David Segal
Sr. Director,
FA&D Industry

ENTERPRISE INTEGRATED HEALTH MANAGEMENT SYSTEMS FOR RELIABLE SUSTAINMENT, MAINTENANCE AND LIFECYCLE MANAGEMENT

22nd Annual Systems and Mission Engineering Conference – October 2019

ptc

- $1.25B global software company, headquartered in Boston, MA
  - Innovation Platform: IOT & AR/VR
  - Digital Twin Solutions: CAD & PLM
- 28,000 active customers
- 6,000 employees
- Strategic technology partner to world-leading manufacturing companies
- NASDAQ:PTC - market cap ~$10B

CONVERGENCE HAS SHAPED OUR **IDENTITY**

ptc

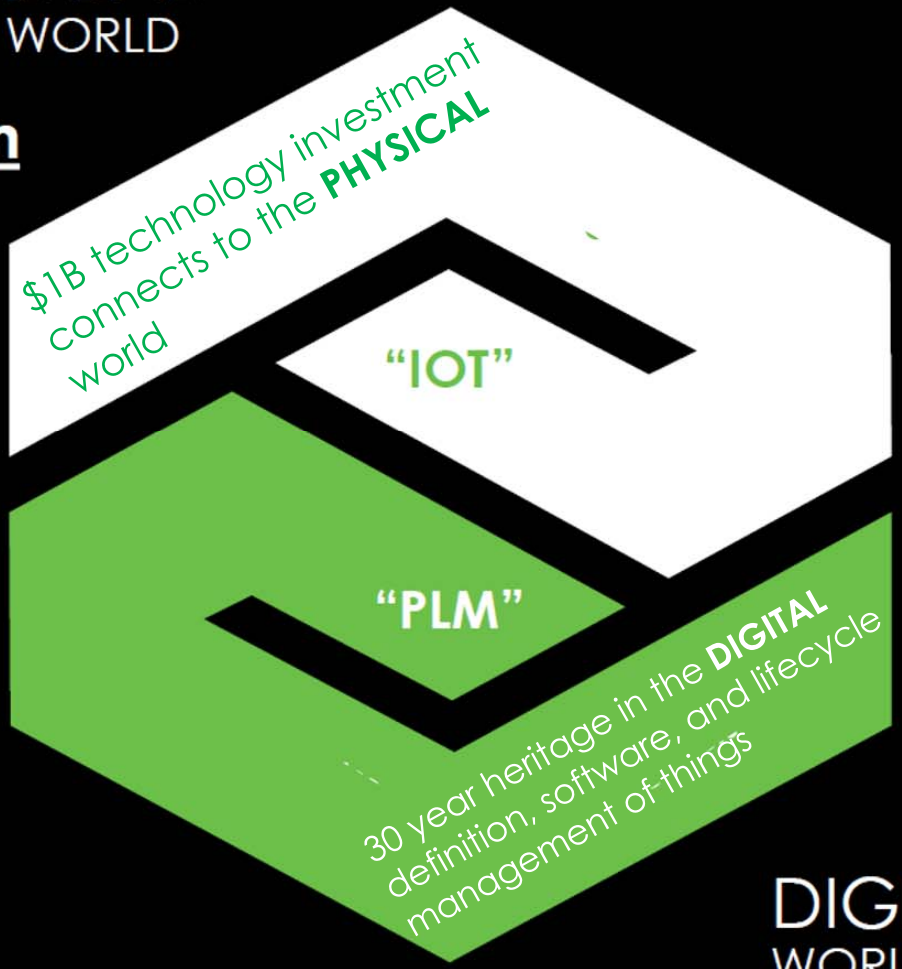
PHYSICAL
WORLD

Innovation Platform

IoT & Analytics | thingworx

AR/VR | vuforia

Industrial Connectivity | kepware



PLM Solutions

CAD | creo

PLM | windchill

ALM | integrity

SLM | servigistics

DIGITAL
WORLD

PTC PRODUCTS ARE WIDELY USED ACROSS FA&D

ptc

ARMY

U.S. ARMY RDECOM

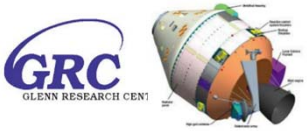
ARL

US Army Corps of Engineers

NAVY

NASA

Langley Research Center



US DoE

Los Alamos NATIONAL LABORATORY EST. 1943

Lawrence Livermore National Laboratory

Sandia National Laboratories

OAK RIDGE National Laboratory

A&D

Raytheon

BOEING

Honeywell

LOCKHEED MARTIN

BAE SYSTEMS

ULA
United Launch Alliance

NORTHROP GRUMMAN

OSHKOSH

GENERAL DYNAMICS

FED

Federal Highway Administration

RELIABLE SUSTAINMENT & LIFECYCLE MANAGEMENT CHALLENGE

DOD GUIDE FOR ACHIEVING RELIABILITY, AVAILABILITY, AND MAINTAINABILITY

AUGUST 3, 2005

DOD RELIABILITY, AVAILABILITY, MAINTAINABILITY, AND COST RATIONALE REPORT MANUAL

JUNE 1, 2009

DOD DIGITAL ENGINEERING STRATEGY

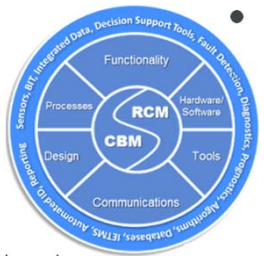
JULY, 2018

- **Operational Availability**
- **Mission Reliability**
- **Logistics Response Time**
- **Total Lifecycle Cost per Unit of Usage**
- **Cost per Unit Usage**
- **Logistics Footprint**

- **Infrastructure – robust, enabling, organized**
- **Data – accessible, real-time, accurate**
- **Extensibility – flexible & adaptive vs rigid**
- **Standards – common reference vs closed**
- **Innovation – systemic vs ad-hoc**
- **Perspective – solution level; process aware**

RELIABLE SUSTAINMENT & LIFECYCLE MANAGEMENT CHALLENGE

- **Performance Based Logistics (PBL)**
  - U.S. DoD Strategy (1998-2014)
  - Implemented in U.S. military and DoD network
  - PBL 3 Levels of Implementation:

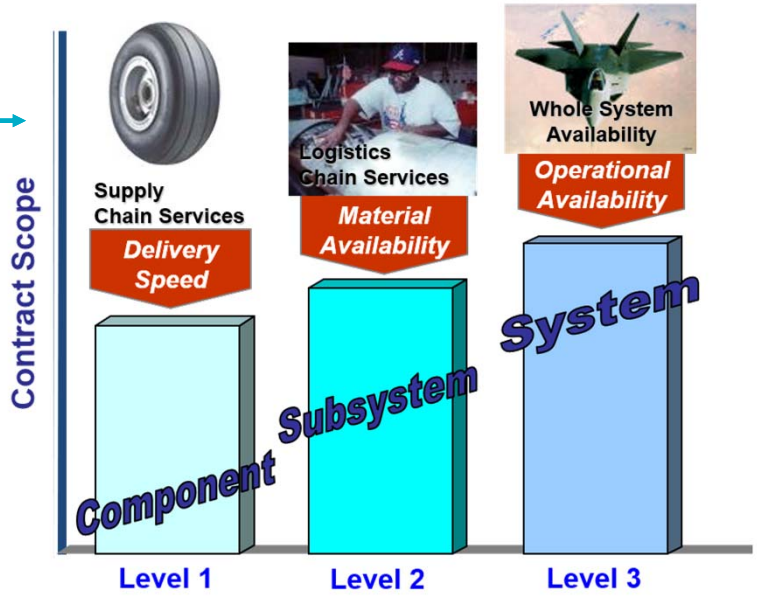


- **Condition-based Maintenance (CBM) Reliability-centered Maintenance (RCM)**
  - L&MR – Supply chain SCOR model
  - Immediate, Deferred, Scheduled, Preventative
  - Data Analytics & Decision Support (CBM+)

- **Enterprise Assets Management (EAM) and Service Parts Management (SPM)**
  - In-Service Parts Management
  - Inventory management, optimization and forecasting

- **Integrated system health management (ISHM/IVHM)**
  - Asset Performance Management (APM)
  - Health and usage monitoring systems (HUMS)

PBL Levels:

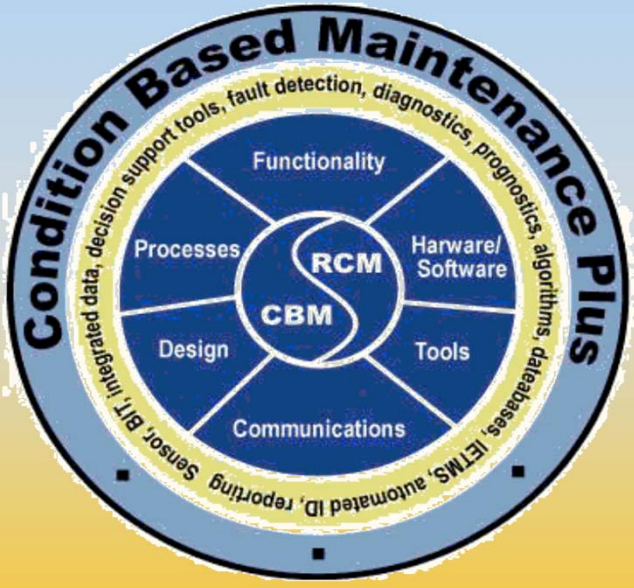


<- Contracts, Procurement, Regulations ->

TIME-BASED OR USAGE-BASED MAINTENANCE CHALLENGE

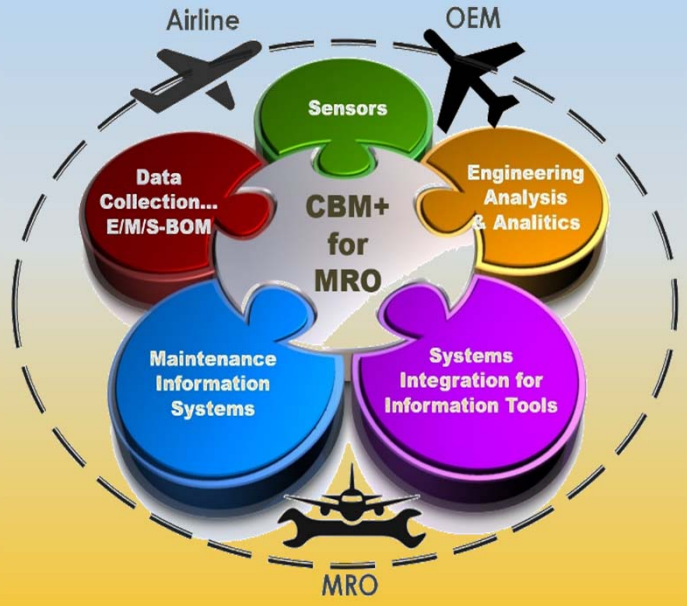
Depot Operations, Overhaul and Manufacturing

CBM+ in the U.S. DoD:



U.S. DoD Strategy (1998-2014)

MRO Network and Supply Chain:



Field Maintenance & Field Service Operations

- **Time Based Maintenance (TBM)** *(Immediate, Deferred, Scheduled, Planned, Periodic)*
- **Time Based Condition Assessment (TBCA) - ISO 13374 – Machine Conditions Assessments**
- **Preventive Maintenance (PM) – part of RCM**
- **Risk Based Maintenance (RBM)**
- **Repair/Corrective Maintenance**

PBL | **Quality** | **Safety**

Availability & Reliability KPIs

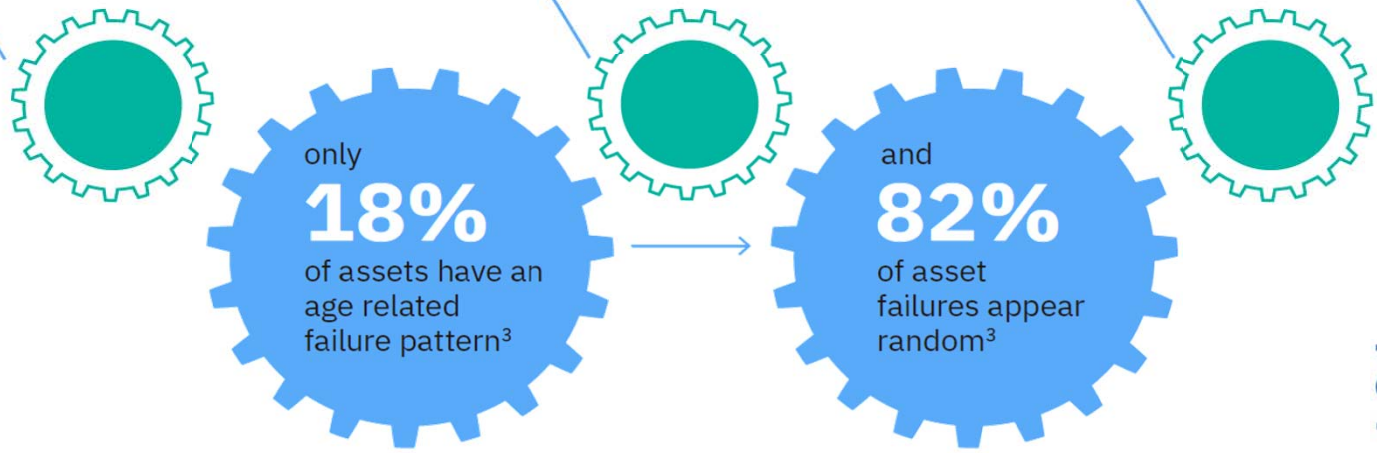
TIME-BASED OR USAGE-BASED MAINTENANCE CHALLENGE

Preventative Maintenance – "THE PROBLEM OF OVER-MAINTANING"

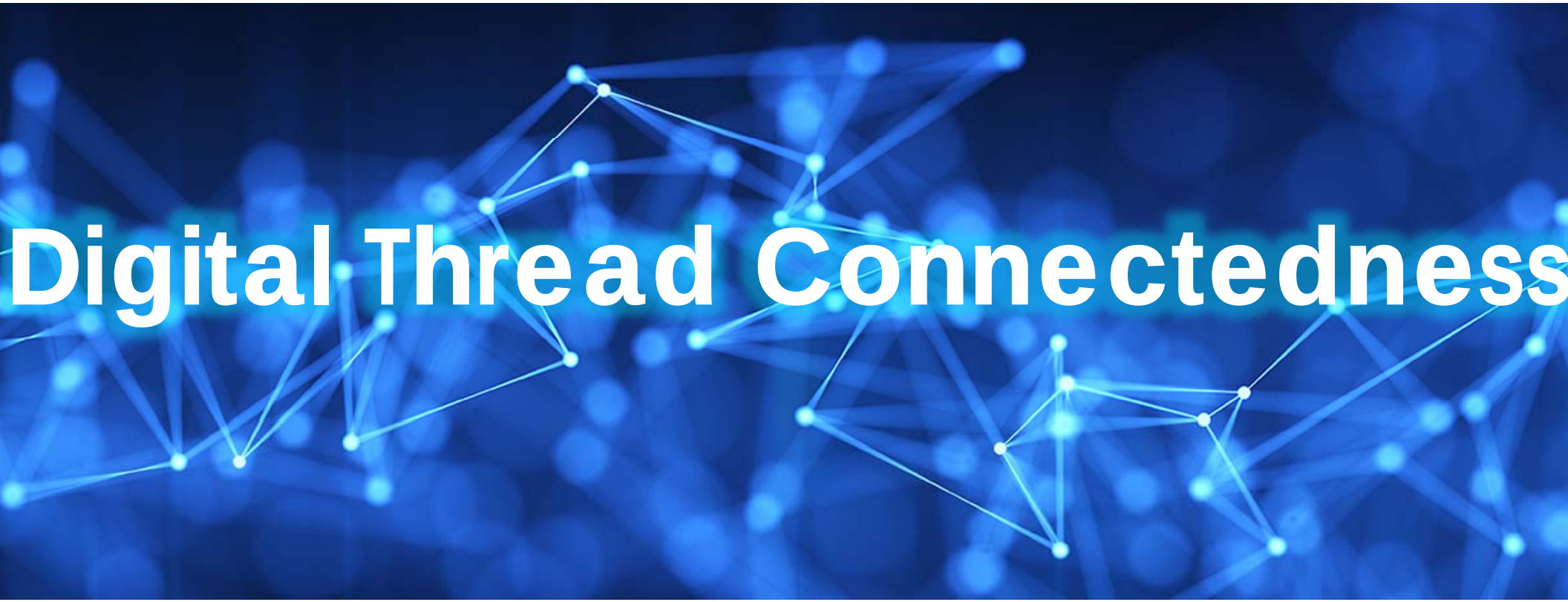
40%
of scheduled maintenance costs are spent on assets with negligible effect on uptime failure[1]

30%
of maintenance activities are carried out too frequently[1]

45%
of all maintenance efforts are ineffective[2]



INNOVATION AND MODERNIZATION APROACH:



IIOT PLATFORM CONNECTEDNESS ENABLES:

THINGWORX CONTROLS ADVISOR | THINGWORX PRODUCTION ADVISOR | THINGWORX ASSET ADVISOR | THINGWORX OPERATOR ADVISOR

Maintenance Production Execution

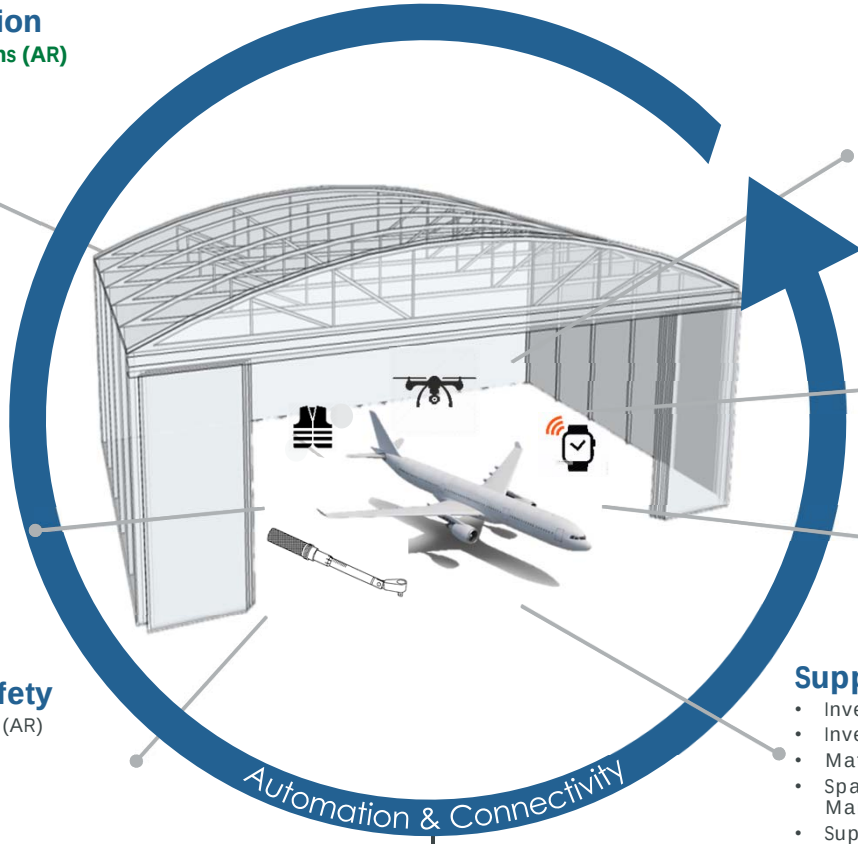
- **Digital assembly & maintenance instructions (AR)**
- **Unified operator screen**
- As maintained Digital Twin
- Labor tracking & shift management
- Digital interactive Illustrated Parts Catalog
- Interactive job Cards with Text to speech (AR)
- Tools tracking and monitoring
- Smart tools
- **Real time production monitoring**
- Augmented workspace management
- Paperless operations
- Remote expert guidance and assistance
- Knowledge management

Maintenance planning and optimization

- Maintenance and service workflow management
- Visualization, Dashboarding and sequencing of maintenance activities
- Maintenance performance KPIs and analysis
- Condition-based maintenance planning
- Service parts utilization planning
- **Asset tracking**
- Digital repair & service instructions (AR)

Environment, Health, & Safety

- Health, safety, & training procedures (AR)
- Automatic inspections (AR)
- Zone inspections (AR)
- **Flexible & adaptable workforce**
- Energy management



Asset health and performance monitoring

- **Real time alert & fault identification**
- **Asset trending & troubleshooting**
- **Monitor operating conditions to alert of anomaly or risk**
- Condition-based, Predictive & prescriptive analytics (multiple assets/fleet)
- Deferred defects tracking and monitoring
- Asset condition dashboard
- Advanced algorithms for failure prediction
- Airframe structural damage detection and analysis

Retrofit – Major/Minor Changes

- BOM transformation
- Digital process planning and workflow
- 3D work instruction Authoring (AR)

Quality & Test

- **Real-time quality KPIs**
- **Zone quality inspections (AR)**
- Robotic inspection monitoring
- Testing monitoring & calibration

Supply chain and Logistics (SPM)

- Inventory management and tracking
- Inventory levels optimization, demand forecasting
- Materials handling, tracking and availability
- Spare Parts Management (SPM), Life Limited Parts Management (LLP), Parts Catalogs
- Supplier management and visibility

Ubiquitous machine & device connectivity | **Sensor & IoT gateway connectivity** | **Secure access to industrial operations data** | **OPC server monitoring** | **M2M advanced tags**

CONDITION-BASED AND **PREDICTIVE** MAINTENANCE

Maintenance performed based on evidence of need (*only when it is needed*)

Real-time operational data for anomalies or undesirable trends integrated with RCM (Preventative) analysis

- Condition Monitoring using sensors
- Assets/Tools Health Monitoring
- Prognostic Fault and Failure Prediction
- Data Analytics and AI for **Prescriptive Maintenance**

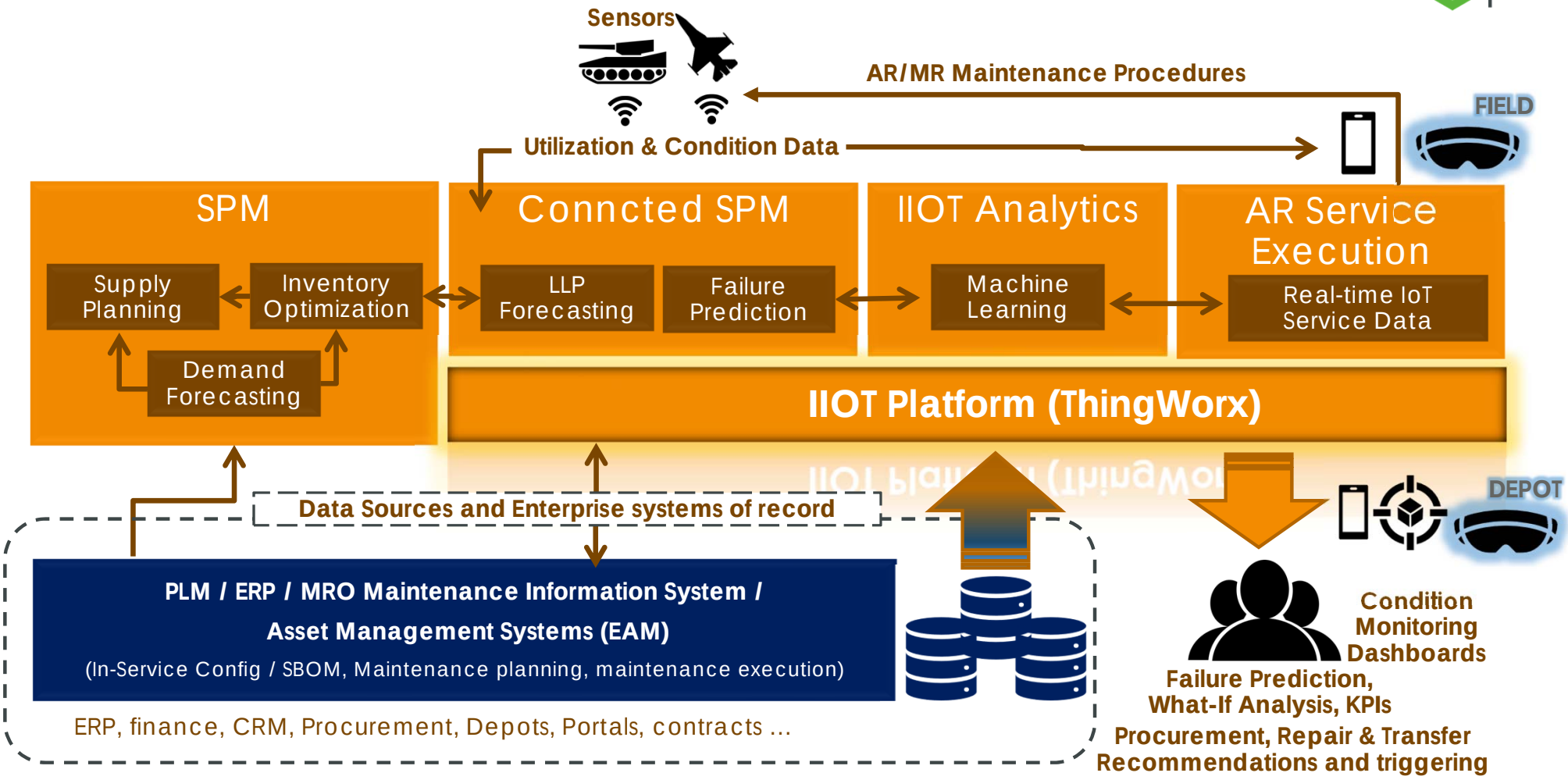
- **Integration of Preventative Maintenance Methods, LM&R and PBL**
- **Integration of Service Parts and Supply Chain Management**

Interoperability between:

- ***MIS – Maintenance Information Systems***
- ***Enterprise Assets Management (EAM) Systems***
- ***Reliability, Quality, FRACAS and Risk Mgt. systems***
- ***Depot, Repair and Stock***
- ***Warehouse, Warranty and Freight Systems***
- ***Procurement, Order, Financial and ERP Systems***
- ***PLM Systems for E-BOM, M-BOM and In-Service BOM management***

CBM+ 4.0

CBM+ 4.0 BUILDING BLOCKS



DIGITAL TRANSFORMATION THROUGH CBM+ 4.0

ptc

ThingWorx IIOT Platform
- *Seamless connectivity between the systems*

Service Parts Management (SPM):
- *Supply-chain planning*
- *Availability based Inventory Optimization*
- *Demand Forecasting*

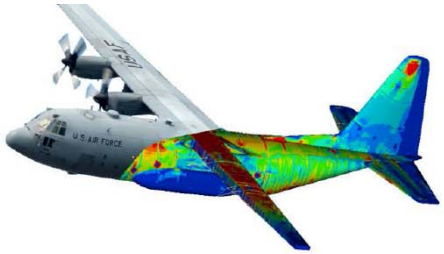
Connected Service Parts Management (C-SPM):
- *Proactive assets and parts utilization planning*
- *Failure prediction*

Vuforia AR
- *Interactive AR based work instructions*

PRODUCTS	PEOPLE	PROCESSES
Prognostic service and maintenance monitoring of assets deployed in the field **Life-limited spare parts management and SPM forecasting** **Inventory and operations optimization based on demand forecasting – connected maintenance** **Asset tracking, trending & troubleshooting**	▪ **Health, safety, & training procedures with Augmented Reality (AR)** ▪ **Interactive 3D Digital repair & service instructions with Augmented Reality (AR)** ▪ **Remote assistance**	▪ **Real time triggering of maintenance events** ▪ **Energy and supply optimization for the shop floor** ▪ **Release to service digital workflow** ▪ **Real time maintenance production monitoring**

Digital Twin for

Systems Engineering



Real-time data and Digital Twin systems engineering approach

ON ASSET MAINTENANCE - INTEGRATION SCENARIO

ThingWorx IIOT Platform
- *Seamless connectivity between the systems*

Service Parts Management (SPM):
- *Supply-chain planning*
- *Availability based Inventory Optimization*
- *Demand Forecasting*

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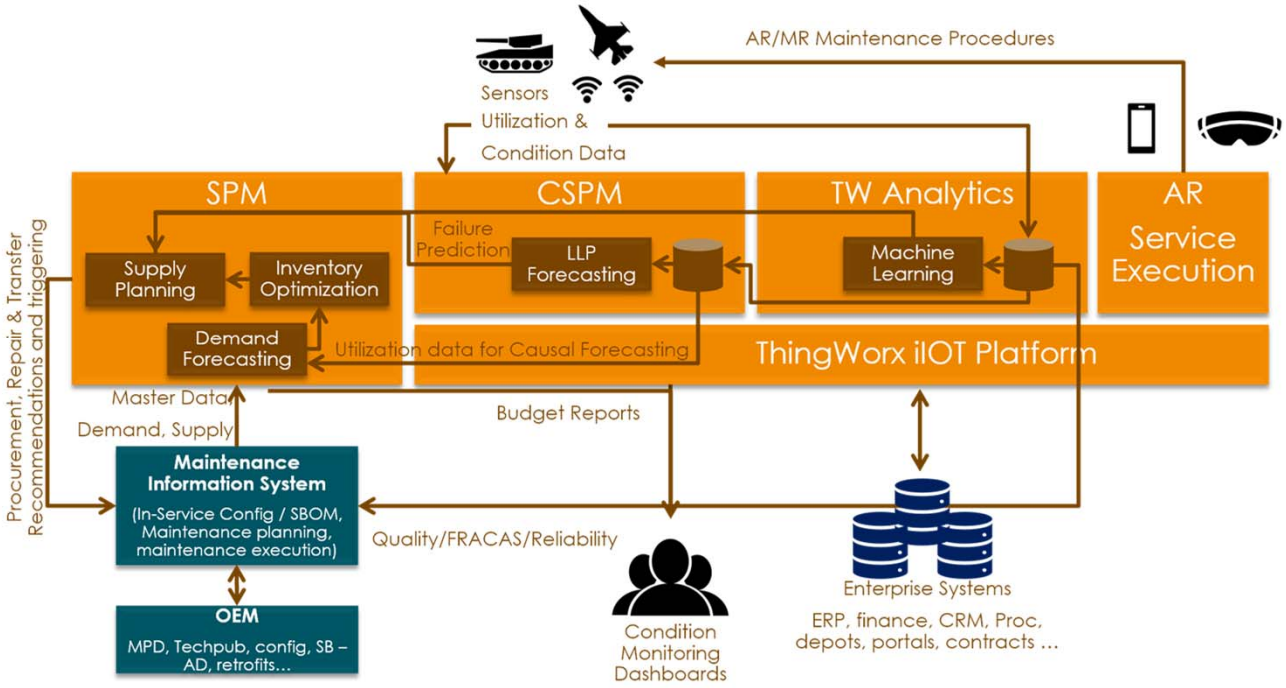
Vuforia AR
- *Interactive AR based work instructions*

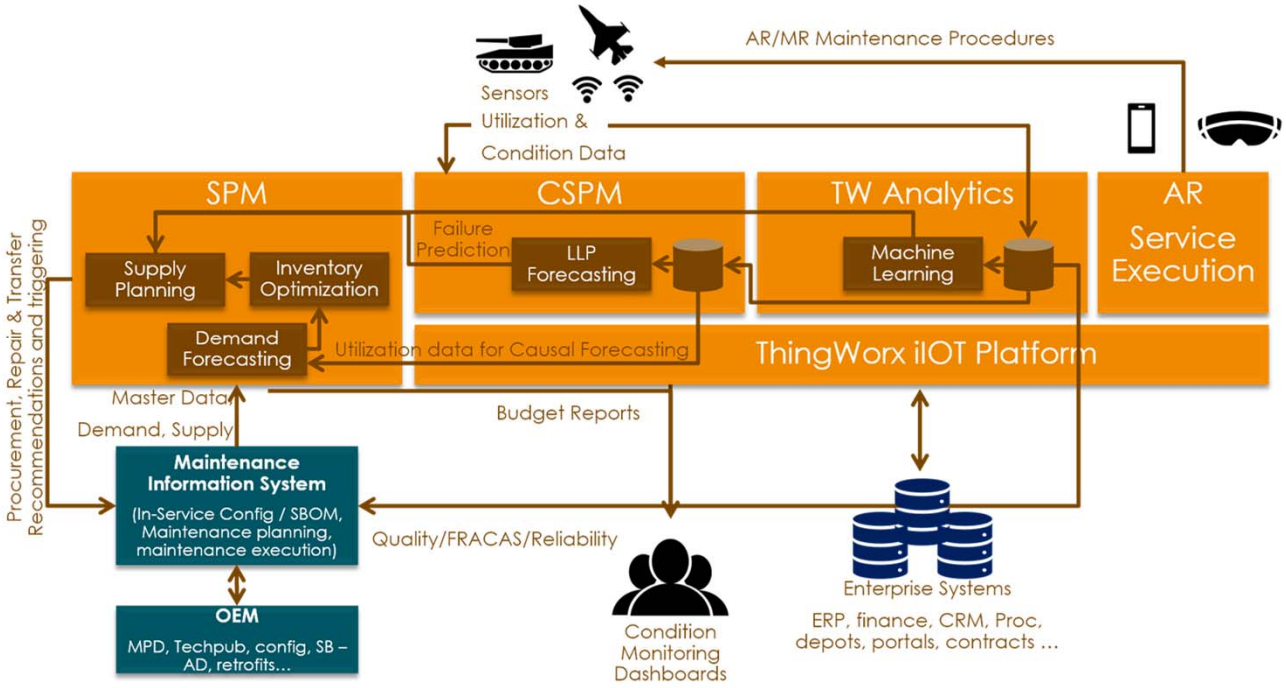
Fully Integrated through connected systems workflow process



- DOD Supply Chain operations reference model (SCOR)

ON ASSET MAINTENANCE - INTEGRATION SCENARIO

Fully Integrated through connected systems workflow process



- DOD Supply Chain operations reference model (SCOR)

CONDITION-BASED MONITORING FOR PREVENTATIVE AND PREDICTIVE MAINTENANCE

41.6%
Lowering costs

38.1%
Improving productivity

28.5%
Improving business process

91%
Accuracy
Predicting alarms 24 hours in advance

35%
Unnecessary Parts Exchanges

10%-20%
Savings from Inventory Optimization

PBL KPIs:

20%
FTFR

I luvw#wlp h#il{#
udwhv

10%
Asset Uptime

V|vwhp v#
R shudwlrqdo#
dydlodelolw|#
+DR,

52%
MTTR

P hdq#Wlp h#wr#
Uhsdlu

P ruh#Hiihfwlyh##
P dlqwhqdqfh#
Wudlqlqj

REMOTE MONITORING BENEFITS…

ptc

…to **ENTERPRISE**

- **Increase company profit**
- **Achieve sustainable competitive advantage**

…to **SERVICE ORGANIZATION**

- **Understand your equipment performance**
- **Improve first-time fix rates**
- **Reduce onsite service visits**
- **Increase service profitability**

…to **CUSTOMER**

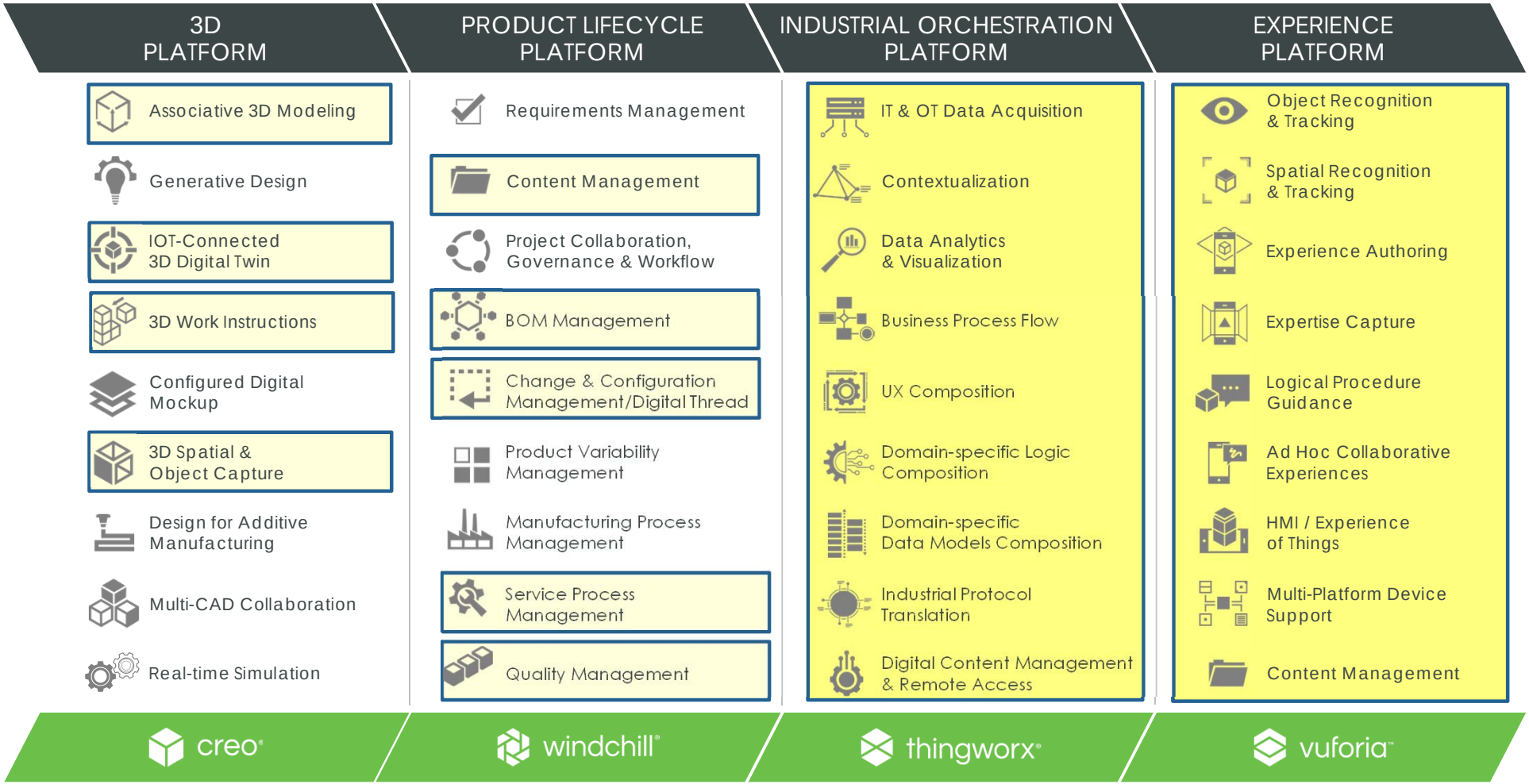
- **Improve product and service outcomes**
- **Increase equipment uptime**
- **Increased customer satisfaction**

20%
Improvement in equipment uptime

15-25%
Reduction in onsite service visits

5-20%
Improvement on first time fix rate

PTC'S SOLUTION FRAMEWORK IN MRO SECTOR



CBM+ CASE STUDIES

THE "END GAME" SCENARIO FOR IOT BASED MAINTENANCE

ptc

Integrating Systems to Life Management Processes

Diagnostics

3) Diagnostics rules and maintenance schedules are used to identify or predict maintenance needs

Supply, Provisioning

4) Required parts are identified or ordered via optimal supply location, owner, utilization, condition.

Alerting

2) ThingWorx application monitors sensor data and confirms that problem or other conditions exist that trigger maintenance

Work-order Automation

5) Work Order generated in the maintenance systems with parts status for technician scheduling

Data Capture

1) Sensor data gathered from connected asset inside depot

Asset Restored

7) Service is performed, restoring asset to proper condition

Technical Data Integration

6) Required technical data and instructions are located and attached to work order

UAV ENGINE HEALTH MONITORING AND ANALYSIS

Assets health monitoring, fault and failure prediction

- Sensor data captured and gathered from equipment on board in various modes:
  - In-flight mission
  - Pre-flight mission readiness tests
  - Take-offs and landings
  - Etc..
- Data log files downloaded in the depot after mission and uploaded into ThingWorx-based CBM system
- Predictive models have been built in ThingWorx, based on analysis of:
  - 500 flight with 18 critical equipment failures

IAI Heron UAV

Objective: failure alerts/alarms 48-24 hours prior actual equiplemt failure

Engine health monitoring

Off | Refresh Now | Export

Administrator

On | Refresh Now

Real EGT1

Predicted EGT1

Real Fuel FLow

Predicted Fuel FLow

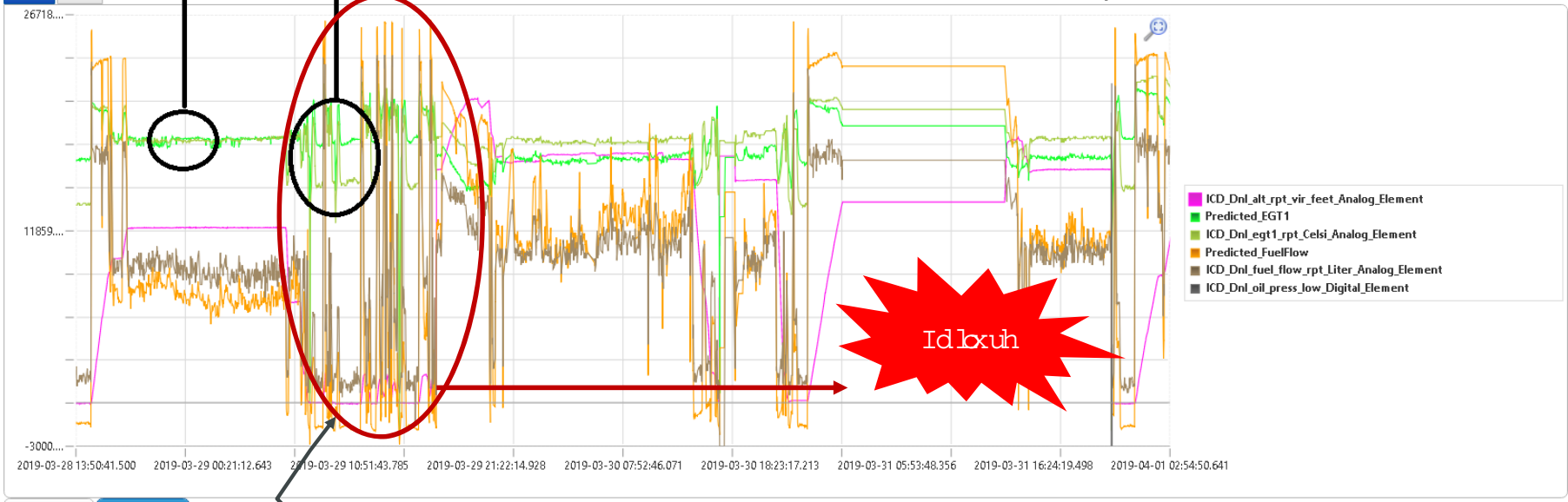
Altitude (ft)

Engine Behaving

Start of anomaly

Boom!

Chart | Data



Idlxuh#suhglfwlrq

Active alarms | Alarm history

1 of 13 Active Filter(s) | Add Filter

sourceProperty *Contains* "oil"

Id	EventName	TimeStamp	AlertType	Source	Name	Location	SourceProperty	Message	Priority
6876	AlertReset	2019-04-02 09:57:10.467	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
6875	Alert	2019-04-02 09:57:00.062	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
6328	AlertReset	2019-04-01 15:52:17.952	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
6327	Alert	2019-04-01 15:52:05.893	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
6009	AlertReset	2019-03-31 22:26:10.568	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
6008	**Alert**	**2019-03-31 22:26:02.081**	**EqualTo**	**Drone001**	**LowOilPressureAlarm**	**0.0000 : 0.0000**	**DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element**	**1**	**1**
5679	AlertReset	2019-03-30 20:46:03.725	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1
5678	Alert	2019-03-30 20:45:56.128	EqualTo	Drone001	LowOilPressureAlarm	0.0000 : 0.0000	DroneFeed_Drone001_Combined_csv_ICD_Dnl_oil_press_low_Digital_Element	1	1

GENERAL ATOMICS AERONAUTICAL

SEEING THE FUTURE WITH CBM+

GENERAL ATOMICS AERONAUTICAL
THE WORLD'S BENCHMARK

OSHKOSH DEFENSE DEMO STORYBOARD – CBM THREAD

Start

FIELD

1 AR-Enabled CBM

OFFICE

2 Connected Fleet Management

3 Generative AI Redesign and Review

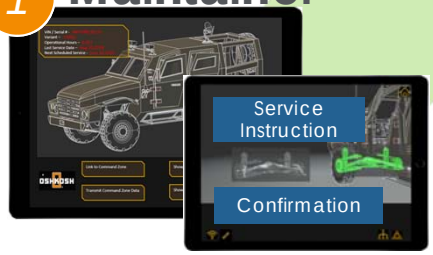
MFG

4 Mfg. Planning & Work Instruction

End

Warfighter/ Maintainer

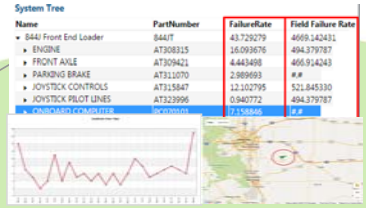
1



AR-Enabled Condition-Based Maintenance

WARFIGHTER - Condition-based maintenance performed by the field operator (warfighter) based on sensor data combining scheduled and planned maintenance with predictive maintenance.

MAINTAINER - Preventative Maintenance procedures in the depot (Wheel End, Brakes, Damage Repair)



2

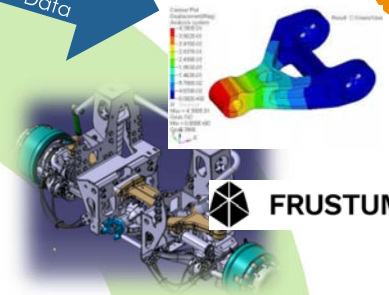
Risk Reliability/Quality Analysis based on maintenance Data

Connected Fleet Management

SERVICE OPERATION MANAGER- Depot-driven maintenance – see the vehicles in the depot. Estimate when all the vehicles will be repaired – Scheduled and planned procedures – order spare parts based on planned & scheduled maintenance (SPM).

QUALITY & RELIABILITY MANAGER - Analyze based on Quality and Risk across fleet ->initiate ECR/ECN initiates generative design

3



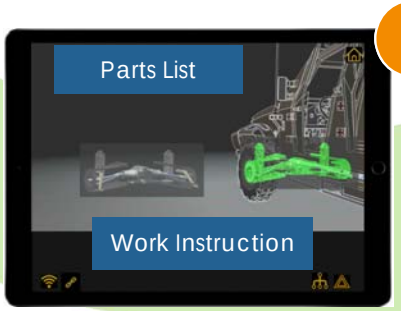
Generative AI Redesign & Review

DESIGN ENGINEER: Digital Twin-driven design investigation and change Change is justified by the risk analysis
ECR is created with justification

AR Design Review

Engineering Manager Visualize new suspension design with analysis results Visualize JLTV Variant designs in AR (other design variants)

4



AR-Enabled Work Instruction

ASSEMBLER– Choose from multiple truck configurations which impact the Roxtec wire config

POST-MISSION INSPECTION EXPERIENCE

1. NOTE AIR RESTRICTION IS GREEN, WARNING ICON IS GONE, MISSION CAPABLE AUTO CHECKED

SMART, CONNECTED, MRO

Lufthansa Technik Group Drives Digital Transformation with PTC Windchill & ThingWorx

Written By: Katie Scherbel

PLM • 8/21/2019 • Read Time : 2 min

Creating and orchestrating a digital thread from internal teams and also externally to partners, suppliers and customers

For Lufthansa Technik, the seamless integration between Windchill® and ThingWorx® will enable new levels of collaboration both internally and among many suppliers.

Windchill will serve as the engineering backbone to enable R&D and manufacturing to work concurrently. The secure data repository will also help the company protect its Intellectual Property across its global supply chain while generating greater revenue streams through new and innovative digital business models.

DRIVING DIGITAL TRANSFORMATION ON THE SHOP FLOOR

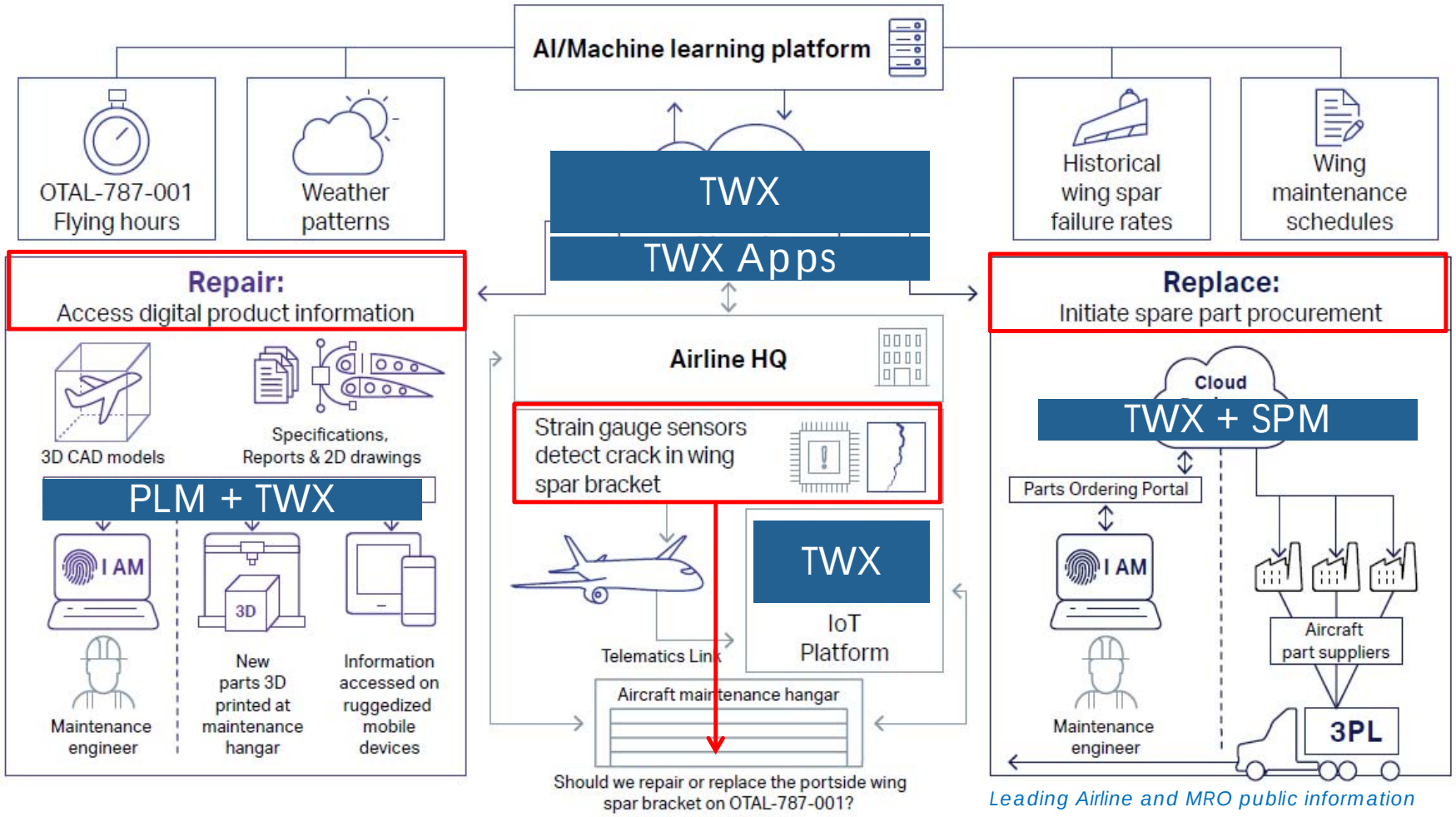
A THINGWORX & KEPWARE CASE STUDY FOR CBM+

ptc

Created a fully connected shop floor for real-time asset health monitoring and predictive maintenance to improve quality and speed of maintenance, repair, and overhaul services

Lufthansa Technik

PTC THINGWORX FOR IIOT ORCHESTRATION PLATFORM (AIRLINE)

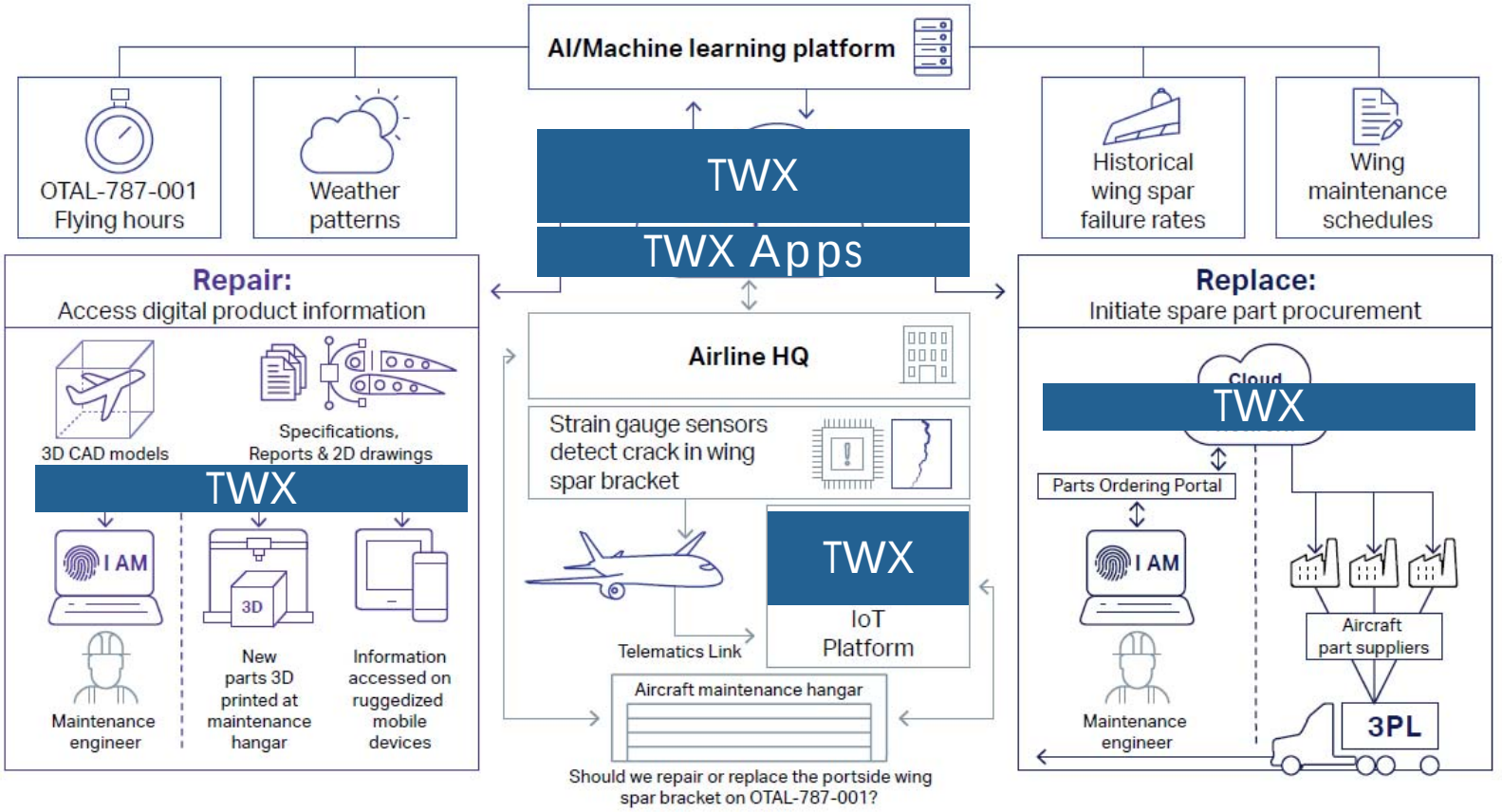


Leading Airline and MRO public information

PTC THINGWORX FOR IIOT ORCHESTRATION PLATFORM (AIRLINE)

Interoperability between:

- *MIS – Maintenance Information System*
- *Reliability, Quality, FRACAS and Risk Mgt systems*
- *Depot, Repair and Stock*
- *Warehouse, Warranty and Freight Systems*
- *Procurement, Order, Financial and ERP Systems*
- *PLM Systems for E-BOM, M-BOM and In-Service BOM management*



June 7, 2019 - Lufthansa Technik Group Embarks on Digital Transformation Journey with PTC Windchill and ThingWorx
https://www.ptc.com/en/news/2019/lufthansa-technik-selects-ptc-windchill-thingworx

Thank You!

ptc

David Segal
Sr. Director, Business Transformation, FA&D Industry
dsegal@ptc.com

THINGWORX ANALYTICS

Interactive Predictive Analytics Dashboards