DIGITAL TWINS DEVELOPMENT AND DEPLOYMENT IN BOTTOM UP APPROACH

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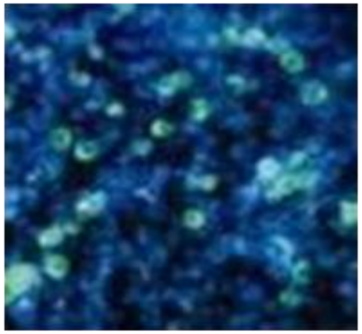
Lulea *University* of technology

The world is getting smarter – more instrumented, interconnected, intelligent.

Smart traffic systems

Intelligent oil field technologies

Smart healthcare



Smart water management

Smart supply chains

Smart energy grids

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Digitization approaches smart assets…

New possibilities.
New complexities.
New risks.

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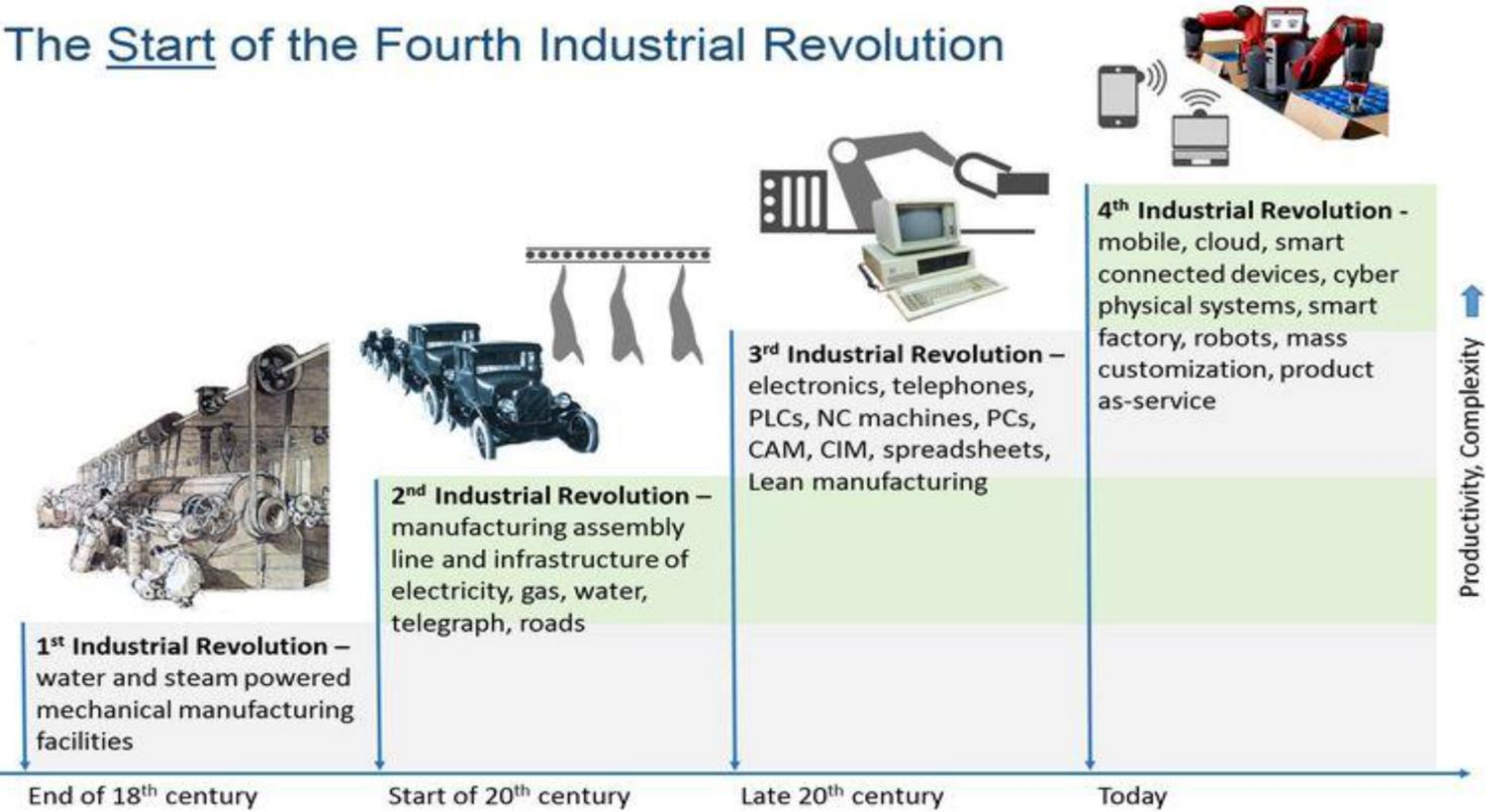
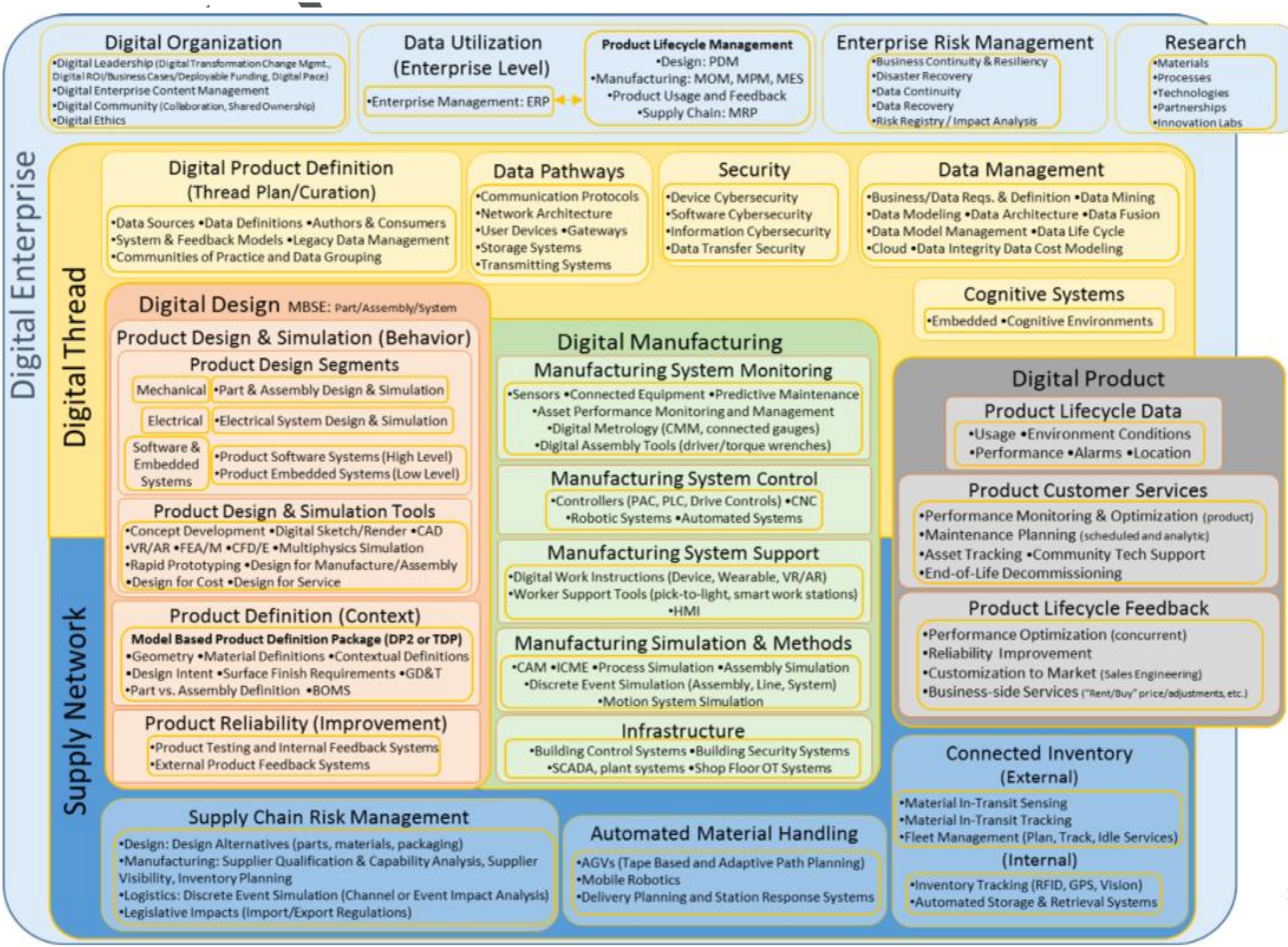
The Fourth Industrial Revolution





Digital Enterprise
Digital Organization
•Digital Leadership (Digital Transformation Change Mgmt., Digital ROI/Business Cases/Deployable Funding, Digital Pace)
•Digital Enterprise Content Management
•Digital Community (Collaboration, Shared Ownership)
•Digital Ethics
Data Utilization (Enterprise Level)
•Enterprise Management: ERP
Product Lifecycle Management
•Design: PDM
•Manufacturing: MOM, MPM, MES
•Product Usage and Feedback
•Supply Chain: MRP
Enterprise Risk Management
•Business Continuity & Resiliency
•Disaster Recovery
•Data Continuity
•Data Recovery
•Risk Registry / Impact Analysis
Research
•Materials
•Processes
•Technologies
•Partnerships
•Innovation Labs
Digital Thread
Digital Product Definition (Thread Plan/Curation)
•Data Sources •Data Definitions •Authors & Consumers
•System & Feedback Models •Legacy Data Management
•Communities of Practice and Data Grouping
Data Pathways
•Communication Protocols
•Network Architecture
•User Devices •Gateways
•Storage Systems
•Transmitting Systems
Security
•Device Cybersecurity
•Software Cybersecurity
•Information Cybersecurity
•Data Transfer Security
Data Management
•Business/Data Reqs. & Definition •Data Mining
•Data Modeling •Data Architecture •Data Fusion
•Data Model Management •Data Life Cycle
•Cloud •Data Integrity Data Cost Modeling
Cognitive Systems
•Embedded •Cognitive Environments
Digital Design MBSE: Part/Assembly/System
Product Design & Simulation (Behavior)
Product Design Segments
Mechanical
•Part & Assembly Design & Simulation
Electrical
•Electrical System Design & Simulation
Software & Embedded Systems
•Product Software Systems (High Level)
•Product Embedded Systems (Low Level)
Product Design & Simulation Tools
•Concept Development •Digital Sketch/Render •CAD
•VR/AR •FEA/M •CFD/E •Multiphysics Simulation
•Rapid Prototyping •Design for Manufacture/Assembly
•Design for Cost •Design for Service
Product Definition (Context)
Model Based Product Definition Package (DP2 or TDP)
•Geometry •Material Definitions •Contextual Definitions
•Design Intent •Surface Finish Requirements •GD&T
•Part vs. Assembly Definition •BOMS
Product Reliability (Improvement)
•Product Testing and Internal Feedback Systems
•External Product Feedback Systems
Digital Manufacturing
Manufacturing System Monitoring
•Sensors •Connected Equipment •Predictive Maintenance
•Asset Performance Monitoring and Management
•Digital Metrology (CMM, connected gauges)
•Digital Assembly Tools (driver/torque wrenches)
Manufacturing System Control
•Controllers (PAC, PLC, Drive Controls) •CNC
•Robotic Systems •Automated Systems
Manufacturing System Support
•Digital Work Instructions (Device, Wearable, VR/AR)
•Worker Support Tools (pick-to-light, smart work stations)
•HMI
Manufacturing Simulation & Methods
•CAM •ICME •Process Simulation •Assembly Simulation
•Discrete Event Simulation (Assembly, Line, System)
•Motion System Simulation
Infrastructure
•Building Control Systems •Building Security Systems
•SCADA, plant systems •Shop Floor OT Systems
Digital Product
Product Lifecycle Data
•Usage •Environment Conditions
•Performance •Alarms •Location
Product Customer Services
•Performance Monitoring & Optimization (product)
•Maintenance Planning (scheduled and analytic)
•Asset Tracking •Community Tech Support
•End-of-Life Decommissioning
Product Lifecycle Feedback
•Performance Optimization (concurrent)
•Reliability Improvement
•Customization to Market (Sales Engineering)
•Business-side Services ("Rent/Buy" price/adjustments, etc.)
Supply Network
Supply Chain Risk Management
•Design: Design Alternatives (parts, materials, packaging)
•Manufacturing: Supplier Qualification & Capability Analysis, Supplier Visibility, Inventory Planning
•Logistics: Discrete Event Simulation (Channel or Event Impact Analysis)
•Legislative Impacts (Import/Export Regulations)
Automated Material Handling
•AGVs (Tape Based and Adaptive Path Planning)
•Mobile Robotics
•Delivery Planning and Station Response Systems
Connected Inventory
(External)
•Material In-Transit Sensing
•Material In-Transit Tracking
•Fleet Management (Plan, Track, Idle Services)
(Internal)
•Inventory Tracking (RFID, GPS, Vision)
•Automated Storage & Retrieval Systems

Enterprise Virtualization

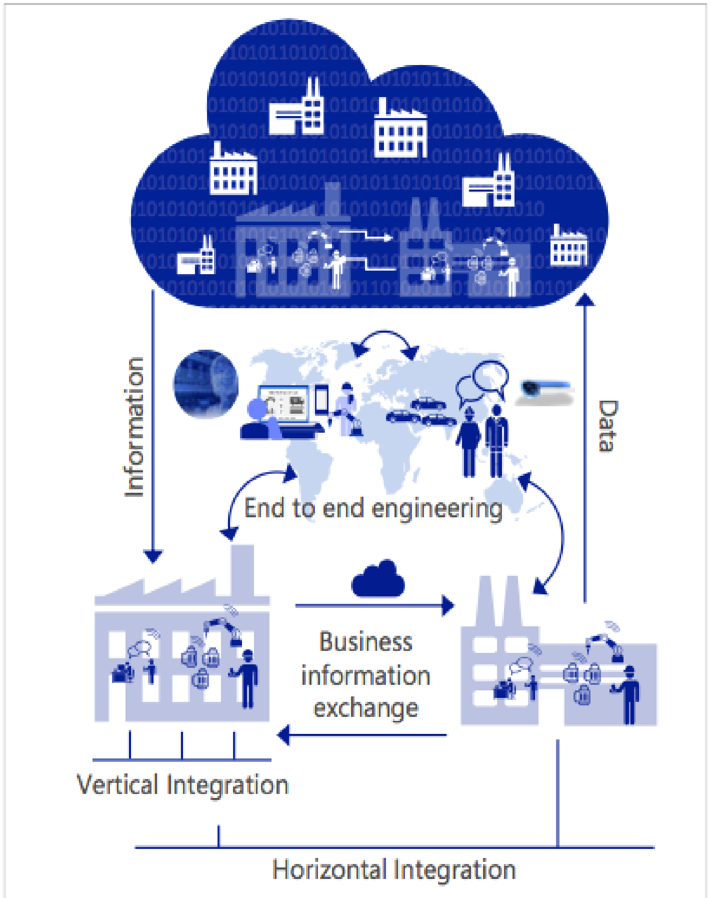
- Value of Pursuing Digital Excellence
- Digital Transformation
- Digital Twin
- Digital Thread
- Digital Workplace
- Digital Workforce

The Value of Pursuing Digital Excellence

Leading manufacturers have mastered operational and manufacturing excellence.

Now, is the time to differentiate by mastering on digital excellence as well.

- An Automotive Value Network
- An Industrial Equipment Value Network
- Digital Factories
- The Field and Engineering Service Economy
- Immersive Experiences Delivering Business Value



Courtesy of Microsoft 2017

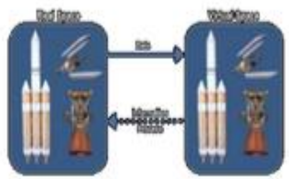
Excellence in Digital Manufacturing, Today

Accelerate value creation and drive sustained improvement through immersive human-machine interaction and innovative partnerships, using a trusted cloud platform

Courtesy of Microsoft 2017

A New Class of Digital Twin

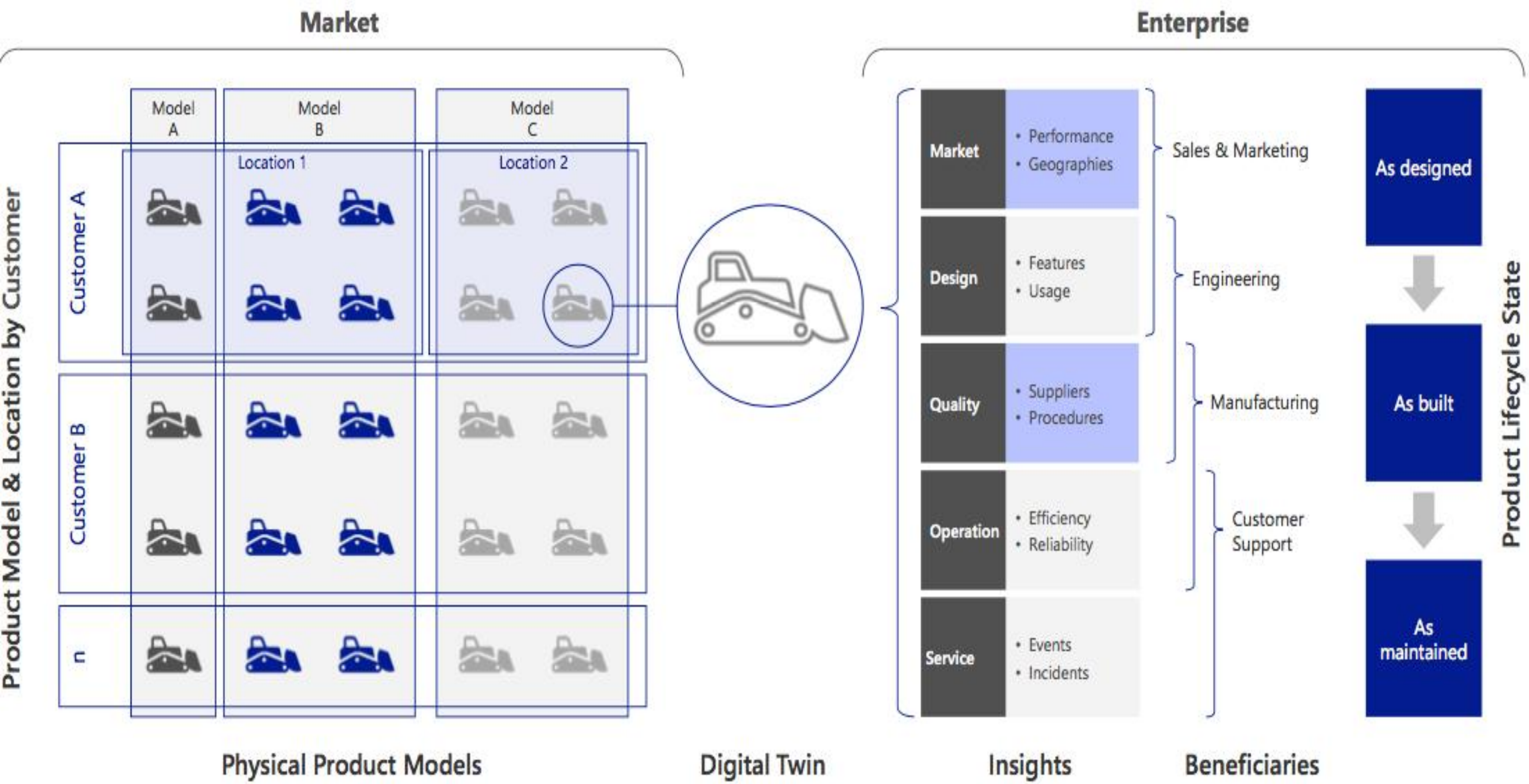
Digital Twin evolution

Information Mirroring* Model	Digital Simulations, 3D Printing	Value Chain interaction	Connected Operations and Industrial Services
Digital Twin as concept R&D & engineering focused	Product development Simulation and engineering workflow	Data unification across physical and virtual Digital Thread	Mixed Reality Cognitive services Artificial Intelligence
2002	2003–2014 (12 years)	2014–2016 (3 years)	2017
			
Powerful modeling and analysis	Digital design, virtual assembly, and simulation before physical commitment 3D printing mainstream	Rapid feedback across design, manufacturing, operation Products augmented with digital services	In-process guided interactions Immersive human-machine collaboration Autonomous and self healing

*Dr. Michael Grieves and John Vickers – University of Michigan

Courtesy of Microsoft 2017

Digital Twin: A virtual instance of a customer's smart connected physical product



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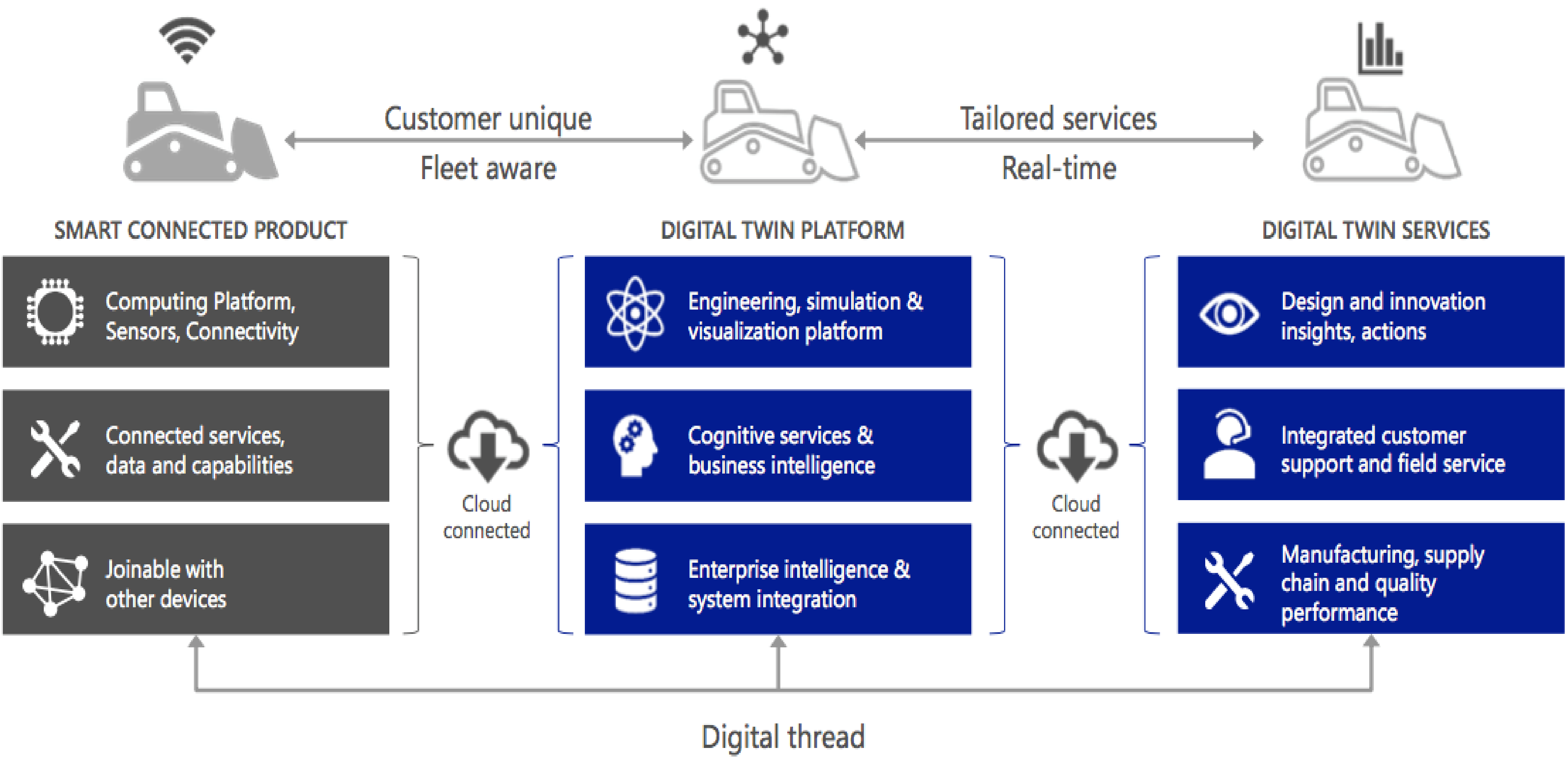
Digital Twin Solution Architecture



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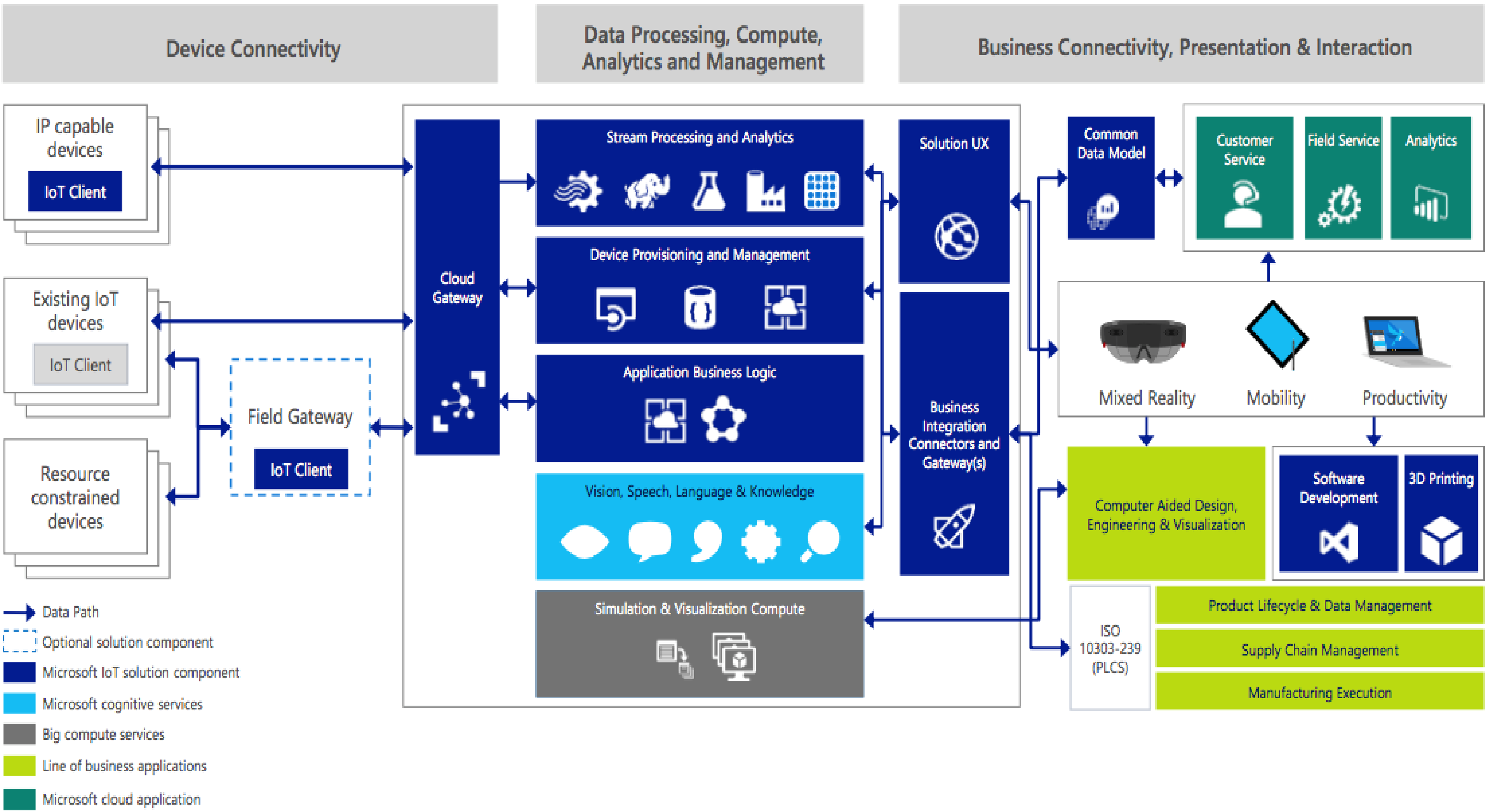
Digital Twin System Architecture



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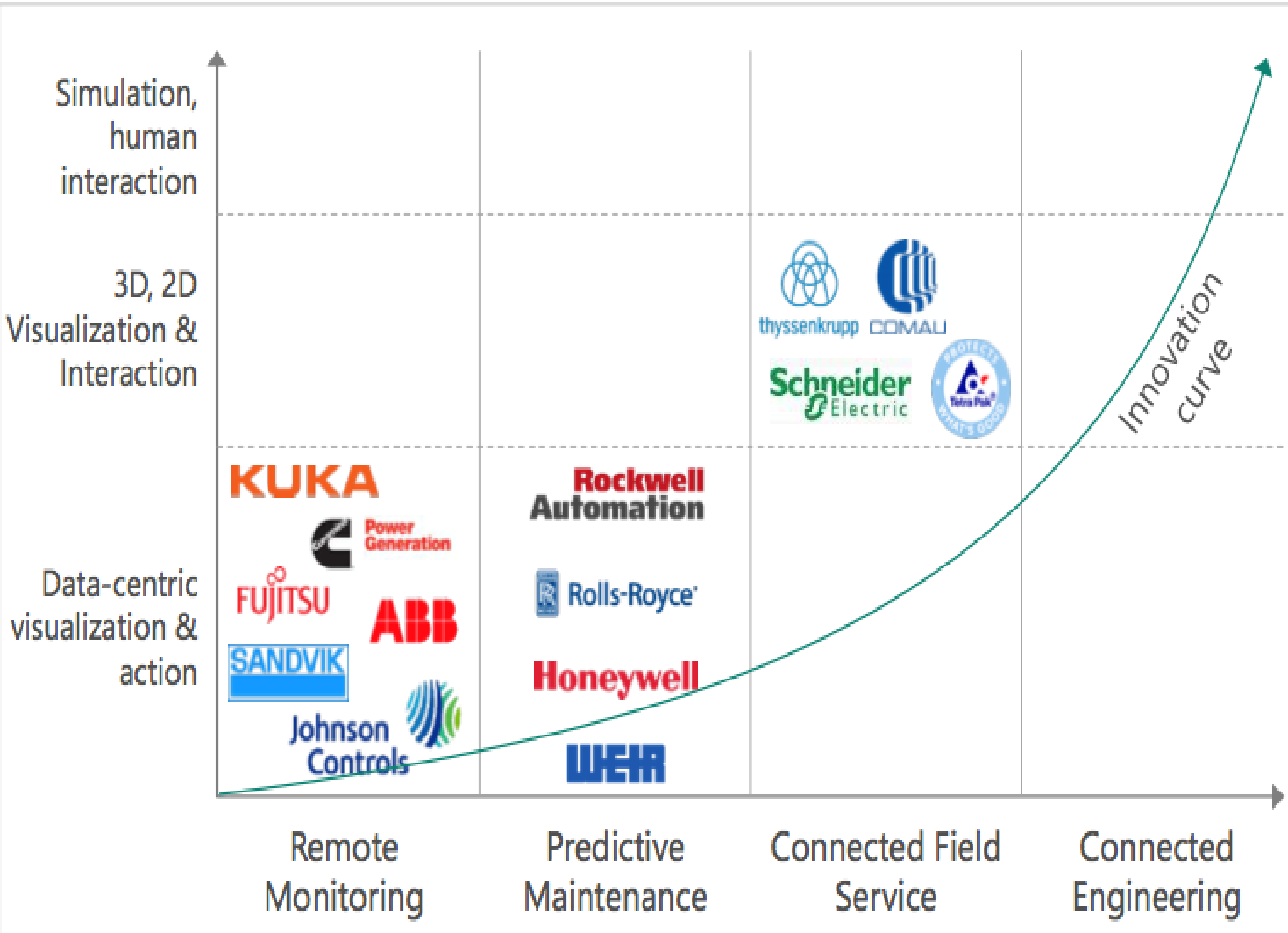
Digital Twin is a Strategic Journey



The Connected Customer

- Monitor performance & maximize efficiency, reliability
- Refine or add value-added equipment features & services
- Mitigate downtime and increase availability

The Connected Enterprise

- Drive design & engineering innovation through customer & equipment insights
- Improve quality and reliability
- Differentiate with 360 degree customer service

Courtesy of Microsoft 2017

Digital Transformation: An Imperative

40% of operational processes will be self-healing and self-learning by 2022[2]

70% of manufacturers will put operations at the forefront of digital transformation projects by 2020[1]

I4.0 Digital First Movers simultaneously achieve new revenue and cost reduction

30% revenue

30% Operational cost

Only 4% of digital first movers that integrate vertically, horizontally and with Customers. The average digital company improves 2.9% p.a. revenue and reduces 3.6% p.a. cost[3]

Mastering digital

up to **15% revenue increase** and simultaneous **reduction in cost to serve of more than 20%**[4]

48% manufacturers are ready for new forms of human-machine interaction[5]

77% CEOs see agility as a growing source of competitive advantage[6]

Forces driving digital manufacturing

I4.0 Design Principles

Vertical integration | Horizontal integration | End-to-end engineering

Digital Twin

A virtual representation of a product, process, or service

Evolution of Digital Twin

Courtesy of Microsoft 2017

The Fourth Industrial Revolution: Digital Manufacturing and Design

IoT – Industrial Internet of Things

Smart Factory

Data-driven factory of the future

Manufacturing 4.0

Digital Thread

Industry 4.0

Intelligent Factory

Factory of the Future

"Digitizing the shop floor"

The Fourth Industrial Revolution

What forces are driving the digitization of manufacturing operations?

Challenges

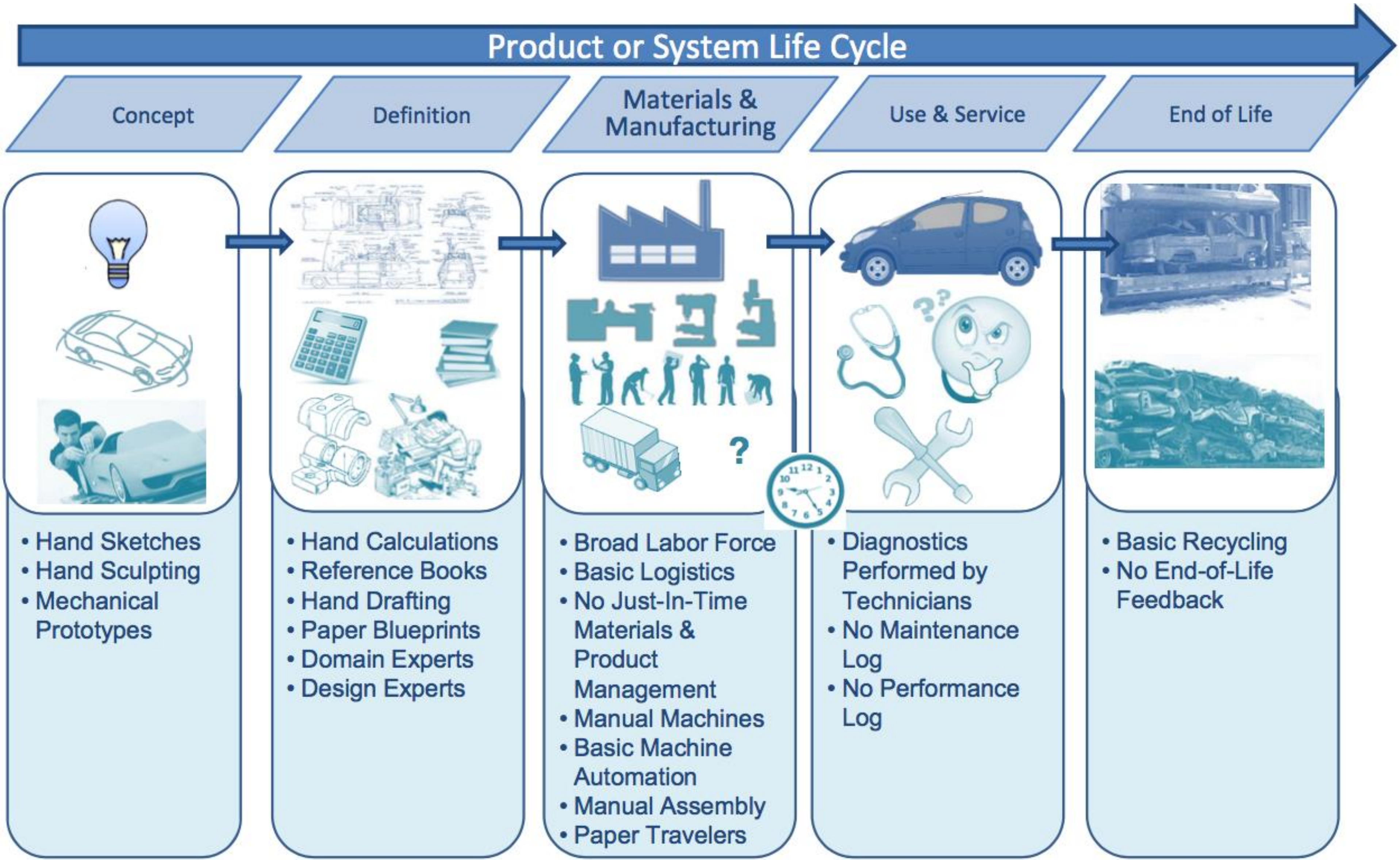
- **Separation of designers and makers** has slowed innovation
- **Barriers for Sharing Data and Information** including: technology, skills, incentives, security, trust, IP, standards
- **Increasing cost of labor globally**, skills gap
- Rising costs of materials and **supply constraints**

Opportunities

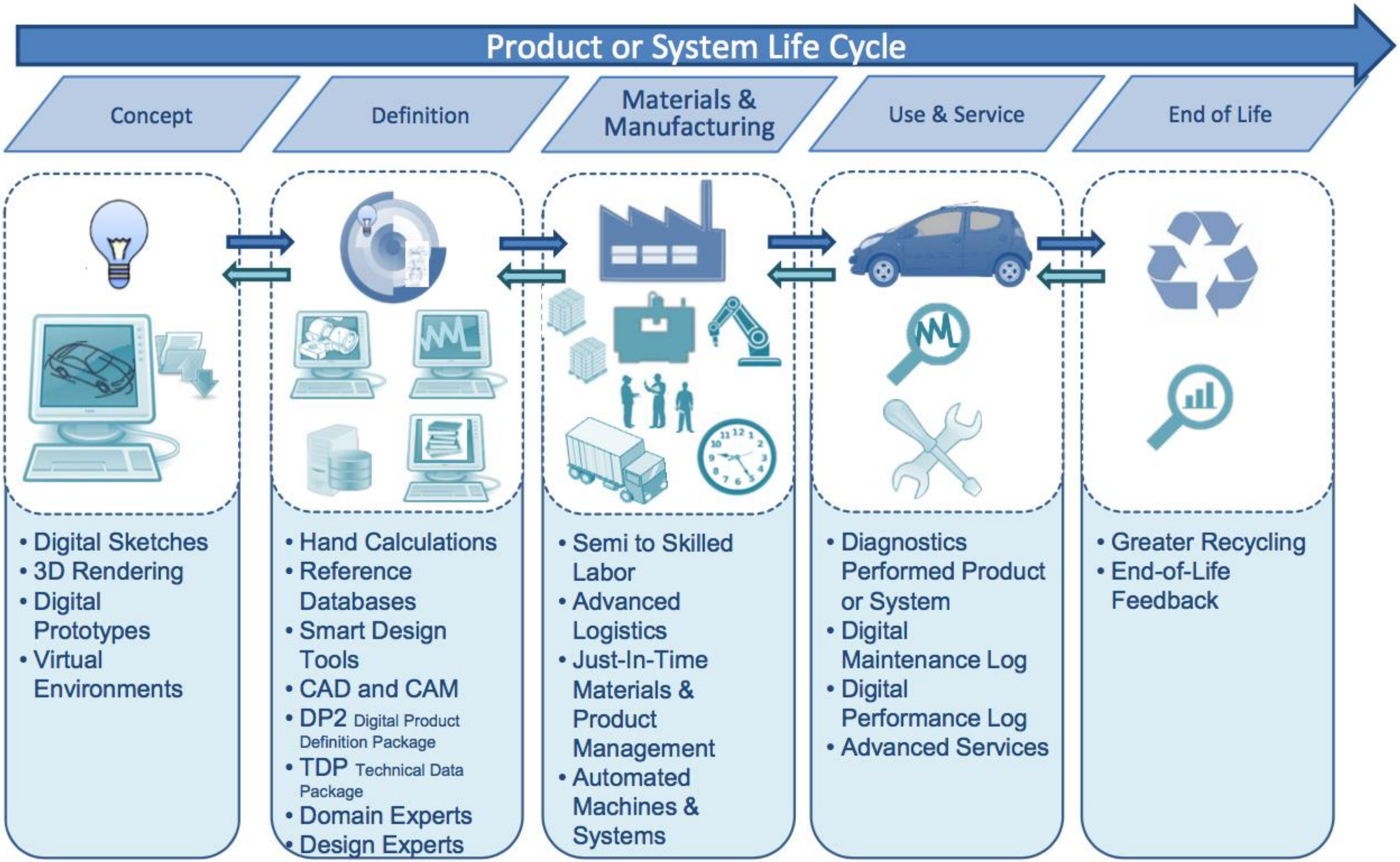
- **Digital link** between designers and makers
- **Digital connections to physical assets** machines, factories, and supply chains
- **Data aggregation and analysis** to do more with existing resources

The Fourth Industrial Revolution

Traditional Product Lifecycle



Product Life Cycle

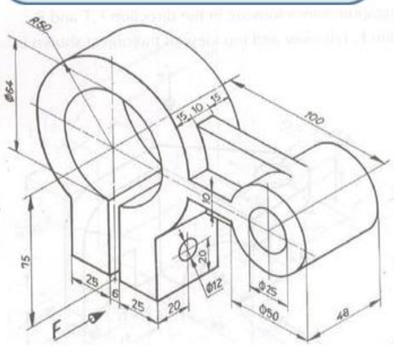


Product or System Life Cycle

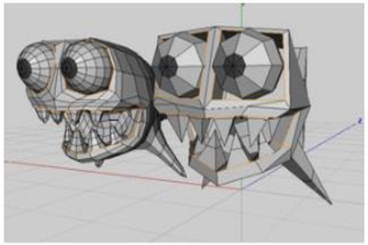
Product or System Life Cycle

Concept | Definition | Materials & Manufacturing | Use & Service | End of Life

- Hand Sketches
- Hand Sculpting
- Mechanical Prototypes



- Digital Sketches
- 3D Rendering
- Digital Prototypes
- Virtual Environments



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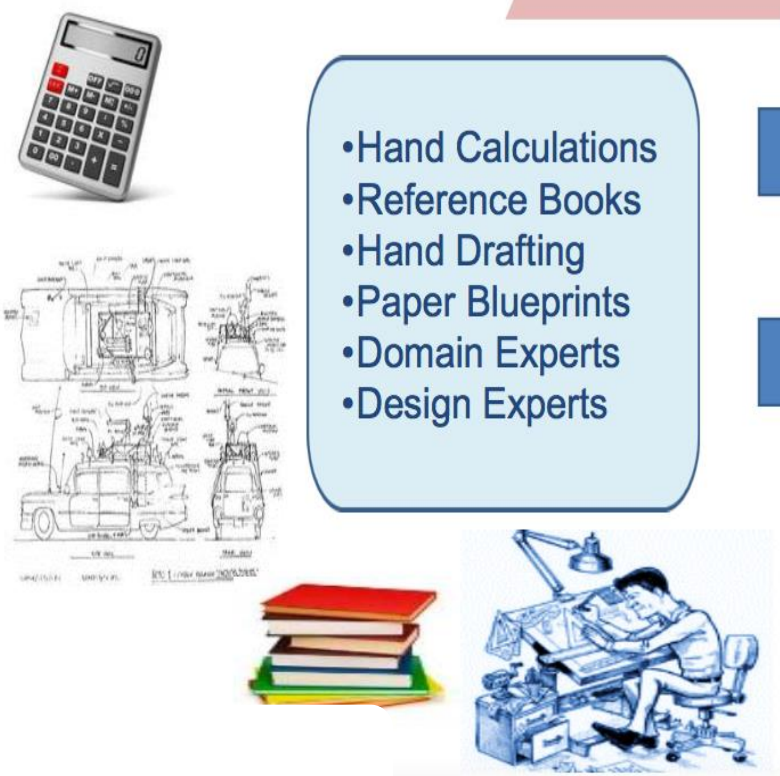
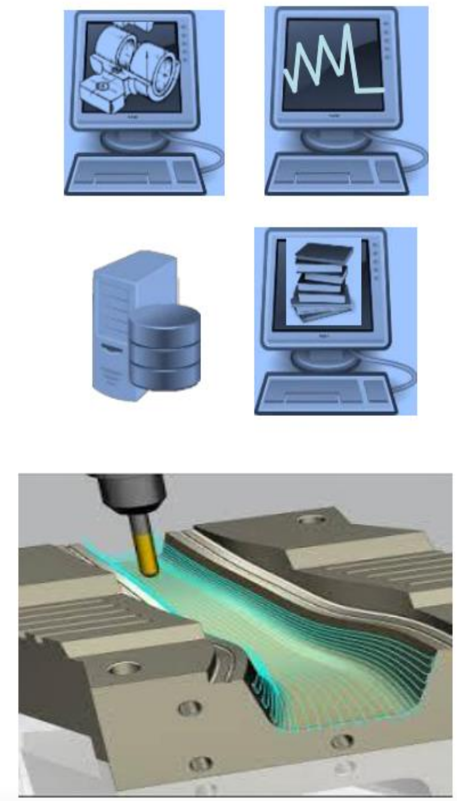


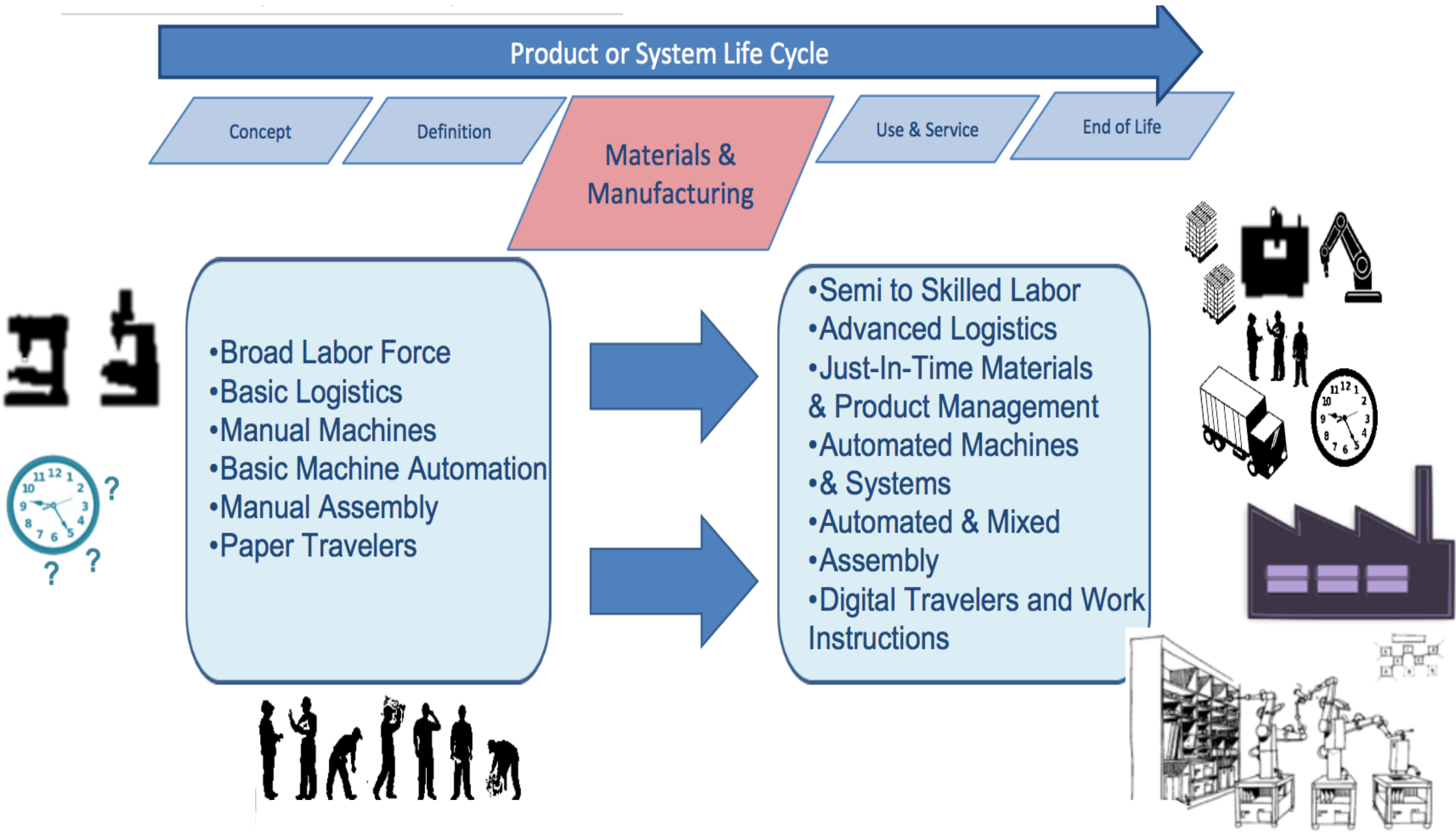
- Hand Calculations
- Reference Books
- Hand Drafting
- Paper Blueprints
- Domain Experts
- Design Experts

→

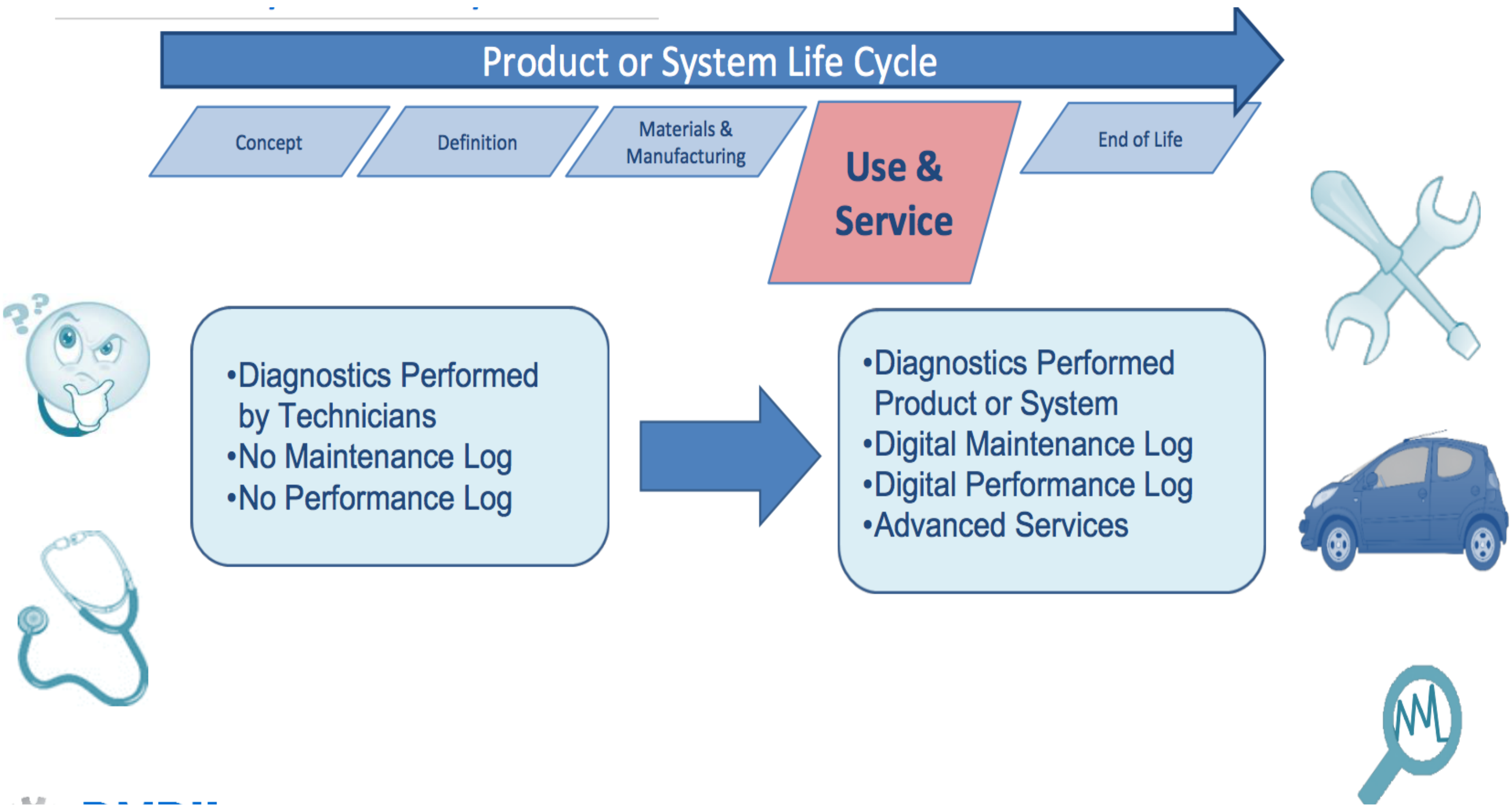
- Smart Design Tools
- CAD
- CAM
- DP2 Digital Product Definition Package
- TDP Technical Data Package



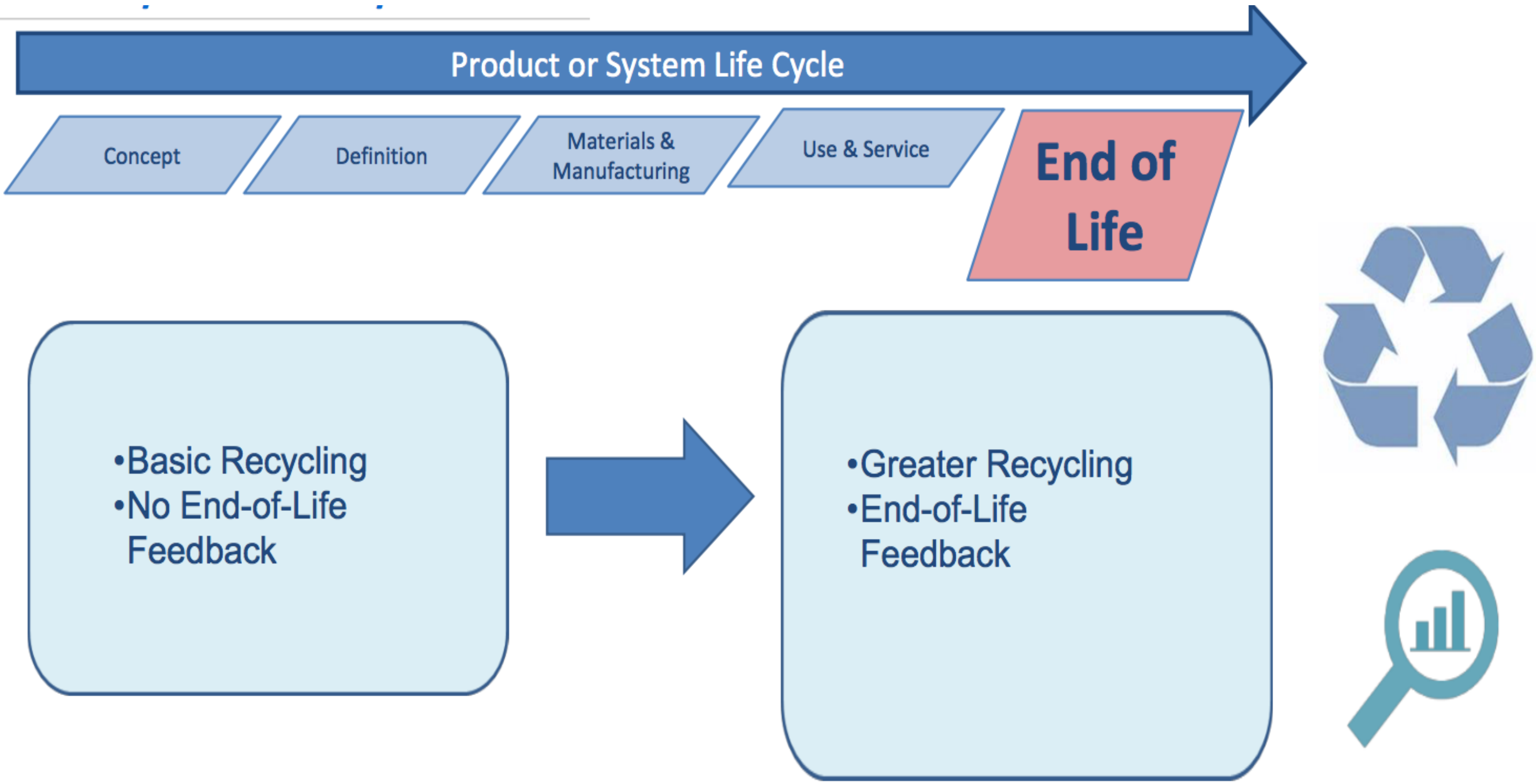
Product or System Life Cycle



Product or System Life Cycle



Product or System Life Cycle



Digital Thread: Heart of Digital Manufacturing

- The digital thread is a single, seamless flow of information that connects a series of data-driven events and stretches across the 5 phases of the product life cycle (PLC) below:
  - 1) CONCEPT - Requirements Development (Customer Requirements),
  - 2) DEFINITION - Design and Analysis (Product Technical Data Package [TDP]),
  - 3) MATERIALS & MANUFACTURING - Manufacturing and Assembly (Process/Production Planning),
  - 4) USE & SERVICE - Repair/Maintenance
  - 5) END OF LIFE – Recycle and Disposal

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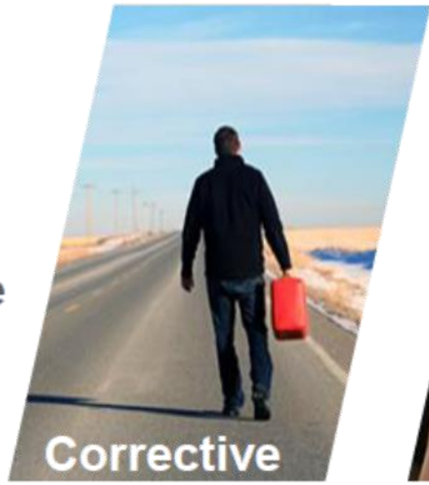
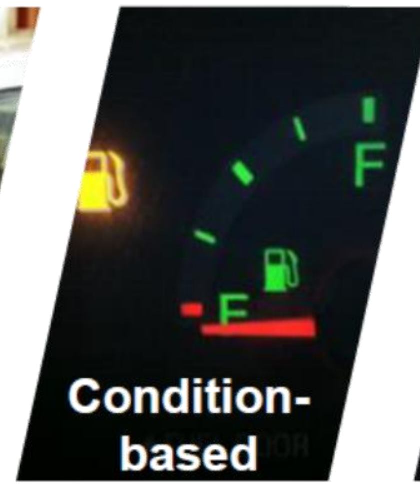
What is predictive maintenance?

Preventive





Type of maintenance	Corrective	Systematic	Condition-based	Predictive
	When it fails	Every day	Upon low fuel indication	Upon a measurement (gauge) and a prognostic
# of Refills	Fewest	Many	Few	Minimal and planned
Car Availability	Lowest	Medium	High	High
Breakdown risk	100%	Low (if no change in usage)	Low	Lowest (if accurate algorithms)

Prognostics & Health Management (PHM)

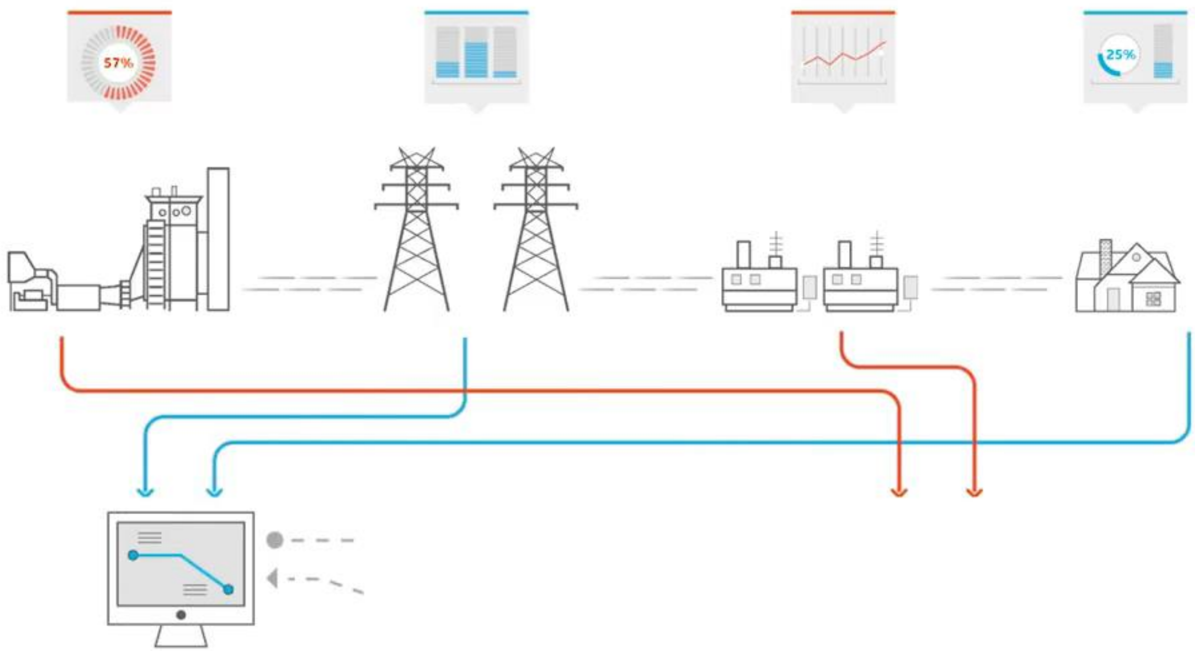
Detecting that there is an anomaly in the behavior of the monitored component

Diagnosing the type of problem occurring, identifying the affected components

Predicting the probability of the monitored component failing within a time frame or estimating RUL

- Being able to identify when a failure is about to occur: no unexpected failures
- Specific target actions identified for affected components
- Less troubleshooting time
- Fewer maintenance interventions necessary
- Minimal inspections on field
- Reduced downtimes
- An efficient tool for scheduling maintenance operations

TRADITIONAL DATA SILOS



NETWORK PLANNING

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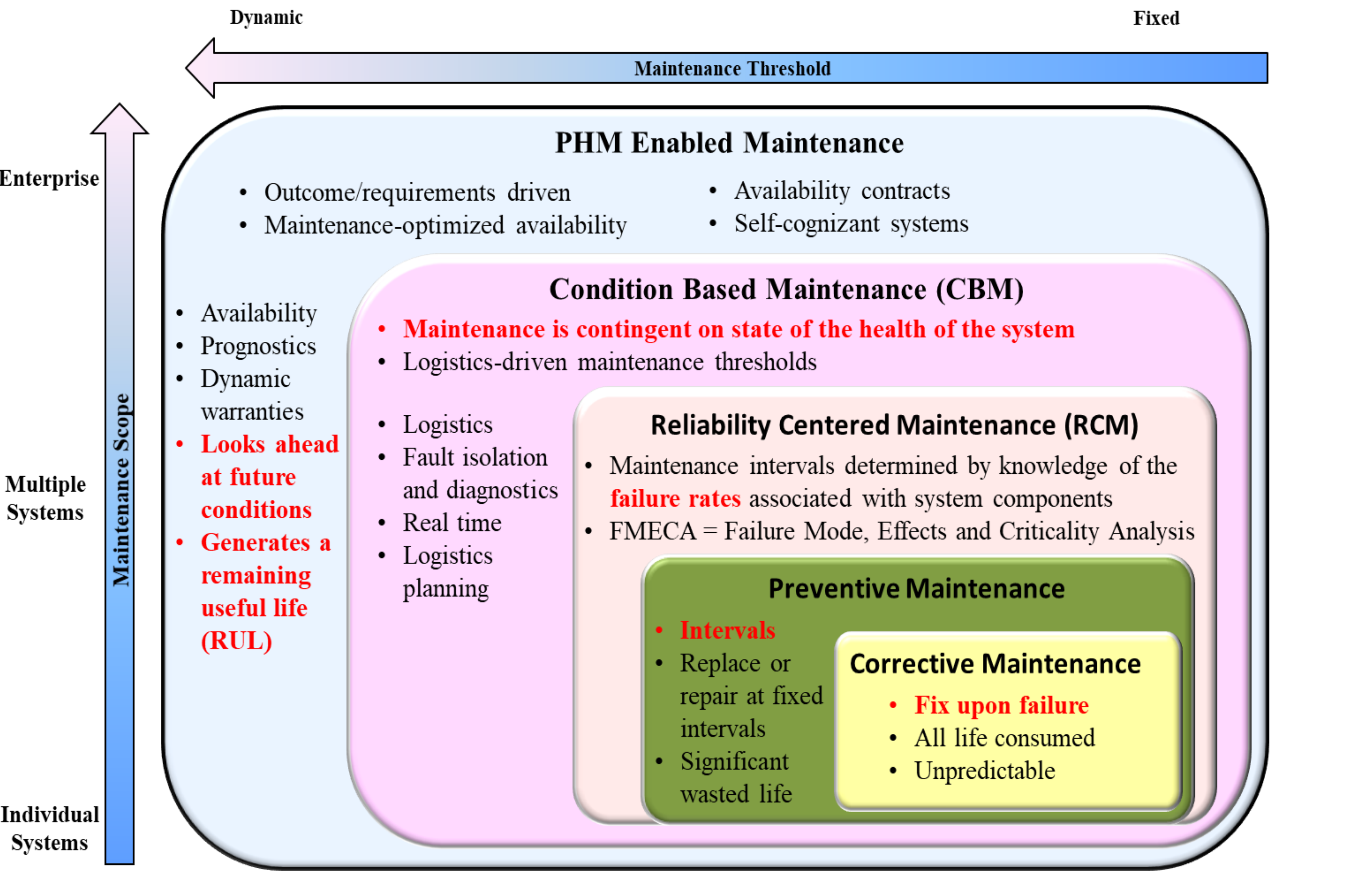
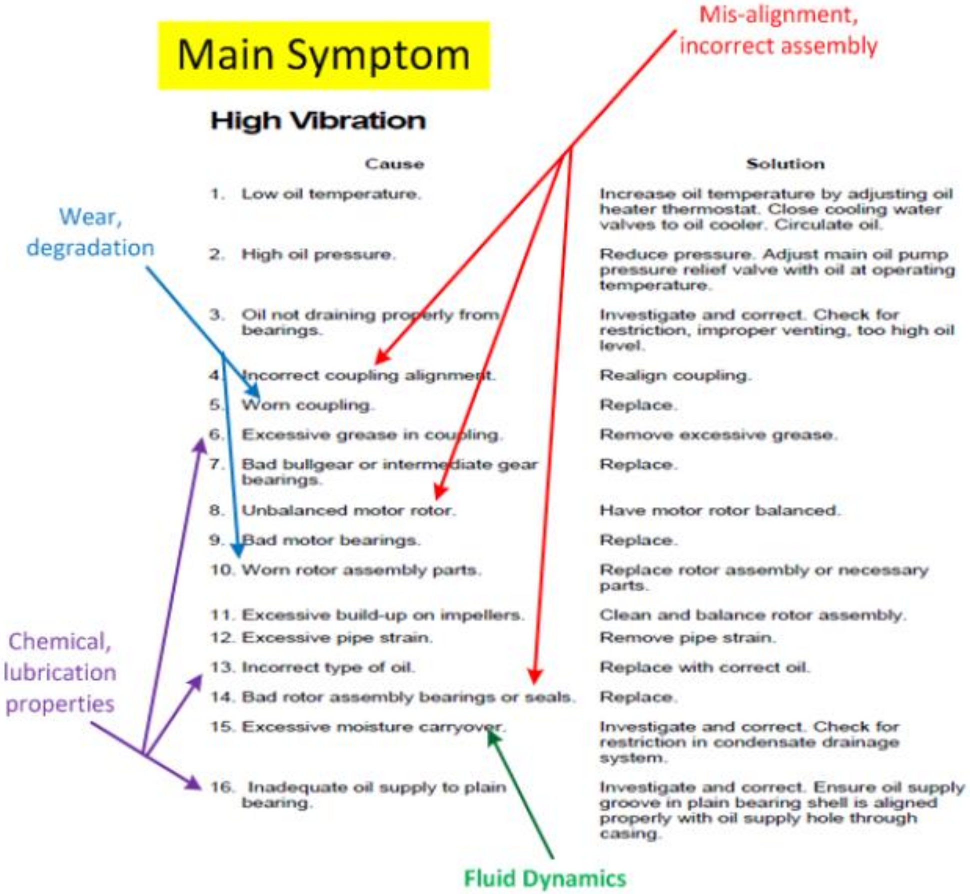


Why Diagnostics, Prognostics?

Single Symptom,
Multiple fault modes, failure possibilities and mitigations

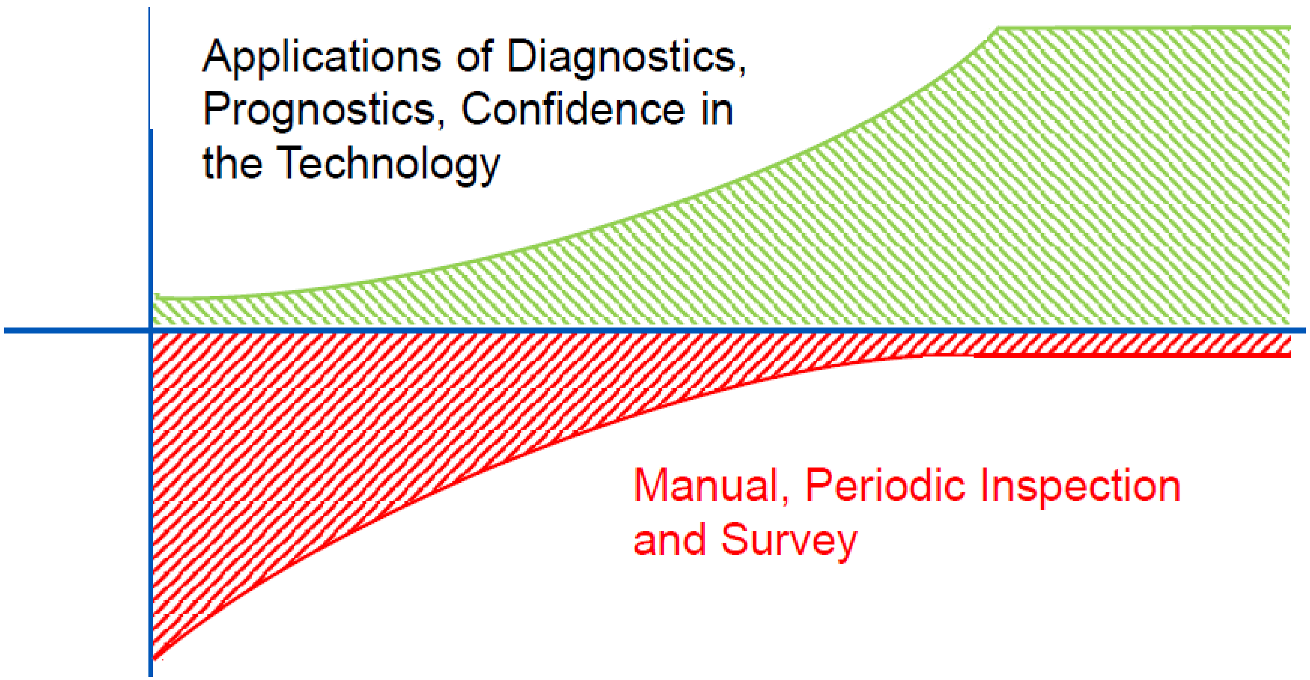


Main Symptom

High Vibration

Cause	Solution
1. Low oil temperature.	Increase oil temperature by adjusting oil heater thermostat. Close cooling water valves to oil cooler. Circulate oil.
2. High oil pressure.	Reduce pressure. Adjust main oil pump pressure relief valve with oil at operating temperature.
3. Oil not draining properly from bearings.	Investigate and correct. Check for restriction, improper venting, too high oil level.
4. Incorrect coupling alignment.	Realign coupling.
5. Worn coupling.	Replace.
6. Excessive grease in coupling.	Remove excessive grease.
7. Bad bullgear or intermediate gear bearings.	Replace.
8. Unbalanced motor rotor.	Have motor rotor balanced.
9. Bad motor bearings.	Replace.
10. Worn rotor assembly parts.	Replace rotor assembly or necessary parts.
11. Excessive build-up on impellers.	Clean and balance rotor assembly.
12. Excessive pipe strain.	Remove pipe strain.
13. Incorrect type of oil.	Replace with correct oil.
14. Bad rotor assembly bearings or seals.	Replace.
15. Excessive moisture carryover.	Investigate and correct. Check for restriction in condensate drainage system.
16. Inadequate oil supply to plain bearing.	Investigate and correct. Ensure oil supply groove in plain bearing shell is aligned properly with oil supply hole through casing.

Where are we today?



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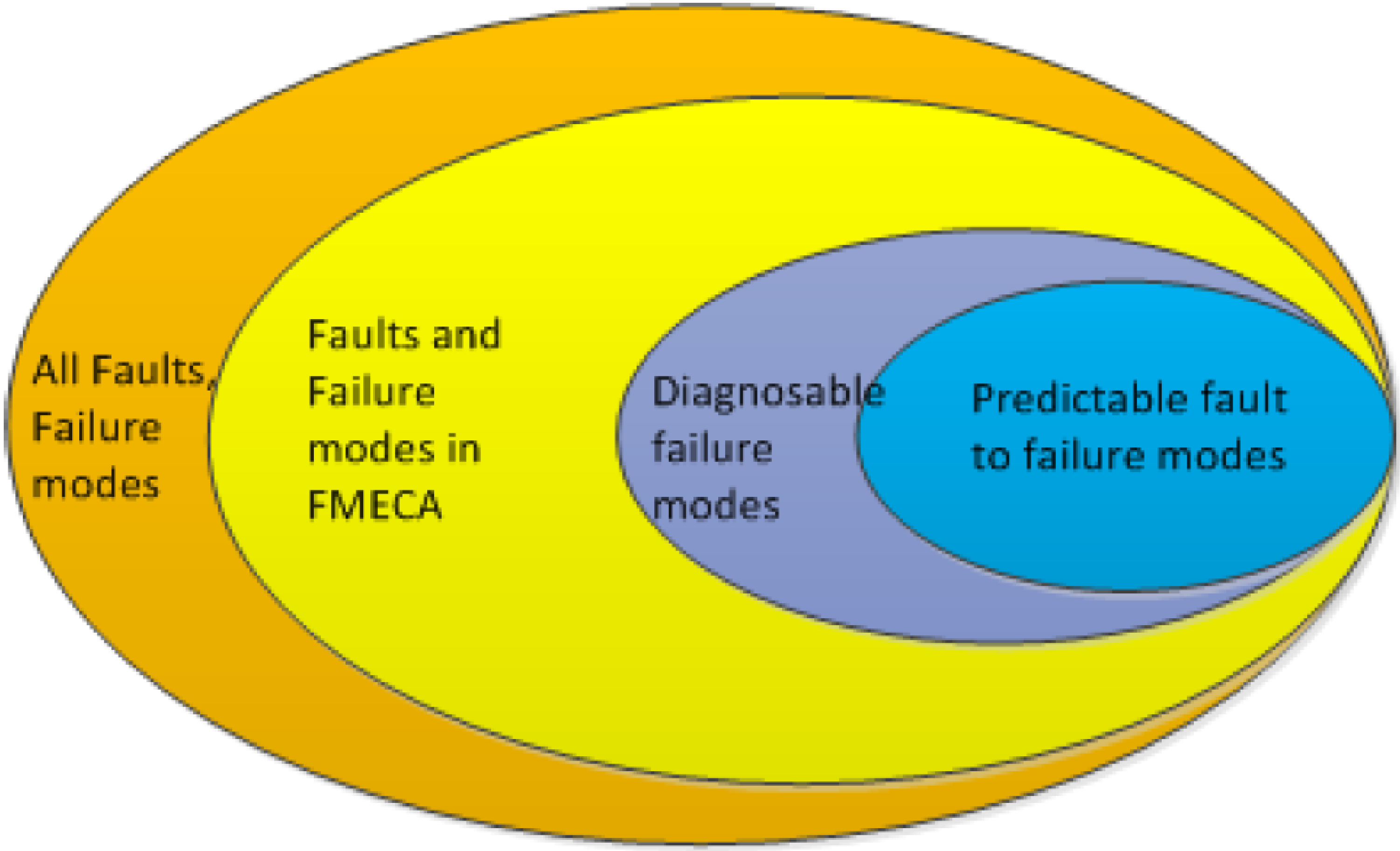
Why Validate Diagnostics and Prognostics?



Understanding of Risk

- Corporate Risk Register
  - Risk Appetite
    - Service Risk
      - Asset Risk
        - Criticality
        - Resilience
          - Reliability

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Benefits of Diagnostics, Prognostics

Maintenance engineer and technicians
- Opportunistic maintenance
- Maximise uptime
- Minimise unnecessary maintenance

Maintenance Manager
- Spares Positioning
- Reduced Spares Count
- Logistics Efficiency

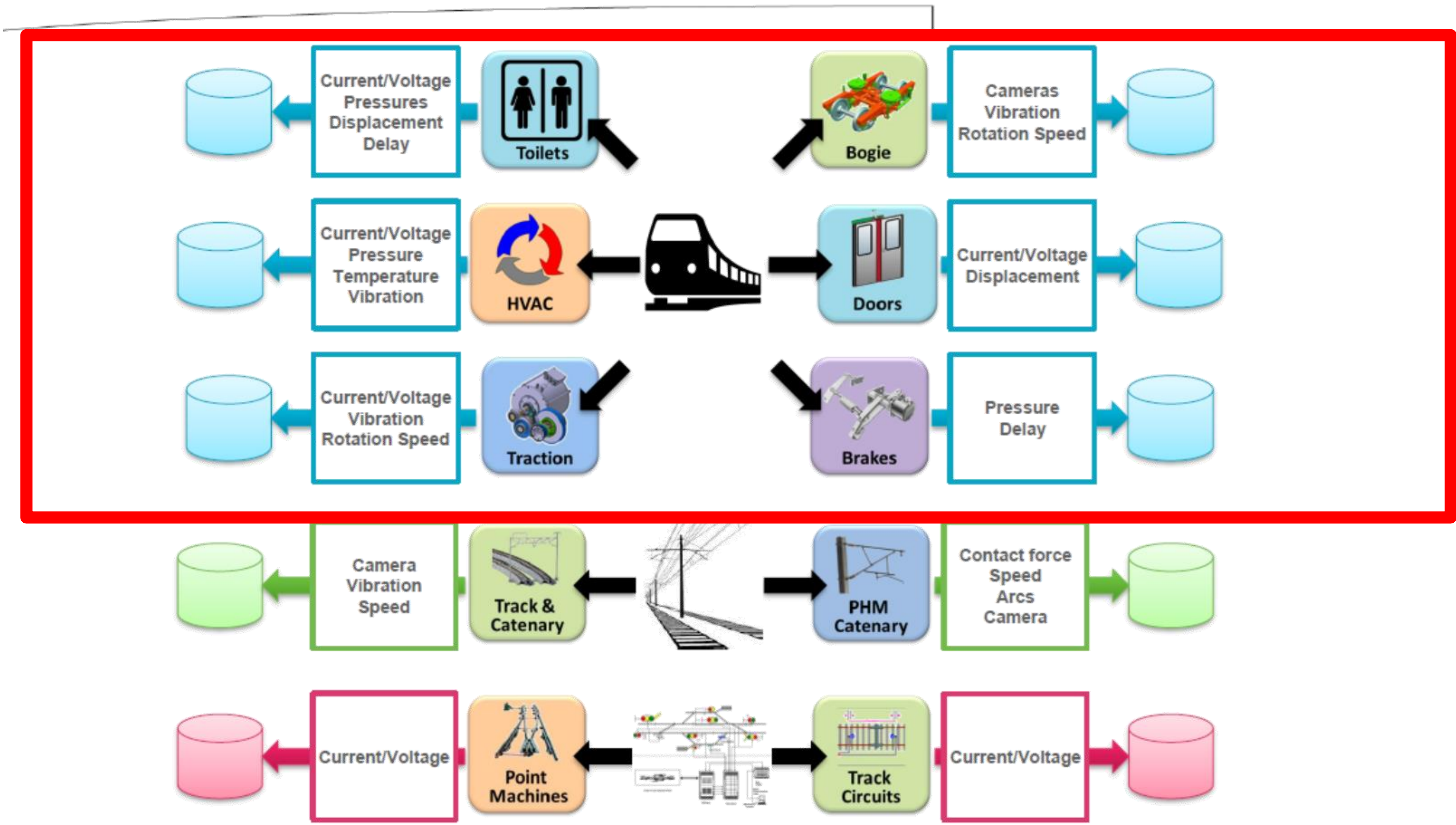
Regulatory Bodies
- Increase Asset Safety
- Eliminate Catastrophic Failures
- Understand and minimise impact on society

Manufacturers and Service Providers
- Re-defining and exceeding customer expectations
- "As a service" business models
- Through-life monetisation of asset activities.

Asset Manager
- Best Lifecycle Cost
- Business Planning
- Maximising Capability

Insurers
- Enhancement of actuarial science, accurate pricing of risks
- Objective evidence for claims
- Better management of insurance premiums

Dealing with most subsystems of a Railway network



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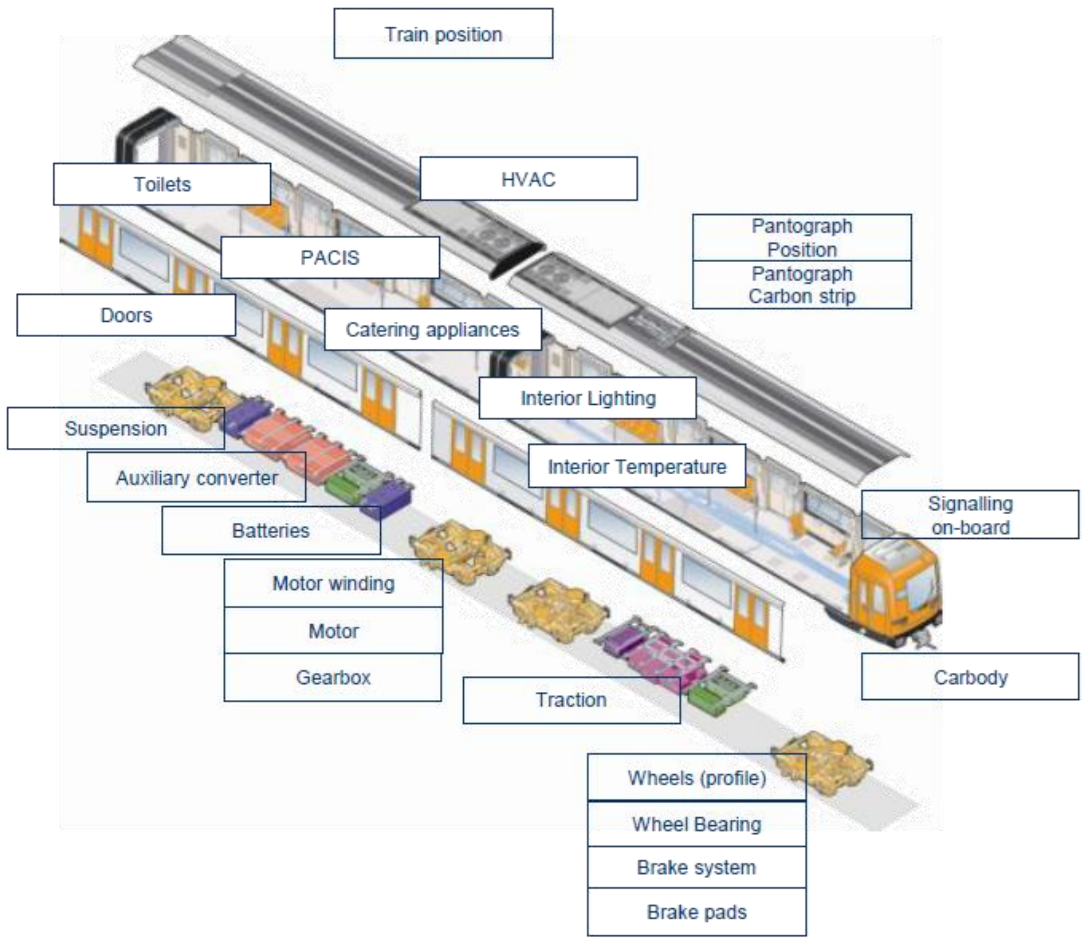
What assets are we monitoring?

Prognostics

Health assessment & monitoring

Data capture

Rolling stock



Infra

- Track
- Catenary
- Sub-stations

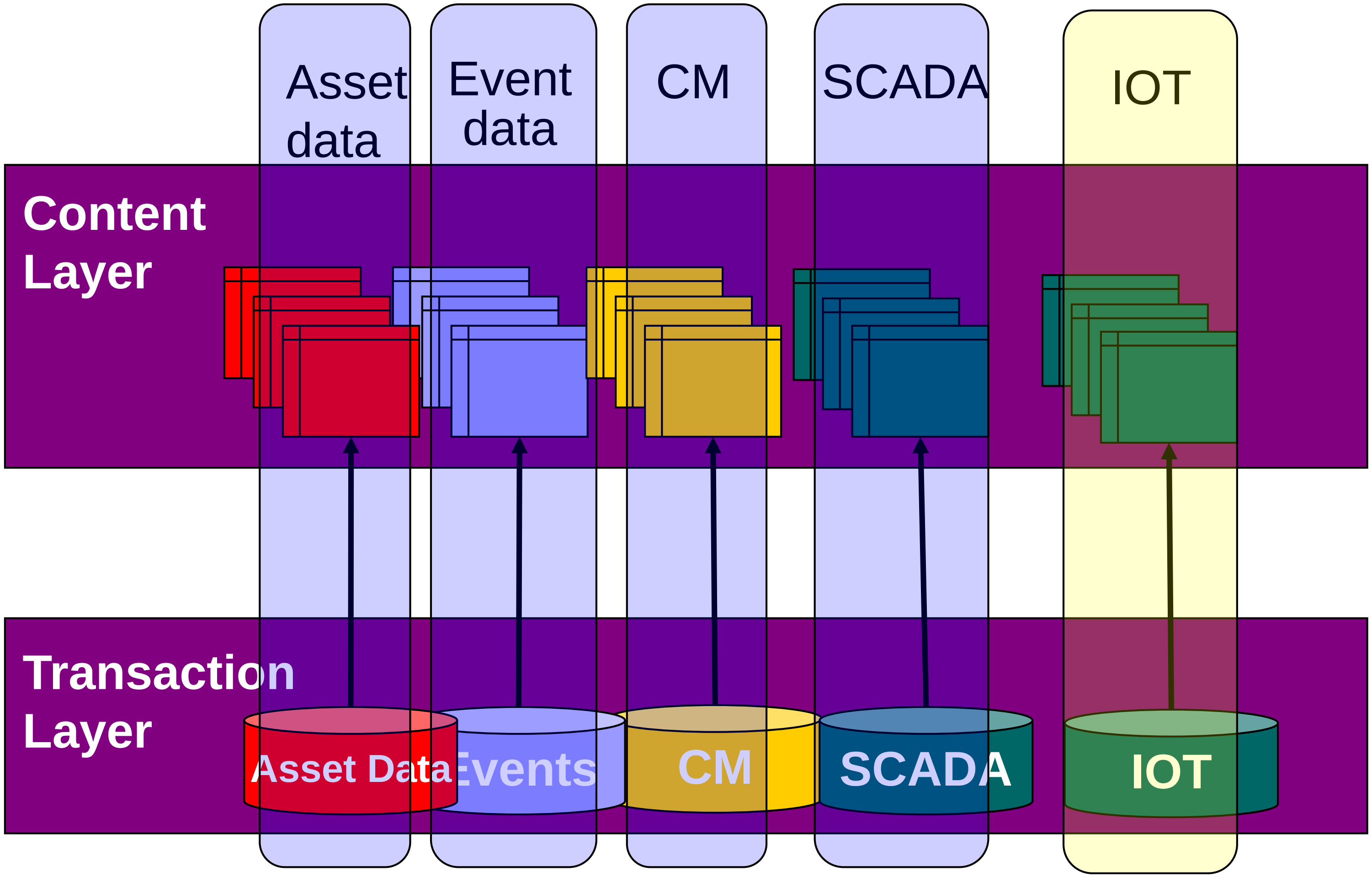
Signalling

- On-board ATP/ATO
- Wayside (IXL, ATP)
- Trackside/ Points
- On-board video feed
- On-board PIS

Station

- Station PIS
- Station Eqt (Elevator,...)
- Station security

What data we gather and what connections are needed?



Silos of data by functional area

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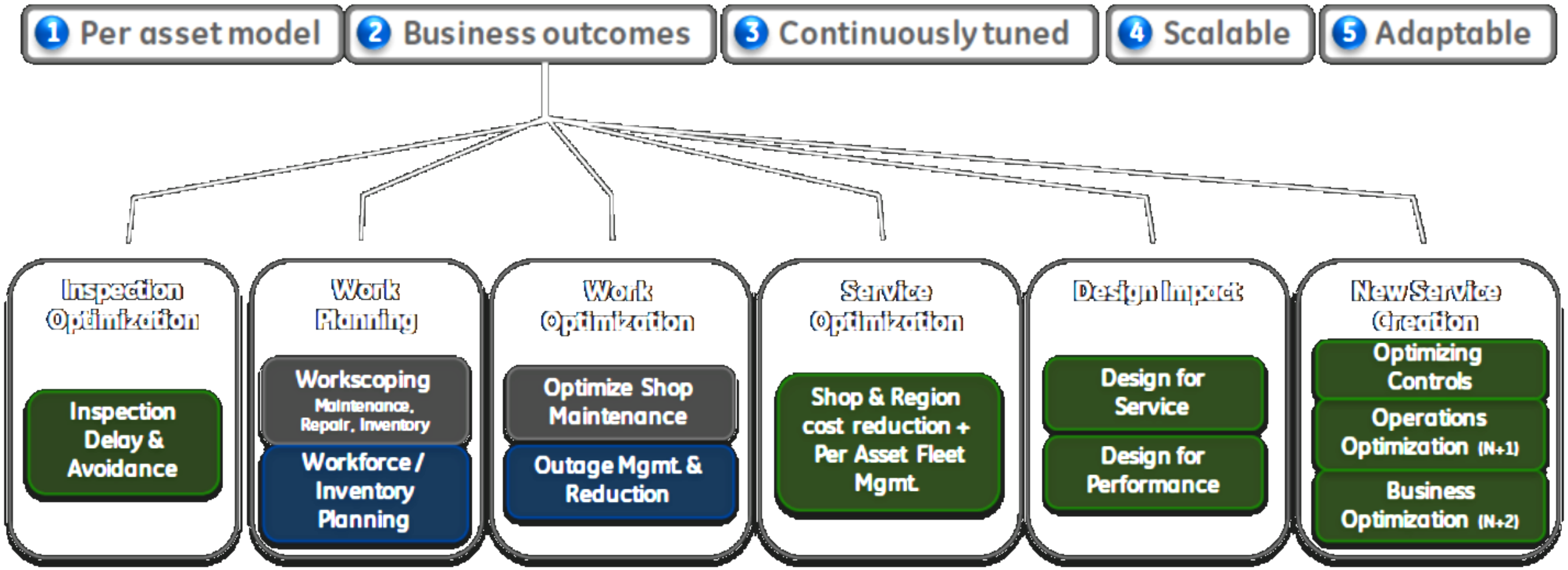
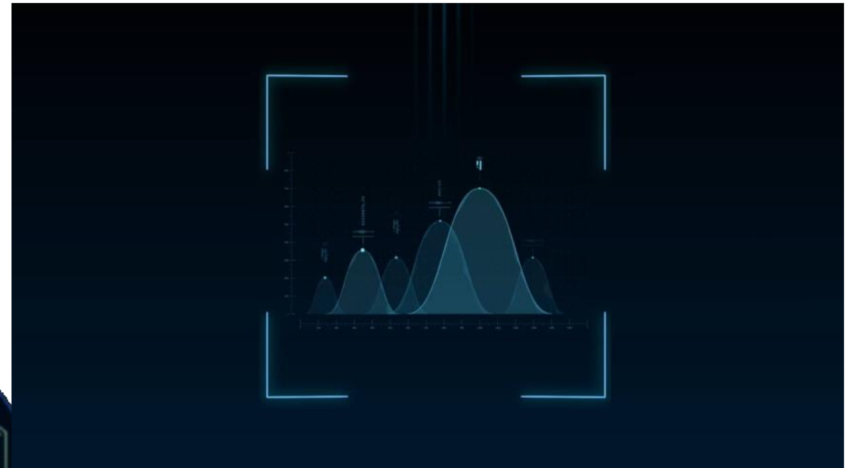
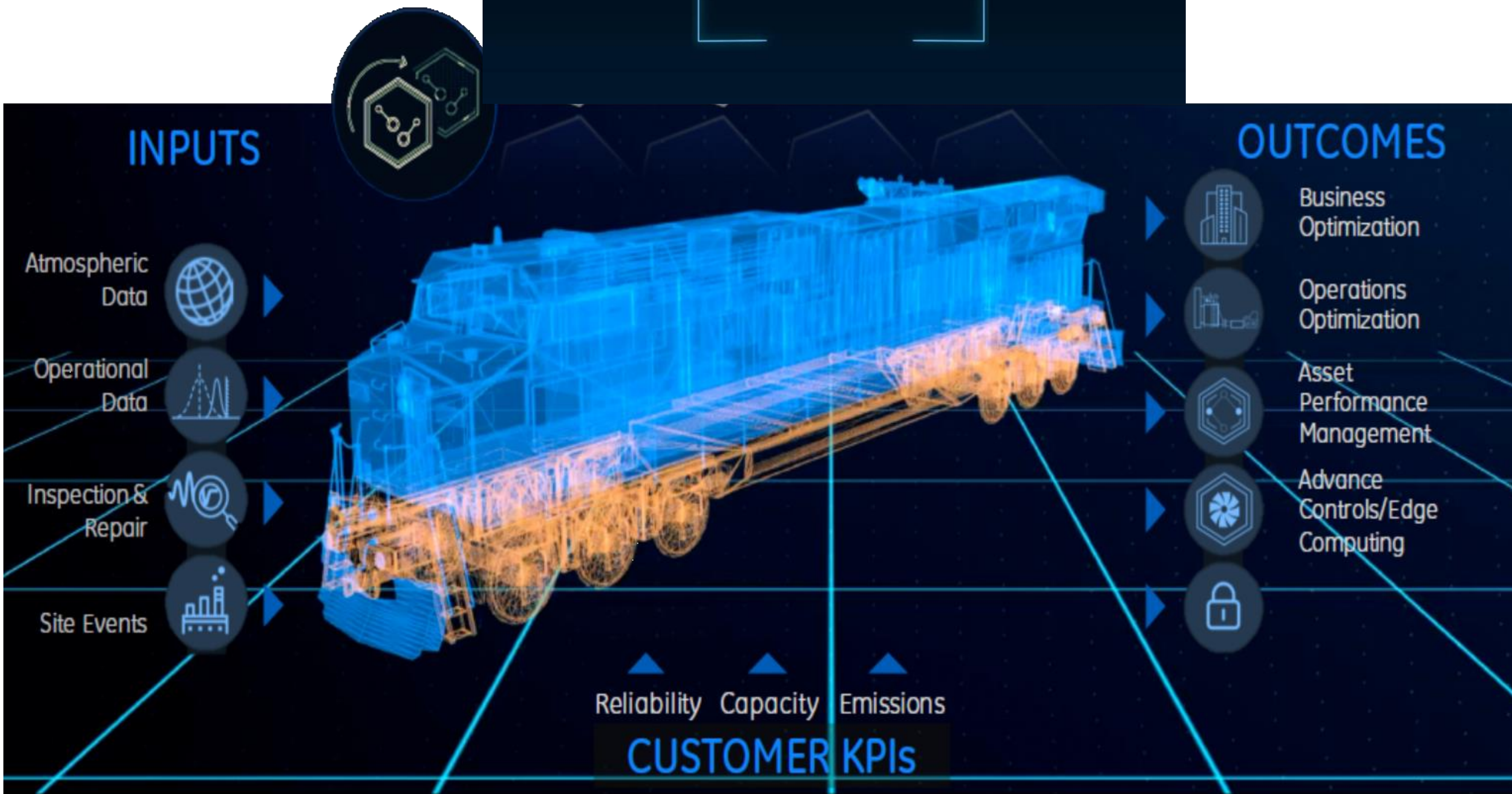
Digital Twin – Definition

Engineering models that continuously increase insights into each asset to deliver specific business outcomes






INPUTS
Atmospheric Data
Operational Data
Inspection & Repair
Site Events
OUTCOMES
Business Optimization
Operations Optimization
Asset Performance Management
Advance Controls/Edge Computing
Reliability
Capacity
Emissions
CUSTOMER KPIs

Introduction to Digital Twin Technology

What is a digital twin?

A digital twin or digital replica is a virtual model of a physical asset such as a product, process, system or a facility. Said digital replica takes and uses data from an actual physical asset to better understand and augment its performance. For example, engineers can identify the safety risks of an aircraft engine by assessing different temperatures and stresses on parts, surgeons can navigate a digital visualization of an organ before operating on it, a digital twin of a rocket that displays its maximum wind resistance can ensure a launch in bad conditions, and so on.

Powered by a combination of artificial intelligence (AI), machine learning, and data analytics, digital twins can mirror a physical twin and reveal issues before they occur. To do so, they rely on a range of sensors embedded in the physical world to transfer real-time data about the operative process and environment. The data collected from the connected sensors is then analysed on the cloud and is accessible via a dashboard.

Internet of Things an integral part of digital twin technology

From the very definition, it's clear that digital twins ought to depend on IoT technologies. Driven by sensors, artificial intelligence, machine learning, data and analytics, IoT acts as the foundation for digital twins, as it leverages specific data about physical assets to help companies make better decisions.

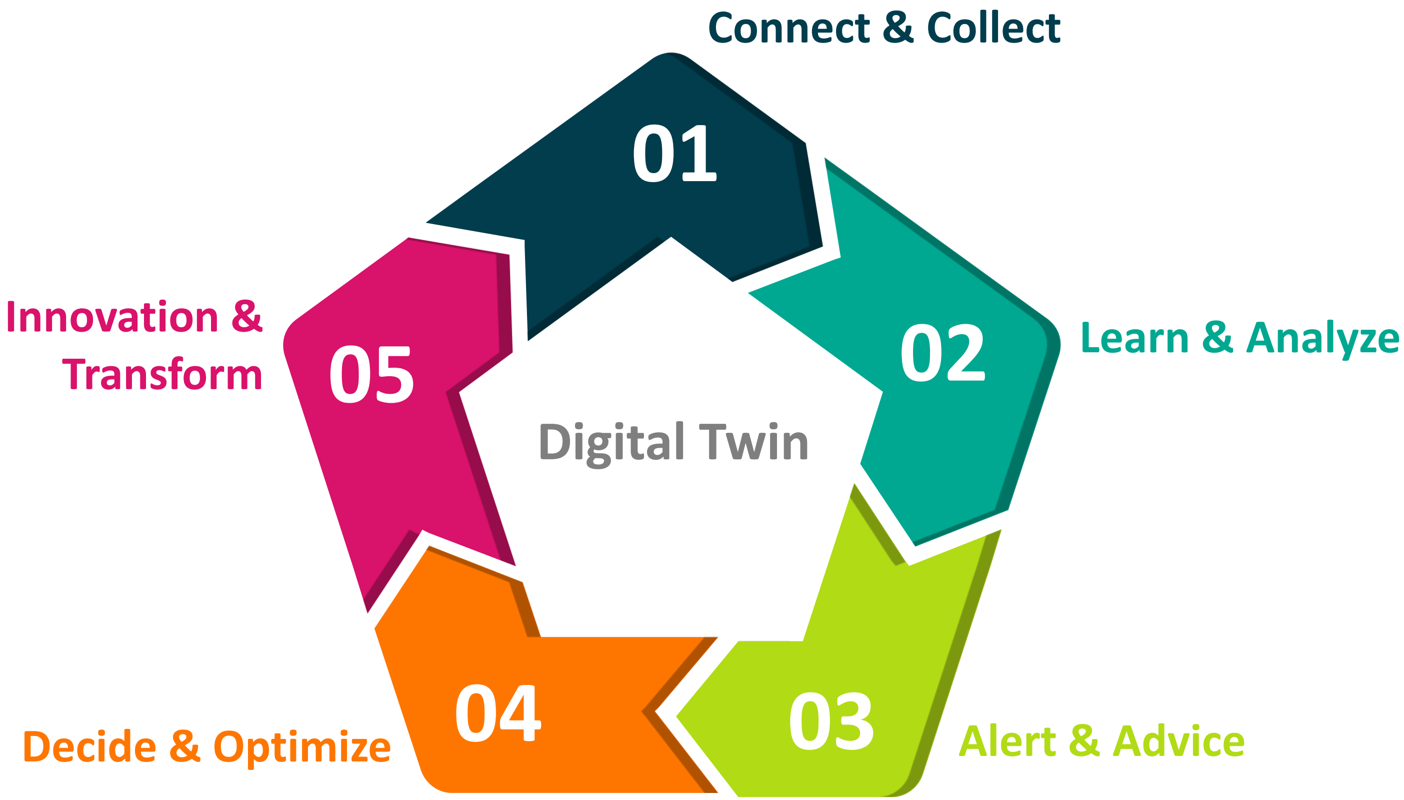
Digital twin is, therefore, expected to increase IoT deployments given its ability to add value for end-customers.

Experts predict that, within the next five years, digital twins will be adopted by 85% of all IoT platforms.

Insight

The term "Digital Twin" was defined for the first time by Dr. Michael Grives at the University of Michigan 2002/03 in Virtually Perfect Driving Innovative and Lean Products through Product Lifecycle Management.

Introduction to Digital Twin Technology



How it works & Why it matters

Digital Twin, the virtual counterparts of a physical asset is created as the digitalized duplicate of a machine/ equipment or aa physical site. These digital assets can be created even before an asset is built physically. To create a digital twin of any physical asset, engineers collect and synthesize data from various sources including physical data, manufacturing data, operational data and insights from analytics software. All this information along with AI algorithms is integrated into a physics-based virtual model and by applying Analytics into these models we get relevant insights regarding the physical asset. The consistent flow of data helps in getting the best possible analysis and insights regarding the asset which helps in optimizing the outcome.

Digital twins are powerful masterminds to drive innovation and performance. Imagine it as your most talented product technicians with the most advanced monitoring, analytical, and predictive capabilities at their fingertips. By 2018, companies who invest in digital twin technology will see a 30 percent improvement in cycle times of critical processes, predicts IDC.

Also, the digital twin technology helps companies improve the customer experience by better understanding customer needs, develop enhancements to existing products, operations, and services, and can even help drive the innovation of new business.

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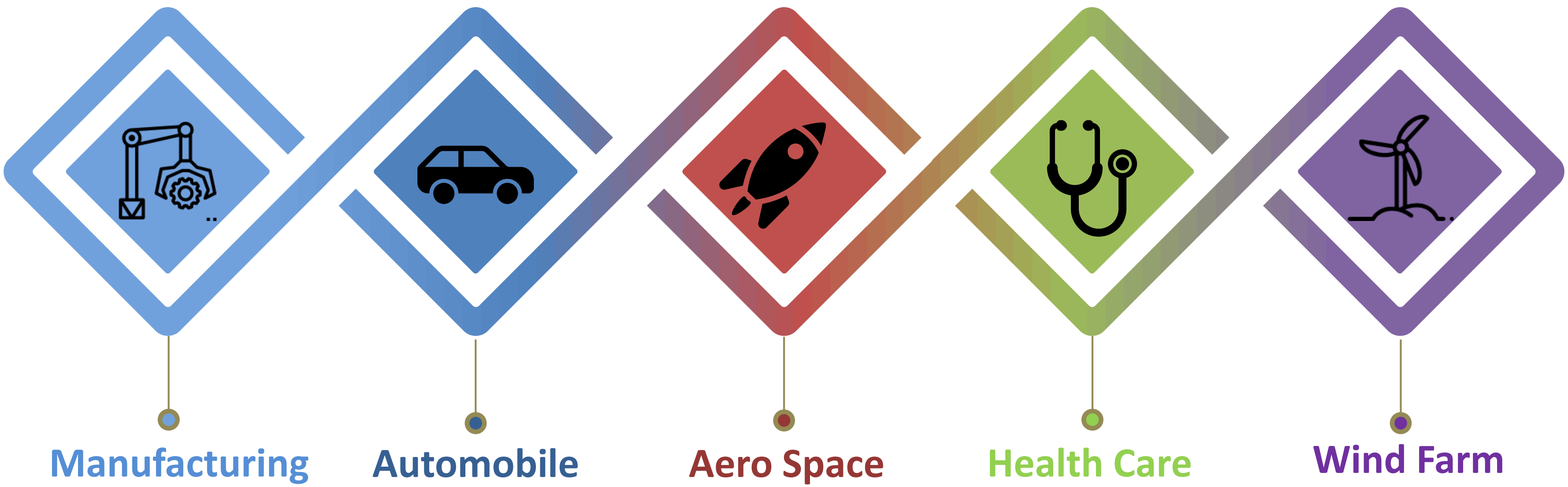
Major Applications-Digital Twin Technology



Other Applications

Retail, Infrastructure, Oil & Gas Industry and Gas Turbines

Economic value of Digital Twin

The economic value of the digital twins technology will vary widely, depending on the monetization models that drive them. For complex, expensive industrial or business equipment, services or processes, improving utilization by reducing asset downtime and lowering overall maintenance costs will be extremely valuable, making internal software competencies critical to driving value with digital twins.

As such, the costs of developing and maintaining digital twins must be driven by both business and economic models. Digital twins are not developed in a vacuum. Both the business concept and model must be tested against an economic architecture – revenue, profits, return on investment (ROI), cost optimization – and a way to measure progress as the products/services are rolling out.

To obtain the highest value from digital twins, the enterprise must address the digital ethics issues raised by different parties interacting with the data from not just the enterprise, but also its partners and customers. This will require the enterprise to think about the value of the data and its contributions to the business and partners, and also to identify potential areas where its customers or its own data could drive value but also could be at risk.

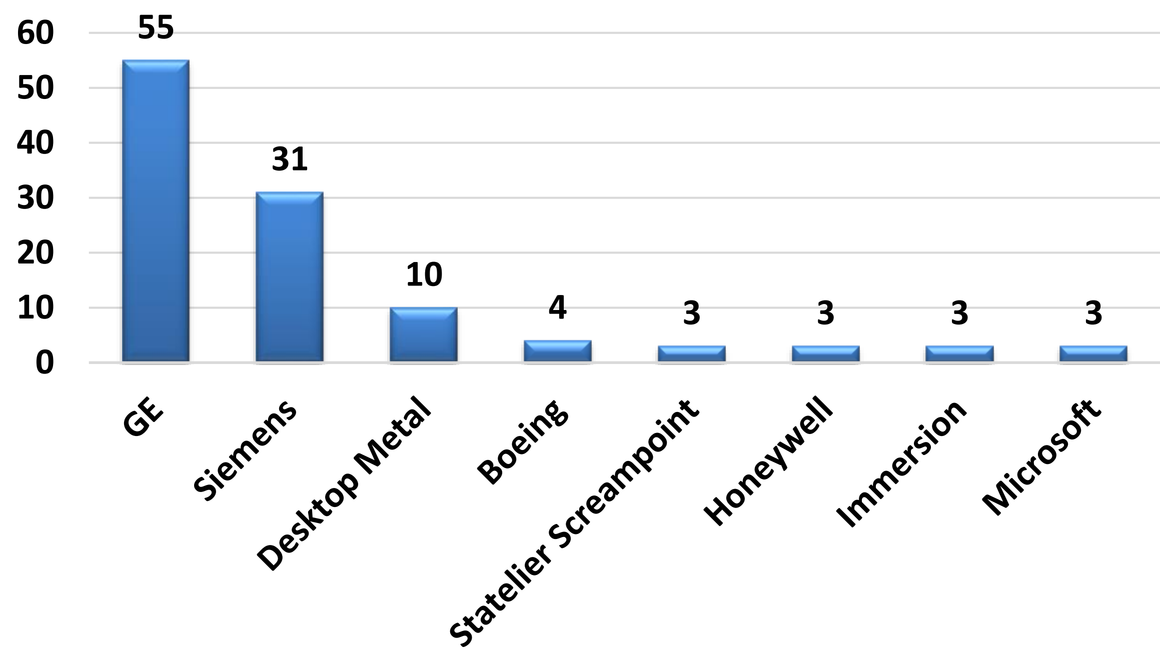
Future of Digital Twin

In the future, expect to see the expansion of the IoT, and with it, some version of digital twin technology. According to predictions, by 2022, 85 percent of all IoT platforms will include some kind of digital twinning.

As more and more products in our homes and workplaces evolve into smart devices (i.e., they connect to the Internet, providing remote access and control), we'll also see an increase in the availability of digital twin technology. These digital twins already allow you to remotely adjust the temperature in your smart home, for example. Or to make calls using your business number on a "softphone" that's available on all your personal devices.

Benefits of Digital Twin

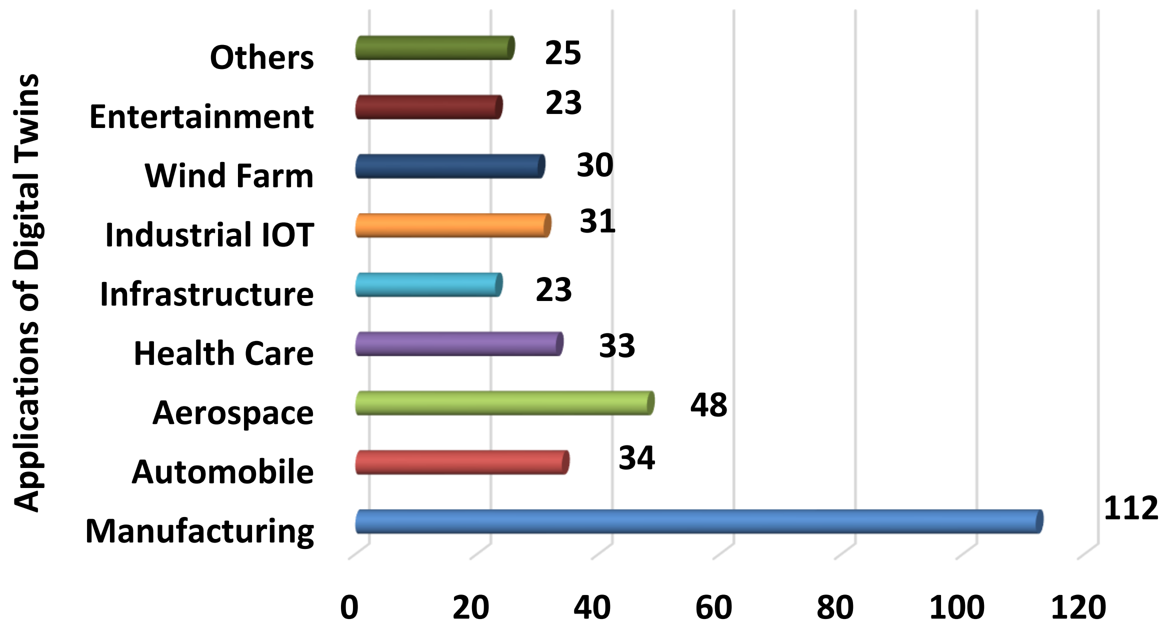
Top Practising Entities (PEs)



Insight

General Electric (GE) is the leading patent applicant in Digital Twin Technology, followed by Siemens and Desktop Metal.

Digital Twin Application Analysis



Insight

Digital Twin Application Analysis demonstrates that maximum number of Digital Twin patent applications were filed in Manufacturing Industry followed by Aerospace and Automobile Industries.

IoT -Internet of Things

- The Internet of Things (IoT) is the network of items embedded with ***electronics***, ***software***, ***sensors***, ***actuators***, and ***network connectivity***
- which enable these objects to ***connect and exchange data***

IoT is what we need to ***connect***

Cloud computing

- Cloud computing is an information technology paradigm that enables ***access*** to shared pools of configurable system ***resources***
- In some presentations the term Internet of Services (IoS) rather than cloud computing

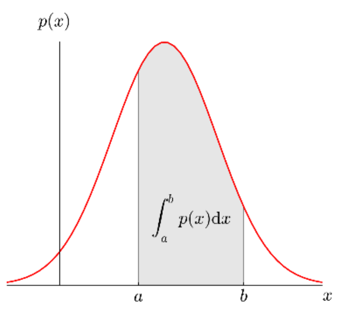
With cloud computing we do not need to think about platforms, how to connect etc

Digital twin

- The digital twin refers to a digital ***replica*** of physical assets, processes and systems that can be used in real-time for control and decision purposes
  - Computerized mathematical model (what we have done over years)
  - Real-time, thanks to IoT
- In contrast to a physical asset, the digital twin can immediately respond to ***what-if*** inquiries

Stochastic digital twin

- A stochastic digital twin is a computerized model of the ***stochastic behavior*** of a system where
  - the model is updated in real-time
    - based on sensor information and other information
    - accessed via the internet and the use of cloud computing resources
- What-if inquiries result in ***pdf***'s rather than single values



Real-time model

- A real-time model is a model where it is possible to obtain values of system performance and system states in ***real-time***
- With real-time we mean that data referring to a system is analysed and ***updated at the rate at which it is received***

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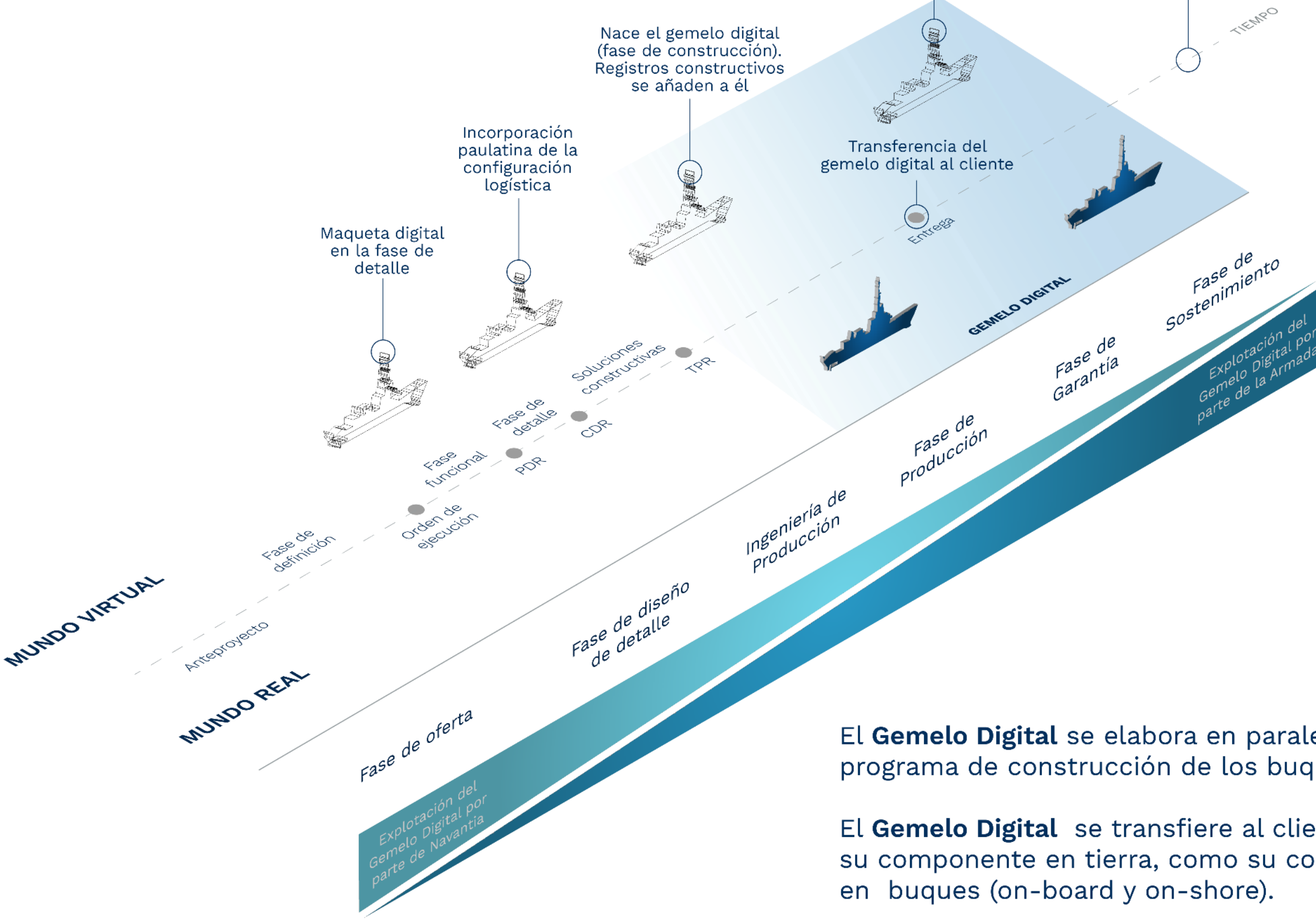
CICLO DE VIDA DEL GEMELO DIGITAL



El **Gemelo Digital** se elabora en paralelo al programa de construcción de los buques.

El **Gemelo Digital** se transfiere al cliente, tanto su componente en tierra, como su componente en buques (on-board y on-shore).

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EVOLUCIÓN DE LA F-100

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2002 2004 2006 2008 2010 2012 2014 2016 2018

F-101

F-102

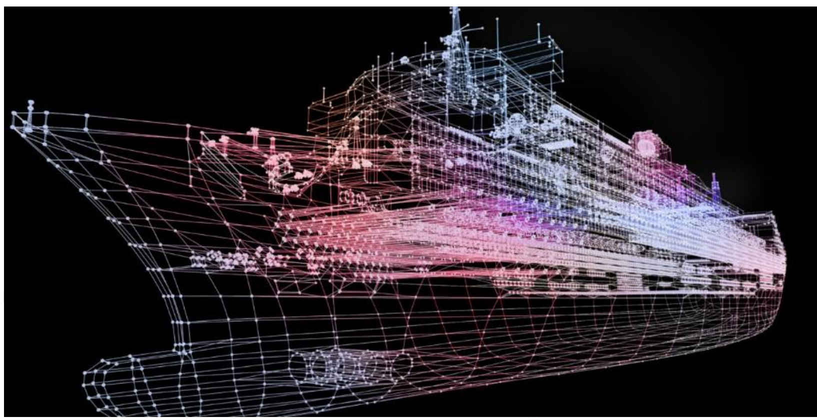
F-104

F-105

AWD

AWD

AWD



(2012)

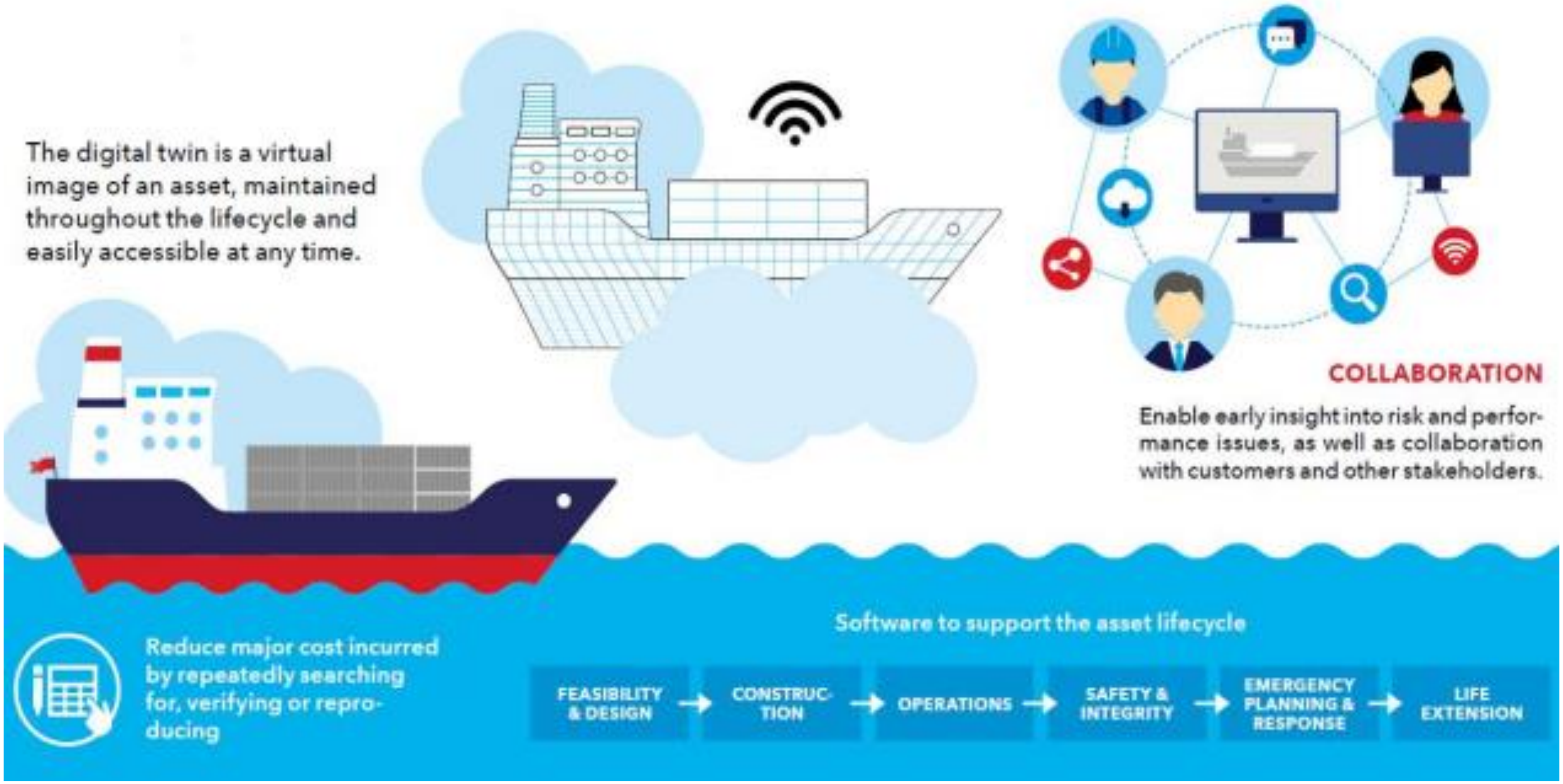
dad incorporó las lecciones e
la responsabilidad frente a
Lockheed Martin

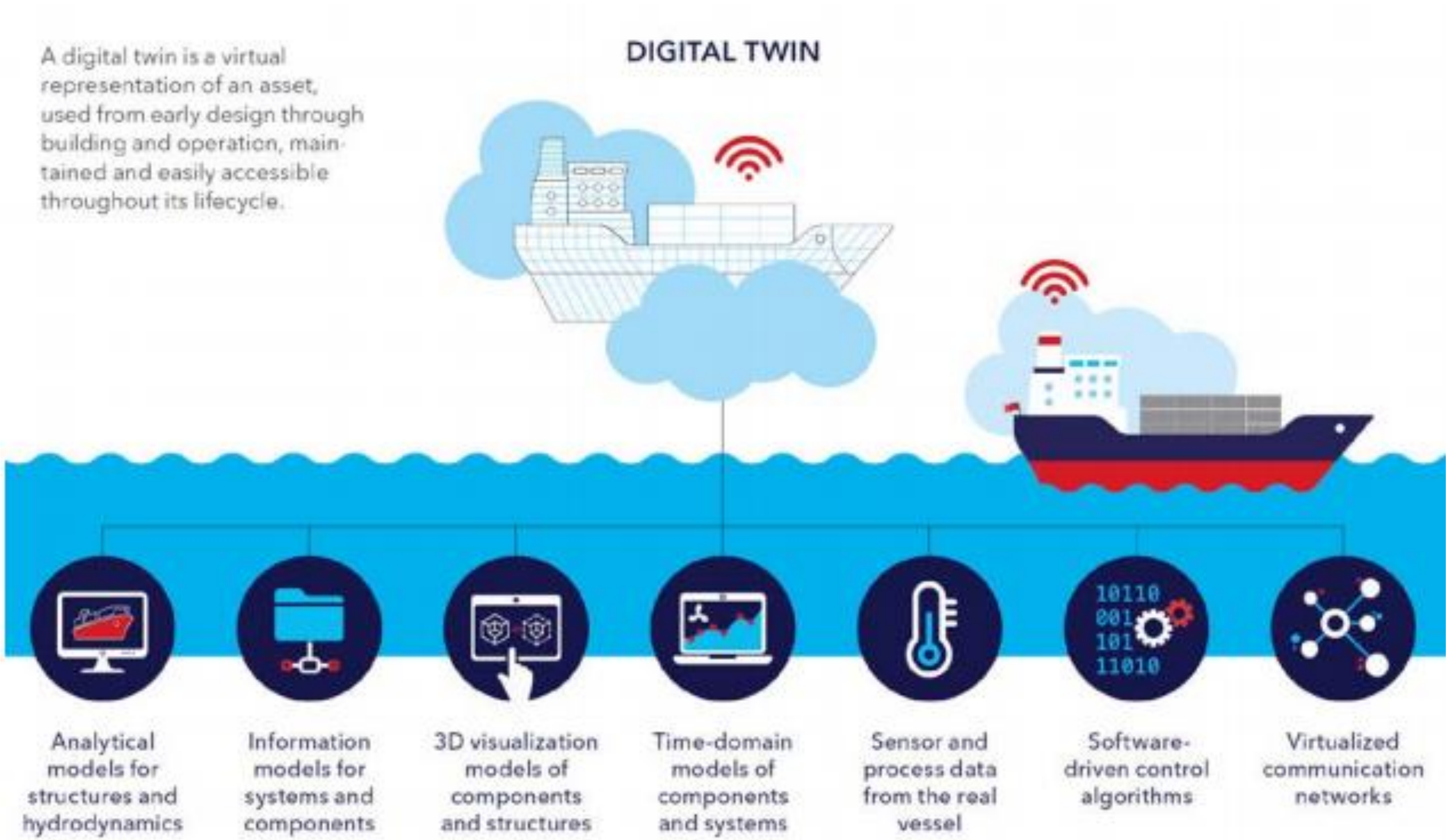
(2006 - 2010)

Entrega a la marina Noruega de 5 unidades adaptadas a la guerra antisubmarina y al radar SPY-1F de Lockheed Martin

(2016 - 2018)

Contrato de los AWD para Australia. Adaptación a diferentes escenarios de construcción y trasferencia de tecnología, garantizando que cualquier imprevisto es afrontado con flexibilidad para mitigar sus efectos


The digital twin is a virtual image of an asset, maintained throughout the lifecycle and easily accessible at any time.
COLLABORATION
Enable early insight into risk and performance issues, as well as collaboration with customers and other stakeholders.
Reduce major cost incurred by repeatedly searching for, verifying or reproducing
Software to support the asset lifecycle
FEASIBILITY & DESIGN
CONSTRUCTION
OPERATIONS
SAFETY & INTEGRITY
EMERGENCY PLANNING & RESPONSE
LIFE EXTENSION



A digital twin is a virtual representation of an asset, used from early design through building and operation, maintained and easily accessible throughout its lifecycle.
DIGITAL TWIN
10110
001
101
11010
Analytical models for structures and hydrodynamics
Information models for systems and components
3D visualization models of components and structures
Time-domain models of components and systems
Sensor and process data from the real vessel
Software-driven control algorithms
Virtualized communication networks


Gemelo Digital

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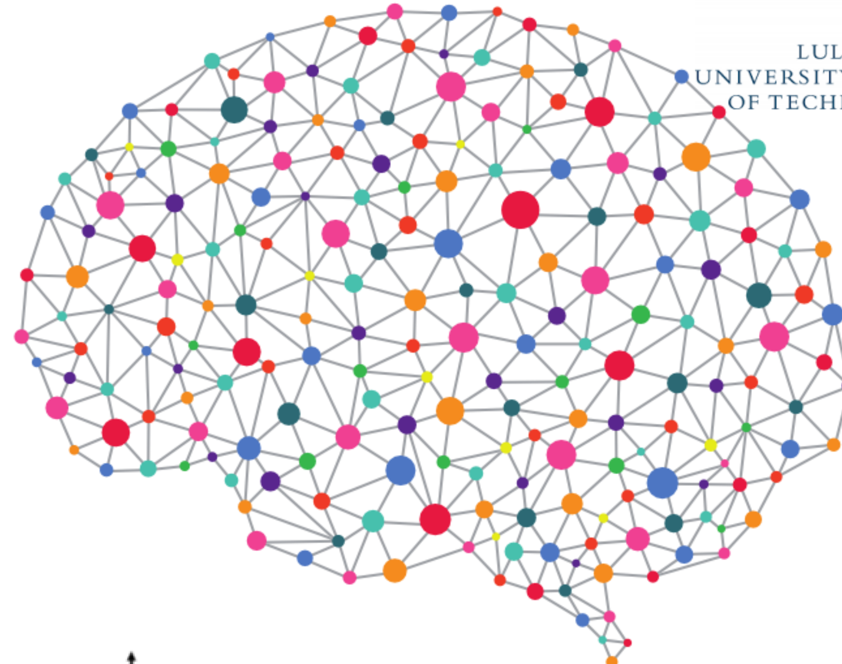
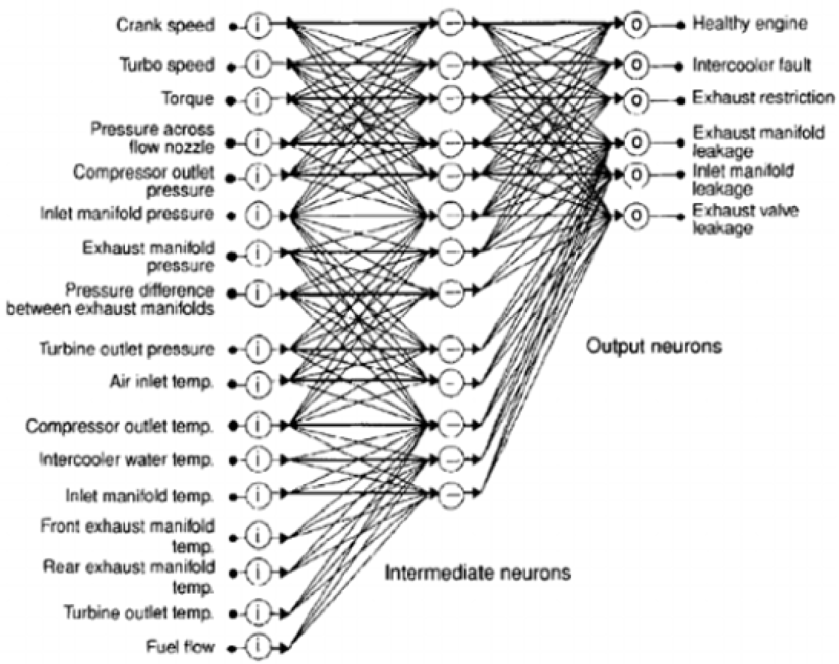
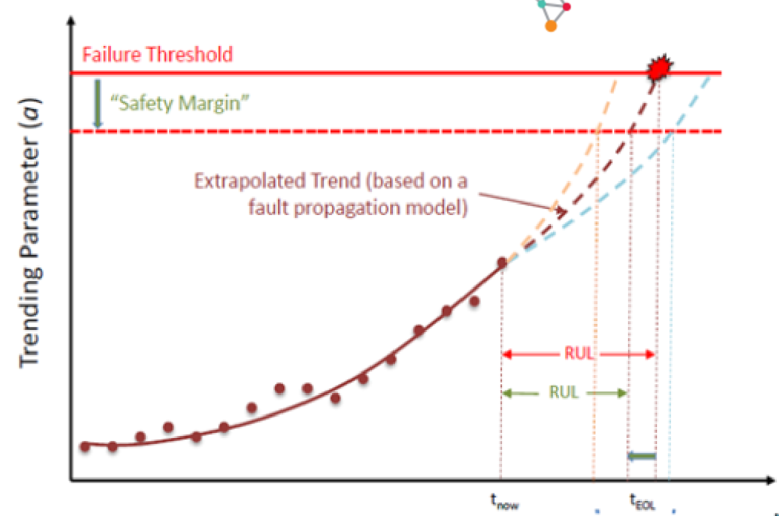
Digital twin 1.0



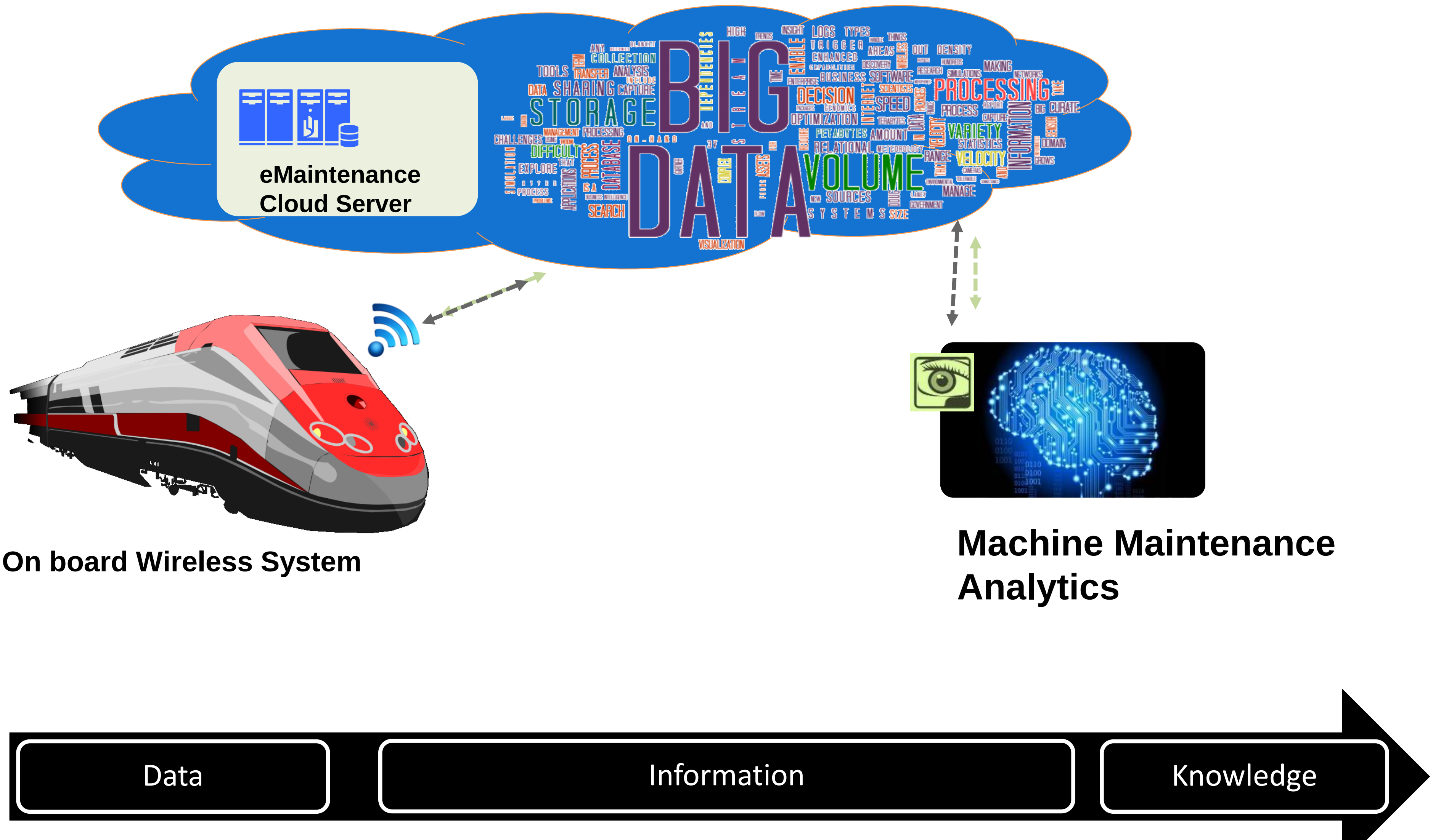


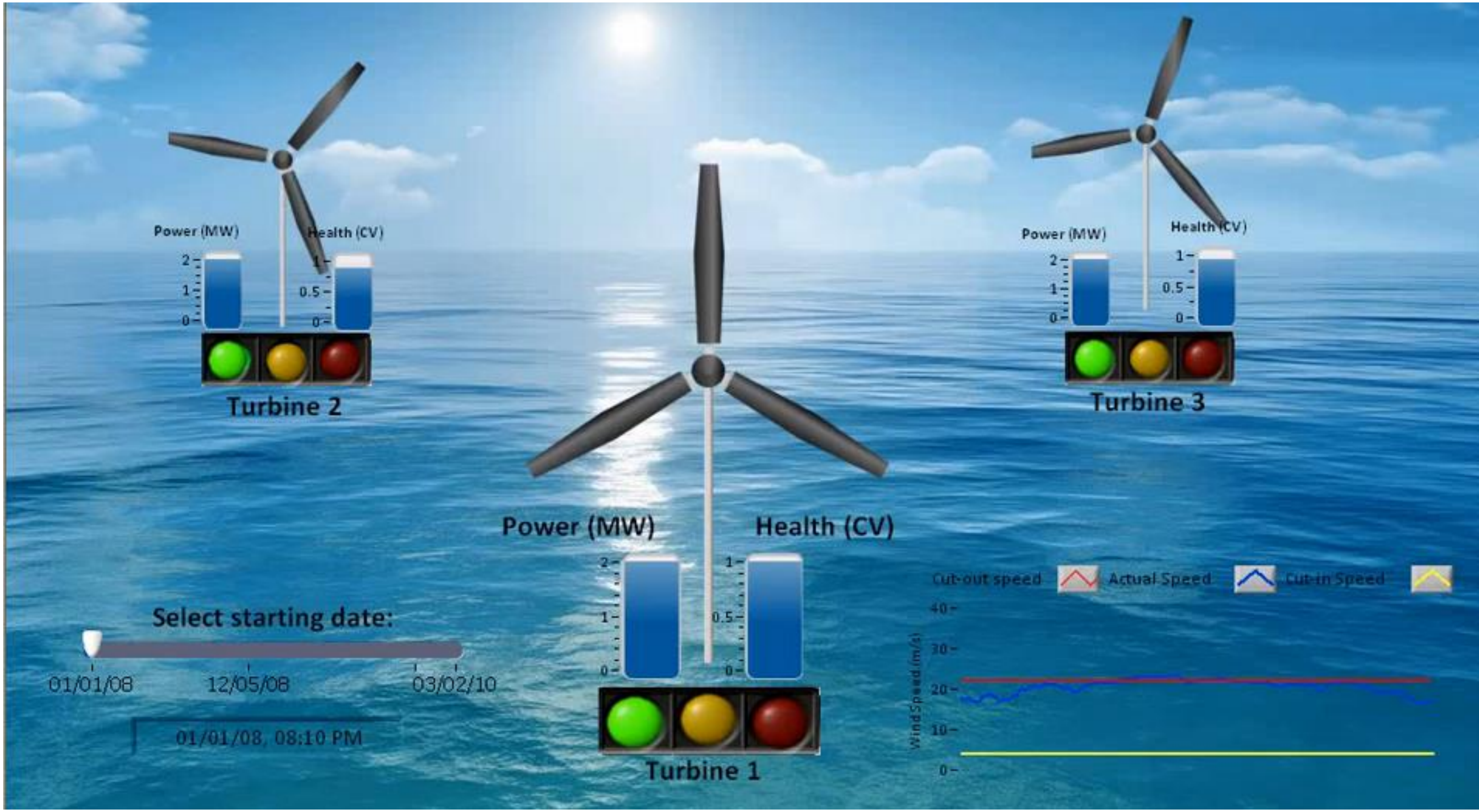


Diagnostics

Prognostics

Digital twin 1.0





Power (MW)
Health (CV)
Turbine 2
Power (MW)
Health (CV)
Turbine 3
Power (MW)
Health (CV)
Turbine 1
Select starting date:
01/01/08
12/05/08
03/02/10
01/01/08, 08:10 PM
Cut-out speed
Actual Speed
Cut-in Speed
Wind Speed (m/s)

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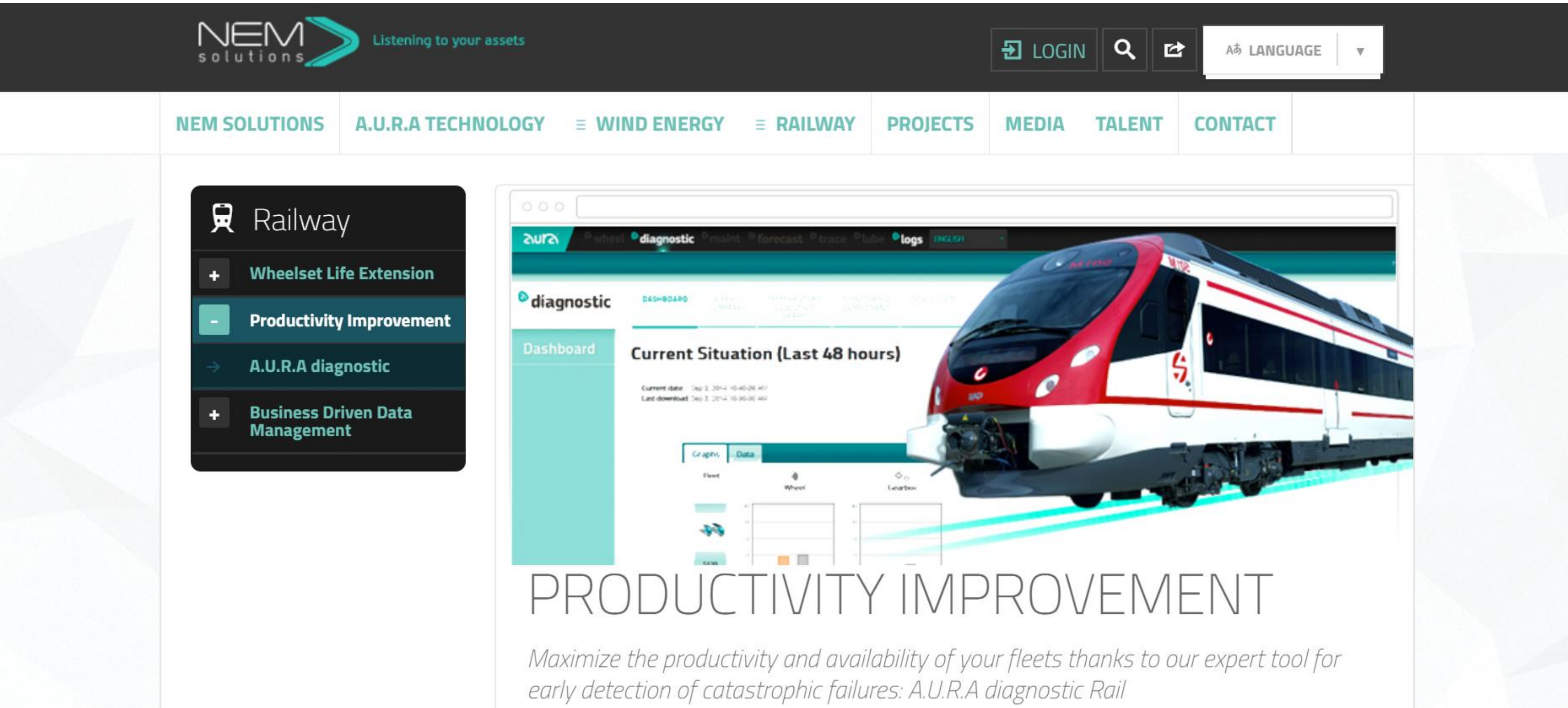

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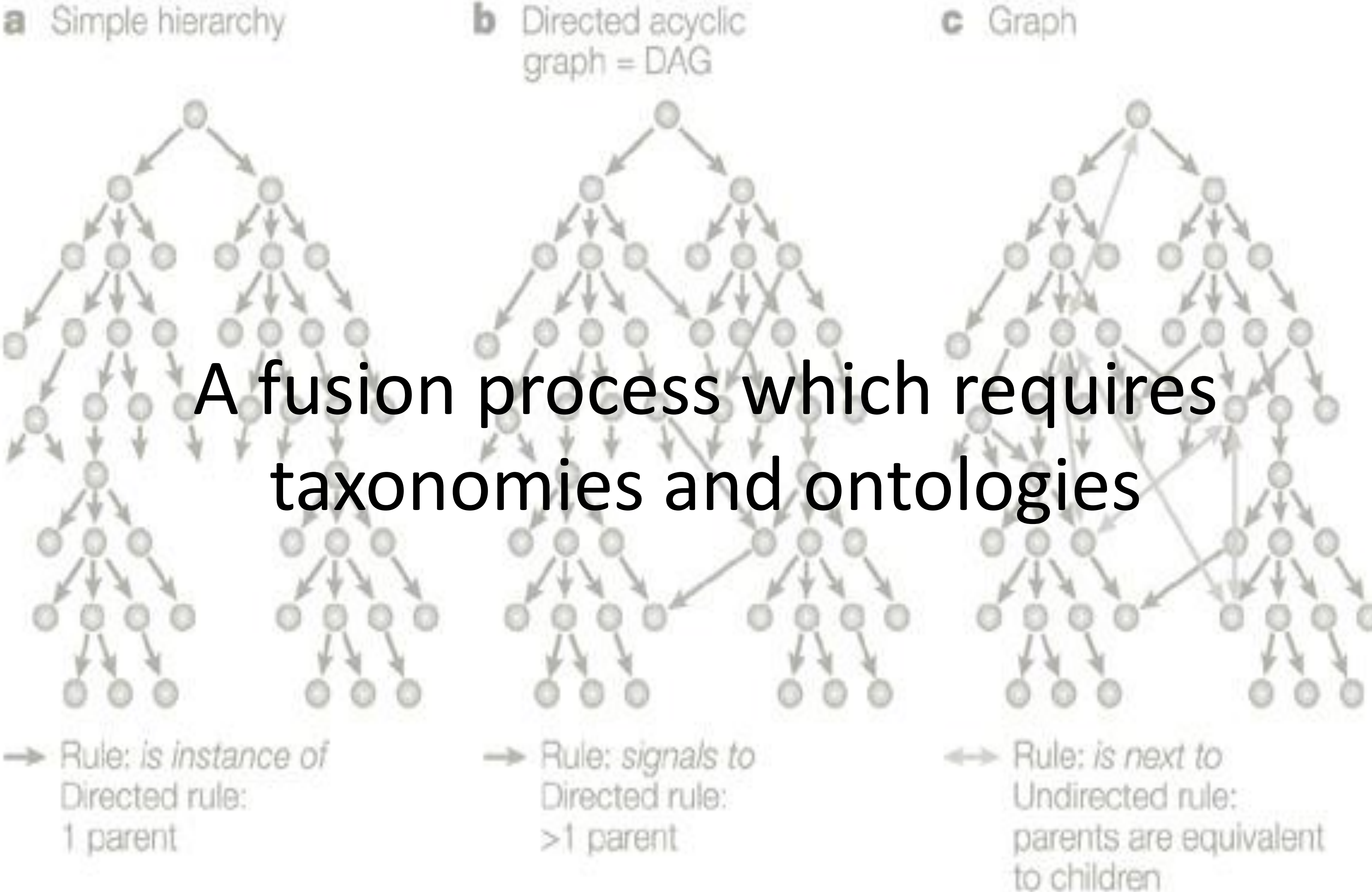
What about IT systems?

A fusion process which requires taxonomies and ontologies



Nature Reviews | Genetics

Taxonomy vs. Ontology

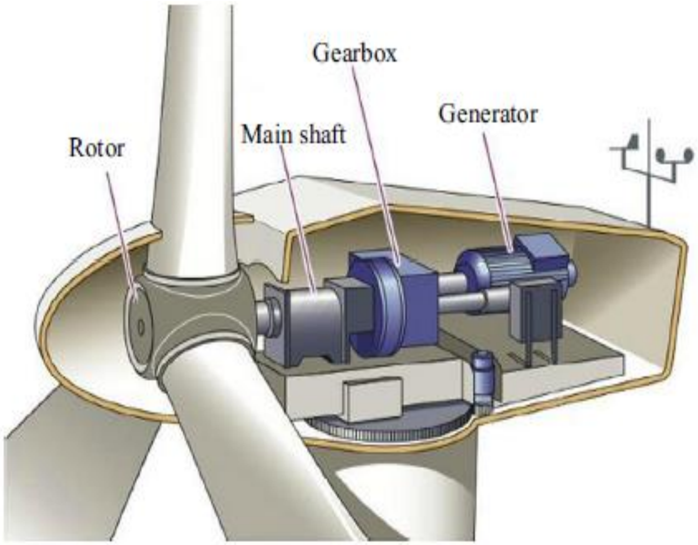
Taxonomies:

- Usually are a single, hierarchical classification within a subject
- Primarily focused on "is-a" relationships between classes
- Limited in inferencing potential due to lack of relational expressiveness.

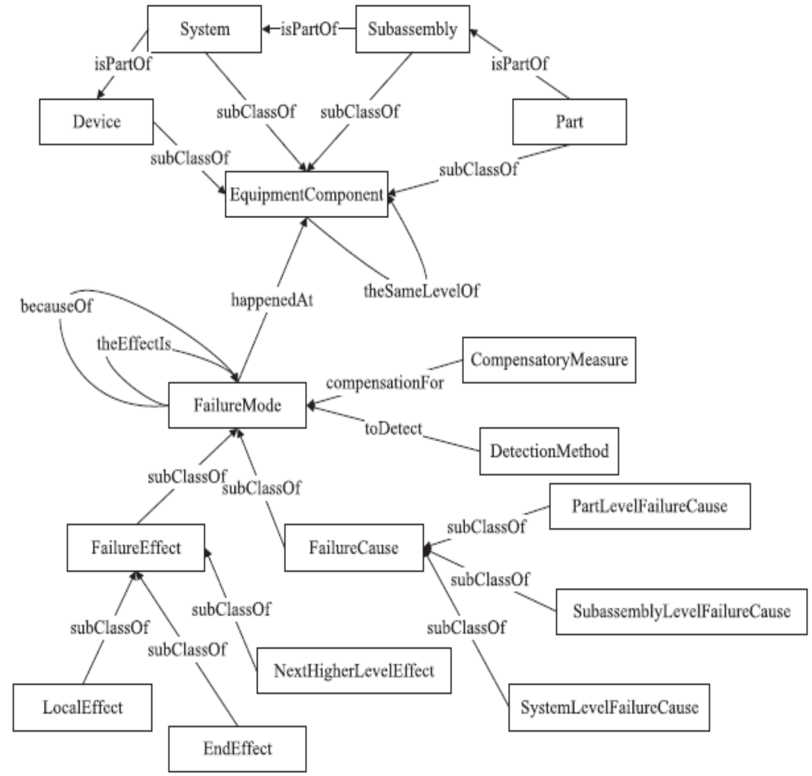
Ontologies:

- Subsume taxonomies.
- Include attributes with cardinality and restricted values.
- Unlimited relationships between entities.
- Superior inferencing support due to relational expressiveness.

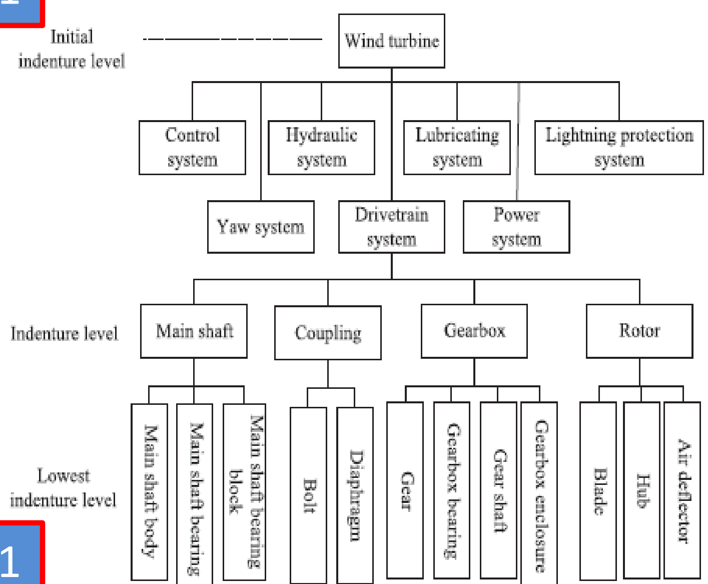
Taxonomies and ontologies



1



2

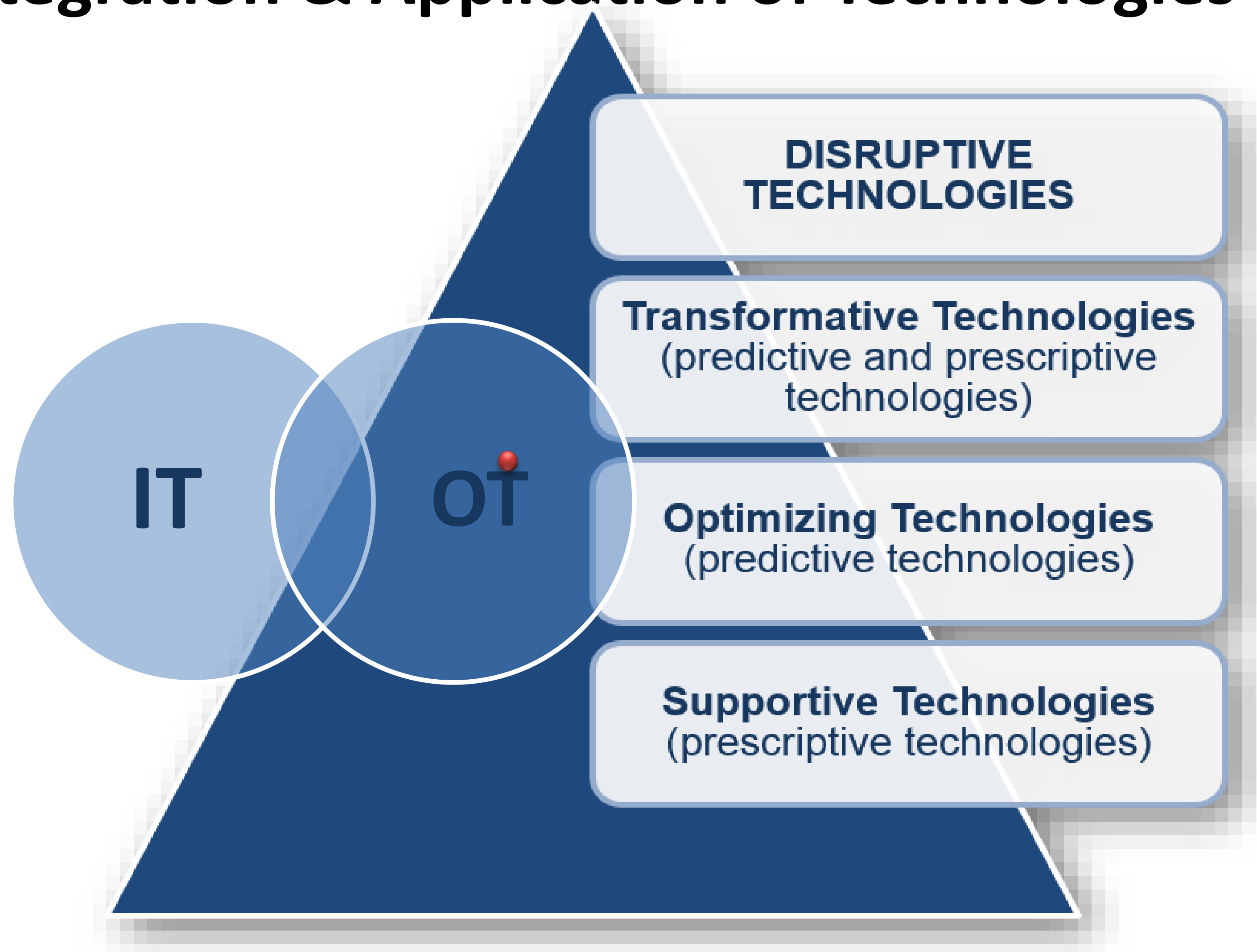


1

Rule-1
FailureMode(?x) ^ hasHappened(?x, true) ^ Device(?y) ^
happenedAt(?x, ?y) ^ FailureMode(?z) ^ theEndFfectIs(?z,
?x) ^ FailureMode(?a) ^ theHighEffectIs(?z,
?a)?theDirectFailureCauseIs(?x, ?a) ^ hasHappened(?a, true)

2

TRANSFORMATIVE MAINTENANCE SOLUTIONS
Integration & Application of Technologies



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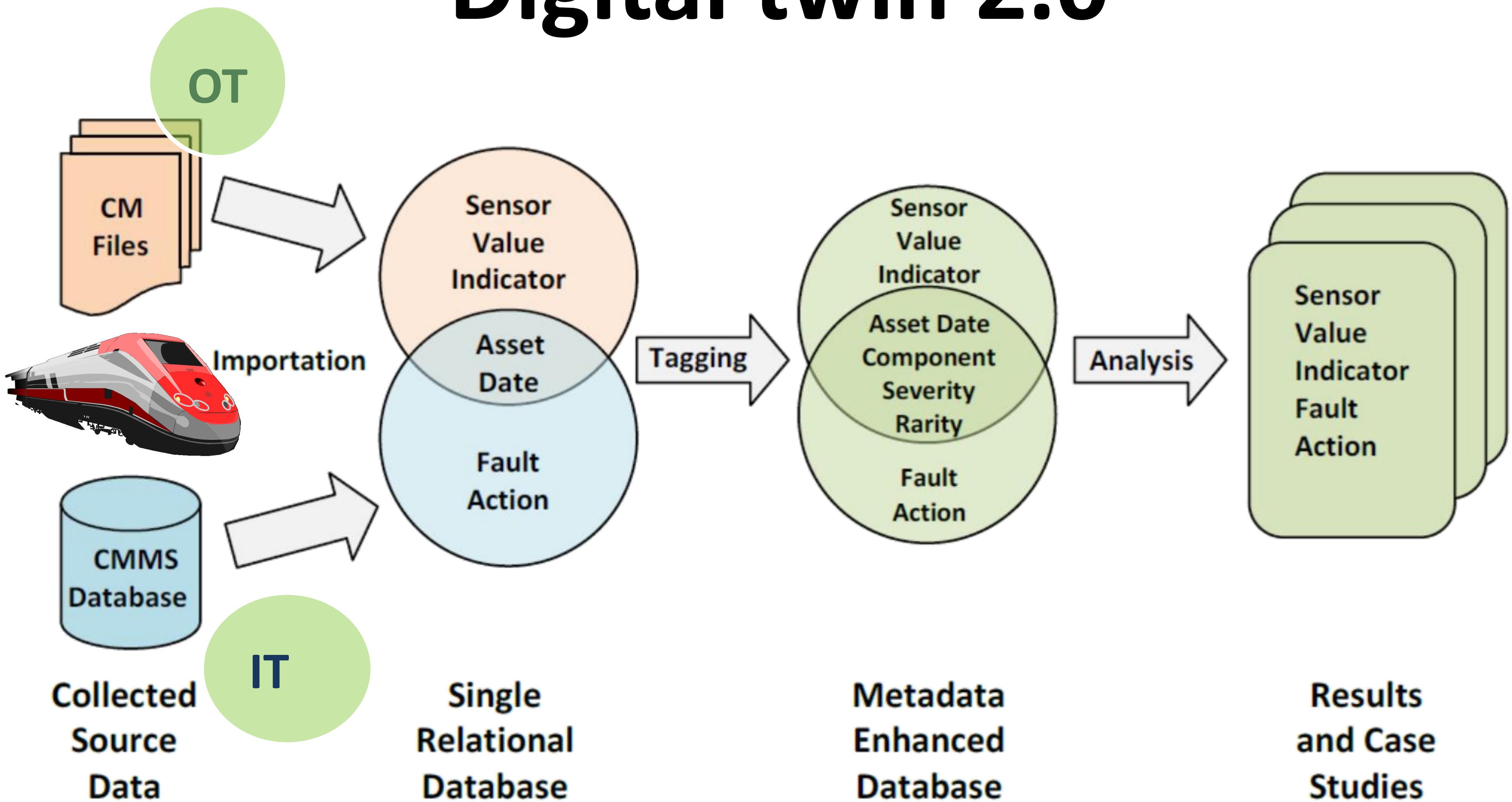
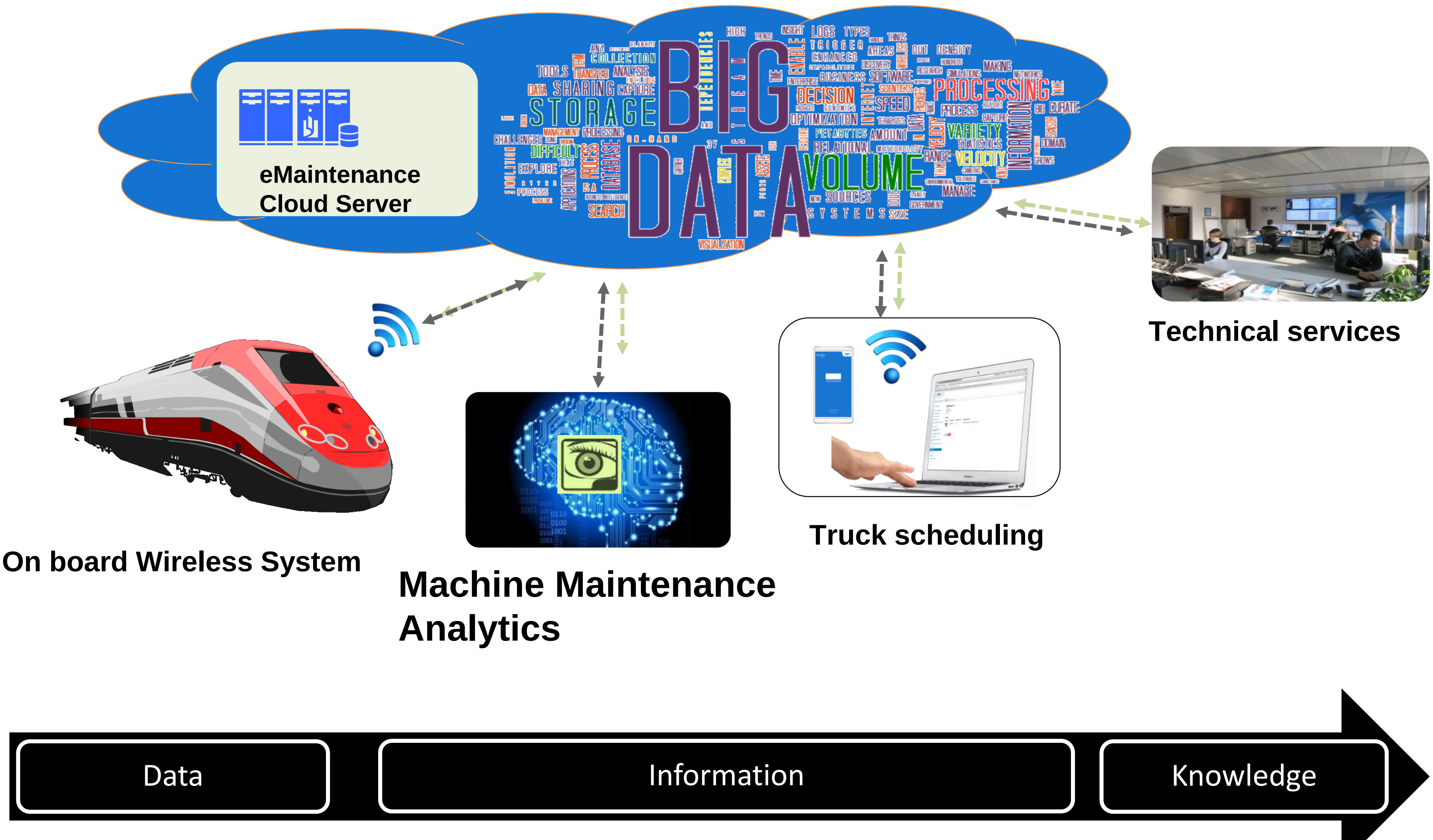
Digital twin 2.0

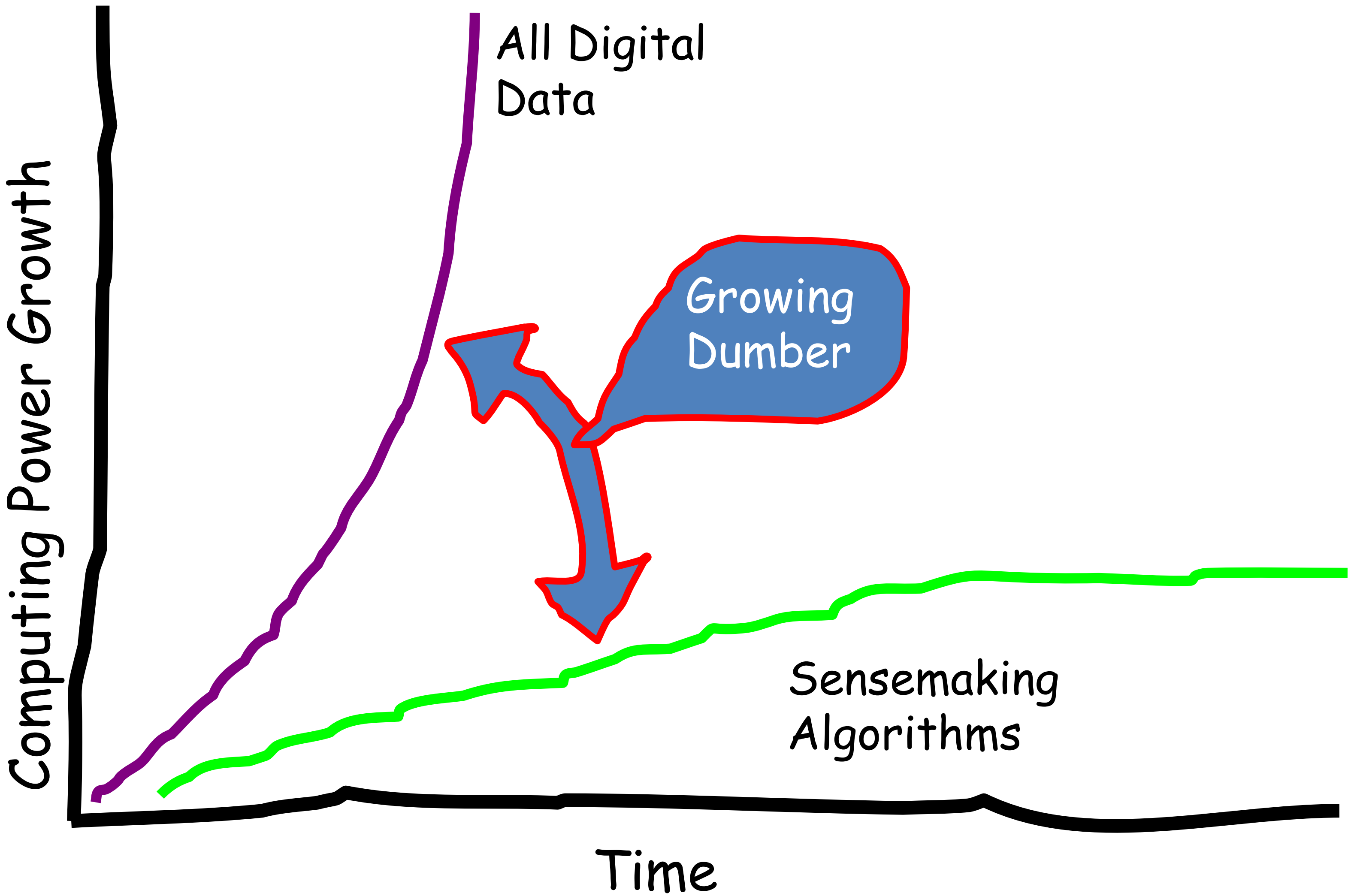


Digital twin 2.0

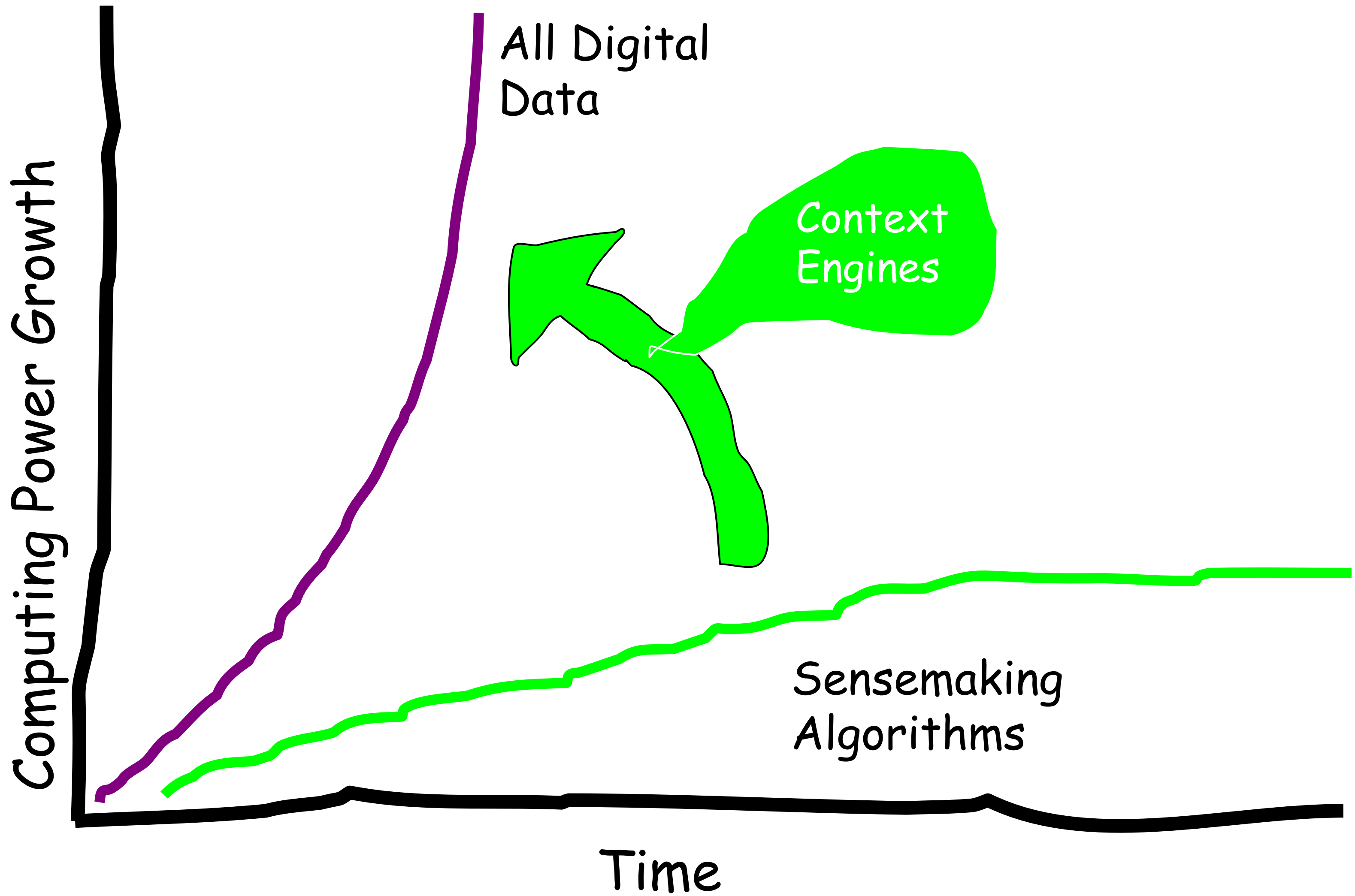


The need for sensemaking Maintenance Analytics

Trend: Organizations are Getting Dumber



The Way Forward

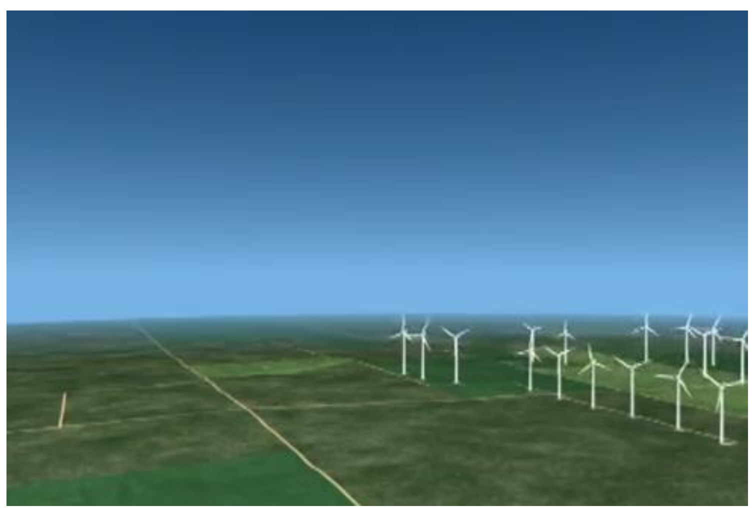


What is context?

"Any information that can be used to characterize the **situation of entities that are considered relevant** to the interaction between a user and an application"

Dey et al.

"A pattern of behavior or relations among variables that are outside of the subjects of design manipulation and potentially affect user behavior and system performance"



Sato

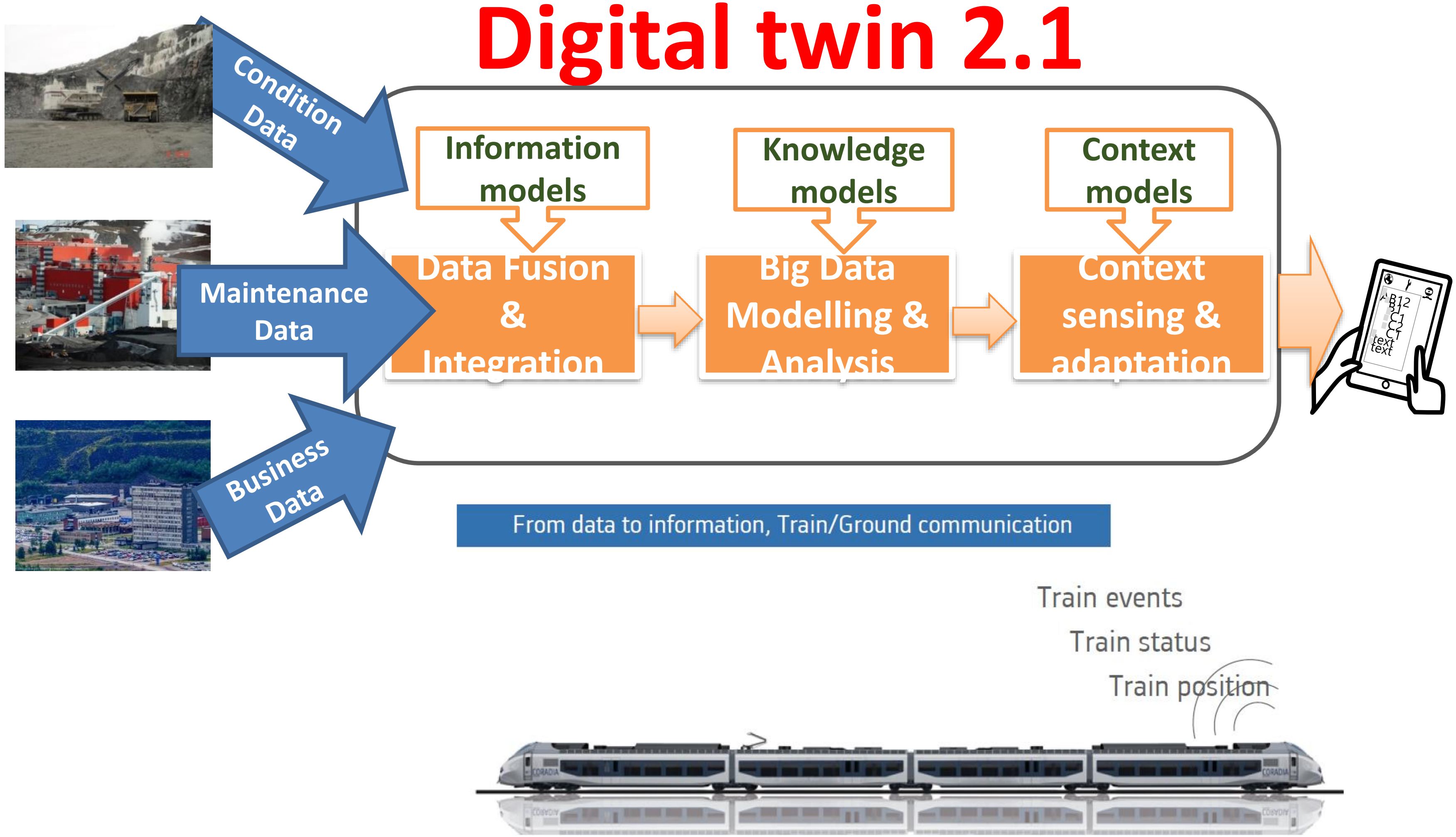
What is context awareness?

- “An application’s ability to adapt to changing circumstances and respond according to the context of use”

- Issues in context awareness system implementing
  - How is context represented?
  - How frequently does context information have to be consulted?
  - What are the minimal services an environment needs to provide to make context awareness feasible?
  - ...

Context-aware Maintenance Decision Support Solution

Digital twin 2.1



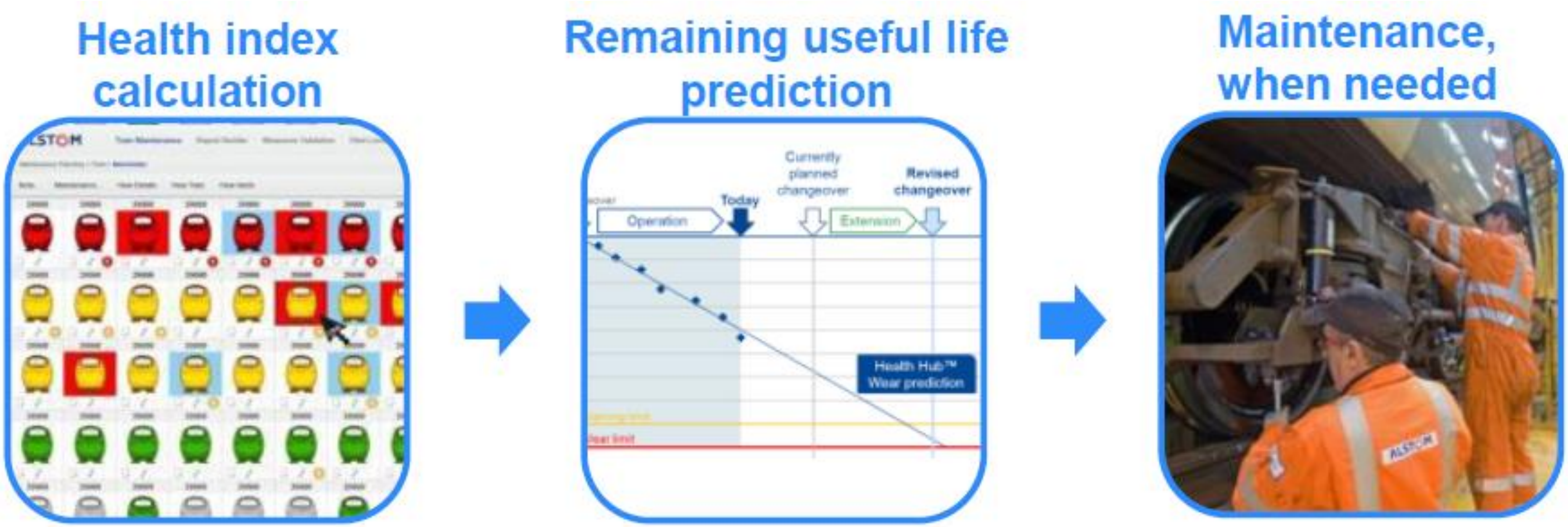
What can I see in my data?

Now casting

1) What has happened
2) What is happening

Forecasting

3) What will happen in the future
4) When will it happen



DETECTION, ISOLATION & PROGNOSIS

Detection

Through sensors, Models etc

Isolation

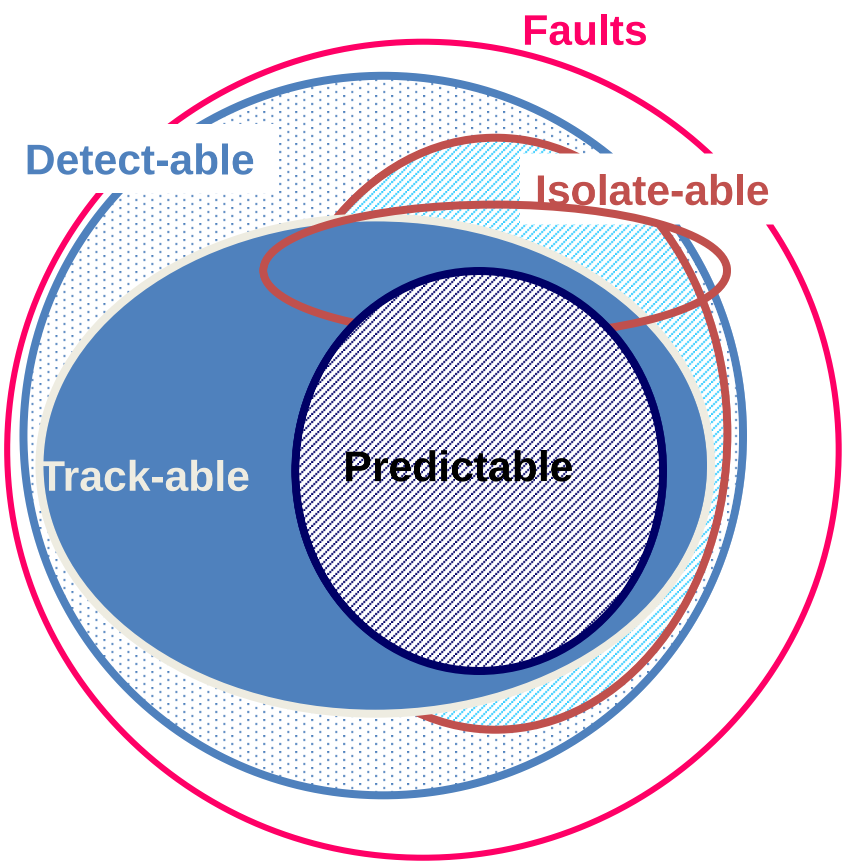
Information fusion from sensors, Models etc.

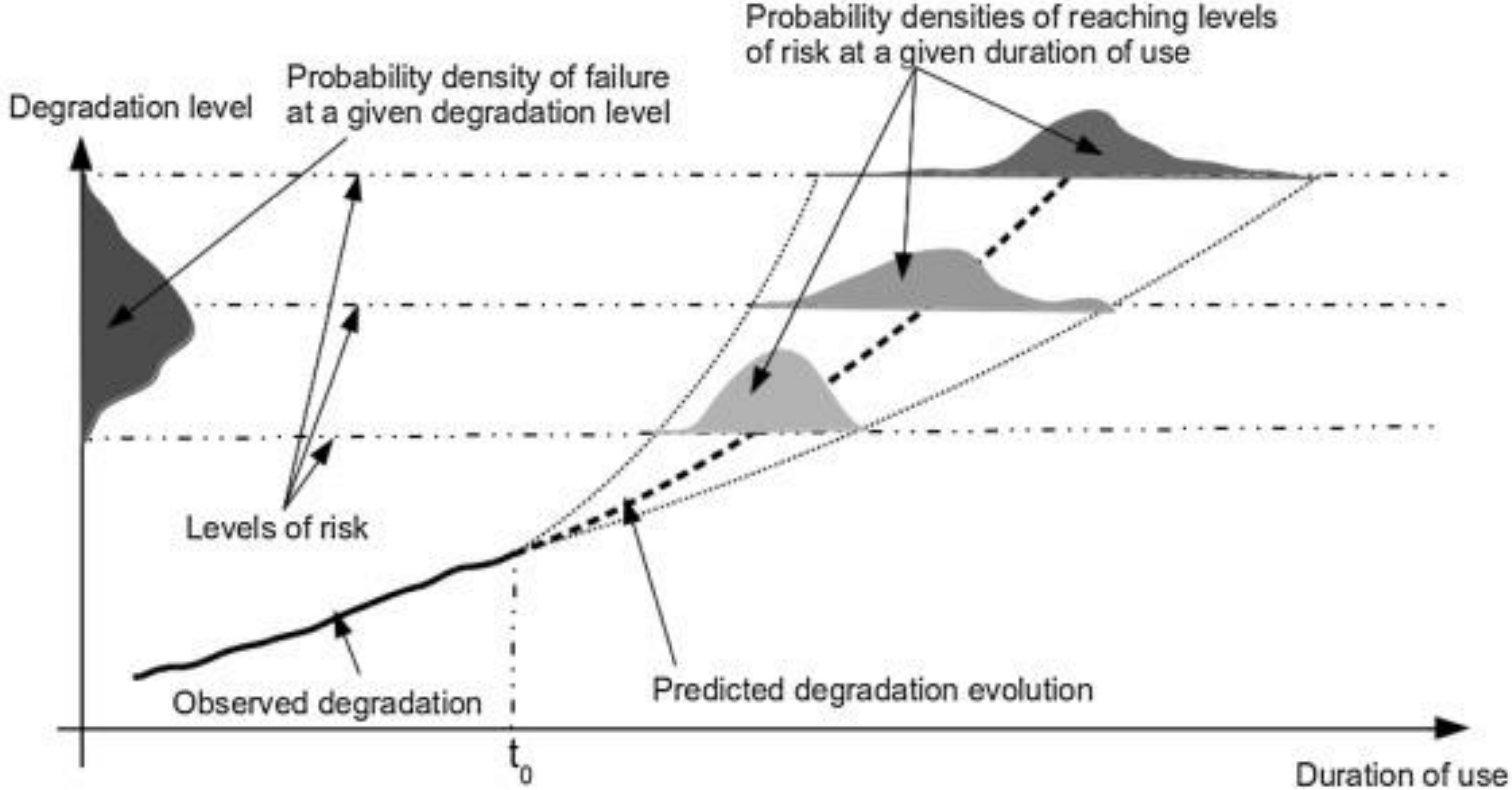
Tracking/Trending

Processed PHM data

Prediction/Prognosis

Based on tracking/trending, & lifing models





1. In the absence of direct "stressors, loading meters" how can we infer the best (descriptors/features) to capture future damage dimensions?
2. How can we accurately predict the progression of a specific failure mode? Considering that multiple failure modes may occur at any time in a complex equipment, system?
3. Given the numerous sources of uncertainty, how do we assign confidence associated with the predictions?

Data science…
Narrow vision and mistakes

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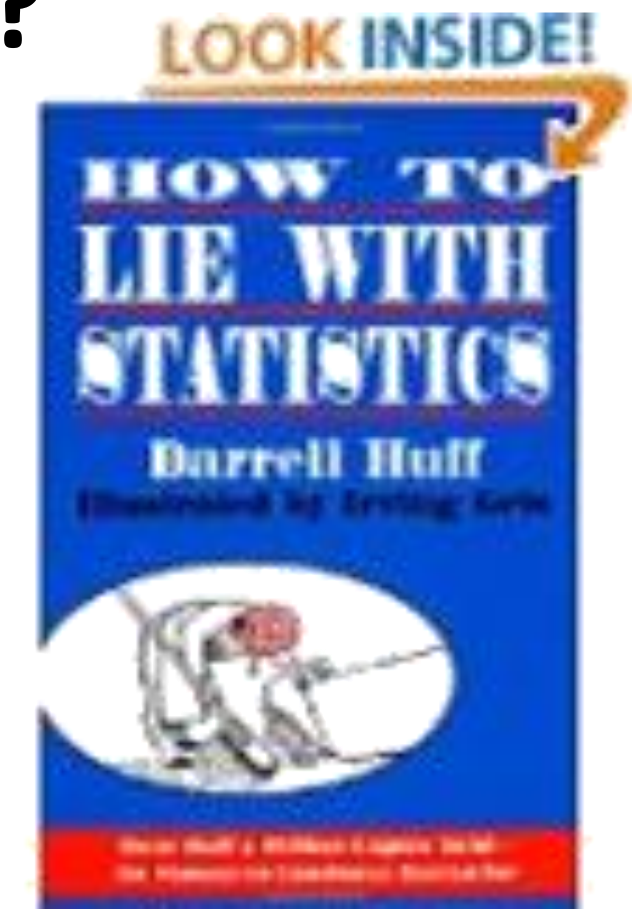
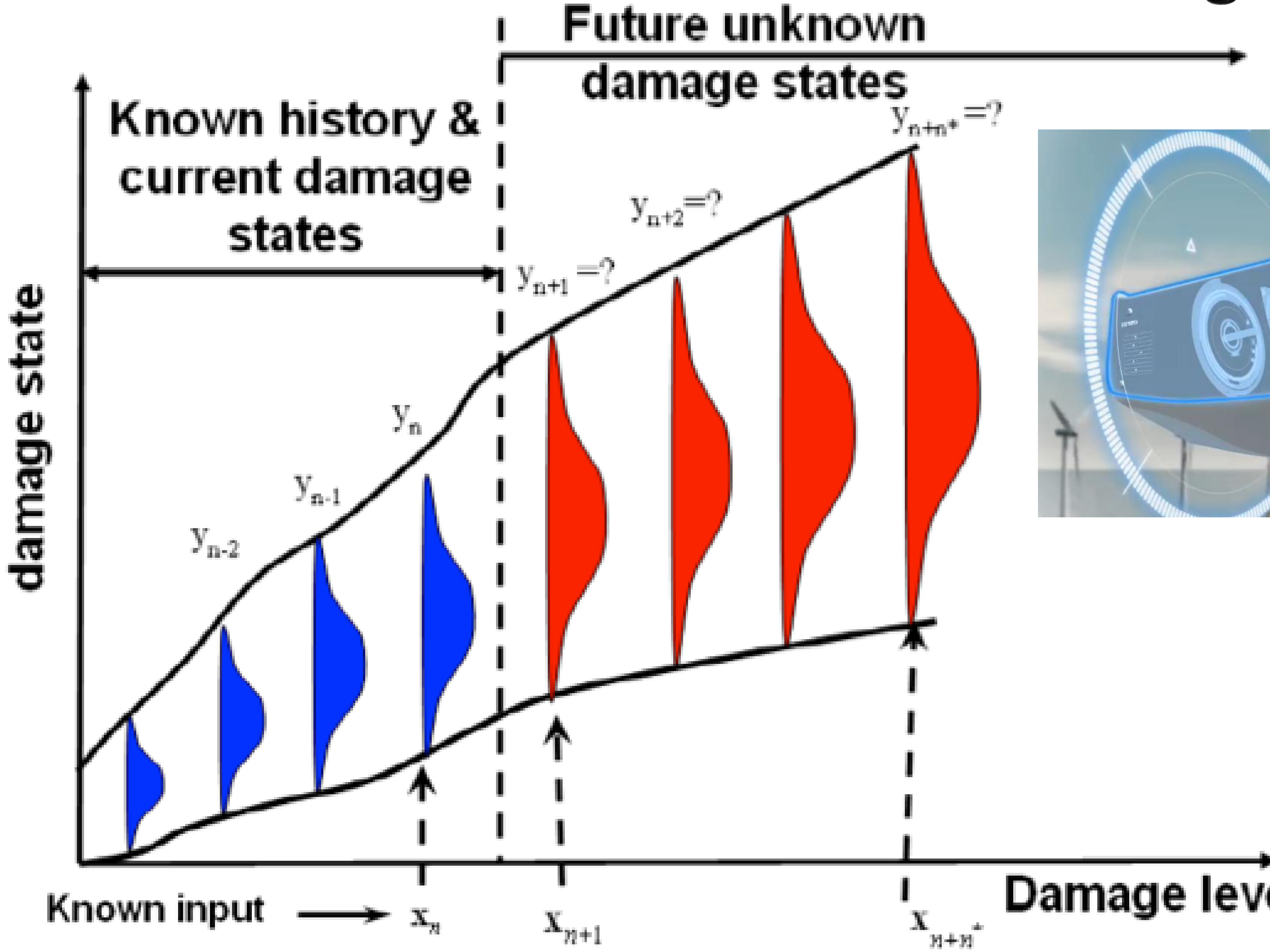
Let us be careful bigger = smarter?

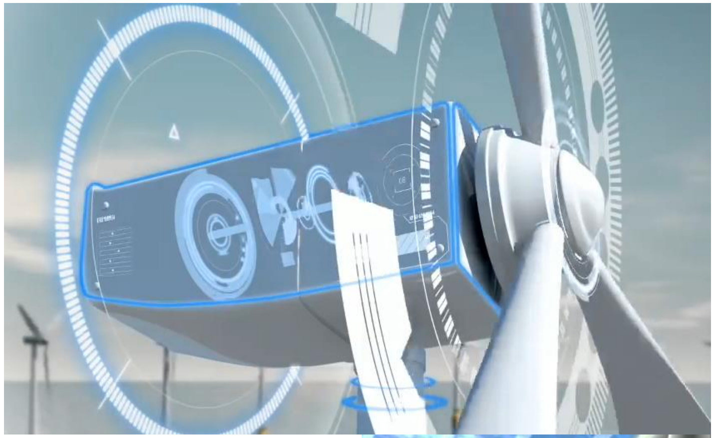
- tolerate errors?
- **discover the long tail and corner cases?**
- more data, more error (e.g., semantic heterogeneity)
- still need humans to ask right questions, lack of analytics

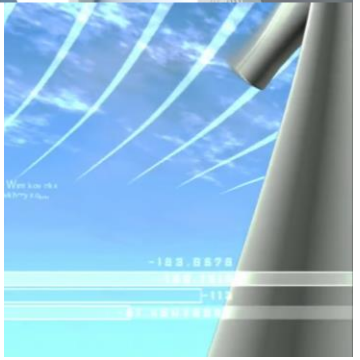


Prognosis when ignorant.....?

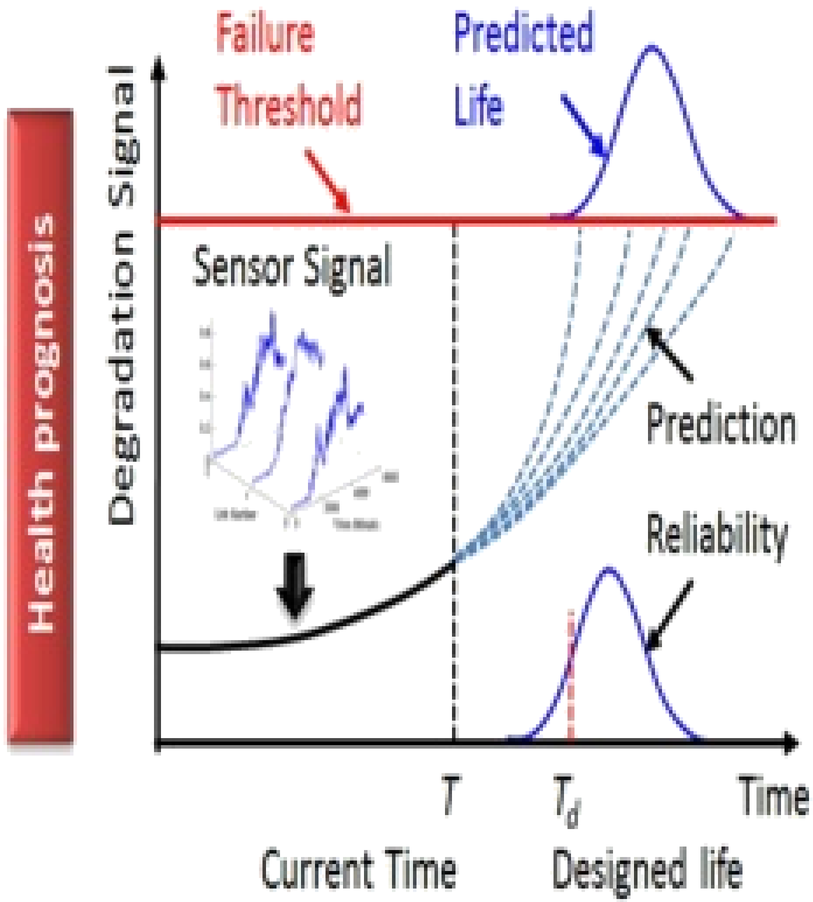
Remember the unknown stages

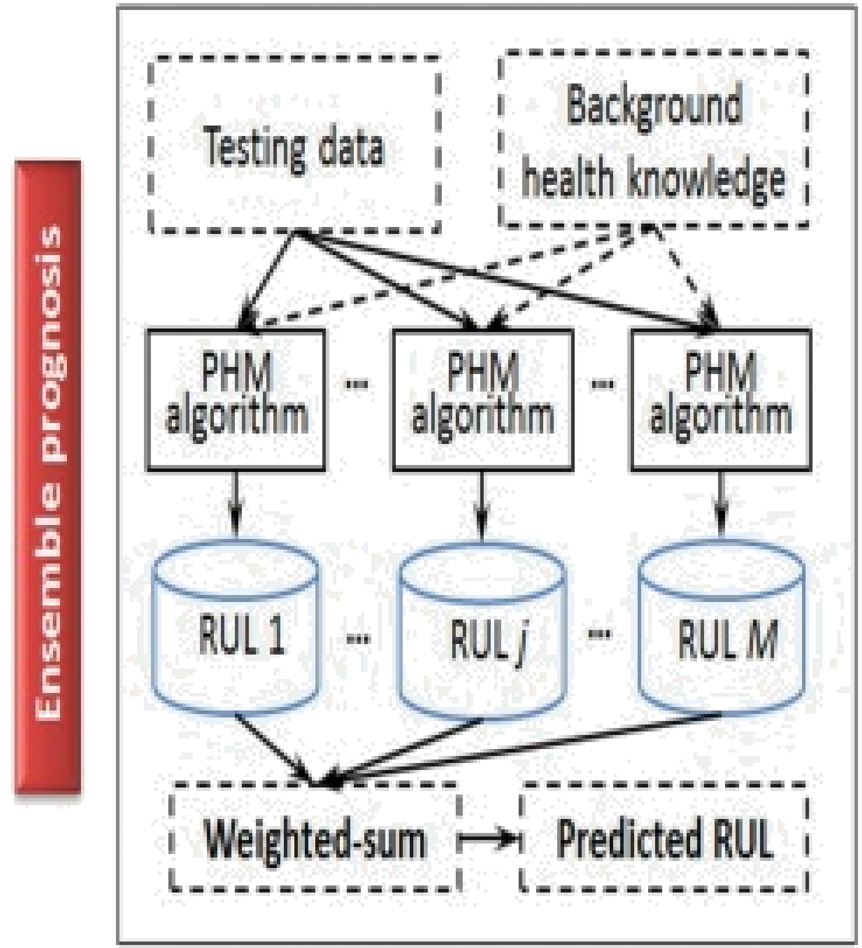






And the Uncertainty in RUL minimized with physics, maximized with data





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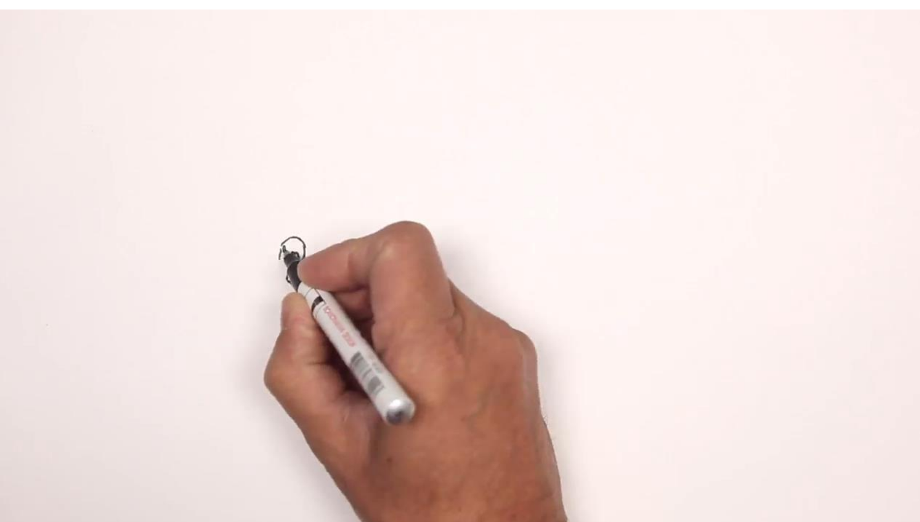
Black Swan Losses

- Loss Distribution
  - Tail events are rare – very little data
  - Typically strong model assumptions



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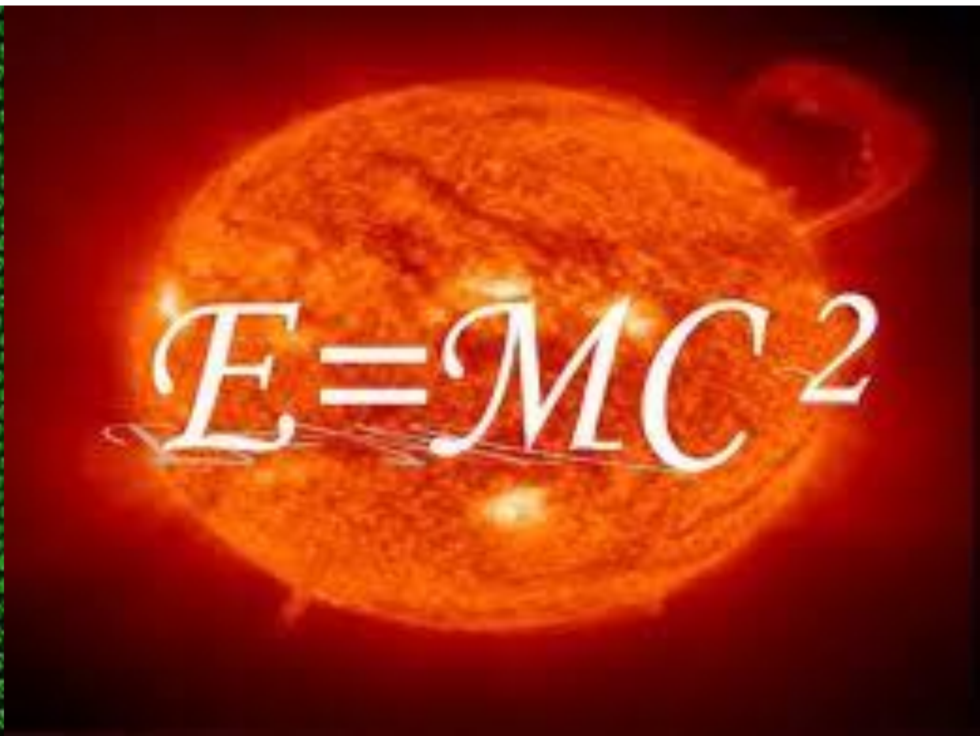
Data driven or model based?

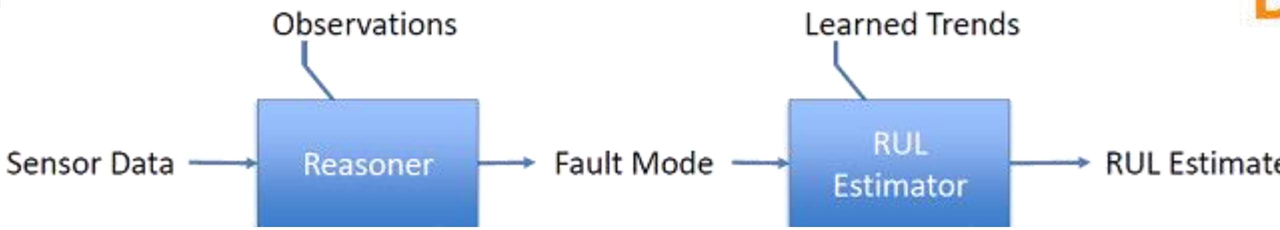
Data-Based or Physics-Based Models? – That is the question!



The promise of Data Science

- Techniques that make it possible to extract useful information from data
  - Finding hidden structures in data:
    - Clustering (unsupervised learning)
    - Pattern recognition
  - Classifying labeled data: putting data in pre-specified classes: supervised learning
  - Predicting future values based on past observations: regression analysis
- New algorithms have evolved and IT capabilities (data bases, parallel processing, etc.) make them applicable
- Machine learning techniques have matured and are used increasingly

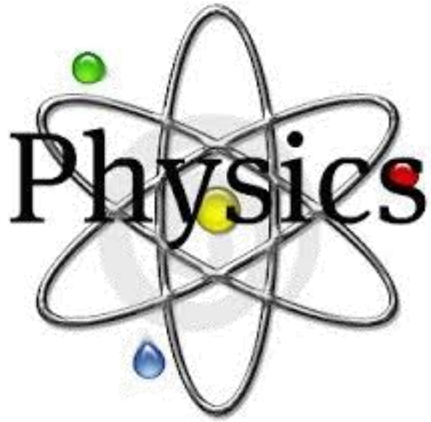
Data driven methods



- Fit mathematical model to observations (trending)
  - No guaranty that extrapolation will be meaningful
- Collect statistics of failures as a function of current state
  - Requires volumes of data and is difficult to know when you have enough

Physical based methods

- Physics of Failure Model Driven
  - Capture physical basis of failure in model that relates the forces that cause damage to their effect
    - Requires a detailed understanding of the problem
- Many Implementations Are a Combination of Both



Therefore, data science is not for PHM

- PHM goal: detection, diagnostics and prognostics of a target component in presence of different sources of uncertainty.

  - present uncertainty (e.g. noisy measurements)
  - future uncertainty (e.g. loading and operating conditions)
  - modeling uncertainty (e.g. model parameters, unmodeled dynamics).

- Availability of a robust set of data is crucial for design of effective PHM algorithms.

- Field data only are generally not informative enough for the purpose of designing a PHM algorithm with adequate performance:

  - Time for degradation excessively long, evolution difficult to track.

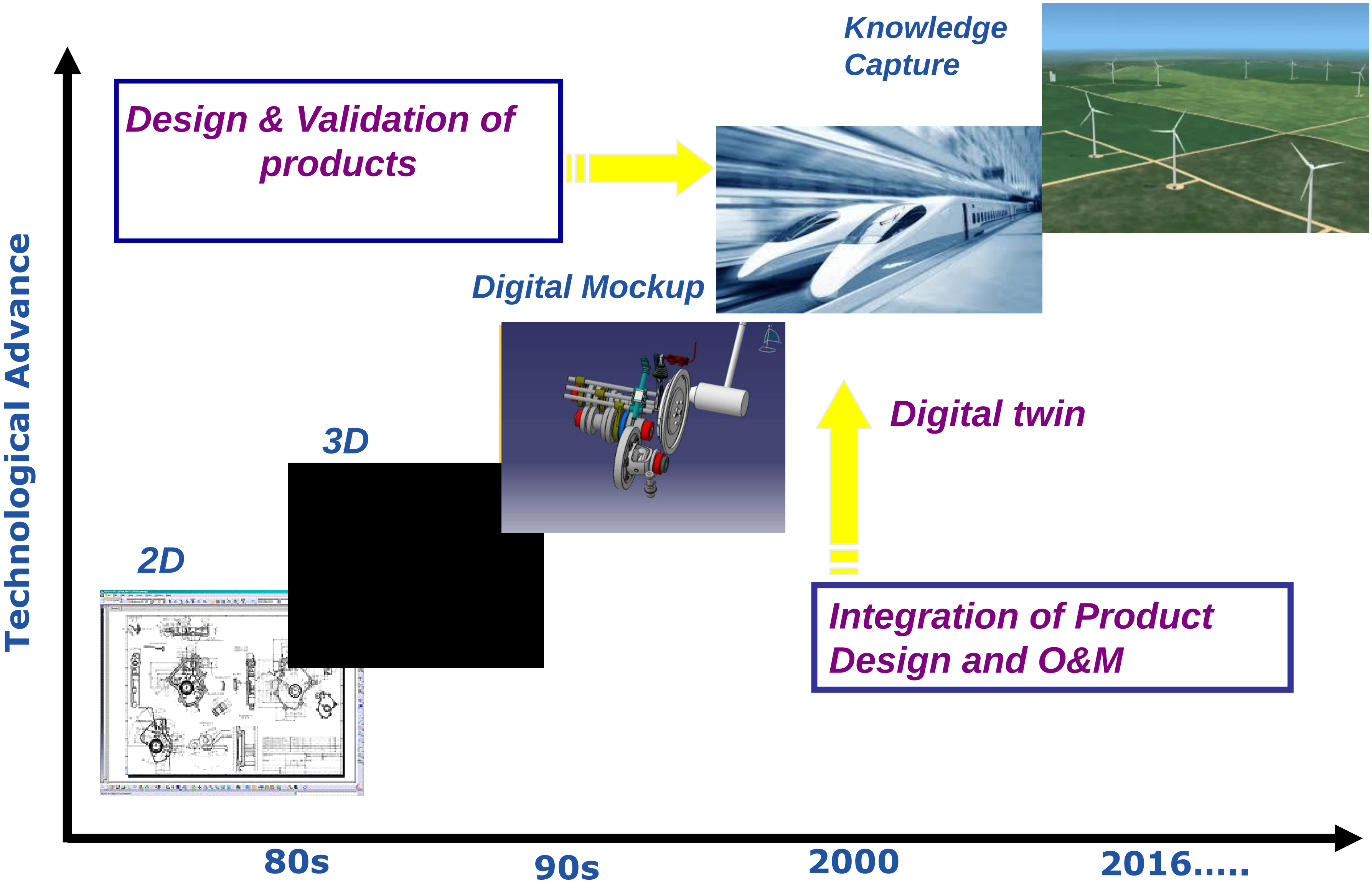
Hybrid models

- Combine knowledge about the physical process and information from sensor readings to enhance prognostics capabilities.

- Integration of measured data and physics can lead to a reduction of uncertainty (e.g. adjust predictions from model using observed data).

- Integration can be implemented at different levels of the PHM process:
  - Online model parameters updating.
  - Model predictions correction based on observed data.
  - Measure current damage level and propagate.
  - Build empirical degradation models from data.

Evolution of the Process



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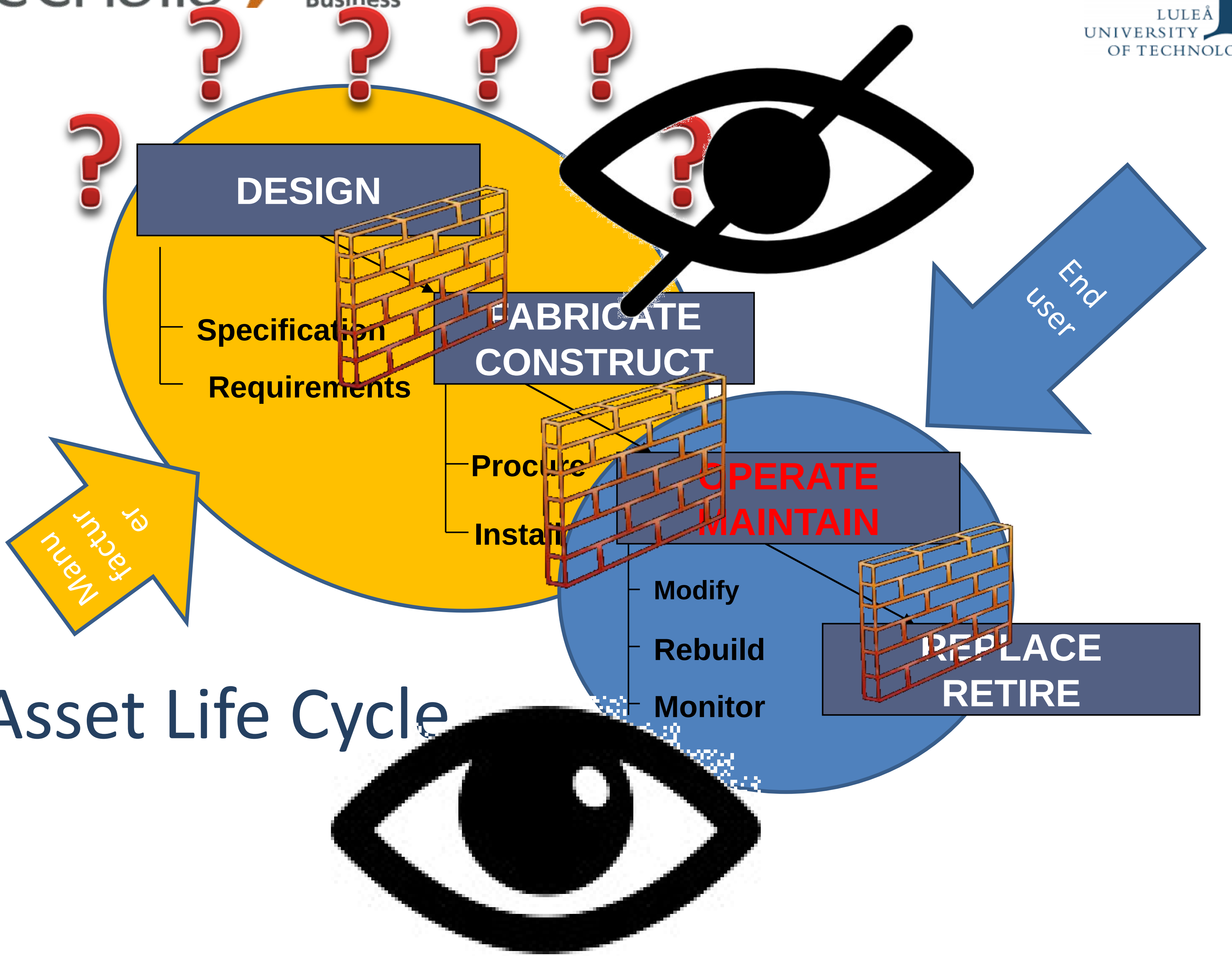
Asset Life Cycle



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PLM and digital twins

← Product Lifecycle Processes →

Design ⇨ Build ⇨ Operate ⇨ Maintain

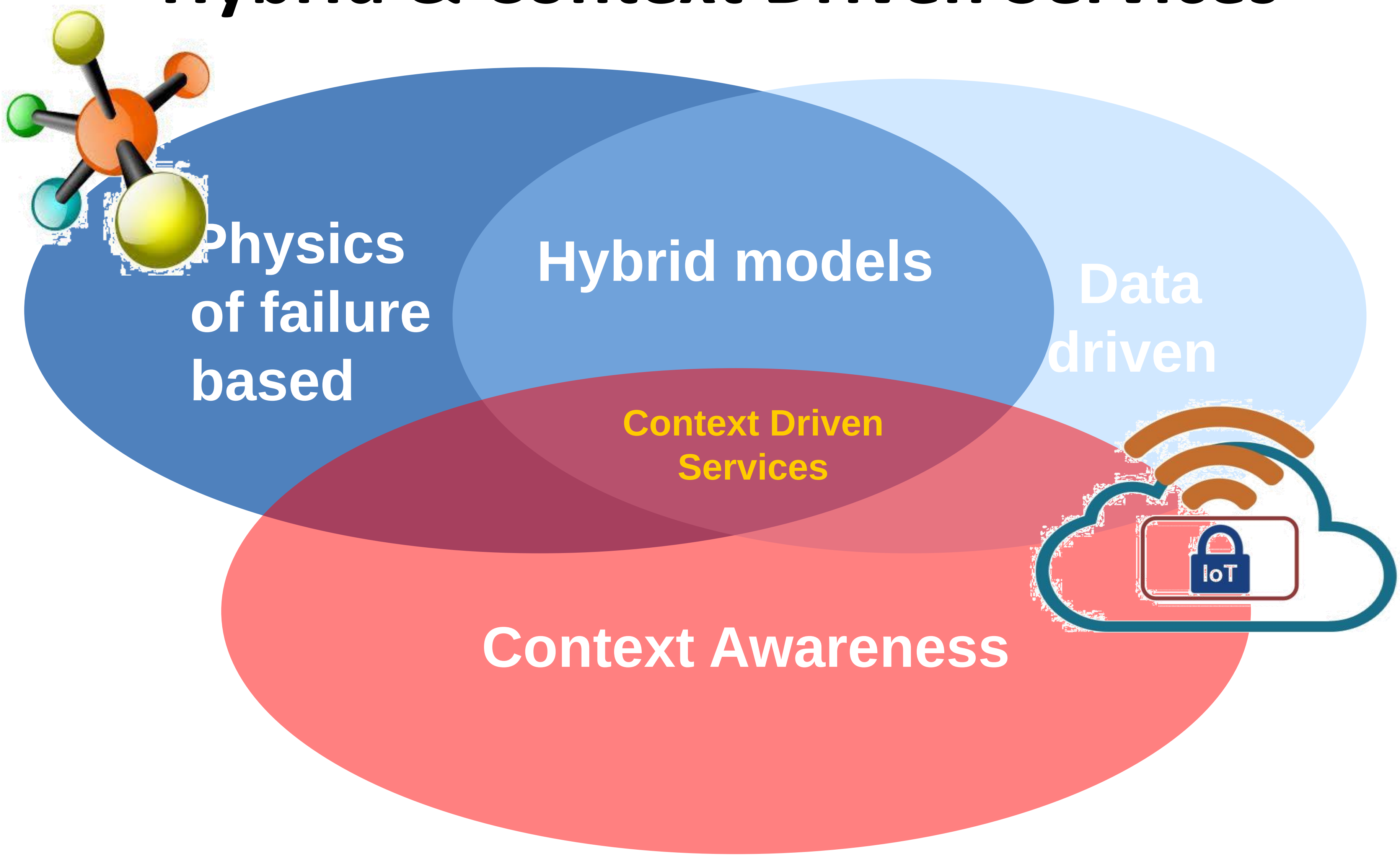
O&M Processes

Digital Wind Solutions

Create Processes → Plan Processes → Simulate & Validate Processes → Execute Processes

Engineering Design ⇦ Validate ⇦ As – Built Records

Hybrid & Context Driven Services



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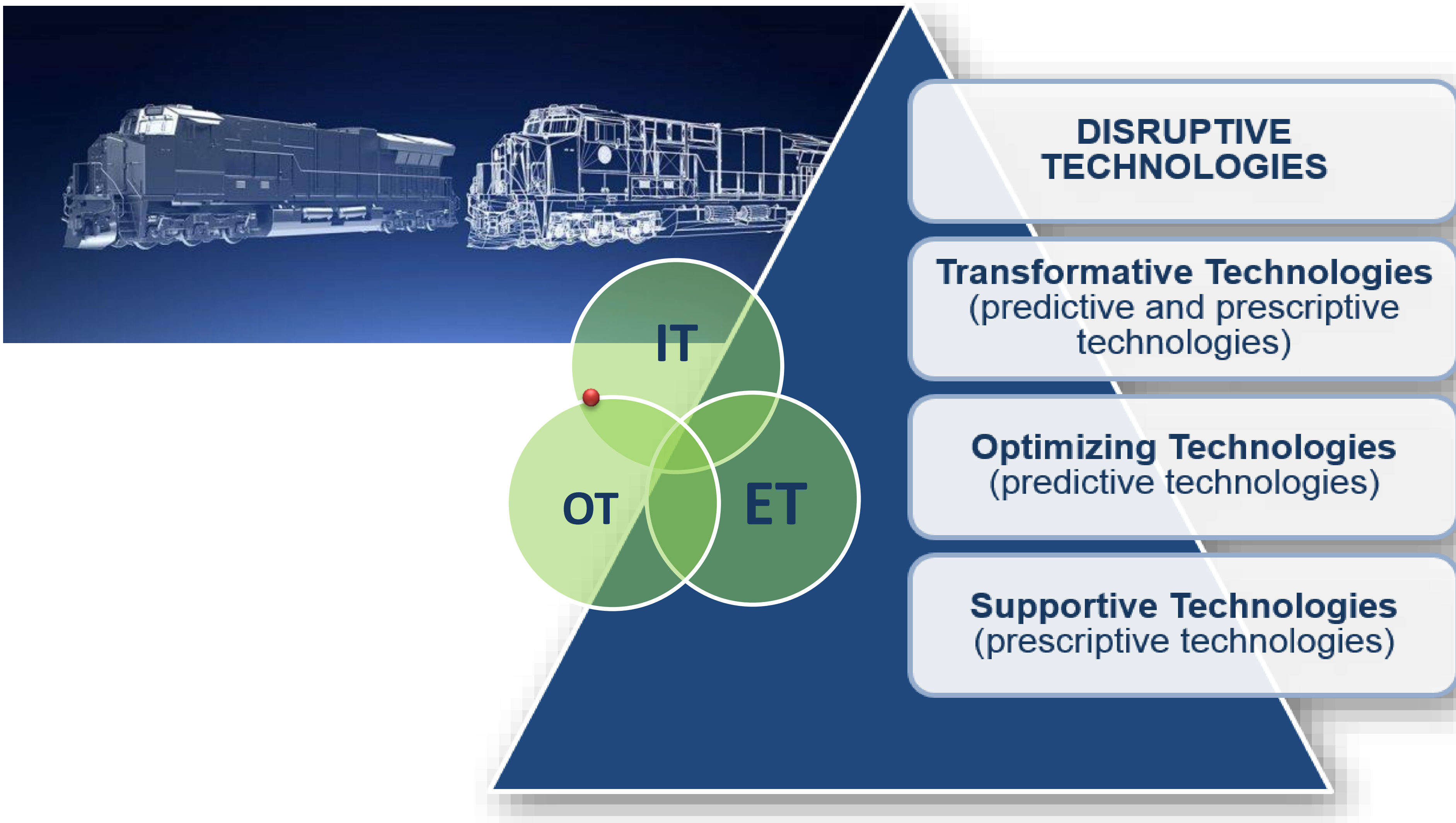
Digital twin 3.0



PRODUCT DEVELOPMENT
PRODUCT DEVELOPMENT
PERFORMANCE MODELING
ENGINEERING DESIGN

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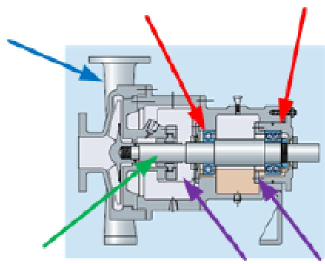
Digital Turnout Management

Vossloh focuses on Digital Turnout Management and inspires with digital innovations and platform solutions. Forwardlooking IoT sensors not only serve as a data source for realtime analysis that reflects the current state of rail and track systems: their microprocessors prequalify the raw data. Virtual images of physical components or systems - so-called "digital twins" - provide insights into the functional and service diversity of tomorrow using the example of the Easyswitch MIM-H point machine.

Digital Twin

The process of twin 3.0 building

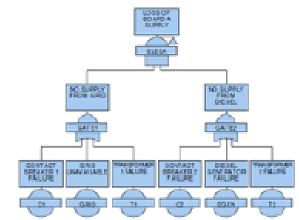
The asset (machine, equipment, electronics, system, structure, etc.



Defining taxonomy of parts within the asset

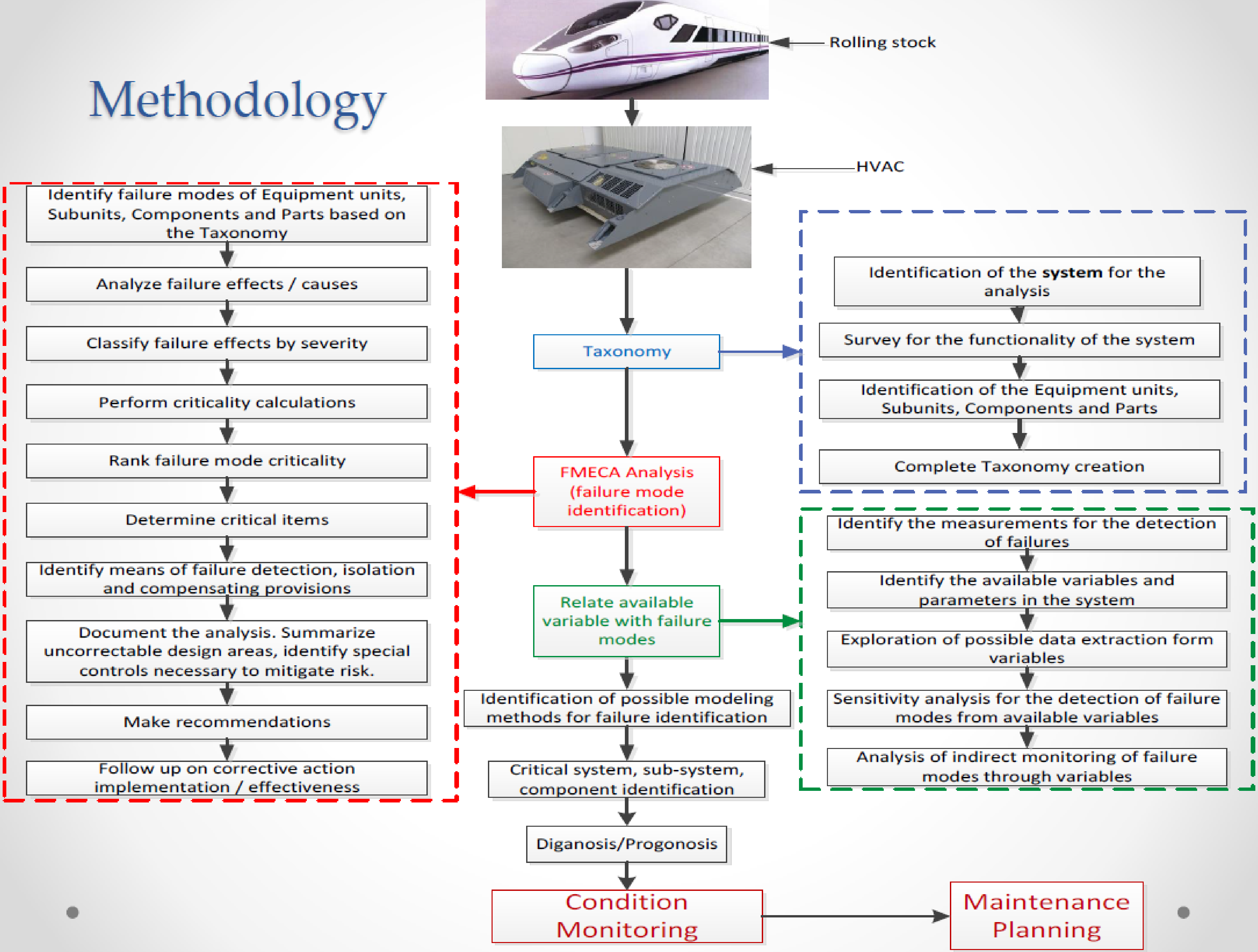
FMECA identifying monitored failure modes and parts taxonomy

Severity (Consequences)	Likelihood				
	A	B	C	D	E
0			2	1	
1	1	1	2	1	
2		2	2		
3		1	1		
4					
5	1			1	

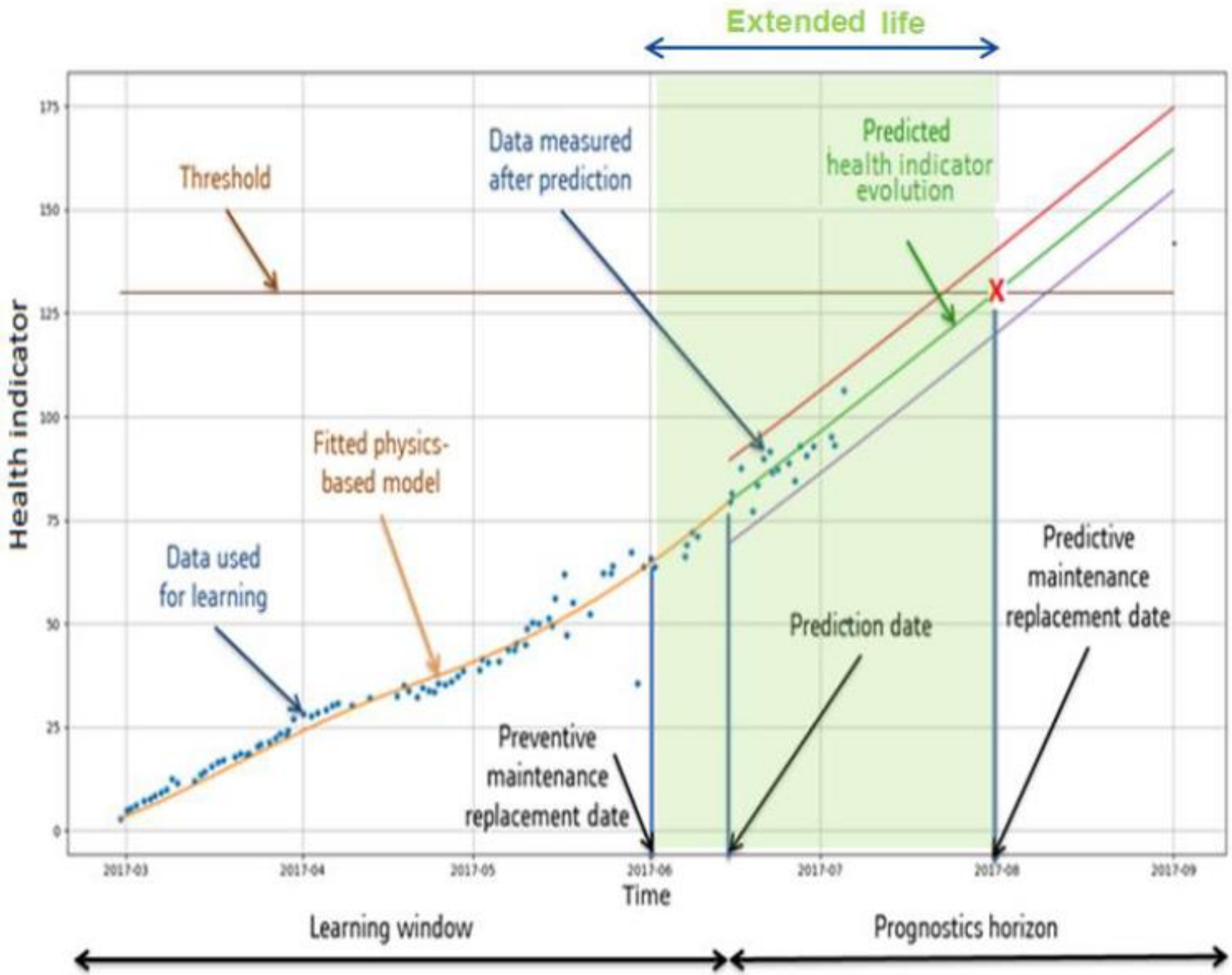


Articulation of Failure Physics

Methodology

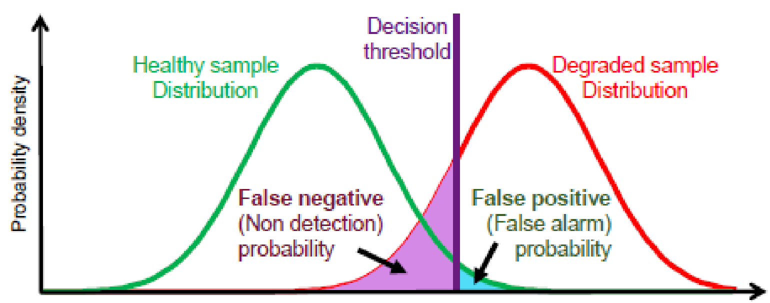


HVAC life extension

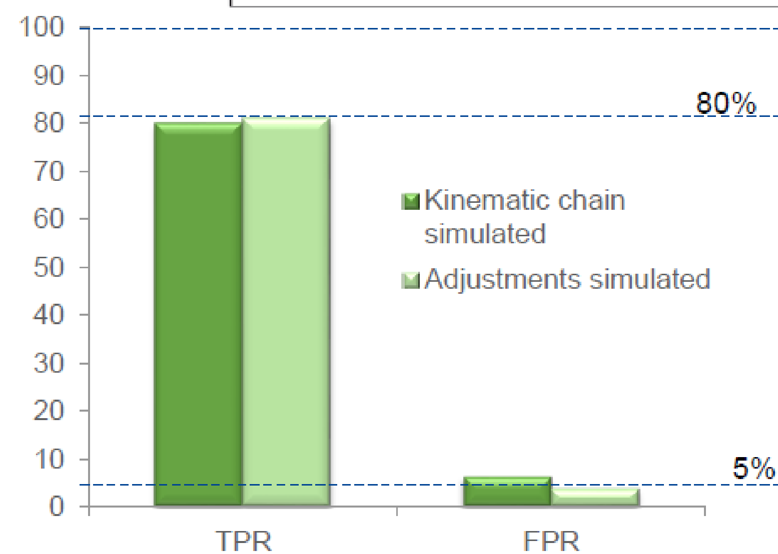


Example :PHM applied to Passenger Access Door

Observability:State Detection



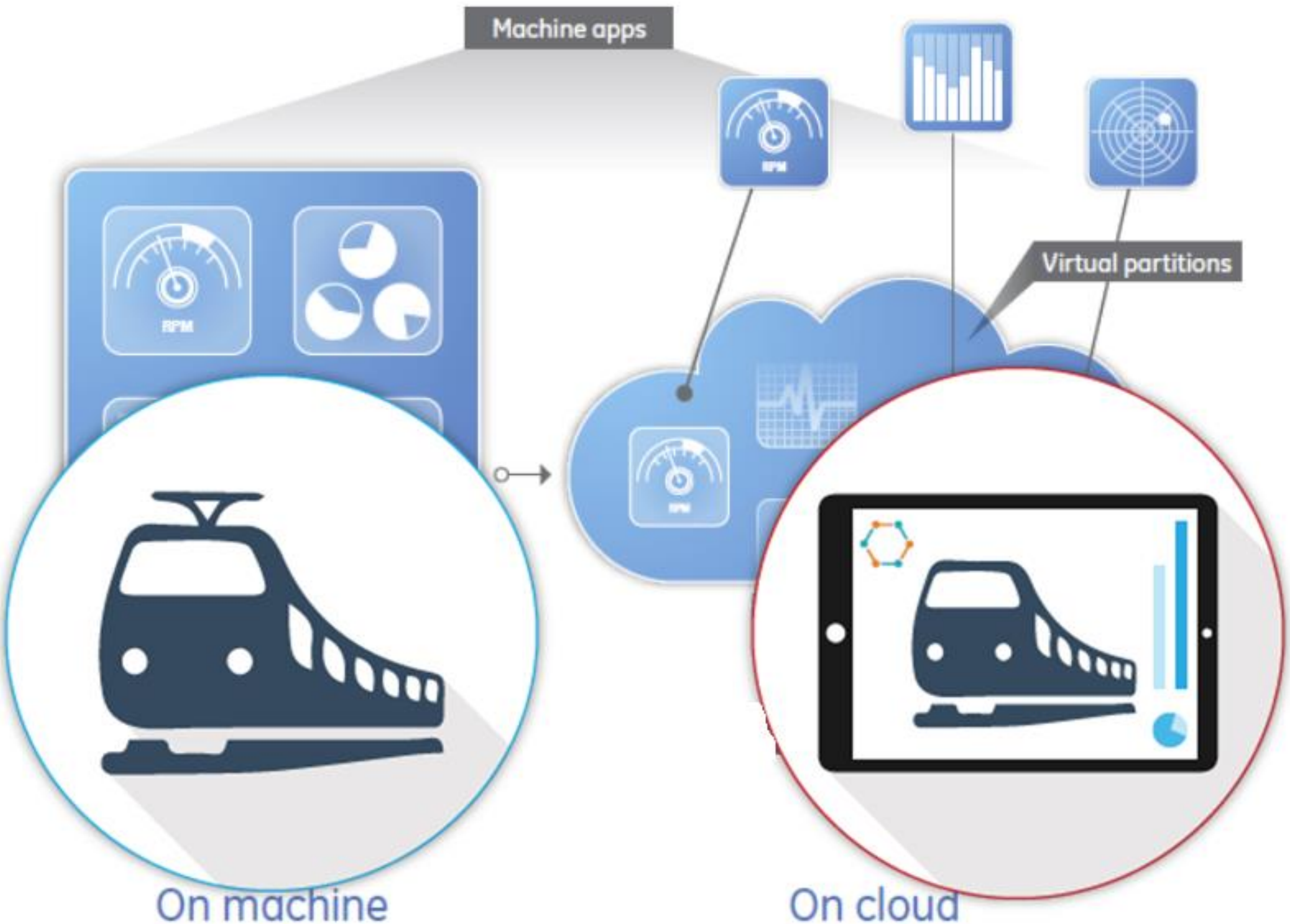
		Predicted condition	
	Total population	Degraded	Healthy
True condition	Degraded	True Positive	False Negative
	Healthy	False Positive	True Negative



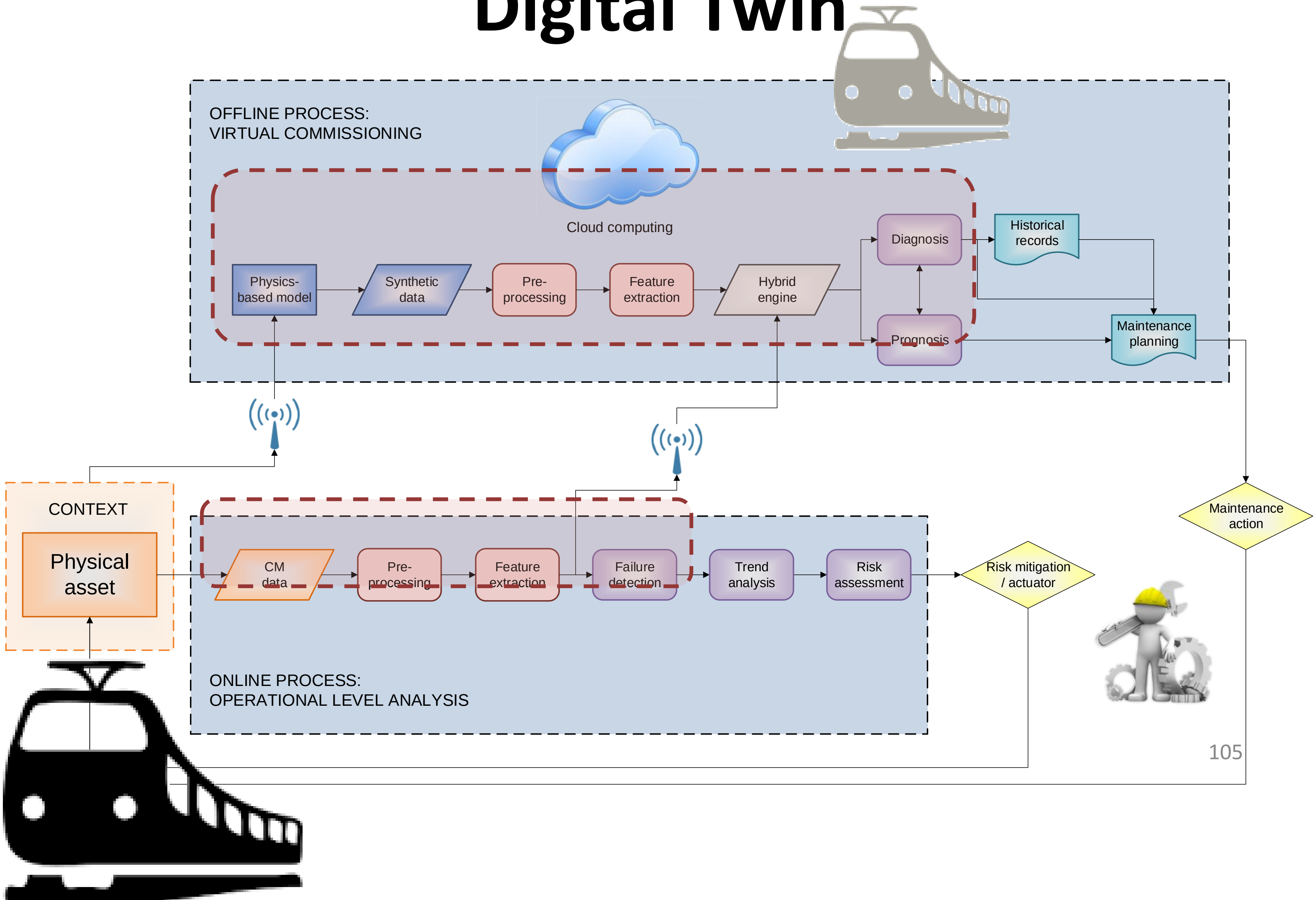
$$False\ Positive\ Rate(FPR) = \frac{False\ Positive}{False\ Positive + True\ Negative} \leq 5\%$$

$$True\ Positive\ Rate(TPR) = \frac{True\ Positive}{True\ Positive + False\ Negative} \geq 80\%$$

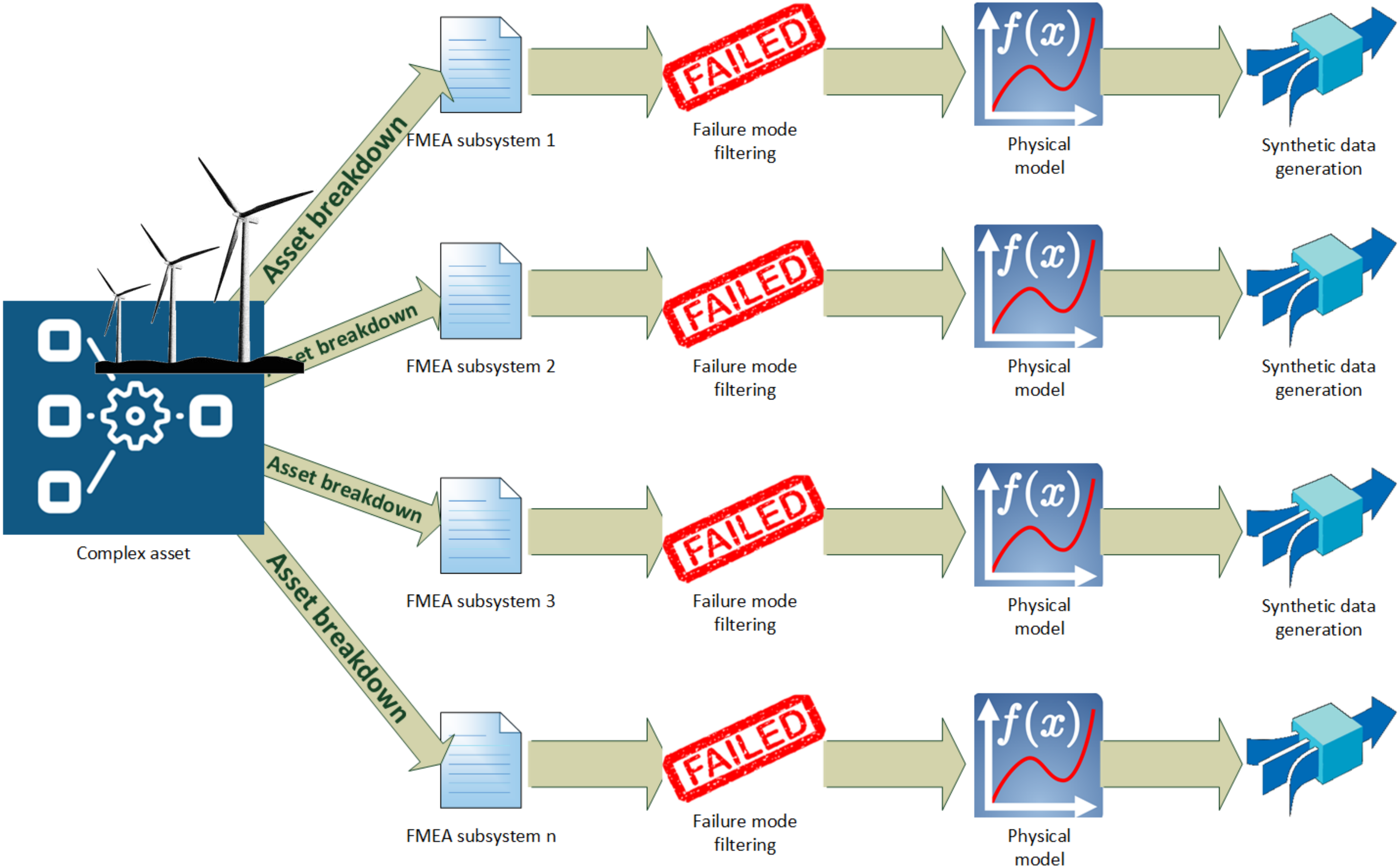
Virtual railway assets



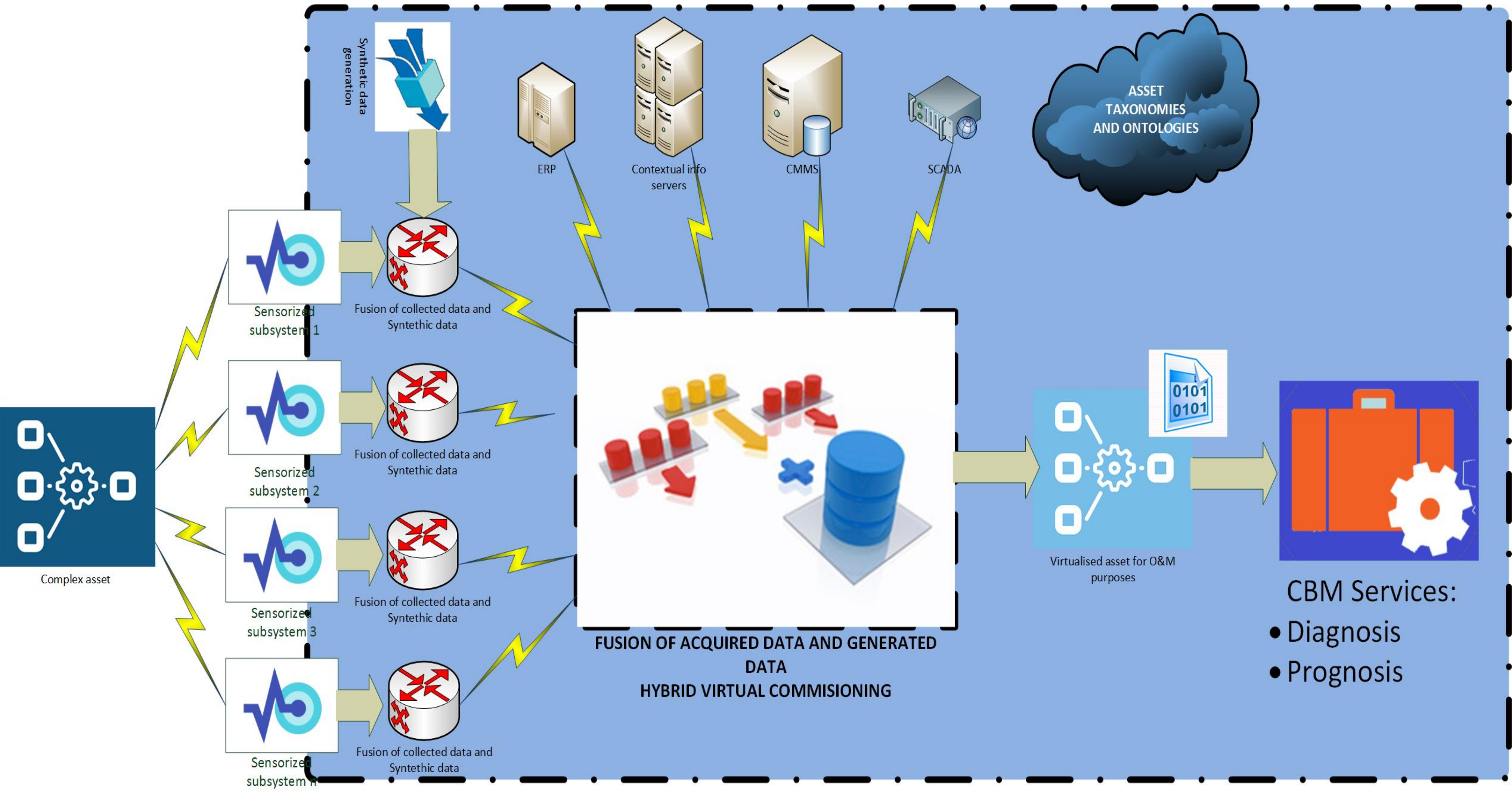
Hybrid Digital Twin



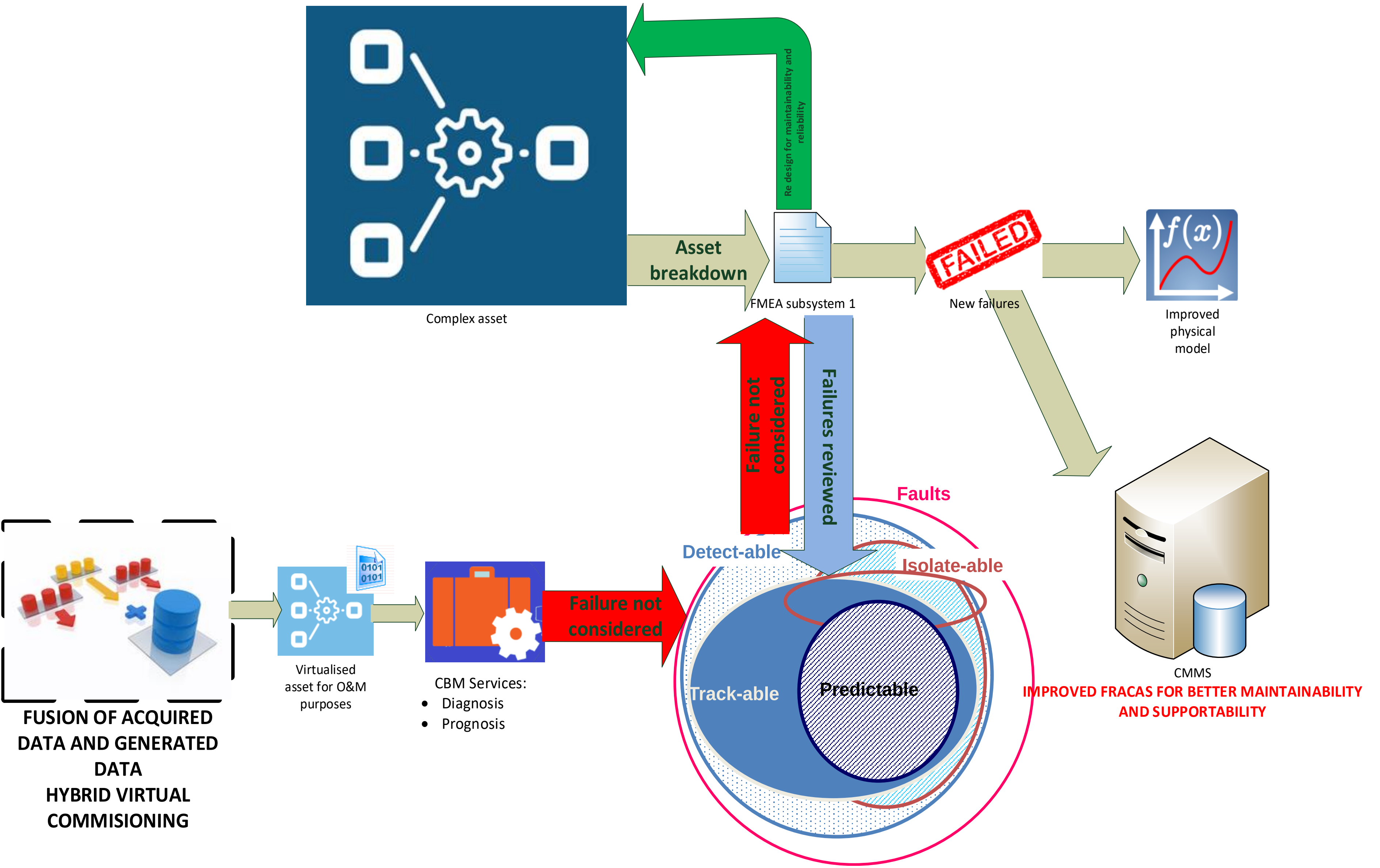
Steps of hybrid and VC



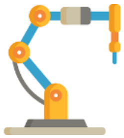
Steps of hybrid and VC



Steps of hybrid and VC



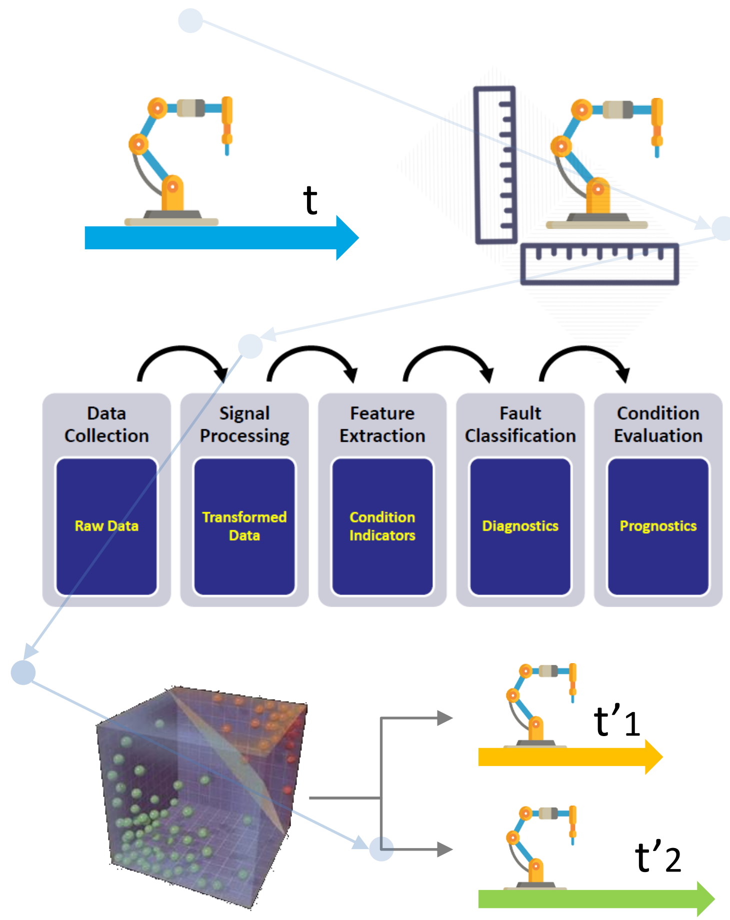
Application of digital twin for refurbishment



PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

Objective: development of reference metrics and data sets, assessment protocols and tests equipment and SW to:

- assess the current health status of a robot in a test bench at the end of its mission
- know how health degradation will be affected by other missions operational profiles and contextual requirements
- estimate repairing costs, if any
- to decide about the re-use and life extension of robots in best fitting mission

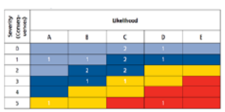


PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

The process of twin 3.0 building

RAMS ANALYSIS

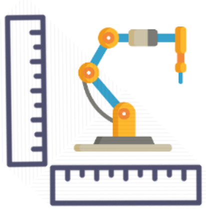
FMECA identifying monitored failure modes and parts taxonomy



Critical Failure Modes and available variables to acquire and process

TESTS BENCH

Current, accelerometer, vibration sensors
Pre-defined path movements



Health data fingerprint acquisition and generation

CHARACTERIZED REUSABLE ROBOT FLEET database

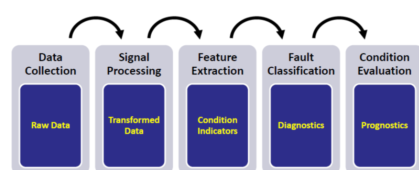
REPAIRMENT COSTS

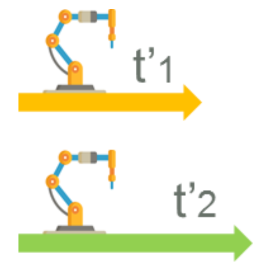
MISSIONS PROFILES

DIAGNOSIS

PROGNOSIS

DATA ANALISYS AND KNOWLEDGE EXTRACTION

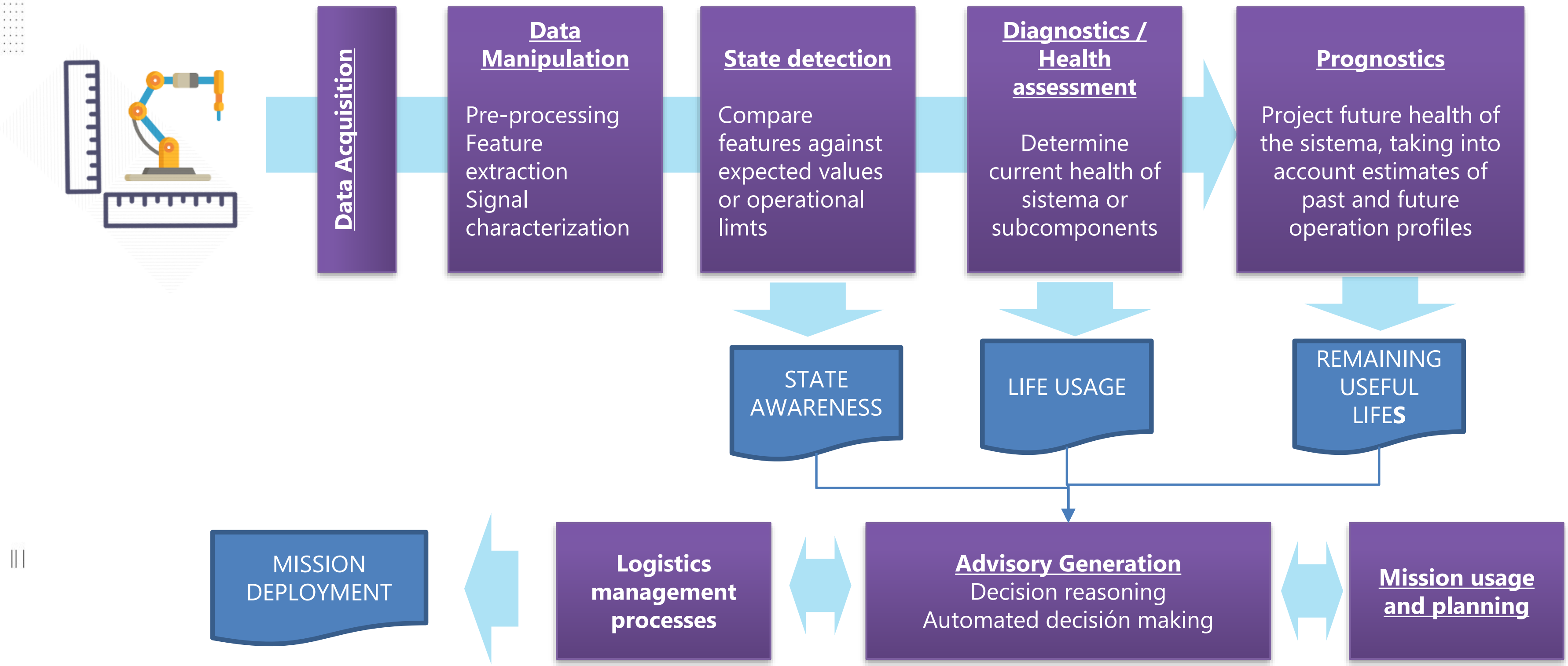


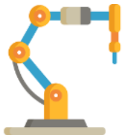


Remaining useful life calculation for each of mission profile requirements

PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

The process of twin 3.0 building





PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

The process of twin 3.0 building

Data Manipulation

Pre-processing
Feature extraction
Signal characterization

State detection

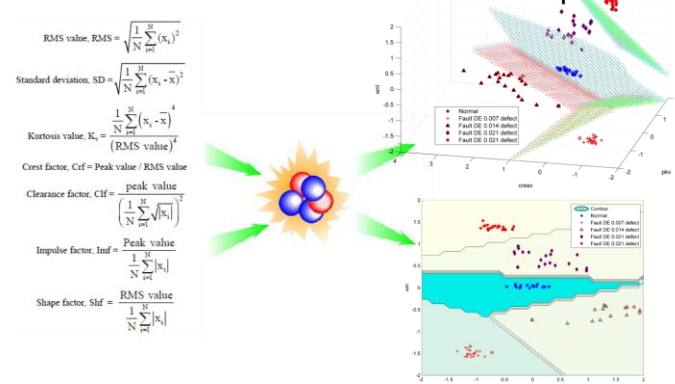
Compare features against expected values or operational limts

Diagnostics / Health assessment

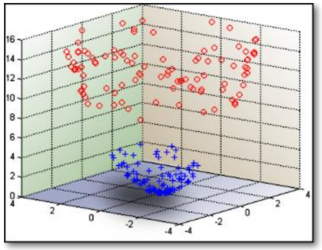
Determine current health of sistema or subcomponents

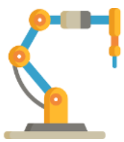
- Pre-defined movement tracks for diagnosis assessment will be defined
- operational information will be acquired in the test bench
- Health features will be analyzed to get a diagnosis of the current health status

Feature fusion in feature map



Support Vector Machine (SVM)
as Diagnosis tool





PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

The process of twin 3.0 building

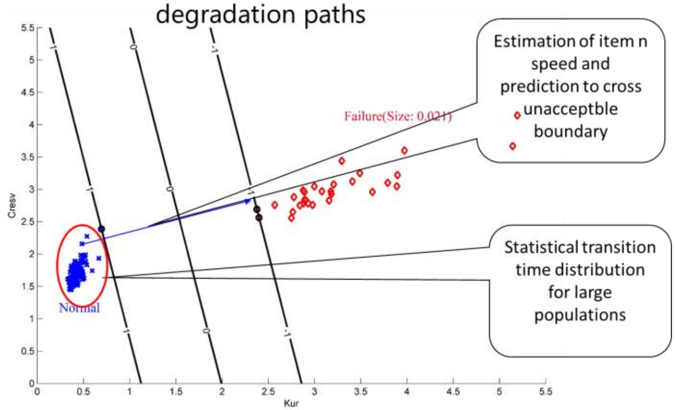
Prognostics

Project future health of the sistema, taking into account estimates of past and future operation profiles

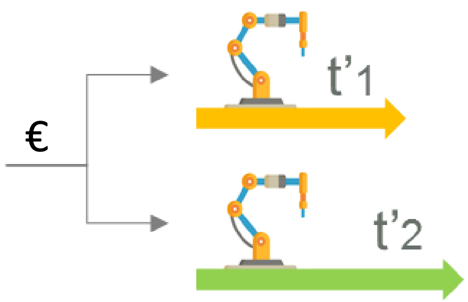
REMAINING USEFUL LIFES

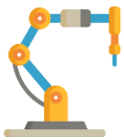
Failures found and new missions operation profiles will help to define specific movement tracks tests to assess the impact of the missions under consideration in the RUL

Different mission profiles will take the health fingerprint thorugh different degradation paths



Prescriptive analytics will allow to determine the most appropriate next mission for the robot



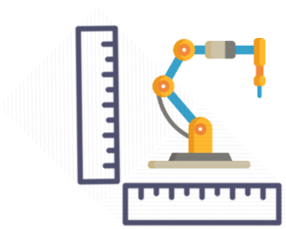


PROGNOSTICS HEALTH MANAGEMENT for ROBOTS

Expected Budget:
- Concept proof: 200k
- Pilot study: 50k

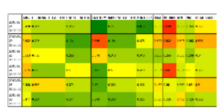
Expected duration: 6 months

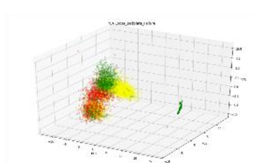
Physical test bench



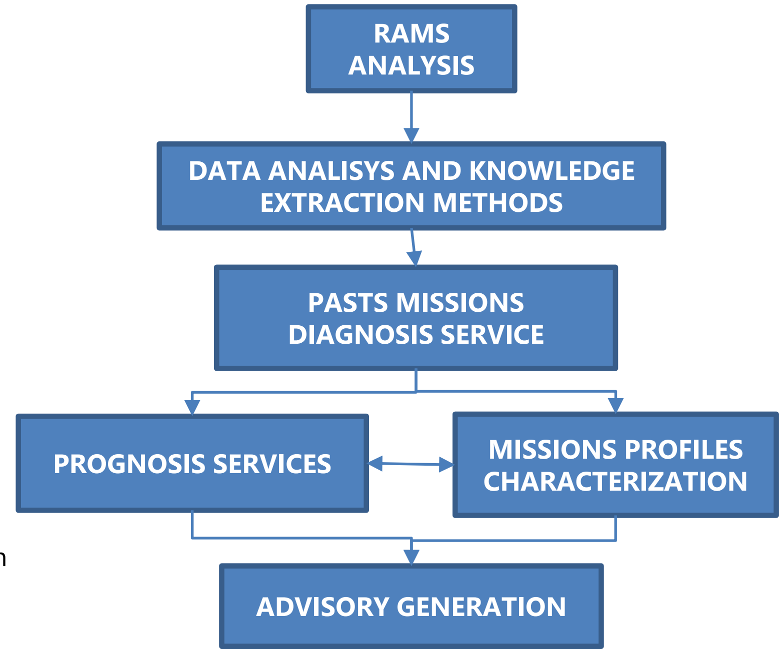
Pre-defined paths
DAQ system

Methods for diagnosis & prognosis



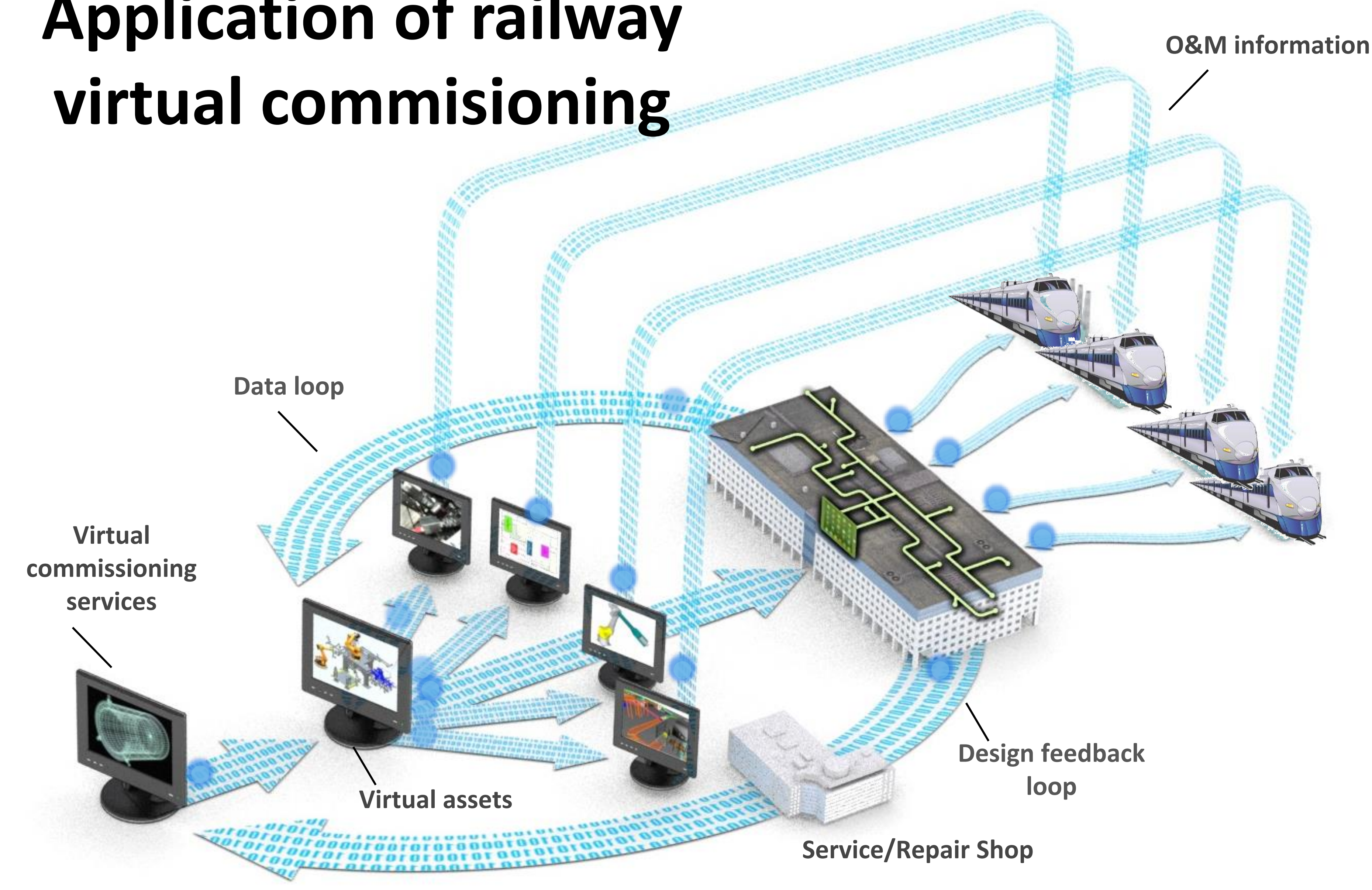


Advisory Generation system with information interchange with GESTAMP Reusable Robot Fleet database



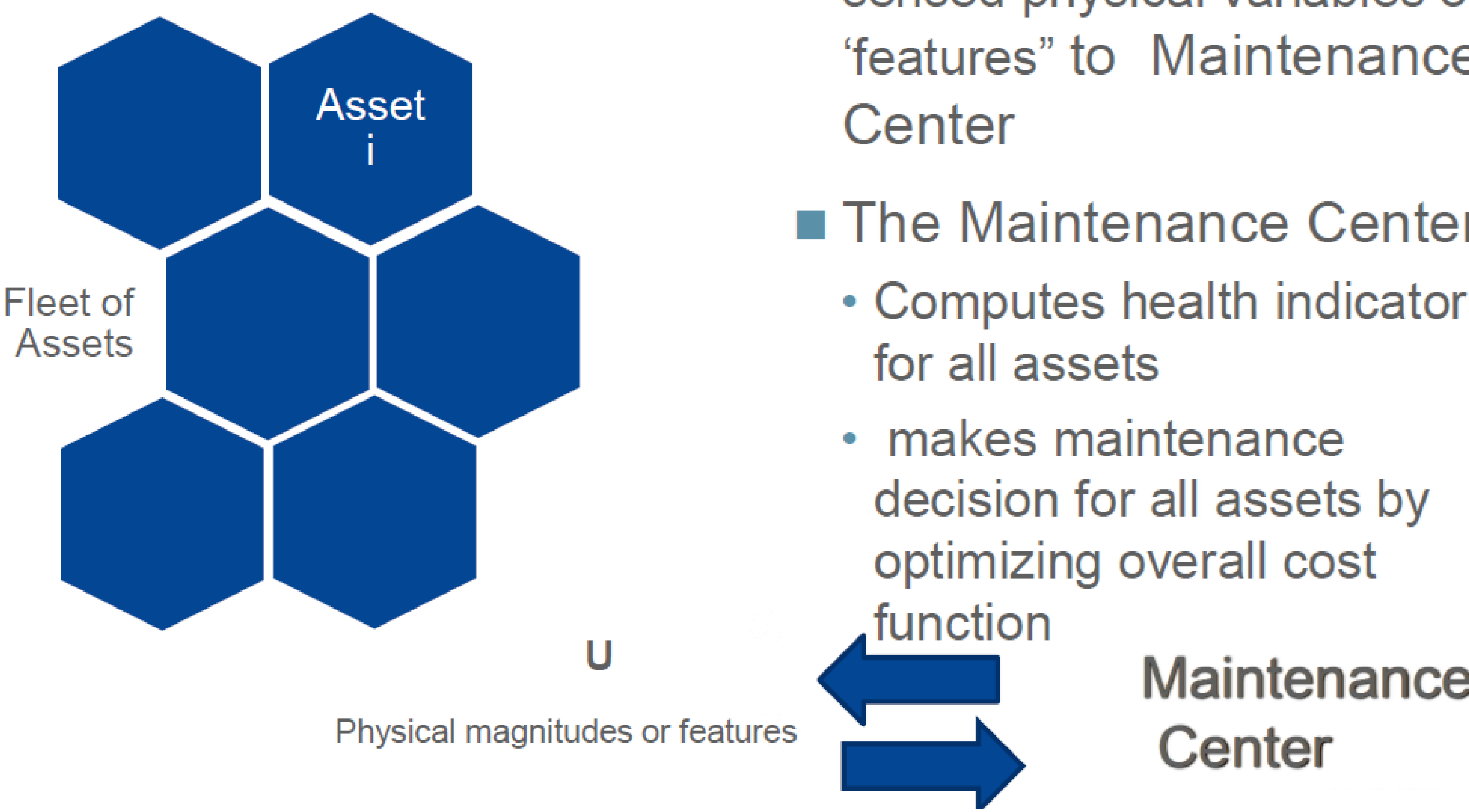
PHM4Robots

Application of railway virtual commisioning



From individual assets to System maintenance

1.Fully centralized Decision system

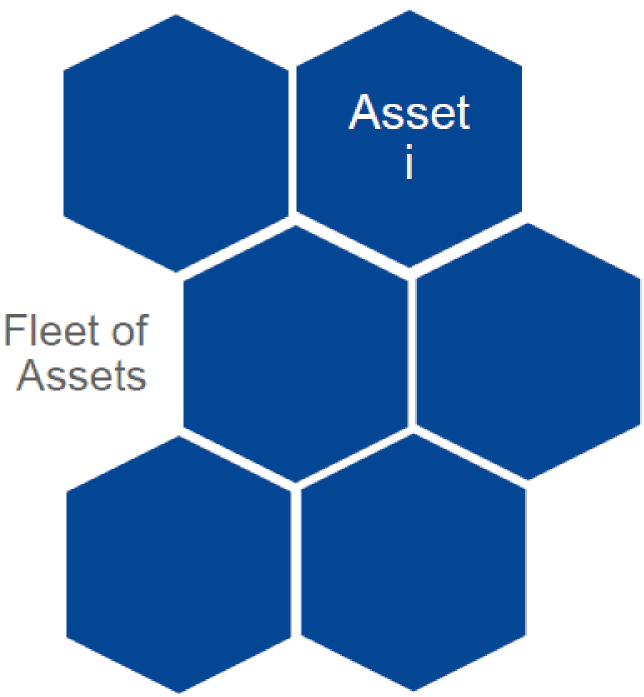


- Each asset communicates sensed physical variables or 'features" to Maintenance Center
- The Maintenance Center
  - Computes health indicators for all assets
  - makes maintenance decision for all assets by optimizing overall cost function

From individual assets to System maintenance

2.Semi -centralized Decision system

- Each asset communicates only its health indicator to Maintenance Center
- The Maintenance Center
  - makes maintenance decisions for all assets by optimizing overall cost function



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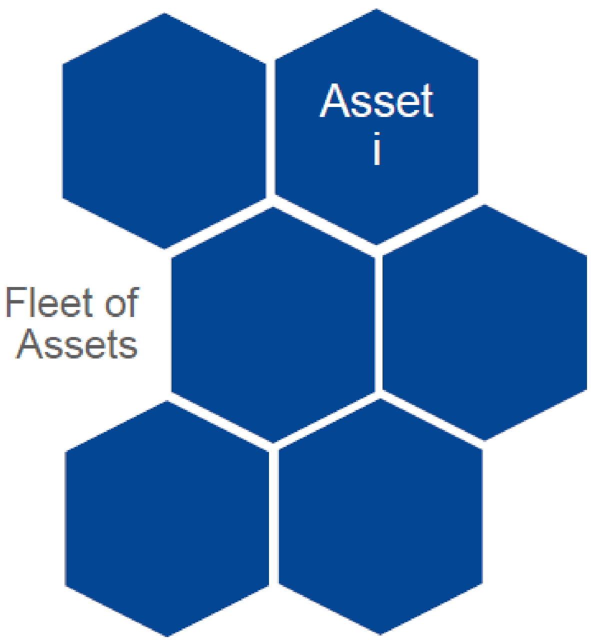
From individual assets to System maintenance

3.Fully Decentralized Decision System



- Decision Logic at local level

$u_{*i} = K_i (y_i, Z)$ **:asset i**

Z = aggregate information over 'all other assets '

Assets can share information

Multi-agent Systems concept

Maintenance Center just manages high-level resource constraints

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What characterizes Railway Systems?

- Geographical Distribution (especially for Main Lines)
- Bandwidth constraints (often)
- Cybersecurity threats (the threat looms over the Cloud…)

- Rolling Stock and Fixed Equipment
- Punctual vs Linear Asset (e.g. track)

- **Decentralized approaches probably preferable ?**
  - **Compute as much as possible locally ?**
  - **Compute on-board and transmit to ground or transmit raw data to ground and compute features there (at local points) ?**

Concluding remarks

- Digital twins and Hybrid models are needed for virtual commisioning to deliver O&M services
- O&M based on Data driven solutions can lead to catastrophic failures
- Life extension is not possible with big data analytics
- Manufacturers must provide the integration of systems and data
- Digital twin 4.0 will consider evoltionary models and normality dynamics

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