# Evolution of Maintenance Technology & LR's Digital Compliance Framework

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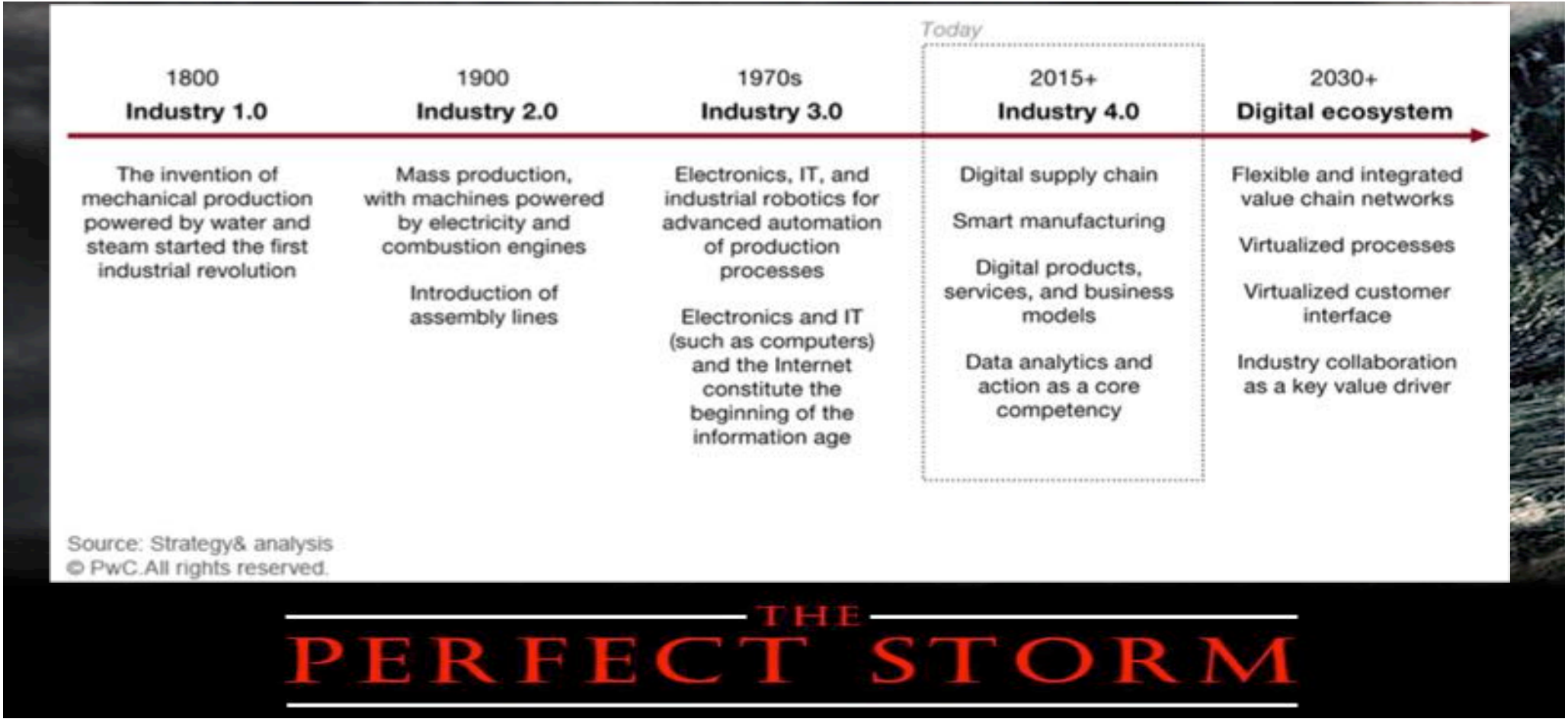
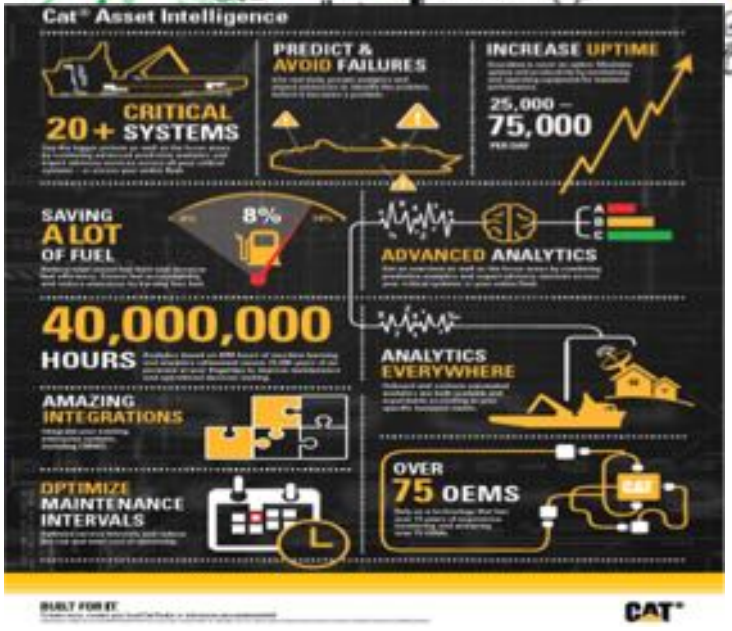
# Contents

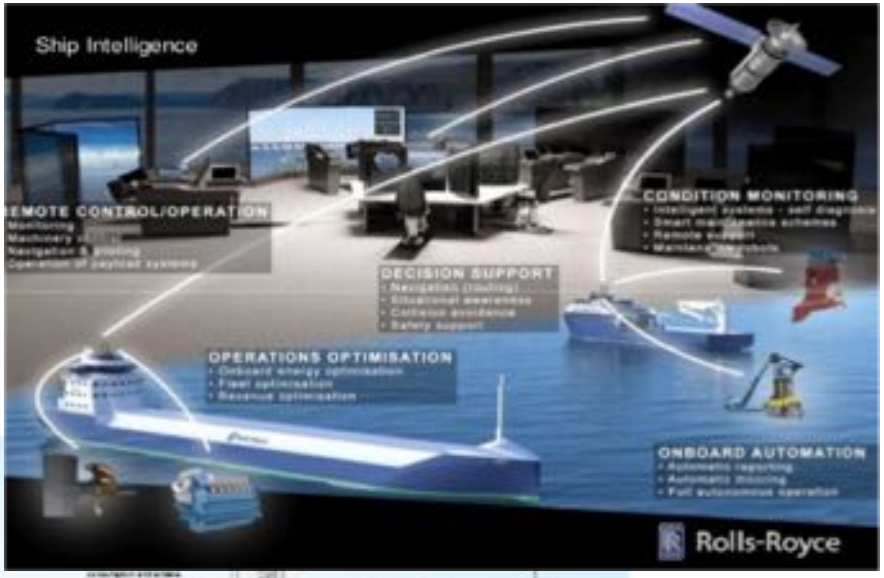
# The Industry 4.0, revolution

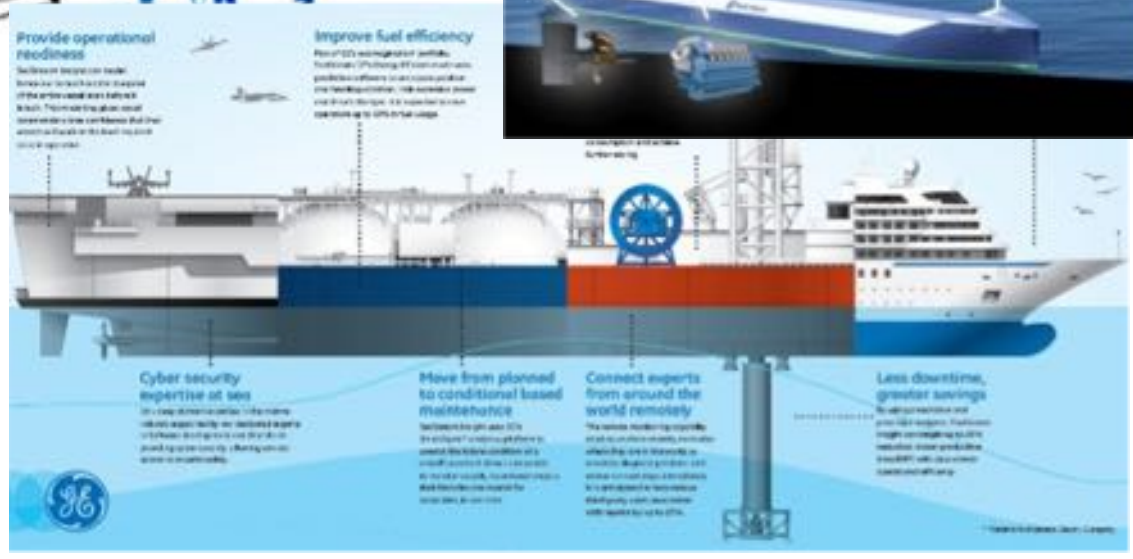


# Periodic, Discrete, Time Based is being Disrupted

*….to opportunistic, just-in-time maintenance*

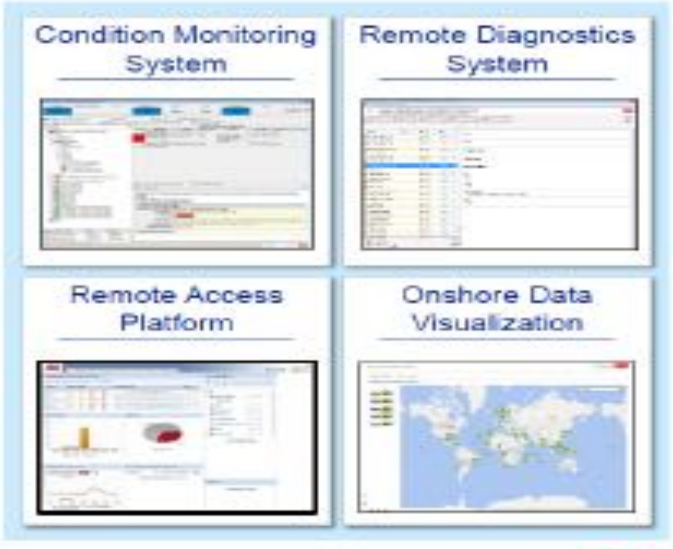



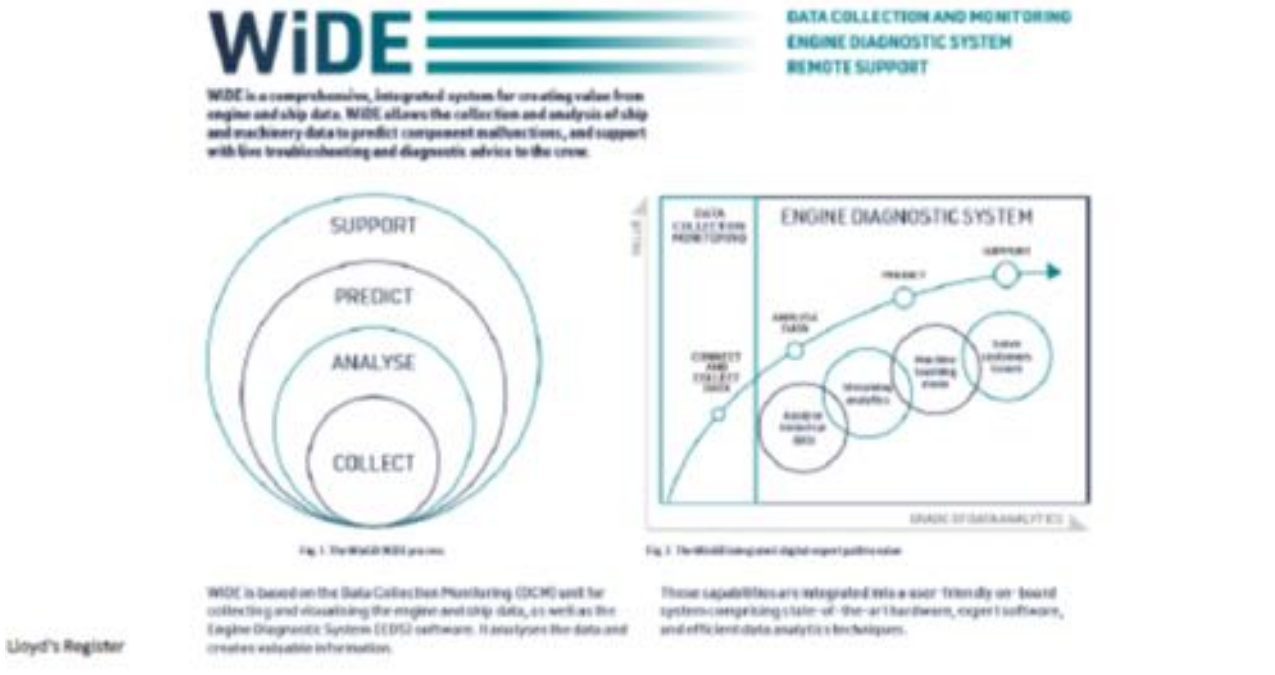



# Periodic, Discrete, Time Based is being Disrupted

## ABB Ability



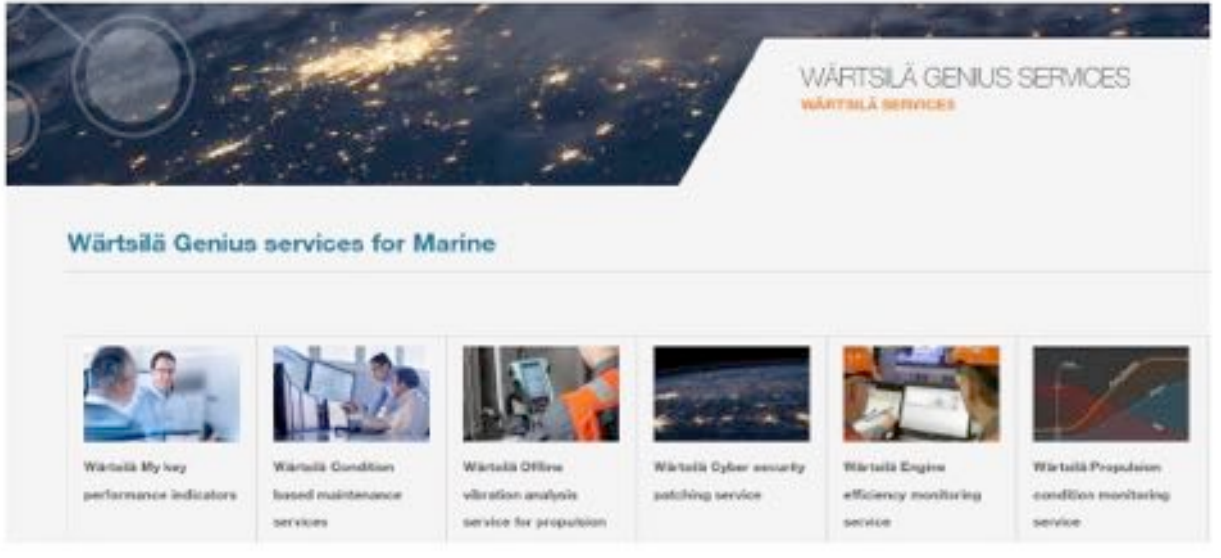

## Win GD Integrated Digital Expert (WIDE)



# Periodic, Discrete, Time Based is being Disrupted

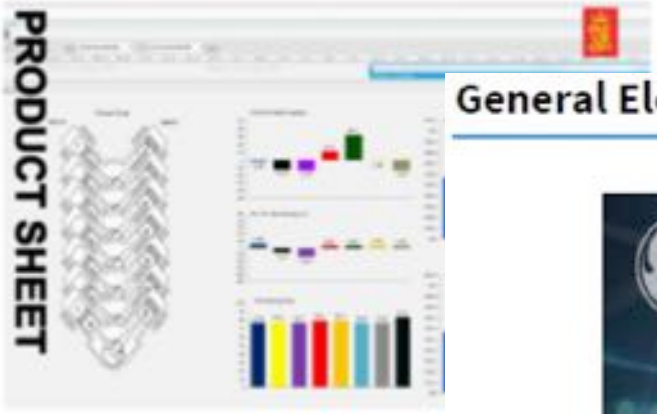
## Cummins Connected Diagnostics


## Wartsila Genius



# Periodic, Discrete, Time Based is being Disrupted

## Kongsberg Predictive Maintenance

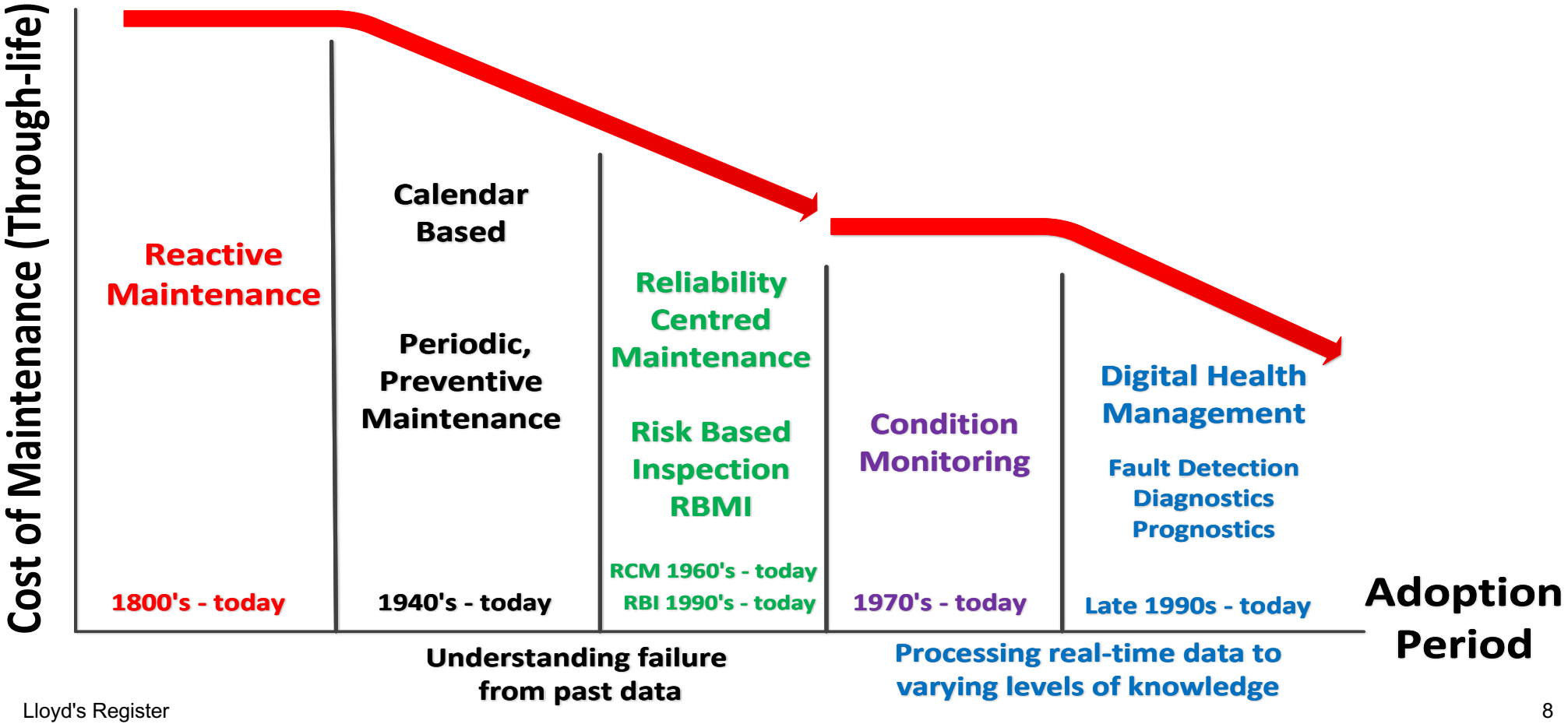



## General Electric Predix

## SKF Remote Diagnostics




# Maintenance Technology History



# Reactive Maintenance

Entire Life of the asset is consumed.  However consequences are unpredictable and can be disastrous


Source: Alamy, Boiler Explosion Beaver Mills


Source: St. Mary's Hospital Accident Investigation

# Calendar Based, Preventive Maintenance

- Planned Maintenance Routines are typically built up from Original Equipment Manufacturer (OEM) recommendations in isolation from the specific application or asset.
- Little justification for maintenance interval and typically resistance to change without a good justification
- Maintenance burden typically remains constant over asset life despite changing production or use of the application and/or economic circumstances

# Reliability Centred Maintenance, Risk Based Inspection (RBI, RBMI)

- RCM is a methodology that answers the following questions to determine an appropriate maintenance regime…

1. What is the item supposed to do and its associated performance standards?

2. In what ways can it fail to provide the required functions

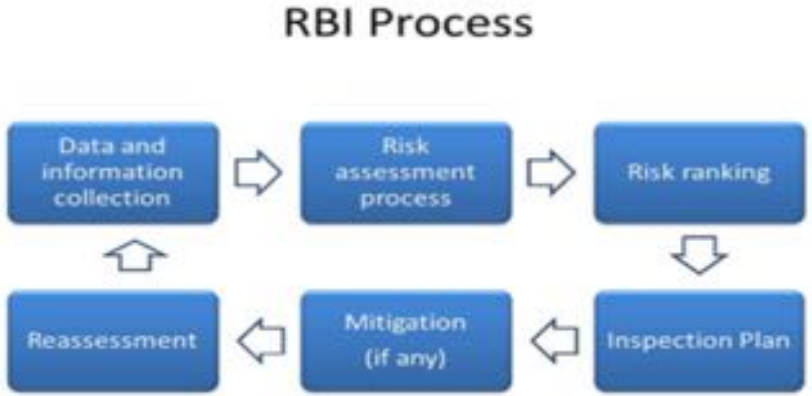
3. What are the events that cause each failure?

4. What happens when each failure occurs?

5. In what way does each failure matter?

6. What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?

7. What must be done if a suitable preventive task cannot be found?



# Evolution of Condition Monitoring

1970s

Exceedance recording

Temp, RPM, Vibes

1980s

Damage accumulation
Remaining Useful Life
(post flight calculation)

Temp, RPM, Throttle position

Goal: reduce uncertainty and retain conservatism in estimating component life limit

Method: rainflow cycle counting, limits monitoring

1990s

Digital Fuel Controls

Engine data collection

Condition Monitoring

Fault Detection and Isolation (Diagnosis)

1990s – 2000s

Prognosis – time to failure, recommended maintenance action

Goal: Extend time between overhauls by automatically detecting incipient failures in real time with embedded sensors

Method: vibration monitoring, oil debris detection, performance trending

**Source: ADS 79E HDBK**

Figure 5. Late 1960s laboratory vibration measurement instruments.

# Age of Analytics – Advancement of Diagnostics & Arrival of Prognostics

Sensing Techniques

Physics of Failure Techniques | Machine Learning Techniques

| Diagnostic model/ monitoring technique | Knowledge-based | | | Statistical methods | Case-based reasoning | Data-driven | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rule-based | Causal fault | First principle | | | Neural network | Classification trees | Random forest | Logistic regression | Support vector machines |
| Vibration | M | D | P | M | D | D | — | D | — | — |
| Thermography | M | — | — | M | — | D | — | P | — | — |
| Oil analysis | M | P | — | M | D | D | — | D | D | D |
| Process parameters | M | — | D | M | M | M | M | M | M | M |
| Performance | M | — | D | M | M | M | M | M | M | M |
| Acoustic emission | M | — | — | M | — | D | P | D | — | — |
| Acoustic monitoring | M | — | — | M | — | D | — | D | — | — |
| Electrical monitoring | M | — | — | M | — | D | — | — | — | — |

M: Mature and commonly applied in industrial applications.

D: Under development and some initial applications.

P: Promising and potential.

Source: ISO 13379-1 published 2012

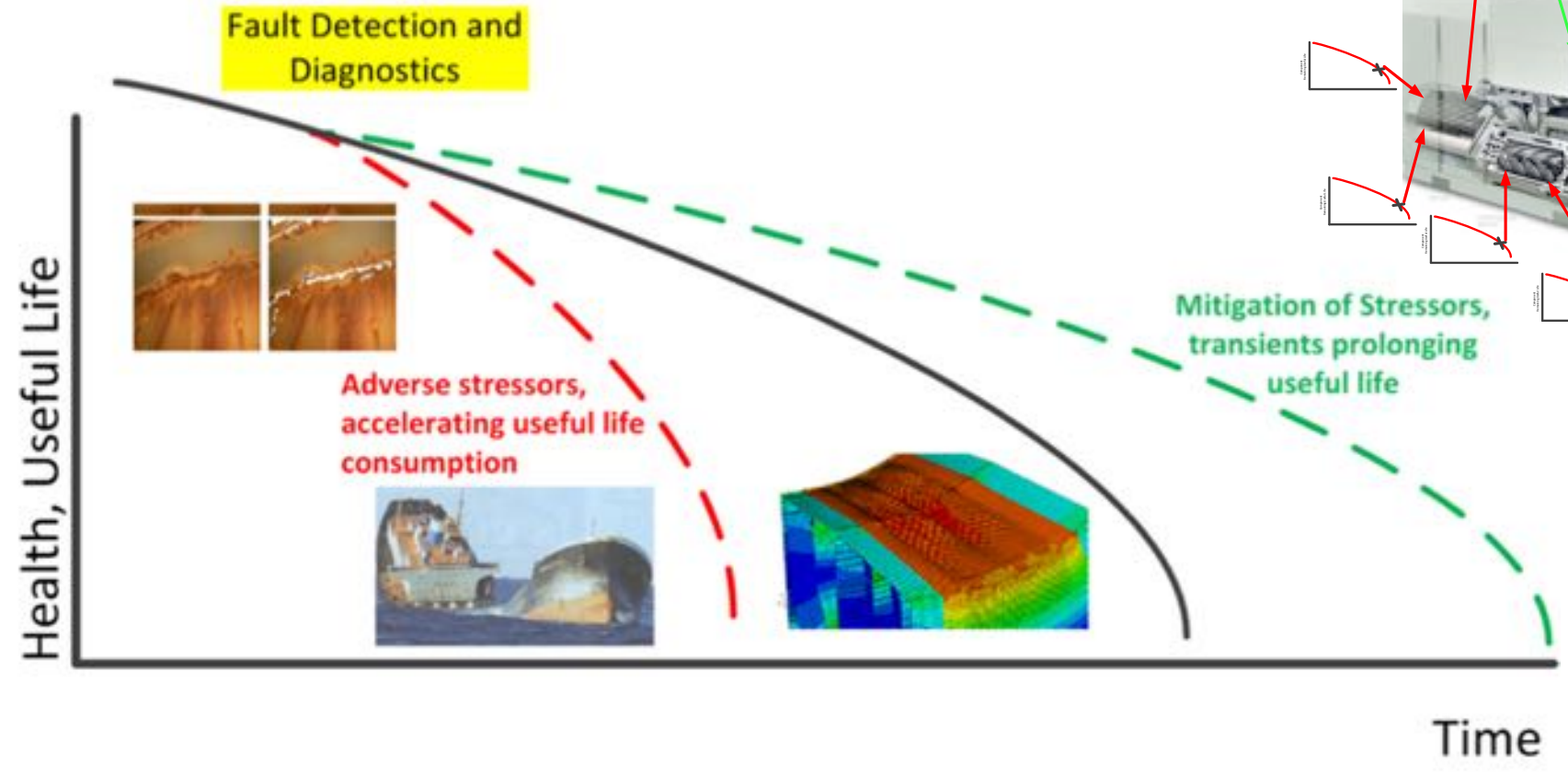
ISO 13379-1 showing Sensing Techniques and Analytics

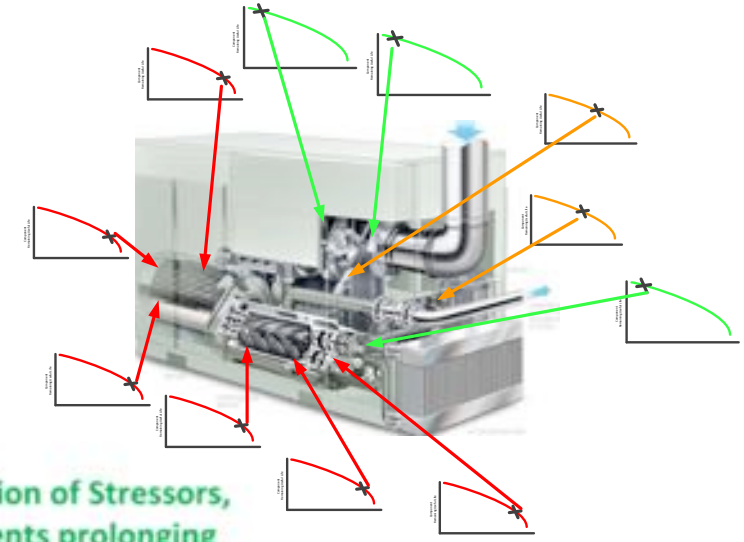
Today sensing, connectivity, computing and UI/UX hardware are more sophisticated and affordable than ever.

Furthermore the increasing use of algorithms – both physics based and data driven has grown exponentially.

# Digital Health Management (DHM) Technology

## Digital Twins are fundamental to DHM



# Digital Twins are fundamental to DHM

Sensor Conditioning
E.g. adjusting for drift, bias, fault, sensor-level

Sensor Data

Data Processing
"signal conditioning"

State Detection

Fusion and weighting of Model Based and Data Driven Techniques based on multiple data

Features Extraction

Diagnostics, Prognostics

Aggregated First principles, empirical, simulation models

Physics of Failure (multi-physics) Based Techniques

FMECA, FTA, ETA, first principles derived failure modes

Simulated Failure Models

Synchronised, Historical, Operational, Maintenance, Failure Data

Machine Learning Techniques

Results Management

# Roadmap to Systems Effectiveness & Maintenance Optimisation

**Maintenance Strategy** based on existing AMOS or equivalent data

RCM Applied

**Optimize Planned Maintenance**

Apply Condition Monitoring

**Routine Condition Monitoring**

Apply Condition Based Maintenance

**CBM**

Take Advantage of your investment.

(LR's MCBM-CBM & Digital Maintain Descriptive Notes)

**Class Approval of Maintenance Scheme**

Take Advantage of your investment.

**LR Digital Compliance**

Framework

**Digital Health Management**

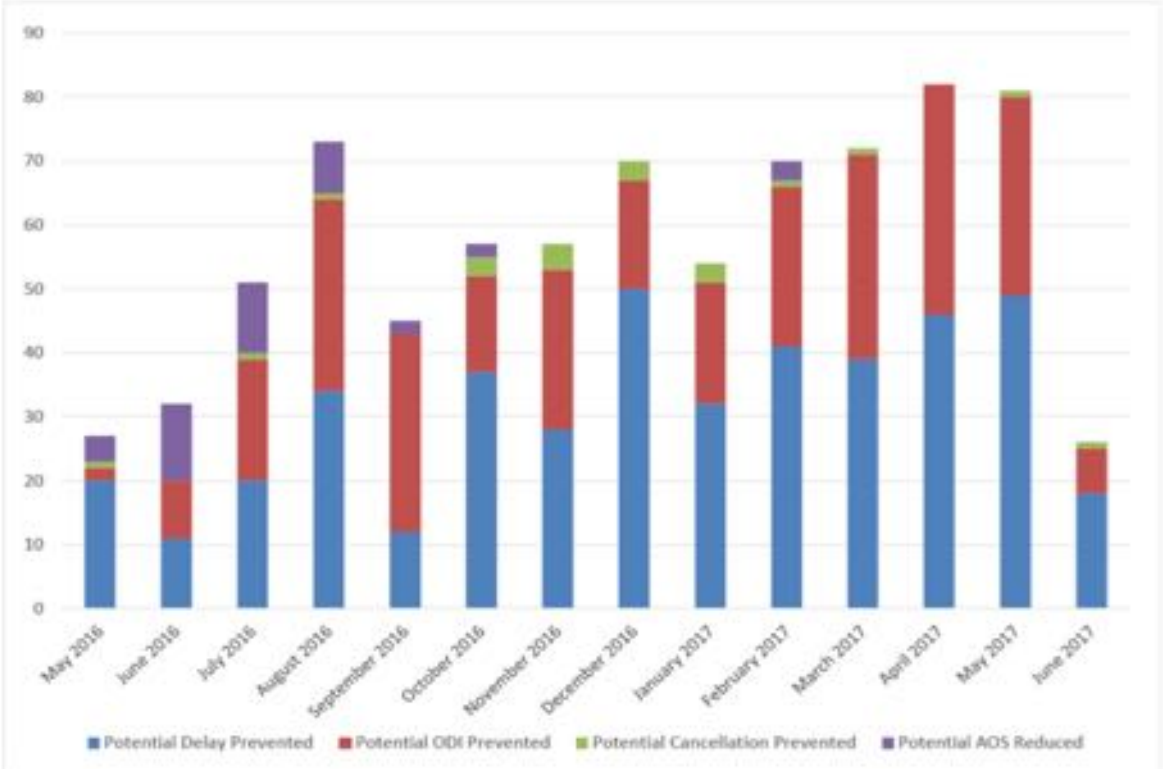
# Why Digital Health Management?

# DHM Drives Business Results (Aviation)

## Predictive Benefits

DELTA TechOps

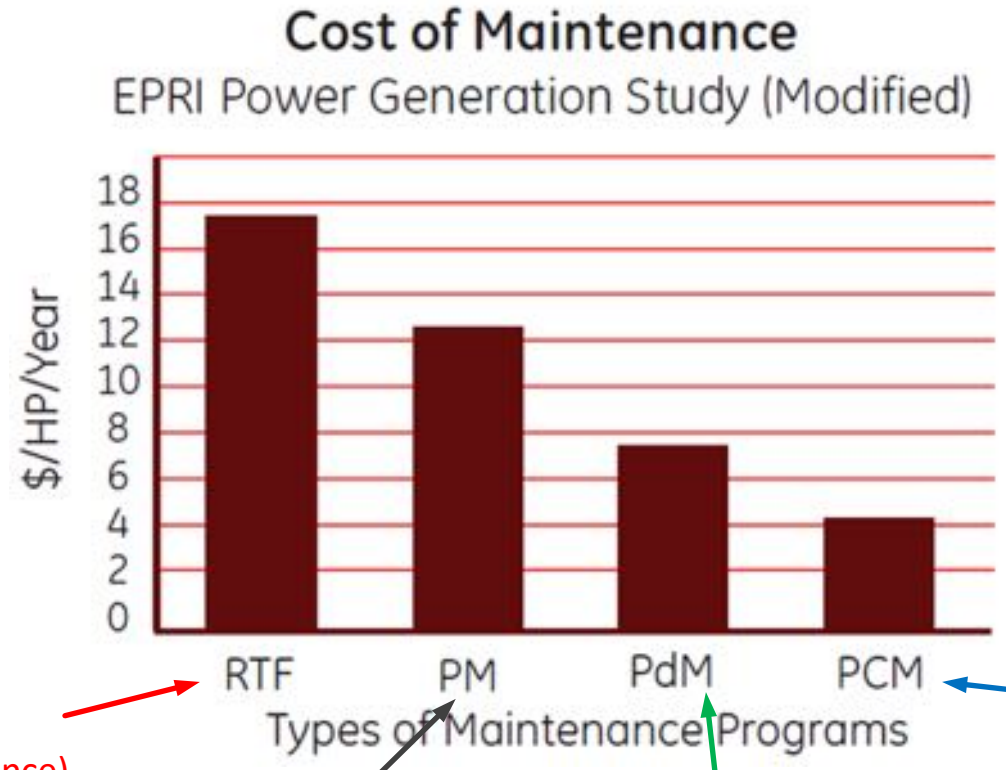
~1000 potential delays, cancellations, ODI's Mitigated in past 12 months!




**Delta TechOps Develops Innovative Structural Health Monitoring Application**

Source: Delta Tech Ops SHM Management

# DHM Drives Business Results (Power Generation)




65% Maintenance saving comparing calendar based maintenance with DHM

Run to Failure (Corrective Maintenance)

Preventive Maintenance (Calendar based maintenance)

Predictive Maintenance (Fault Detection, Diagnostics, Prognostics)

Prioritised Corrective Maintenance (DHM enabled maintenance)

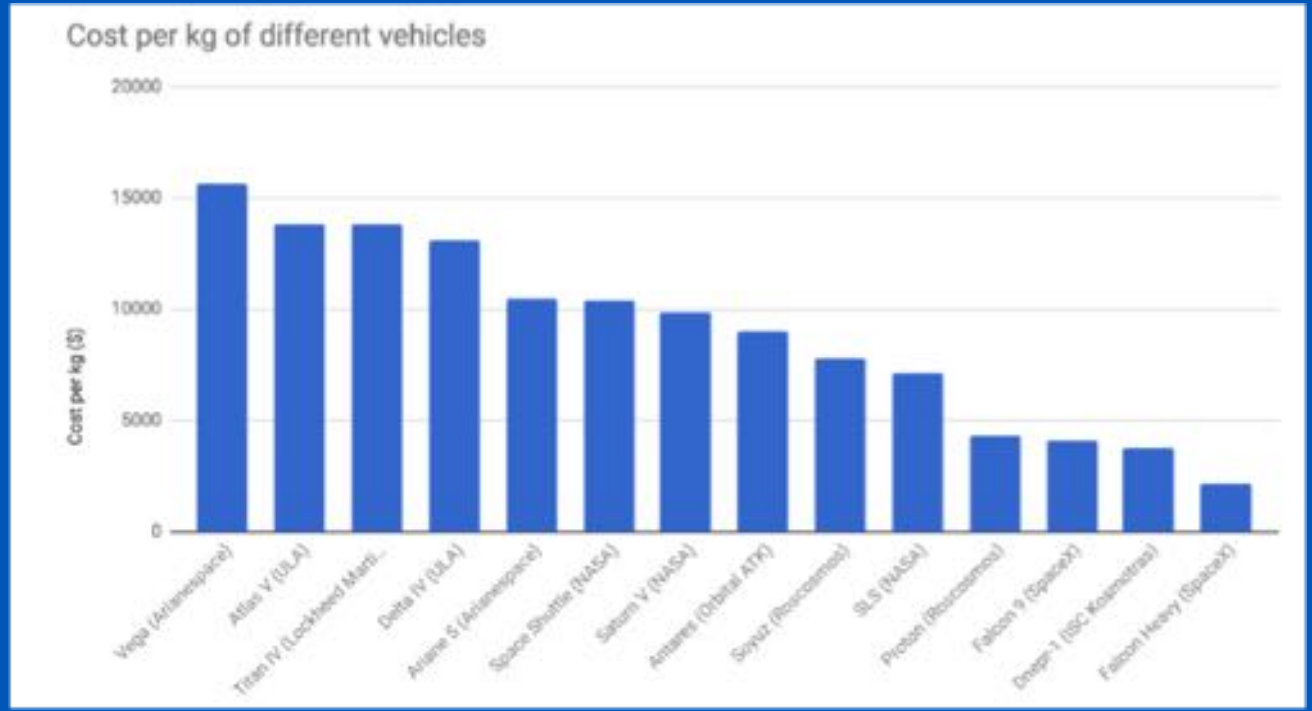
**Source: EPRI with LR annotations**
(Electric Power Research Institute)

# **DHM** (and Autonomy too!) **Disrupted the Space Industry**

***Autonomy and DHM (i.e. reusable rockets) are the two biggest reasons why Space X and their contemporaries can launch assets into space 80% cheaper than United Launch Alliance and other incumbents***

***Space X Falcon 9***

Source: Space X




Source: CB Insights Space X tear down Analysis

# DHM Benefits a Spectrum of Maritime Stakeholders

**Maintenance engineers and Chief Engineer**
- Opportunistic maintenance
- Maximise uptime
- Minimise unnecessary maintenance

**Vessel Superintendent**
- Spares Positioning
- Reduced Spares Count
- Logistics Efficiency

**Flag Administration**
- Increase Asset Safety
- Eliminate Catastrophic Failures

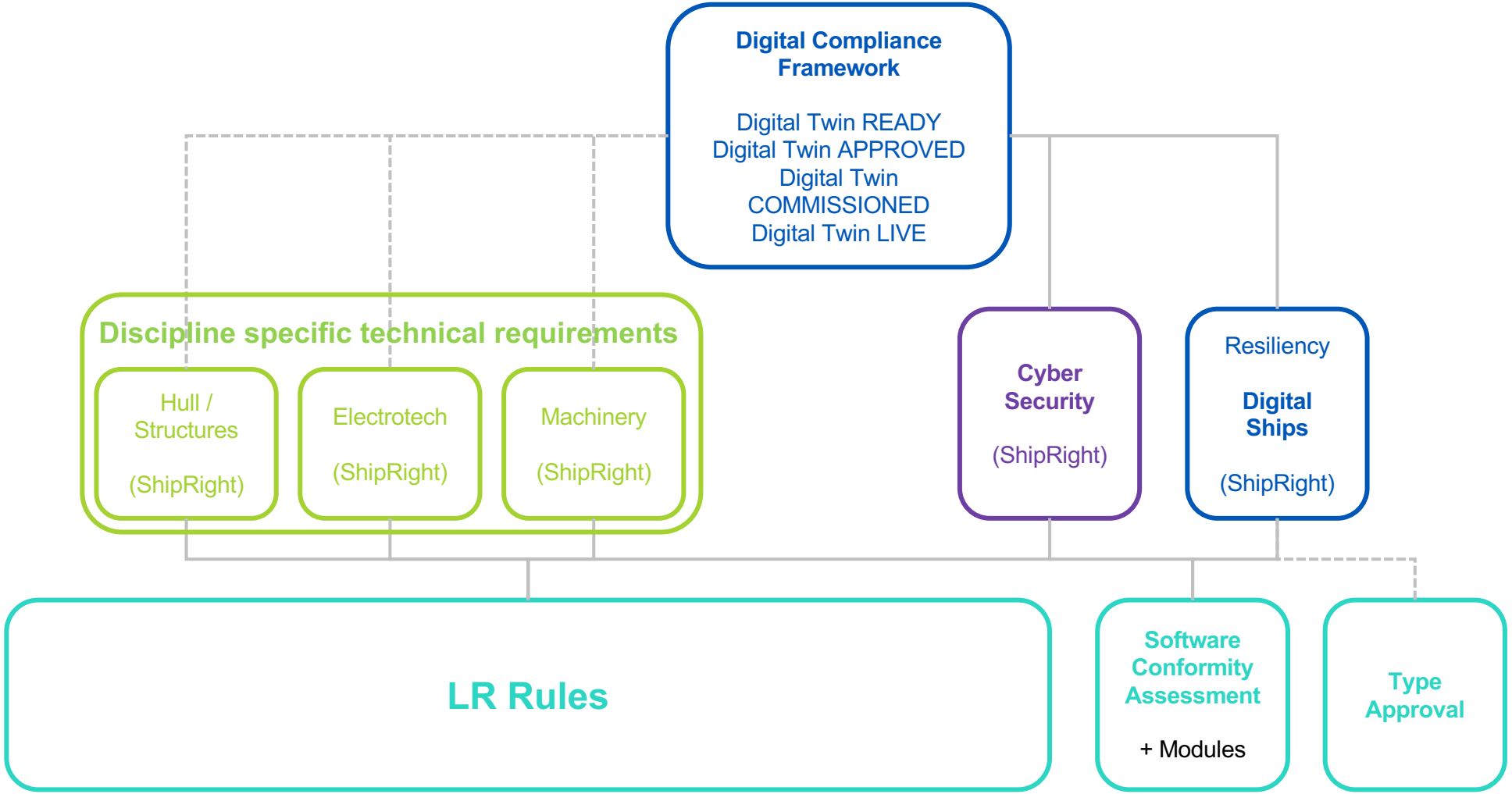
**Manufacturers, Shipyards,Service Providers**
- Re-defining and exceeding customer expectations
- ”As a service” business models
- Through-life monetisation of asset activities.

**Shipping Company Managing/Technical Director**
- Best Lifecycle Cost
- Business Planning
- Maximising Capability

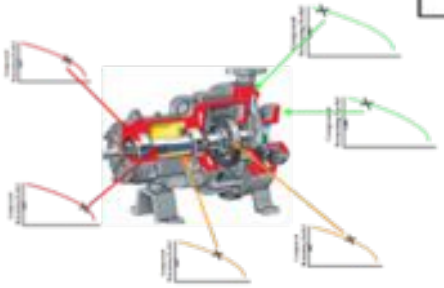
**Insurers**
- Enhancement of actuarial science, accurate pricing of risks
- Objective evidence for claims
- Better management of insurance premiums

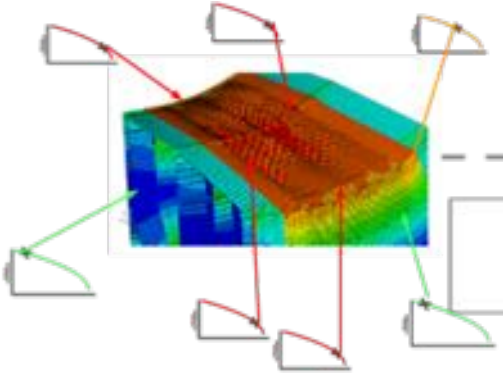
# LR Digital Compliance Framework

# Digital Compliance in Wider Context of LR Rules



# Digital Class/ Digital Compliance Framework – 4 Approval Levels





| Supporting Requirements | LR Approval Level | |
|---|---|---|
| | Digital Twin READY | DHM Provider approved |
| | Digital Twin APPROVED | Asset specific digital twin developed and approved at DHM Provider |
| Digital Maintain* | DHM system integrated with vessels systems | Digital Twin COMMISSIONED — Asset specific digital twin approved and commissioned at The DHM Operator |
| ShipRight MPMS | Approval for a flexible maintenance regime | Digital Twin LIVE — Digital twin function and performance demonstrated over time |

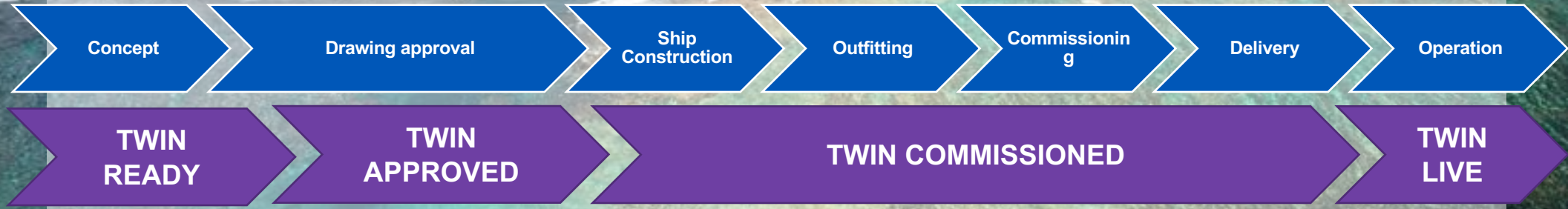
The DHM Provider

The DHM Operator

**Digital Class**

*Lloyd's Register Digital Ships ShipRight Procedure

# The New Classification Continuum




- ✓Trust  the individual Twin
- ✓Achieve confidence in the performance of each digital twin
- ✓Improve the performance of each digital twin through validation

# Thank you

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