



T6.2.3 Hybrid ship control system

Session 01 Maintenance and Fault Detection Techniques

09/07/2025

FLEXSHIP



Table of contents

1. Training 1: Predictive and preventive maintenance approaches
2. Training 2: Monitoring battery health and electrical systems

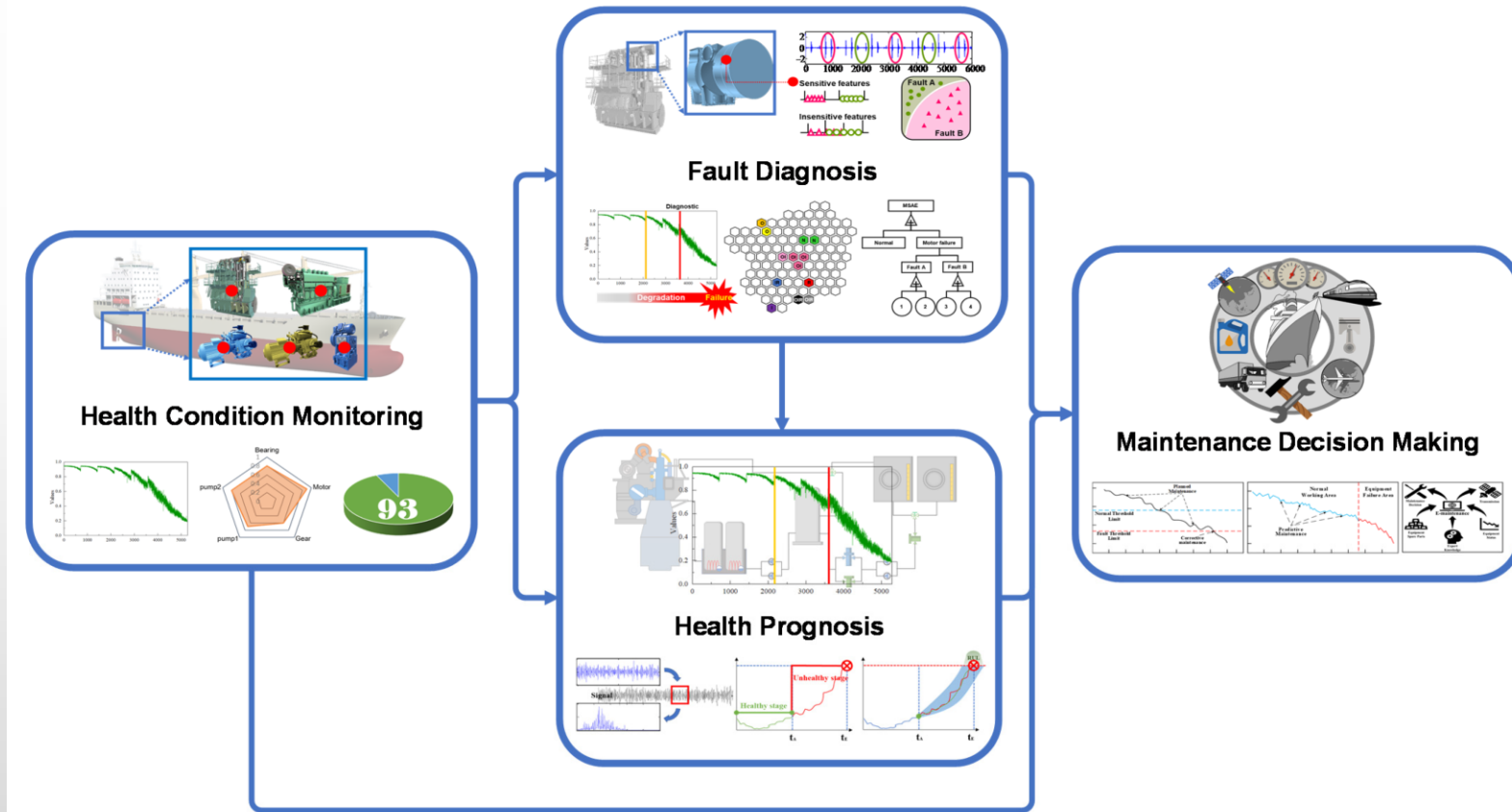


Table of contents

1. **Training 1: Predictive and preventive maintenance approaches**
2. Training 2: Monitoring battery health and electrical systems

Maintenance and safety of marine vessel systems

- Common issues
- Best practice for sustainable use
- Emerging situations
- Post-Incident Procedure



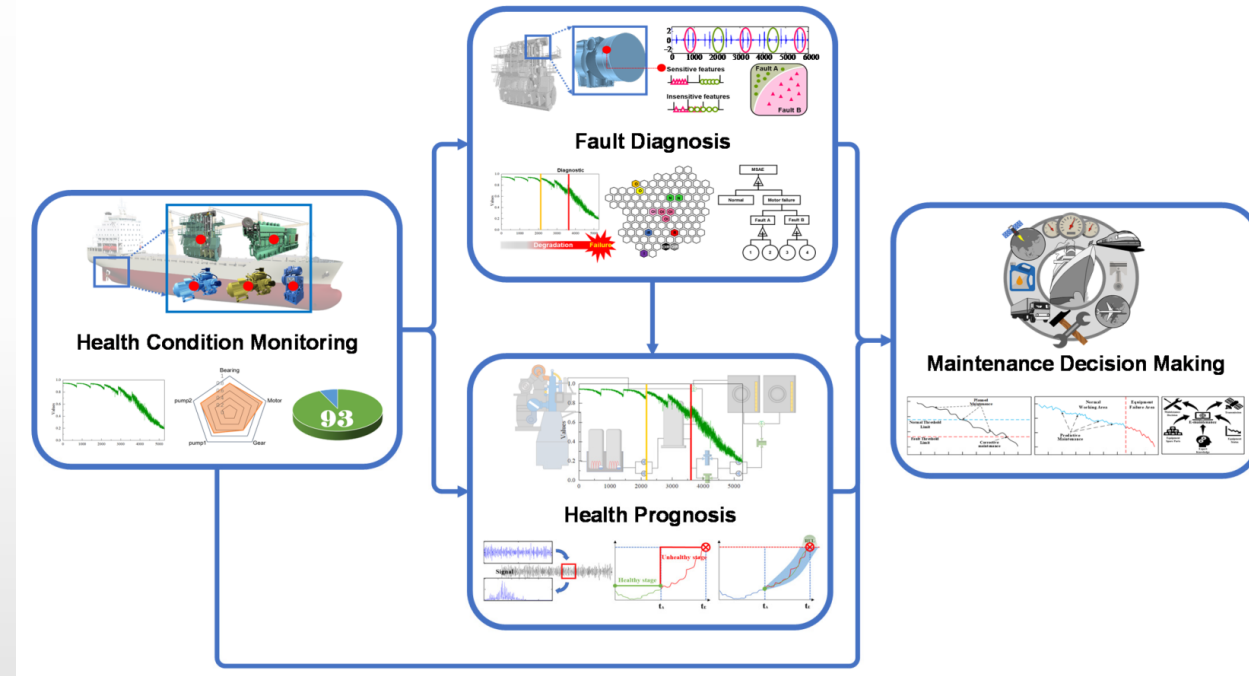
Zhang, P., Gao, Z., Cao, L., Dong, F., Zou, Y., Wang, K., Zhang, Y., & Sun, P. (2022). Marine Systems and Equipment Prognostics and Health Management: A Systematic Review from Health Condition Monitoring to Maintenance Strategy. *Machines*, 10(2), 72. <https://doi.org/10.3390/machines10020072>

Maintenance refers to all activities aimed at preserving the **functionality, efficiency and safety** of a system throughout its lifecycle.

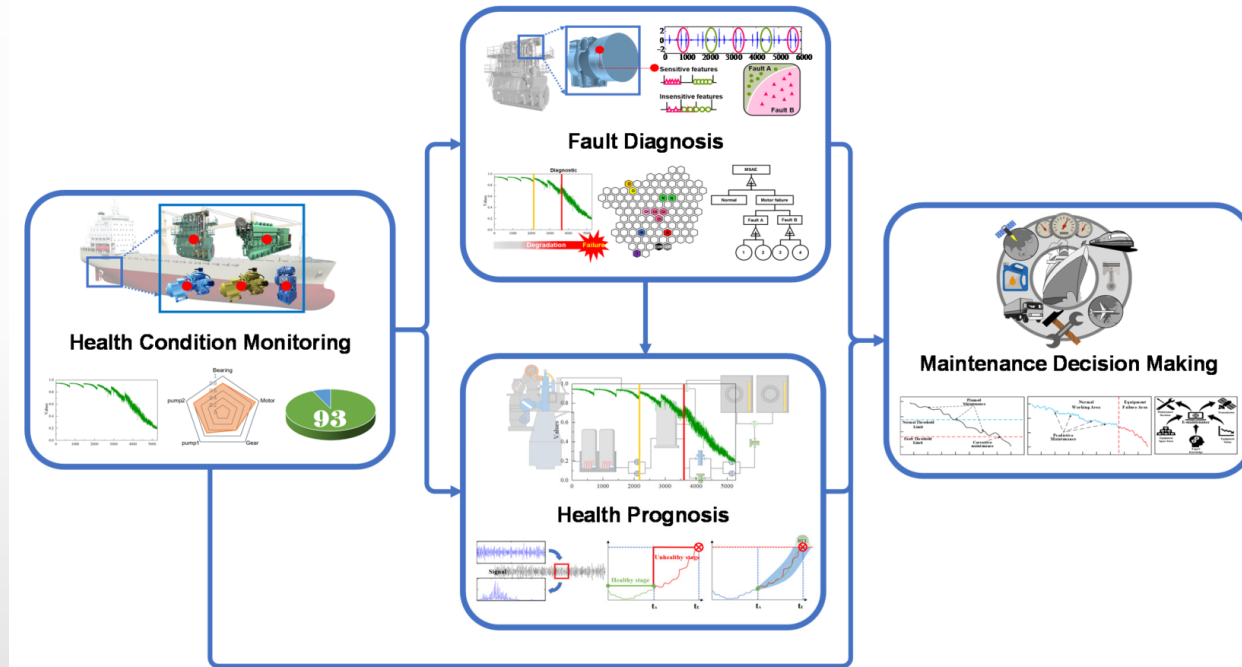
In the context of maritime energy systems, especially hybrid and battery-based propulsion systems, maintenance is essential to **prevent critical failures** that can lead to costly downtime or hazardous incidents.

It involves not only physical inspections and repairs, but also the use of **diagnostic tools, data collection and condition-based analysis**.

A well-executed maintenance strategy improves **equipment longevity, reduces operational risks and ensures regulatory compliance**.



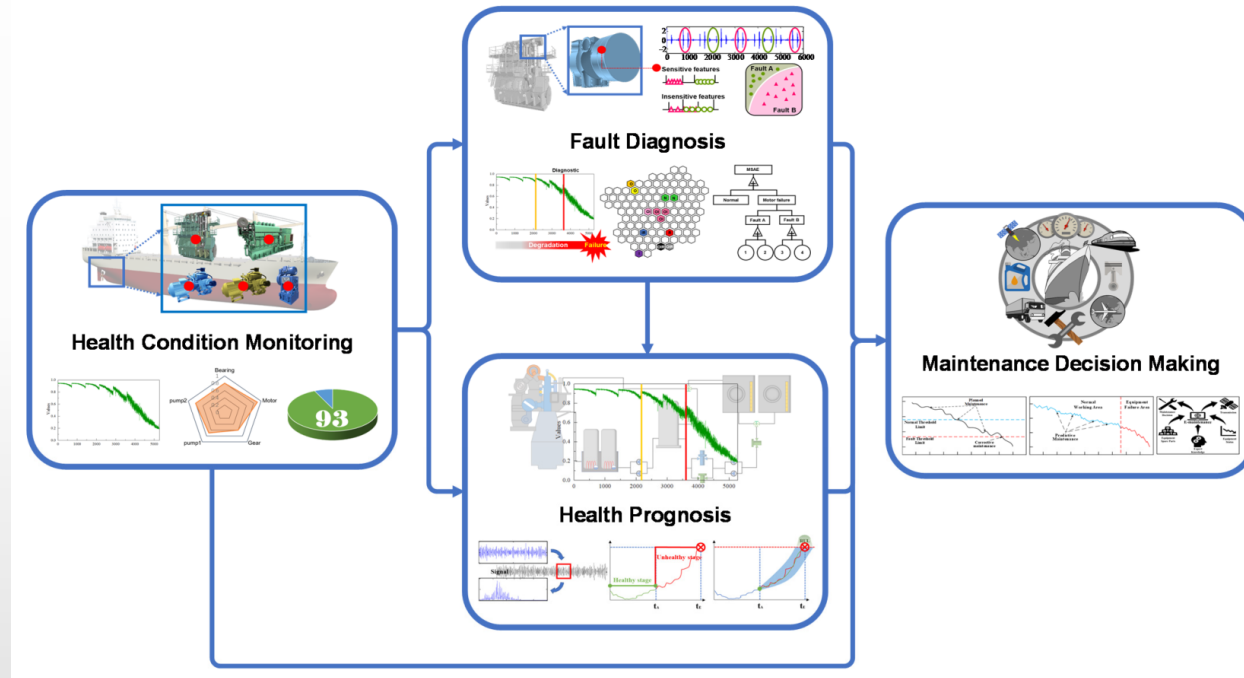
- Preventive maintenance is performed on a scheduled basis, regardless of the current condition of the equipment. It includes **routine checks, part replacements, and system calibrations**. The goal is to reduce the **probability of failures** through periodic attention.
- Predictive maintenance, on the other hand, is driven by **real-time data, sensor feedback, and historical trends**. It aims to **predict** when a component is likely to **fail**, allowing targeted interventions before any **malfunction occurs**. This approach reduces **unnecessary maintenance, improves safety and enhances system availability**.
- Key difference:** Preventive is time-based; predictive is condition-based.



Maritime vessels operate under demanding environmental conditions. Any system failure—especially in **battery, propulsion, or energy storage**—can lead to **safety incidents, mission delays, or environmental risks**. Maintenance strategies play a crucial role in ensuring:

- Continuous propulsion and power delivery
- Safe operation in critical missions or isolated waters
- Compliance with IMO and SOLAS regulations
- Reduced emissions and optimized energy efficiency

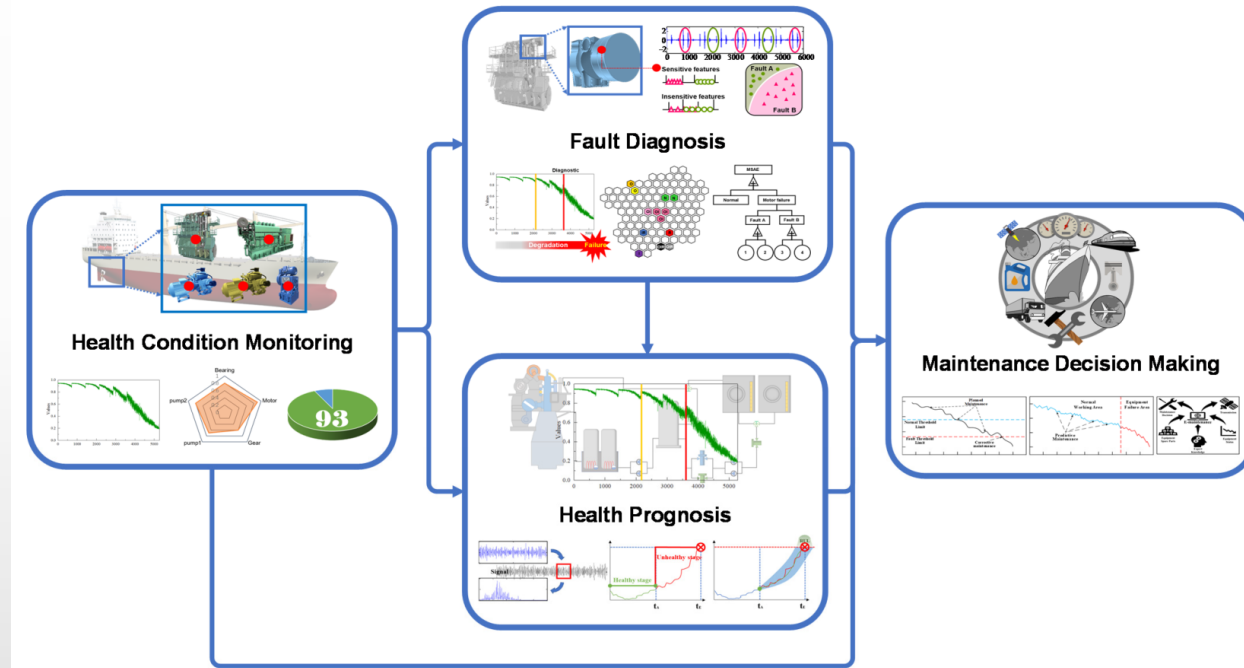
By implementing smart maintenance, ship operators can **extend battery life, reduce fuel consumption and ensure uninterrupted service**.



A solid preventive maintenance program involves predefined routines, documentation, and standardized actions to ensure system readiness. Typical protocols for hybrid marine battery systems include:

- Regular inspection of electrical connections and insulation
- Cleaning of terminals to avoid corrosion
- Monitoring battery SoC (State of Charge) and SoH (State of Health)
- Checking the integrity of battery casings and ventilation paths
- Verifying the operation of cooling systems and temperature sensors
- Applying firmware updates to BMS and related control systems

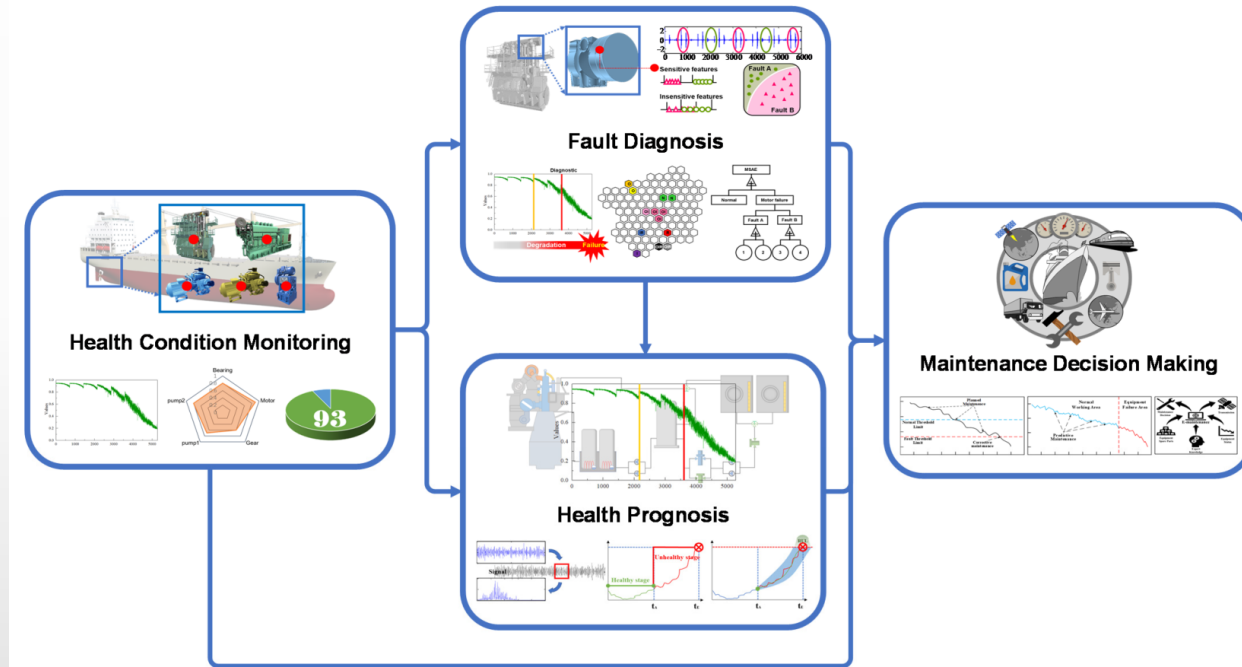
These procedures are vital for minimizing risks such as overcharging, cell imbalance, or thermal runaway.



Scheduled tasks are categorized based on operational frequency and equipment sensitivity. A typical maintenance timeline may include:

- **Daily Tasks:** Quick visual inspection, check for any system warnings on the BMS, basic parameter logging.
- **Weekly Tasks:** Verification of SoC/SoH trends, battery temperature checks, inspection of cable routing and physical housing.
- **Monthly Tasks:** Terminal cleaning, firmware verification, logging calibration data.
- **Quarterly or Annual Tasks:** Load testing, Electrochemical Impedance Spectroscopy (EIS), IR thermal scans, internal resistance measurements, capacity balancing.

These tasks ensure that degradation is identified early and maintenance is performed before system reliability is compromised.



Visual and electrical inspections are the foundation of preventive maintenance, offering early detection of physical and electrical faults.

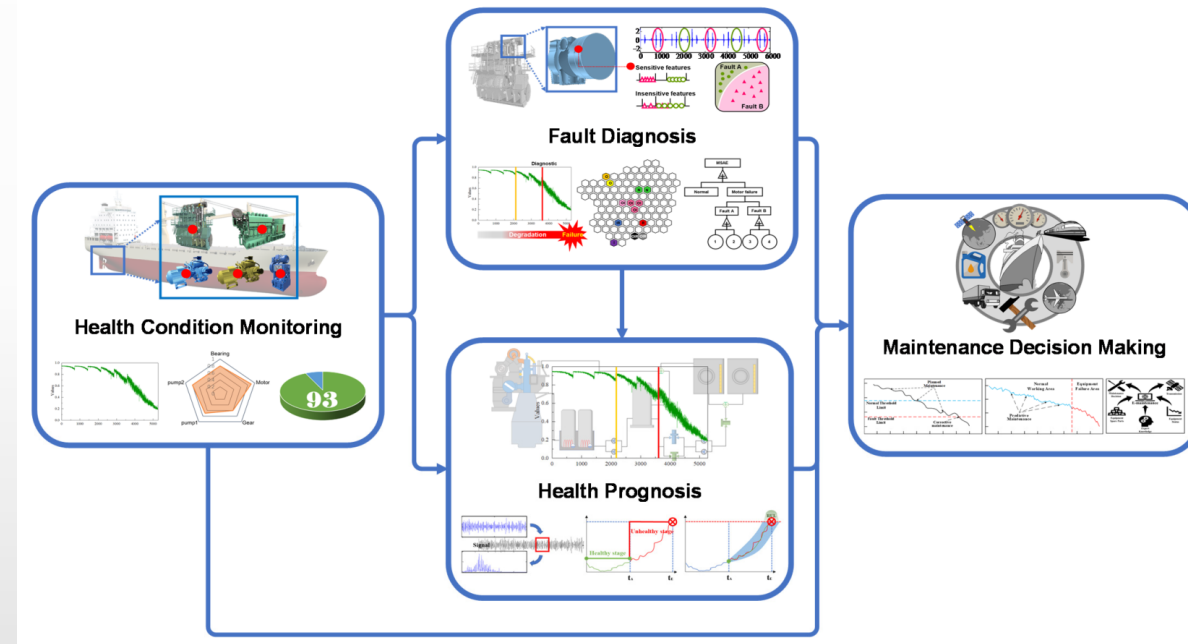
Visual inspection focuses on:

- Signs of corrosion, saltwater intrusion or humidity accumulation
- Cracked, swollen or leaking battery enclosures
- Damaged insulation, frayed cables or loose terminal connections
- Cooling fan or heat exchanger blockages

Electrical inspection includes:

- Verifying voltage levels and current draw consistency
- Identifying insulation resistance drops
- Checking grounding continuity
- Detecting abnormal voltage sag or irregular power supply profiles

Regularly scheduled inspections allow crews to detect issues before they escalate into system-wide failures.

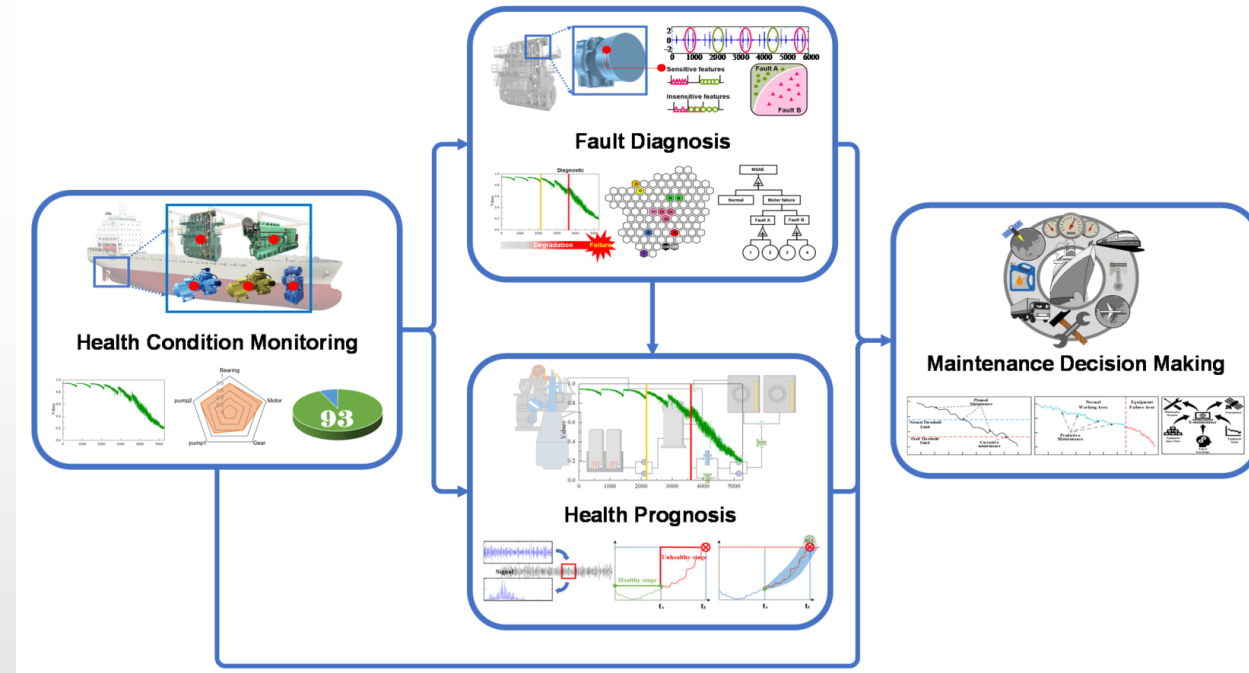


A range of diagnostic tools is used to assess the performance, health, and safety of battery and hybrid systems. These tools enable predictive strategies by quantifying hidden degradation or risks.

Common tools include:

- **Multimeters and Clamp Meters:** Measure voltage, current, resistance
- **Infrared (IR) Cameras:** Detect abnormal heat signatures, identify hot spots
- **Electrochemical Impedance Spectroscopy (EIS):** Analyze internal resistance and battery health
- **Battery Testers / Analyzers:** Measure capacity, charge/discharge cycles
- **Data Loggers & Communication Tools:** Capture BMS data over time

Using these tools helps technicians detect issues such as high impedance, thermal irregularities or cell imbalance with precision.

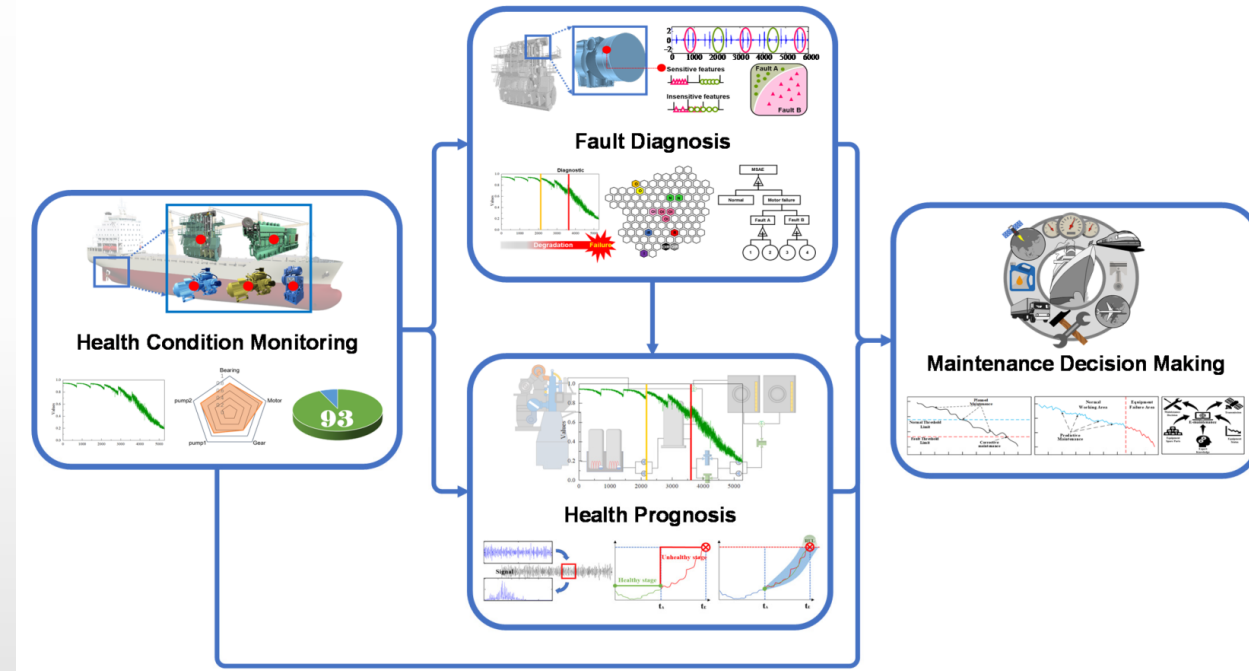


The Battery Management System (BMS) is the digital core of modern maritime energy storage systems. It continuously monitors the performance, safety and status of batteries.

BMS functions include:

- Monitoring cell-level voltage, current and temperature
- Calculating SoC (State of Charge) and SoH (State of Health)
- Balancing cells to ensure uniform charging/discharging
- Triggering alerts in case of thermal or electrical anomalies
- Recording historical data for trend analysis
- Enabling communication with other shipboard systems (EMS, PMS)

Advanced BMS systems enable integration with predictive analytics and allow remote monitoring for fleet-wide optimization.

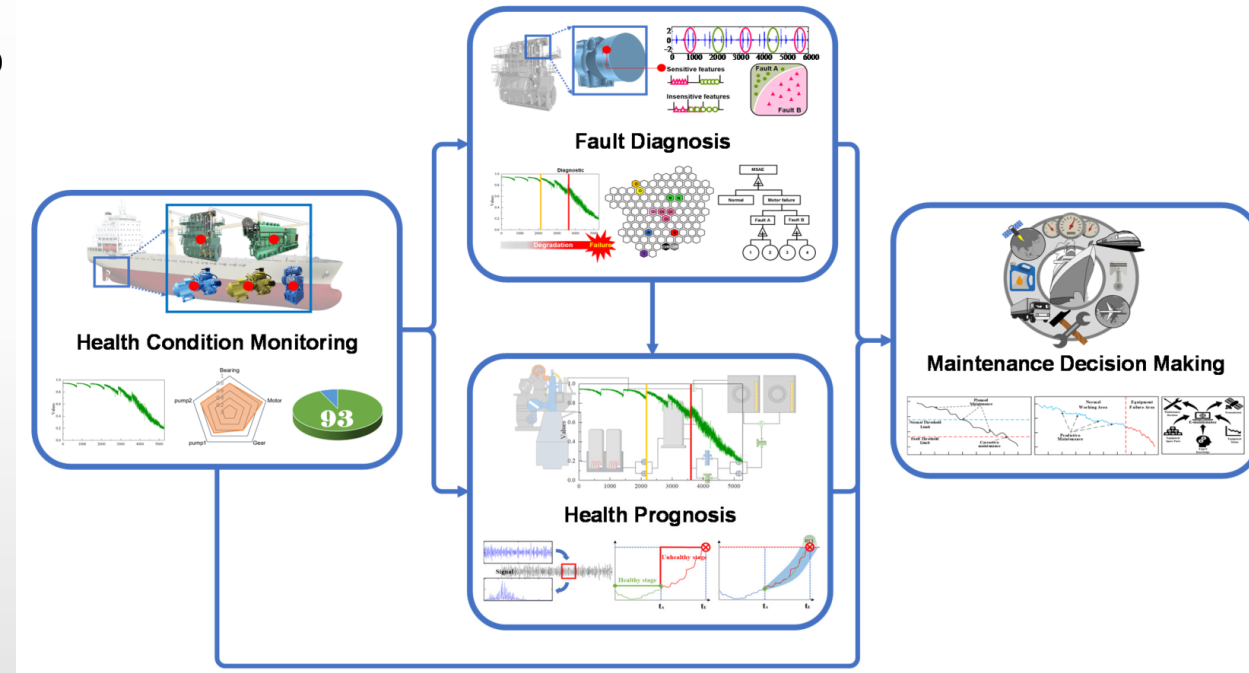


The BMS plays a crucial role in detecting anomalies before they become critical failures.

Typical issues identified by BMS include:

- **Voltage imbalance:** Between cells or modules, often due to unequal degradation
- **Overtemperature:** From blocked airflow, excessive current, or cell failure
- **SoC/SoH Drift:** Suggesting aging, capacity fade, or calibration errors
- **Communication Failures:** Loss of data between modules or between BMS and EMS
- **Overcharge / Overdischarge cycles:** Affecting battery lifespan and safety

BMS fault codes and logs serve as early-warning systems, enabling quick interventions.



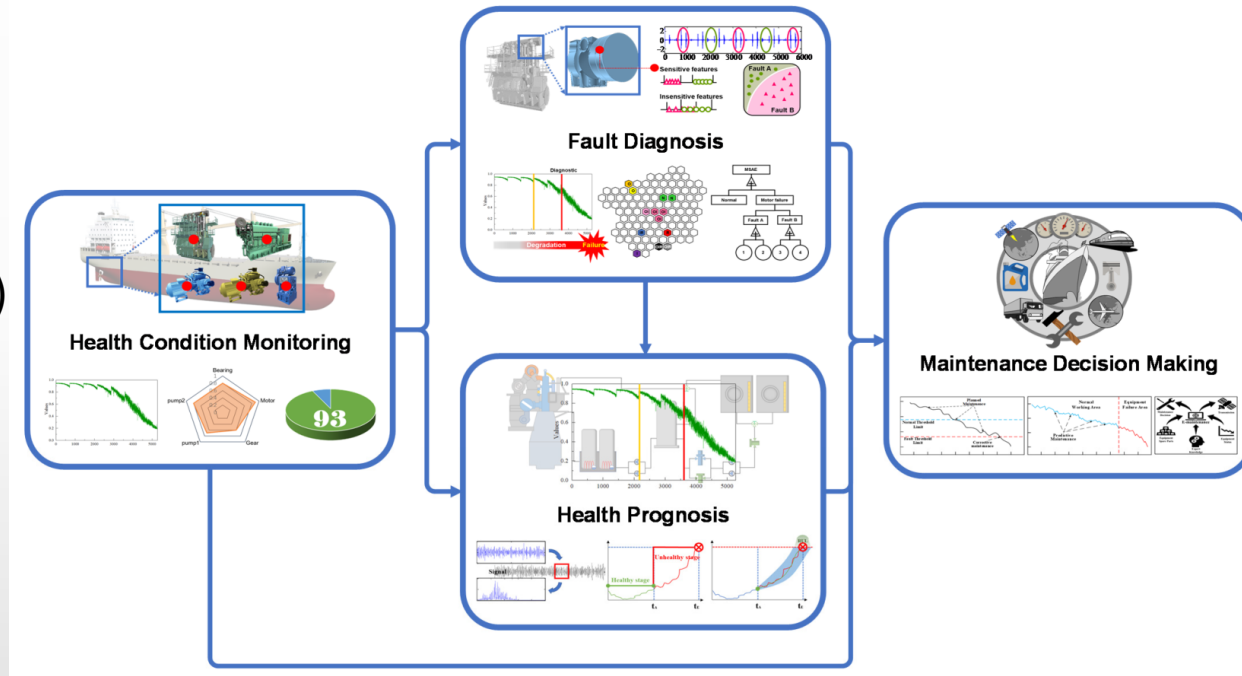
Predictive maintenance is a proactive strategy that relies on **real-time data, trend analysis, and condition monitoring** to forecast when a component will likely fail.

Instead of maintaining components at regular intervals, predictive maintenance focuses on actual operating conditions and degradation behavior.

Core principles:

- Use sensor data (temperature, voltage, current, impedance)
- Compare real-time readings to historical baselines
- Apply machine learning or rule-based models for prediction
- Schedule maintenance only when indicators show upcoming risk

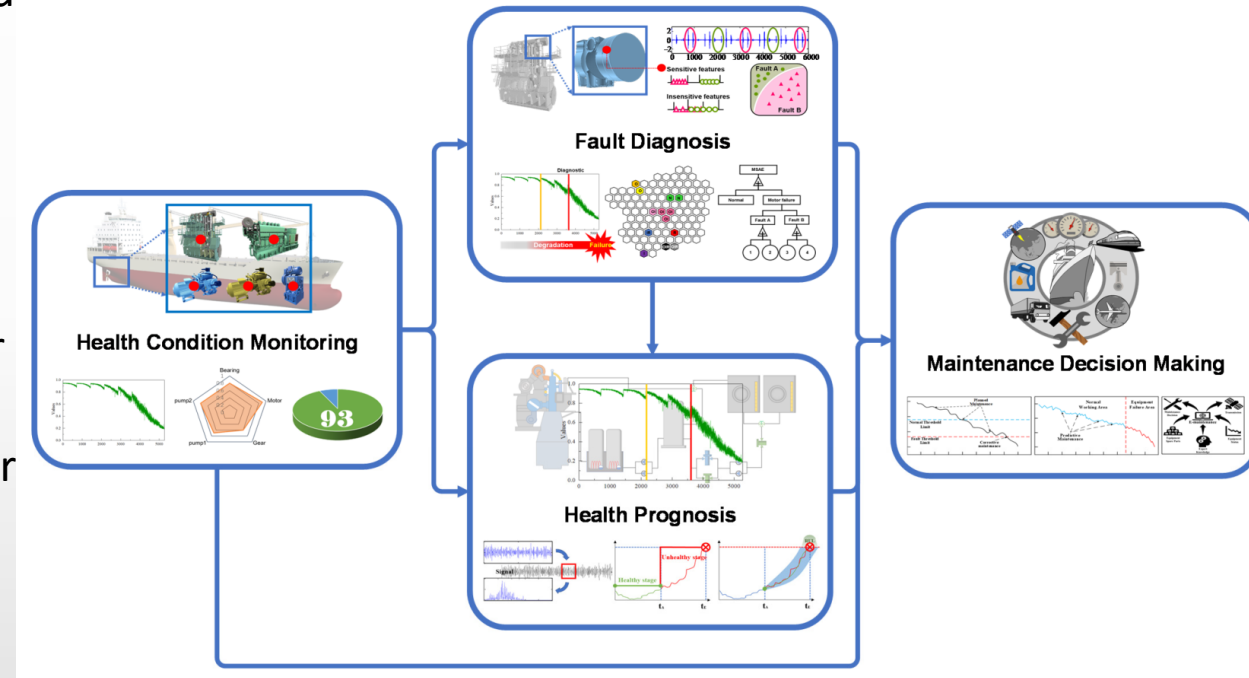
This approach minimizes downtime, extends system life, and ensures maintenance resources are used efficiently.



Predictive maintenance depends on continuous data acquisition from multiple sources. Key data channels include:

- **BMS Logs:** Longitudinal data on SoC, SoH, temperature, and fault events
- **Thermal Imaging Trends:** Detect localized heating or thermal propagation
- **Electrochemical Impedance Profiles:** Reveal internal aging mechanisms
- **Charging/Discharging Behavior:** Unusual power demand or low recovery rates
- **Historical Maintenance Records:** Identify recurring issues or weak components
- **Operating Conditions:** Environmental factors such as vibration, humidity, and load cycles

By correlating these datasets, maritime operators can build models that forecast component degradation with high accuracy.



Effective maintenance of battery and hybrid systems is essential to ensure

- safe,
- reliable and
- efficient vessel operation

A well-structured maintenance protocol minimizes

- the risk of failures,
- extends battery lifespan and
- helps optimize energy performance

Regular inspections, preventive maintenance, and diagnostic testing are crucial to identifying potential issues before they escalate into costly failures

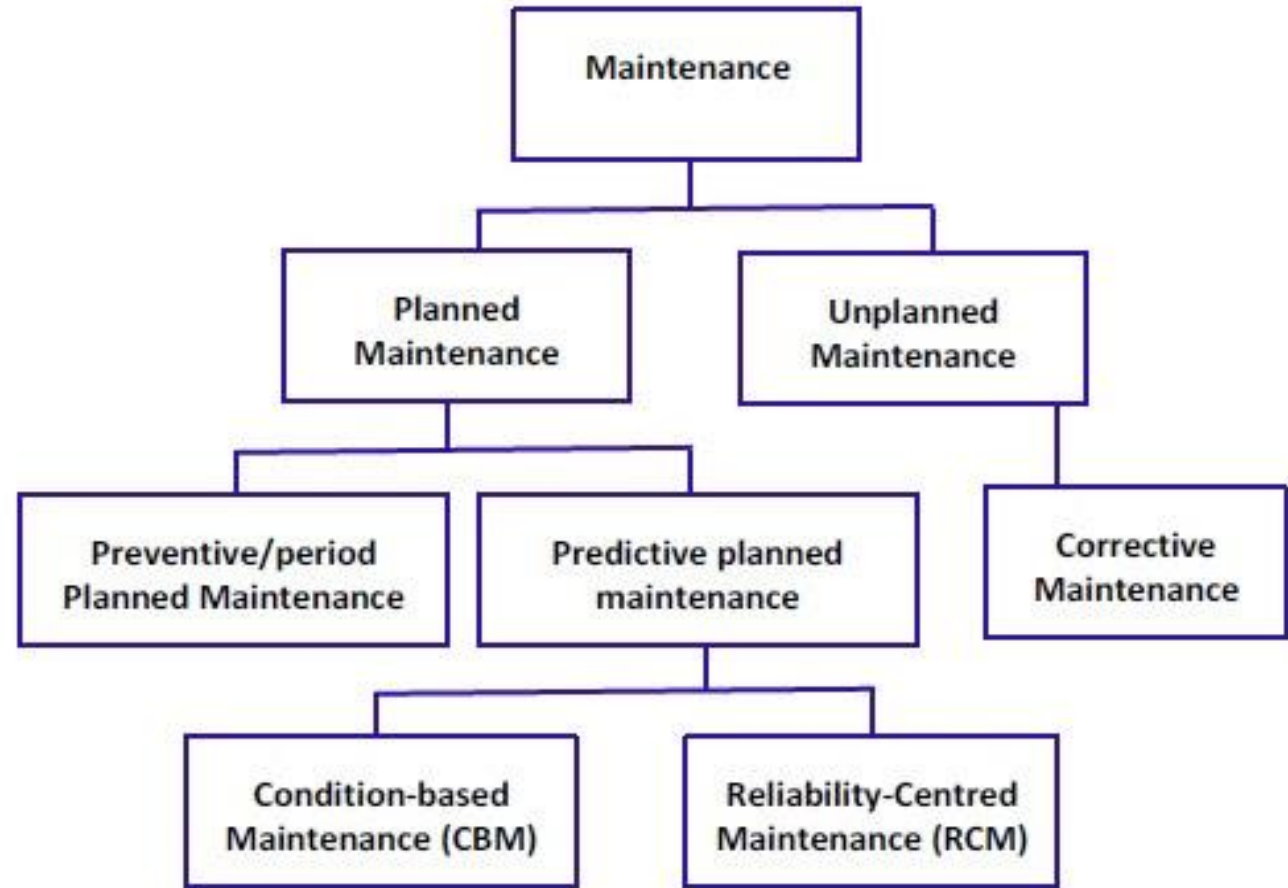




Table of contents

1. Training 1: Predictive and preventive maintenance approaches
2. Training 2: Monitoring battery health and electrical systems

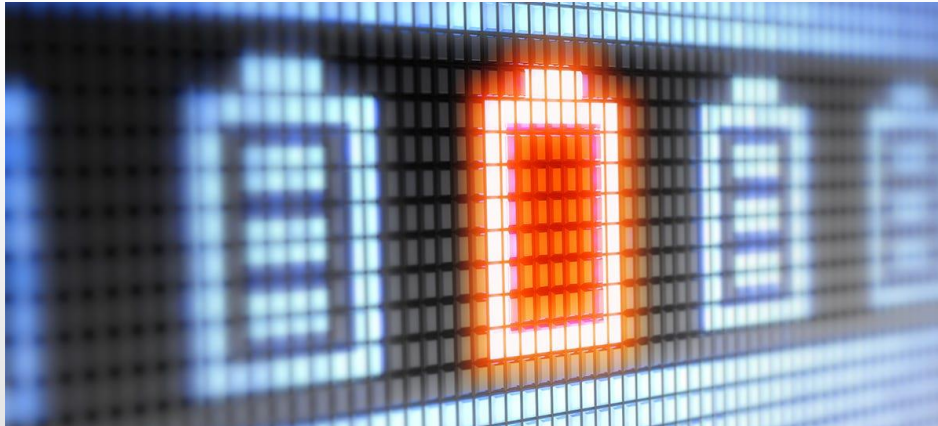
Introduction

- Importance of battery health in modern electrical systems
- Relevance to electric vehicles (EVs), grid storage, and consumer electronics
- Overview of monitoring objectives: **safety, performance, lifespan**



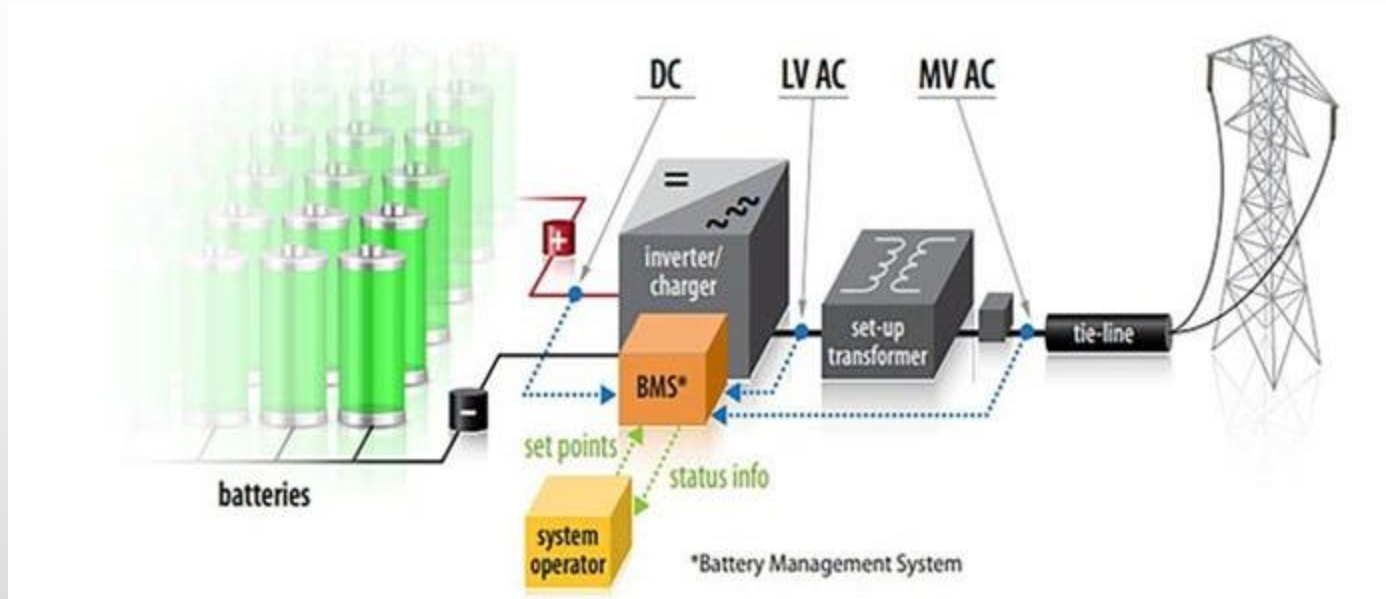
What is Battery Health?

- **Definition:** State of Health (SOH), State of Charge (SOC), Remaining Useful Life (RUL)
- Key indicators:
 - Capacity fade
 - Internal resistance
 - Voltage stability
 - Temperature response



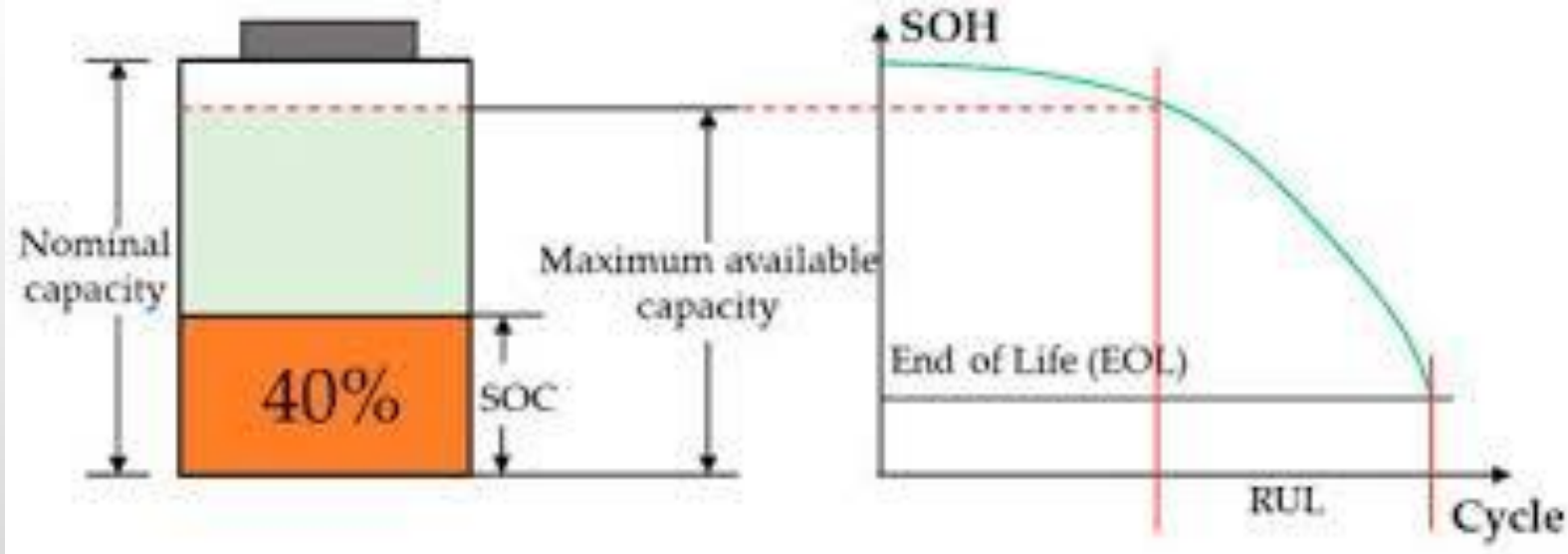
Electrical System Overview

- Components of battery electrical systems:
 - Cells, Modules, Packs
 - Battery Management System (BMS)
 - Power electronics (inverter, charger, DC/DC converter)
- Role of **real-time monitoring**



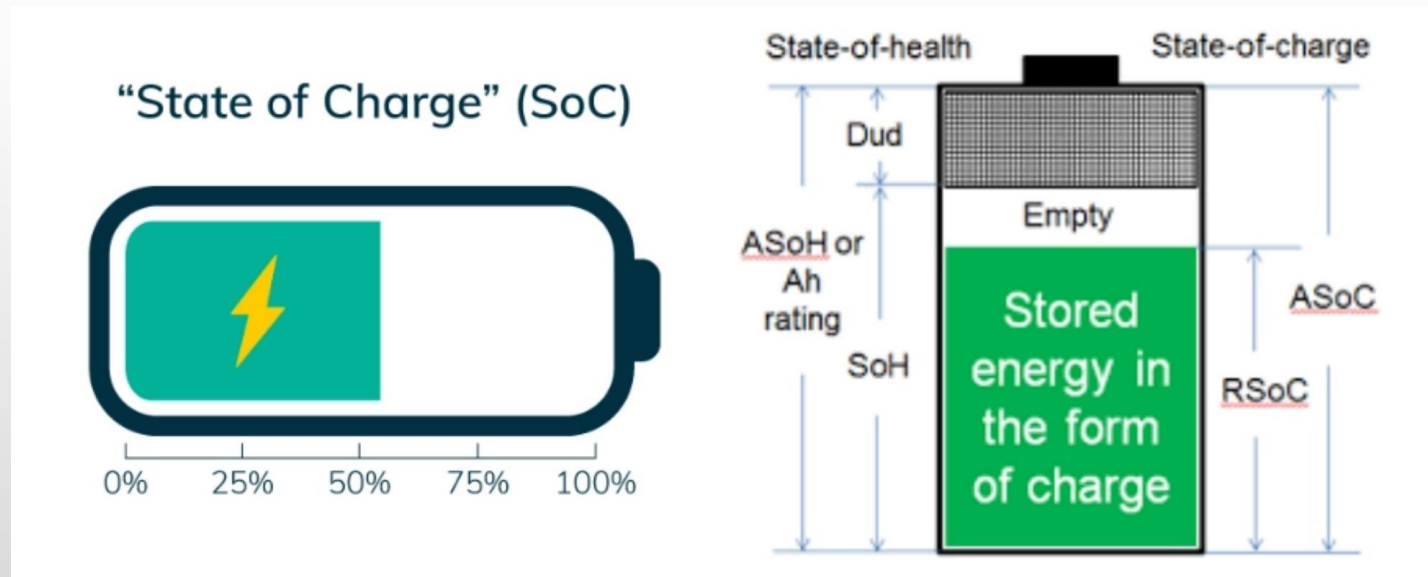
What is Battery Health?

- **Definition:** State of Health (SOH), State of Charge (SOC), Remaining Useful Life (RUL)
- Key indicators:
 - Capacity fade
 - Internal resistance
 - Voltage stability
 - Temperature response



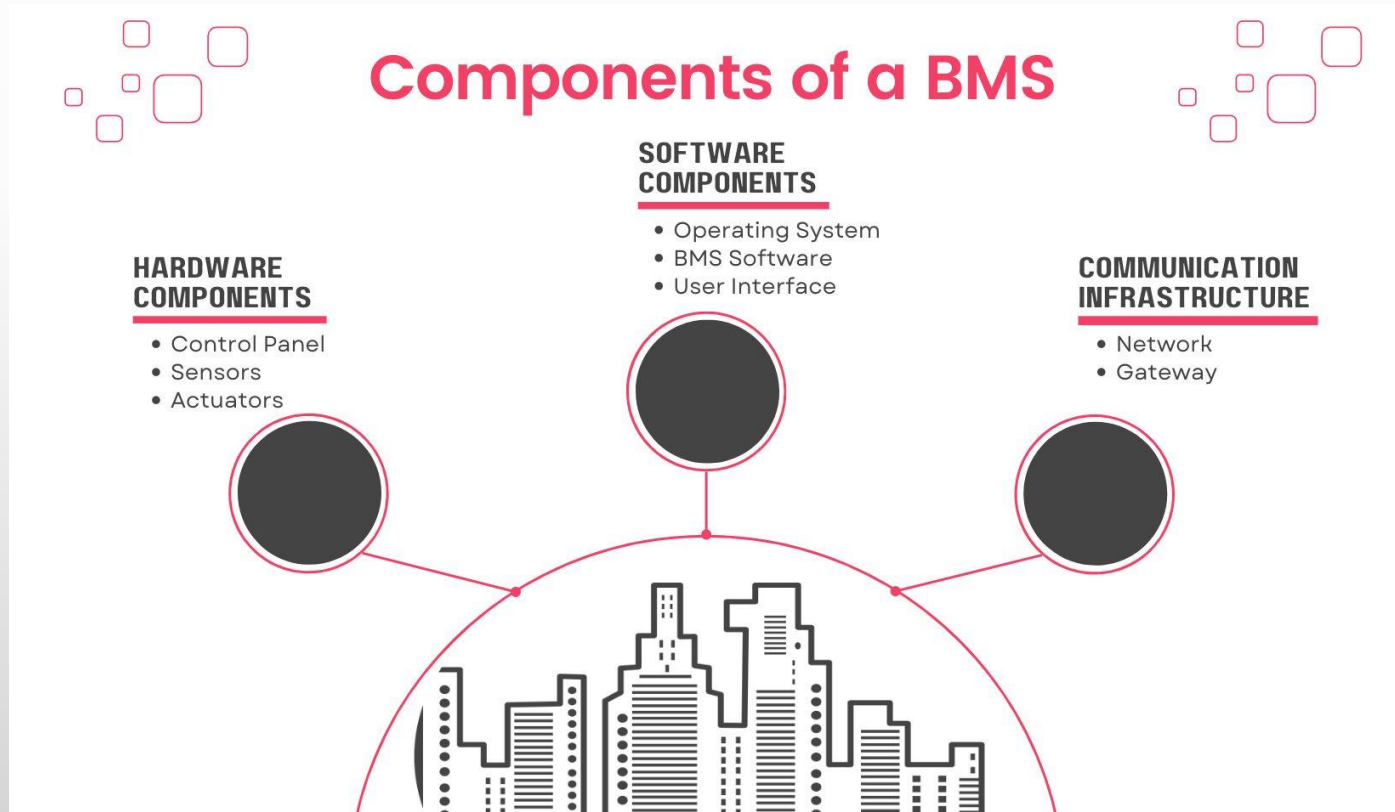
Parameters to Monitor

- **Voltage** (cell/module/pack level)
- **Current** (charge/discharge behavior)
- **Temperature** (thermal management)
- **Impedance/Resistance**
- **SOC/SOH Estimations**
- **Cycle count & charging patterns**



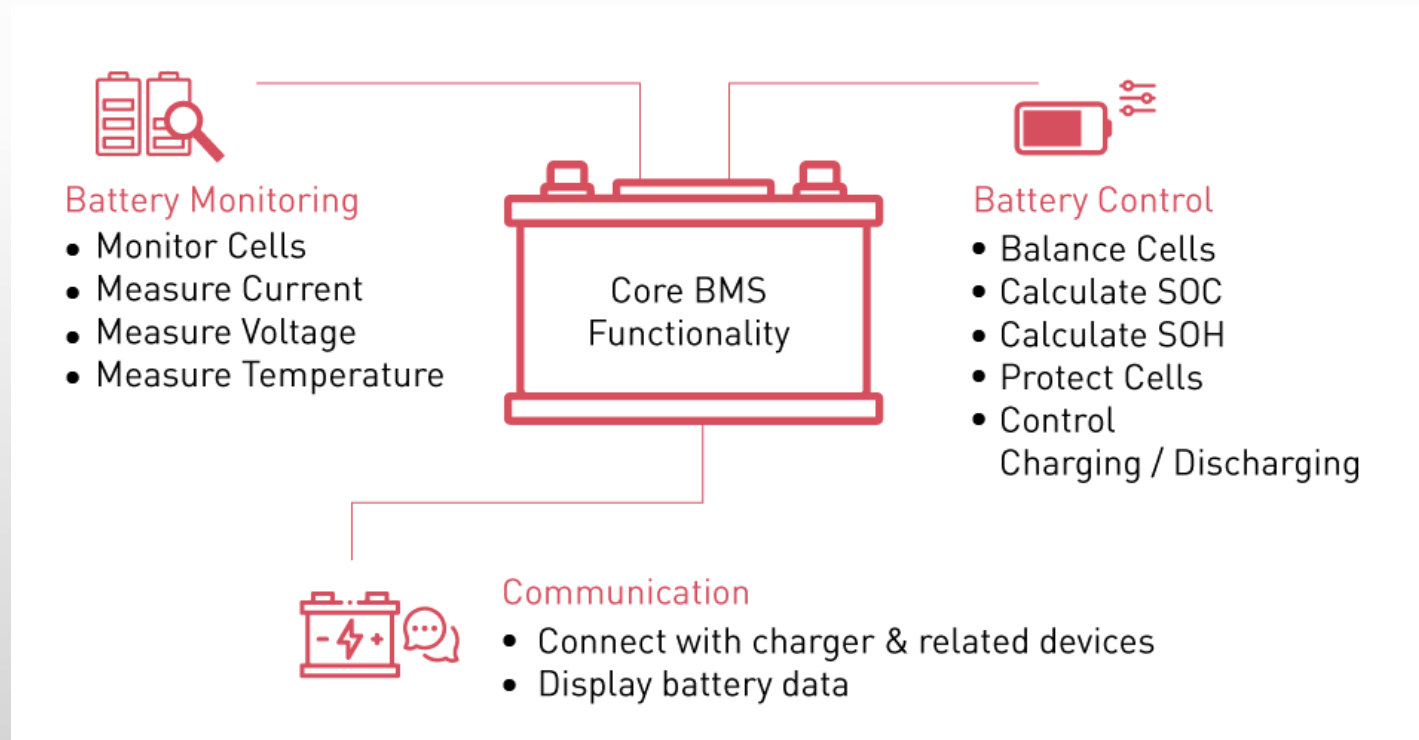
Sensing Technologies

- Voltage sensors
- Current sensors (shunt, Hall-effect)
- Thermistors & RTDs
- Electrochemical impedance spectroscopy (EIS)
- Optical & ultrasonic sensors (advanced)



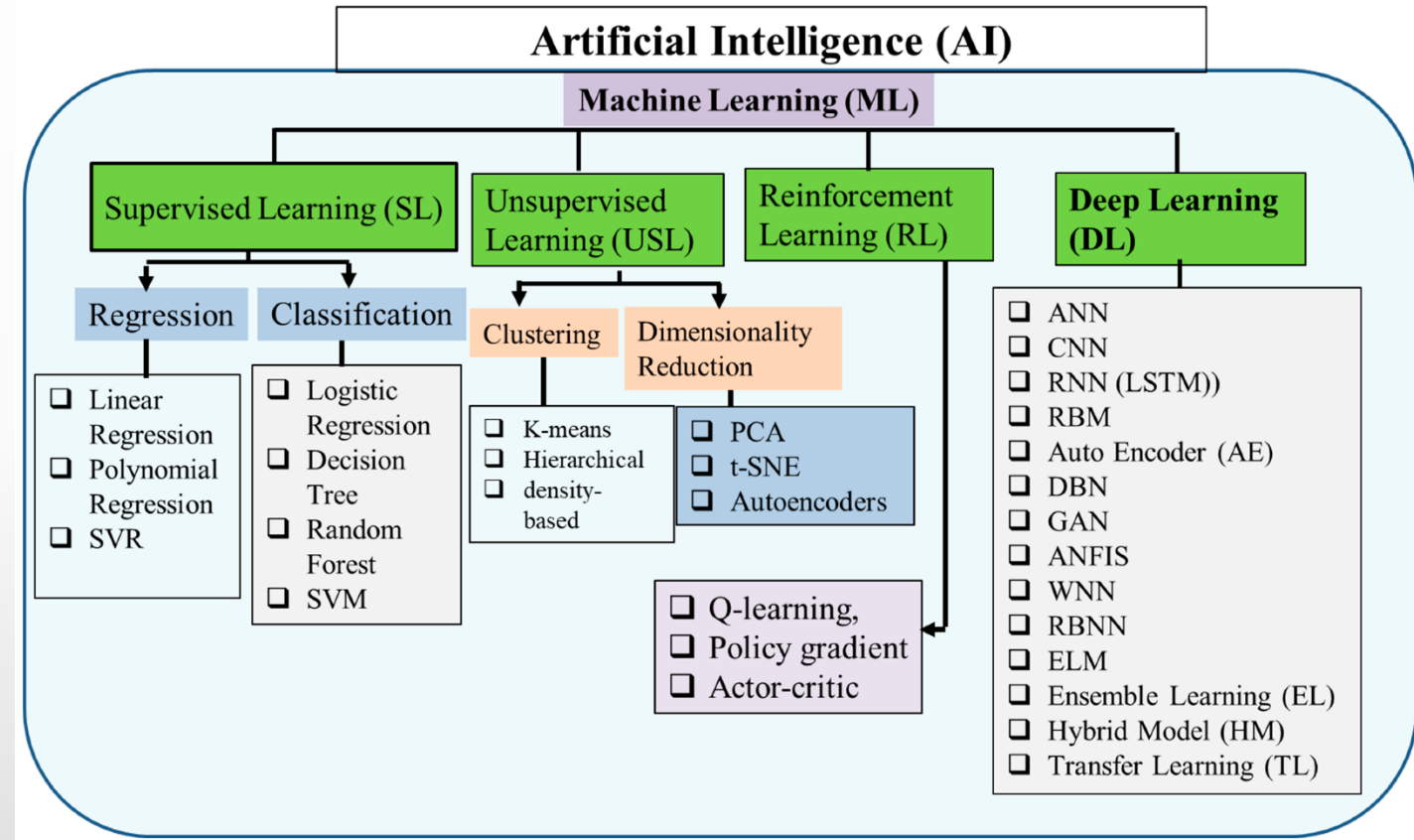
Role of the Battery Management System (BMS)

- Functions:
 - Data collection
 - Protection (over-voltage, over-temp, short circuit)
 - SOC/SOH estimation algorithms
 - Communication with vehicle/grid controllers
- Centralized vs. Distributed BMS



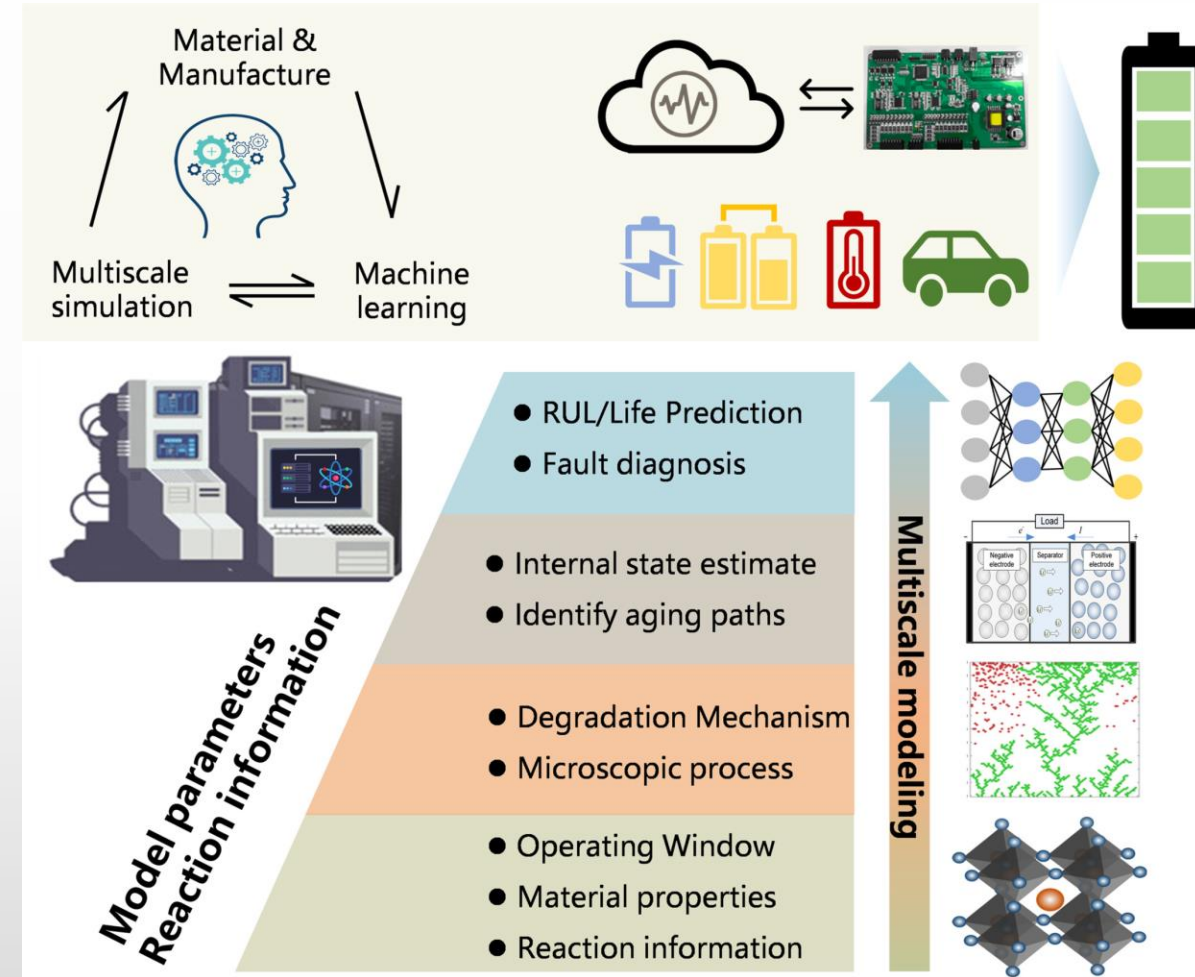


- Signal filtering and anomaly detection
- **Estimation methods:**
 - Kalman Filters
 - Neural Networks
 - Support Vector Machines (SVM)
 - k-Nearest Neighbors (k-NN)
- Machine learning in predictive maintenance



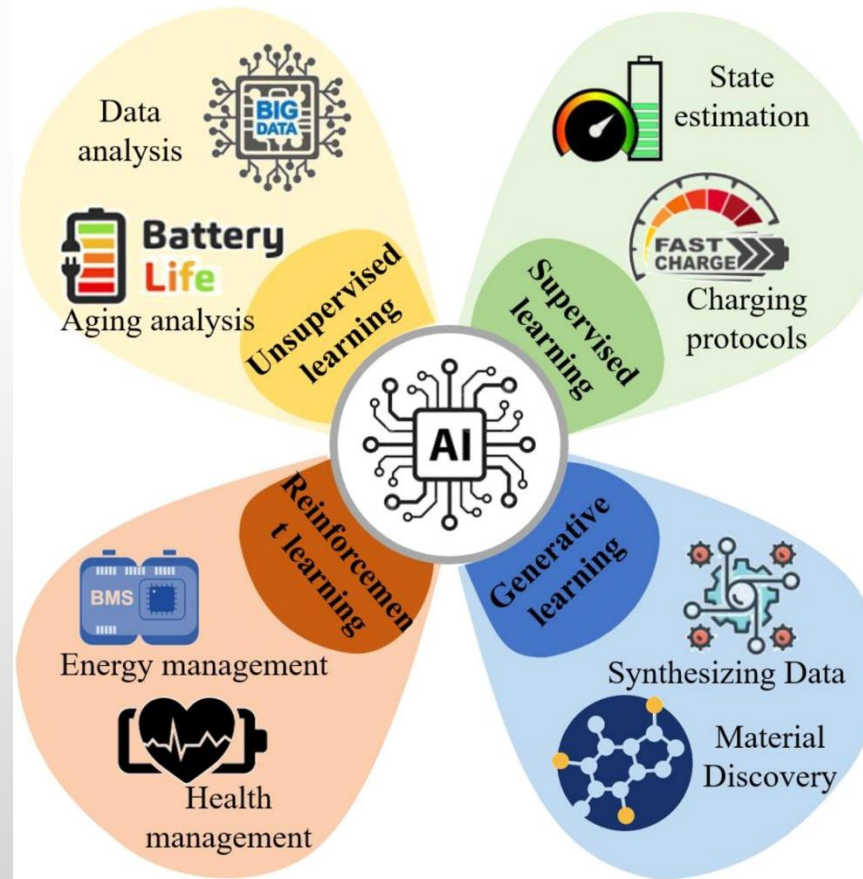
Future Trends

- AI-driven BMS systems
- Self-healing algorithms
- More advanced physics-informed digital twins
- Multi-scale monitoring (nano to system level)



Conclusion

- Battery health monitoring is critical to ensure **safety, reliability, and performance**
- Integration of sensors, algorithms, and communication tools is key
- Advances in AI and digital technologies will revolutionize monitoring capabilities



Thanks for your attention!