural Language Models to Provide Real Time Insight

- Objective: Deliver insights to an actionable request for the maintenance team about the status of an asset
- Connect the real time insights from the edge
 - Leverage to modify the GPT prompt in real time
- Provide a real time assistant analyzing the response across multiple edge-based analytics apps
 - Are there any issues across my system?

AI: Hey there!

I'm your system assistant and I'm here to help you with your questions.

Ask away!

User: Are there any active alarms in my system?

AI: Hey Jon! I checked your system, and I found an active alarm:

Device Name	Alarm Code	Alarm Description	Alarm Time	Alarm Active
Floor 1 - Pump System Drive	10041	PrechargeOpenAlm	2023-07-25T10:45:33.1384035-04:00	True

This alarm is related to the Precharge Open Alarm. Let me know if you need more information or if you have any other questions!

User: How do I solve that alarm?

AI: The Precharge Open Alarm (Alarm Code 10041) could be caused by one or more of the following reasons:

1. Parameter 00:0037 [Prchrg Control] is set to disabled
2. The input that Parameter 00:0190 [DI Precharge] is set to is disabled
3. The DC bus voltage of the motor side inverter is less than the calculated precharge open voltage

To solve the alarm, you can follow these steps:

1. Make sure Parameter 00:0037 [Prchrg Control] is set to "Enabled".
2. Check and correct the input assigned to Parameter 00:0190 [DI Precharge].
3. Verify the DC bus voltage of the motor side inverter is correct and within the appropriate range.

If the issue persists after following these steps, it could be an indication of a hardware issue, and you may need to inspect components

CBM + Maintenance Lifecycle

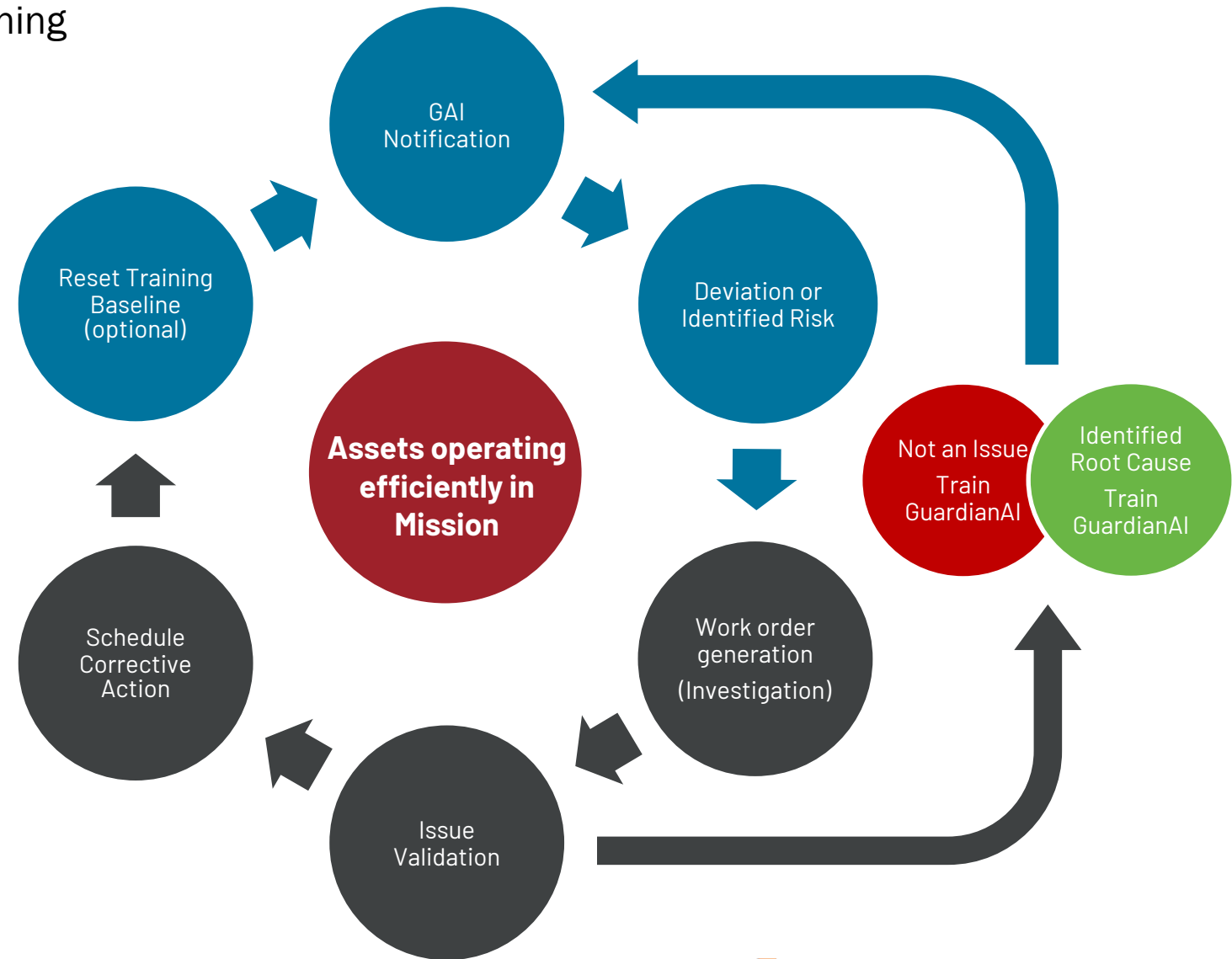
From Anomaly Detection to Maintenance Planning

Leverage CMMS:

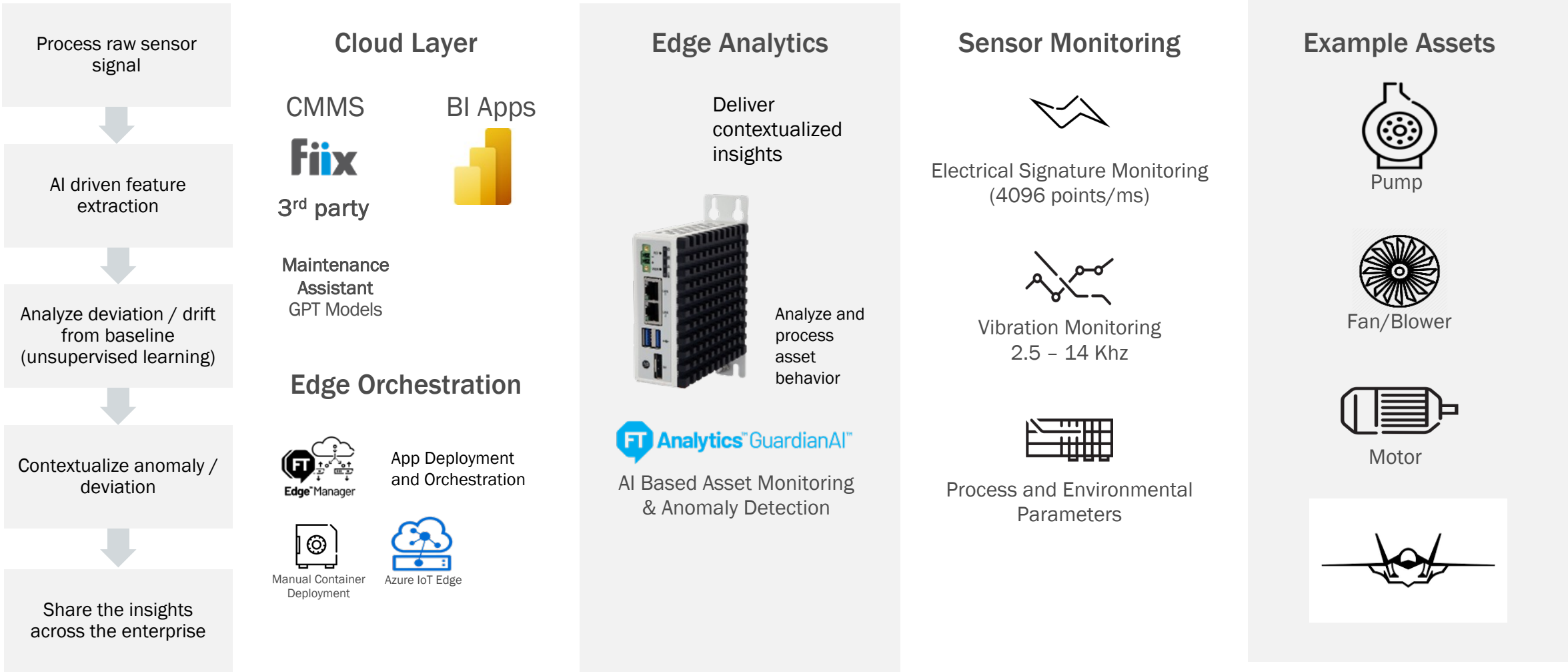
- What is the remaining asset life?
- How should I optimize maintenance planning around scheduled downtime?
- Where do I schedule work orders to deploy maintenance resources?



Maintenance Engineer



GuardianAI Architecture



Use Cases

Glenn Reis, *Federal Aerospace & Defense Lead*

Richard Resseguie, *AI Solutions Product Manager*

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CBM + Maintenance Lifecycle

Heavy Machinery



Objective

Reduce and identify equipment faults in the flask transfer system at a metal foundry. Unplanned downtime was frequent, and faults were often preceded by a very slow drift in mechanical performance over time, making it difficult to detect upcoming failures and plan maintenance.

Approach

Leverage GuardianAI for electrical signals to provide continuous monitoring of the assets. Create a baseline of the process behavior and monitor drift.

When a drift in mechanical performance became critical, an alert was sent to the operator so they could plan when to take the system offline, perform maintenance, and return it to operation.

Results

- Avoided unplanned downtime events through early detection of loose pinions, gearbox failures, and bearing faults
- Optimized maintenance resources by understanding the type of equipment failures in advance and planning for repairs appropriately

Mining



Objective

Mitigate any unplanned downtime in a mining ventilation system critical to worker safety. Ensure the safety and well-being of the miners by circulating fresh air and removing stale air, hazardous gases, and dust from the mine.

Approach

Leverage GuardianAI for electrical signals to provide continuous monitoring of the assets. Create a baseline of the process behavior and monitor drift.

Use the electrical data coming directly from the medium voltage drive powering the fan motor as a data source to identify anomalies.

Alert the maintenance team when anomalies occur so they can perform the required maintenance on the system and correct the issue.

Results

- Prevented unplanned downtime by detecting fan blade alignment issues
- Increased miner safety by predicting equipment failure before they occur

Fiber Pultrusion



Objective

Reduce scrap parts and provide early warning of process anomalies in the pultrusion process to manufacture fiber reinforced plastic

Approach

Leverage a combination GuardianAI for electrical signals and process data to monitor the individual fiber pultrusion to identify early deviations from normal process. The data collection occurred via the controller to capture and correlate process changes along with the drive electrical signal to monitor the behavior of the pultruder motors.

Results

- Reduced scrap parts by predicting four unique faults
- Prevented unplanned downtime

CBM+ Remaining useful life (RUL)

Kalypso used **ThingWorx Analytics** to predict “Remaining Useful Life” (RUL) of key components on E2D platform

Phase 1

- Assess client's data assets for completeness and viability of predicting RUL.
- Used flight mission and historical operations (error code) data to build analytical models.
- 20 predictive models built and run in PTC ThingWorx Analytics.
- To increase accuracy Kalypso built ML models using time series failure data to predict of RUL.
- Results- ML models matured to support accurate RUL component-level prediction.

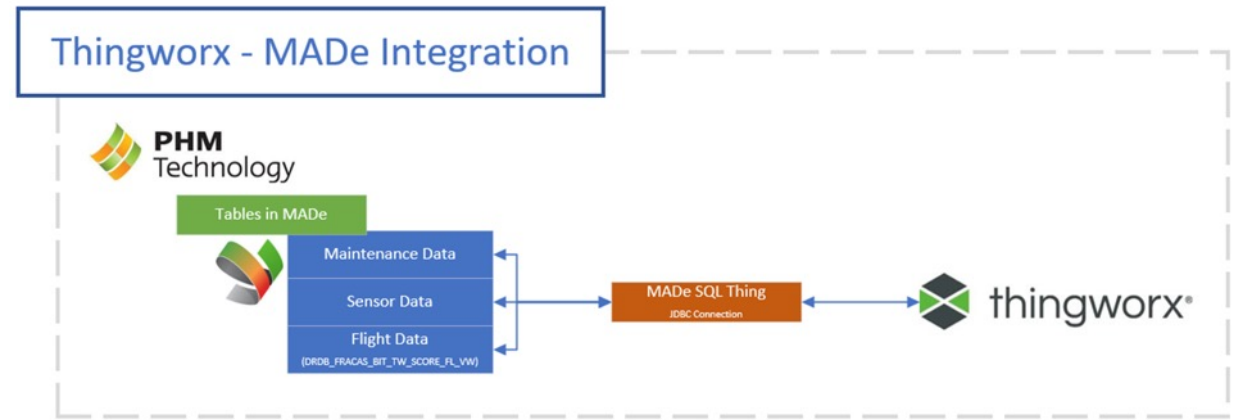
Phase 2- Planned

- Client expanding Kalypso's Data Science expertise and use of **ThingWorx** to drive higher-fidelity and improve accuracy of ML analytic models.
- Kalypso invested weeks upfront in engagement to client to prep, advise and aid in correlating joins pre-project.
- Client now has 12 years of flight and operations data. Kalypso is helping cleanse, map/join 3 data sources i.e., Maintenance, Sensor and Flight.
- Data science RUL capabilities is a candidate for insertion on Sentinel 2 Program.

E2D ISR Platform



U.S. Air Force's LGM-35A Sentinel weapon system



IIOT Enterprise Platform with CBM + capabilities for the Air Force Sustainment Centers

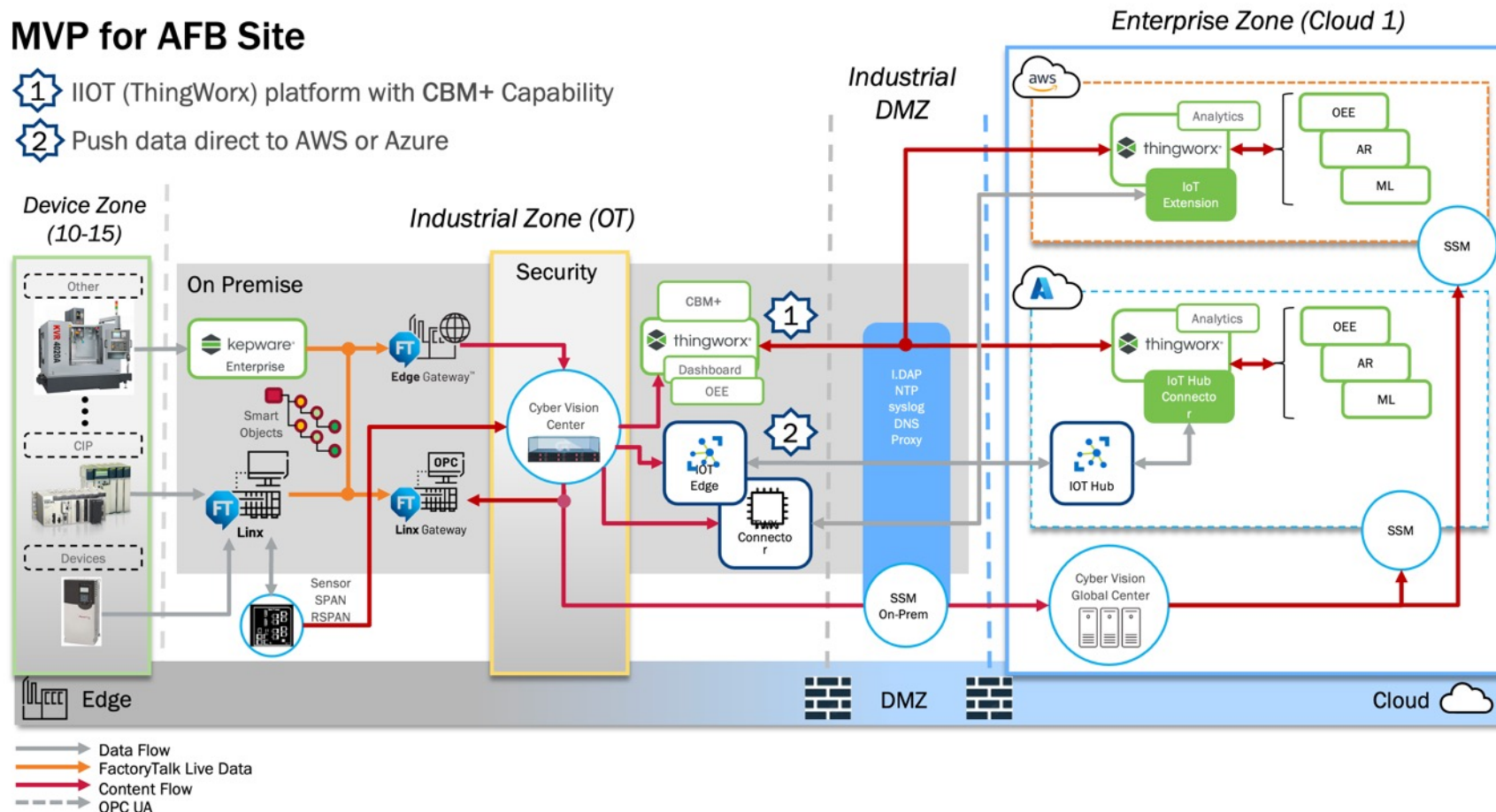


Modernize AFSC MRO Manufacturing Sites with a scalable IT/OT Framework Predictive Maintenance capability

- Scope includes all major Air Force MRO Logistics complexes in the US.
- Deploy a Platform to access all IIoT device data across the AFSC Enterprise monitor & compute TEEP, OEE, OTIF of a variety of equipment, i.e., CNC, vacuums, air handlers, compactors, paint booths, clean rooms
- Digital Infrastructure Backbone must have integrated performance monitoring, robust predictive maintenance and active cyber defense.
- Cloud architecture supporting On-Prem Cloud (AWS "Outpost") and AF One Cloud infrastructure

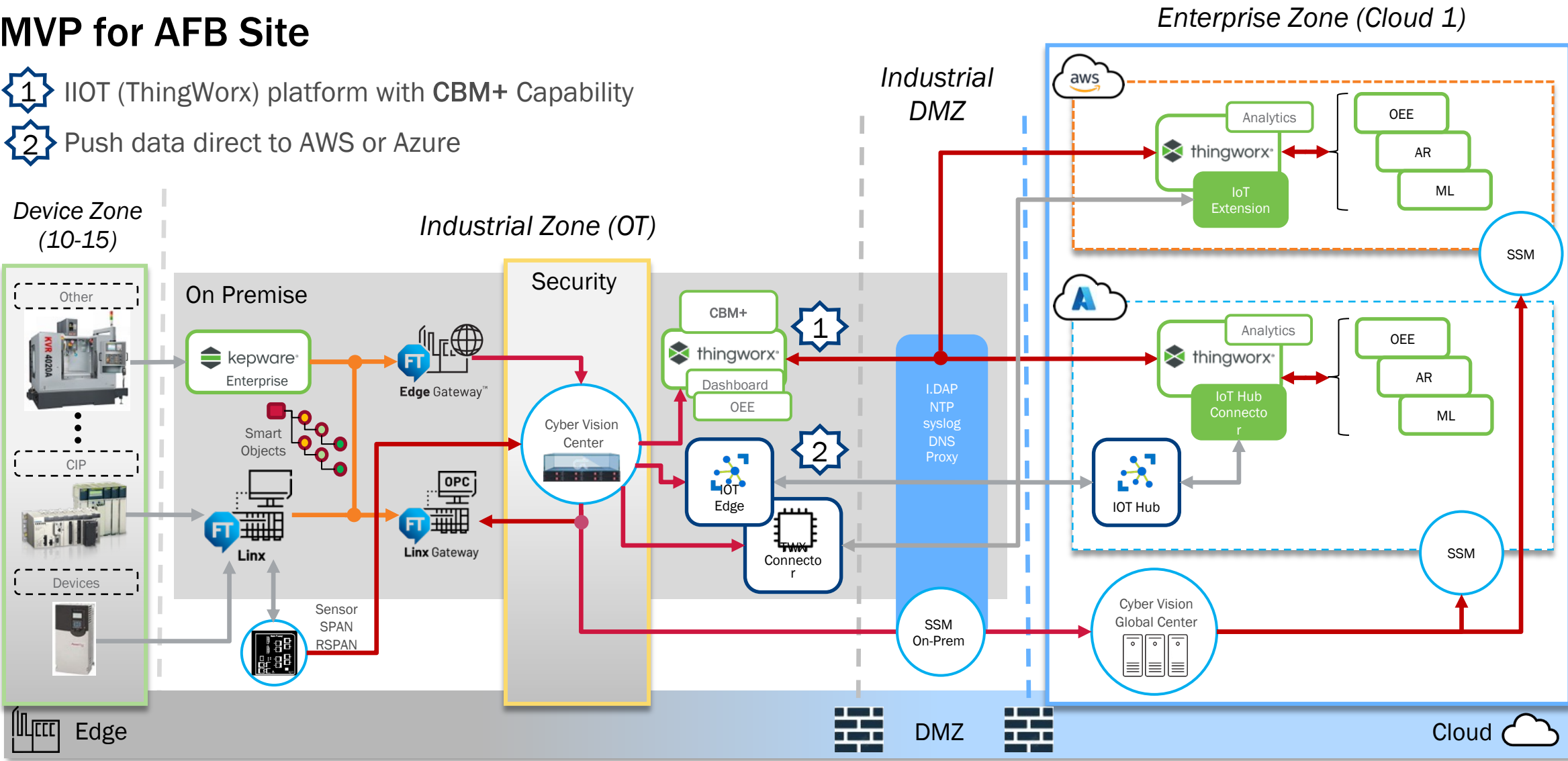
MVP for AFB Site

- 1 IIoT (ThingWorx) platform with CBM+ Capability
- 2 Push data direct to AWS or Azure



MVP for AFB Site

- 1 IIOT (ThingWorx) platform with CBM+ Capability
- 2 Push data direct to AWS or Azure



- Data Flow
- FactoryTalk Live Data
- Content Flow
- - - OPC UA

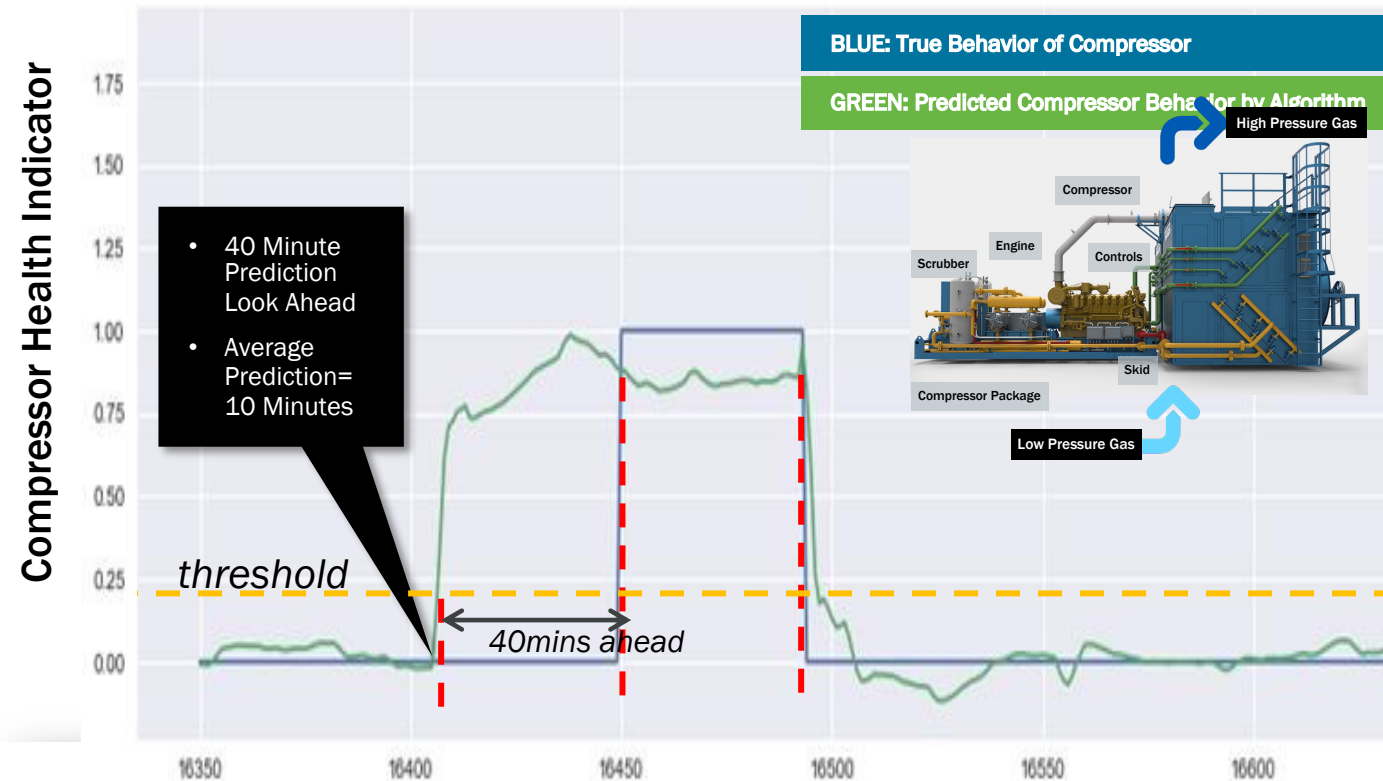
Use Case: Predictive Maintenance

Project Objective:

- Predict if reciprocating compressor will fail approximately 30 minutes before it happens using an Industrial AI model

Solution

- Developed a gradient boosted tree predictive AI model that monitors machine health and predicts failure points
- Model collects equipment, service and real time operational data
- Prescriptive Alerts provide notification and recommendations before failure is realized
- Developed Correlation Heat Map that identifies important variable which help in Predicting Compressor Failures



- ✓ Prediction of compressor failure 40 minutes early
- ✓ Improved OEE and reduced equipment downtime

Session Takeaways



1 Analytical models paired with real-time condition monitoring for predictive maintenance can:

- Reduce the time required to plan maintenance by 20% to 50%
- Increase equipment uptime and availability by 10%-20%
- Reduce maintenance costs by 5-10%

2 Leverages Edge computing to advance AI/ML processing capability of the solution

- Data captured and processed at the Edge.
- Optimal for processing and training AI/ML based predictive models
- API Integration and automation opportunities cost-effective.

3 Scaling CBM+ capability across the enterprise

- Eight requisite Capabilities
- See Chart 10

4 CBM+ enterprise operating model:

- Digital Thread enablement
- Asset Health Visualization
- CBM+ AI/ML Predictive capability
- Logistic Support Integration
- Closing the Digital Loop

5 Multi-industry and application Innovation

- GuardianAI
- Natural Language Processing
- Secure scaled solutions

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**Rockwell
Automation**

Q&A



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**SCAN TO DOWNLOAD
PRESENTATION**

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Better Products with Digital

Bonus Content: AI Innovation- Sensor Fusion

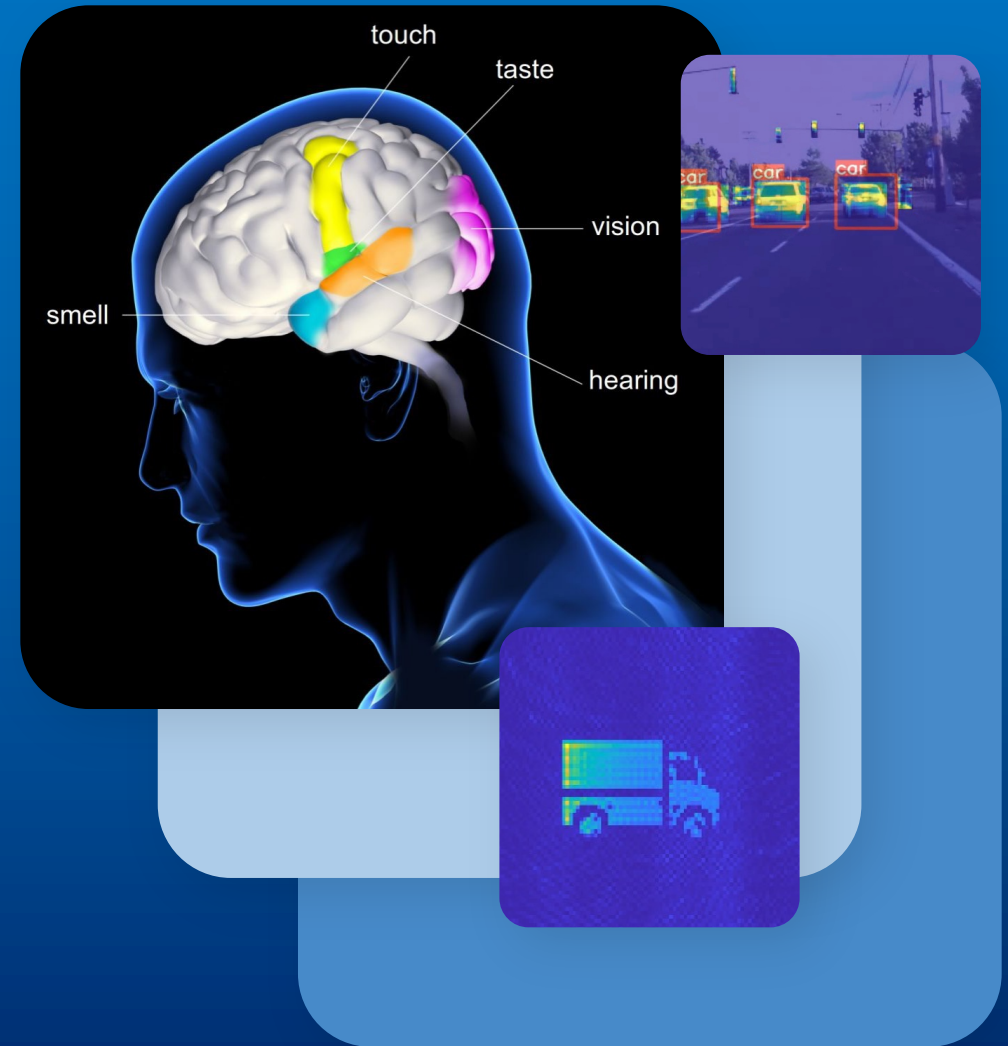
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Intelligent **AI** Driven **CBM+**

<https://bluefusion.tech>

August 2023



What We Do?

We design and integrate **multi-modal sensors** to leverage complementary strengths of each of the modalities

We provide the hardware and firmware for **streaming unaltered raw sensor data** in a time synchronized manner

We provide the **platform expertise** to handle **high speed data** path at the Edge compute engine

We provide the **sensor fusion software stack** to process this unique data set from signal processing to AI/ML on general purpose compute

We provide the **cloud-based data processing**, model training, analytics software and **custom AI/ML models** for multi-spectrum sensing

Our Pedigree

2G – 5G Transition

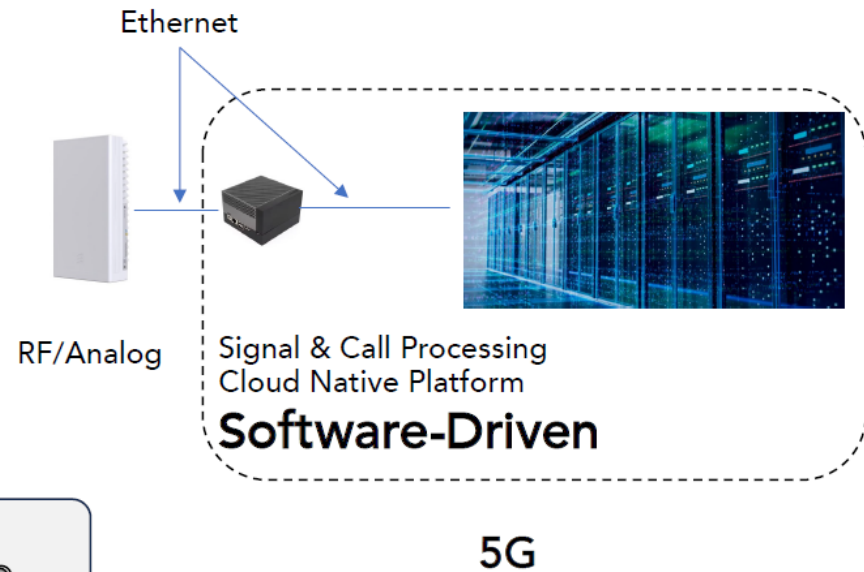


RF/Analog
Signal Processing
Call Processing
T1/E1 input
Coax RF Output
Proprietary Platform

Hardware-Driven

2G

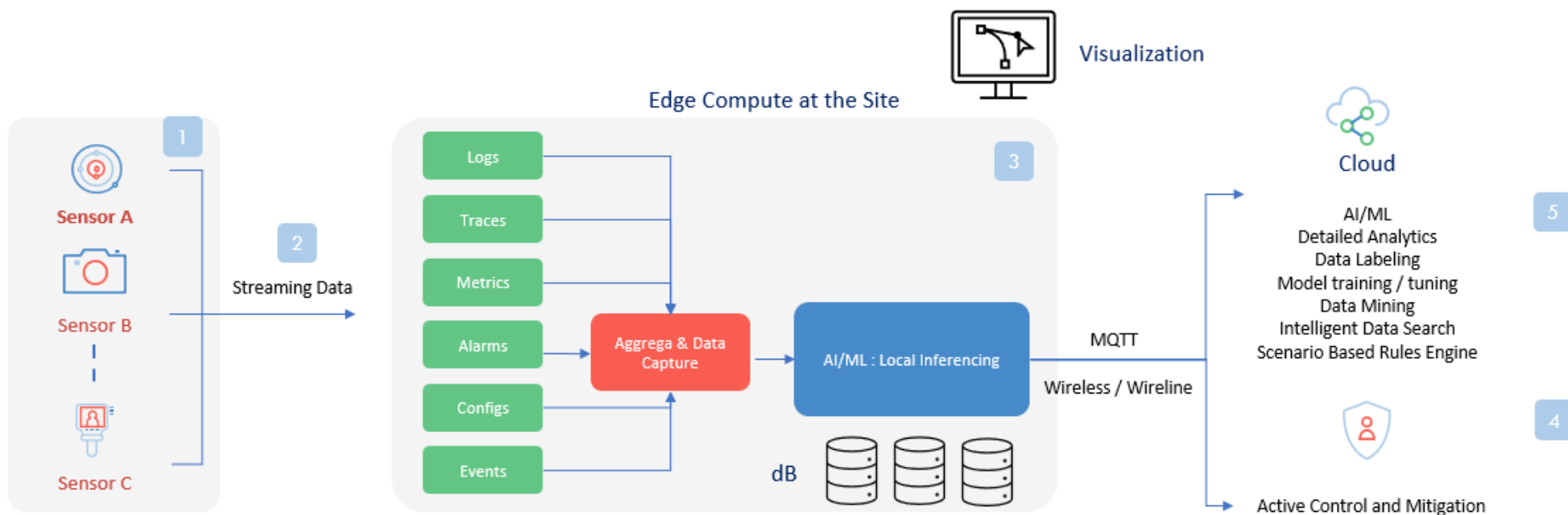
1998 – 2022
2 decades of R&D



5G

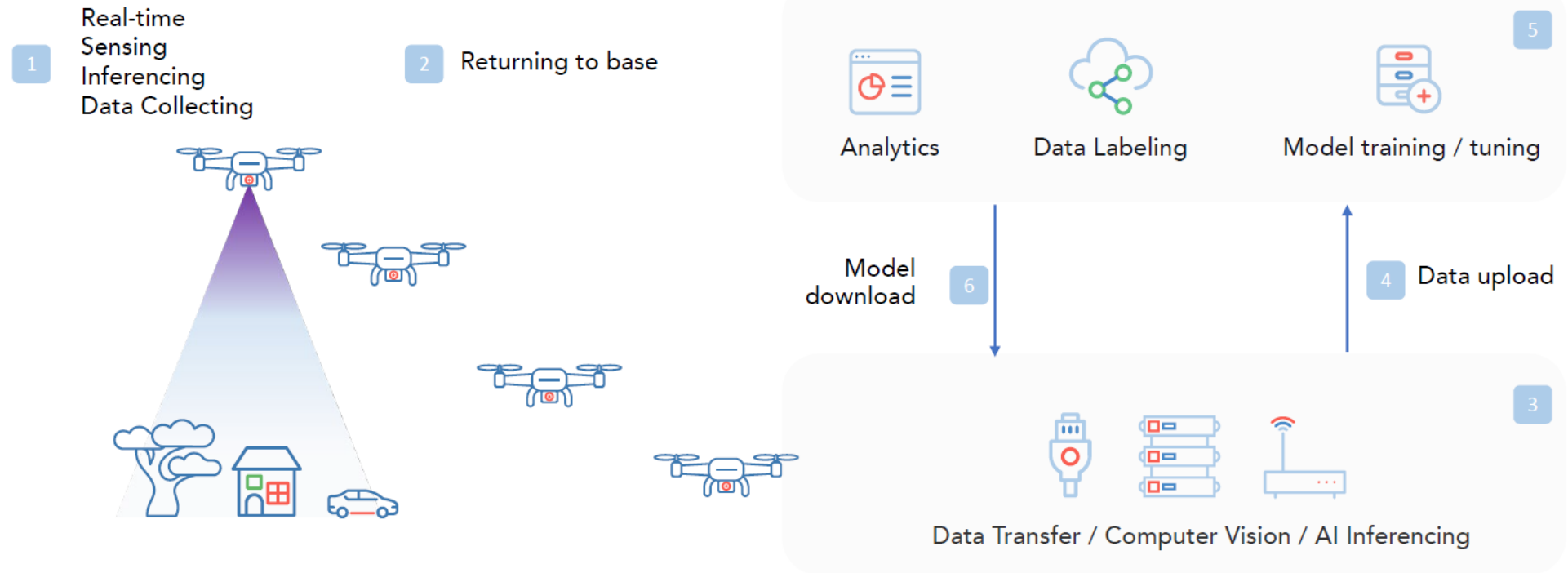
BlueFusion Founder's Pioneered This Transition

AI Driven CBM+



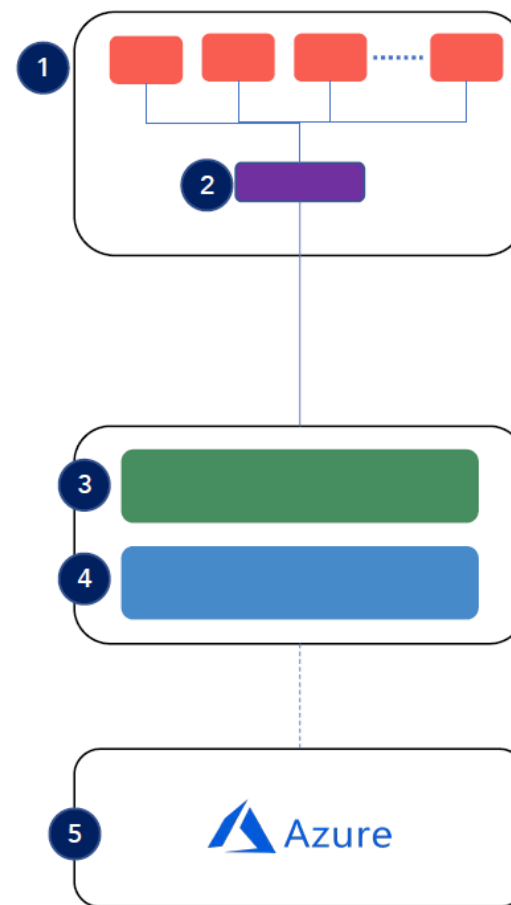
- 1 Sensors either embedded or discrete gather various information
- 2 Sensor data is streamed to the Edge Computer
- 3 Various data elements (e.g., logs, traces, metrics etc.) are aggregated and fed into databases as necessary and AI/ML inference algorithms run on them in real time
- 4 Inferences are fed to higher layer intelligent systems for active control / mitigation
- 5 Data sets are uploaded to cloud for AI/ML model training and long-term prediction and trending analysis

Sensor Fusion and AIOps for Smart UAS



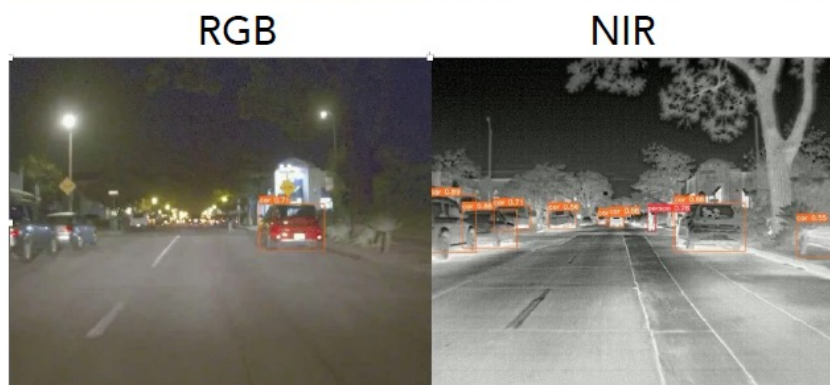
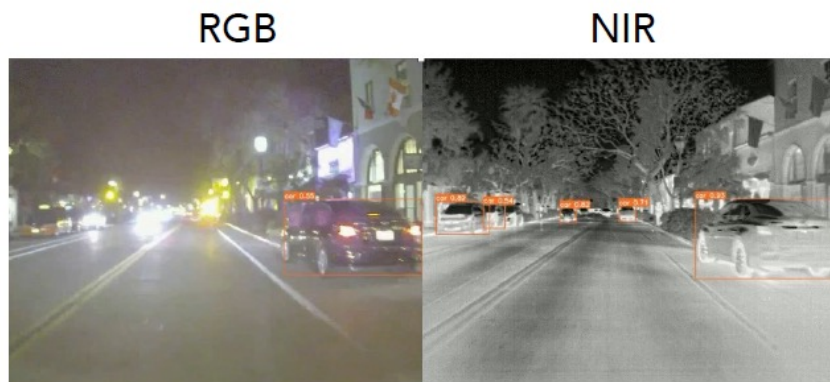
Key Solution Components

- 1 Multi modal sensor:
Imaging radar
Optical Sensors (NIR, RGB, SWIR..)
Synchronized FoV and raw data
- 2 Data capture card with CSI/SPI/I²C cascading, CSI termination, CSI relay, Streaming over Ethernet, GMSL
Data compression / decompression
Single control for multiple modalities
- 3 Signal processing on HPC (GPU), Radar and/or ISP
- 4 AI/ML inferencing for multi-modal dataset
Custom trained inference engine



- 5 Analytics, AI/ML performance tuning
AI/ML Model training

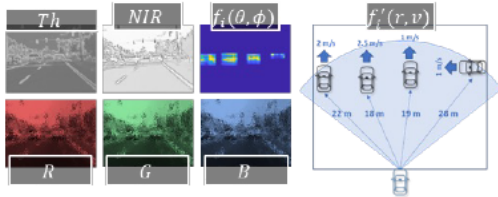
Custom AI/ML Model for NIR Data Processing



Improving AI/ML KPIs in Software

BlueFusion's Sensor Fusion

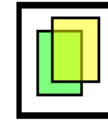
Object Detection



- Access to unaltered raw data available in software stack
- Raw data fusion is done prior to any detection:
 - Increasing mAP
 - Lowering mATE
- Range, Doppler attributes available for every object:
 - Lowering mAVE
 - Lowering mAOE

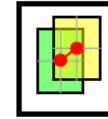
Common Object Detection / Classification KPIs

Mean Average Precision (mAP)



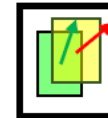
$$f\left(\frac{\text{Area of Intersection}}{\text{Area of Union}}\right)$$

Mean Average Translation Error (mATE)



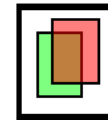
Euclidean centre distance in 2D in meters

Mean Average Velocity Error (mAVE)



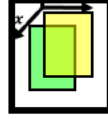
Absolute velocity error in m/s

Mean Average Attribute Error (mAAE) / Classification



1 – ACC (mis-classification) Attribute Classification Accuracy

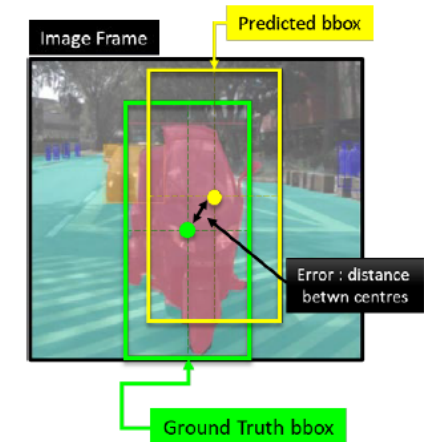
Mean Average Orientation Error (mAOE)



Smallest yaw angle difference between prediction and ground-truth

High/Low Level Fusion

Object Detection



- Chain of cascaded detections along with errors are fused
- Lowering the Precision
- Increasing the Errors
- There is nothing much you can do to fix these!

Benefits of Our Solution



Ability to harness valuable data in cloud, and deploy newer AI/ML models with **AI Ops for Sensor Fusion**



Increased software agility to implement new revenue generating features at a faster pace



Ability to upgrade to latest generation of computing hardware **without total forklift**



Ability to learn and **innovate on AI/ML faster** w/o incurring any hardware limitation



Control and configure all modalities with a single control application



Ability to run latest and greatest signal processing algorithms for **super resolution**



De-coupled sensing and computing for independent evolution of respective hardware



Aggregate and stream raw data captured from all modalities



Enable **UAS mesh** for inferencing and data sharing