bachmann.

Knowledge Based Operational Excellence

David Futter, Bachmann Monitoring
Department Head, Condition Monitoring Consultancy
Approved Training Coordinator

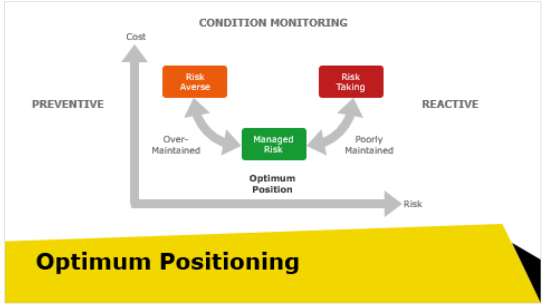
Knowledge Based Operational Excellence

Optimised Asset management

Prologue

Discussion points today

- Condition Monitoring (CM) Systems can bring huge benefits, but only when applied in the correct context.
- Choice of CM Systems is only a small part of the wider topic of Asset Mangement
- Knowledge availability greatly influences operational decisions



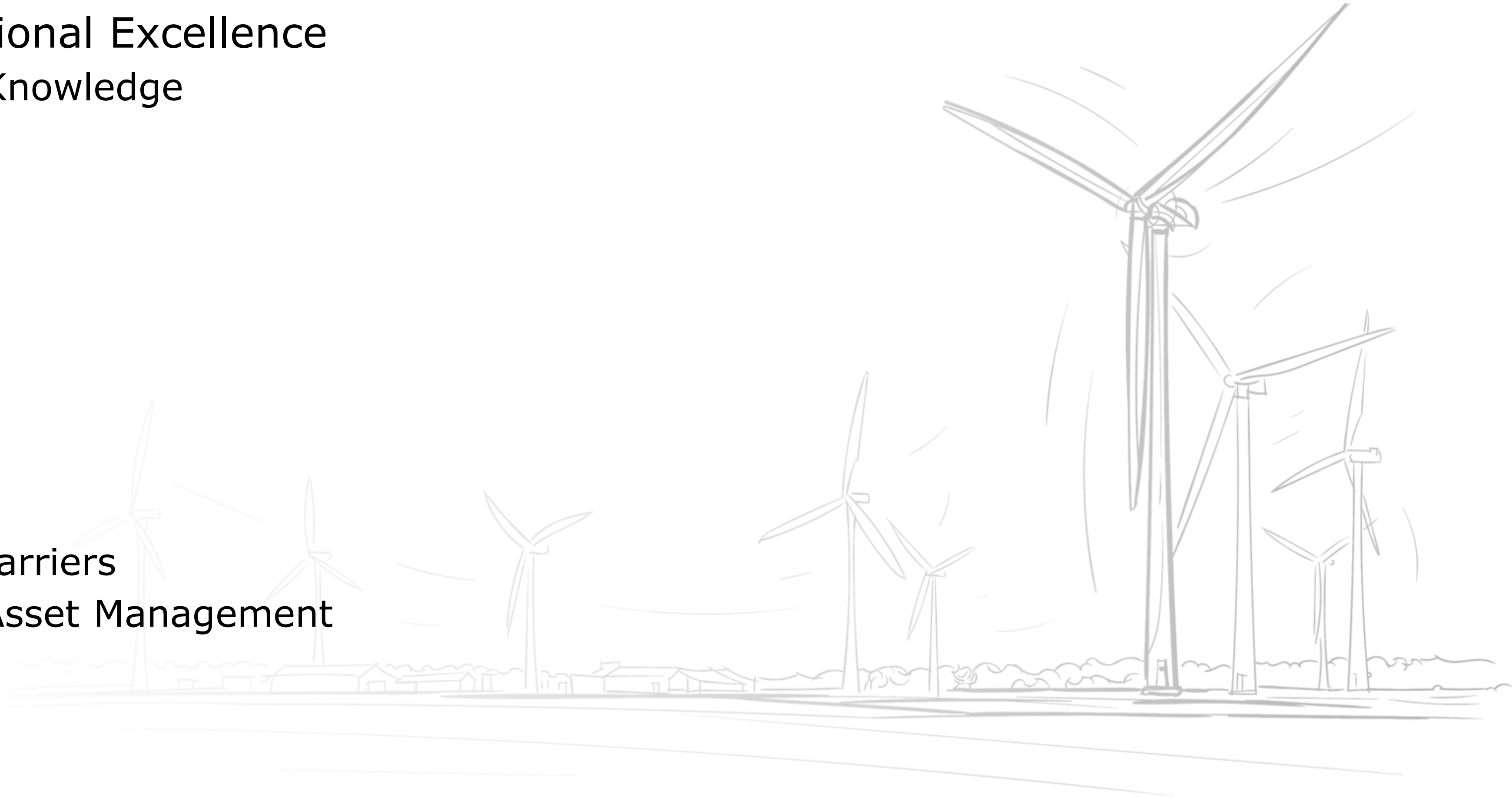
Prologue

Information flows

- Each system delivers knowledge to the asset owner
- Externalities also influence the asset
  (eg weather, demand, prices, resource availability)
- Using this knowledege effectively is the key to
  Operational Excellence
- Integrating such systems simplifies the process

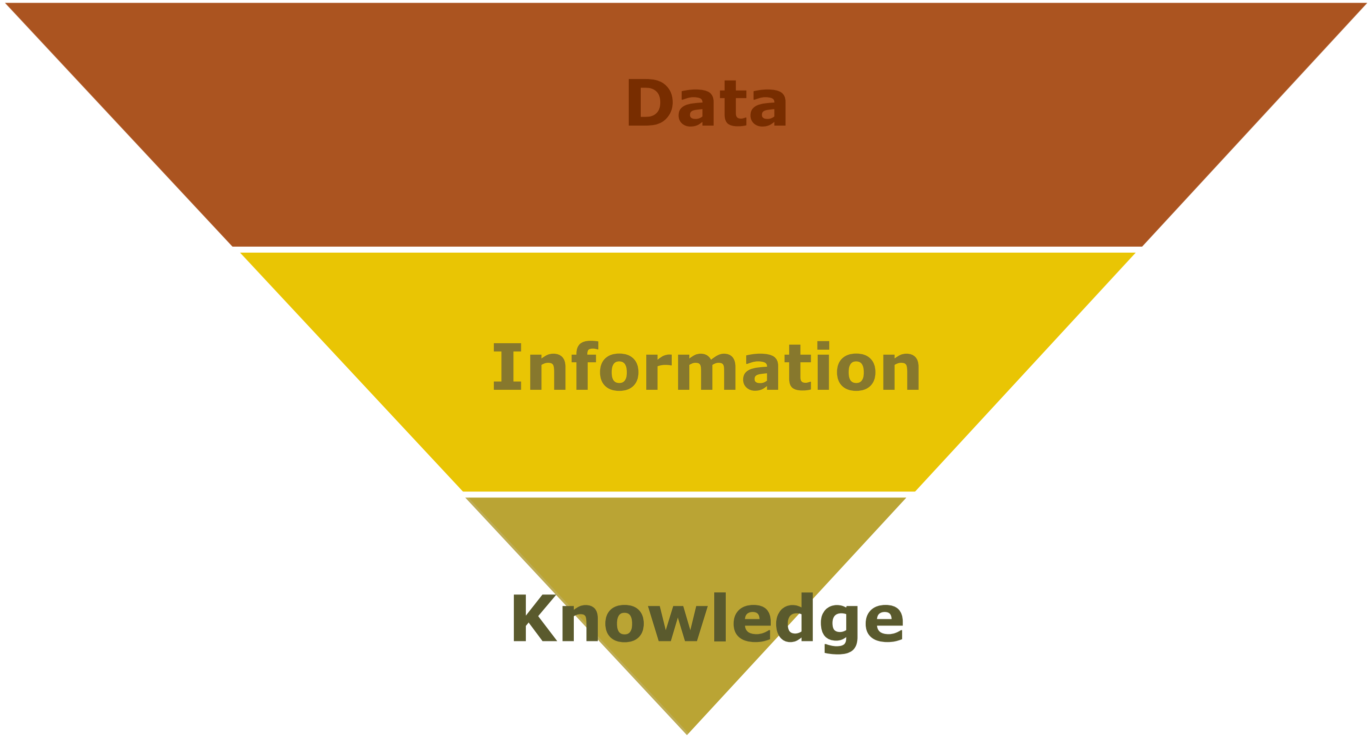
Contents

- Knowledge Based Operational Excellence
  - Data, Information and Knowledge
  - Approach
- Some Examples
  - CMS
  - SHM
  - Data
- Implementation
  - Hints and overcoming barriers
  - Bachmann Supporting Asset Management
- Conclusions



Knowledge Based Maintenance

Data → Information → Knowledge



Example - Vibration Monitoring

- Vibration of bearings; speed marker; process parameters

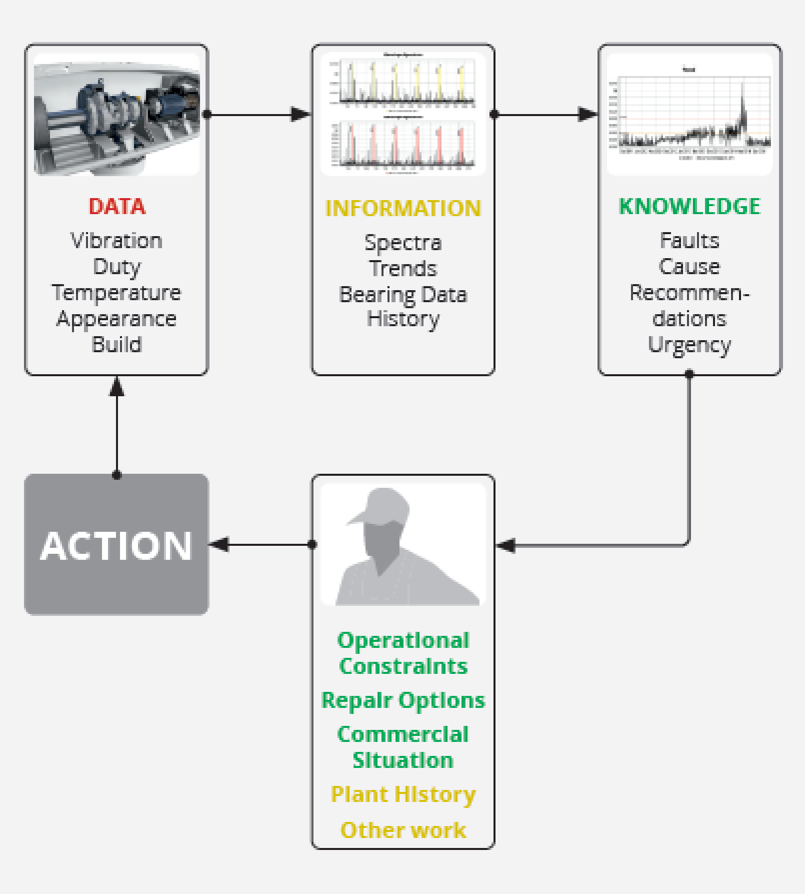
- Converted into signals by sensors and fed to CMS hardware
- Order related data; CVs trends; history; machine build
- Analysed daily for long term trends

- Current state of machine; cause of any anomalies; recommendations
- Transmitted via weblog e-mails; stored in logs; work orders; reports

Approach

Knowledge Based Maintenance

- **Data** is recorded to from the machines‵ operation
- **Information** is created by putting the data into context. Multiple sources of information are collated
- **Knowledge** is generated from the information and experience
- Actions are taken at the optimum opportunity to reduce costs and increase availability
- Reviewing the results of the process enables continuous improvement



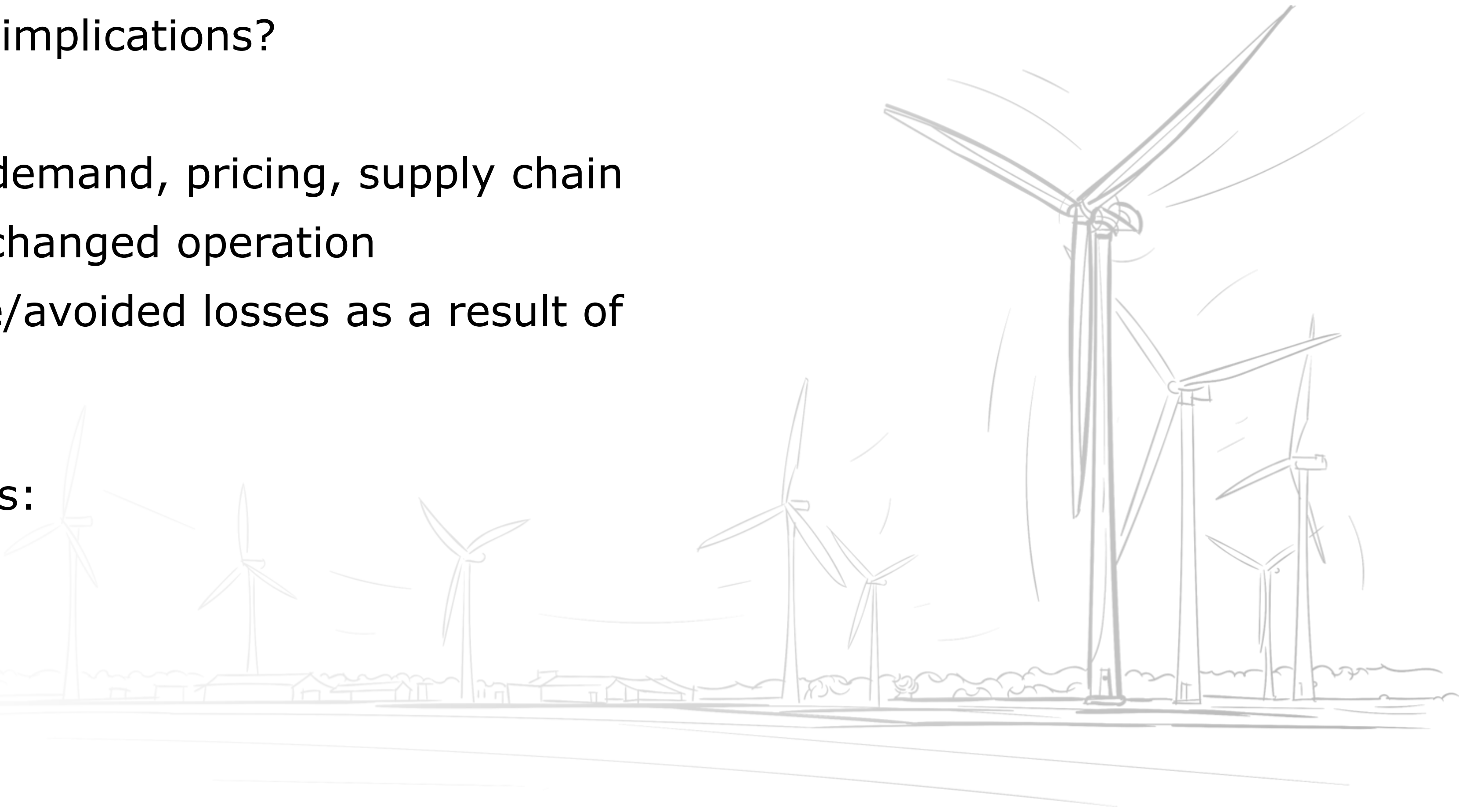
Asset Management

Additional Information to bring in

- Are there safety or integrity implications?
- Resource availability
- External factors – Weather, demand, pricing, supply chain
- Mitigations – reduced load, changed operation
- Cost benefits – extra income/avoided losses as a result of an intervention

Operational Excellence requires:

- Prioritisation
- Risk management
- Capitalising on opportunities



Knowledge Based Maintenance

Maintenance strategies

Lots of names:

- Run to Failure
- Maintenance Optimisation
- Breakdown Maintenance
- Preventive Maintenance
- Reactive Maintenance
- Predictive Maintenance
- Time-based Maintenance
- Total Productive Maintenance
- Scheduled Maintenance
- Firefighting
- Reliability Centred Maintenance
- On Condition Maintenance
- …

But only three strategies:

- Reactive Maintenance (Run to Failure)

  Run the machine until it fails – high repair costs, poor availability

- Predictive Maintenance (Condition Based)

  Monitoring of selected parameters to assess the condition of the machine so that maintenance can be planned.

- Preventive Maintenance (Time- or Duty-based)

  Run the plant for a pre-determined period then overhaul

Knowledge Based (Smart) Maintenance

Choose your strategy

Reactive Maintenance	Preventive Maintenance	Predictive Maintenance	Smart Maintenance
▪ Repair item on failure ▪ Unplanned downtime ▪ Consequential damage ▪ Suitable for consumables in non critical plant	▪ Choose repair time based on interval ▪ Good parts replaced ▪ Maintenance induced problems ▪ Some parts will fail early – CM also needed for critical items ▪ Can be augmented with equivalent operating hours	▪ Requires condition indication ▪ Failure indicator must give sufficient lead time ▪ Probability of detection must be high ▪ Plant must have opportunities for maintenance	▪ Strategy based on plant item ▪ Reduces unnecessary work ▪ Reduces unplanned unavailability ▪ Supports planning for major items ▪ Inputs from Big Data and AI methods to improve prognostics

Asset Management

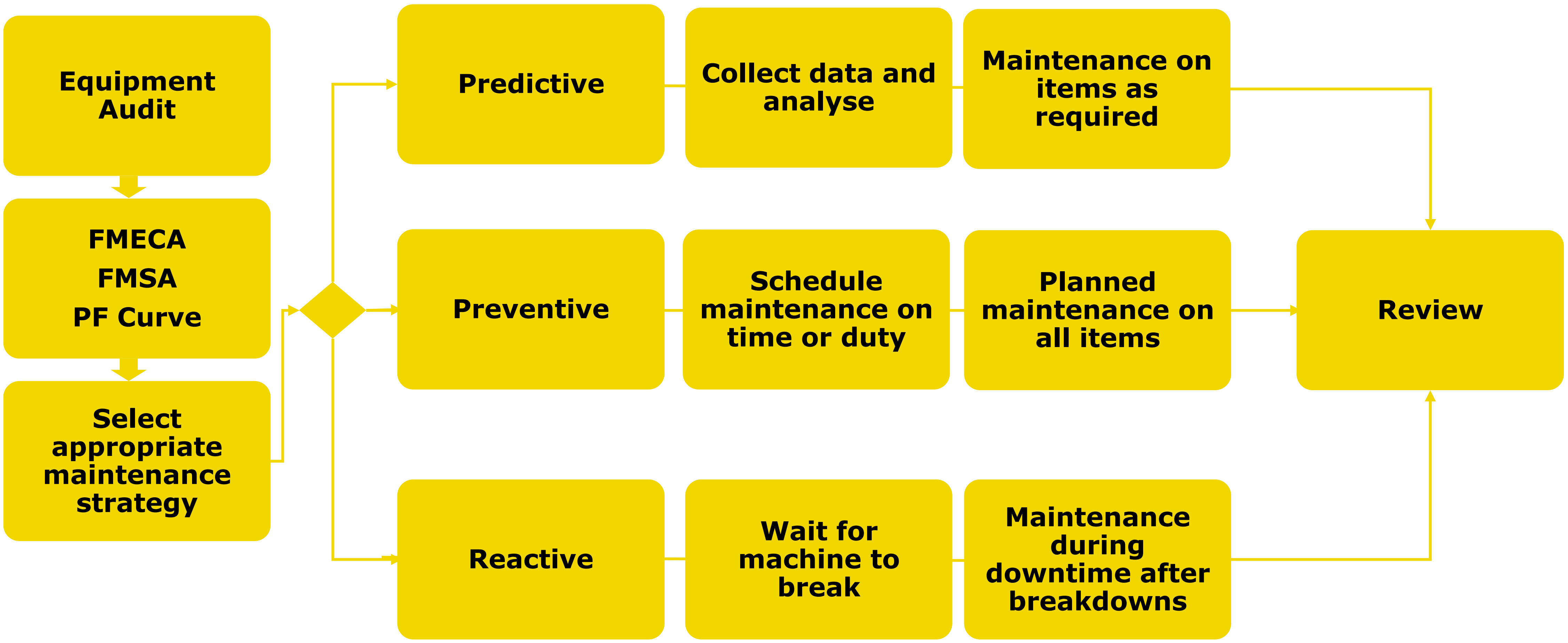
Interface with maintenance strategy

- Equipment inventory – which assets need to be maintained
- Identify the failures which cause losses to the plant - FMECA
- Identify the faults which lead to these failures
- Identify the symptoms which can identify these faults - FMSA
- Identify the equipment which can measure these symptoms
- Cost-benefit analysis to decide whether it is worthwhile

- ISO17359 describes the process
- ISO13373, ISO13379 provide further information

Knowledge Based Maintenance

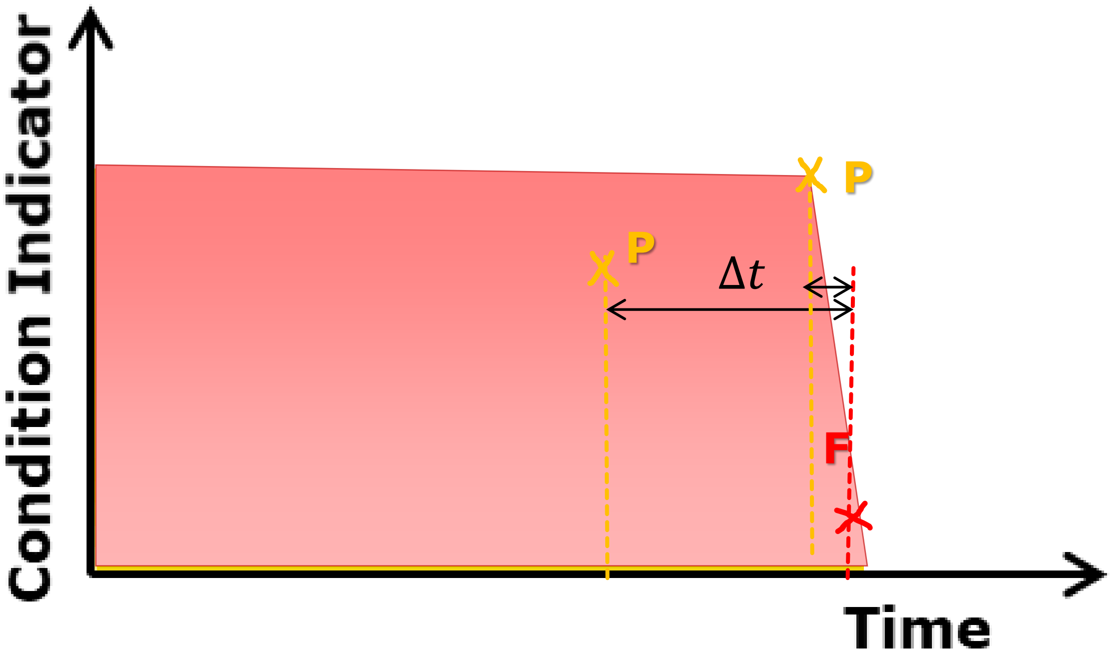
Choose your Strategy

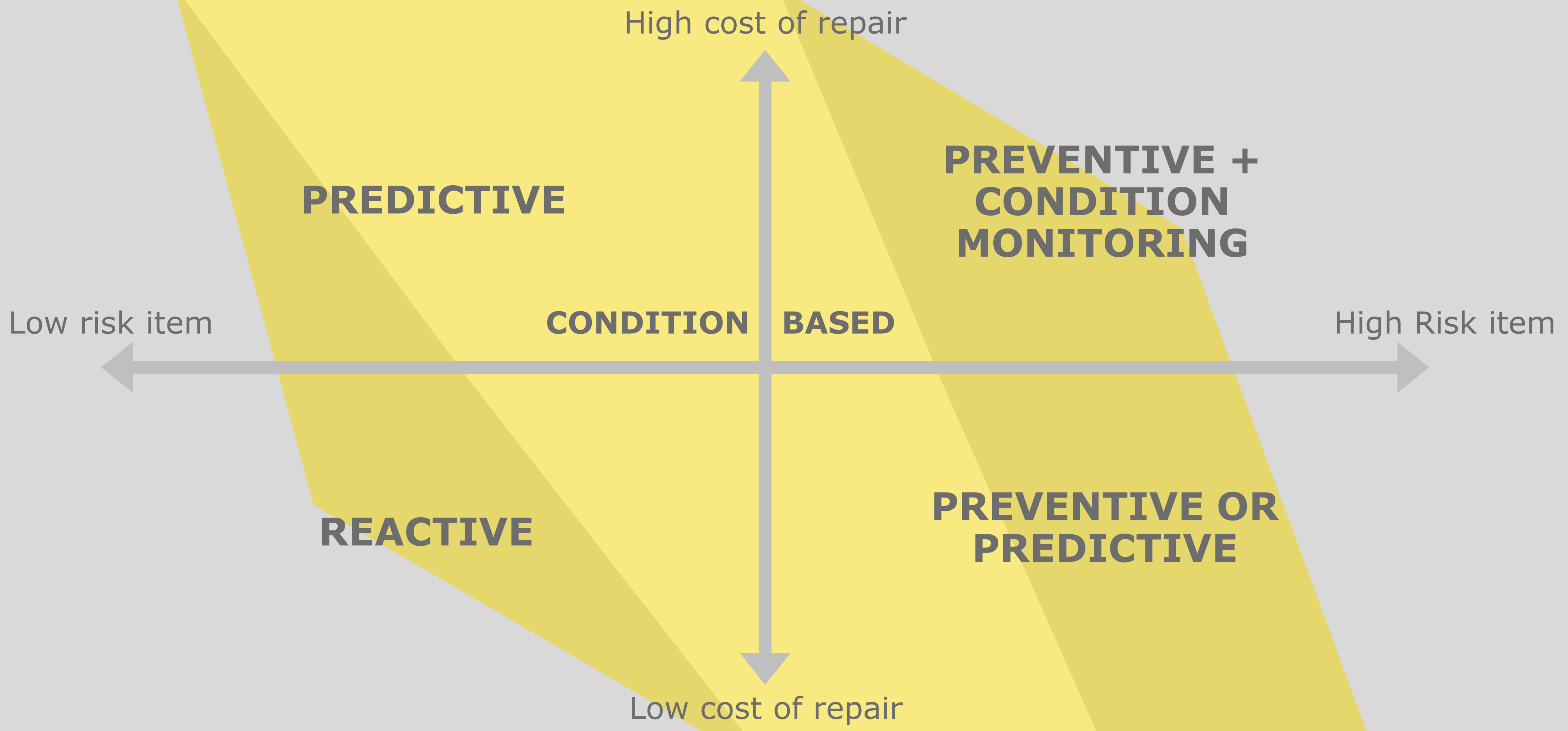


Equipment Audit

Identify everything – and how it can fail – and how you can spot that coming.

- Machine 1
  - Component 1
    - Failure Mode 1
    - Failure Mode 2
  - Component 2
    - Failure Mode 1
    - Failure Mode 2
  - Component 3
    - Failure Mode 1
    - Failure Mode 2
    - Failure Mode 3
- Machine 2
  - etc



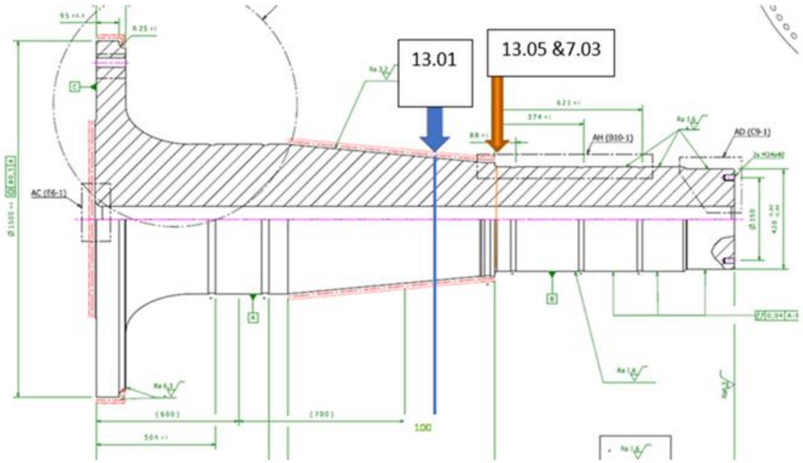


Cost vs Criticality

Some Examples

Vibration Analysis – Main Shaft Crack

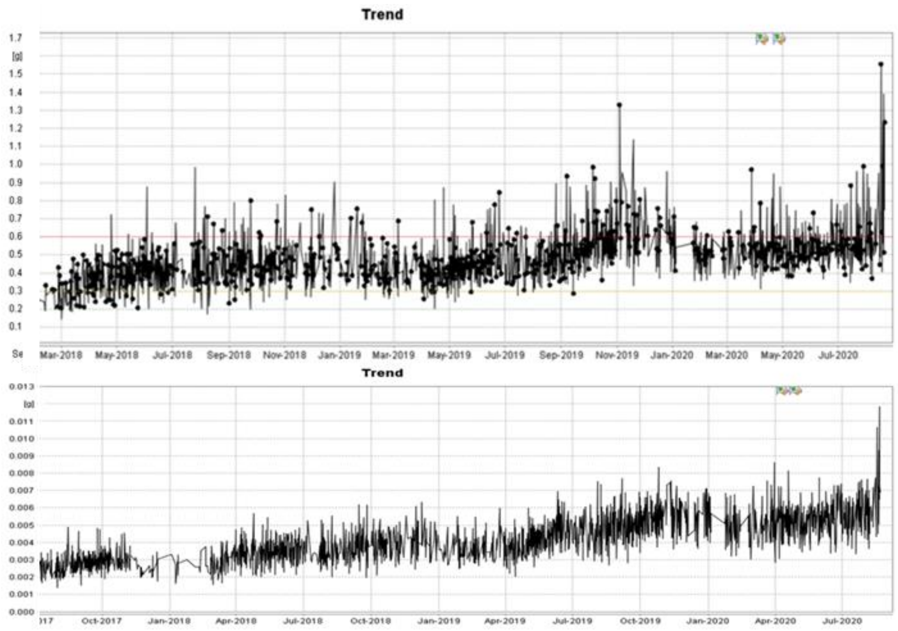
- Machine with cracked main shaft
- Examples on selected examples of similar turbines
- Asset management requirements:
  - Protection against complete failure
  - Identification of at-risk turbines
  - Root cause analysis

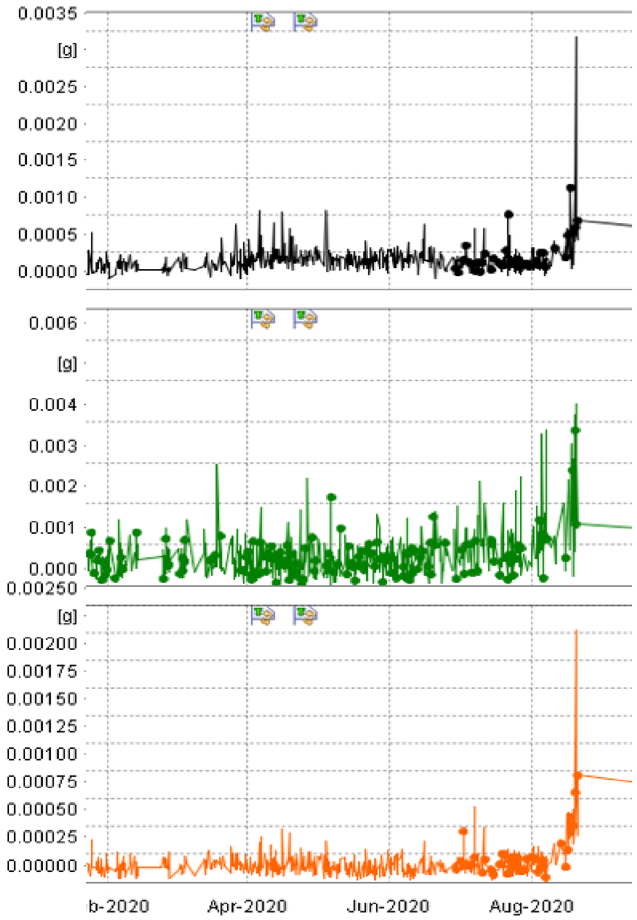


Some Examples

Vibration Analysis – Main Shaft Crack

- Protection against failure
- Existing analysis can be used
- Little forewarning without further processing

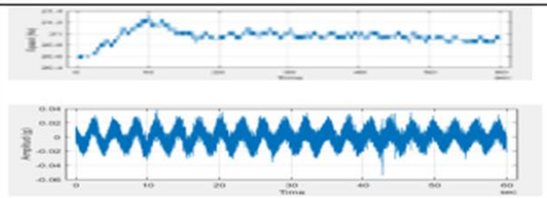
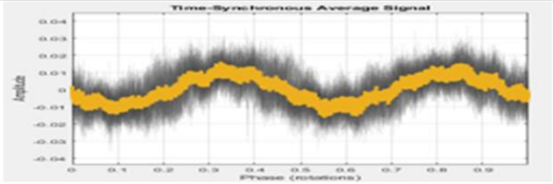
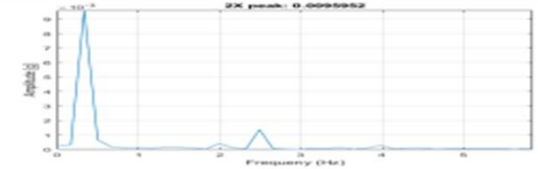
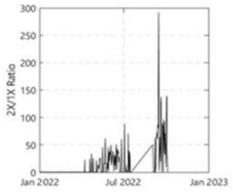
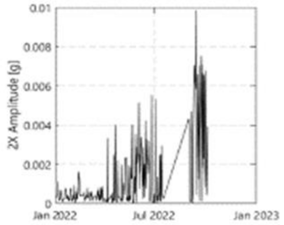
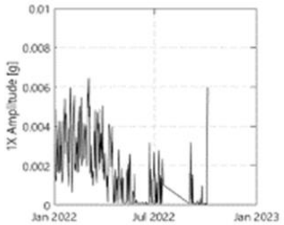




Some Examples

Vibration Analysis - Main Shaft Crack

- Identification of at-risk turbines
  - Post processing
  - Identifies a parameter to identify at-risk turbines
  - Results can be used to prioritise inspecions and replacement
  - List of turbines can help with RCA
- RCA
  - Idenitifed turbines all had degraded elastomers in the torque arms
  - Not clear if correlation or association

Description	Example Signal/Chart
Time and Speed signal	
Time Signal averaging (TSA).	
FFT of the TSA signal	
Trend over time of the 1X/2X harmonics 	 

Some Examples

Structural Health Monitoring

- Structural Health Monitoring is a requirement for some offshore turbines
- The data is used to verify the structural integrity.
- What else can we learn from the data?
- Is the structure performing as expected
- Which conditions use up the most turbine life (fatigue cycles, ultimate loads etc.)
- How extreme are specific events

Some Examples

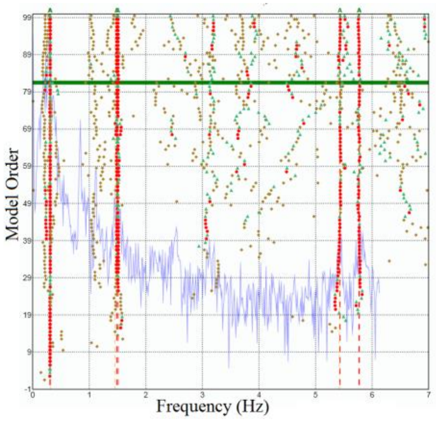
Use SHM data for O&M and asset management

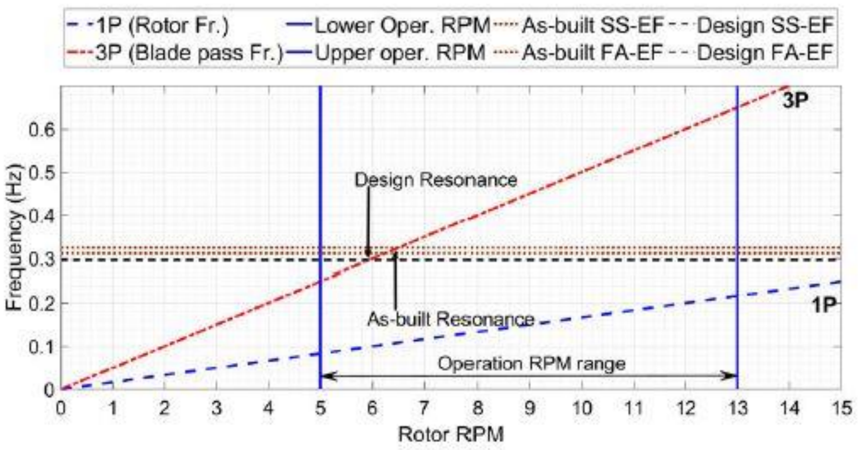
Structural Health Data allows:

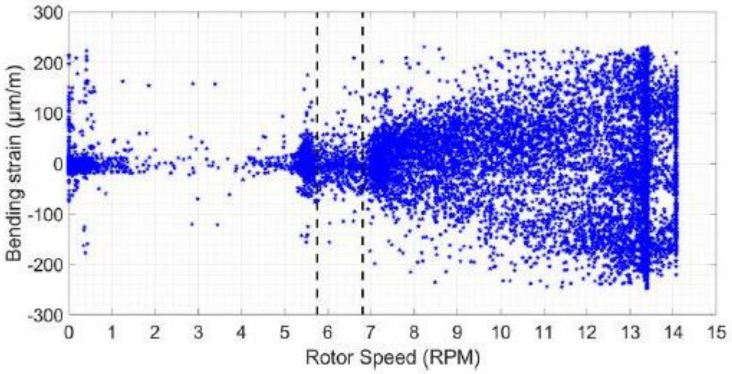
- Design verification
- Review of extreme loads
- Fatigue analysis
- Identification of extreme events
- Eigenfrequency monitoring

Information can be used for:

- Extending of inspection intervals
- Adjusting operating parameters to optimize structural response
- Early detection of problems
- Basis for lifetime extension (LTE)







Some Examples

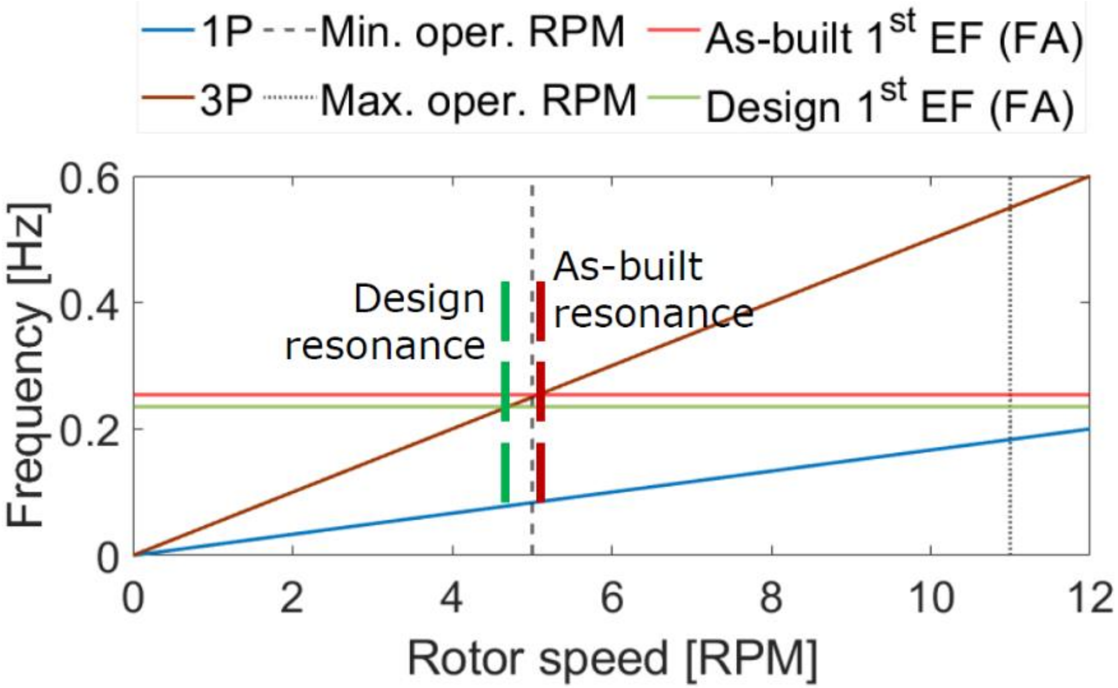
Tower Eigenfrequency overlaps operating ranges

- Small underestimate of tower stiffness
- Resonance now overlaps Blade Pass Frequency
- Asset management question?

Extend life of the tower

Or

Maintain power output



Some Examples

SHM for Lifetime extension

SHM data

+

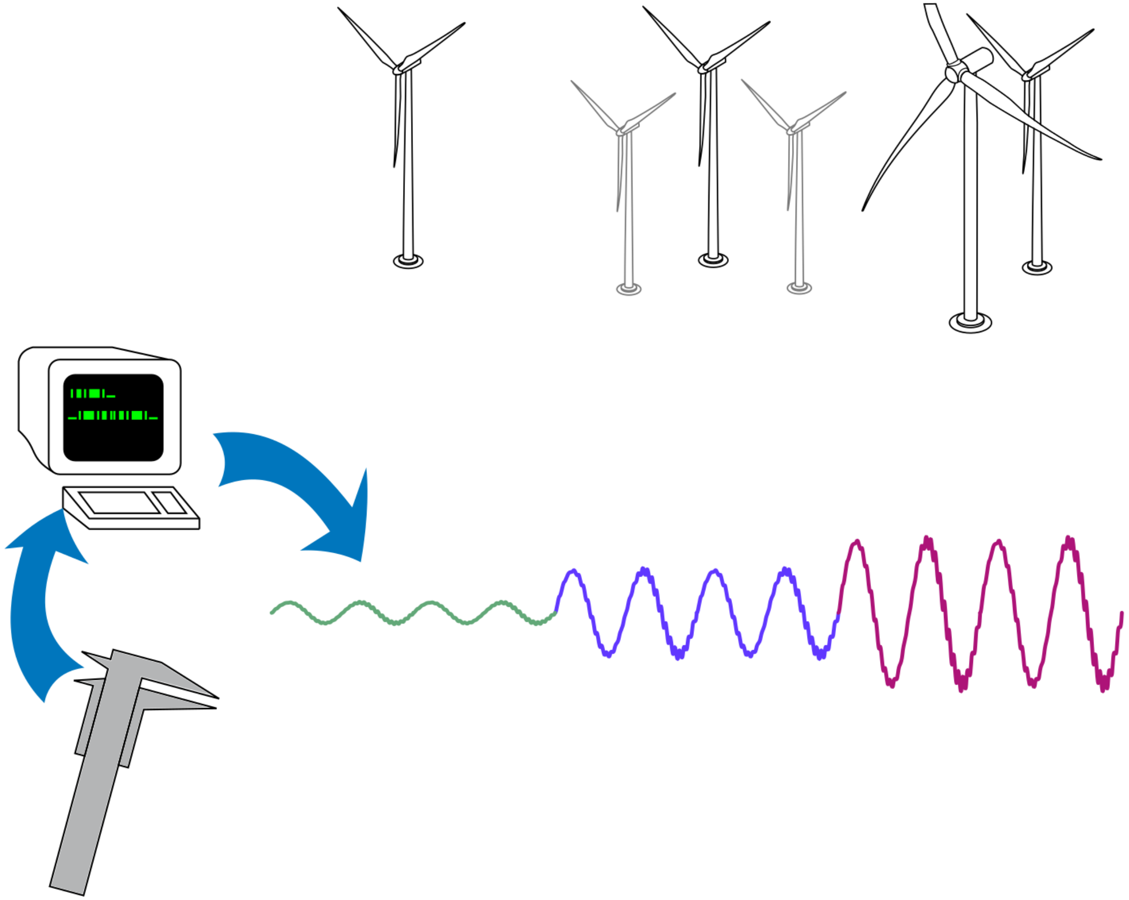
SCADA Data

+

Mathematical Model
(digital twin)

=

More accurate assessment
of remaining useful Life



Some Examples

SHM Exemplary results

Remaining useful life MD77

Component	Before Measurement	After Measurement
Blade root	6.9	11.9
Blade bearing bolts	7.3	**(7.9)**
Hub	7.3	**11.3**
Rotor shaft	18.8	>20
Main frame	>20	>20
Yaw bearing bolts	8.0	>20
Tower & foundation	**0.0**	>20
other	>20	>20

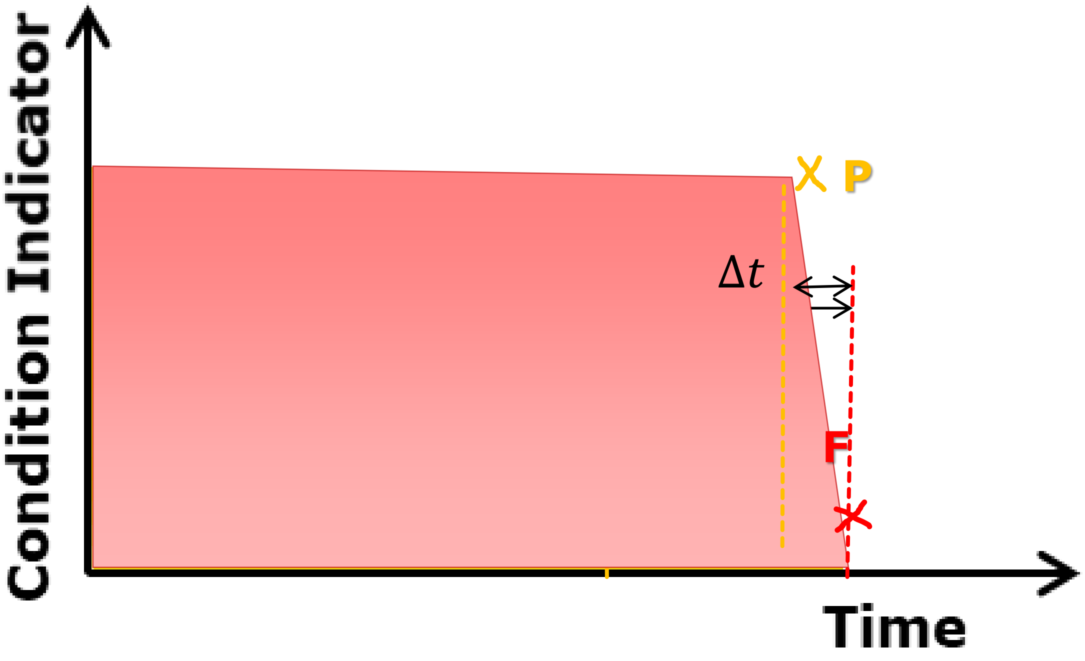
Remaining useful life NM72c

Component	Before Measurement	After Measurement
Blade root	**0.0**	6.1
Blade bearing bolts	2.6	**(2.8)**
Hub	3.2	**3.8**
Rotor shaft	15.5	>20
Main frame	**0.0**	11.1
Yaw bearing bolts	8.2	18.1
Tower & foundation	2.8	10.4
other	>20	>20

Some Examples

Data Analysis

- Operational data used for driving the turbine, rather than for condition monitoring.
- Why?
- Lead Time To Failure often quite short
- How do we change this?
- Use data correlation, to generate an expected value for each parameter under any given condition.
- This extends the LTTF

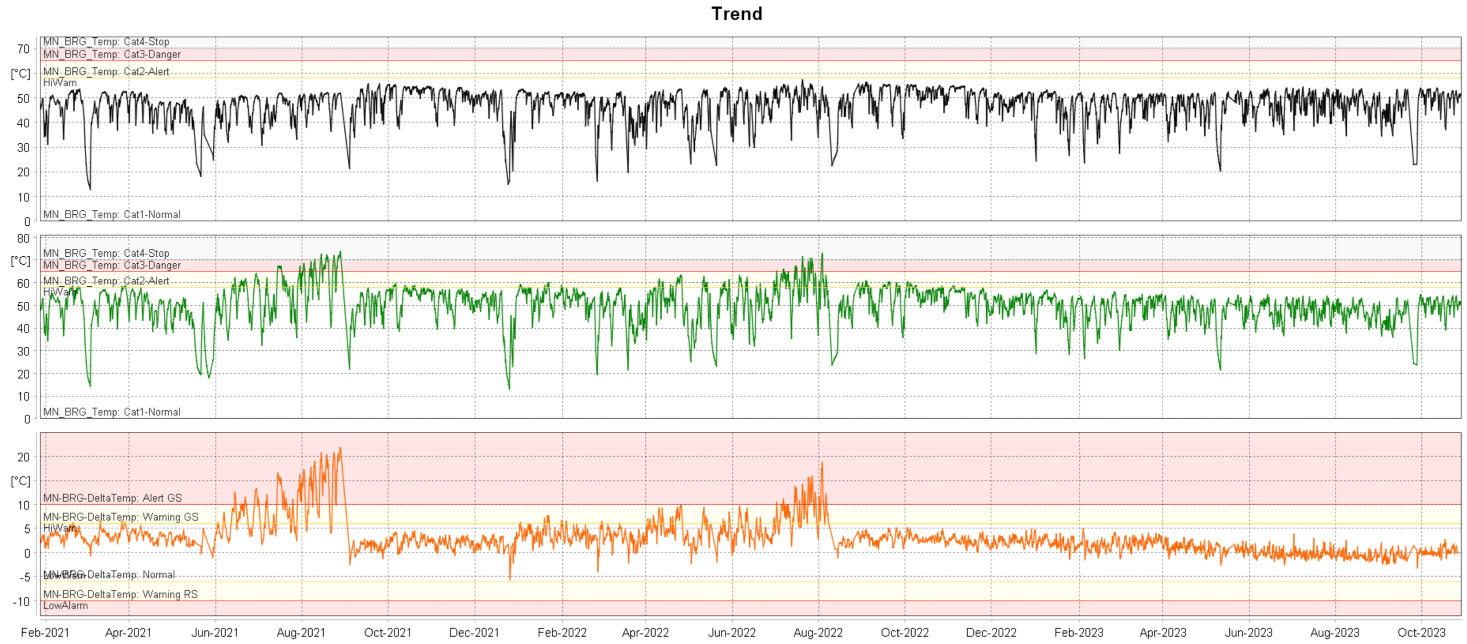


Some Examples

Bearing Temperature analysis

Basic example:

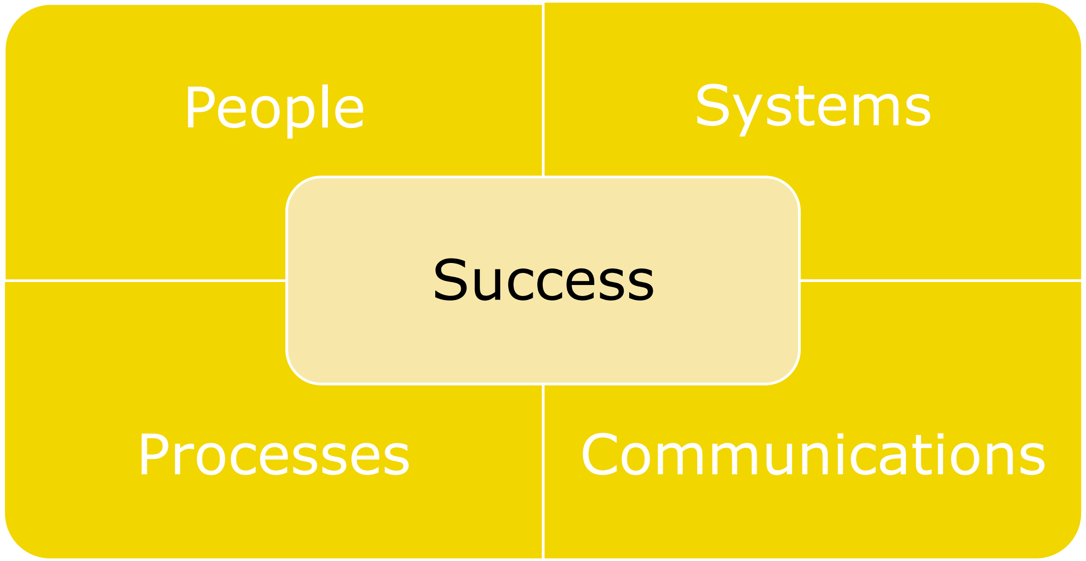
- Main Bearing RS and GS temperatures
- Temperature difference is more sensitive and repeatable than individual temperatures
- Can be expanded into multi dimensional analysis
- AI methods are laregly based on this principle.



Implementation

Changing work practices

- Stepwise implementation
- Apply first on troublesome plant items
- Demonstrate the usefulness
- Gradually expand to other items as confidence increases
- Take the team with you
- Consider the elements required for success
  - People
  - Systems
  - Processes
  - Communication



Implementation

Barriers

- People – Wary of change: Stepwise approach proves the principle
- People – Training: Certified training in condition monitoring technologies provides confidence
- People – Job Security: Show that analysing data is just as valid as re-building a machine
- Processes: Clear process for raising alerts and providing feedback
- Processes: Clear roles and responsibilities, and team organisation
- Systems: Monitoring system should be more reliable than the machine it is monitoring
- Systems: Integration provides familiarity
- Communications: Simple unified tool for reporting all maintenance related issues

- BINDT Approved training in Vibration Analysis to ISO18436-2 Categories 1,2 or 3

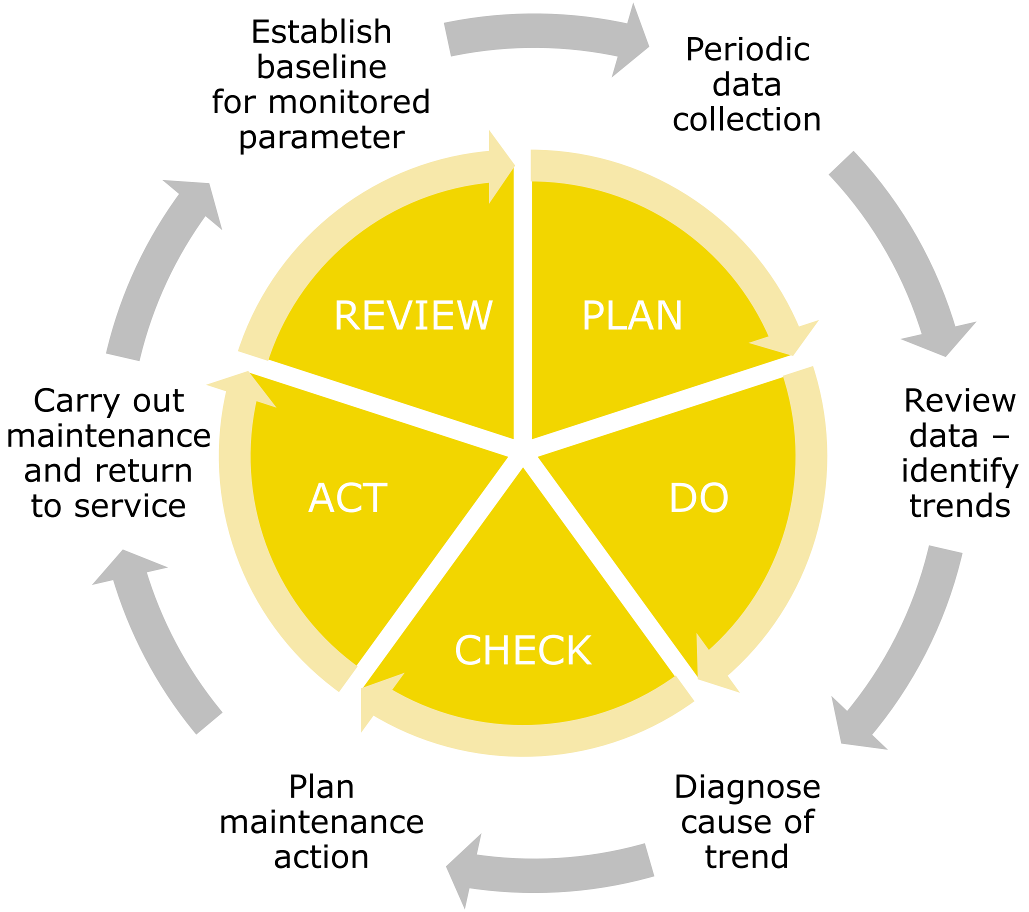
APPROVED TRAINING ORGANISATION

Review the Process

Check you are doing it right, and continuously improve

- Start slowly
- Step-by-step rollout
- Test with single components
- Track results
- Optimize

- Check the interface with other asset management activities
- Modify with changes to knowledge



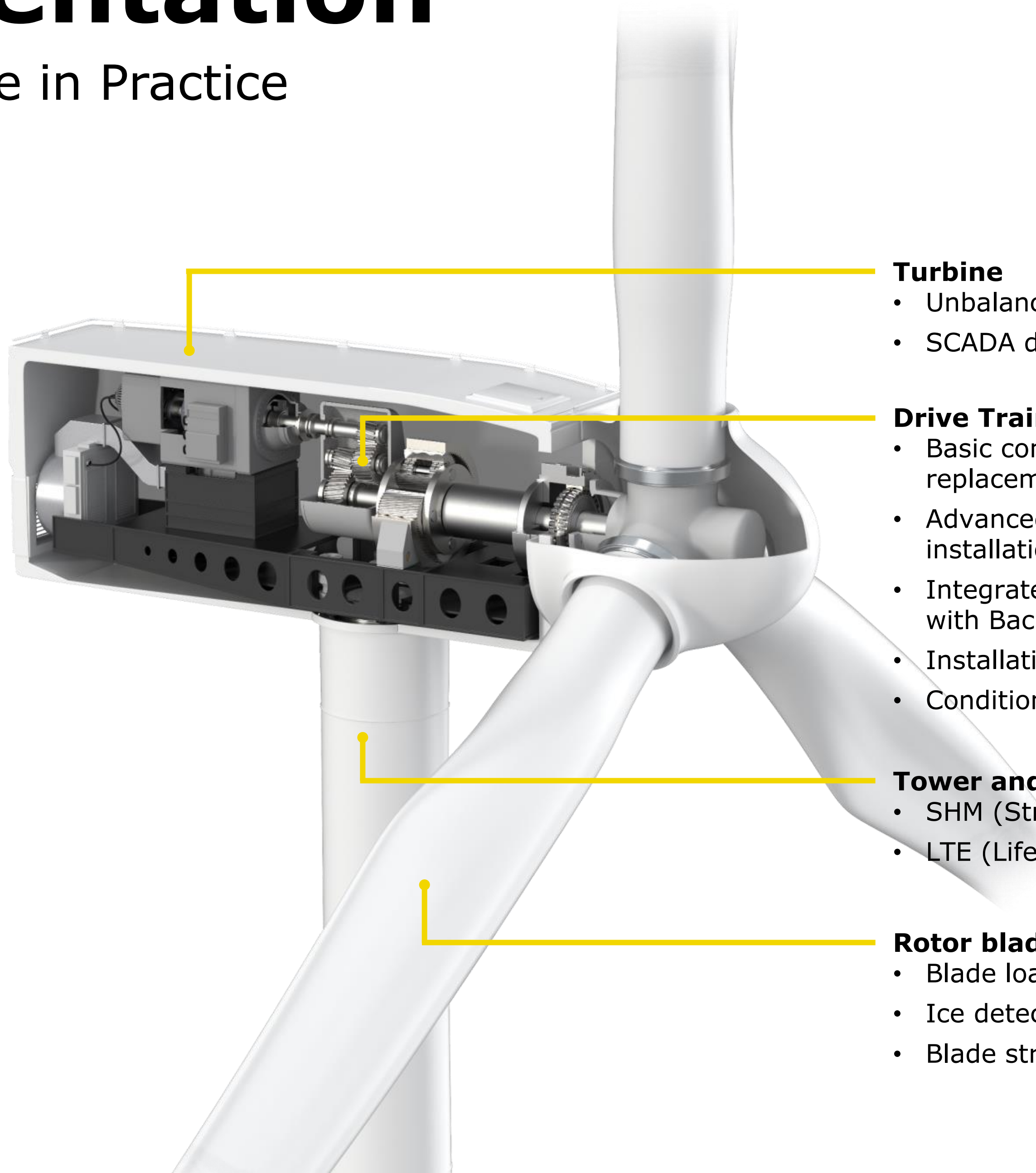
Implementation

Data to Knowledge in Practice

Data

Information

Knowledge



Turbine
- Unbalance detection and monitoring
- SCADA data integration and visualization

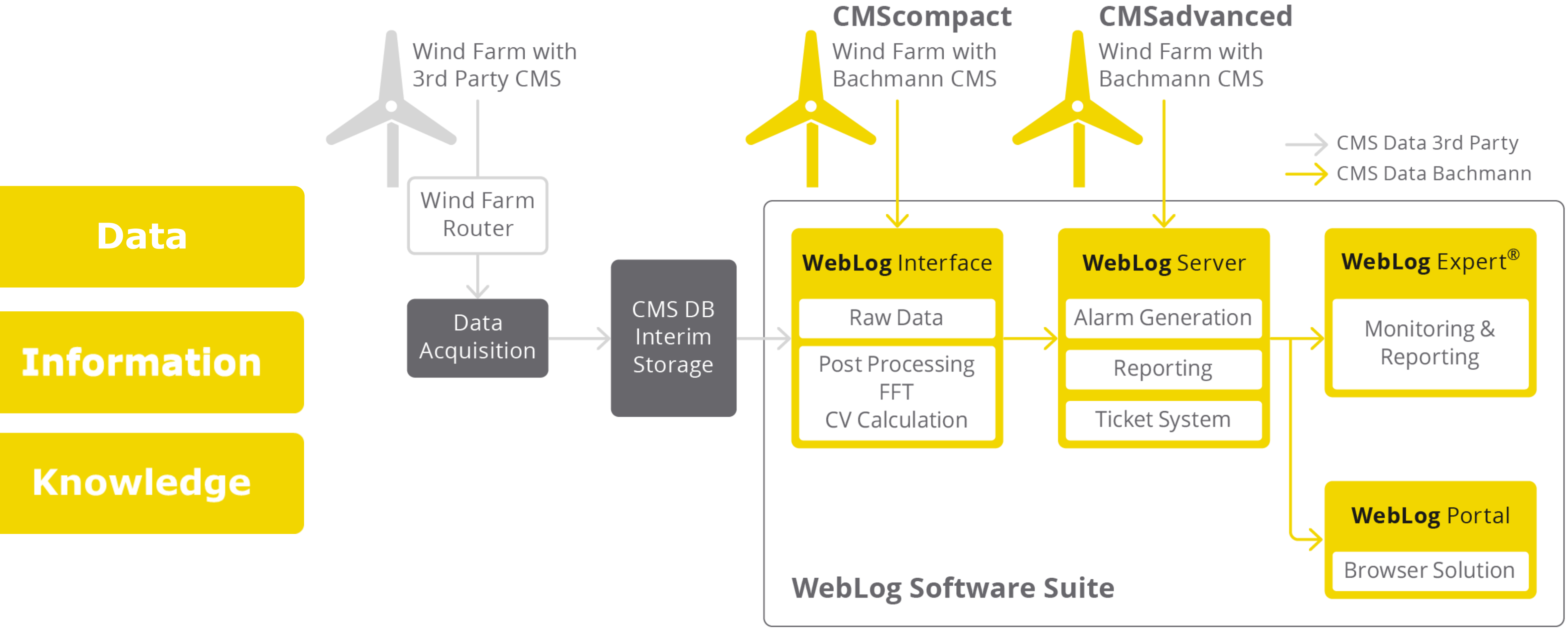
Drive Train
- Basic condition monitoring for retrofits & replacements
- Advanced condition monitoring for OEM installations
- Integrated condition monitoring for WTG equipped with Bachmann controller
- Installation and remote monitoring services
- Condition Monitoring with 3rd party CMS

Tower and substructure
- SHM (Structural Health Monitoring)
- LTE (Lifetime Extension)

Rotor blade
- Blade load acquisition
- Ice detection
- Blade structure monitoring

Implementation

Bachmann Product Landscape



Implementation

Condition Monitoring in Practice

Data

- Data Acquisition
  Offline & Online CMS

Stand-alone CMS

CMS Compact
CMS Advanced

Drivetrain sensors

Acceleration sensors

Cantilever sensors

Tower or blade

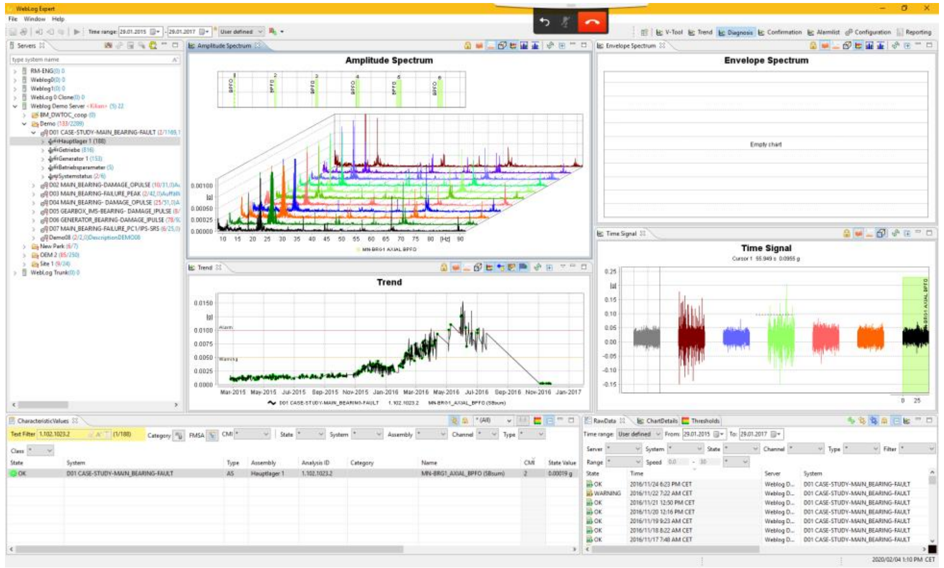
Structural sensors

Measurement Chain

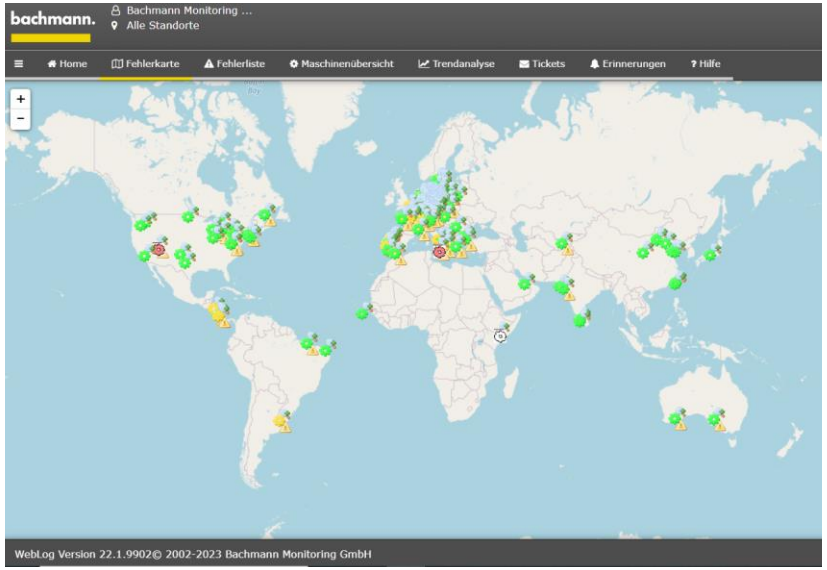
Condition Monitoring in Practice

Information

- Data Analysis & Reporting



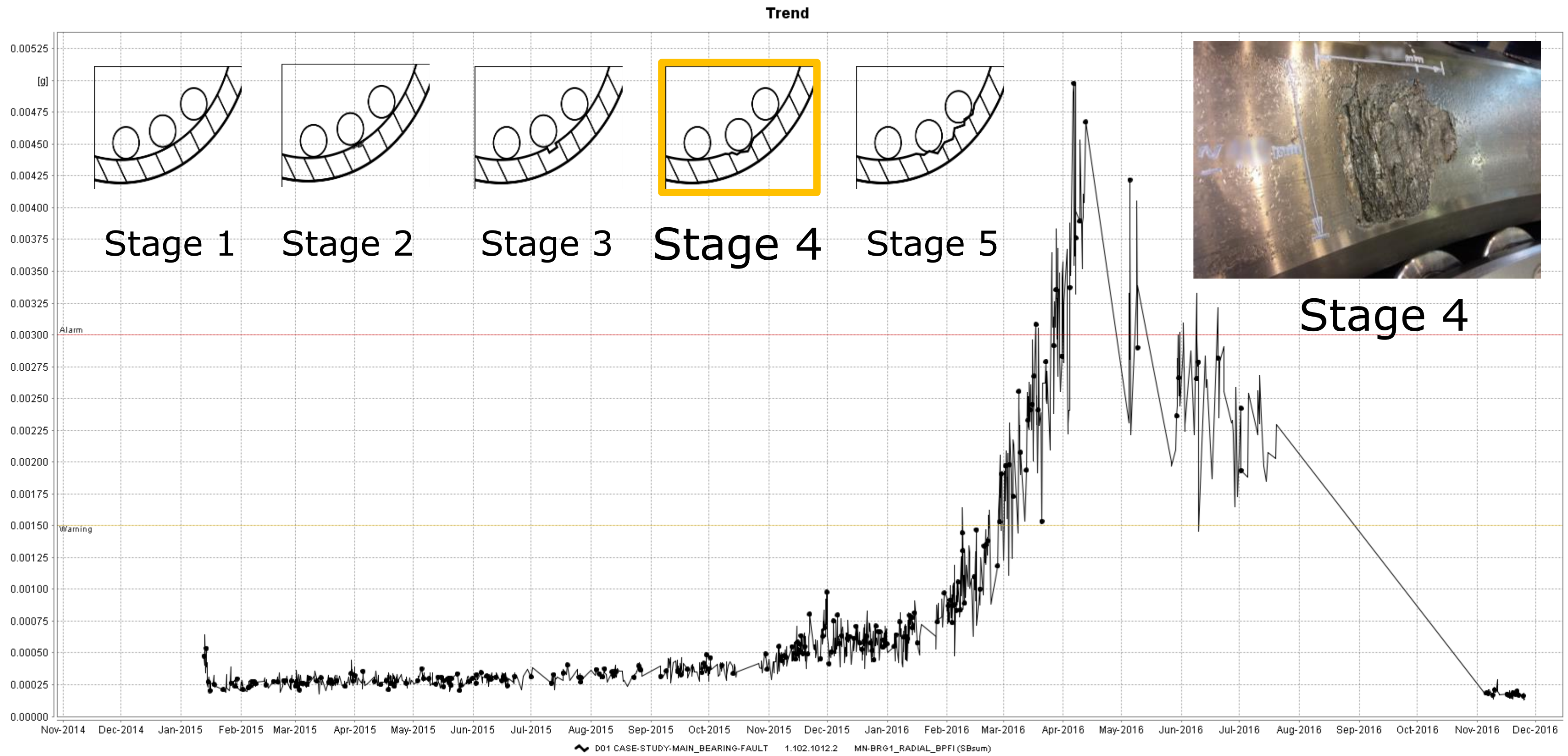
WebLog® Expert



WebLog® Customer Portal

Data Acquisition and Analysis

Detect failures early and estimate a prognosis

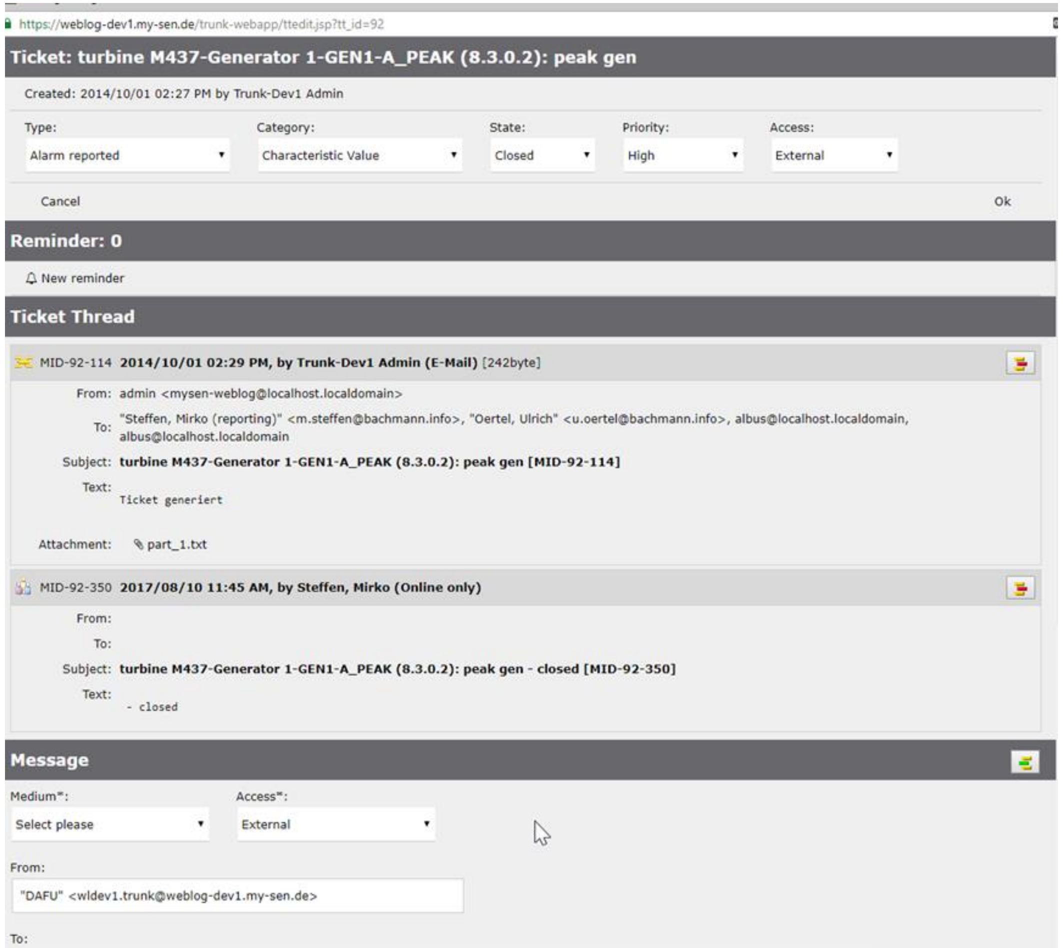


Information

- Data Analysis & Reporting

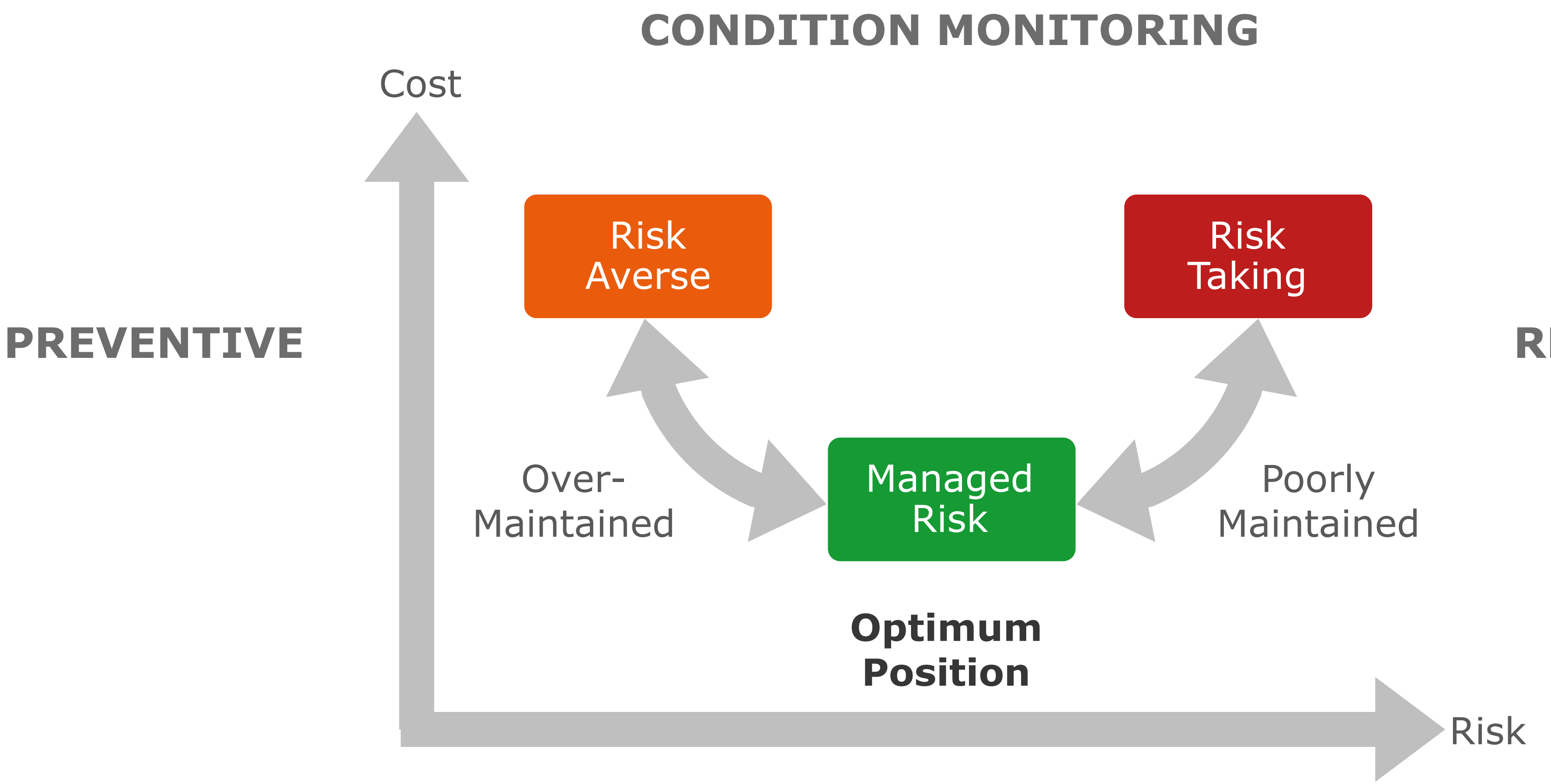
Knowledge Capture

Condition Monitoring in Practice



Knowledge

Optimum Positioning



Conclusions

Knowledge Based Operational Excellence

- Interfaces with many aspects of Asset Management
- Optimises Maintenance Strategy
- **Acting on knowledge and learning from the process is key to operational excellence**