OVERVIEW OF DIGITAL ASSET MANAGEMENT FOR INDUSTRIAL GAS TURBINE APPLICATIONS

Solar® DIGITAL

The Future of Gas Turbine Technology
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Condition Based Engineering

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- Legal Disclaimer:

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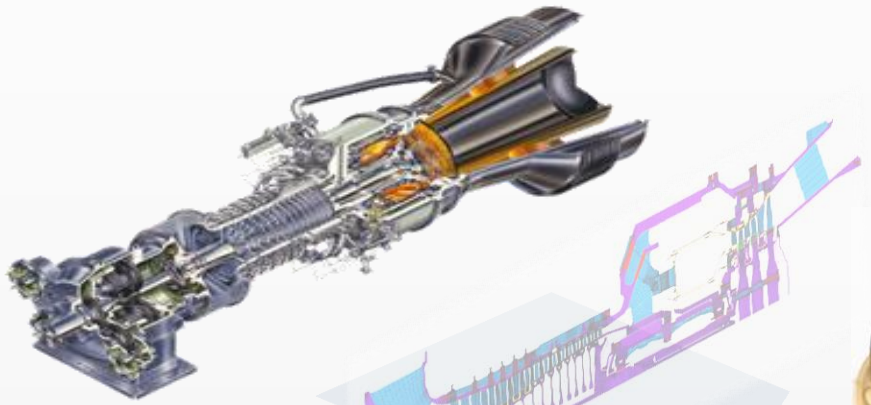
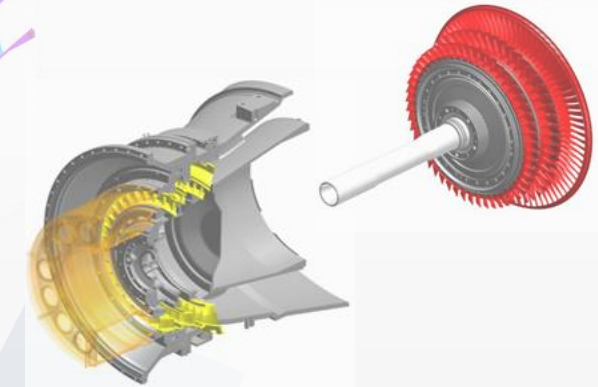
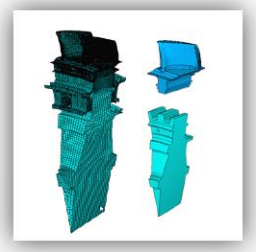
Overview

Digital Asset

Definition

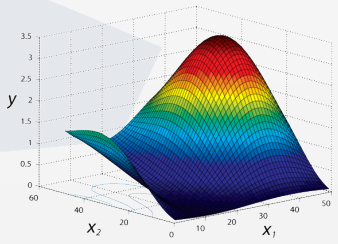


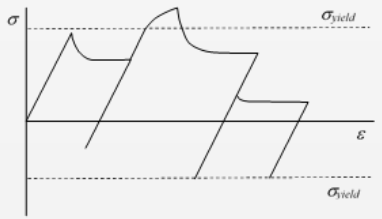




- Collection of data driven, physics based & hybrid models which replicates the key aspects of the engine

- Models which utilize operational data to predict the actual condition of the engine





- Enhancing Equipment Health Management (EHM)

- To optimize the equipment and maximize value for the customer

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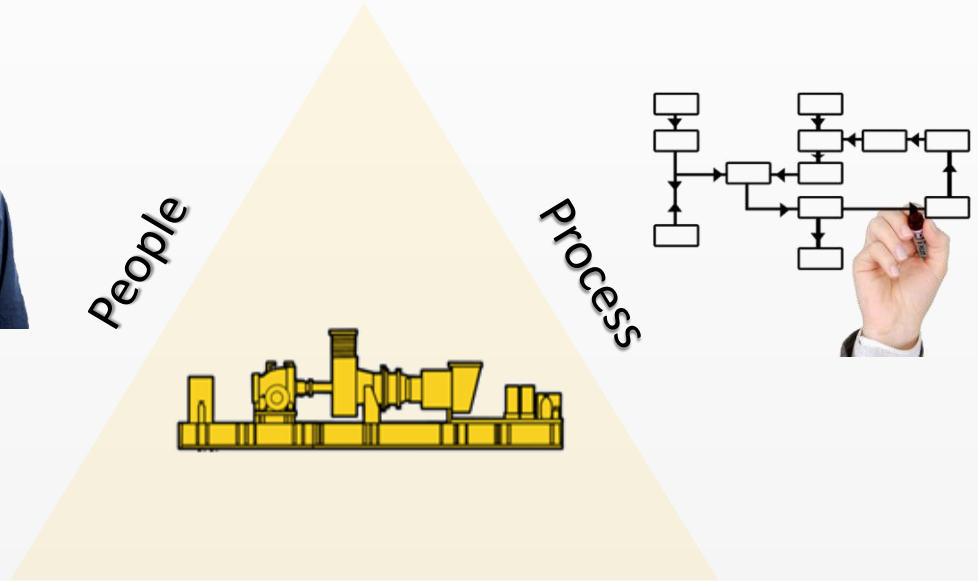
Digital Asset

Enabling Framework

- A managed care philosophy for turbomachinery maintenance, operation and optimization which is based on three fundamental elements:



Digital Asset

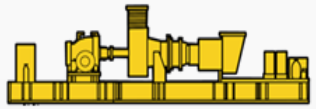
Benefits

Operational data is used:

- To predict the actual condition of the engine, (in place of assumption)
- To forecast a continuous and accurate risk profile for optimal asset management

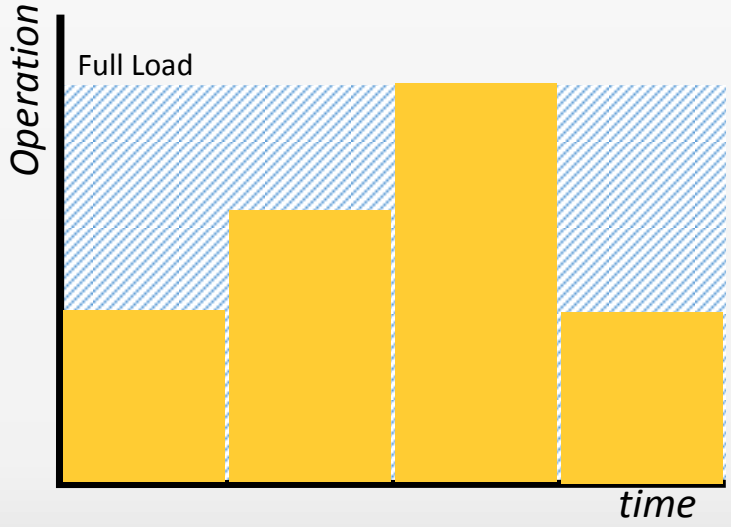
Physical Asset

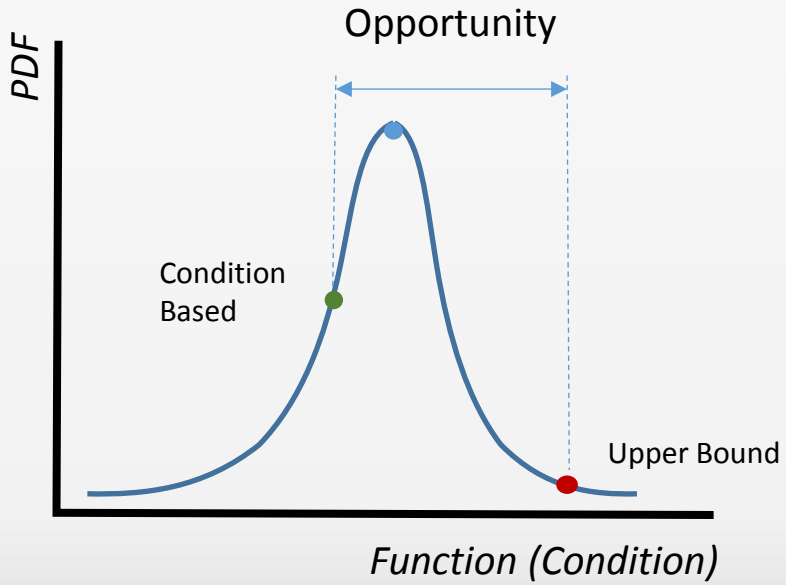
Operational Data



Digital Asset

Predicts Remaining Useful Life





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Digital Asset

Summary

- Mirror the fundamental behavior of physical assets using operational data
- A combination of data driven, physics based and hybrid models
- Enabled through the framework of, people, process and technology
- For optimal asset management in order to maximize value
- The customers dictate the desired functionality

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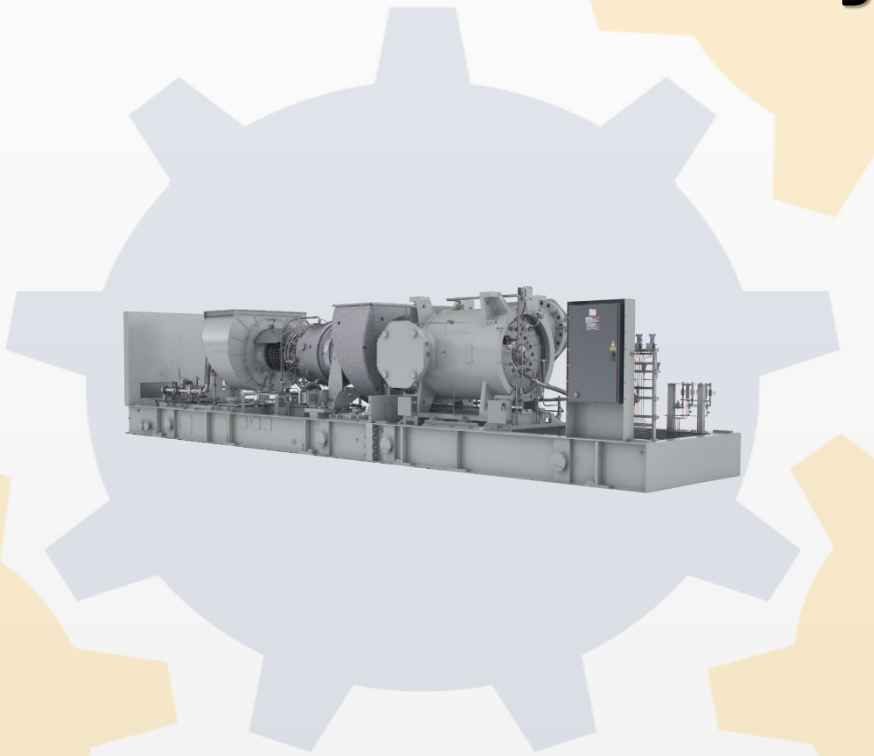
Machine Data

Machine Data

Availability

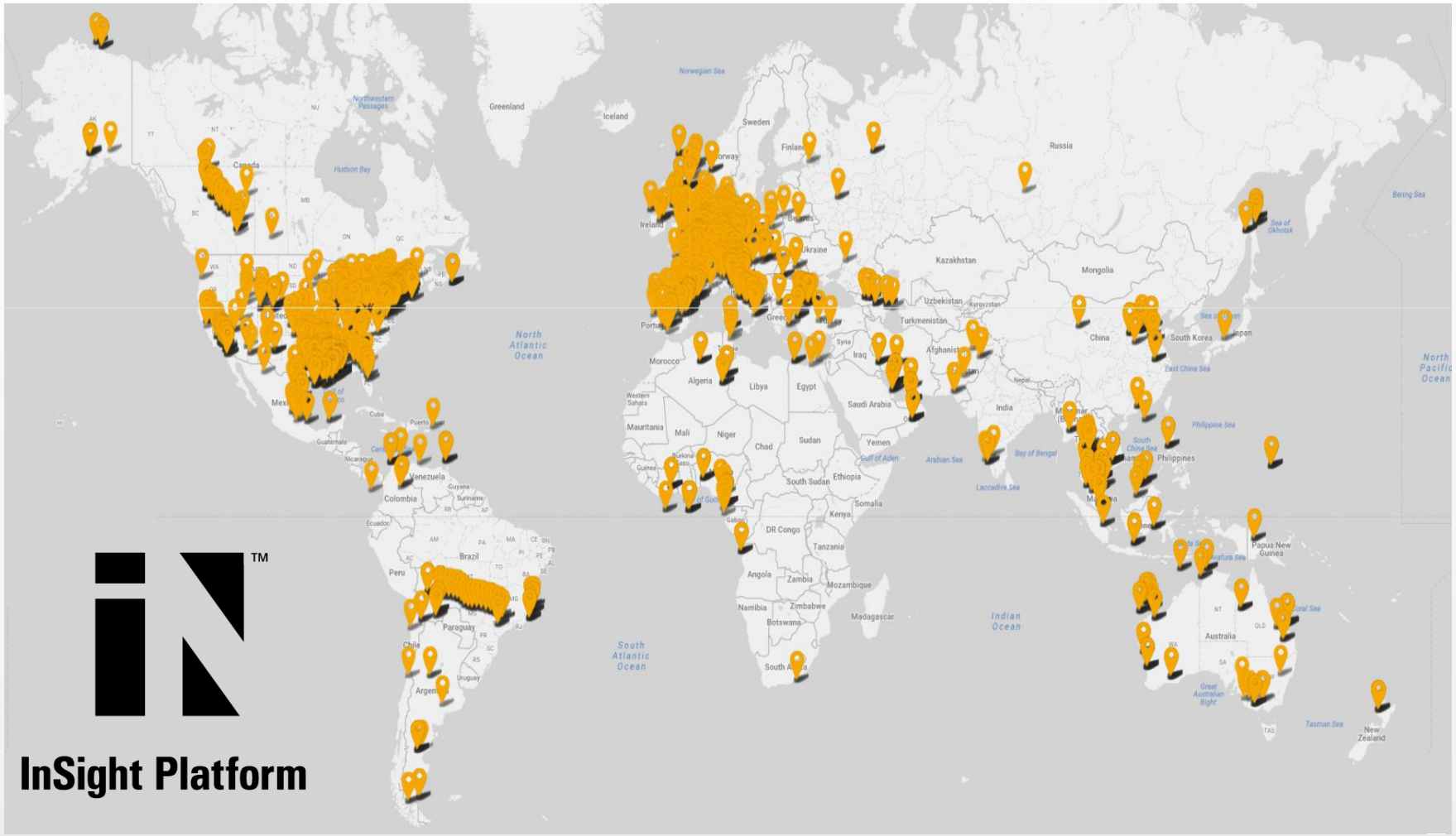
- Significant challenge
- Enables the desired functionality of the Digital Asset



Machine Data

Availability

- Remote solutions offers the most versatility and value
- With 2000+ units connected world wide, Solar requires a robust, scalable data acquisition solution to enable digital assets



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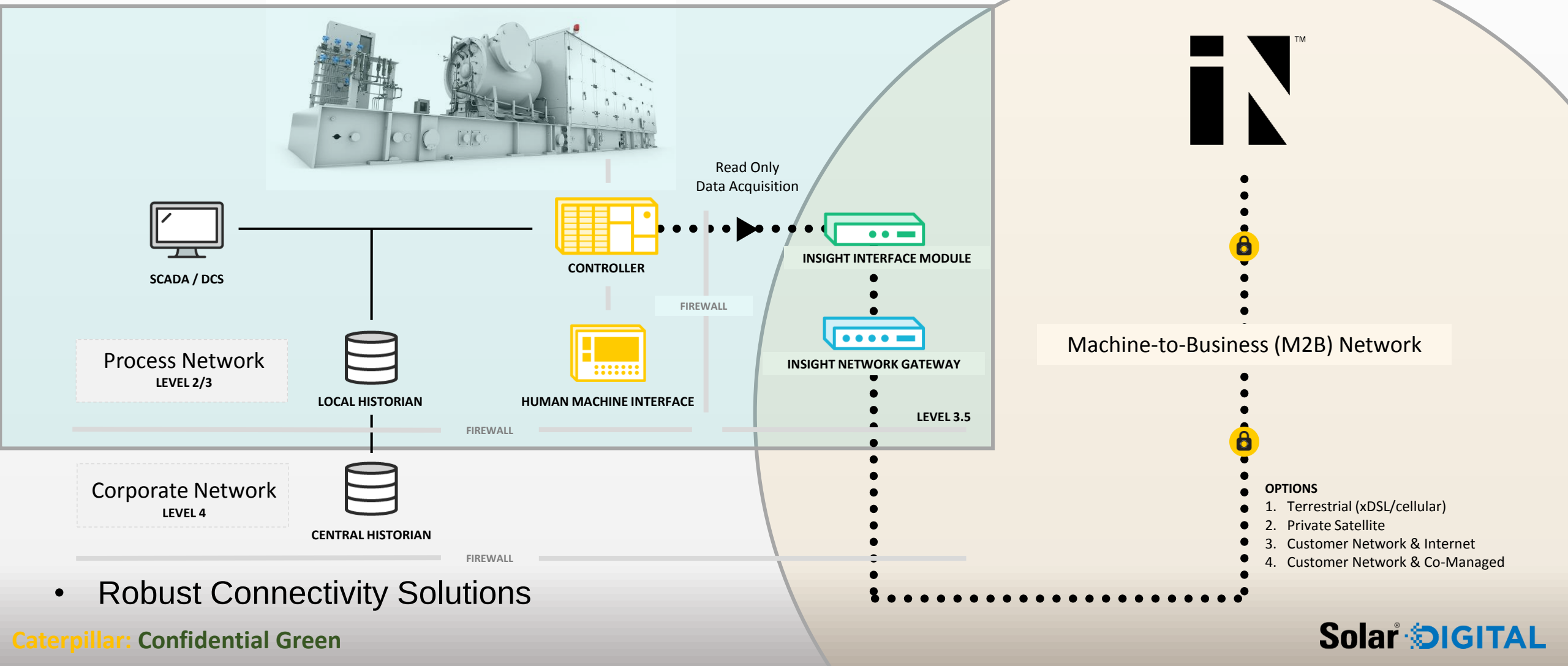
Machine Data

Security

INSIGHT CONNECT

CUSTOMER SITE



- Robust Connectivity Solutions

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Machine Data

Security

499 CONNECTED CUSTOMERS AROUND THE WORLD
10+ YEARS OF EXPERIENCE

Secure Development Lifecycle (SDLC)

Secure Build-to-Release
Iterative Regression Testing
Dedicated Cyber Assurance Labs

Purpose Built Security Architecture

Multi-Layered Defense-in-Depth
Zones & Conduits – Purdue Reference Model
Embedded Security – Standardized & Automated

Industry Peering & Partnerships

Customers
Industry Research Projects
Cyber Security Work Groups

LOGIIC

WIB
The Process Automation Users' Association

Dedicated Security Team

Multiple Domains
Converged IT & OT Expertise

IT OT

Industry Recognized Standards

Based on Industry Recognized Standards
ISA/IEC 62443, NIST

ISA IEC NIST National Institute of Standards and Technology U.S. Department of Commerce

Guaranteed READ-ONLY Design

READ-ONLY Data Acquisition & Visualization
Non-Configurable - *Plug & Protect*

Independent Security Assessments

End-to-End Attack & Penetration Testing
Black-Box Testing
Customer Risk Assessments

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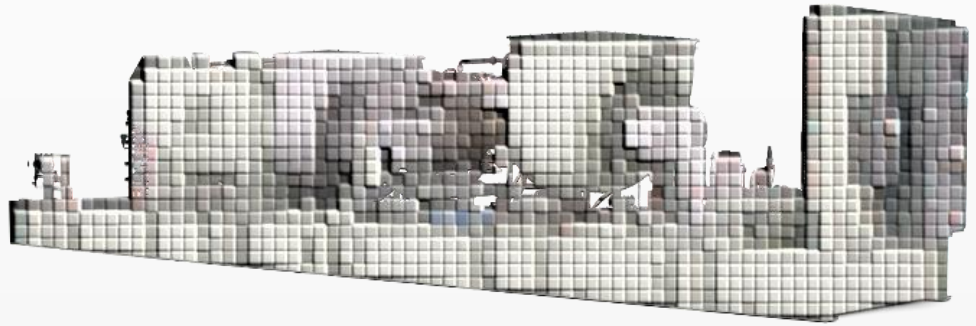
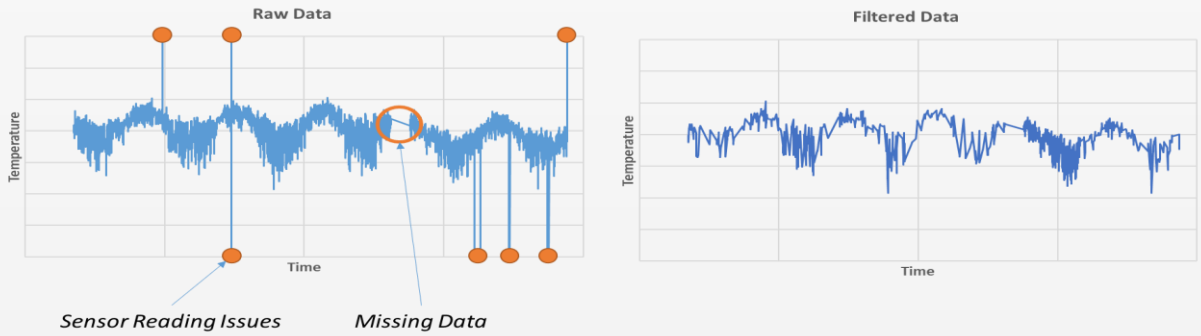
Machine Data

Quality

- Quality is ultimately driven by the customers needs
  - Dictate the required functionality
- Digital Asset development requires an Iterative approach
  - Between data quality and functionality
- Shapes the capability of the Digital Asset

Missing data, faulty sensors, data corruption all result in a fragmented interpretation of the physical asset



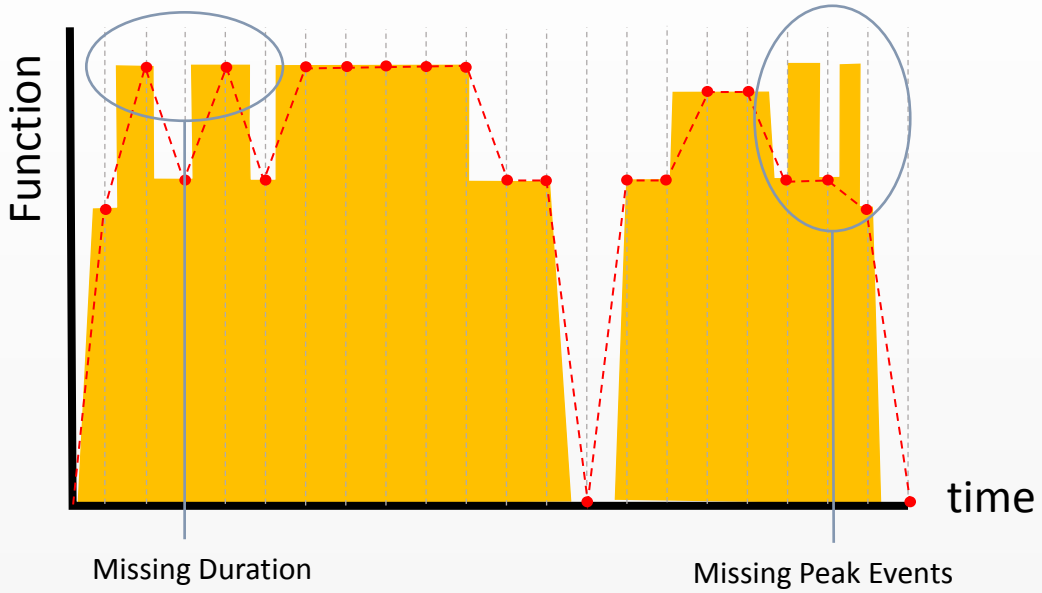


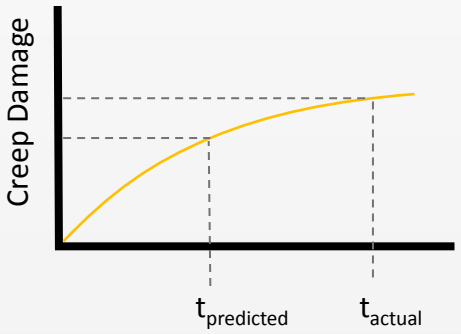
A robust Digital Asset needs to be functional in spite of data quality issues

Machine Data

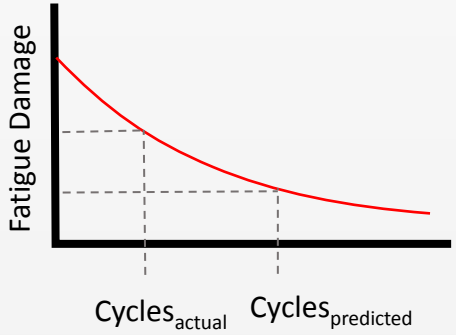
Fidelity

- Fidelity can be defined as the combination of the measurement accuracy and the sampling rate
- Determines the accuracy of the Digital Asset as well as the functionality
  - Without the necessary fidelity, a desired functionality maybe unattainable





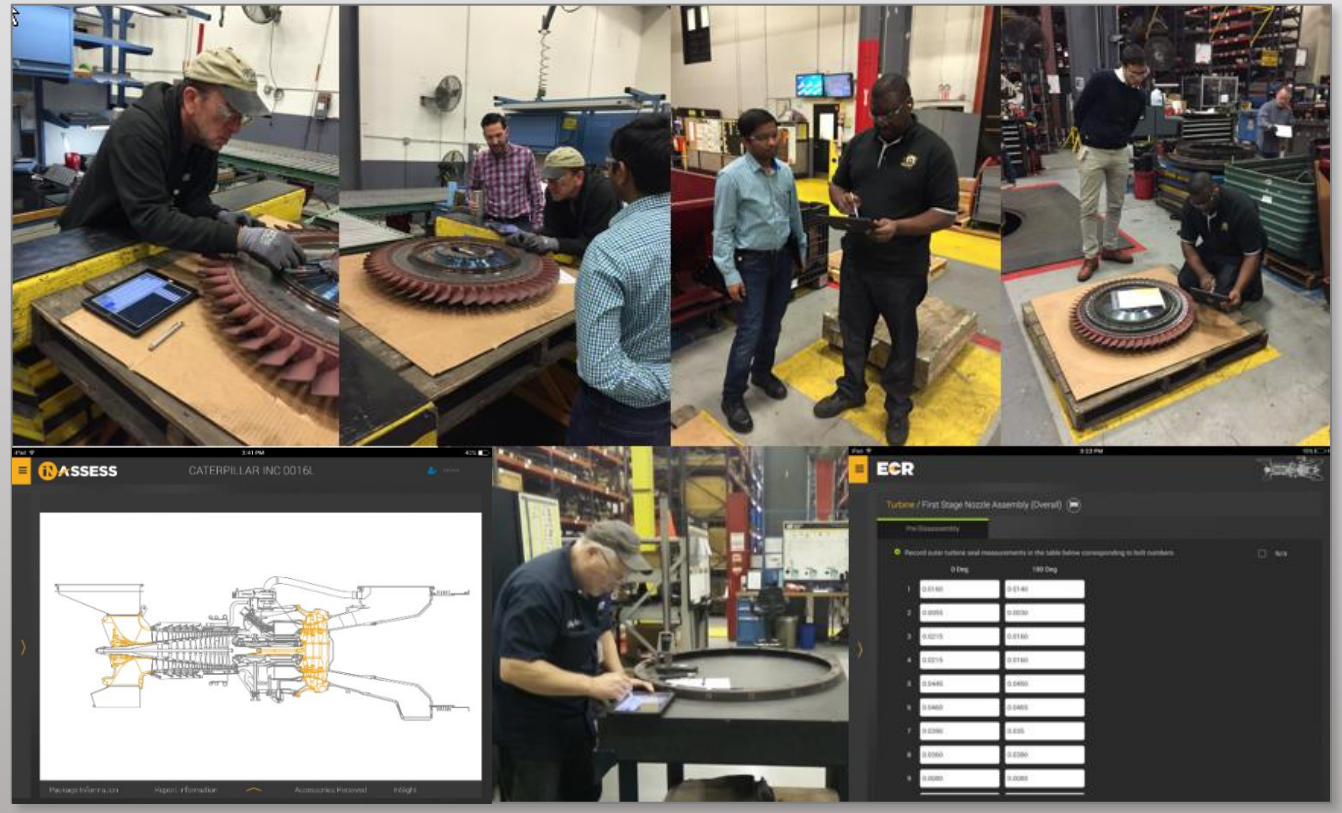
Creep Damage = *Fn* (time, Stress & Temperature)

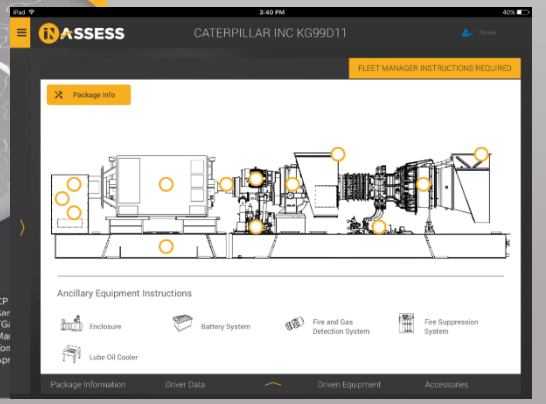


Fatigue Damage = *Fn* (Stress Range & Temperature)

Validation

Through Physical Evaluation & Expertise





Domain expertise and product knowledge is a critical element in calibrating a Digital Asset

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Machine Data

Summary

- Data determines effectivity the Digital Asset
- Will define the capabilities of the Digital Asset:
  - Availability
    - A significant challenge, enables the desired functionality
  - Security
    - Critically important, especially for industrial assets
  - Quality
    - Potential to render the Digital Asset ineffective if not robust
  - Fidelity
    - Impacts accuracy
- Validation is key to calibrating the Digital Asset

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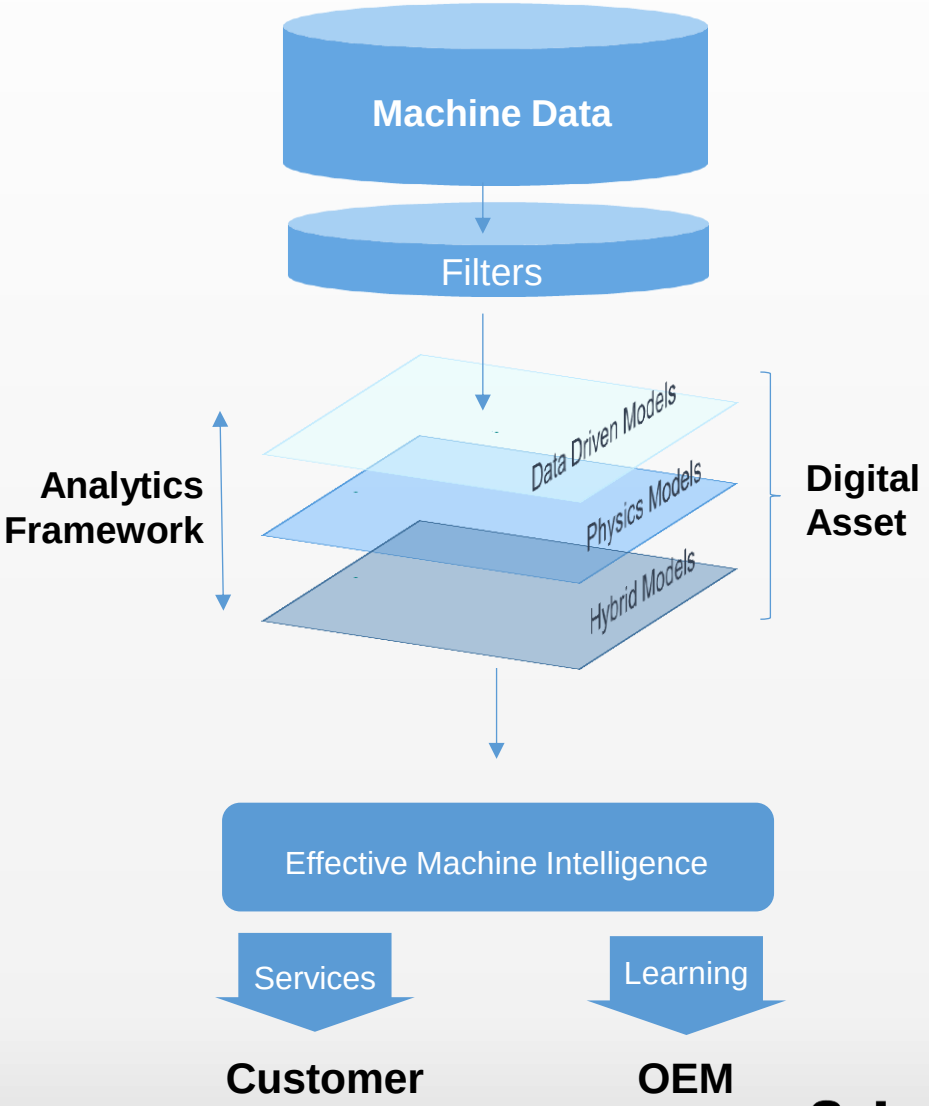
Analytical Framework

Analytical Framework

Model Definition

- Models can be categorized as:
  - Data Driven
  - Physics Based
  - Hybrid
- The Digital Asset is a blend of these model types
  - Working to provide the desired functionality within an analytical framework
- Models definition is determines by:
  - Customers needs
  - Data



Analytical Framework

Data Driven Models

- Are unbound and are based solely on the input data and model selection

- Advantages:
  - Simulate complex systems
  - Fast and effective
  - Unstructured and can be deployed universally

- Disadvantages:
  - Correlation without causation
  - Requires expertise to setup & manage
  - Risk with extrapolating beyond bounds of data (forecasting) or the data volume needed to ensure confidence

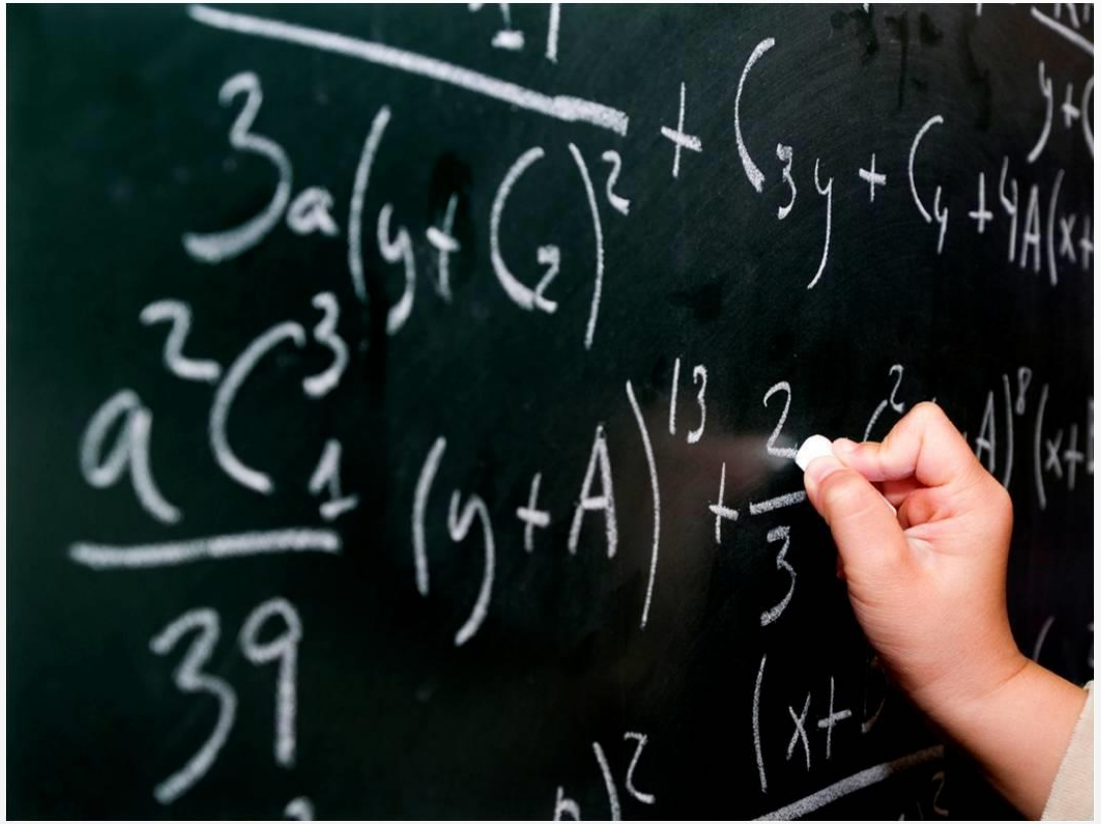
Analytical Framework

Physics Based Models

- First Principal Engineering, bound models that require specific (coupled) data

- Advantages:
  - Simulate complex systems
  - Can be extrapolated with confidence
  - Stable, and predictable

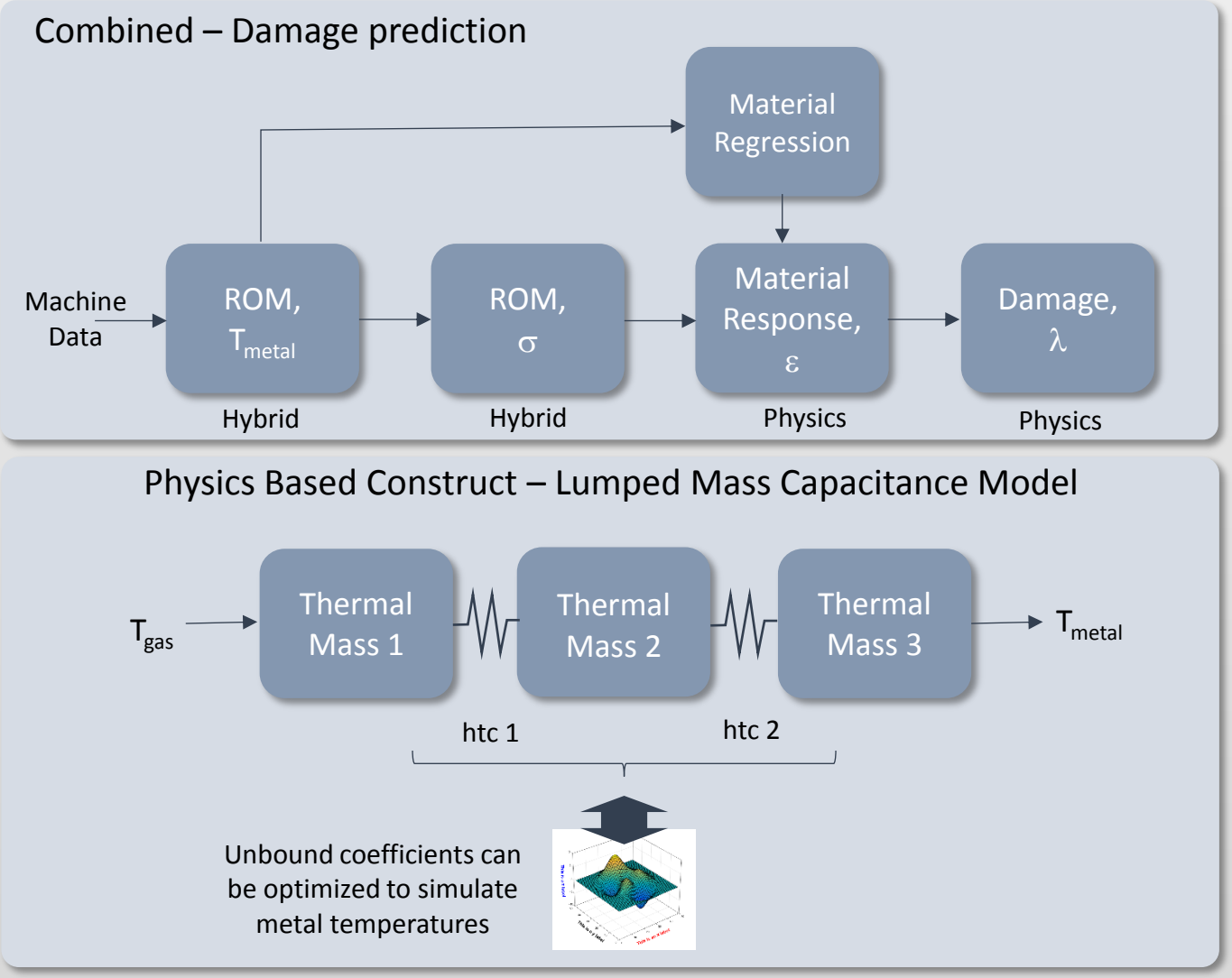
- Disadvantages:
  - Traditional approaches can be computationally inefficient, requires surrogates to be effective
  - Requires specific data inputs to function, so can be limited in execution



Analytical Framework

Hybrid Models

- Is a collection of physics based and data driven sub models which interact to provide a specific function
  - Combined:
    - Data driven & physics models to create a specific output
  - Physics based construct:
    - Physics based model with unbound (non physical) coefficients
- Leverages advantages and offset disadvantages of both approaches



Analytical Framework

Summary

- Effective Digital Assets are a blend of modeling approaches which work together within an analytical framework
- Data Driven
  - Unbound and university applicable
- Physics Based
  - Bound, provide reliable forecasting
- Hybrid models
  - Leverages advantages and offset disadvantages of physics based and data driven models

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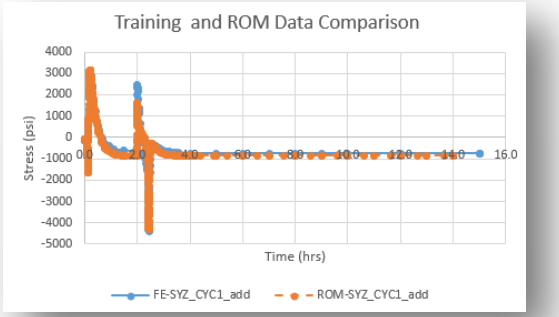
Examples

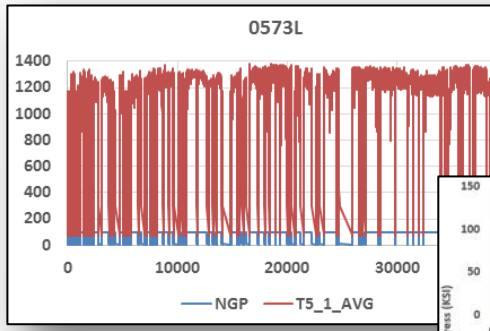
Physics Based & Hybrid

Predicting the Remaining Useful Life (RUL) of Turbine Disks

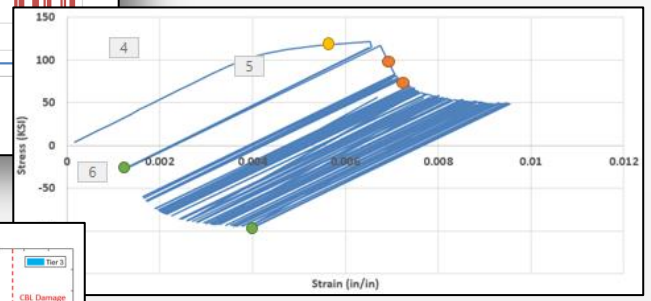
- Rotating hot section components represent a significant risk
- Traditional methods (FEA) would be impractical
  - Requiring excessive computational effort
- ROMs (Hybrid Models) can be trained as surrogates
  - Capable of accurately simulating stresses and temperatures
- ROMs are tested for computational efficient & speed
- Probabilistic models are built to manage uncertainty

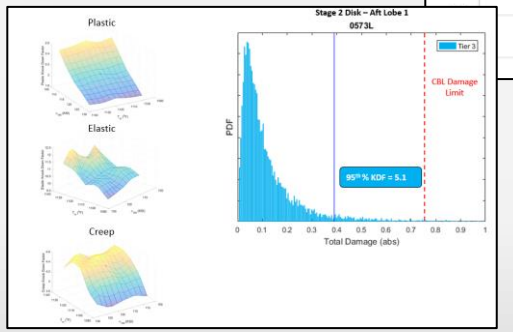
Train





Test





Determine Uncertainty

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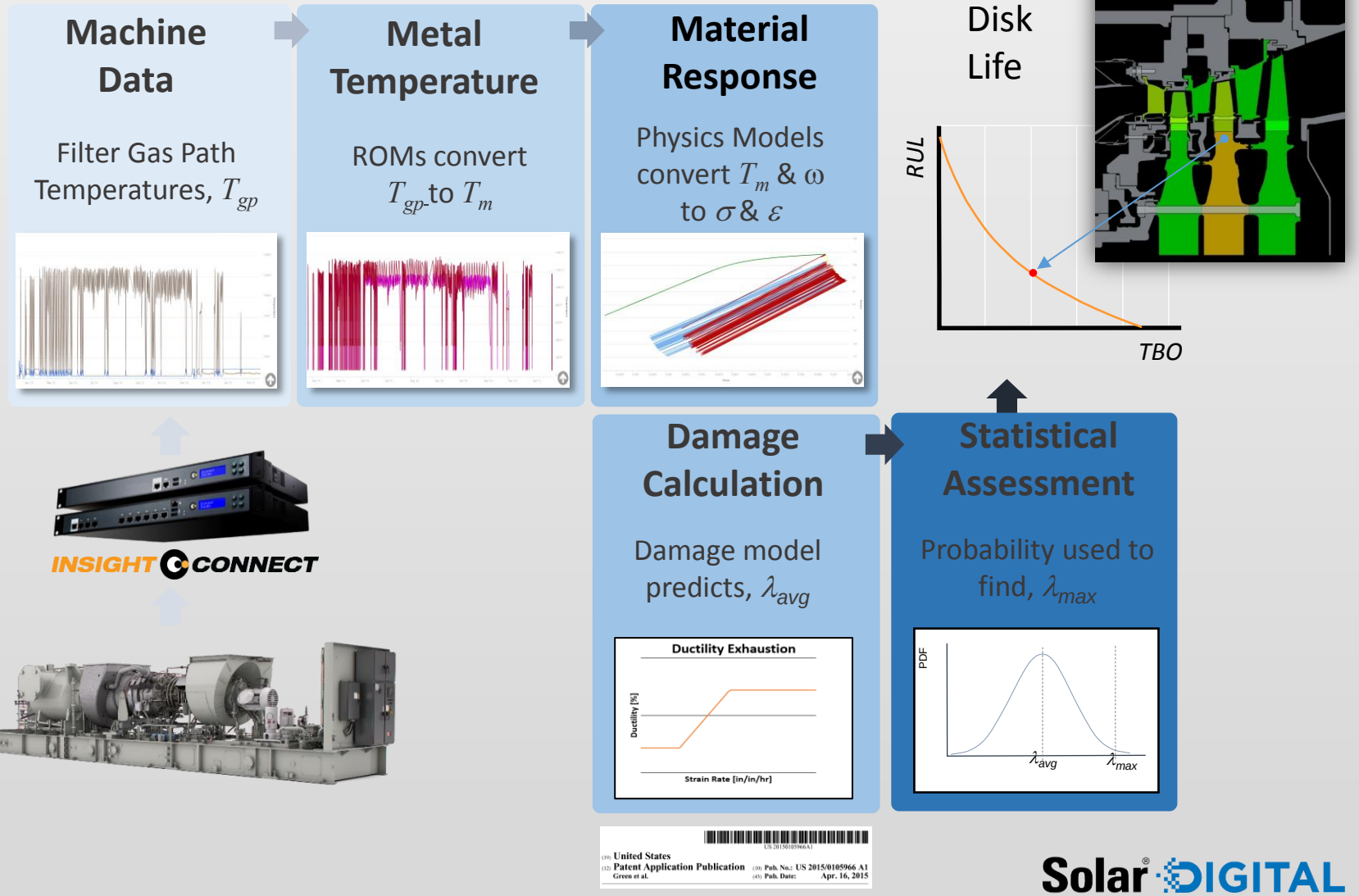
Physics Based & Hybrid

Predicting the Remaining Useful Life (RUL) of Turbine Disks

- ROMs are used to process machine data, predicting;
  - Metal Temperatures
  - Stress Tensors
- Material response is determined
- Nominal damage (λ_{avg}) is calculated
- Apply uncertainty and determine upper bound damage (λ_{max})
- Predicted remaining useful life *(RUL)*



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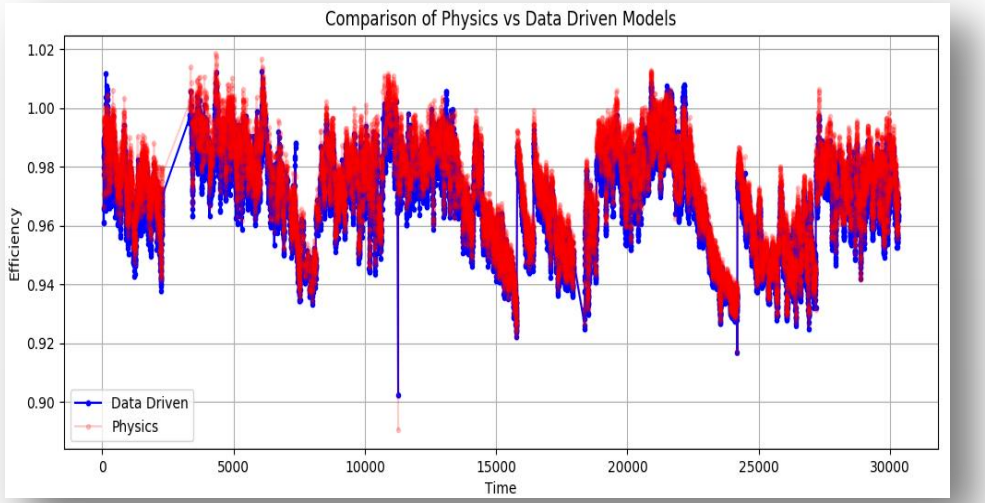
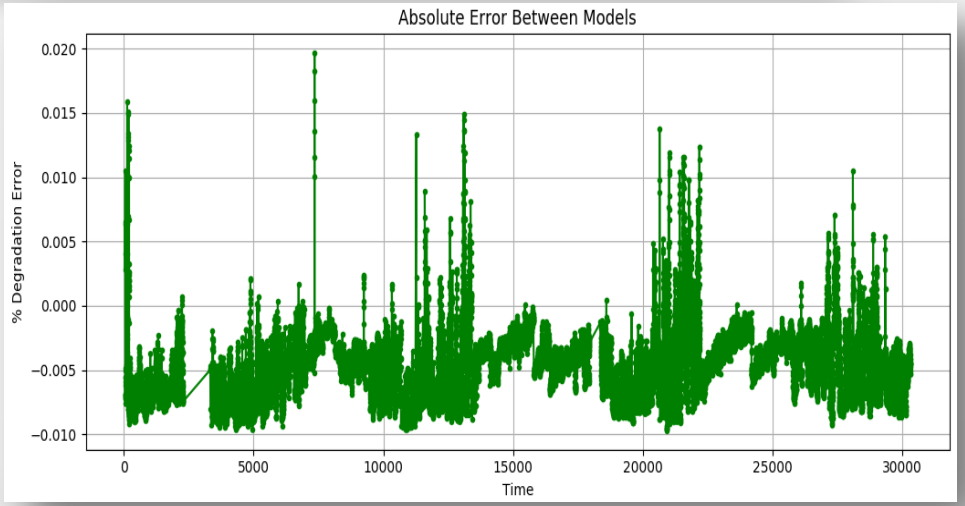
Data Driven

Recoverable Performance Estimation

- Through basic adiabatic efficiency calculations we can deduce axial compressor health
- High fidelity models can be used to approximate this behavior
  - Computational Fluid Dynamics (CFD)
- Data driven model can also be developed to predict discontinuous behavior:
  - Decision trees or neural networks
- Comparison of both models shows good agreement
- Note, domain expertise if critically important to ensure confidence in this approach





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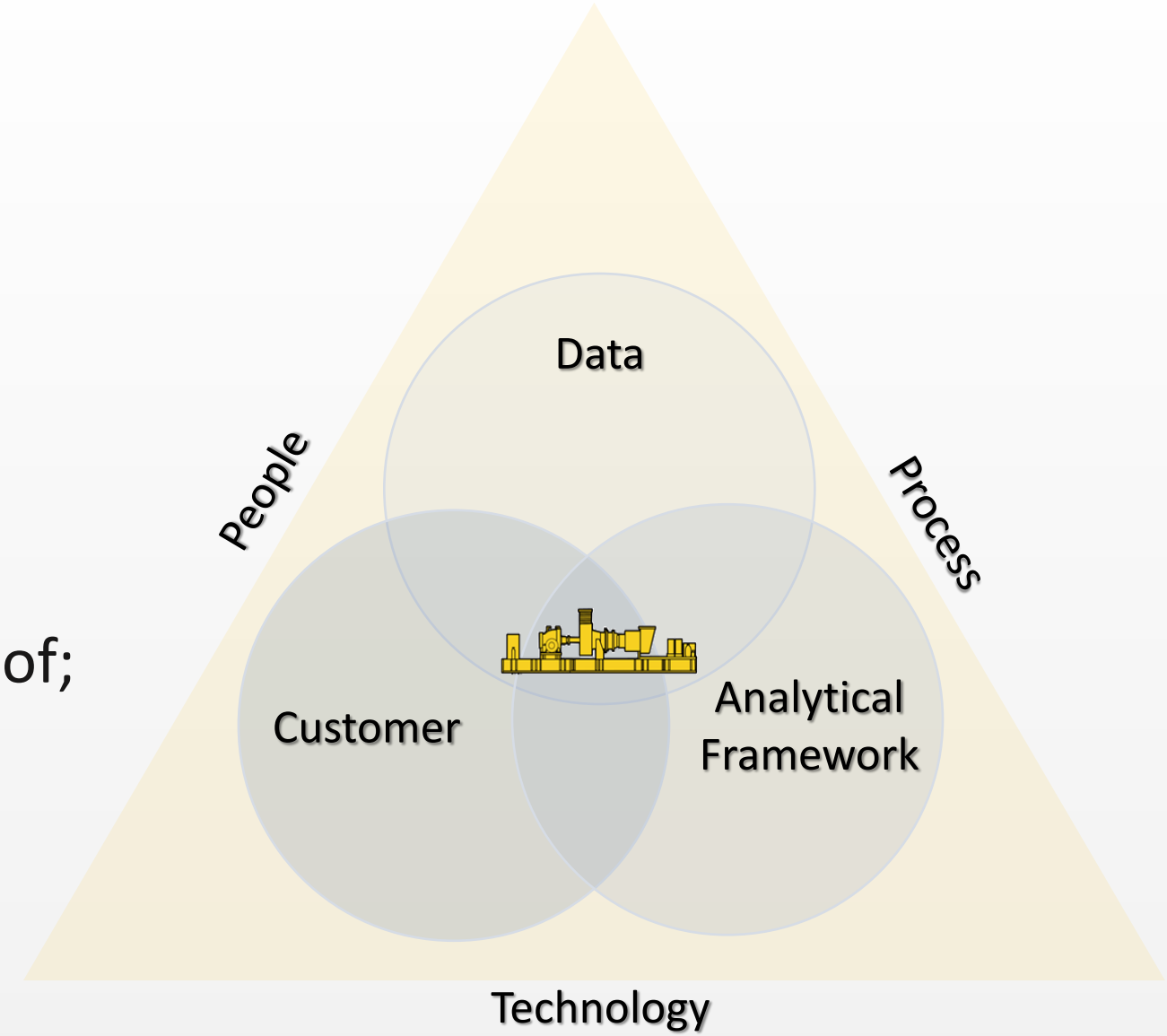
Conclusions

Conclusions

- Successful Digital Assets are a combination;
  - Data
  - Analytical framework
  - Customer engagement
- Supported within a framework of;
  - People
  - Process
  - Technology



Thank You

Questions?

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