INOVIQ
TECHNOLOGIES
Engineering Intelligent Industry

PREDICTIVE MAINTENANCE

A PRACTICAL CUSTOMER GUIDE

Using IoT, AI and machine learning to monitor equipment health and reduce downtime and cost
Companion to the INOVIQ Digital Transformation Primer and Maturity Self-Assessment

Contents

1 Executive summary
2 Maintenance strategies: from reactive to prescriptive
3 Key concepts: the P-F curve and core terms
4 Condition monitoring techniques
5 Critical vs non-critical equipment
6 Continuous protection vs surveillance monitoring
7 Reference architecture: from sensor to work order
8 AI and machine learning methods
9 Use cases
10 Standards reference
11 Implementation, KPIs and next steps

1 EXECUTIVE SUMMARY

Predictive maintenance (PdM) uses measured equipment condition, rather than the calendar or a breakdown, to decide when maintenance is needed. Sensors and IoT connectivity collect the data, and analytics, from simple limits to AI and machine learning (ML), detect developing faults early enough to plan the repair. The result is fewer unplanned stops, less unnecessary maintenance, longer asset life and safer operation.

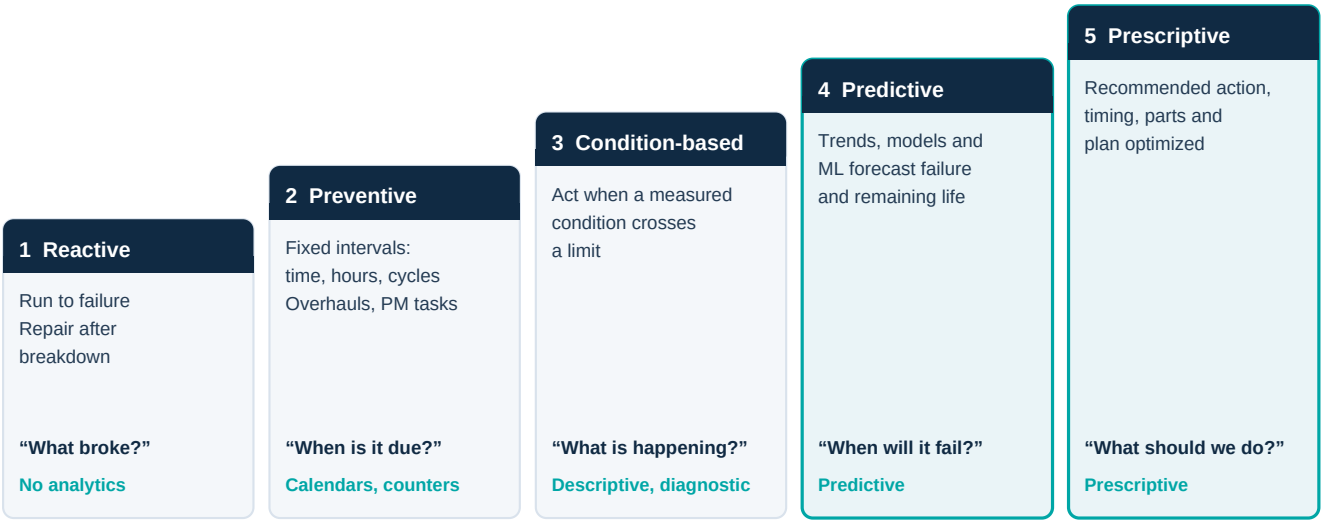
Predictive maintenance is not one technology applied everywhere. The right method for each asset depends on its criticality, its failure modes and how much warning those failure modes give. Critical machines justify continuous protection and online diagnostics; most other equipment is well served by online surveillance or periodic routes.

Key messages

- **Match strategy to criticality:** a formal criticality assessment decides where each monitoring method pays off.
- **Protection and prediction are different jobs:** protection trips the machine in milliseconds; monitoring informs people in time to plan.
- **Use the P-F interval:** choose techniques and intervals that detect each failure mode well before functional failure.
- **Start with physics, add AI:** proven limits and diagnostics first; ML adds early anomaly detection and remaining-life estimates.
- **Close the loop:** findings must become work orders, and repair results must feed back to improve the models.

2 MAINTENANCE STRATEGIES: FROM REACTIVE TO PRESCRIPTIVE

EN 13306 defines maintenance types as corrective (after failure) or preventive (before failure), with preventive maintenance being either predetermined (fixed intervals) or condition-based. Predictive maintenance is condition-based maintenance that forecasts the future condition. Prescriptive maintenance adds a recommended action and timing. Analytics mature alongside: descriptive (what is happening), diagnostic (why), predictive (when) and prescriptive (what to do).



Strategies are combined, not replaced: each asset gets the strategy its criticality and failure modes justify.

Figure. Maintenance strategy maturity and the matching level of analytics. Steps 4 and 5 are the focus of this guide.

Strategy	Trigger for work	Strengths	Limitations	Best suited to
Reactive (corrective, run-to-failure)	Breakdown	No planning or monitoring cost	Unplanned downtime, secondary damage, safety risk	Cheap, redundant, low-consequence items
Preventive (predetermined)	Time, running hours, cycles	Simple to plan	Most failures are not age-related; parts replaced too early or too late; maintenance-induced faults	Wear-out failures with known life; statutory tasks
Condition-based (descriptive)	Measured condition crosses a limit	Work only when needed	Needs reliable measurements and limits	Equipment with detectable degradation

Strategy	Trigger for work	Strengths	Limitations	Best suited to
Predictive	Forecast of when a limit will be reached	Planned repair at the best time; parts and labor ready	Needs data history, models and skills	Critical and essential equipment
Prescriptive	Recommended action from diagnosis, prognosis and business constraints	Optimizes timing against production, spares and risk	Needs integration with planning and maintenance systems	Mature programs with good data

3 KEY CONCEPTS: THE P-F CURVE AND CORE TERMS

The P-F curve shows how an asset's condition declines once a failure mode begins. Point P is the earliest moment the developing failure can be detected; point F is functional failure, when the asset can no longer do its job. The time between them, the P-F interval, is the warning available to plan and act.

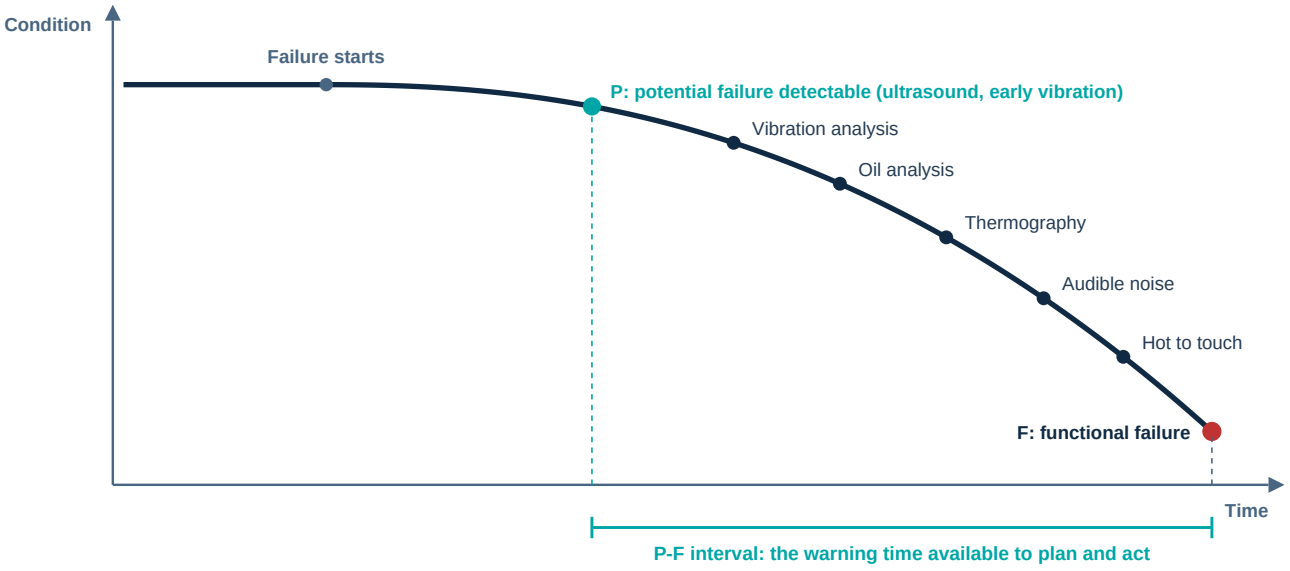


Figure. Typical P-F curve for a rolling-element bearing. Each technique detects the fault at a different stage; the earlier the detection, the longer the warning time. Actual intervals vary by failure mode and operating conditions.

Term	Meaning
Failure mode	The way an asset fails (for example bearing outer-race defect, impeller wear, insulation breakdown); identified through FMEA or FMECA (IEC 60812)
P-F interval	Warning time between detectable potential failure and functional failure; monitoring interval is commonly set to half of it or less
RCM	Reliability-centered maintenance: a structured method (SAE JA1011, IEC 60300-3-11) to choose the right strategy per failure mode
Criticality	Ranking of assets by the consequence and likelihood of failure; decides how much monitoring is justified
RUL	Remaining useful life: estimated time until the asset reaches a defined limit or functional failure
MTBF / MTTR	Mean time between failures / mean time to repair: core reliability and maintainability measures
Alert and danger	Two-stage alarm levels: alert prompts investigation; danger may trigger an automatic shutdown on protected machines
Evaluation zones A–D	ISO 20816 vibration severity zones: A newly commissioned, B acceptable long term, C restricted operation, D damage likely

4 CONDITION MONITORING TECHNIQUES

No single technique detects every failure mode. Programs combine techniques according to the failure modes of each asset type.

Technique	Detects	Typical sensors and indicators	Key standards
Vibration analysis	Imbalance, misalignment, looseness, bearing and gear defects, resonance	Accelerometers, velocity sensors; overall velocity (mm/s RMS), spectra, envelope (demodulation), bearing defect frequencies	ISO 20816, ISO 13373, ISO 18436-2
Shaft relative vibration and position	Fluid-film bearing instability, rubs, thrust wear on critical machines	Non-contact proximity probes; orbits, gap voltage, axial position, phase reference	ISO 20816, API 670
Oil and lubricant analysis	Wear, contamination, lubricant degradation	Wear metals, particle count (ISO 4406 code), viscosity, water, ferrography; online particle sensors	ISO 14830, ISO 4406
Infrared thermography	Hot connections, overloaded or unbalanced phases, bearing and coupling heat, insulation loss	Thermal cameras, fixed IR sensors; temperature rise (ΔT) against reference	ISO 18434
Airborne and contact ultrasound	Early bearing lubrication problems, leaks, steam trap failure, electrical arcing	Ultrasonic detectors and sensors; dB level against baseline	ISO 29821
Electrical signature and insulation	Broken rotor bars, eccentricity, winding and insulation faults	Motor current signature analysis, insulation resistance, partial discharge (IEC 60270)	IEC 60034 series
Process and performance parameters	Efficiency loss, fouling, cavitation, valve wear	Pressure, flow, temperature, power; performance curves and heat balance	ISO 17359
Transformer and switchgear diagnostics	Insulation degradation, overheating, arcing	Dissolved gas analysis (IEC 60599), partial discharge, temperature	IEC 60599

5 CRITICAL VS NON-CRITICAL EQUIPMENT

A criticality assessment ranks every asset by the consequences of its failure and the likelihood of that failure. Consequence categories usually include safety, environment, production loss, quality, repair cost and repair time. Redundancy (an installed spare) lowers criticality; long lead-time parts raise it.

Class	Typical assets	Consequence of failure	Recommended monitoring	Analytics
A: Critical	Turbines, main and process gas compressors, large high-speed machines, unspared critical pumps, main transformers	Safety or environmental risk; plant or unit outage; very high repair cost or long lead time	Continuous online protection plus online diagnostic monitoring; oil analysis; periodic thermography	Expert diagnostics, ML anomaly detection, RUL; prescriptive advice
B: Essential	Spared process pumps, large motors, fans, blowers, gearboxes, compressors, cooling towers	Production slowdown or quality impact; moderate cost	Online surveillance (wired or wireless, sampled), supplemented by routes	Trends, alarms, ML anomaly detection
C: General	Small motors and pumps, auxiliary fans, conveyors, non-process equipment	Little or no production impact; low repair cost	Periodic route monitoring or operator inspections; run-to-failure where justified	Simple limits and trends

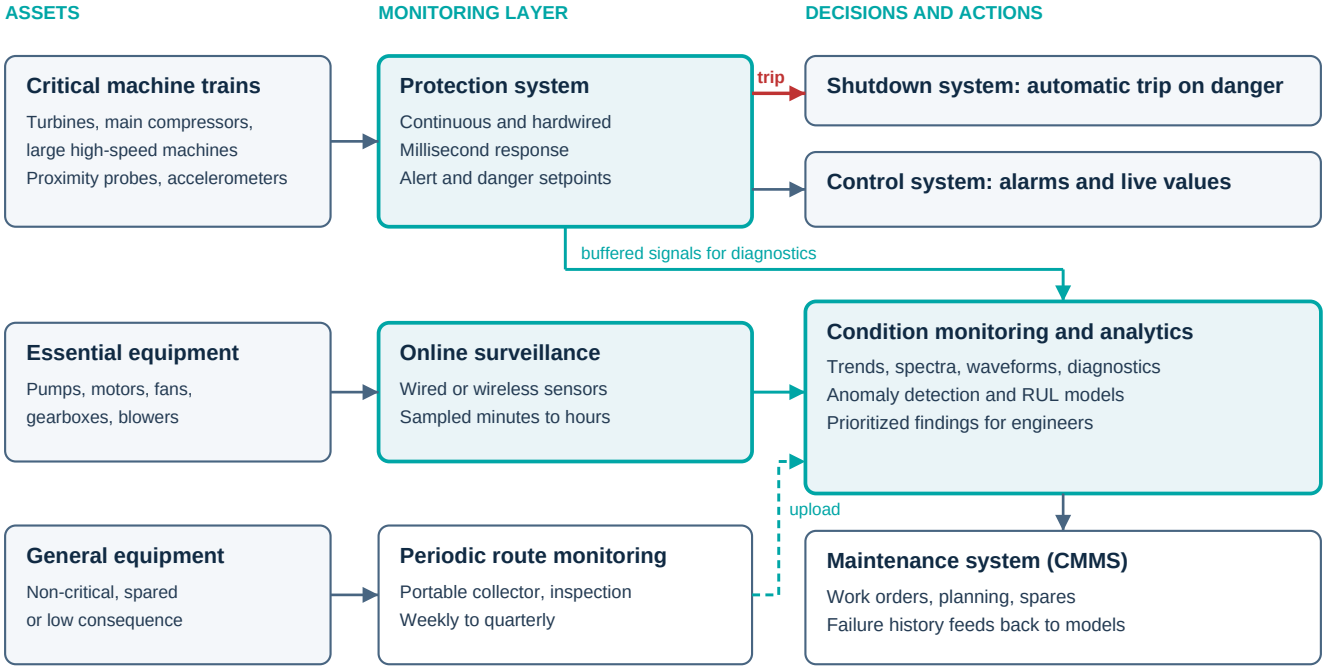
Keep the ranking current

Criticality changes over time. Review the ranking after process changes, major failures or changes in spare parts strategy, and at least every few years. Record the reasoning, so the monitoring decision can be audited.

6 CONTINUOUS PROTECTION VS SURVEILLANCE MONITORING

These two approaches answer different questions and must not be confused. **Protection** asks “is this machine about to damage itself or harm people?” and shuts it down automatically. **Condition monitoring**, continuous or periodic, asks “how is the machine’s health developing, and when should we intervene?” and informs people.

Aspect	Continuous protection	Continuous online surveillance	Periodic (route) monitoring
Purpose	Prevent catastrophic damage; automatic shutdown	Early detection and diagnosis	Early detection at low cost per asset
Data	Continuous, every channel, real-time	Scanned or sampled every minutes to hours; spectra and waveforms	Snapshot each visit, weekly to quarterly
Response	Milliseconds; trip relays to the shutdown system	Alarms and notifications to people	Analysis after data upload
Design rules	Hardwired, fail-safe, alarm time delays and voting, independent of networks; API 670 for machinery protection	Networked, wired or wireless; IoT gateways; cybersecurity per IEC 62443	Portable collectors, consistent measurement points and settings
Typical assets	Class A machine trains	Class A diagnostics; Class B assets	Class B and C assets
Relationship	Always takes priority; monitoring must never interfere with it	Uses buffered signals from protection where available	Complements online systems; also covers inspection-only items



Protection acts on its own in milliseconds; monitoring and analytics inform people who plan the repair.

Figure. One program, three monitoring layers matched to asset criticality. All condition data reaches one analytics platform and one maintenance system.

Where a protection function is part of a safety instrumented system, it follows the functional safety standards IEC 61508 and IEC 61511. Analytics and AI support decisions; they do not replace engineered protection.

7 REFERENCE ARCHITECTURE: FROM SENSOR TO WORK ORDER

ISO 13374 defines six processing blocks for condition monitoring data. Using them as a reference keeps responsibilities clear and lets different tools work together. Early blocks usually run at the edge, near the machine; later blocks run on a platform, on-site or in the cloud, where AI and ML models and history are available.

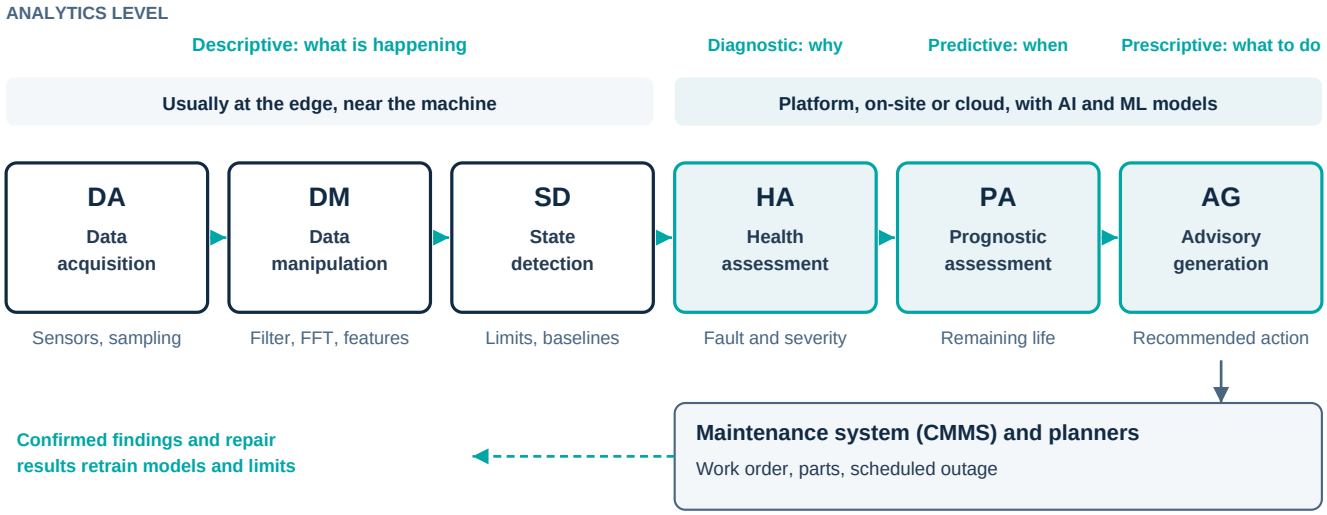


Figure. The ISO 13374 processing chain mapped to analytics levels and to where processing typically runs. Advisories become work orders, and confirmed findings flow back to improve models.

- **Edge processing** reduces data volume (features rather than raw waveforms), keeps alarms working if the network fails and protects the control network.
- **The platform** holds the asset hierarchy, history, failure records and models; it may run on-site, in the cloud or as a hybrid.
- **Integration with the maintenance system** turns advisories into planned work orders and records the as-found condition, closing the loop.
- **Open interfaces** such as OPC UA and MQTT, and a consistent asset taxonomy (ISO 14224), avoid lock-in and make data reusable.

8 AI AND MACHINE LEARNING METHODS

AI and ML extend, rather than replace, established diagnostics. The best method depends on how much data and failure history exists. Most programs start with rules and anomaly detection, then add failure classification and remaining-life models as labeled history grows.

Method	What it does	Data needed	Best for
Rules and limits	Compare measurements with standard or baseline limits (for example ISO 20816 zones)	Measurements; standard or site-specific limits	Every program; clear, explainable alarms
Statistical baselines	Learn normal behavior per asset and operating state; flag deviations	Weeks of normal operation	Assets with varying load or speed
Unsupervised anomaly detection	Find unusual multivariable patterns (clustering, isolation forests, autoencoders)	Normal data only; no failure labels	Early warning across many similar assets
Supervised fault classification	Identify the likely failure mode from features	Labeled examples of each failure mode	Common, repeated failure modes
Remaining useful life models	Estimate time until a limit is reached (trend extrapolation, survival and degradation models)	Run-to-failure or degradation histories	Gradual wear mechanisms
Physics-informed and hybrid models, digital twins	Combine engineering models with data to compare expected and actual behavior	Design and process data plus measurements	Critical, complex, high-value equipment

- **Context matters:** always record speed, load and operating mode with condition data, or models will mistake normal changes for faults.
- **Keep people in the loop:** qualified analysts (ISO 18436 categories) review advisories before major interventions, especially on Class A assets.
- **Explainability:** show the evidence behind an alert (trend, spectrum, contributing variables) so technicians trust and act on it.
- **Feedback:** record the as-found condition at every repair; this is the training data that makes models better.

9 USE CASES

Asset	Typical failure modes	Techniques	Early indicators	Typical action
Centrifugal pump	Bearing defects, cavitation, misalignment, seal wear, impeller wear	Vibration, temperature, pressure and flow, ultrasound	Rising envelope at bearing frequencies; broadband noise; head falling off curve	Plan bearing or seal change; correct suction conditions
Electric motor	Bearing wear, rotor bar damage, insulation degradation, overheating	Vibration, current signature, thermography, insulation resistance	Bearing frequencies; slip-frequency sidebands; hot spots	Lubricate or replace bearings; schedule rewind
Gearbox	Tooth wear and pitting, lubrication failure, bearing defects	Vibration, oil analysis, temperature	Gear-mesh sidebands; rising wear metals and particle count	Change oil or filter; plan gear inspection
Fan or blower	Imbalance, looseness, belt wear, bearing defects	Vibration with phase, temperature	1× running-speed increase; harmonics	Clean and balance; tighten; replace belts
Air or process compressor	Valve wear, cooler fouling, bearing and rotor issues	Vibration, temperatures, pressures, power	Discharge temperature rise; efficiency loss	Valve overhaul; clean cooler
Critical turbo-machine	Rubs, fluid-film bearing instability, thrust wear, misalignment	Proximity probes, axial position, protection system, oil analysis	Orbit shape change; sub-synchronous vibration; axial drift	Diagnose with experts; plan outage; trip on danger
Conveyor	Idler bearing seizure, belt misalignment, drive wear	Thermal and acoustic sensing, vibration on drives	Hot or noisy idlers; drive vibration trend	Replace idlers in planned stops
Transformer and switchgear	Insulation aging, hot joints, partial discharge	Dissolved gas analysis, thermography, partial discharge	Key gas trends; temperature rise; discharge activity	Re-torque, clean, plan outage or replacement

Use case 1: online surveillance of spared pumps

A water treatment plant runs six spared pumps (Class B). Wireless vibration and temperature sensors are fitted to motor and pump bearings and report every hour through a gateway. An anomaly model learns each pump's normal behavior across its duty points. Weeks before any audible noise, the model and the envelope spectrum flag an outer-race defect on one pump. The planner switches duty to the spare, orders the bearing and replaces it during a normal shift, avoiding an emergency call-out and secondary damage to the seal.

Use case 2: protection and diagnostics on a critical compressor

A process gas compressor (Class A) has proximity probes and an axial position probe wired to a protection system with alert and danger setpoints and a trip to the shutdown system. Buffered signals feed a diagnostic platform. A slow change in orbit shape and rising sub-synchronous vibration raise an alert well below the danger level. Analysts diagnose a developing bearing instability, operations adjust oil supply temperature as a temporary measure, and the bearing inspection is moved into the next planned outage. Protection remained armed throughout.

Use case 3: route-based monitoring of general equipment

Around 300 small motors and fans (Class C) are covered by a monthly route with a portable collector and a quarterly thermography survey of motor control centers. Route data is uploaded to the same platform as the online systems, so trends, alarms and work orders follow one process, at a fraction of the cost of permanent sensors.

10 STANDARDS REFERENCE

Standard	Subject
EN 13306	Maintenance terminology: corrective, preventive, condition-based and predictive maintenance
ISO 55000 series	Asset management systems
ISO 17359	Condition monitoring and diagnostics of machines: general guidelines and program set-up
ISO 13374 (parts 1–4)	Condition monitoring data processing, communication and presentation (DA, DM, SD, HA, PA, AG)
ISO 13379 / ISO 13381-1	Data interpretation and diagnostic techniques / prognostics
ISO 20816 series	Measurement and evaluation of machine vibration (replaces ISO 10816 and ISO 7919)
ISO 13373 series	Vibration condition monitoring of machines
ISO 18436 series	Qualification and certification of condition monitoring personnel
ISO 14830 / ISO 4406	Tribology-based machine condition monitoring / fluid cleanliness code
ISO 18434 / ISO 29821	Thermography / ultrasound for condition monitoring
ISO 14224	Collection and exchange of reliability and maintenance data; equipment taxonomy
SAE JA1011, IEC 60300-3-11	Reliability-centered maintenance
IEC 60812	Failure modes and effects analysis (FMEA and FMECA)
API 670	Machinery protection systems
IEC 61508 / IEC 61511	Functional safety of safety-related and safety instrumented systems
IEC 60599 / IEC 60270	Dissolved gas analysis / partial discharge measurement
IEC 62443	Security for industrial automation and control systems

11 IMPLEMENTATION, KPIS AND NEXT STEPS

Step	Activities
1 Assess criticality	Build the asset register and hierarchy; rank criticality; select a pilot area with known pain
2 Analyze failure modes	Run FMEA or RCM on pilot assets; list failure modes, P-F intervals and suitable techniques
3 Design monitoring	Choose protection, online surveillance or routes per asset; define measurement points, intervals and alarm limits
4 Connect and integrate	Install sensors and gateways; set up the analytics platform; integrate with the maintenance system
5 Operate and learn	Review findings weekly; act through work orders; record as-found condition; tune limits and models
6 Scale	Template the approach by asset type; extend to further areas and sites; add predictive and prescriptive models

KPI	What it shows
Unplanned downtime hours	Direct effect on availability and output
MTBF and MTTR	Reliability and speed of repair
Planned vs reactive work ratio	Shift from firefighting to planned maintenance
Work orders from condition findings	How much work the program generates and how much is acted on
Failures detected before functional failure	Effectiveness of techniques and intervals
Maintenance cost per unit or as % of replacement asset value	Overall cost effectiveness

Next steps

- ☐ Rank asset criticality for one area and confirm Class A, B and C assets
- ☐ List the top failure modes for the highest-ranked assets and their warning signs
- ☐ Check existing protection systems and whether their buffered signals are used
- ☐ Choose a pilot: online surveillance of a group of Class B assets is often the fastest win
- ☐ Agree KPIs and a baseline, and connect findings to the maintenance system from day one

Important: This guide is general guidance, not a design specification. Protection systems must be engineered to the applicable standards by qualified personnel. For a criticality review or a predictive maintenance pilot, contact INOVIQ Technologies at www.inoviqtech.com.