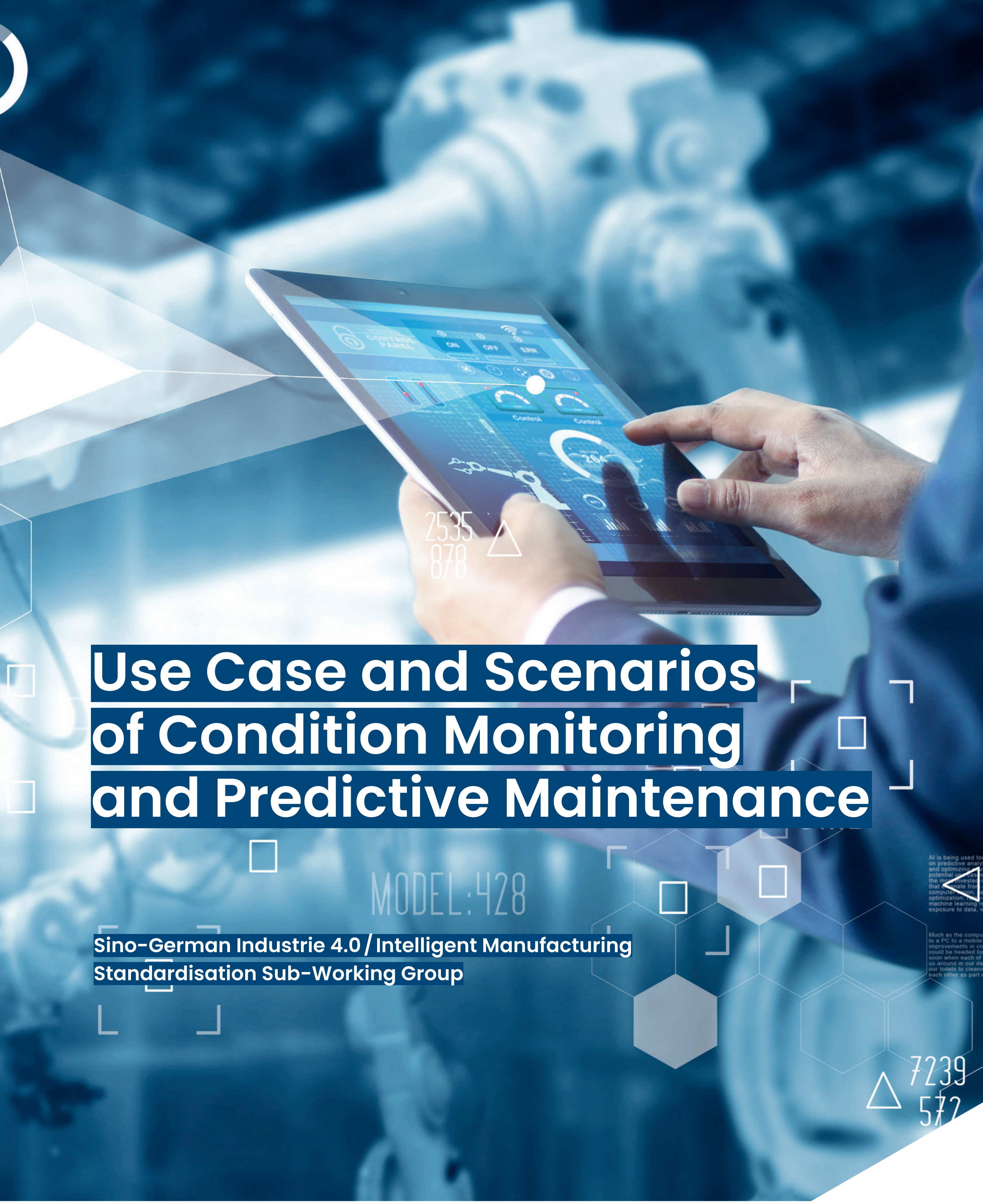

Use Case and Scenarios of Condition Monitoring and Predictive Maintenance

Sino-German Industrie 4.0 / Intelligent Manufacturing Standardisation Sub-Working Group

IMS 国家智能制造标准化总体组
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National Intelligent Manufacturing Standardisation Administration Group

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PLATTFORM INDUSTRIE 4.0

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NATIONAL INTELLIGENT MANUFACTURING STANDARDISATION ADMINISTRATION GROUP
The National Intelligent Manufacturing Standardisation Administration Group (IMSG) was established to promote and accelerate the progress of intelligent manufacturing in China under the leadership of the Standardisation Administration of China (SAC) and Ministry of Industry and Information Technology (MIIT). It is responsible for carrying out practical work on intelligent manufacturing standardisation, including participation in international standard-setting on intelligent manufacturing as well as organising exchange and cooperation on international standards.

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The Standardization Council Industrie 4.0 (SCI 4.0) was founded at the Hannover Messe 2016 as a German standardisation hub by Bitkom, DIN, DKE, VDMA and ZVEI. The initiative aims to initiate standards for digital production and to coordinate these standards nationally and internationally. SCI 4.0 orchestrates implementation of the standardisation strategy of the German Platform Industrie 4.0, which includes coordination with standardisation organisations (SDOs) and international partners as well as interlocking with pilot projects. The aim of this coordinated approach is to ensure that standards exploiting the potential of Industrie 4.0 are developed in a coordinated manner. SCI 4.0 is supported by DKE and the German Federal Ministry for Economic Affairs and Climate Action (BMWK).

PLATTFORM INDUSTRIE 4.0
The Plattform Industrie 4.0 is the central network in Germany for advancing the digital transformation in production. More than 350 stakeholders from more than 150 organisations are actively involved in the Plattform, in close cooperation between politics, business, science, trade unions and associations. As one of the largest international and national networks, the Plattform supports German companies in implementing Industrie 4.0, especially by making existing Industrie 4.0 practical examples known to companies and bringing them into the mainstream. In addition, it provides important impetus, with concrete recommendations for action in over 200 specialist publications and refers to support services and test environments. The Plattform's numerous international collaborations underline its strong role in international discussions on the topic of Industrie 4.0.
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The German Federal Ministry for Economic Affairs and Climate Action (BMWK) established the Global Project Quality Infrastructure (GPQI) to promote the development of well-functioning and internationally coherent quality infrastructures. GPQI supports political and technical dialogue and implements bilaterally agreed activities in collaboration with all relevant stakeholders. The project aims to reduce technical barriers to trade and enhance product safety through bilateral political and technical dialogue on quality infrastructure (QI) with some of Germany's key trading partners.

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Introduction

Efficient production relies significantly on the availability of production equipment. In order to guarantee the intended use of such equipment and to avoid unplanned downtimes, the status of the equipment and its components – in future referred to here as 'assets' – needs to be monitored and assessed. This process is called Condition Monitoring (CM).

Based on the assessment and with knowledge of the intended processes to be carried out, it is possible to predict the remaining error-free operation of the equipment and plan possible activities for maintenance. This process is called Predictive Maintenance (PM).

Changes to the production workflow can also be initiated, targeting in particular re-organisation of equipment use. Figure 1 shows an architecture of a production system with condition monitoring and life prediction function.

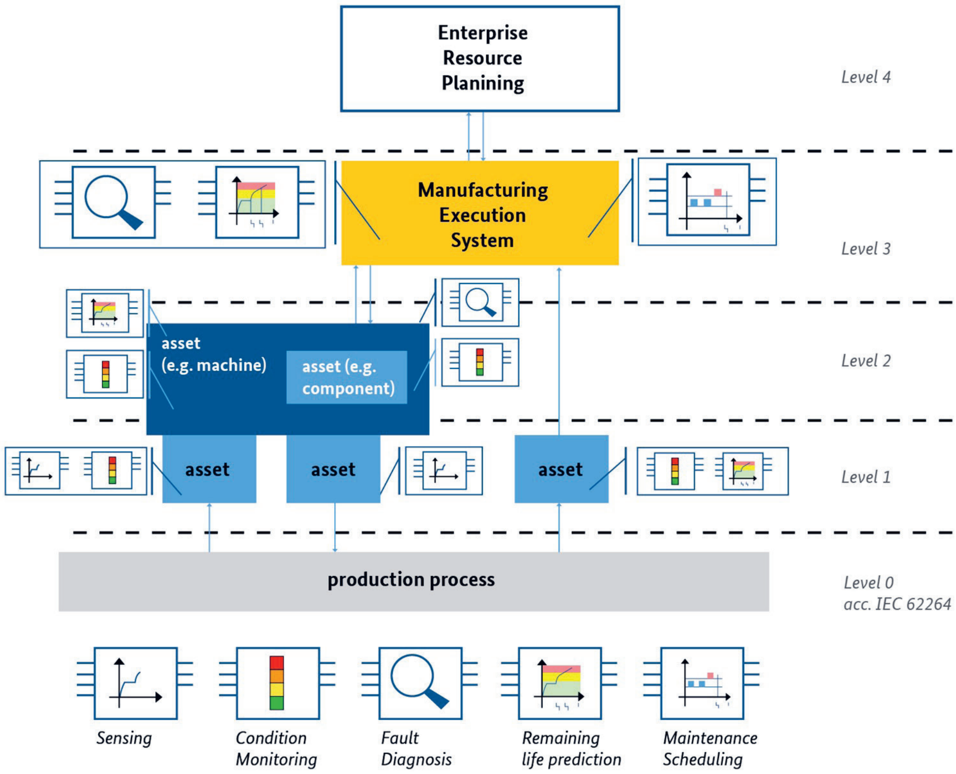


Figure 1 – Positioning of condition monitoring, prediction and maintenance scheduling in a production system.

Part 1: Use case of condition monitoring and predictive maintenance

Overview

In the overall community the term 'use case' is understood and applied very differently. In the standardisation roadmap Industrie 4.0, Version 3, it was therefore recommended to distinguish basically three different categories of use cases:

- business scenarios describing a value-network of business roles, where each business role is characterised by a business model;
- use cases describing the interaction of technical roles with a technical system, where the context of a technical system and high-level requirements are specified, how the technical system interacts within its context;
- example projects, case studies, technical solution concepts, etc.

Within the scope of the Condition Monitoring & Predictive Maintenance Working Group of the Sino-German Standardisation Cooperation Commission (TEG CM&PM), the term 'use case' is understood as being the second of the three categories mentioned.

Thus, the second and third categories above will be included in the TEG CM&PM publication *Use Case and Scenarios of Condition Monitoring & Predictive Maintenance*.

IEC TC65 WG23 and in particular the Smart Manufacturing Use Cases task force have the goal of analysing the impact of Smart Manufacturing on standardisation. The approach adopted by the Smart Manufacturing Use Cases task force is to collect and evaluate use cases.

Use Case and Scenarios of Condition Monitoring & Predictive Maintenance applies the methodology of IEC TC65 WG23 and extends the scope of Use Cases Condition Monitoring of Production Resources in WG23.

Objective

Production managers are often less concerned with the condition of assets than with how long they can be used and how to deliver the most cost-effective approach to maintenance. Meeting the demands of production managers requires considerable experience, large amounts of data and computing power, and this is difficult for any stakeholder to achieve independently. For this reason, standardised definitions, structures, methods and examples of use are required to create the conditions for establishing predictive maintenance 'data pools'.

Efficient production relies significantly on the availability of production equipment. In order to guarantee the intended use of such equipment and to avoid unplanned downtimes, the status of the equipment and its components – in future referred to here as 'assets' – needs to be monitored and assessed. Based on the assessment and with knowledge of the intended processes to be carried out, it is possible to predict the remaining error-free operation of the equipment and plan possible activities for maintenance. This process is called Predictive Maintenance. Changes to the production workflow can also be initiated, targeting in particular re-organisation of equipment use.

The core of this use case is to predict the future health status of assets based on condition monitoring, using data-driven or mechanism-based methods, optimise maintenance resource allocation and provide reasonable recommendations to stakeholders.

From a technical point of view, predictive maintenance covers sensing, condition monitoring, fault diagnosis, remaining life prediction and maintenance management technologies, etc. Sensing and condition monitoring are input of predictive maintenance; fault diagnosis and remaining life prediction are processes; maintenance management is output. Fault diagnosis and remaining life prediction can be carried out based on data-driven, mechanism models or mixed method, including neural network, support vector machine, deep learning. A deep understanding of assets and possible faults is a prerequisite for predictive maintenance.

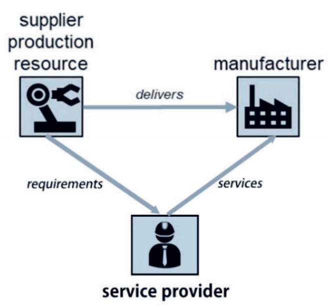
The hardware and software that support predictive maintenance can be called infrastructure; the internal interfaces of infrastructure and external interfaces to relevant systems will be standardised. In addition, all infrastructure components will contain functions for common identification, self-description and management of components; these functions can be realised using an asset administration shell.

So the roles involved in this use case include asset supplier and users (asset operators). Service providers provide services to both parties in their areas of expertise, including diagnostic and predictive model building. Although more and more asset suppliers have the ability to provide predictive maintenance services, the addition of service providers is more conducive to sharing experience and standardising infrastructure.

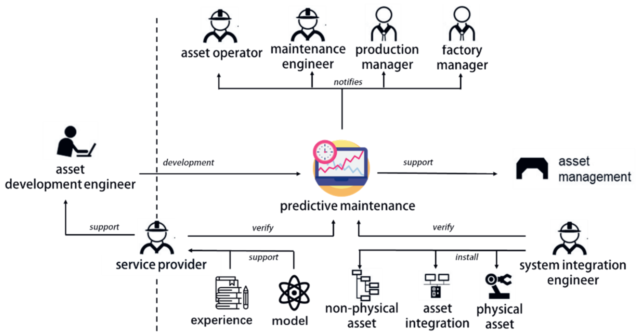
This use case includes service providers. In describing this use case, a description method consistent with the use case 'management of assets' is used.

Overview of roles

Business context



Technical perspective



Description

Interaction of roles

The asset development engineer develops the predictive maintenance function of assets, during which the service provider can provide support in terms of experience, data, and model. The results of predictive maintenance should provide information to the asset management system.

The service provider is a professional role engaged in predictive maintenance consulting, solutions, software and hardware equipment, system integration and data/model support. The service provider can be an independent company or a department within an asset supplier or manufacturer.

The system integration engineer is responsible for linking the predictive maintenance function with the manufacturer's hardware and software to achieve the necessary communication of information. If necessary, the system integration engineer needs asset integration to provide the required computing capabilities for health prediction (in the case that the asset itself does not provide appropriate computing capabilities).
The predictive maintenance function continuously monitors the use information provided by the asset and updates the condition of the asset in asset management. In critical situations, the asset operator, maintenance engineer, production manager and factory manager are notified in a timely manner.

New compared to today

Due to the real-time requirements of industrial production, one of the development trends of predictive maintenance is edge computing, i.e. process data and feedback maintenance information through edge devices with computing capabilities.

With the requirement for accuracy of prediction results, another development trend of predictive maintenance is platform computing, i.e. relying on the update of communication technology, uploading as much data as possible to the platform for calculation to obtain more computing capabilities. Because platform computing and edge computing are different in their implementation methods, edge computing is usually used to process alarm information, and platform computing is used for prediction functions.

In addition to the model, the implementation of predictive maintenance also requires the support of experience. For this reason, the 'data pool' is also a development trend of predictive maintenance. Generally, supplier data cannot be shared, but with the advent of predictive maintenance service providers, the establishment of a 'data pool' becomes necessary, which also creates a standardised demand.

Part 2: Classification

Whether for a workshop/plant or the asset, predictive maintenance functional blocks are applicable. However, the difference lies in the implementer of each functional block and the technical implementation plans.

PM for a workshop/plant is usually implemented by the user, which means the operator of the asset. Alternatively, it may be entrusted to a professional third-party technical service company. The results of PM are usually presented in the form of maintenance programs. In terms of technical implementation schemes, they will hope to use existing resources to reduce the impact on the manufacturing process, such as PLC, MES, etc.

PM for the asset is usually implemented by the manufacturer of the assets. This is because they have a better understanding of the assets and there are more methods to implement predictive maintenance. The results of predictive maintenance are often presented in the form of predictions of the remaining lifetime, since information about the operating and maintenance plan of assets is unknowable for manufacturers. In terms of technical implementation, they will make greater use of sensors and independent software systems.

The collection therefore introduces cases from the above two categories, but the technical realisation of different examples can be merged. The premise is to standardise their system architectures, infrastructure interfaces and functional blocks.

Part 3: Scenarios of CM & PM for workshop or plant

Scenario 1: Value-based service based on asset health information

Overview

Nowadays, a product provider typically delivers a product to a customer and does not receive any feedback on the use of his product. The application scenarios VBS (value-based service) and TWP (transparency and adaptability of delivered products), as defined in Platform Industrie 4.0: *Fortschreibung der Anwendungsszenarien der Platform Industrie 4.0*, are focusing on creating new services based on asset health information. Providing this feedback data to the product provider will enable him to develop updates and new releases for the product type. This will enhance the product for future use and will enable the product provider or an independent service provider to adapt the product instances in cooperation with the customer.

In order to achieve VBS, the predictive maintenance system should cover Level 0, Level 1, Level 2, Level 3, and Level 4 of the system levels.

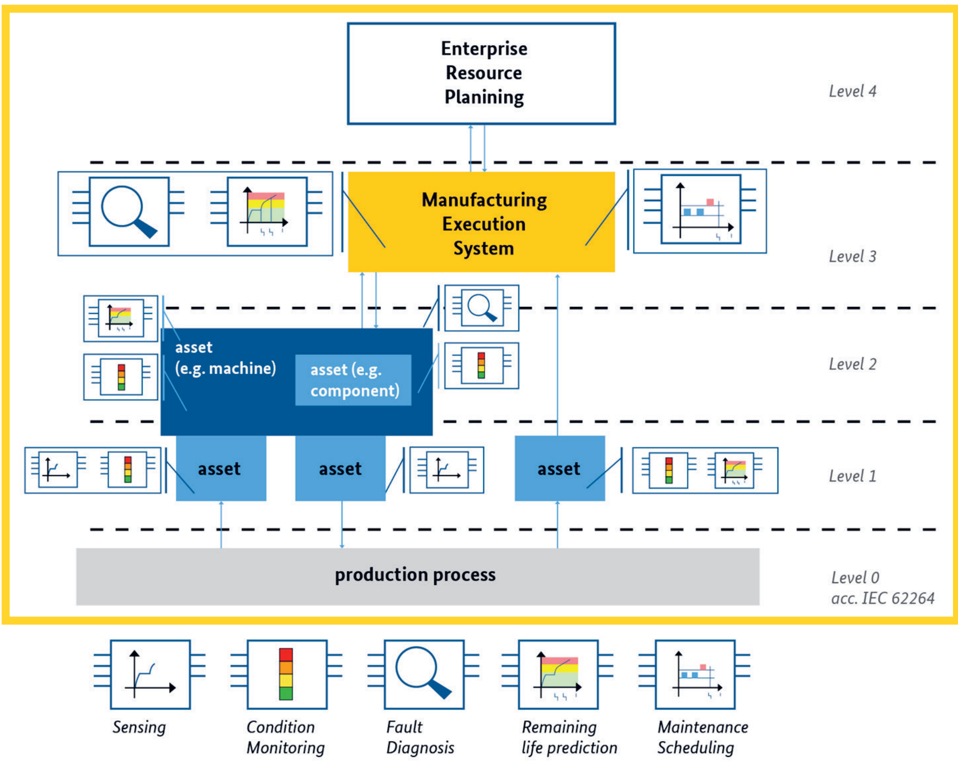


Figure 3-1-1 – System level diagram

To realise a VBS smart factory, the predictive maintenance system should have complete predictive maintenance functions, including sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management and other functions of the manufacturing equipment, as illustrated in the figure below.

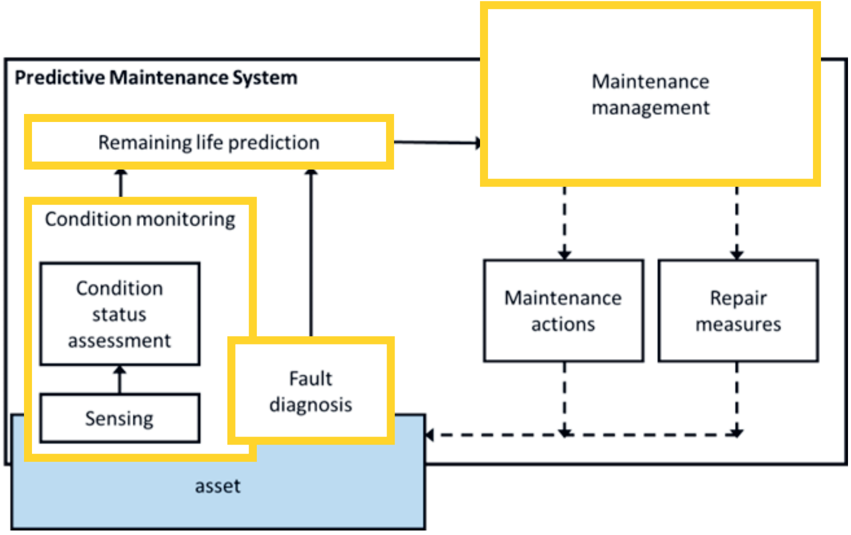


Figure 3-1-2 – System function diagram

Roles

The implementation model for this case is a predictive maintenance platform jointly operated by service providers and asset users. The platform may also be independently operated by asset users.

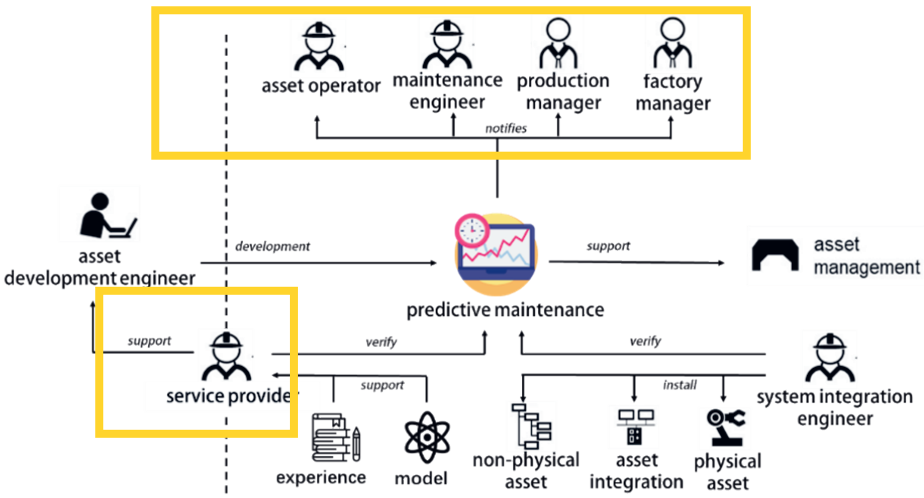


Figure 3-1-3 – Implementation role diagram

Functions and methods

The product used at the customer's site is constantly monitored to calculate health status and carry out necessary maintenance measures. The product-related raw data and calculated health status can be delivered back to the product provider, together with context and application information from the use of the product instance. The specific volume of data must be agreed between product provider, possible service providers and the customer. Based on the provider's models and detailed knowledge of the product, the feedback data can be evaluated in order to identify and predict potential failures and product errors in advance. Since the customer may collect such data from a multitude of customers, different application scenarios can be considered and evaluated, perhaps by using big data and data analytics approaches. Possible findings can be fed back into product development processes.

Visualisation

Compared to the use cases above, this use case focuses on a longer feedback loop, covering product providers and customers. The product updates enhance the product's robustness and thus allow for its optimal use at the customer's site. In addition, updates may help to create new services to better tailor the products to individual customers' needs. These services may be offered by the product provider and by new service providers.

Scenario 2: Use of predictive maintenance measures to support adaptable factory concepts, user background and problems

Overview

The installation of a plant is currently pre-engineered and fixed for a long time. To support flexibility in production, the adaptation of the plant to changing production and market conditions needs to be enhanced. This is in the focus of the Industrie 4.0 application scenarios WFF – Adaptable Factory and DDA – Seamless and Dynamic Engineering of Plants. The plant needs to be able to adapt itself to new situations by changing its structure and components. However, adaptation currently does not consider the actual station of available components, in terms of their individual future capacity and availability or their specific history.

In order to support adaptable factories, the predictive maintenance system should cover Level 0, Level 1, Level 2, Level 3, and Level 4 in the system levels.

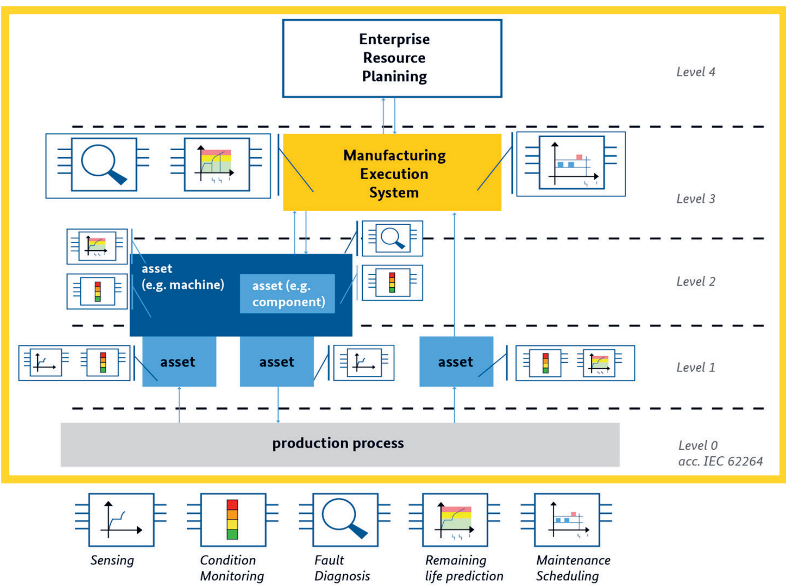


Figure 3-2-1 – System level diagram

Smart factories with adaptive functions should have complete predictive maintenance functions, including sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management and other functions of manufacturing equipment, as shown in the figure below.

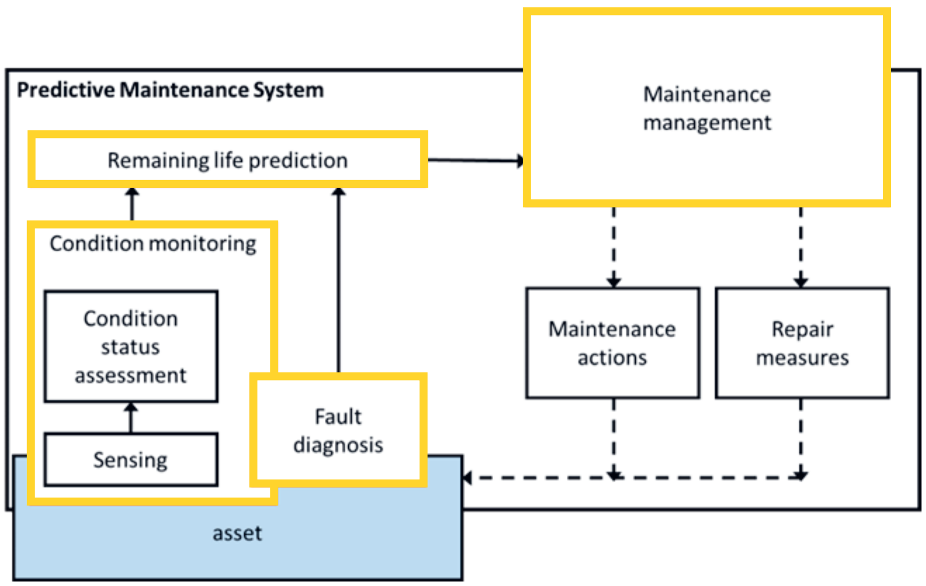


Figure 3-2-2 – System function diagram

Roles

The implementation model for this case is a predictive maintenance platform, jointly operated by service providers and asset users. The platform may also be independently operated by asset users.

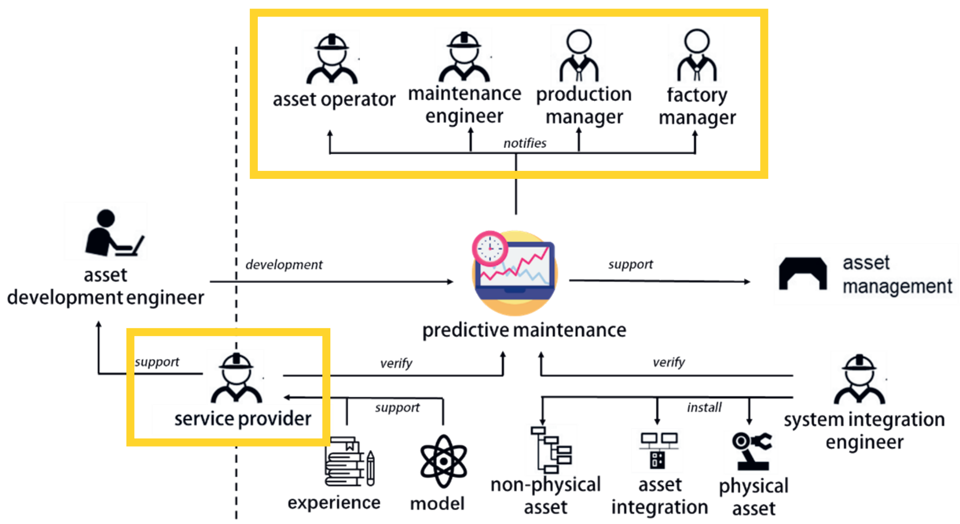


Figure 3-2-3 – Implementation role diagram

Functions and methods

The focus in this use case is to maintain a historical list of component-specific conditions and events. This will include health state prognoses, results of maintenance actions from MES, repair records, performance evaluations, etc. Together with logs of production contexts and their changes, a better prognosis can be created to characterise the effects of potential adaptations in a plant. It is possible to work out in advance, if a combination of individual components, which – based on their specifications – ought to fulfil a functional requirement, will actually fulfil this requirement based on the individual status of components. It may also enhance calculation of the remaining time of life for the new combination. Data analytics may support the decision, enhancements using artificial intelligence systems can also be expected.

Visualisation

By better estimating the results of a possible adaptation of the plant, it is easier to assess the value of adaptations, either proposed by the components themselves or by an engineering process at runtime. This will support the process of determining an optimal adaptation and provide a more accurate performance prognosis.

Scenario 3: Predictive maintenance of a customisation factory

Overview

The customised factory was jointly developed by Mitsubishi Electric Automation (China) Ltd. (Mitsubishi) and Instrumentation Technology & Economy Institute, P.R. China (ITEI). CNC machine tools and intelligent robots are key equipment, so normal operation is vital to ensure stability. Sudden failure will lead to the breakdown of CNC machine tools and intelligent robots, resulting in interruption to production, which in turn leads to an increase in production costs and reduction in production efficiency. Therefore, it is very necessary to carry out predictive maintenance for CNC machine tools and intelligent robots and very urgent to deploy the predictive maintenance platform to improve the cost-effectiveness and reliability of intelligent equipment and improve operational stability at the production plant.

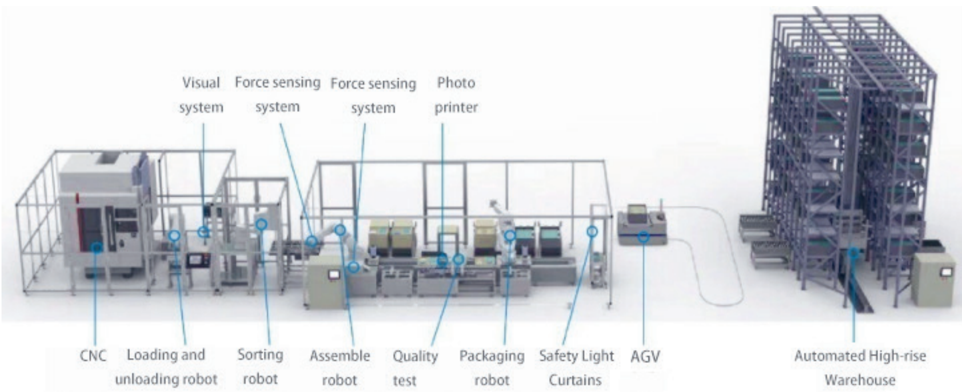


Figure 3-3-1 – Customised factory *Copyright: ITEI*

ITEI and Mitsubishi developed a predictive maintenance platform for the customised factory, implementing predictive maintenance of CNC machine tools and intelligent robots, which is the key equipment in the customised factory. The position of the predictive maintenance platform at system level is shown below, covering Level 0, Level 1, Level 2, and Level 3.

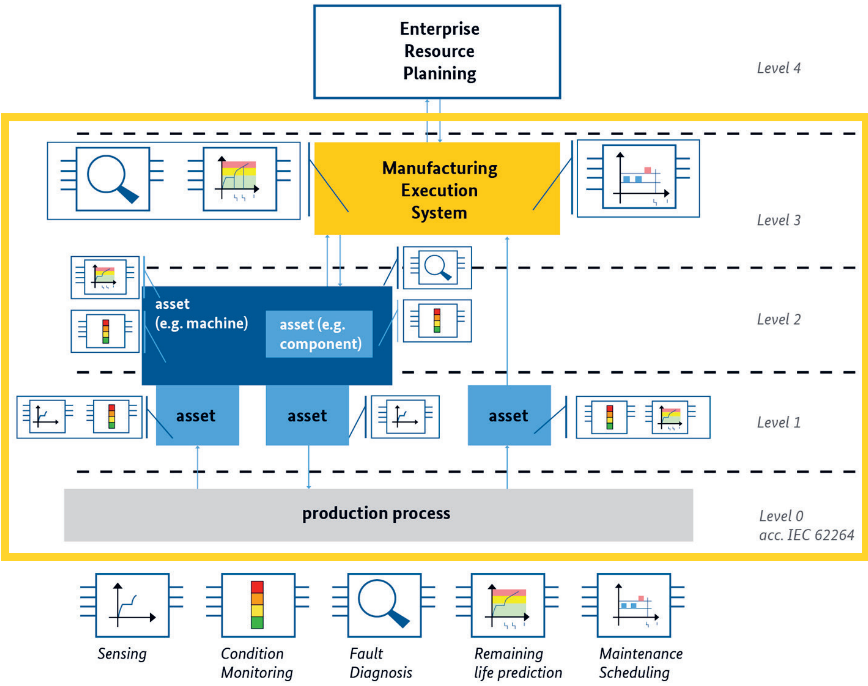


Figure 3-3-2 – System level diagram

The predictive maintenance platform of the customised factory can perform sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management and other functions of CNC machine tools and intelligent robots, as shown in the figure below.

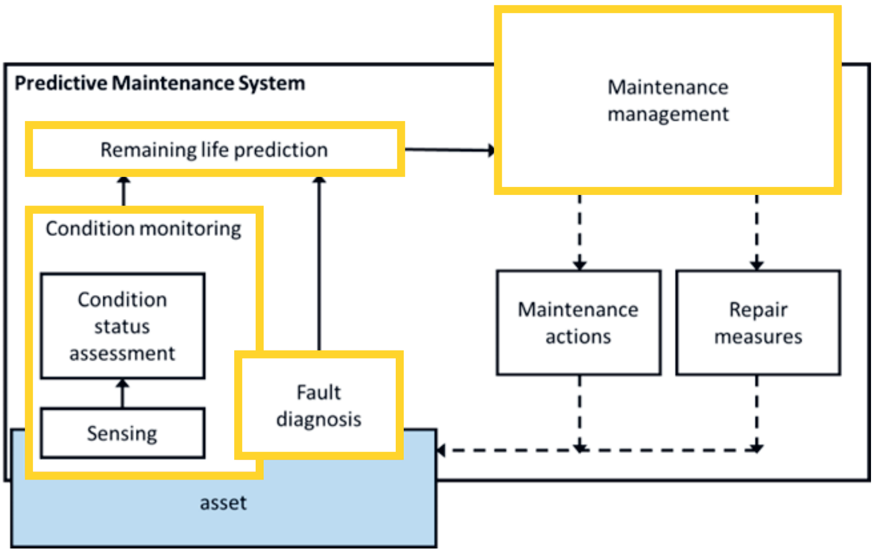


Figure 3-3-3 – System function diagram

Roles

The implementation model of this case is the co-operation between service provider and system integration engineer to develop the predictive maintenance platform. During construction of the predictive maintenance platform, the role of ITEI is service provider, mainly providing predictive maintenance technology, platform construction solutions and data/model support; Mitsubishi's role is as system integration engineer, mainly responsible for connecting predictive maintenance functions with the manufacturer's hardware and software for system integration.

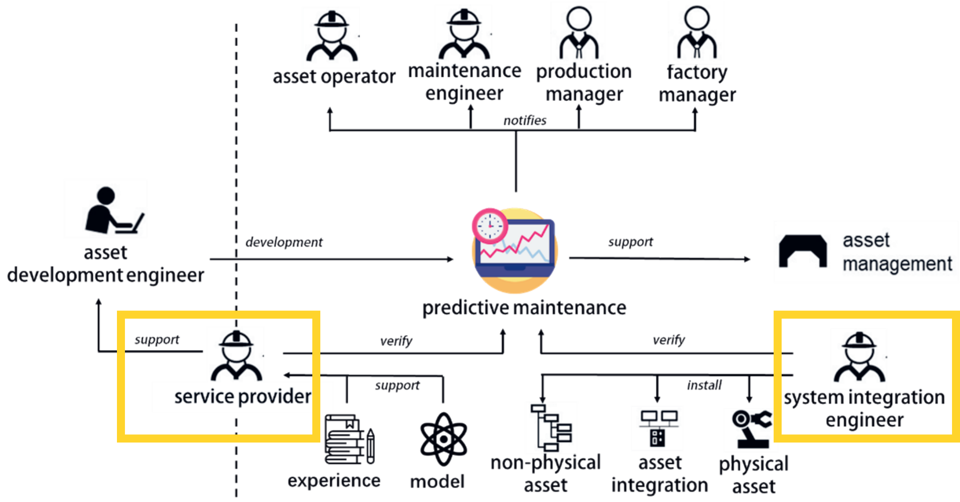


Figure 3-3-4 – Implementation role diagram

System architecture

The architecture of the predictive maintenance platform for the customised factory is shown in the figure below. The hardware mainly includes CNC machine tools, intelligent robots, and data acquisition devices. The software mainly includes the edge computing management system, condition status assessment and health management system, intelligent modelling and model verification system.

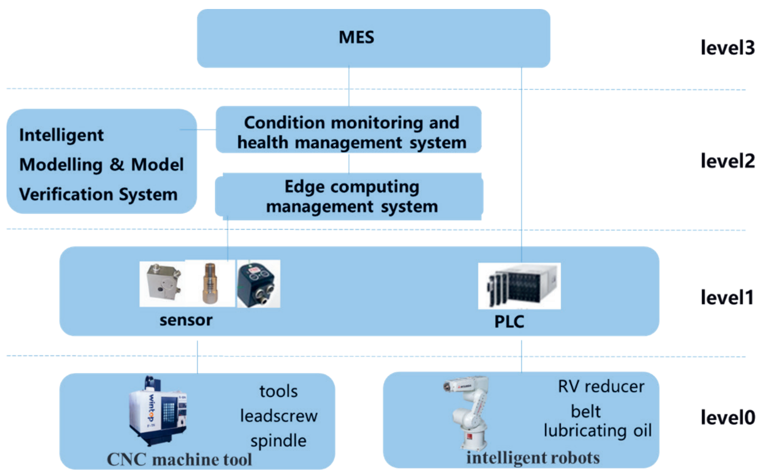


Figure 3-3-5 – System architecture diagram

Functions and methods

The predictive maintenance platform of the customised factory can perform the condition status assessment, fault diagnosis of the CNC machine tool spindle, prediction of remaining tool life (a tool change request is made one day in advance), life prediction of the ball screw, remaining life prediction of the intelligent robot, load management and position accuracy analysis, etc. The main functions are:

- edge computing management: this performs edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management and other modules;
- predictive maintenance cloud platform: this mainly realises construction of the predictive maintenance algorithm model operating environment, data analysis and processing, including process management, model management, equipment management, access services, data services, system management and other modules;
- intelligent modelling and model verification: this performs offline training and validity verification of models, including modules such as modelling, training, optimisation and data source management;
- condition status assessment and health assessment: this carries out visual analysis of equipment status and prediction results, including temperature trend analysis, current trend analysis, vibration RMS value trend analysis, vibration spectrum analysis, RUL value display and other modules.

Feature highlights

Feature highlights of the predictive maintenance platform for the customised factory are as follows:

- Edge-end intelligent Industrial Personal Computer (IPC): the edge-end intelligent IPC integrates PLC controllers, gateways, motion control, I/O data collection, field bus protocols, equipment networking and other functions together. At the same time with 'real-time control' and 'edge computing', it has high-speed, large-capacity data transmission and processing capabilities, high-precision, low-latency control performance, space-saving, expandable and easy-to-maintain use characteristics.
- PLC and sensor fusion collection: the intelligent collection terminal deployed in the customised factory has six measurement channels, which integrate sensor data collection such as vibration, temperature and PLC data collection, ensuring the quality and unity of data.
- Intelligent robots with predictive maintenance: intelligent robots in the customised factory are equipped with condition status assessment and life prediction of RV reducers, belts and lubricants. The built-in predictive maintenance function modules provide a guarantee for the stable operation of intelligent robots.

Visualisation

The predictive maintenance platform can create a visual display of the temperature, battery, current, speed and other parameters of the CNC machine tool spindle, Y-axis, and Z-axis, as well as the state parameters, such as vibration acceleration and RMS value. Blue, yellow and red indicate the three states of equipment normal, equipment abnormal and equipment failure respectively, which provide both visual display and early warning. The interface is shown in the figure below.

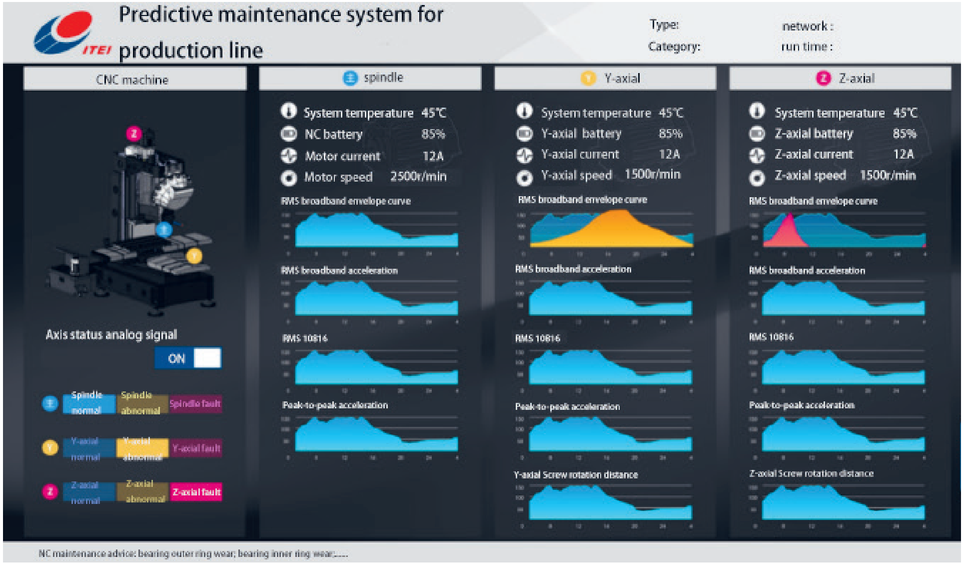


Figure 3-3-6 – CNC machine tools predictive maintenance interface *Copyright: ITEI*

The predictive maintenance platform of the customised factory can generate a visual display of the current of the J1-J6 axis of the intelligent robot, the temperature of the encoder, the motor speed, consumption of the RV, consumption of lubricating oil and other parameters. Blue, yellow, and red indicate the three states of equipment normal, equipment abnormal, and equipment failure respectively, which provide both a visual display and early warning. The interface is shown in the figure below.

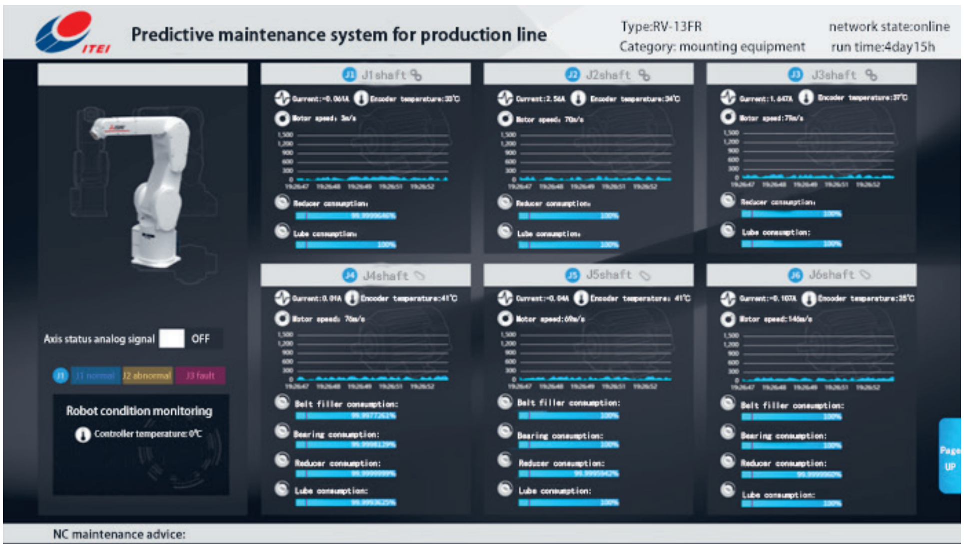


Figure 3-3-7 – Intelligent robot predictive maintenance interface *Copyright: ITEI*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
CNC machine tools	bearing	bearing fault	vibration, temperature	sensor
			speed load	PLC
		rotor eccentricity	speed, current, voltage	PLC
		stator winding insulation degradation	speed, current, voltage	PLC
		rotor demagnetisation / winding fault	speed, current, voltage	PLC
		rotor bar broken	vibration	sensor
			speed, current	PLC
	cutting tools	tool wear	vibration	sensor
			using times	counter
	spindle	spindle bending	vibration	sensor
		spindle erosion	vibration	sensor
	battery	battery life	current, voltage	PLC
	leadscrews	screw rotation distance	running distance	counter
intelligent robot	RV reducer	position error	encoder, vibration	sensor (internal)
	driving motor	bearing fault	vibration	sensor (internal)
			speed, current, voltage	PLC
		overload	current, voltage	PLC
	lubricating oil	excessive consumption of lubricating oil	lubricating oil consumption	counter (internal)
	belt	belt erosion	belt consumption	counter (internal)

Table 3-3-1 – Data requirements for scenarios

Scenario 4: Application of predictive maintenance system for a punch line

Overview

Stamping is the first step of the four major processes of automobile manufacturing, which involves the manufacture of 60% to 70% of the metal parts in automobile production. If a sudden shutdown occurs due to equipment failure, it will directly affect normal operation of subsequent processes, especially when the safety inventory cannot meet the demand of high intensity production. This case provides an online predictive maintenance system based on artificial intelligence and big data analytics, combining vibration analysis, machine learning and expert experience to train monitoring models using historical data collected from the target equipment and perform status analysis on real-time data. When equipment operates abnormally, alarms are triggered promptly, notifying the maintenance team and scheduling maintenance to avoid unplanned downtime.

The press line consists of six main motors and other auxiliary equipment. The workpiece enters from the left, is formed after six stampings, and exits on the right, as shown in the figure below.

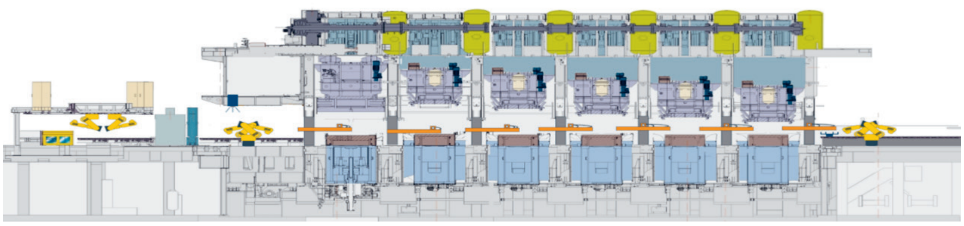


Figure 3-4-1 – Press line sketch *Copyright: Siemens*

A predictive maintenance system based on vibration analysis is provided for the main motor and gearbox of the key equipment of the press line, as well as for the motor of auxiliary facilities, which can give a warning before equipment failure and show the deterioration trend of equipment. As shown in the figure below, vibration, temperature and other data during operation of the target device are collected using appropriate data acquisition hardware, sensors, etc., and stored on the private cloud for use by users, domain experts and predictive maintenance systems.

The predictive maintenance platform covers Level 0, Level 1, Level 2, and Level 3 in the production system architecture, as shown in the figure below.

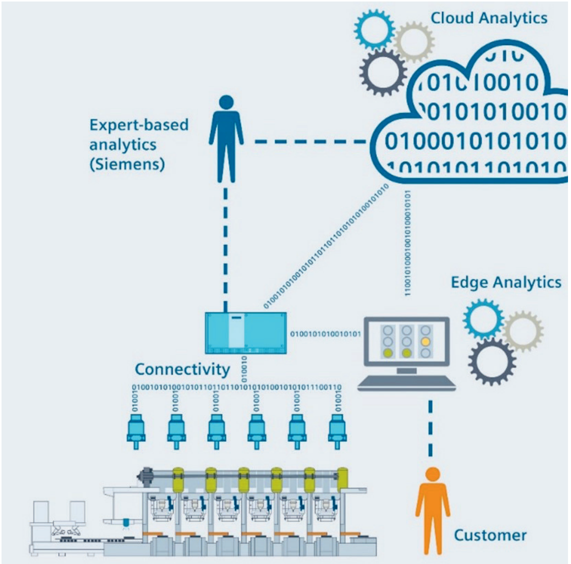


Figure 3-4-2 – Data diagram

The predictive maintenance system for the press line, based on artificial intelligence, can perform the functions of press sensing, condition assessment, fault diagnosis, operation trend prediction, asset management and so on, as shown in the figure below.

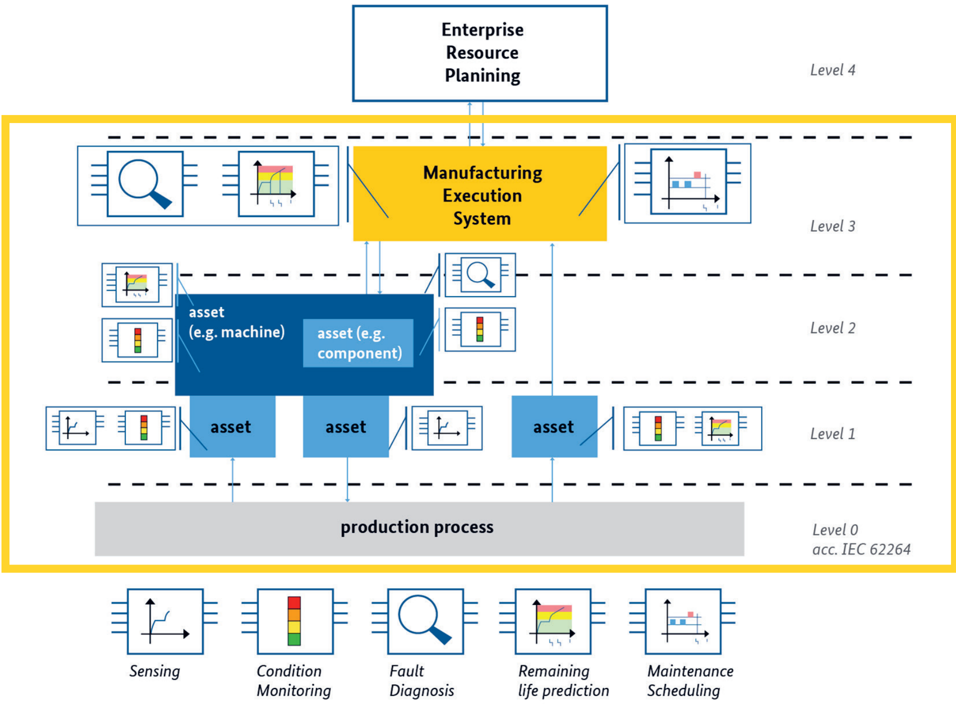


Figure 3-4-3 – System level diagram

The predictive maintenance system for the press line, based on artificial intelligence, can perform the functions of press sensing, condition assessment, fault diagnosis, operation trend prediction, asset management and so on, as shown in the figure below.

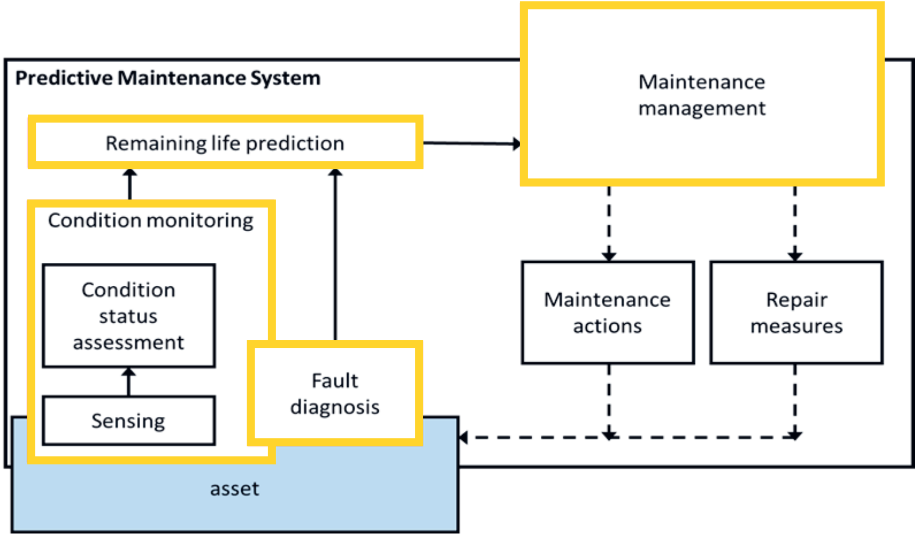


Figure 3-4-4 – System function diagram

Roles

The implementation model in this case is a collaboration between the customer, the system integrator and the service provider to develop a predictive maintenance platform; where the customer is a leading automotive manufacturer, the system integrator is Siemens Factory Automation Engineering Co., Ltd. (Siemens), and the service provider is Siemens Research Institute China. Siemens Factory Automation Engineering Co., Ltd., worked with the customer to build a data collection and analysis platform based on the existing production network of the corresponding equipment in the press line, while Siemens Research Institute China provided data analysis services and predictive maintenance technology.

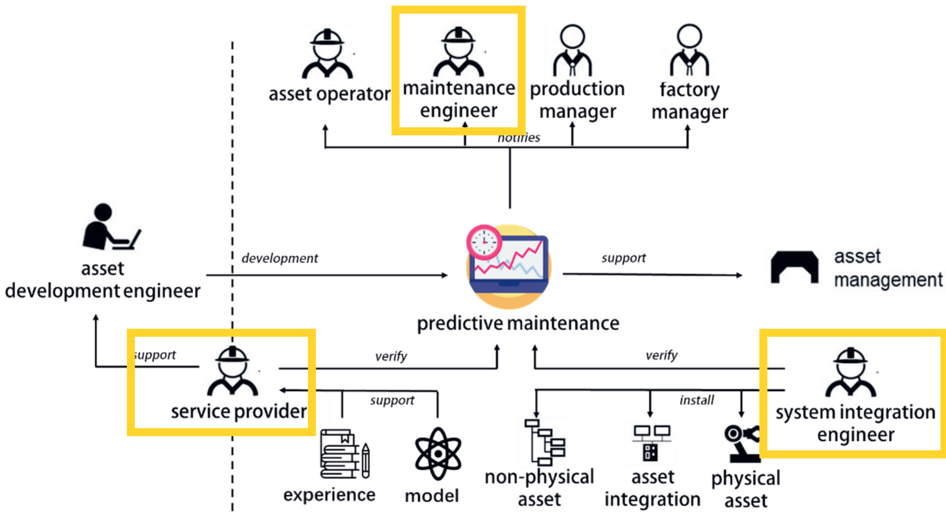


Figure 3-4-5 – Implementation role diagram

System Architecture

The hardware design of the system includes data acquisition scheme design and data analysis hardware architecture design, which can be divided into sensor selection, sensor installation scheme, data transmission scheme, data storage scheme, data analysis framework etc.

The sensor, especially the vibration sensor, is selected according to the operating condition of the equipment and sensor parameters as mentioned above. The cable outlet position of the sensor installed inside the device selects a proper outlet mode based on site cabling, fixing, cable direction and operating space. The installation and wiring diagram of the sensor is shown in the figure below. The sensor is connected to the programmable logic controller (PLC) via a special cable. The data is collected by the data acquisition box and transferred to the industrial computer equipped with the data analysis and acquisition management software Xtools, the database server and application server, and then used by users in the form of web service.

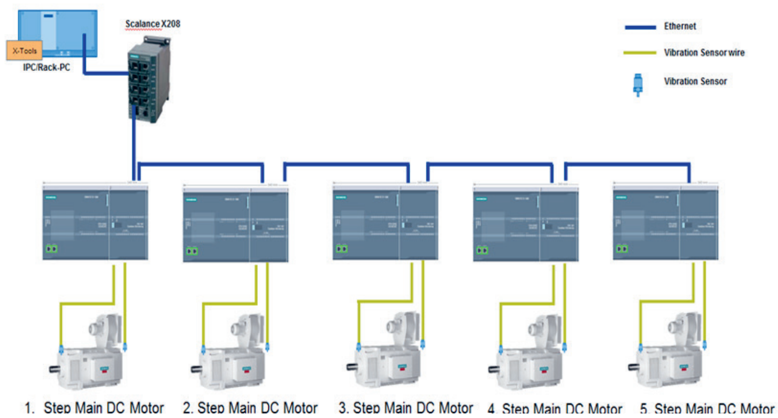


Figure 3-4-6 – Data transmission diagram

The hardware architecture of the system is shown in the figure below. The Siemens Condition Monitoring System (CMS) is used for data collection, which consists of SM1281 and PLC1200. The corresponding Xtools software located in the server parses the collected data. In addition, temperature and motor control signals such as current, torque and speed are collected through another PLC. The collected data is saved on the server to a database for use by the Data Analysis Module (ADA). Users can access analysis results and data visualisation via a browser, etc.

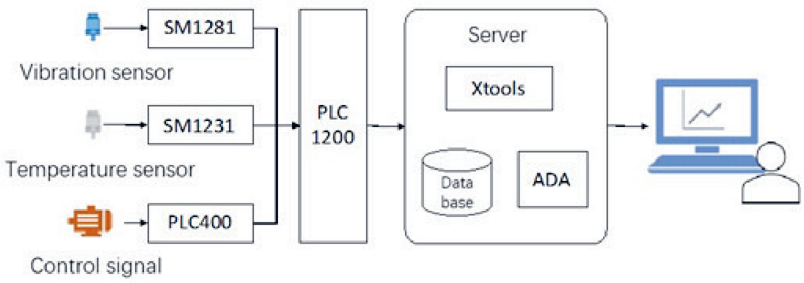


Figure 3-4-7 – Hardware architecture of the system

Functions and methods

The press line predictive maintenance system integrates monitoring data of the equipment system and sensors to carry out online monitoring of the equipment health status, the prediction of equipment working trend and the early warning of faults, and provides decision support for production operation and maintenance, as shown in the figure below.

- The system acquires information such as vibration and temperature from sensors on equipment such as motors, bearings and gearboxes, uses different industrial data transmission protocols, parses the raw data and stores it in a database and provides the required interfaces for upper-level services and applications.
- Data management also integrates raw data pre-processing and feature engineering services to complete data cleaning and feature extraction based on domain knowledge and driven by data.
- The model layer trains the monitoring model based on feature data, evaluates the status of real-time data after deployment and triggers different levels of alarm in line with the alarm mechanism when anomalies are detected.
- The user interface provides basic operations such as overview, alarm management, asset management, user management, model management, etc.

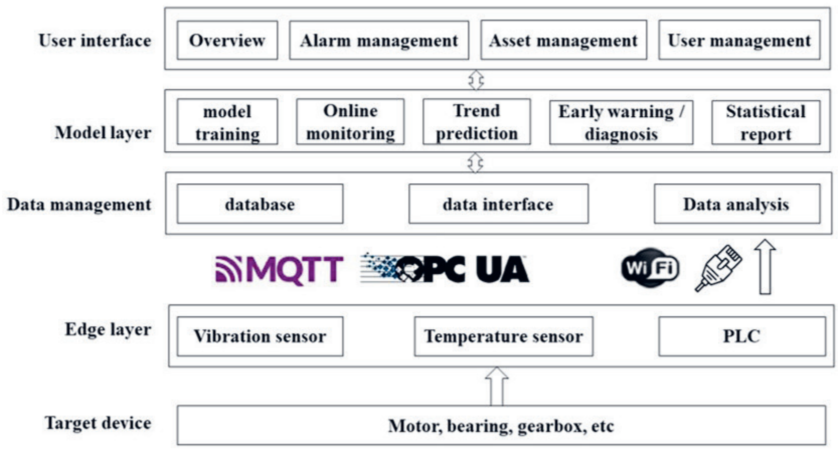


Figure 3-4-8 – System diagram

Feature highlights

The outstanding features of the system are as follows:

- private cloud deployment;
- fusion analysis of multiple monitoring methods: a fusion analysis is performed on the vibration sensor, temperature sensor and control signal of the press to predict the working trend of the equipment and to provide fault warning;
- AI-based model training and deployment enables online monitoring and trend prediction, providing early warning when anomalies are detected;
- device operation risk analysis – enables device operation information to be obtained anytime and anywhere via PC, mobile tablet, mobile phone and other terminals.

Visualisation

In the predictive system, the information overview page under the homepage summarises and displays monitoring, alarm and statistical information of a higher level, which is the most efficient way to master the factory's production and equipment situation initially. There are hyperlinks in the information card of each partition. When browsing, you can click the information card directly and the system will automatically jump to the corresponding page, which is convenient for dealing with problems at an early stage.

As shown in the picture below, the homepage of the system panel provides data on the daily factory/production line overview, alarm information and equipment with operation risks, etc.

Figure 3-4-9 – Predictive maintenance interface *Copyright: Siemens*

The following figure shows the mobile terminal interface, which can be used for mobile tablets and mobile phones.

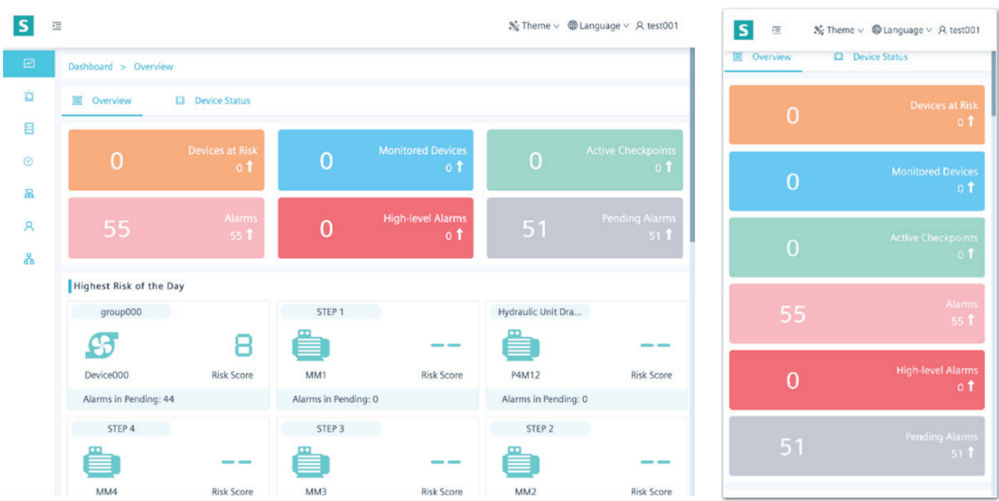


Figure 3-4-10 – Predictive maintenance interface *Copyright: Siemens*

Data requirements

Equipment	Part	Failure Mode	Data requirements	Monitoring measures
Stamping machine	Bearing fault		vibration, temperature	Sensor
			speed, load	PLC
	Rotor fault		vibration, speed, current, voltage	Sensor PLC

Table 3-4-1 – Data requirements for scenarios

Scenario 5: Predictive maintenance of automobile stamping factory

Overview

The automobile stamping factory of Beijing Benz Automotive Co., Ltd. (BBAC) has been in operation for 15 years. Damage to the main motor and the motor of the hydraulic station will cause a major shutdown of at least 3 hours, resulting in a shutdown of production. Therefore, for a series of important equipment at the automobile stamping factory, a complete set of equipment status monitoring and fault prediction systems are established, so as to detect and intervene at the earliest possible stage of the fault and reduce the negative impact on production as far as possible. The automobile stamping factory is shown in the figure below.

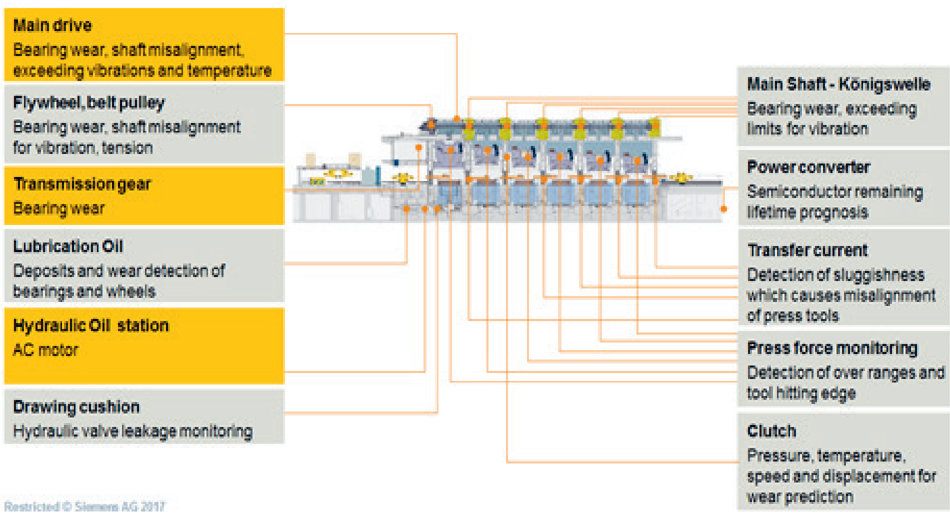


Figure 3-5-1 – Automobile stamping factory of car

More than 70 sensors are installed in the predictive maintenance system of the automobile stamping factory. The PLC1200 system is added to collect high-frequency signals and PLC signals of the entire factory. It uses vibration data pre-processing, feature extraction, expert analysis based on big data, and in-depth analysis. The learning neural network algorithm and other algorithm fusion methods can monitor and analyse the real-time status of the equipment. It can monitor the historical status and real-time status of the equipment at any time. At the same time, it provides an assessment of the health status of the equipment and can enter the corresponding equipment. An early warning is given in the case of an abnormal early state. The hardware architecture is shown in the figure below.

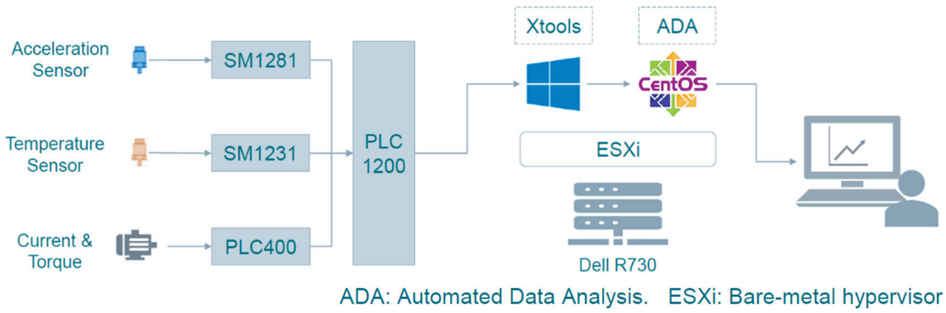


Figure 3-5-2 – Hardware architecture

The position of the predictive maintenance system in the system level is shown in the figure below, covering Level 0, Level 1, Level 2, and Level 3.

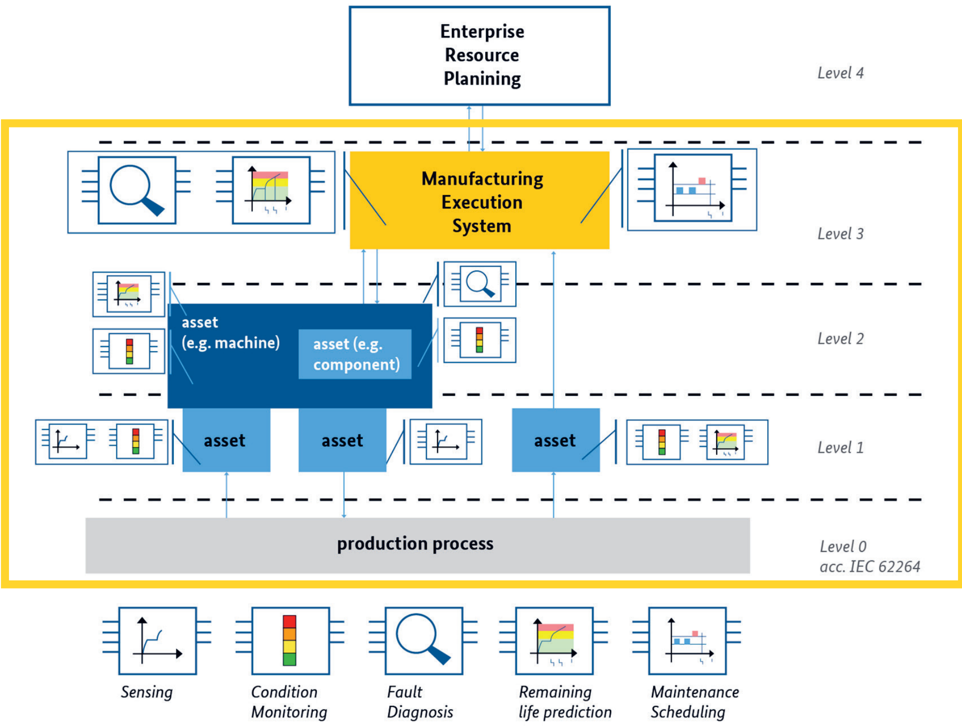


Figure 3-5-3 – System level diagram

The system can perform the functions of sensing, condition assessment, data management, equipment condition assessment, early warning and maintenance management of important equipment, as shown below:

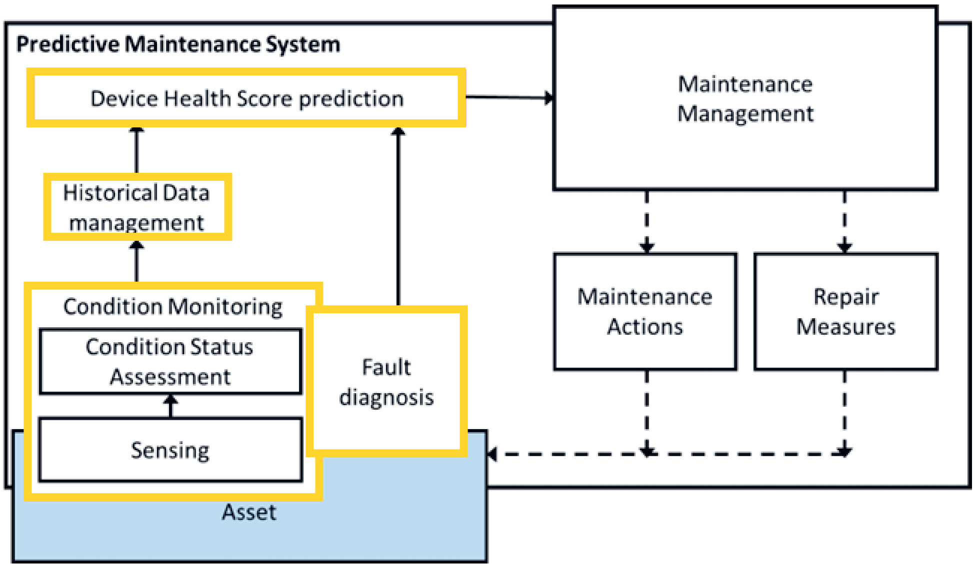


Figure 3-5-4 – System function diagram

Roles

The system is jointly formulated, developed and implemented by the BBAC and Siemens component teams. The division of roles is shown in the figure below. As a service provider and integrator, Siemens provided project experience, hardware installation, commissioning, predictive maintenance technical theoretical support, vibration analysis modelling support, etc. The BBAC team participated in the whole process of the project.

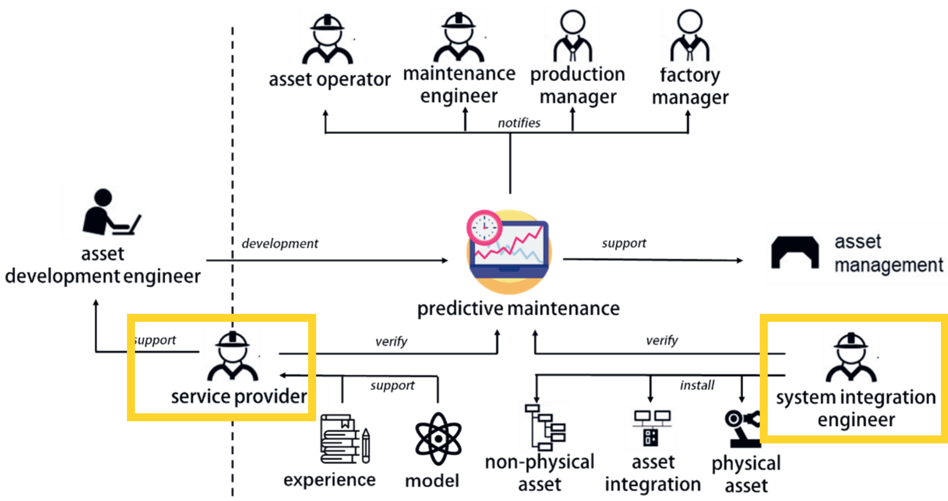


Figure 3-5-5 – Implementation role diagram

System architecture

The figure shows the system architecture of the predictive maintenance system for the automotive stamping factory. Vibration and temperature sensors are deployed for three types of important equipment: main motor, hydraulic station motor and main transmission system of the automobile stamping factory. PLC signals are collected synchronously, which perform functions such as condition status assessment and fault prediction. At the same time, due to the huge amount of equipment data collected in this project, the CASSANDRA database was deployed in order to improve system performance. The system architecture diagram is shown below.

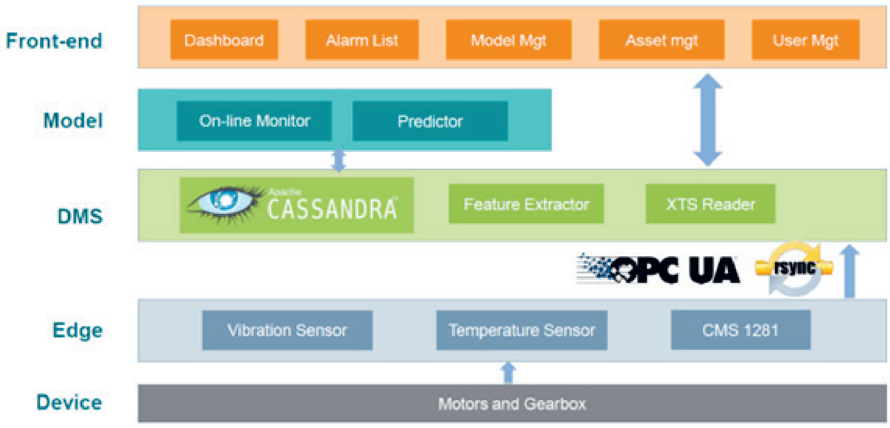


Figure 3-5-6 – System architecture diagram

Functions and methods

The predictive maintenance system for automotive stamping lines performs online data collection, real-time condition monitoring, fault diagnosis and equipment condition prediction functions for a total of three types of key equipment on automotive stamping lines: main motors, hydraulic station motors and main drive systems.

- IOT and data pre-processing: carry out data collection and pre-processing functions through sensors, PLC1200, XTools;
- data management: through deployment of the CASSANDRA database, to meet high-performance data input and output and historical data management;
- intelligent modelling and model management: the establishment, optimisation and management of predictive models can be achieved by using algorithms such as Regression, NN, and the Gaussian Process; the accuracy of the model can be gradually optimised by adjusting the training set of the model;
- Condition monitoring and health assessment: the condition monitoring of equipment is carried out by processing and visualizing real-time data; real-time health assessment and fault warning of equipment is performed using intelligent models, combined with the use of algorithms such as Regression, NN and ARIMA to achieve health prediction of key equipment.

Feature highlights

The outstanding features of the predictive maintenance system for the automotive stamping factory are as follows:

- multi-type signal analysis: by adding vibration and temperature sensors, combined with PLC to collect signals such as torque, speed, current, etc., real-time monitoring of equipment status, fault warning and health prediction functions are performed;
- multi-algorithm fusion based on big data: deploy CASSANDRA database to store

massive equipment data, and use neural network deep learning, Regression, Gaussian Process, ARIMA and other algorithms to implement model construction, improve model prediction accuracy and adjust training data for gradual optimisation model accuracy;

- Health prediction: based on algorithms and models such as Regression, NN, ARIMA, etc., the equipment health prediction function is carried out.

Visualisation

The predictive maintenance system of the automobile stamping factory can generate a real-time visual display of the current state of equipment operation, historical conditions, vibration data analysis, health trends, and display of fault information. As shown in the figure below, green, yellow, and red respectively indicate three states: good equipment, medium equipment and poor equipment; grey means no data available.

Figure 3-5-7 – Equipment status interface *Copyright: BBAC*

The data visualisation interface of each device can display the original vibration data, data characteristic values (DKW, RMS), FFT spectrum analysis and state distribution visualisation of the predictive analysis model.

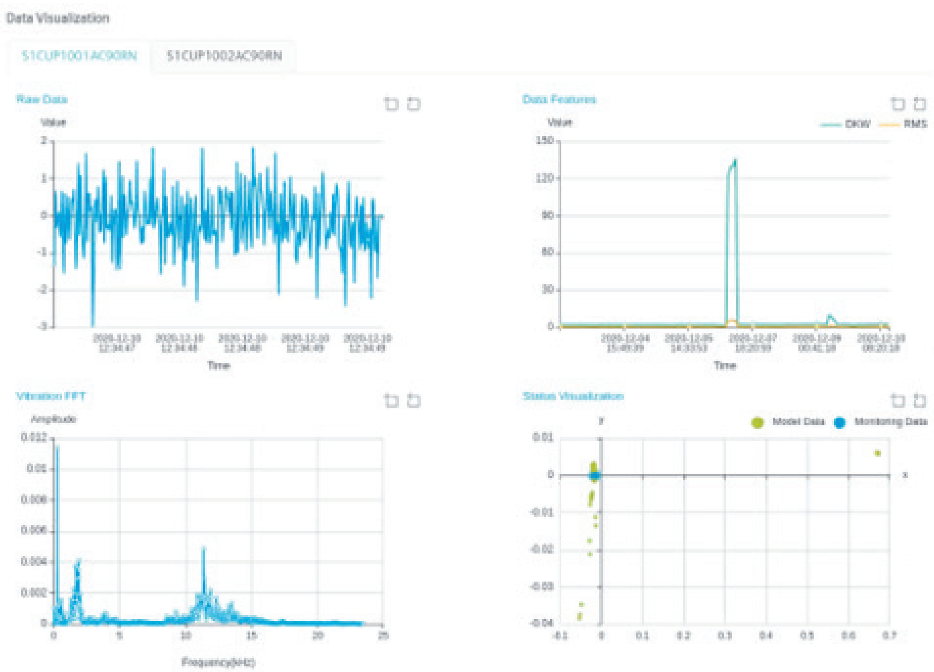


Figure 3-5-8 – Equipment data visualisation interface *Copyright: BBAC*

The predictive model can score the health of each device, draw a curve and predict the subsequent health of the device through the predictive analysis model.

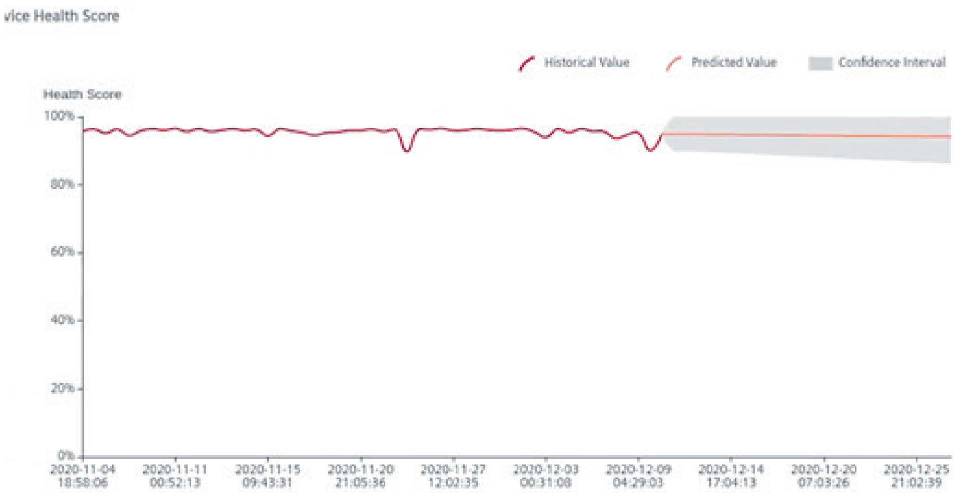


Figure 3-5-9 – Equipment health interface

Copyright: BBAC

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
stamping machine	motor	abnormal vibration	vibration, temperature	sensor
			start signal, speed, current, torque	PLC
		dynamic equilibrium failure	vibration	sensor
			Start signal, speed, current, torque	PLC
	flywheel bearing box	abnormal vibration	vibration	sensor
		abnormal heating	temperature	sensor
	main gearbox	bearing fault	vibration, temperature	sensor
			start signal	PLC
		gear fault	vibration	sensor
			start signal	PLC
hydraulic station	motor	abnormal vibration	vibration	sensor
			start signal	PLC
		dynamic equilibrium failure	vibration	sensor
			start signal	PLC
	pump	pump wear	vibration	sensor
	coupling	coupling wear	vibration	sensor

Table 3-5-1 – Data requirements for scenarios

Scenario 6: Predictive maintenance for a digital machining plant

Overview

As the core of the digital machining plant, the stability of automation and intelligent equipment has a direct impact on production. Sudden failure of the equipment will cause production interruption; it will also lead to a long maintenance failure processing cycle, which consumes a lot of time and cost. Therefore, it is necessary to carry out predictive maintenance on all types of equipment in the machining digital factory, to transform post-processing into pre-prediction and improve equipment operating efficiency.

Delta Electronics (Beijing) Co., Ltd (Delta) is responsible for constructing a predictive maintenance system for CNC machine tools, robots and sub-board machines. The system integrates equipment information and real-time sensor monitoring data from the perspective of cloud-side-end integrated collaboration by connecting to equipment layers, adding sensors, etc., achieving equipment status assessment, abnormal monitoring, remaining life prediction and maintenance strategies.

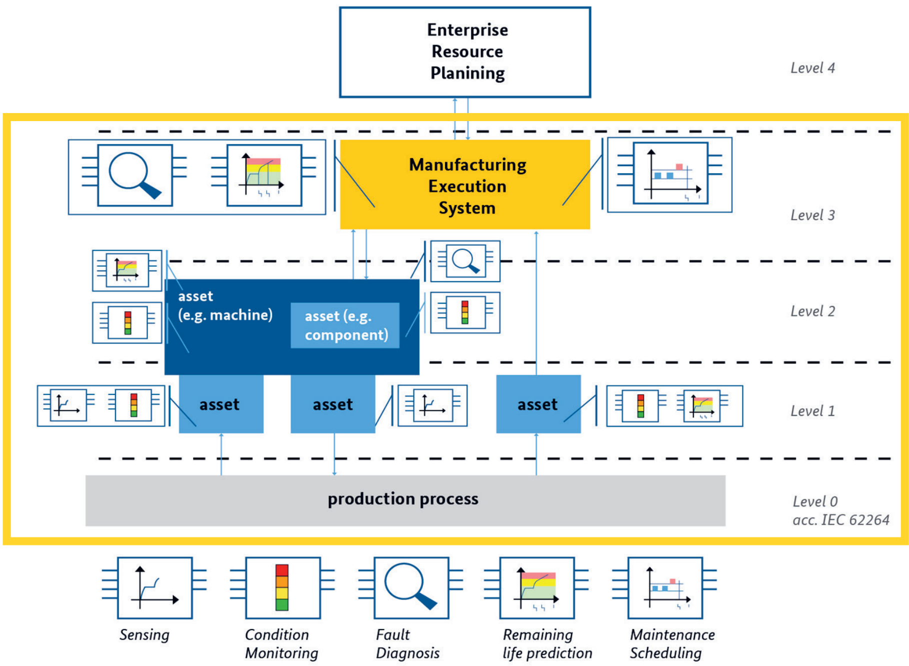


Figure 3-6-1 – System level diagram

The predictive maintenance system of the digital machining factory records data generated during the life cycle of the equipment, performs data storage, calculation and analysis at the edge, and performs data processing in the cloud through state perception, real-time analysis, and intelligent decision-making. This establishes a state prediction method from a field-driven and data-driven perspective to perform condition status evaluation, fault diagnosis, and remaining life prediction, and provide maintenance strategies. In line with the predicted results, different response mechanisms are activated to avoid downtime losses and save costs.

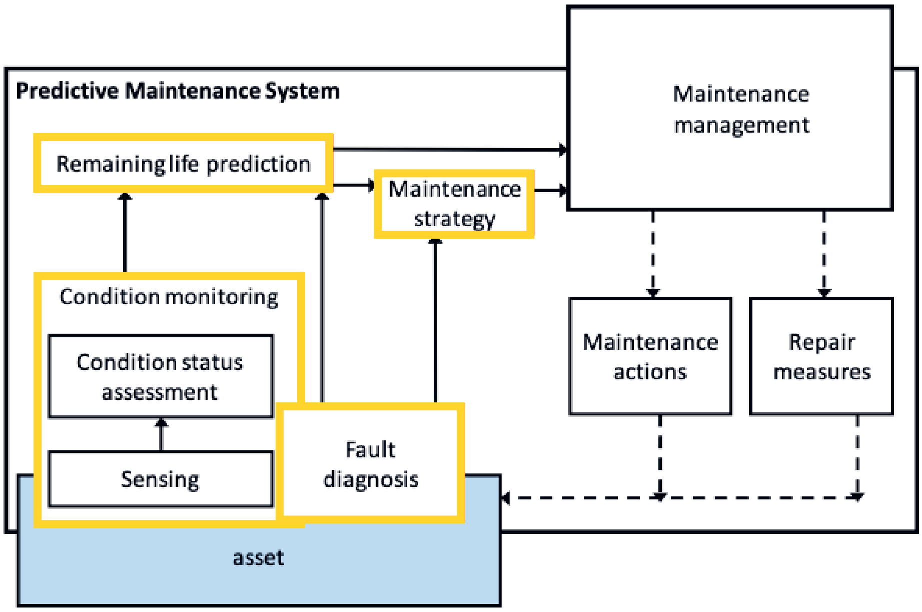


Figure 3-6-2 – System function diagram

Roles

In the construction of this predictive maintenance system, Delta plays the role of service provider and system integrator, mainly providing predictive maintenance technology, platform construction solutions and data/model support.

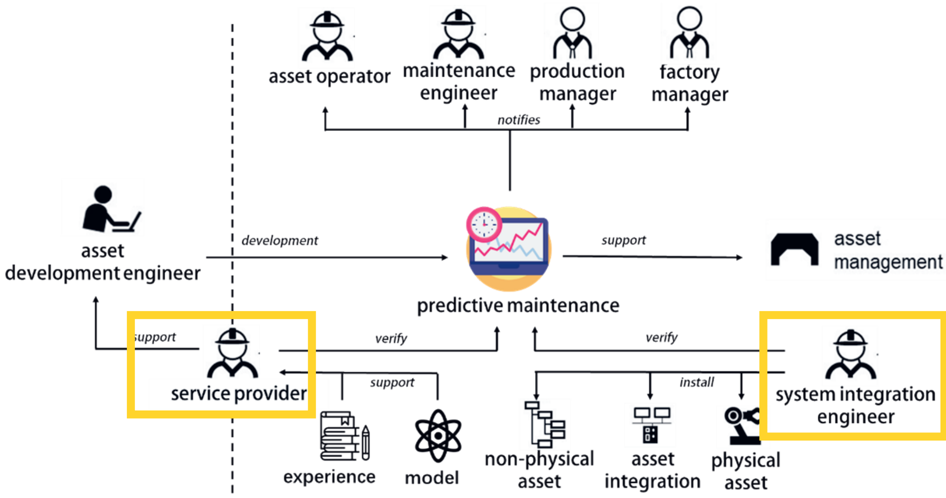


Figure 3-6-3 – Implementation role diagram

System architecture

The system is shown in the figure below. The hardware component mainly includes board splitters, CNC machine tools and horizontal robots, sensors, data acquisition devices, etc.; the software and hardware integration components are edge computing management devices; the software components mainly include predictive maintenance systems, data management platforms, data analysis platforms and central application system (such as MES, AI system, etc.). The equipment information is pre-processed through the data collection and integration system, and then transmitted to the edge computing management device for data storage and processing. The processed data is transmitted to the predictive maintenance system, and finally the diagnosis results are transmitted to the data management platform, data analysis platform and central application system, which perform equipment maintenance scheduling and manufacturing scheduling planning.

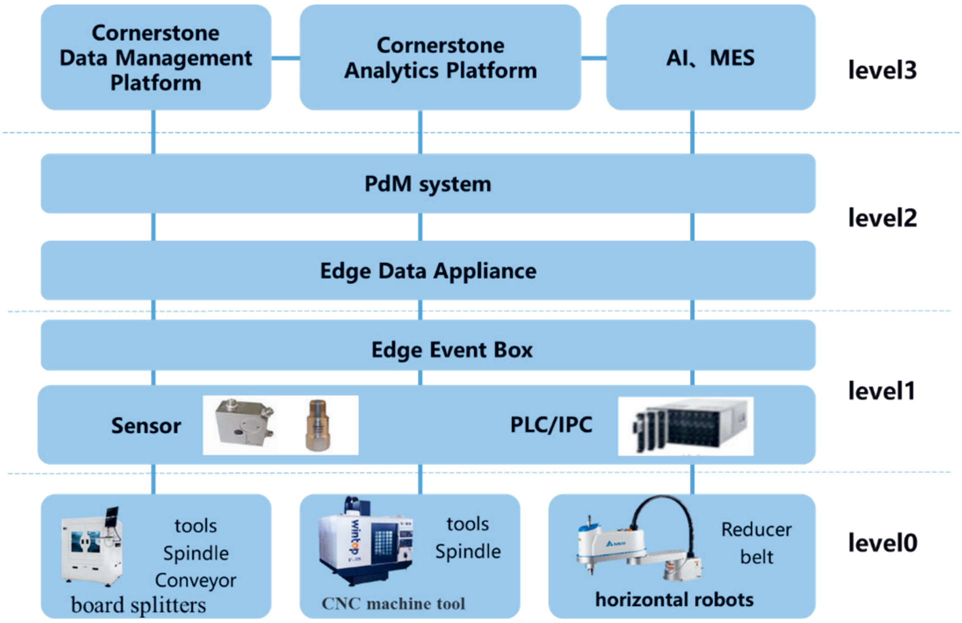


Figure 3-6-4 – System architecture diagram

Functions and methods

The predictive maintenance system in this case mainly performs the status assessment, fault diagnosis, life prediction function and maintenance strategy provision of the micro-milling cutter of the plate cutting machine, the CNC machine tool and the horizontal robot. The main functions are as follows:

- Data collection integration system: collects equipment data and pre-processes the original data; transmits valuable data to the edge computing management device for diagnosis, analysis and prediction.
- Edge computing management device: carries out edge data collection and analysis and guarantees data security. It is used for data governance and AI program deployment, quickly adapts to various application systems, simplifies the 'data to value' process. Deploys background applications on the edge, performs data processing on the edge, uploads the processed data required by the cloud/central application to the cloud, and uses a secure channel to protect data security.
- Condition status assessment and health evaluation: carries out data collection and status monitoring of CNC machine tools (tools/spindles, etc.), robots and sub-board machines, assesses the health status of equipment through training models, predicts the remaining life of the equipment and visualises it, including real-time data display, analysis characteristics, important historical information, health display, speed characteristic analysis, current trend analysis, vibration trend analysis, vibration spectrum analysis, remaining service life, etc.
- Data analysis platform: enable development,

optimisation and model validation of predictive maintenance models; establish a library of models for the full life cycle management of algorithms and improve the accuracy and generalisation of models.
- Data management platform: builds a predictive maintenance system in the cloud, including functions such as data storage, analysis management, model training iteration, entire plant equipment management, maintenance management system, etc., and centralised management in the centre.

Feature highlights

The feature highlights of the systems are as follows:

- Digital knowledge base: establishes mathematical models of equipment through the data analysis platform and iteratively optimises, manages and accumulates solutions for the same type of equipment and provides customer subscription and model update services.
- Controller and sensor fusion collection: records signals from different sources inside and outside of CNC machine tools, robots and sub-boards by collecting equipment controller signals and sensor signals. Diagnoses the health status of the equipment comprehensively.
- Multi-monitoring method fusion analysis: signal fusion and analysis of process parameters, accelerometers, microphone and controller current, speed, temperature and other data from multiple sources, real-time monitoring, fault diagnosis and life prediction functions.
- Health prediction: multi-variate and multi-rule real-time dynamic analysis based on the equipment health model and degradation model; performs the health prediction function of CNC machine tools/robots. It lays the foundation for predictive maintenance of equipment.
- Cloud-side-end collaboration data processing: based on cloud-side-end collaboration data storage, processing and analysis, data is quickly collected at the edge, data processing and analysis are performed on it, then the data is uploaded. Improves data collection and decision-making efficiency through shunting operations, ensures data security, improves process response capabilities and reduces network load.

Visualisation

The predictive maintenance system of this case can generate a visual display of the running status of CNC machine tools, splitting machine tools and horizontal robots, running history status, health trend, real-time current, speed, etc. Among these, the running status is represented by blue, green, yellow and red, which respectively represent the four states of initial, normal, early warning and fault. The interface is shown in the figure below.

Figure 3-6-5 – Predictive maintenance interface for plate cutting machine *Copyright: Delta*

Figure 3-6-6 – Predictive maintenance interface for plate cutting machine *Copyright: Delta*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
plate cutting machine / CNC machine tools	cutting tools	cutting tools wear/ break	vibration	sensor
			speed, current, voltage	PLC
			cumulative machining distance	PLC
			cumulative processing quantity	PLC
intelligent robot	RV reducer	wear	vibration	sensor
			angle, current, temperature	PLC

Table 3-6-1 – Data requirements for scenarios

Scenario 7: Maintenance services for shipping lifting and transportation

Overview

As key and widely used equipment in the shipbuilding industry, lifting and transportation equipment has a high downtime cost and huge accident losses. The equipment requires continuous support personnel and spare parts. This case focuses on lifting and transportation equipment in the shipping industry to systematically improve the efficiency, safety and maintenance capabilities of the equipment, build an industry-level digital operation and maintenance service platform, explore new models of intelligent services and promote the healthy development of the industry.

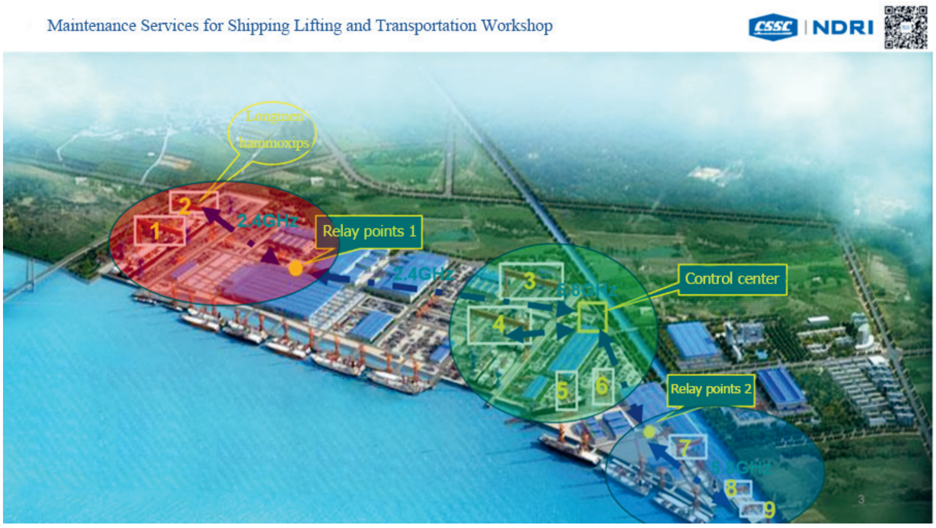


Figure 3-7-1 – Digital operation and maintenance service platform for lifting and transporting equipment in the shipbuilding industry *Copyright: CSSC*

The position of the developed predictive maintenance platform in the system level is shown in the figure below, covering Level 0, Level 1, Level 2, and Level 3.

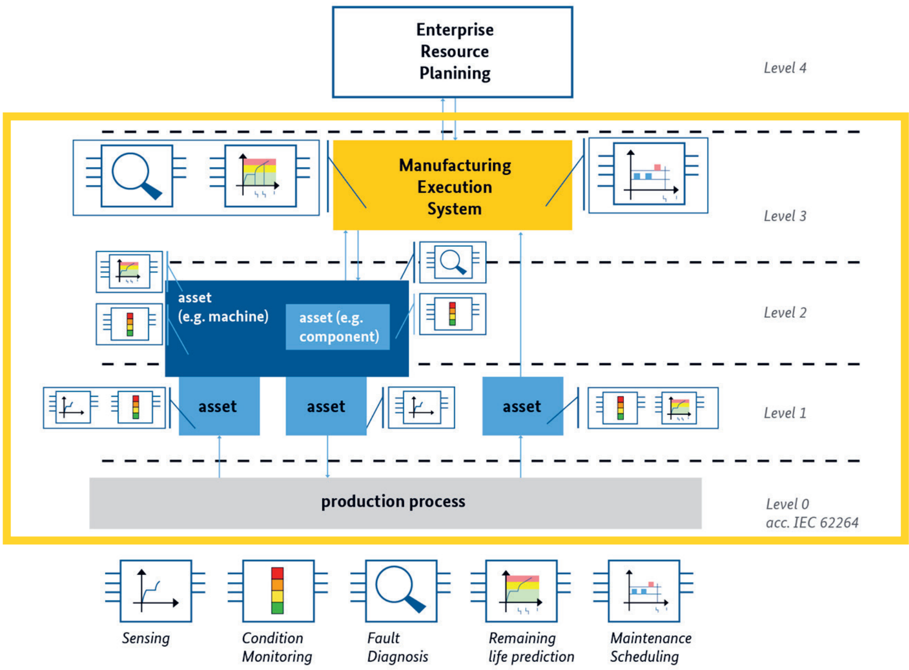


Figure 3-7-2 – System level diagram

The predictive maintenance platform for lifting and transportation equipment can perform the functions of sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management and other functions, as shown below:

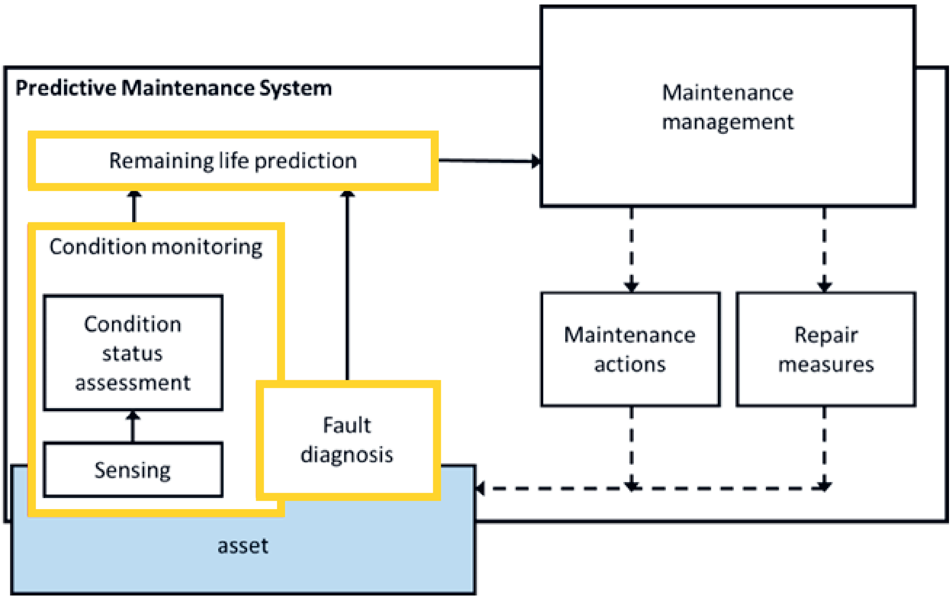


Figure 3-7-3 – System function diagram

Roles

There are various implementation modes of predictive maintenance technology. The implementation mode of this case is to develop a predictive maintenance platform for system integrators. In the construction of the predictive maintenance platform, China Shipbuilding NDRI Engineering Co., Ltd. (CSSC) plays the role of system integrator, providing mainly predictive maintenance technology, platform construction solutions, data/model support and project implementation to achieve system integration.

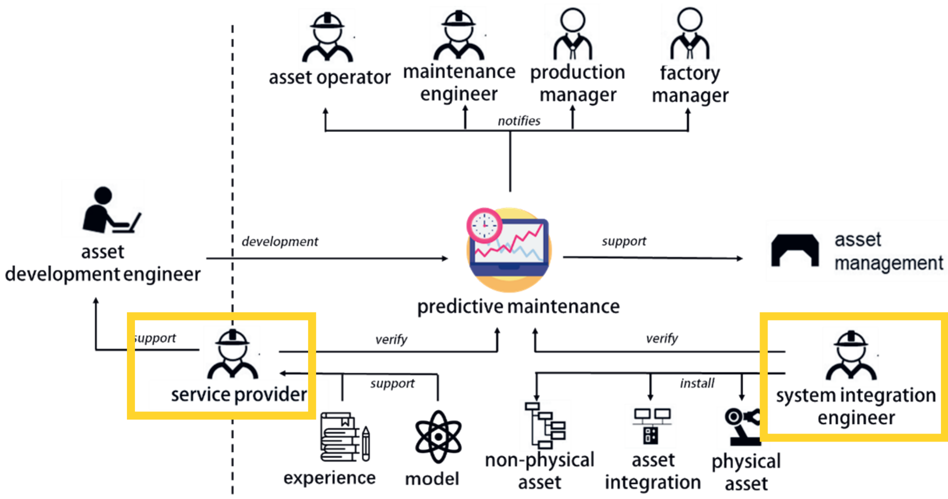


Figure 3-7-4 – Implementation role diagram

System architecture

The system architecture of the predictive maintenance platform is shown in the figure. The hardware mainly includes sensing and actuators, control and monitoring equipment, data acquisition devices, etc. The software mainly includes an edge computing management system, condition status assessment and health management system, intelligent modelling and model verification system.

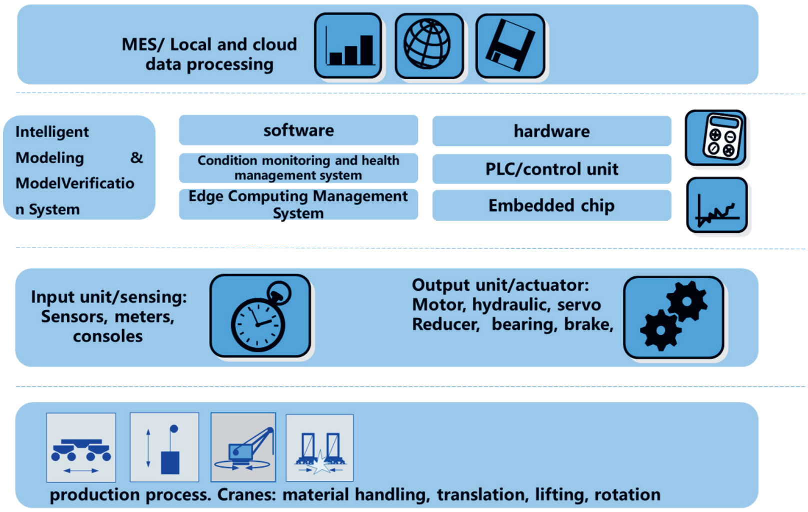


Figure 3-7-5 – System architecture diagram

Functions and methods

The predictive maintenance platform can generate a real-time perception of working conditions from the edge layer to predictive maintenance of the industrial PaaS layer to the workshop layer, including:

- crane status monitoring and fault diagnosis
- life prediction of key components
- equipment utilisation management
- product design feedback for knowledge management
- decision-making operation of spare parts management.

Feature highlights

The feature highlights of the predictive maintenance platform are as follows:

- Crane condition status monitoring and fault diagnosis: multi-source data collection (photoelectric encoder/magnetic induction/ RFID / barcode, GPS/ Beidou /indoor Wi-Fi positioning, laser/microwave/ultrasonic radar) to achieve crane component level, equipment level, enterprise level monitoring and fault diagnosis.
- Life prediction of key components: monitor the bearing vibration of the crane reducer, the state of rail gnawing, the fatigue state of the reel shaft, the wear state of the lifting brake, the force state of the power supply tank chain, etc., and life prediction through data analysis.
- Equipment utilisation management: through enterprise-level data collection, equipment production load rate, energy consumption and other massive data, through data analysis, mining technology etc. to achieve capacity monitoring.
- Product design feedback of knowledge management: based on fault diagnosis data, perform knowledge management according to the map, enter the product design database and improve design quality.
- Decision-making operation of spare parts management: supply chain management based on forecast data, auxiliary decision-making on spare parts purchase inventory.

Visualisation

The predictive maintenance platform can generate hierarchical visual displays and early warning at the crane component level, equipment level and enterprise level, as shown in the figure below:

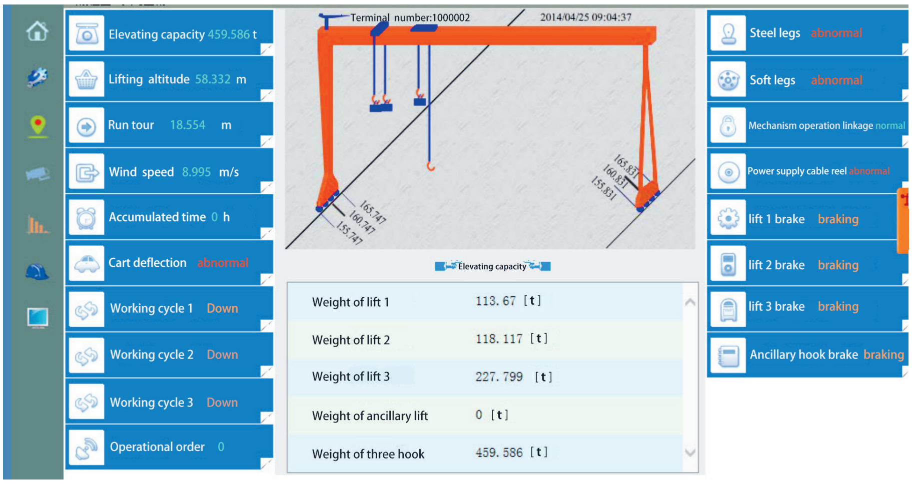


Figure 3-7-6 – Component-level monitoring interface *Copyright: CSSC*

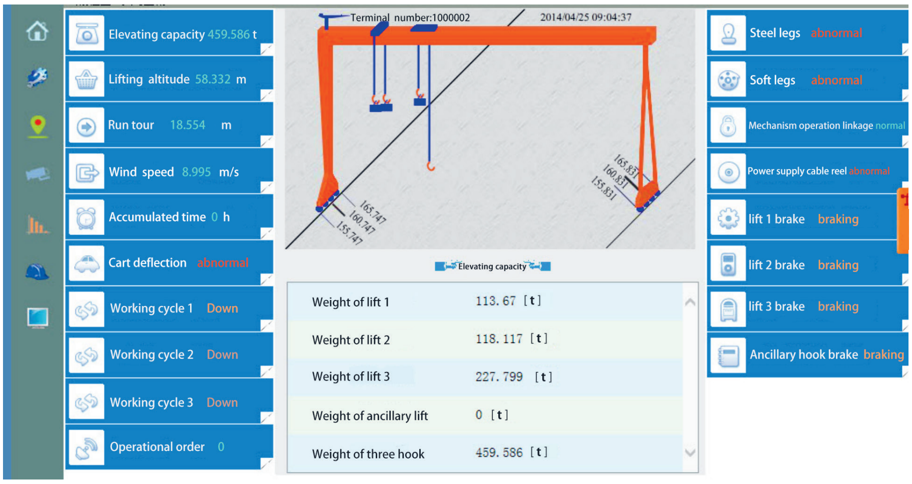


Figure 3-7-7 – Equipment-level monitoring interface *Copyright: CSSC*

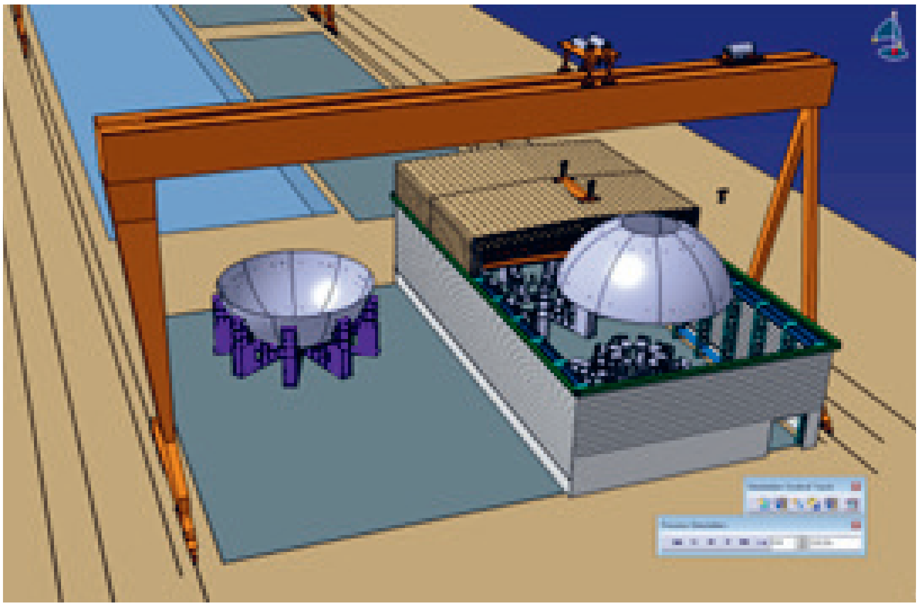


Figure 3-7-8 – Single-machine operation digital twin model interface *Copyright: CSSC*

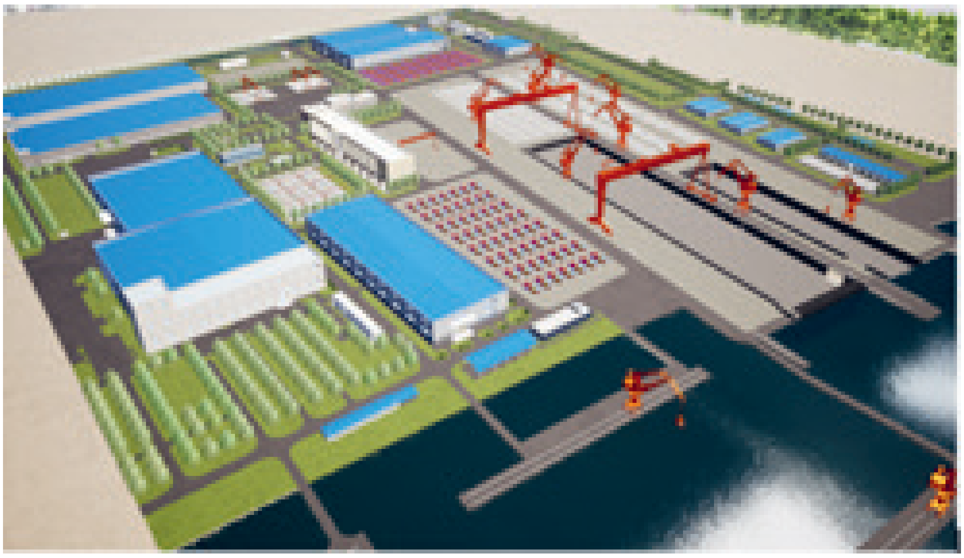


Figure 3-7-9 – Enterprise-level monitoring interface for multiple cranes in the factory area *Copyright: CSSC*

Data requirements

Equipment	mechanism	Part	Failure mode	Data requirements	Monitoring measures
Lifting and trans-portation equipment	Lifting	motor	shaft broken	vibration frequency, speed, voltage, current, temperature	multi-source sensors, control system synthesis data
			bearing wear	vibration frequency, speed, voltage, current, temperature	multi-source sensors, control system synthesis data
			coil open	speed, voltage, current, temperature	multi-source sensors, control system synthesis data
			coil insulation failure, short circuit	speed, voltage, current, temperature	multi-source sensors, control system synthesis data
		reducer	shaft broken	vibration frequency, speed, temperature	multi-source sensors, control system synthesis data
			bearing wear	vibration frequency, speed, temperature	multi-source sensors, control system synthesis data
			gear wear	vibration frequency, speed, temperature	multi-source sensors, control system synthesis data
			lubrication failure	vibration frequency, speed, temperature	multi-source sensors, control system synthesis data
		reel shaft	shaft broken	vibration frequency, speed,	multi-source sensors, control system synthesis data
			deformed	vibration frequency, speed, stress	multi-source sensors, control system synthesis data
		brake	wear	location, voltage, current, temperature	multi-source sensors, control system synthesis data
			overheating	location, voltage, current, temperature	multi-source sensors, control system synthesis data
		wire rope	wear	stress, temperature	multi-source sensors, control system synthesis data
			broken	stress, temperature	multi-source sensors, control system synthesis data

Equipment	mechanism	Part	Failure mode	Data requirements	Monitoring measures
Lifting and trans-portation equipment	walk	wheel	wear	vibration frequency, speed, stress	multi-source sensors, control system synthesis data
			vibration	vibration frequency, speed, stress	multi-source sensors, control system synthesis data
	Assist	cable reel	wear	speed, stress	multi-source sensors, control system synthesis data
		cable drag chain	failure, wear, broken	stress	multi-source sensors, control system synthesis data
		hydraulic system	failure, overheating, pressure failure	pressure, voltage, current, temperature	multi-source sensors, control system synthesis data
	electric	high-voltage switchgear	overheating, short circuit, open circuit	voltage, current, temperature	multi-source sensors, control system synthesis data
		transformer	overheating, short circuit, open circuit	voltage, current, temperature	multi-source sensors, control system synthesis data
		frequency converter	power semicon-ductor short circuit	voltage, current, temperature	multi-source sensors, control system synthesis data
			control unit failure	voltage, current, temperature	multi-source sensors, control system synthesis data
			auxiliary cooling system failure	voltage, current, temperature, speed	multi-source sensors, control system synthesis data
		control and network	electricity failure	voltage, current, temperature	multi-source sensors, control system synthesis data
			CPU failure	voltage, current, temperature	multi-source sensors, control system synthesis data
			communication network failure	voltage, current, temperature	multi-source sensors, control system synthesis data
		fan air conditioner	failure	voltage, current, temperature, speed	multi-source sensors, control system synthesis data
		illumination	failure	voltage, current, temperature, light-sensitive	multi-source sensors, control system synthesis data

Table 3-7-1 – Data requirements of scenarios

Scenario 8: Condition monitoring and remote diagnosis system for offshore oil platform

Overview

China University of Petroleum (Beijing) (CUP) cooperated with China National Offshore Oilfield Services Co., Ltd., by analysing the structural characteristics and failure modes in key equipment of deep-water semi-submersible drilling platforms, formulating platform monitoring plans, developing offshore oil platform condition status assessments and remote diagnosis systems. This system can perform online monitoring and remote diagnosis of key equipment, automatic detection of fault signs and early warnings, and provide a reference for timely equipment maintenance. It is of great significance for improving an intelligent maintenance and management level for platform equipment and ensuring the safe and long-term operation of key equipment. CUP is mainly responsible for the development of the offshore oil platform condition status assessment and remote diagnosis system, performing the predictive maintenance of key equipment, such as the top drive, main generator set and thruster of the offshore oil platform. The position of the system is shown in the figure below, covering Level 0, Level 1, Level 2, and Level 3 levels.

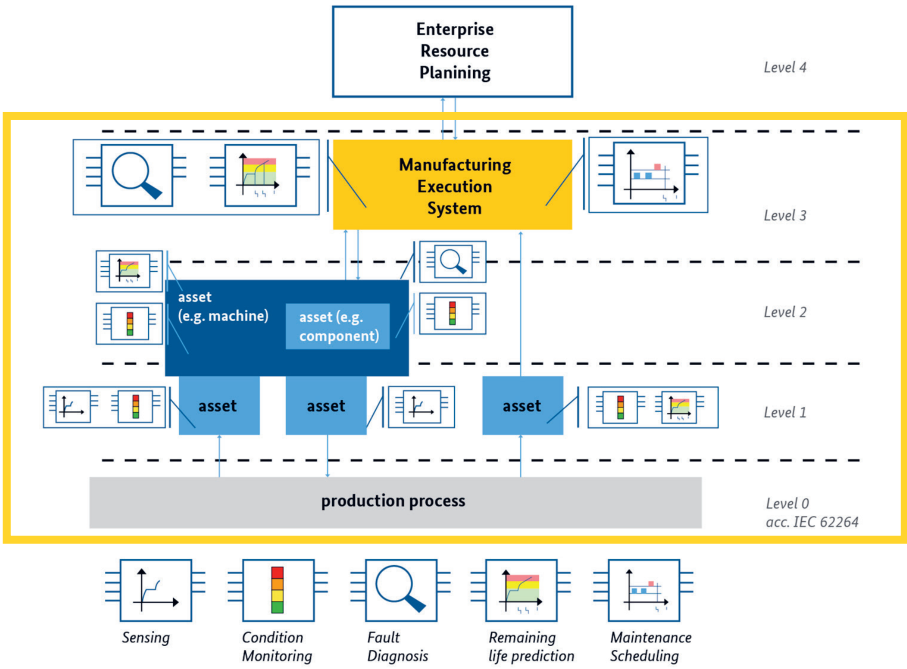


Figure 3-8-1 – System level diagram

The offshore oil platform condition status assessment and remote diagnosis system can carry out the sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management and other functions of key equipment such as the top drive, main generator set and thruster of the offshore oil platform, as shown below:

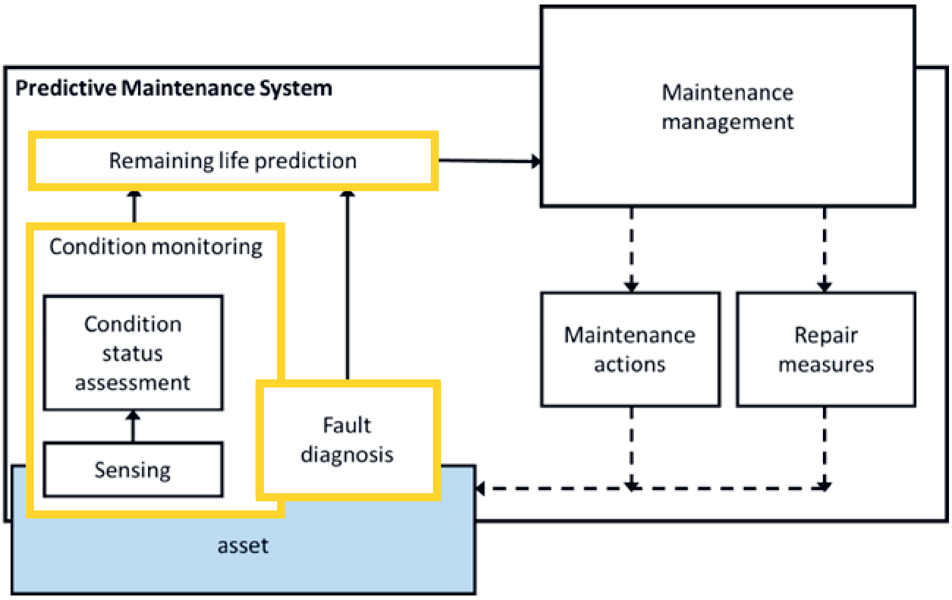


Figure 3-8-2 – System function diagram

Roles

The implementation mode of this case is for the service provider and system integrator to co-operate to develop a predictive maintenance platform. The role of CUP is as service provider and system integrator, mainly providing predictive maintenance technology, platform construction solutions and data/model support.

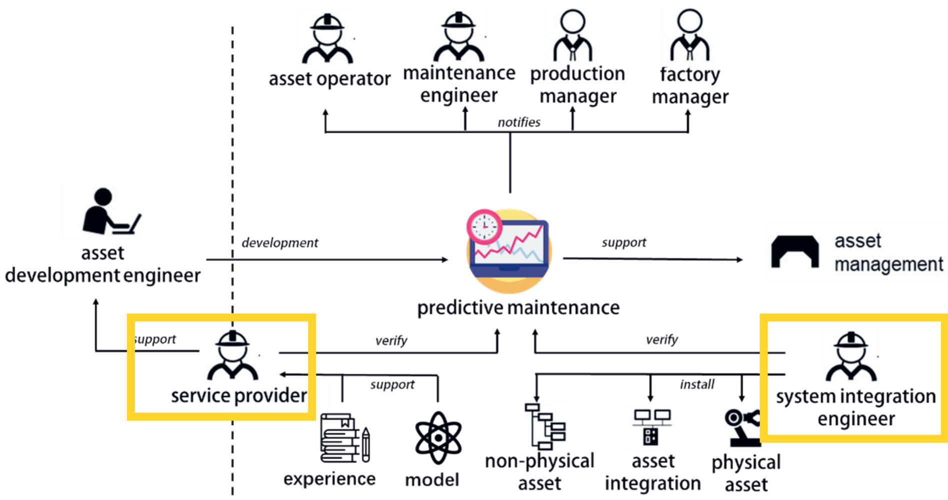


Figure 3-8-3 – Implementation role diagram

System architecture

The system structure of the system is shown in the figure below. The key equipment mainly includes the top drive, main engine and thruster. The hardware includes a data acquisition device, edge computing device and monitoring terminal. The software mainly includes an offshore oil platform condition status assessment and remote diagnosis system.

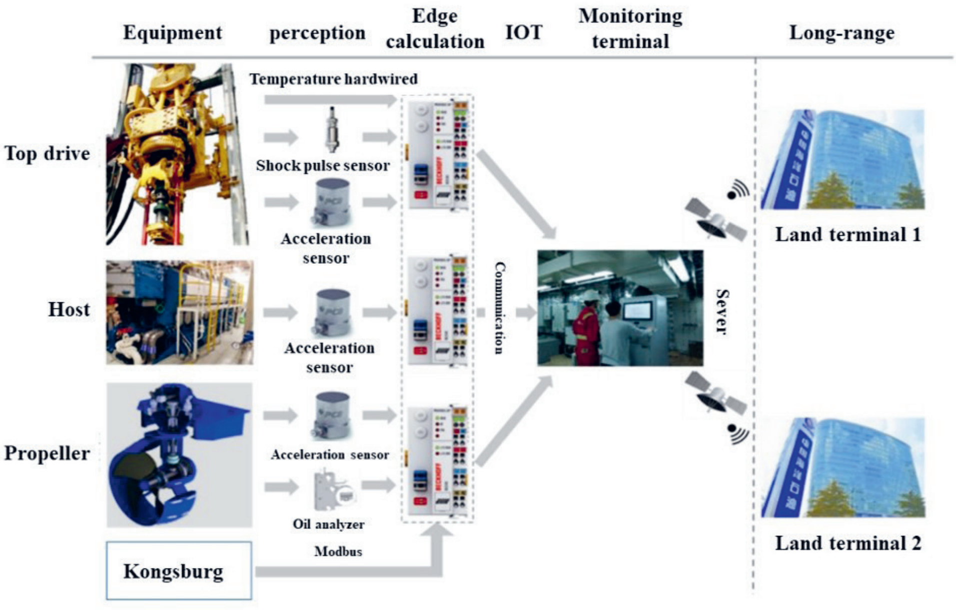


Figure 3-8-4 –System architecture diagram

Functions and methods

The system can carry out a condition status assessment, fault diagnosis and remaining life prediction of the top drive, main engine and thruster. The main functions are:

- Multi-source monitoring parameter collection: including vibration acceleration, shock pulse, online oil analysis, temperature, torque, speed and other multi-dimensional parameters. It is currently the world's largest floating platform with the most monitoring equipment and comprehensive monitoring parameters.
- Edge computing management: real-time analysis of equipment monitoring data and fault indications, with loop self-checking and sensitive monitoring functions; analysis data is transmitted and aggregated to the platform server through optical fibre communication in real time.
- The system has many advantages: it adopts a distributed data collection scheme, which has the advantages of modularisation, scalability, networking, easy upgrade, data transparency and compatibility.
- Good human-computer interaction: the system also has rich human-machine interaction windows, including alarm record module and message record module. The alarm record module shows the system's alarm information within a certain period of time, which is a key guide for prompt discovery of abnormal status of equipment and subsequent maintenance; the message record module is mainly a window for platform management personnel to exchange messages, which helps to achieve collaborative management of key equipment on the platform.

Feature highlights

Feature highlights of the system are as follows:

- Comprehensive monitoring parameters: can collect vibration acceleration, shock pulse, online oil analysis, temperature, torque, speed and other multi-dimensional parameters, which can effectively support the implementation of predictive maintenance technology.
- Open data interface: in addition to collecting equipment status data through additional sensors such as vibration, shock pulse and online oil and gas analysis, the system also obtains key operating parameters for equipment operating conditions such as speed, temperature, pressure and torque through open interfaces of third-party equipment. Carry out all-round perception of equipment operating status.
- Advanced data transmission form: analysis data is transmitted and aggregated to the platform server in real time through optical fibre communication. At the same time, all data will be synchronised to the terrestrial terminal via satellite, supporting remote management and expert support of the platform from the terrestrial terminal.

Visualisation

The system can graphically describe the operating status of the platform's key equipment, strengthen the system's visibility and improve the user-friendliness and operability of the software. The system has designed a historical trend analysis module, which forms a trend chart through data query of any device, any measurement point and any time period, and obtains abnormal data in the equipment life cycle at any time. Based on these historical monitoring data, intelligent algorithms such as machine learning are used to establish a life prediction model for the key equipment on the platform. This model performs an intelligent prediction and provides early warning of the state of the platform's key equipment. The interface is shown in the figure below.

Figure 3-8-5 – Predictive maintenance interface for offshore oil platform *Copyright: CUP*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
top drive	motor	motor overheat	temperature	data reading
		motor abnormal	vibration, impact pulse	sensor
			current, voltage	data reading
		gear fault	vibration, impact pulse	sensor
		bearing fault	vibration, impact pulse	sensor
	gearbox	gear fault	vibration, impact pulse	sensor
		bearing fault	vibration, impact pulse	sensor
main engine	cylinder-piston assembly	abnormal failure of cylinder	thermodynamic data	data reading
		high temperature deformation of cylinder	thermodynamic data	data reading
	generator	generator fault	current, voltage, temperature, load	data reading
			vibration	sensor
	bearing spindle	bearing fault	vibration	sensor
thrustor	motor	motor overheating	temperature	data reading
		abnormal operation of motor	vibration	sensor
			temperature	data reading
	gearbox	lubrication failure	lubricating oil temperature, pressure	data reading
		gear fault	vibration	sensor
		bearing breakage	lubricating oil temperature, pressure	data reading
			vibration	sensor
		bearing wear, tired	lubricating oil temperature, pressure	data reading
			vibration	sensor

Table 3-8-1 – Data requirements of scenarios

Scenario 9: Predictive maintenance of petrochemical factory

Overview

In the petrochemical industry, the guarantee of production efficiency and plant safety are of paramount importance. By collecting and monitoring the vibration data of large-scale equipment in the petrochemical factory, it is possible to ensure the transparency and predictive maintenance of the factory's equipment status.

The predictive maintenance system of NOVA TEST EQUIPMENT Co., Ltd. (NOVA) is mainly aimed at the factory's four reactors. Sensors are installed on the reactors' three bearings, and data is collected through the data acquisition module and uploaded to the monitoring system to complete intelligent data screening and analysis.

NOVA is responsible for the R&D and construction of the predictive maintenance platform of the EVA petrochemical factory, and carries out predictive maintenance for key equipment in the factory. The position of the predictive maintenance platform in the system level is shown in the figure below, covering Level 0, Level 1, Level 2, and Level 3.

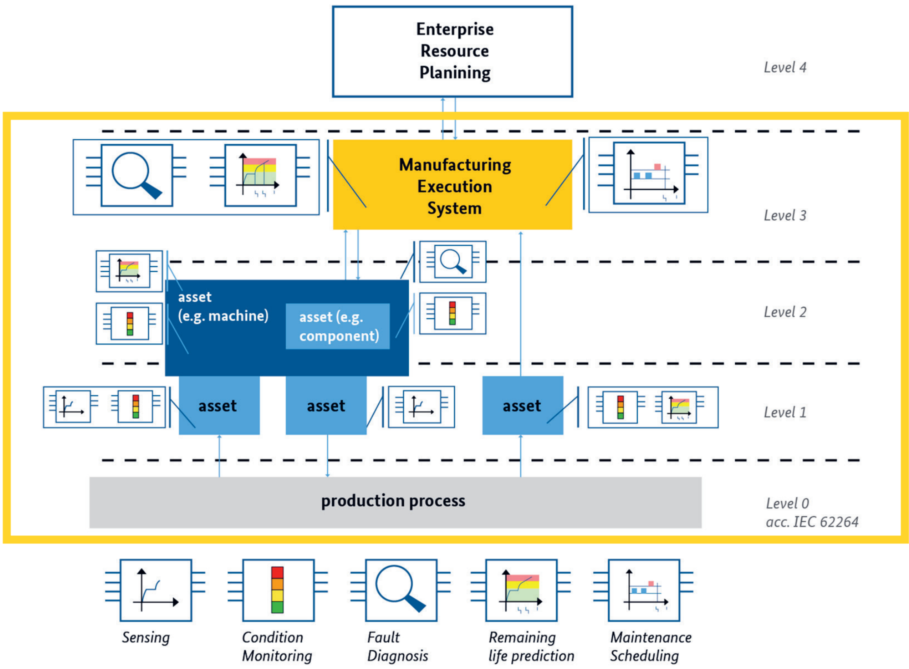


Figure 3-9-1 – System level diagram

The predictive maintenance platform for the EVA petrochemical factory can perform the functions of sensing, condition status assessment, fault diagnosis and remaining life prediction of the factory's key equipment, as shown in the figure below:

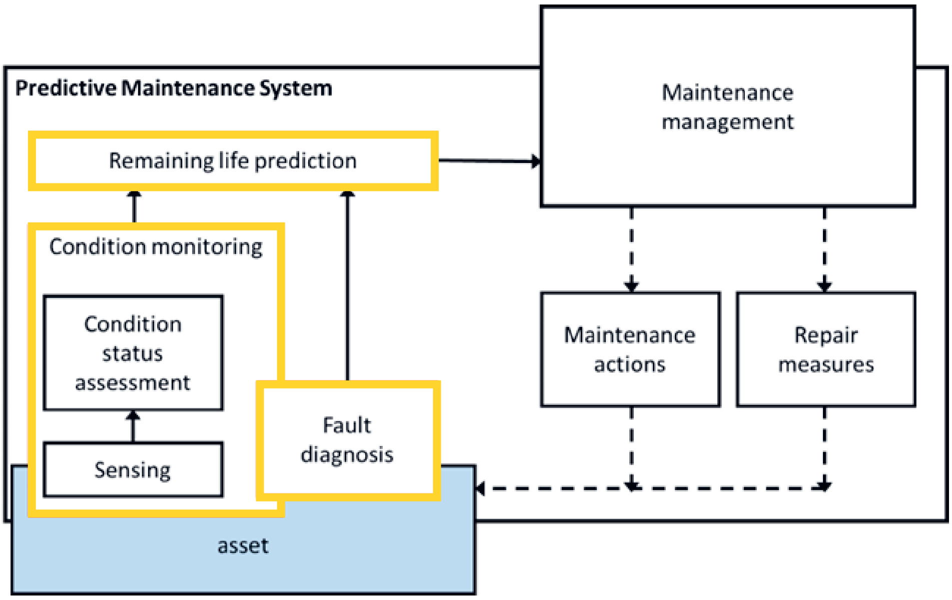


Figure 3-9-2 – System function diagram

Roles

It is for service providers and system integrators to cooperate on development of the implementation model of the predictive maintenance platform. In this case, NOVA's role is as service provider, providing mainly predictive maintenance technology, platform construction solutions and data/model support; at the same time, NOVA is also a system integration engineer, responsible for connecting predictive maintenance functions with the manufacturer's hardware and software, thereby achieving system integration.

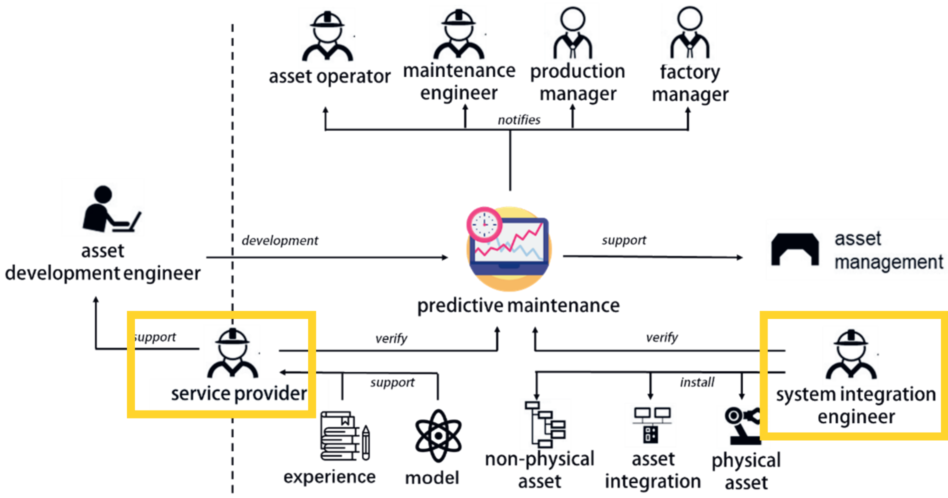


Figure 3-9-3 – Implementation role diagram

System architecture

This case is an EVA petrochemical factory. The company deploys a vibration monitoring system for the factory's four reactors to guarantee both productive efficiency and security in the factory area. The company also provides a set of equipment vibration status monitoring solutions for the petrochemical plant, which includes services/software such as data collection, sensors, vibration monitoring software and data analysis.

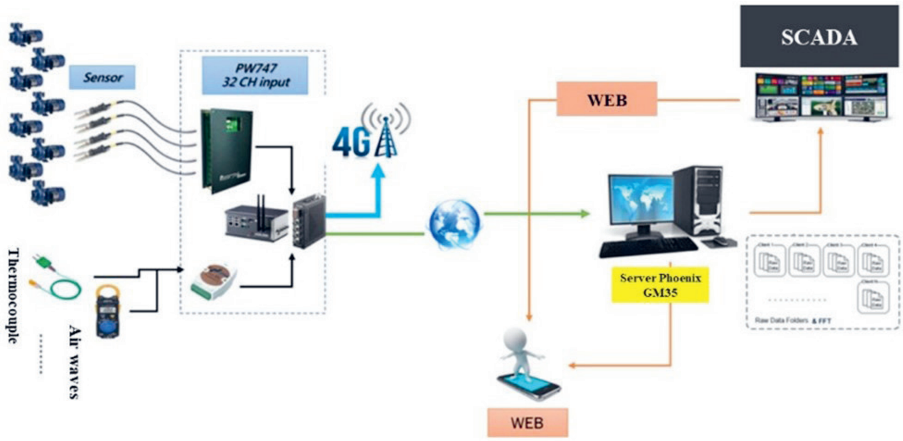


Figure 3-9-4 – System architecture diagram

Functions and methods

This vibration monitoring system is mainly aimed at the four reactors in the factory. Sensors are installed on each of the three bearings of the reactor (from bottom to top: base bearing, middle bearing and motor bearing):

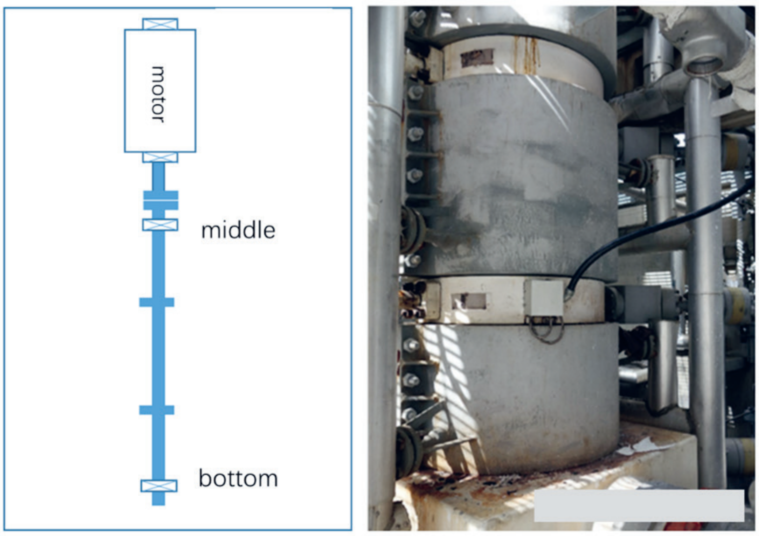


Figure 3-9-5 – Monitoring location diagram

Copyright: NOVA

Collecting data via the data acquisition module and uploading it to the monitoring system to complete intelligent data screening and analysis, the personalised predictive maintenance platform can perform condition status monitoring, fault alarm and diagnosis of the reactor shaft and motor. The main functions are:

- Edge computing management: carry out edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management and other modules;
- Predictive maintenance cloud platform: this mainly performs the running environment construction of the predictive maintenance algorithm model, data analysis and data centre processing, including access services, data services, system management and other modules.
- Condition status assessment and health assessment: this mainly performs the visual analysis of equipment status and prediction results, including temperature trend analysis, current trend analysis, vibration RMS value trend analysis, vibration spectrum analysis, RUL value display and other modules.
- Feature highlights
- The advantages of the predictive maintenance platform are as follows:
- Complete solution: in line with the different needs, restrictions and budgets of customers, provides the most basic to most comprehensive predictive maintenance system solutions.
- Transmission mode customisation: in view of varying local environmental restrictions, it can provide limited, wireless, semi-wireless and other solutions.
- Data management: the vibration monitoring system is optimised for managing a large number of pieces of equipment and is extremely easy to operate, from the database structure to the operation interface.
- Non-intrusive monitoring: sensors set up outside the device, without destroying the device, and without concerns for the hidden dangers of importing.
- Flexible data storage: the cloud and local storage can be deployed in line with the user's actual situation.

Visualisation

The predictive maintenance system can create a visual display of parameters, including temperature, current, speed and other parameters, as well as state parameters such as vibration acceleration and effective value. Green, yellow, and red respectively indicate the three states of equipment normal, equipment abnormal, and equipment failure, providing a visual display and early warning. The visual interface is shown in the figure below.

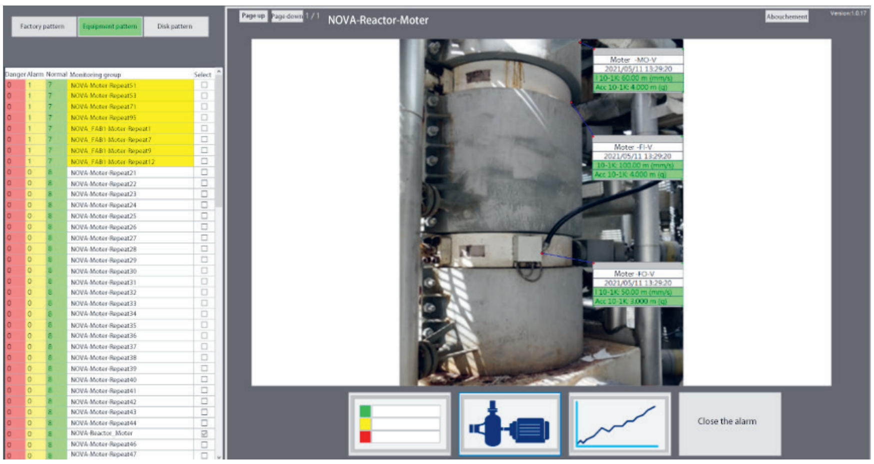


Figure 3-9-6 – Predictive maintenance interface

Copyright: NOVA

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
reactor	bearing	bearing bending/wear	vibration	sensor
		ball wear	vibration	sensor
		maintainer deviation	vibration	sensor
		inner ring/outer ring damage	vibration	sensor
	motor	rotor eccentricity	vibration	sensor
		electrofusion abnormal sound	vibration	sensor
		base instability	vibration	sensor

Table 3-6-1 – Data requirements for scenarios

Part 4: CM & PM scenarios for assets

Scenario 1: Predictive maintenance for printing systems as a basis for data-driven service engineering

Overview

A manufacturer of printing machines has been offering customers a remote troubleshooting service. The vibration analysis and current monitoring sensors integrated in the printing machine can be used to obtain a large amount of condition data and operating data. Customers have had trust in this manufacturer for years and accept the online transmission of their condition and operating data to the manufacturer.

Thanks to condition monitoring and analysis of condition data, the manufacturer has been able to detect wear and damage to the machine at an early stage over the last few years and thus significantly increase the availability of printing systems. Further analysis of condition data in connection with the operating data has led the manufacturer to realise that many of the effects of wear result from incorrect or suboptimal operation of the printing machines.

The predictive maintenance system for the copy system covers level 0, level 1 and level 2 at the system level.

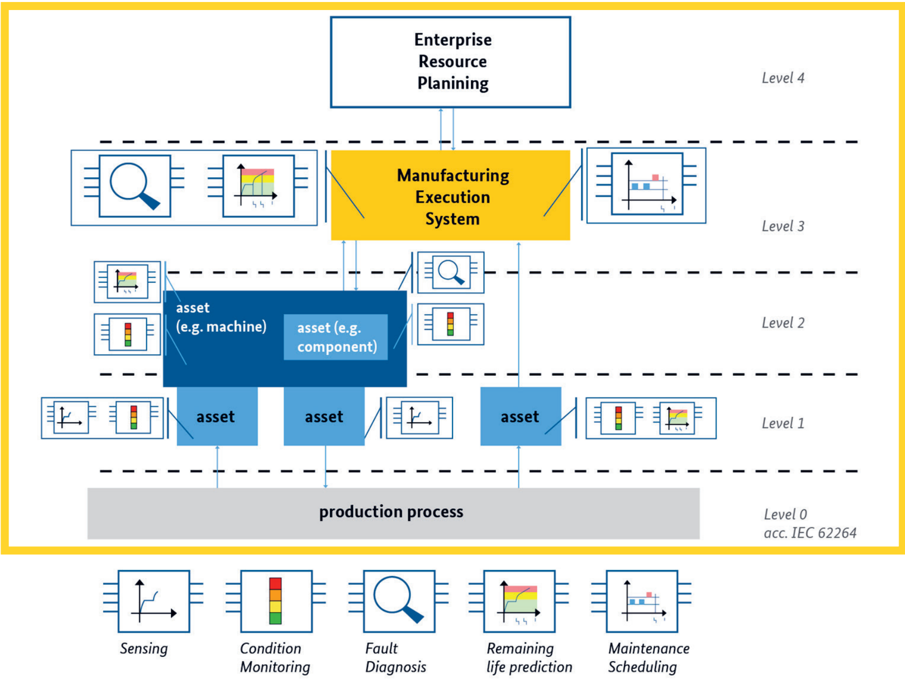


Figure 4-1-1 – System level diagram

The predictive maintenance system has the functions of sensing, condition monitoring and fault diagnosis, as shown in the figure below:

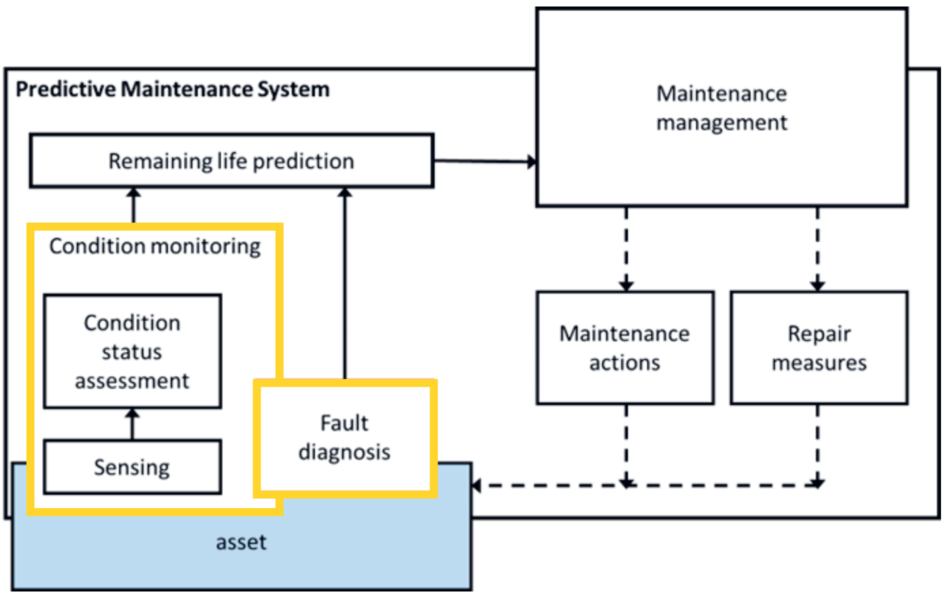


Figure 4-1-2 – System function diagram

Roles

The manufacturer is responsible for implementation of this case. Based on trust for the manufacturer, the user makes available the operating conditions and other data.

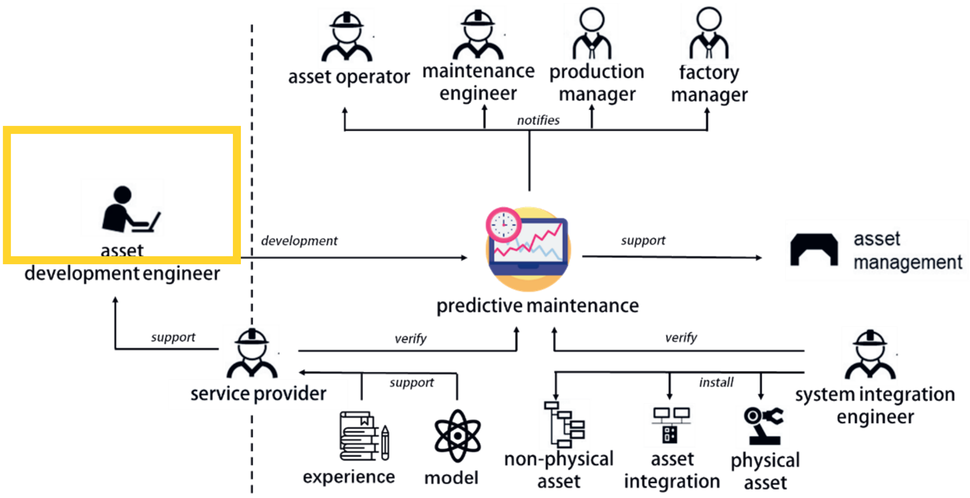


Figure 4-1-3 – Implementation role diagram

Functions and methods

Thanks to detailed combination and analysis of the condition data and operating data, the manufacturer was able to determine very precisely which modes of operation increase certain wear effects and thus increase the maintenance efforts of the operator of the printing machine. The objective of this analysis was not only to determine predictive maintenance activities, but to prevent the need for maintenance by reducing wear on the printing machines and improving the mode of operation, thereby reducing the overall maintenance effort. Thus, the operator will be able to describe in detail any malfunctioning measures taken at press machine start-up and at what point these incorrect measures led to increased wear. Based on this information, the operator is better able to train his plant operators on how to optimally start, ramp up and shut down a pressing system.

Visualisation

The manufacturer of the printing presses has been able to develop new services for customers by combining and analysing condition and operational data, which were originally collected only for predictive maintenance. With these new services, the printing machine manufacturer succeeds in setting themselves apart from the offers of competitors and, at the same time, strengthening customer loyalty.

By including the data-analytical methods in the entirety of all service processes, condition monitoring has on the one hand a very positive effect on the service cost level of the manufacturers. On the other hand, machine operators can use this information to optimise their production processes. The printing machine manufacturer reports significant performance improvements exceeding 15%. Condition monitoring is an important data basis for further digital services in line with Industrie 4.0. However, condition monitoring can only be seen as a first important step on the way to digital transformation. New data-driven business models (e.g. pay per use) across the value chain will follow.

Scenario 2: Condition monitoring and RUL prediction for RV reducer

Overview

The RV reducer is one of the core components of the intelligent robot. Its performance is the key to determining whether the intelligent robot can operate normally and perform the machining correctly. The RV reducer has a precise structure and is small in size, so harsh operating conditions such as variable load and speed have brought great challenges to its reliability. It is vital to carry out condition monitoring, life prediction and establish the predictive maintenance system of RV reducer.

ITEI and CyberInsight jointly built the predictive maintenance system of the RV Reducer to carry out the functions of monitoring, diagnosis and life prediction. The system level is shown in the figure below, covering level 0, level 1 and level 2.

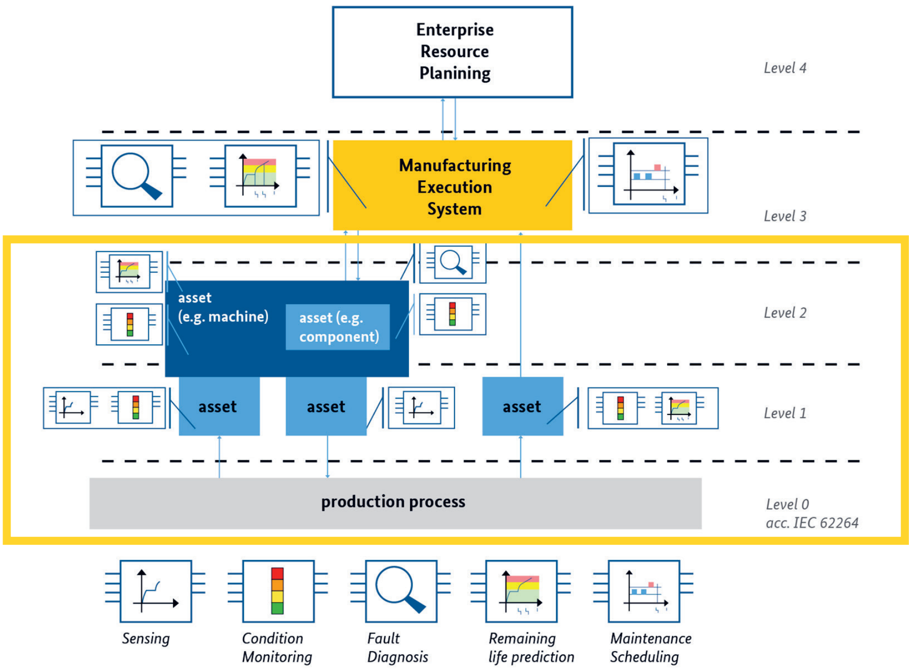


Figure 4-2-1 – System level diagram

The predictive maintenance system of the RV reducer deploys various sensors such as vibration, encoder, temperature, pressure and speed to carry out the functions of sensing, condition evaluation, fault diagnosis and life prediction for the RV reducer, as shown in the figure below.

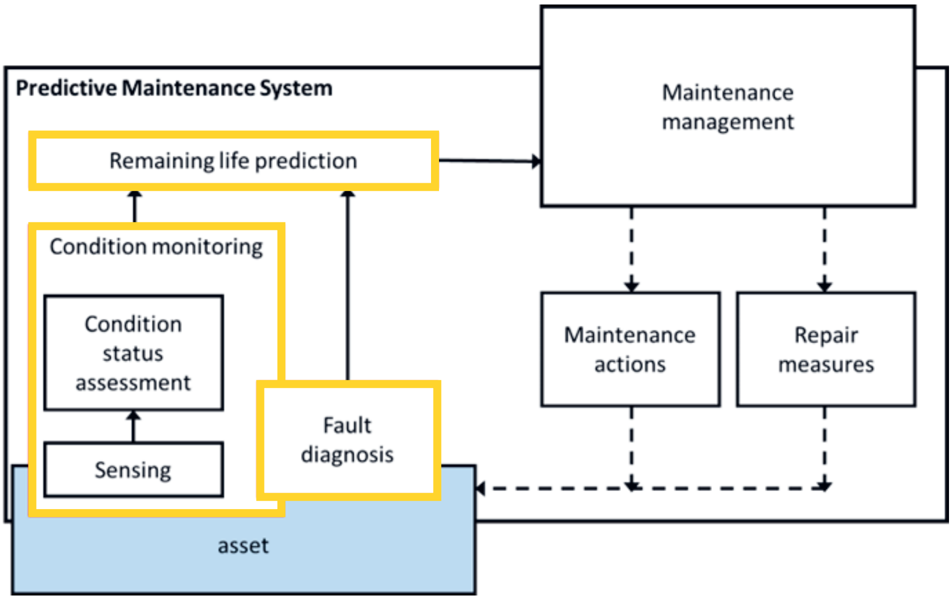


Figure 4-2-2 – System function diagram

Roles

In constructing the predictive maintenance system for the RV reducer, the role of ITEI is as asset operator, and CyberInsight is the service provider. CyberInsight provides the predictive maintenance software and hardware equipment, construction scheme and data/model. In case of emergency, the predictive maintenance system can promptly notify ITEI of equipment status and early warning information.

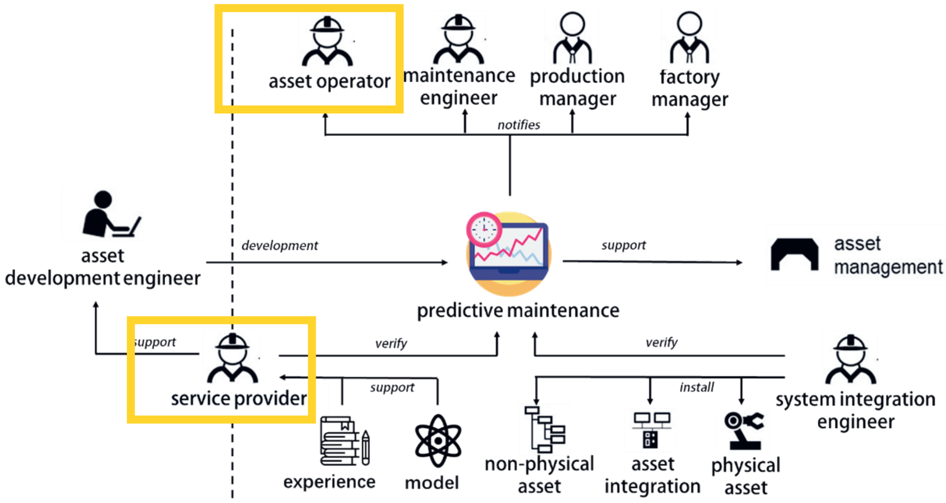


Figure 4-2-3 – Implementation role diagram

System architecture

The predictive maintenance system architecture of the RV reducer is shown in the figure below. For the RV reducer, sensors such as vibration and encoder, synchronously collect sensor and PLC signals, performing the functions of edge calculation management, condition monitoring and health management.

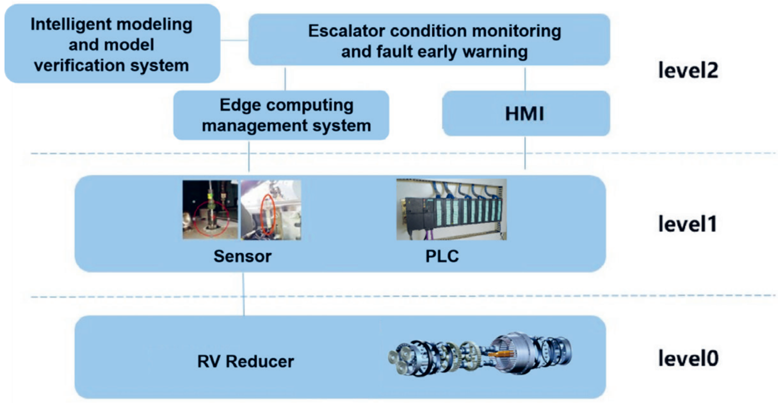


Figure 4-2-4 – System architecture diagram

Functions and methods

The functions realised by the predictive maintenance system of the RV reducer include:

- IOT and edge computing management: the edge end data acquisition and analysis functions include equipment status, trend analysis, hardware management, alarm management, system management, etc.
- Big data service and cloud platform management: mainly responsible for construction of the operating environment for the predictive maintenance algorithm, data analysis and data centre processing, including process management, model management, equipment management, access service, data service, system management and other modules.
- Intelligent modelling and model verification: this realises the development, iterative optimisation and model verification of the predictive maintenance model, establishes the algorithm life cycle management model library and improves the accuracy and generalisation ability of the model.
- Condition monitoring and health evaluation: this performs a visual analysis and cluster management of the status and prediction results of the RV reducer, including health display, temperature trend analysis, current trend analysis, vibration RMS trend analysis, vibration spectrum analysis, RUL display and other modules.

Feature highlights

The prominent features of the predictive maintenance system of the RV reducer are as follows:

- Fusion analysis of multi monitoring means: by collecting the encoder signal of the RV reducer and fusion analysis with sensor signals such as vibration, temperature, current, voltage, speed and load, to carry out the functions of position accuracy analysis, fault diagnosis and life prediction.
- Application of machine learning algorithm: machine learning algorithms such as GAP-CNN, random forest, VMD, TrAdaBoost and SOM are applied to optimise the prediction accuracy and universality of the model.
- Health prediction: based on the equipment health model and deterioration model, the real-time dynamic analysis of multivariable and multi rules is carried out to realise the health prediction function of the RV reducer, which lays a foundation for the implementation of predictive maintenance for the whole intelligent robot.

Visualisation

The predictive maintenance system of the RV reducer can realise the real-time visual display of equipment information, operation history, current status, parameters and health trend. Green, yellow and red represent the states 'normal', 'abnormal' and 'fault' respectively. The visual interface is shown in the figure below:

Figure 4-2-5 – Predictive maintenance interface *Copyright: ITEI*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
intelligent robot	reducer	position error	encoder, vibration	sensor
	bearing	bearing fault	vibration	sensor
	driving motor	bearing fault	vibration	sensor
			speed, current, voltage	PLC
		motor fault	current, voltage	PLC

Table 4-2-1 – Data requirements of scenarios

Scenario 3: Predictive maintenance and life prediction for motion control systems

Overview

Power transmission system (drive chain, for short) is the core of intelligent manufacturing equipment. A sudden failure of key equipment in the transmission chain will lead to production stoppage, production loss and even casualties. Therefore, it is necessary to develop predictive maintenance technology for the drive chain and deploy predictive maintenance and a life prediction system to improve reliability of the drive chain and ensure efficient and stable operation of production.

The common mechanical parts in the transmission chain include drive, motor, coupling, ball screw, belt, gear, etc. A predictive maintenance platform has been developed for automation and motion control equipment, as shown in the figure below. The predictive maintenance system runs on Industrial Edge equipment.

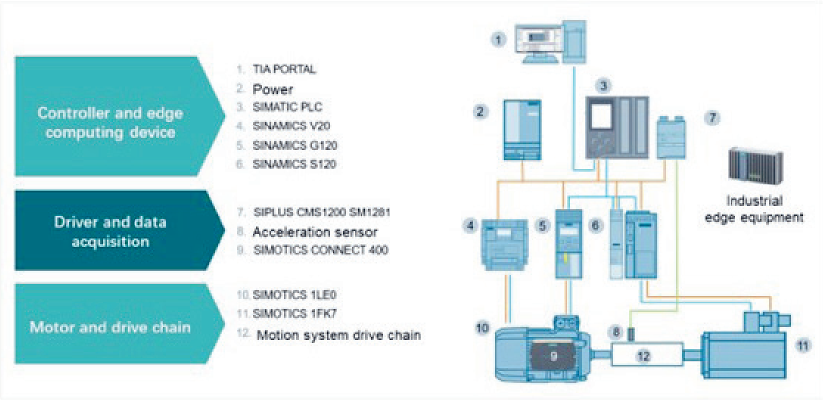


Figure 4-3-1 – Predictive maintenance interface

The system is designed for predictive maintenance and life prediction of the drive chain systems in motion control. Developed by Industrial Edge and Mendix, the system can carry out fault diagnosis and identification of misalignment, imbalance, loosening, shaft bending and resonance of motor bearings. It can also monitor and warn of the status of ball screws, belts and gears. The platform's place in the production system architecture is as follows, covering Level 0, Level 1, and Level 2:

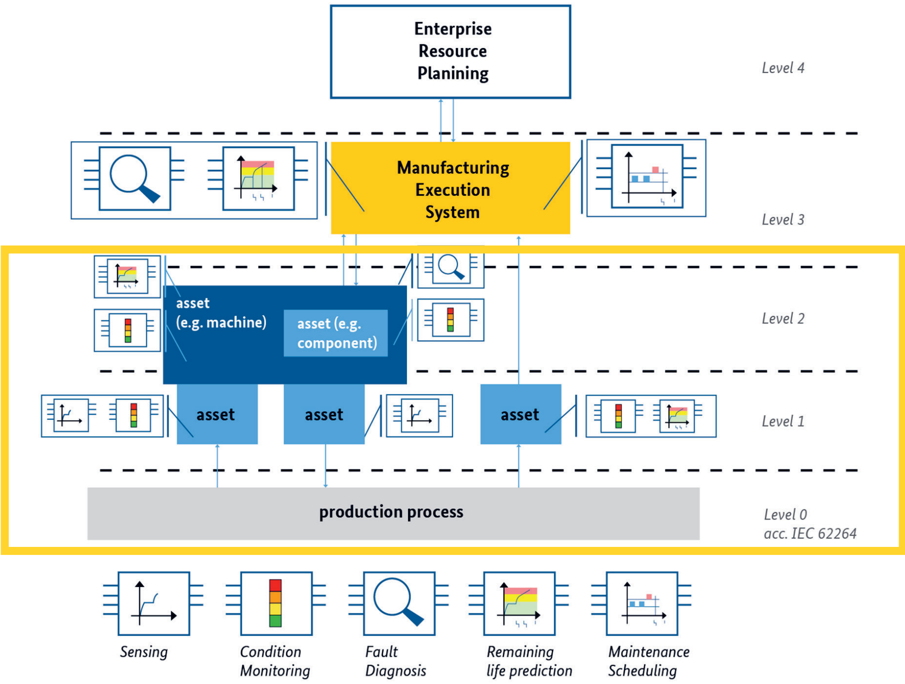


Figure 4-3-2 – System level diagram

The predictive maintenance and life prediction system uses the S7 protocol at the connection layer and the predictive maintenance algorithm library and Mendix App at the application layer, as shown in the figure below. As development continues, predictive maintenance algorithms will support modelling, diagnosis, maintenance, and optimisation.

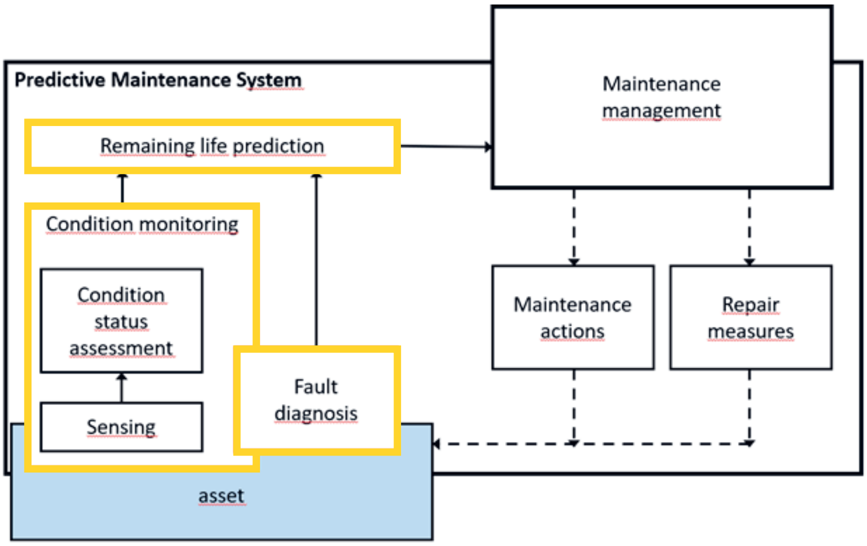


Figure 4-3-3 – System function diagram

Roles

There are various implementation modes for the predictive maintenance technology. The implementation mode for this case is cooperation between the service provider and system integrator to develop the predictive maintenance platform. In constructing the predictive maintenance system platform, Siemens Digital Industry is the service provider, providing mainly the predictive maintenance technology, platform construction scheme, algorithm/model support and the first software deployment. Siemens Factory Automation Engineering Ltd. is the system integrator, responsible for connecting the predictive maintenance functions with the manufacturer's hardware and software for system integration.

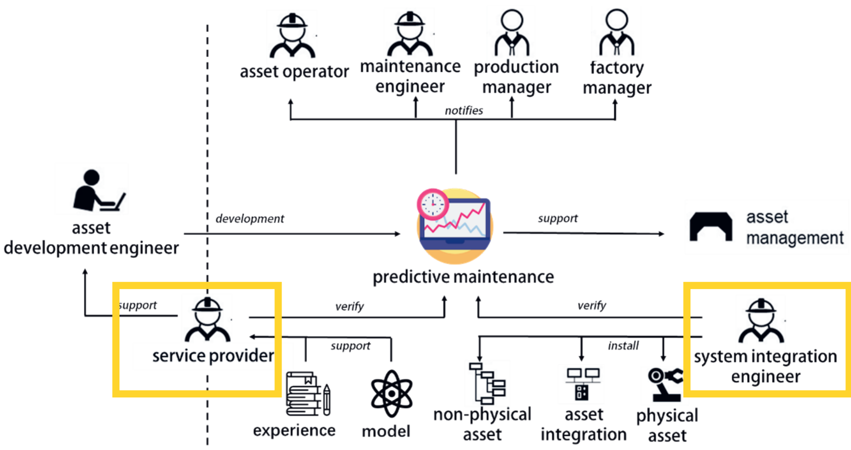


Figure 4-3-4 – Implementation role diagram

System architecture

The system hardware mainly includes the drive chain test bed (mechanical, electronic control equipment) and Industrial Edge. The software includes Industrial Edge and the servo drive communication data acquisition module, predictive maintenance module and Mendix App. In addition, SIMOTICS CONNECT 400, a smart wireless vibration sensor, can be installed on the induction motor to measure and analyse motor vibration, temperature and other data, and send this to the MindSphere SIDRIVE IQ Fleet for further analysis, as shown in the figure below:

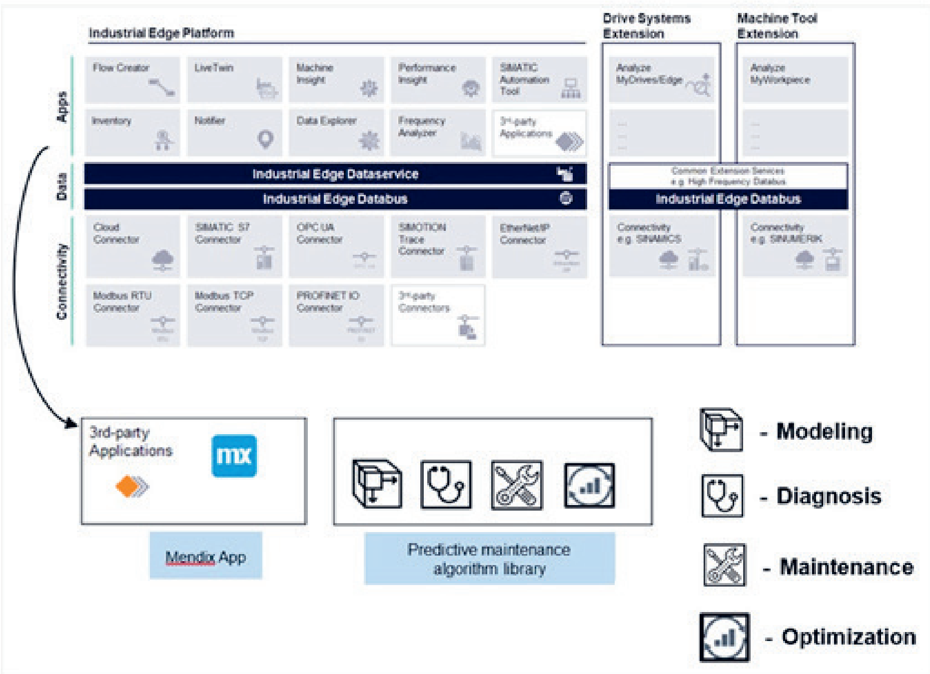


Figure 4-3-5 –System architecture diagram

Functions and methods

The main functions of the system are:

- implements diagnosis and identification of bearing misalignment, imbalance, looseness, shaft bending, resonance and other faults;
- ball screw, belt, gear clearance status monitoring and warning functions;
- through the dynamic friction of the ball screw and static friction of the belt, it can detect and warn about the working status of the ball screw and belt;
- identifies gear backlash offline and provides early warning that a gear needs to be replaced;
- SIMOTICS CONNECT 400 vibration monitor provides recommendations on motor maintenance optimisation.

Feature highlights

The outstanding features of the system are as follows:

- supports vibration sensorless algorithm: the predictive maintenance software algorithms can be based solely on the drive internal current and speed data, without the need for additional vibration sensors;
- Siemens Industrial Edge is open and expandable, facilitating user re-development;
- the low-code Mendix platform enables rapid development of a customised app and interface;
- the user’s operations engineer can expand functions and easily customise a new HMI app using Mendix’s low-code programming tool.

Visualisation

The predictive maintenance app can display the motor current, speed, temperature, vibration and other parameters on the drive chain in real time, control start/stop of the identification algorithm, display identification results of key parameters as well as the working state and life prediction of the motor, ball screw, belt, gear, etc.

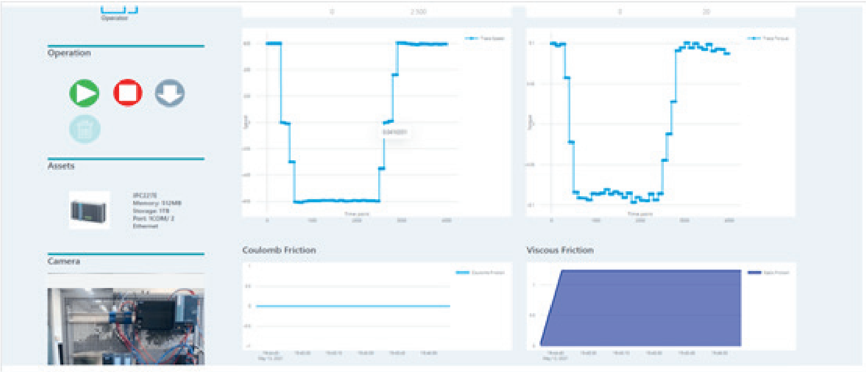


Figure 4-3-6 – Predictive maintenance interface *Copyright: Siemens*

Users can flexibly configure equipment parameters and algorithm parameters on the transmission chain according to the specific situation of intelligent manufacturing equipment. These include the drive model, motor parameters, bearing parameters, drive communication protocol, load side equipment type, friction model, and alarm upper and lower limits of friction, backlash and other important parameters, as shown in the figure below:

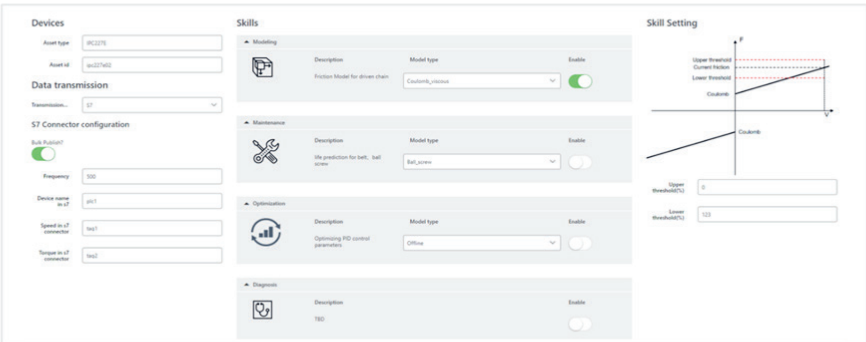


Figure 4-3-7 – Predictive maintenance interface *Copyright: Siemens*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
motion control system	shaft	shaft bending	vibration	CMS1200, SC400
	bearing	bearing fault	speed	sensor (drive internal)
		bearing misalignment	speed	sensor (drive internal)
		unbalance	speed	sensor (drive internal)
		loosening	vibration	CMS1200, SC400
	motor	motor installation misalignment	speed	sensor (drive internal)
		resonance	current	sensor (drive internal)
	ball screw	wear and erosion	current, speed	sensor (drive internal)
	belt	loosening and ero-sion	current, speed	sensor (drive internal)
	gear	large backlash	speed, position	sensor (drive internal)

Table 4-3-1 – Data requirements for scenarios

Scenario 4: Predictive maintenance for mechanical equipment

Overview

Equipment intelligent diagnosis and health management is a digital predictive maintenance service for early identification of mechanical faults. By monitoring and analysing status data such as the speed, vibration and temperature of the equipment, an artificial intelligence model is used to establish a predictive maintenance model for the equipment, in order to perform abnormal detection and basic fault diagnosis of the target equipment and to analyse the future long, medium and short cycle equipment conditions of the equipment, etc. This allows potential failures to be identified months in advance, allowing planned downtime checks to improve maintenance efficiency, extend equipment life and reduce the risk of serious failures.

The system provides state monitoring and fault prediction services for the Siemens DEC Suzhou belt-drive motor and DEC Chengdu belt-drive motor and reaction kettle motor. It also collects vibration state data for the motor, with a total of six vibration collection points. There are two status data collection boxes in total.

This system occupies the following position in the production system architecture, covering Level 0, Level 1 and Level 2, as shown in the figure below:

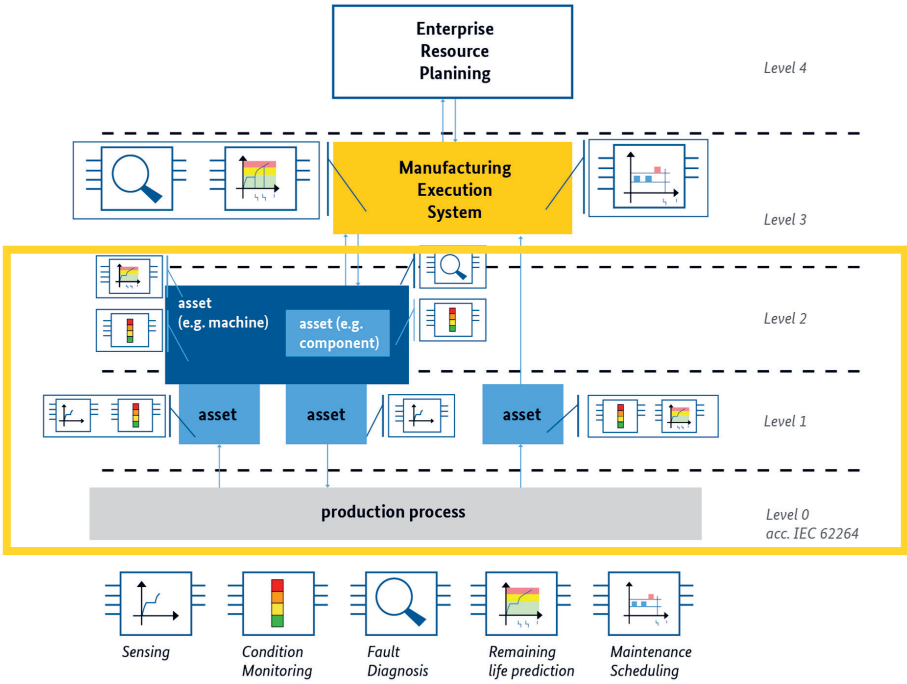


Figure 4-4-1 – System level diagram

It performs data collection, online monitoring, fault prediction automatic alarm and other functions, as shown in the following figure:

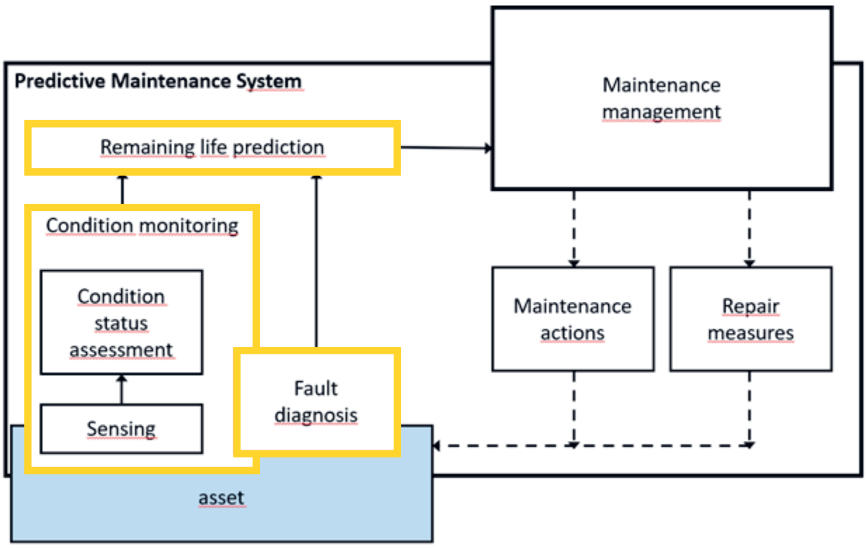


Figure 4-4-2 – System function diagram

Roles

The implementation mode for this case is that the customer, system integrator and service provider cooperate to develop the equipment condition monitoring and fault prediction system. The customer is Siemens DEC, the system integrator and service provider is SFAE. SFAE sets up the data acquisition and analysis platform for transmission line motors from the DEC production line and provides data analysis service and predictive maintenance technology.

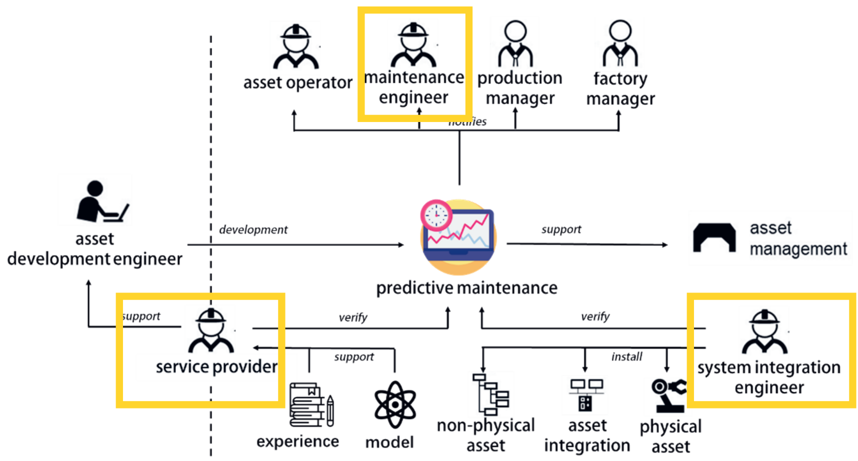


Figure 4-4-3 – Implementation role diagram

System architecture

The system's hardware design includes a data acquisition scheme design and data analysis hardware architecture design, which can be divided into sensor selection, a sensor installation scheme, data transmission scheme, data storage scheme, data analysis framework, etc.
The structure diagram for the intelligent device diagnosis and health management system is as follows:

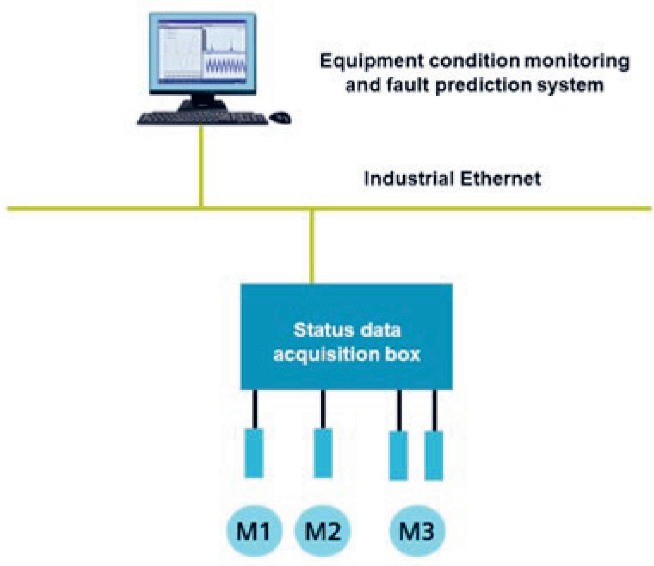


Figure 4-4-4 – System architecture diagram

The vibration state of the motor can be sampled by high frequency and processed locally through the state data acquisition box installed beside the machine. The processed vibration signal can be transmitted to the fault prediction system for fault prediction and displayed in the intelligent diagnosis and health management system of the equipment via the industrial ethernet.

The intelligent diagnosis and health management system provides onsite maintenance personnel with the following information:

- current operating status data of equipment and vibration spectrum;
- current operating health status of the device and exception notification;
- historical trend of device status data.
- The software and hardware of this system include the following components:
- state data acquisition box and vibration sensor;
- equipment status monitoring and fault prediction system.

Functions and methods

The data collected by the field status data collection box can be used to predict faults in the fault prediction system or view the status in the intelligent device diagnosis and health management system. The intelligent device diagnosis and health management system monitors the vibration status and views the current device working status.

The fault prediction system uses advanced data analysis techniques, such as statistical analysis and signal analysis, to diagnose equipment faults. It predicts the life cycle of equipment based on an artificial intelligence algorithm combined with mechanism knowledge and expert experience. The system can automatically detect, analyse, identify and diagnose equipment faults. Fault types include: rotor mass imbalance, eccentricity, shaft bending, misalignment, resonance, bearing damage (distinguishing inner ring, outer ring, roller, cage) and other faults.

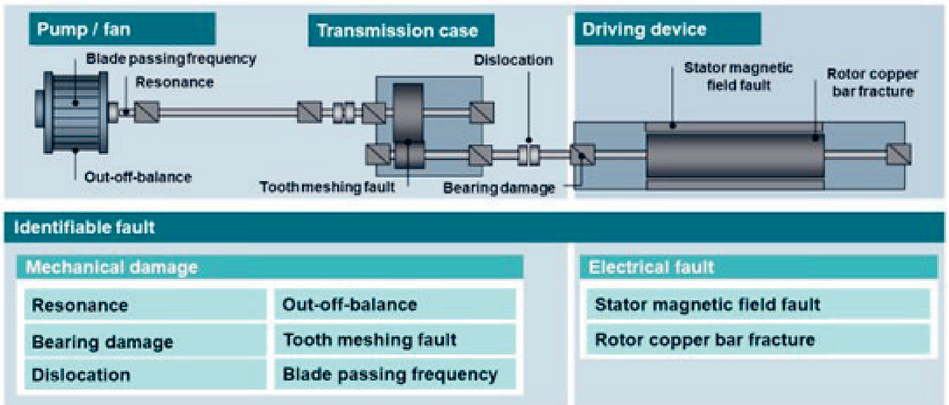


Figure 4-4-5 – Functions and methods diagram

The intelligent device diagnosis and health management system, the vibration status collected by the CMS1200 can be monitored simultaneously. The vibration status of all devices can be viewed on the intelligent device diagnosis and health management system, including:

- real-time status values, such as vibration velocity, vibration acceleration, etc;
- vibration eigenvalues, such as aRMS, vRMS, DKW, etc;
- signal trend chart;
- device status diagnosis;
- event log.

Feature highlights

The outstanding features of the system are as follows:

- state data acquisition box: high-frequency sampling and pre-treatment of the motor's vibration state;
- conditional monitoring: extract vibration eigenvalue and trend diagram of the device, real-time device health status and exception alert;
- device health management and fault prediction.

Visualisation

The visual display and early warning for the operating state of the motor, vibration acceleration, health and other parameters are shown in the figure below:

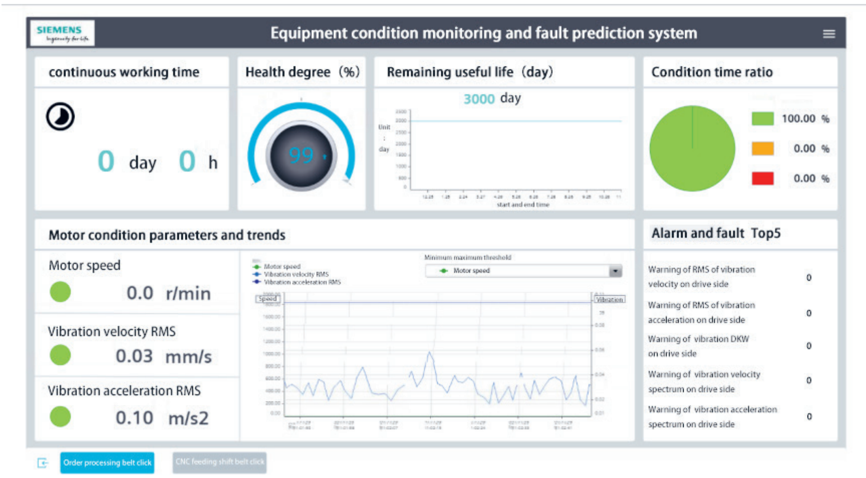


Figure 4-4-6 –Predictive maintenance interface *Copyright: Siemens*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
motor	mechanical damage	unbalanced, eccentric	vibration	sensor
		resonance	vibration	sensor
		misalignment, dislocation	vibration	sensor
		bearing damage	vibration	sensor
	electrical failure	stator field fault	vibration, speed, current, voltage	sensor, PLC
		rotor copper strip fracture fault	vibration, speed, current, voltage	sensor, PLC

Table 4-4-1 – Data requirements for scenarios

Scenario 5: Predictive maintenance for large-scale industrial robots

Overview

Industrial robots are basic industrial equipment used widely in automobile automation factories. More than 3,500 industrial robots are used in all BBAC's factory workshops, which are located in all process workshops. As core equipment in the automated factory, industrial robots must operate normally to ensure factory operations remain stable. With the continuous increase in factory automation levels and production pressure, the traditional maintenance system based on emergency maintenance, corrective maintenance and preventive maintenance shows the following shortcomings: maintenance costs continue to rise, maintenance efficiency is low and downtime risks are increasing. It is difficult to manage the asset information for large machine equipment. For this reason, it is very necessary to carry out predictive maintenance for large-scale industrial robots. The deployment of a predictive maintenance platform for industrial robots can improve the reliability and economy of robot intelligent equipment and improve the stability of factory operation.

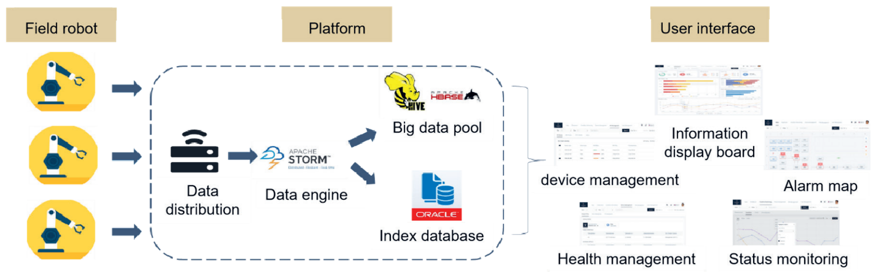


Figure 4-5-1 – Predictive maintenance platform for industrial robots

The predictive maintenance platform for BBAC industrial robots is based on Daimler's MSB (Manufacture Service Bus) system. By capturing, storing and analysing real-time robot data, it generates an information statistical display and alarm maps and performs equipment status monitoring and core component health management. Functions such as device information management are located as shown in the figure below, covering Level 0, Level 1 and Level 2.

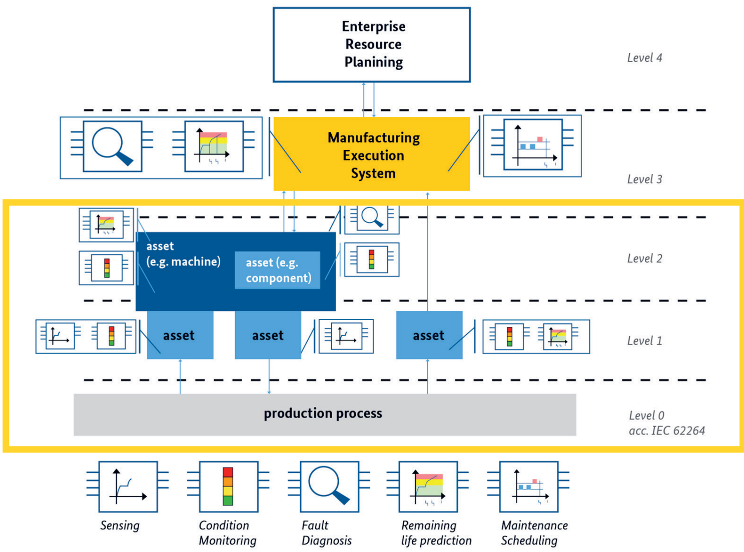


Figure 4-5-2 – System level diagram

Sensors such as for vibration, encoder, temperature, pressure and speed are deployed on the industrial robot predictive maintenance platform to carry out the robot's sensing, condition status assessment, fault diagnosis and life prediction functions, as shown in the figure below.

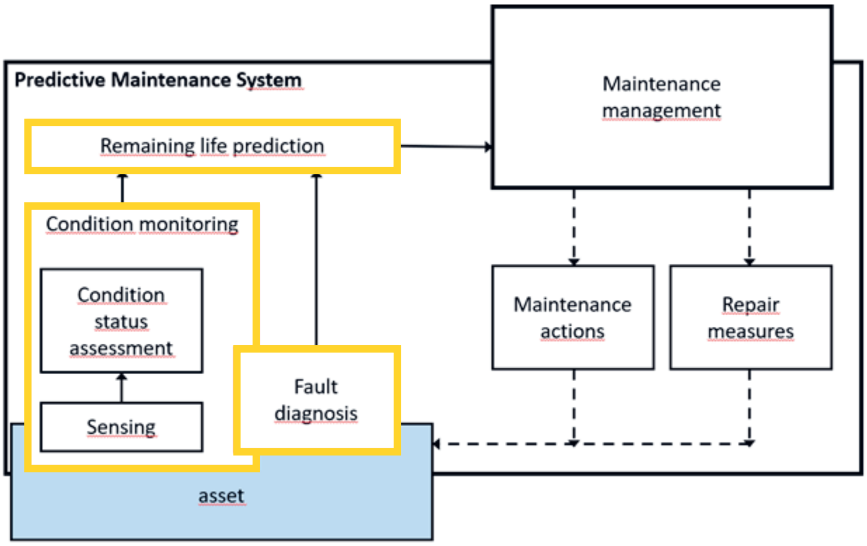


Figure 4-5-3 – System function diagram

Roles

In this case, the BBAC technical maintenance department is responsible for system design, data and technology and for the formulation of platform architecture schemes, function design, provision of condition monitoring and predictive model technology and codes, on-site equipment IoT function deployment and equipment data access. The role of IT consultant is played by the system integration engineer, with responsibility for construction of the back-end data platform and design of the front-end page.

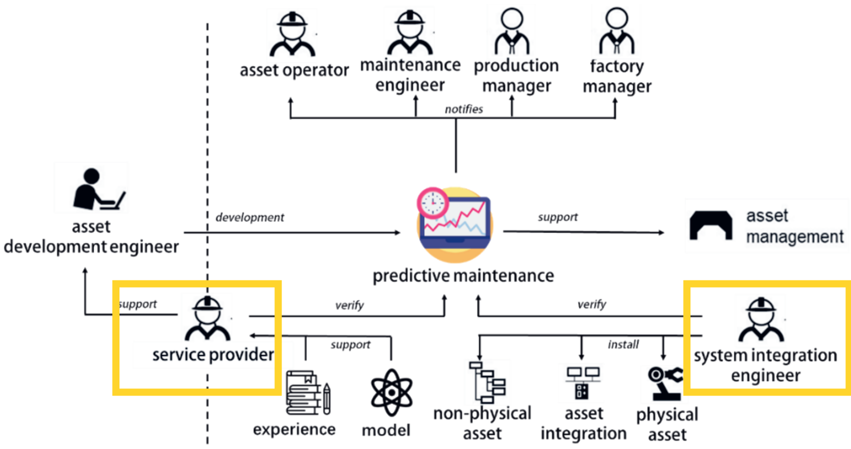


Figure 4-5-4 – Implementation role diagram

System architecture

The architecture of the BBAC Robotic Predictive Maintenance Platform is shown in the figure below. It mainly includes on-site industrial robots, data extraction, aggregation API, big data storage platform, secondary index database, data processing server, front-end page and other parts.

Functions and methods

The predictive maintenance platform for industrial robots can generate the statistical display of robot information, real-time robot status monitoring, core component health management, equipment information management, etc. The main functions are:

- Equipment information statistics and visual display: generate visual displays and carry out trend analysis of equipment information through real-time collection, summary and statistical analysis of status and alarm information from on-site industrial robots. The alarm information can also be displayed in real time on the workshop map, which is convenient for on-site equipment maintenance personnel to locate the problem in a timely and accurate manner.
- Equipment condition monitoring: generate real-time displays and carry out historical trend analysis of field robot core data, such as motor temperature, motor torque, CPU load and other data. It supports limit value setting, trend warning monitoring value setting based on the Kalman filter model, and has an automatic alarm trigger function.
- Monitoring and evaluation of core components: monitor and evaluate core components such as gearbox oil. By establishing a quality prediction model for gearbox oil based on machine learning, oil quality can be evaluated in real time based on robot operating data.
- Equipment information management: real-time collection and display of equipment models, procedures and other important information, and integration of equipment spare parts and maintenance history records.

Feature highlights

The outstanding features of the industrial robot predictive maintenance platform are as follows:

- Active uploading of intelligent data at the edge: on-site industrial robots actively upload real-time data via the MQTT protocol, customise data content and trigger conditions, with high-speed, large-capacity data transmission and processing capabilities.
- Distributed big data storage platform: Hadoop-based distributed big data platform can be used to process and store massive amounts of data efficiently and stably.
- Big data and machine learning: use big data and machine learning technology to reduce lubricating oil costs.
- Customised status monitoring: supports the threshold value of the robot's core data and the trend monitoring setting based on the Kalman filter; the platform actively triggers the alarm.

Visualisation

The predictive maintenance platform for the BBAC industrial robot can visualise the robot's alarm information in the form of a workshop map, which is convenient for on-site personnel to locate the problem in good time. The interface is shown in the figure below.

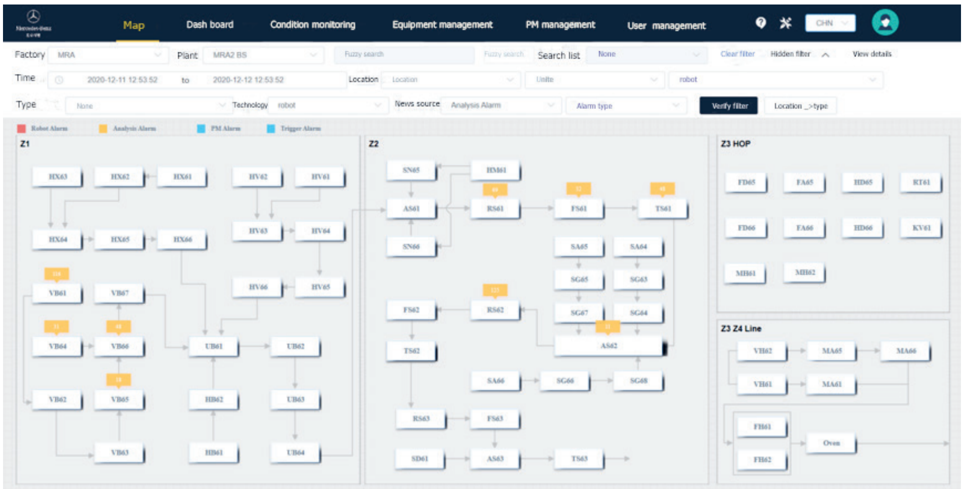


Figure 4-5-5 –Robotic predictive maintenance platform alarm map page *Copyright: BBAC*

The predictive maintenance platform for BBAC industrial robots can integrate and display information such as the robot's current status and procedures, and associate this with information such as spare parts and maintenance records. The interface is shown in the figure below.

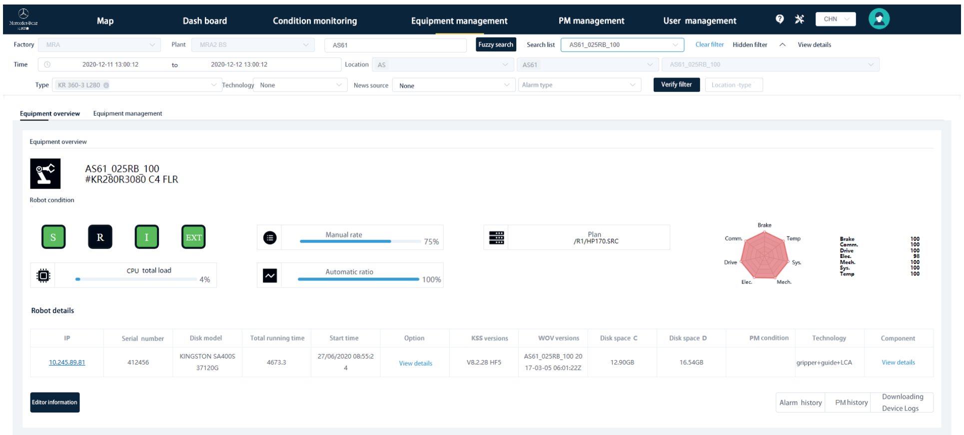


Figure 4-5-6 –Robotic predictive maintenance platform equipment management page *Copyright: BBAC*

The industrial robot predictive maintenance platform establishes a gearbox oil quality prediction model based on machine learning, evaluates oil quality in real time based on robot operating data and marks the oil quality status in different colours. Green stands for good quality, yellow means close to the threshold, red signals that it needs to be replaced. The interface is shown in the figure below:

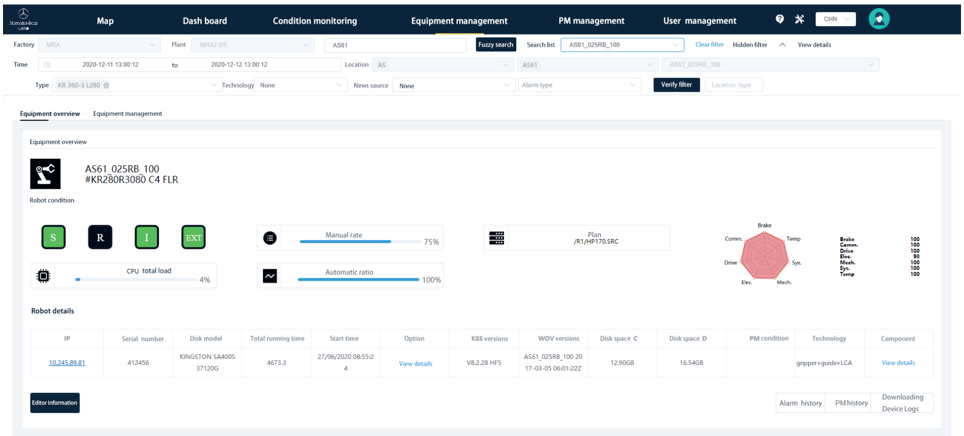


Figure 4-5-7 –Robotic predictive maintenance platform gearbox lubricant quality page *Copyright: BBAC*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
industrial robot	reducer	transmission gear wear	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
		drive shaft fracture	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
		lubricating oil failure	torque, current, temperature	sensor (internal)
			robot running time	system timer
	servo motor	rotor loss of magnetism/ winding failure	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
		brake failure	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
		bearing fault	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
	joint, connecting rod	wear and tear	speed, current, position, torque, temperature	sensor (internal)
			robot program trajectory	robot program
	battery	battery failure	battery voltage	sensor (internal)
	control system	electrical component failure	system diagnosis information	system information

Table 4-5-1 – Data requirements for scenarios

Scenario 6: Predictive maintenance for spot welding equipment

Overview

Spot welding equipment is one of the commonest body connection technologies used in automobile manufacturing companies. Normal operation of spot welding equipment is essential to guarantee stability of the production line and ensure the quality of car body products. The failure of a single piece of spot welding equipment may cause production on the entire line to stop and impact production tasks. At the same time, any failure will also lead to an increase in production costs and reduce production efficiency. Predictive maintenance for spot welding equipment can significantly increase the economy and reliability of intelligent equipment, improve the stability of production lines and ensure excellent product quality.

The BBAC Industrial Internet of Things big data platform has performed real-time data collection, status monitoring, project acceptance support, process optimisation, asset management, predictive maintenance and other functions for spot welding equipment. Among them, for predictive maintenance, the combination of expert experience and real-time data analysis enables advance prediction of failure and guidance on prioritisation of maintenance work for each major component of the spot-welding equipment (e.g. motors, busbars, motor rods, trimmers, etc.). The position of the industrial IoT big data platform in the production system architecture is shown in the figure below, covering Level 0, Level 1, Level 2 and Level 3.

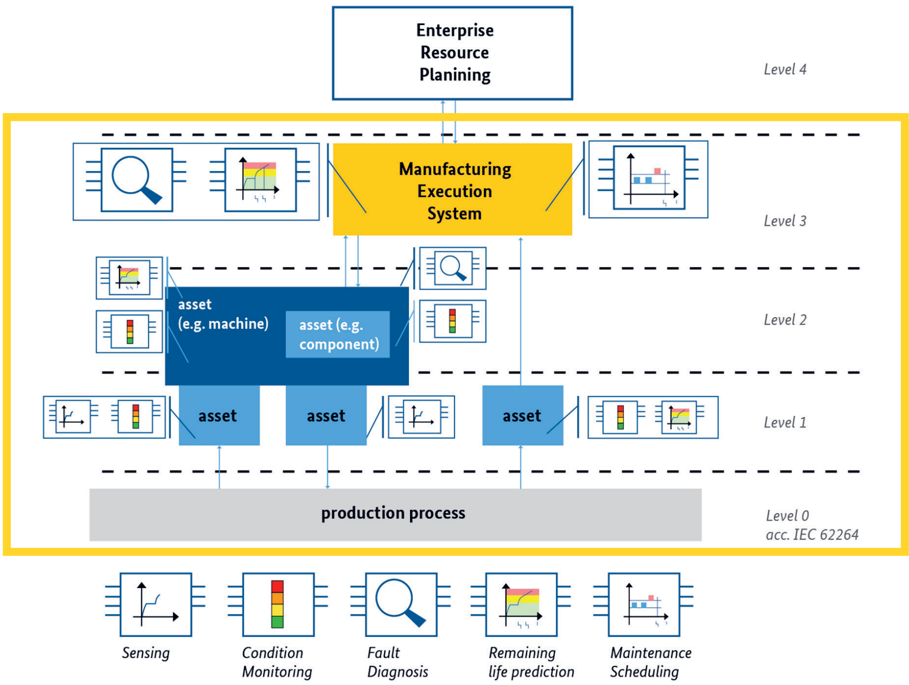


Figure 4-6-1 – System level diagram

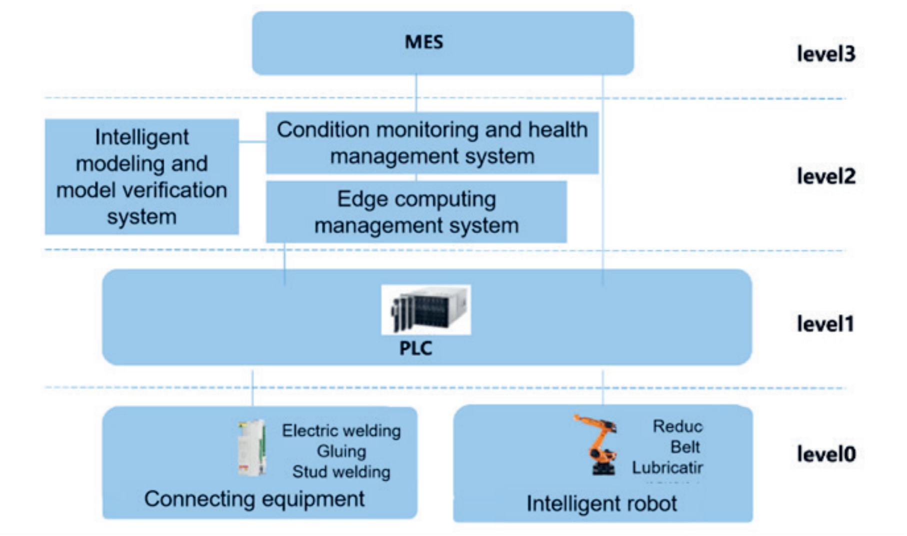


Figure 4-6-2 – Production architecture diagram

The industrial IoT big data platform deploys sensing devices for elements such as vibration, encoder, temperature, pressure and speed, in order to carry out the functions of sensing, condition status assessment, fault diagnosis and failure prediction, as shown in the figure below.

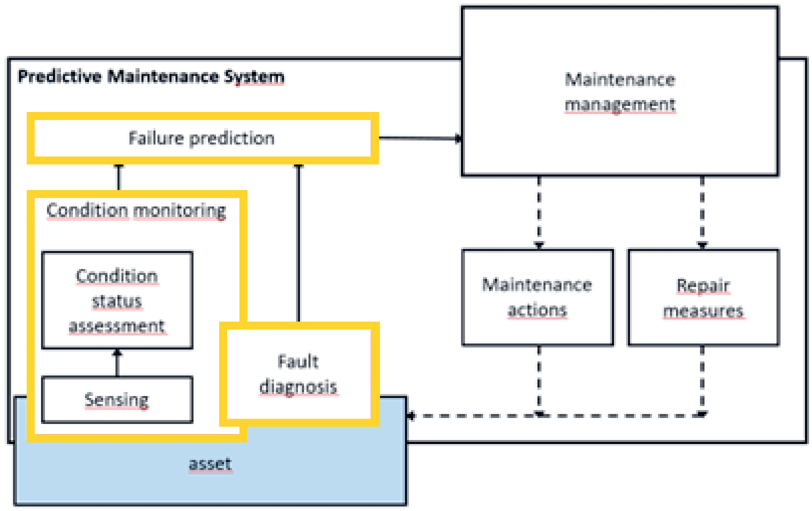


Figure 4-6-3 – System function diagram

Roles

The implementation mode of this case is centred on technical maintenance, as well as perfecting and promoting data applications. IT engineers maintain stable operation of the platform and control user rights. Technical maintenance engineers develop data communication programs, ensure equipment connection rates, develop data display boards, provide training, establish predictive models and formulate data access and usage rules. On-site maintenance personnel, based on the display boards or model information, carry out on-site maintenance actions and close-loop verification of the model effect. In line with customised rules and received training, quality, process and production personnel develop related Kanban applications to drive higher data value.

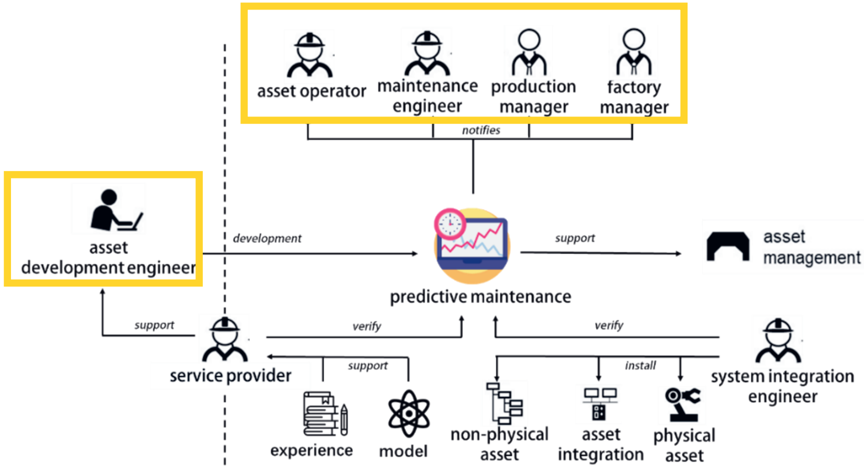


Figure 4-6-4 – Implementation role diagram

System architecture

The predictive maintenance platform architecture for electric welding equipment is shown in Figure 3. The hardware mainly includes field equipment (robots, welding equipment, PLC, etc.), big data centre servers, etc. The software mainly includes NodeRed data transfer, ES database, Kibana&Tableau front-end data display, etc.

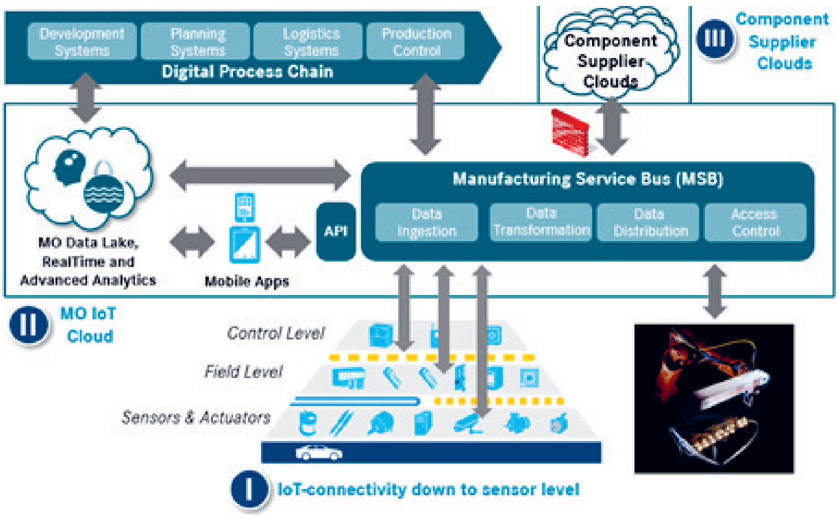


Figure 4-6-5 – System architecture diagram

Functions and methods

The spot welding predictive maintenance platform combines the experience of equipment experts with the real-time log data of equipment. Based on the output of the existing equipment failure analysis model, the equipment log is classified and analysed, so as to scrutinise the main components of the spot-welding equipment, including welding gun motor, busbar, electrode rod, dresser, voltage feedback line, welding control cabinet battery, etc. make predictions and give maintenance priority guidance. Its main functions are:

- monitoring the number of working cycles of the equipment;
- early in-depth maintenance warning for spot welding motors;
- spot welding busbar damage prediction;
- spot welding motor rod wear prediction;

- fault prediction for dresser blade and revolution sensor;
- forecast of battery power in welding control cabinet;
- abnormal prediction of RAM in welding control cabinet.

Feature highlights

The outstanding features of the spot welding predictive maintenance platform are as follows:

- Combines FMEA-based equipment analysis failure model (equipment expert experience) with real-time big data analysis.
- Data collection integrity and stability: high-speed, large-capacity data transmission and processing capabilities, high-precision, low-latency control performance, expandable and easy-to-maintain use characteristics, to ensure complete and stable collection of equipment data.
- Flexibility and easy scalability: based on Node-RED, users can personally define the type and information structure of the transmitted data, realise information fusion and improve data efficiency and application flexibility.
- Predictive maintenance work priority guidance: give work priority guidance through sorting.
- Creates a prediction model verification method and verification process, verifies and optimises the accuracy of each item.
- Creates an evaluation index system for evaluation (optimising).
- Openness: the platform is open and users can quickly get started with developing custom Kanban functions.
- Closed loop work: the prediction result enters easyiPro to form a work order, triggers on-site work and analyses the actual work feedback data in easyiPro to optimise the original model to form a closed loop.

Visualisation

The predictive maintenance interface for spot welding is shown in the figure below, which is concise and clear. The screening and trend area at the top allows you to screen workshops and areas and view the overall trend. Each view of the functional area corresponds to the predictive maintenance for a spot welding equipment component; the title of the view is the maintenance process content, standard working hours and the status of the production line to be repaired for the component. The main body of the view is the predicted location of each device with priority sorting. Devices that exceed the red threshold line require predictive maintenance. Place the mouse on the view and the data details will be displayed. It is easy to view by on-site engineers and managers.

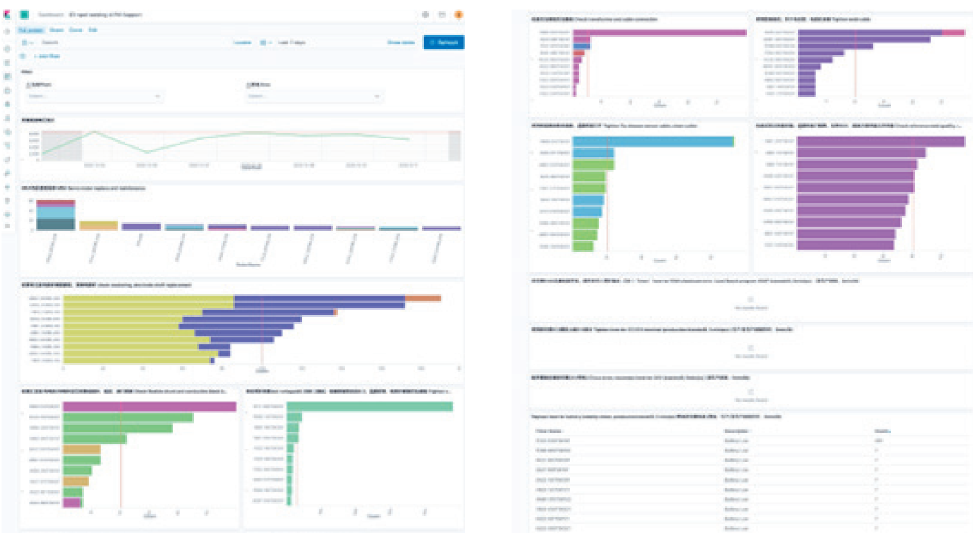


Figure 4-6-6 –Spot welding predictive maintenance page *Copyright: BBAC*

At the same time, if you have doubts about the predicted spot welding equipment or need in-depth analysis, you can view the real-time parameter trend of the spot welding equipment, such as welding current, welding time, etc., through the real-time monitoring page of welding parameters in the figure below.

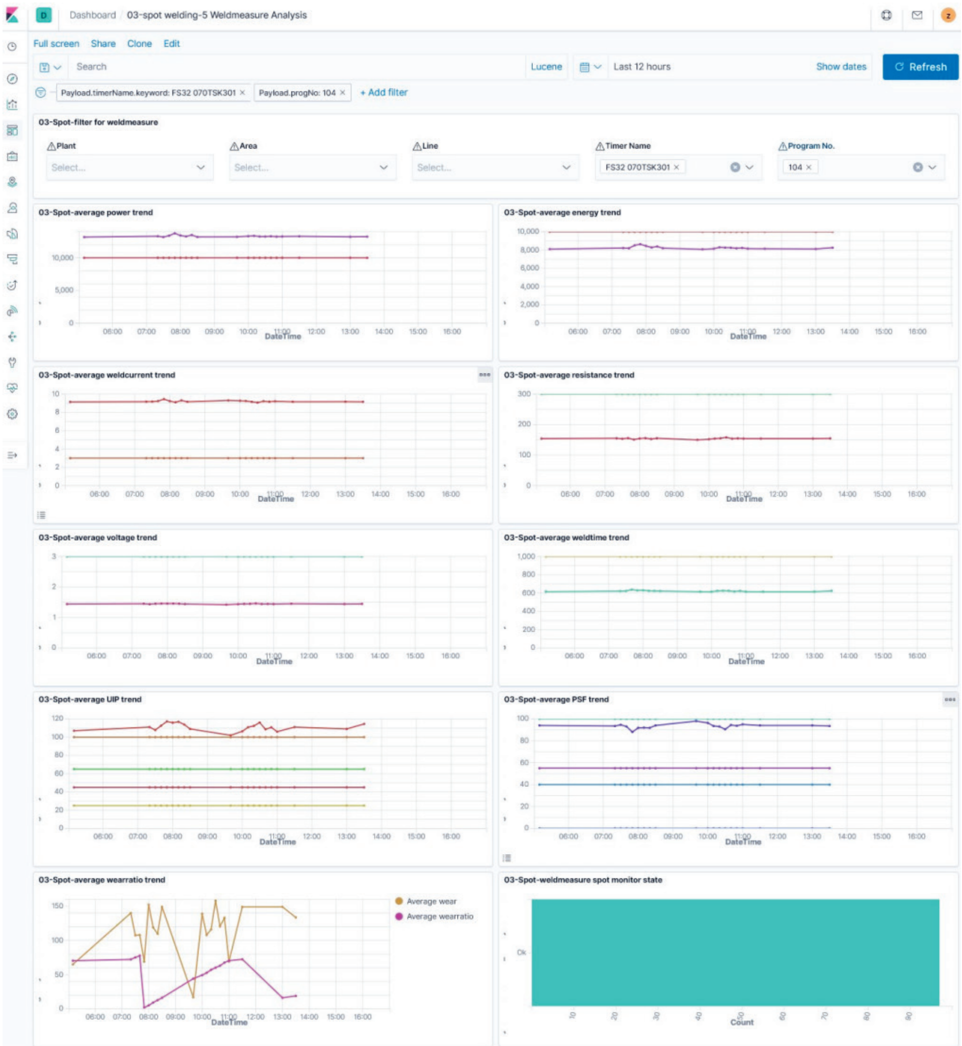


Figure 4-6-7 –Real-time monitoring of welding parameters for spot welding equipment *Copyright: BBAC*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
spot welding equipment	servo motor	motor lead screw wear	Number of working cycles	system timer
			motor pressure	pressure sensor (internal)
			welding current, voltage and time	transformer sensor (internal)
		pressure sensor failure	motor pressure	pressure sensor (internal)
	busbar	busbar wear and ablative	welding current, voltage and time	transformer sensor (internal)
	repair the mould tool	tool wear	speed	sensor (internal)
			number of use	system timer
			welding current, voltage and time	transformer sensor (internal)
	battery	battery failure	battery voltage	sensor (internal)
	electrode stem wear	electrode stem wear	zero offset of the torch	robot system data
			error message of robot	error message of robot
	RAM abnormal	RAM abnormal	system diagnosis information	system information

Table 4-6-1 – Data requirements for scenarios

Scenario 7: Condition monitoring and RUL prediction for CNC machine tools

Overview

The CNC machine tool is a flexible, high-performance automatic machine tool, but in the process of repeated machining, certain key components such as machining tools are prone to damage. Considering the total value of engineering (TVOE), to save operating costs, predictive maintenance for the tools and rotating equipment of CNC machine tools can reduce the entire workshop's life cycle cost (LCC). The savings can be used to expand future investment. Mitsubishi introduced a predictive maintenance system for the CNC machine tools of a mechanical and electrical equipment manufacturing company and installed the system on the edge computing equipment of Mitsubishi Electric to implement predictive maintenance functions for NC tools and rotating equipment. As shown in the figure below, this system carries out monitoring, diagnosis and life prediction functions in the system architecture, covering Level 0, Level 1 and Level 2.

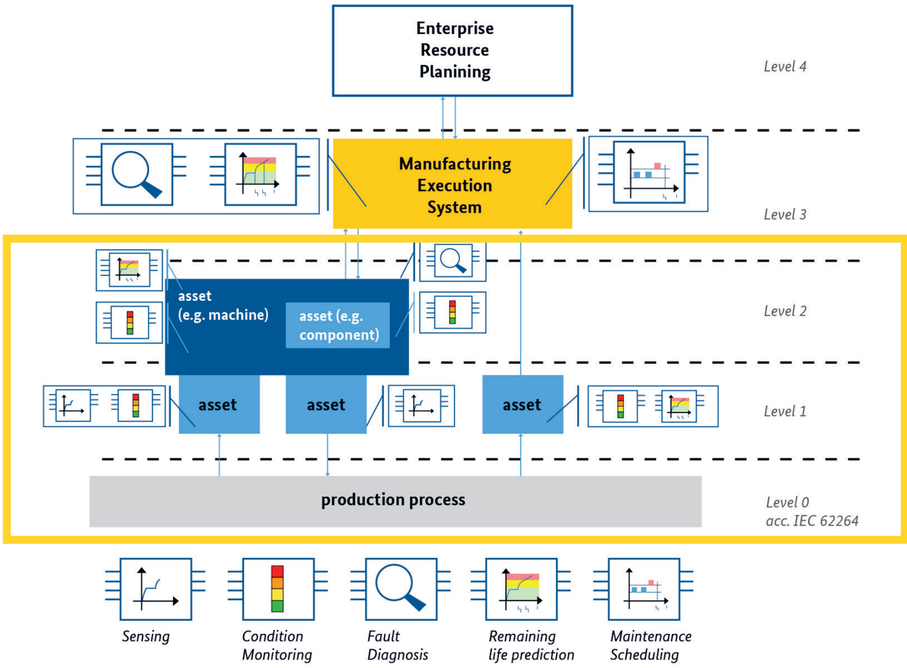


Figure 4-7-1 – System level diagram

The objects of predictive maintenance are divided into NC tools and rotating equipment. For NC tools, tool replacement costs are reduced mainly by transitioning NC tool management from times-based management (TBM) to condition-based management (CBM). In addition, predictive maintenance for NC tools can also be used to predict deviations in machining accuracy and investigate the causes of variations.

For rotating equipment, by installing a vibration detection system, the wear of the bearing can be detected and maintenance can be carried out in time. The predictive maintenance functions of NC tools and rotating equipment are shown in the following table.

	Function	Description
1	Processing IoT data collection	Automatic collection of processing waveforms and data with preset processing conditions
2	Tool wear diagnosis (wear prediction)	Diagnose the tool's wear status (remaining life) based on the trend of the motor load on the spindle/transmission axis.
3	Tool wear diagnosis (tool defect diagnosis)	Detect the lower limit deviation (=defect) of the processing workload and display an alarm.
4	Machining accuracy diagnosis	By analysing the correlation between workpiece dimensions and spindle current values after NC machining, it is possible to predict the dimensions during machining and diagnose machining accuracy.

	Function	Description
5	Beat improvement support	Display the load status and workload of each tool or processing program through visualisation and help customers reduce the beat through optimisation of the processing program.
6	Preventive maintenance	Diagnose the soundness of NC equipment by monitoring the change in machining load and the difference in the standard deviation of characteristic values during the same machining process of the same model (workpiece).
7	Rotating equipment vibration monitoring	By installing vibration detection and uploading vibration data to the server in real time, the wear of the bearing can be detected and the maintenance plan can be formulated only when an alarm occurs, effectively reducing downtime and maintenance costs
8	Alarm display	Display various types of alarms generated by the diagnosis results and alarm information related to system abnormalities.

Table 4-7-1 – The predictive maintenance functions of NC tools and rotating equipment

The predictive maintenance system of Mitsubishi Electric carries out the functions of sensing, condition monitoring, fault diagnosis and life prediction of CNC machine tools, as shown in the figure below:

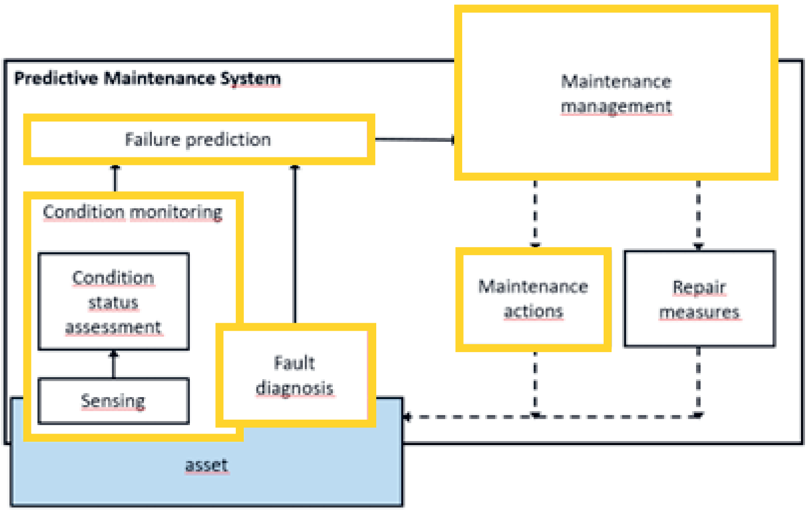


Figure 4-7-2 – System function diagram

Roles

In this case of predictive maintenance of CNC machine tools, Mitsubishi Electric's role is as a service provider and the electromechanical equipment manufacturing company in this case is the main production body. Its role covers asset operators/maintenance engineers/production managers and factory managers. Mitsubishi Electric is mainly responsible for providing predictive maintenance software and hardware equipment, construction plans and data/models, as shown below:

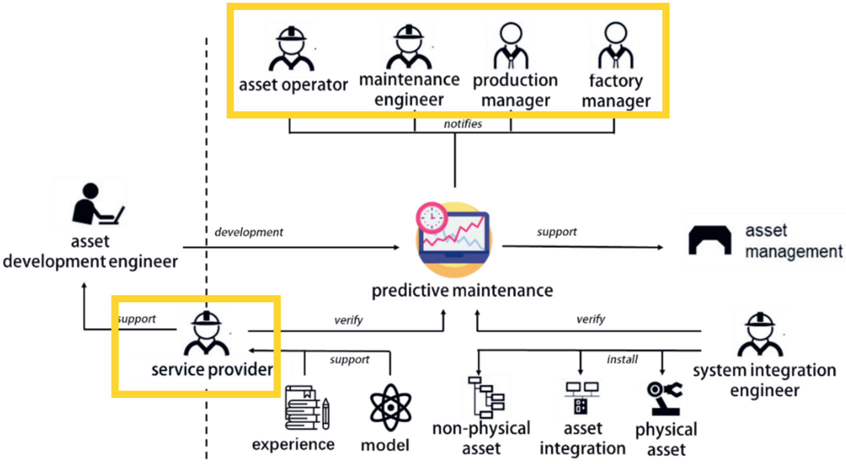


Figure 4-7-3 – Implementation role diagram

System architecture

The system architecture for predictive maintenance of CNC machine tools is shown in the figure below. NC tools and rotating equipment deploy vibration, CT and other sensors, synchronously collect vibration sensor signals and PLC signals and feed them to Level 2 real-time data analysis software (RDA). Functions such as edge computing, condition monitoring and processing beat improvement are carried out.

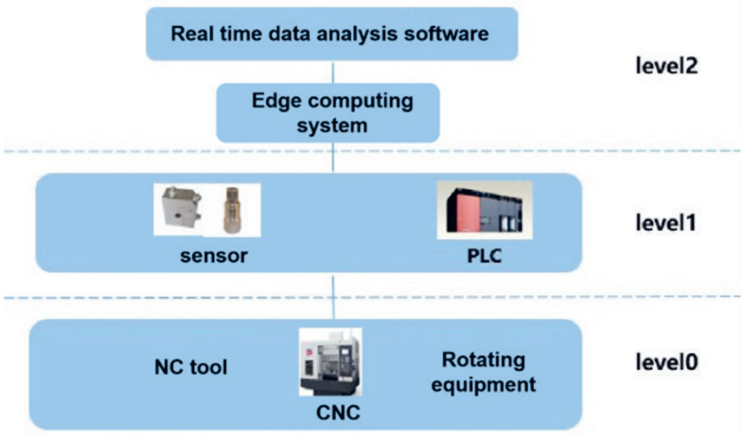


Figure 4-7-4 – System architecture diagram

Functions and methods

Predictive maintenance for CNC machine tools mainly performs the functions of data collection, condition monitoring, fault diagnosis and life prediction for critical components. The functions it recognises include:

- NC tool sharpness monitoring: through current data, threshold judgment, etc., the sharpness/status of the tool can be monitored.
- Improvement of processing speed and processing accuracy: modelling is performed by analysing the data collected by sensors, using tool defect diagnosis to improve speed, optimising production time and improving production efficiency.
- Detect the vibration spectrum of rotating equipment through vibration sensors, thereby reducing the occurrence of bearing failures, tracking equipment operating status, identifying the cause of damage and achieving predictive maintenance. The following figure shows the use of fast Fourier transforms in vibration analysis, identifying status by digitising the vibrations generated from the device and equipment.

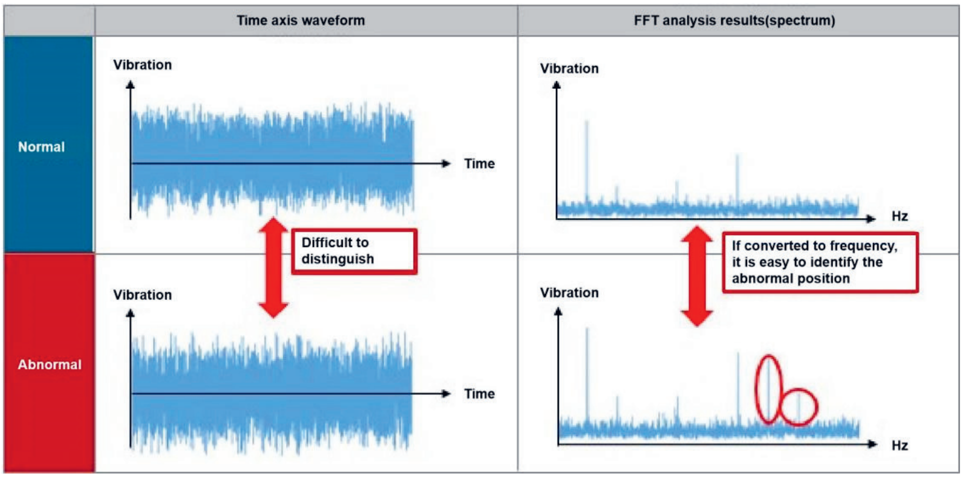


Figure 4-7-5 –Vibration data display for equipment *Copyright: Mitsubishi*

Feature highlights

The outstanding features of the predictive maintenance system for CNC machine tools are as follows:

- use edge computing to realise real-time data analysis; analyse and model through machine learning to perform predictive maintenance;
- installing a predictive maintenance system has little impact on CNC machine tools; the data required by the predictive maintenance system only accounts for 1% of total processing data, which has a low impact on production itself;
- change from TBM (counting of times) to CBM (status analysis): by customising different products, the tool maintenance time can be quantified, such as informing the user of remaining usage times for the tool;
- use predictive maintenance to reduce the operating cost of CNC machine tools with the aim of reducing the LCC of the factory/workshop;
- use big data to judge vibration data and carry out the planned and most suitable maintenance method. Reduce operating costs and improve equipment use.

Visualisation

The figure below is a visual interface for tool diagnosis. The blue curve is the average load of the tool, the red curve is the workload of the device, the yellow curve is the tool deterioration prediction. When the yellow curve is close to the upper threshold, the operator should be notified and assisted to change the tool.

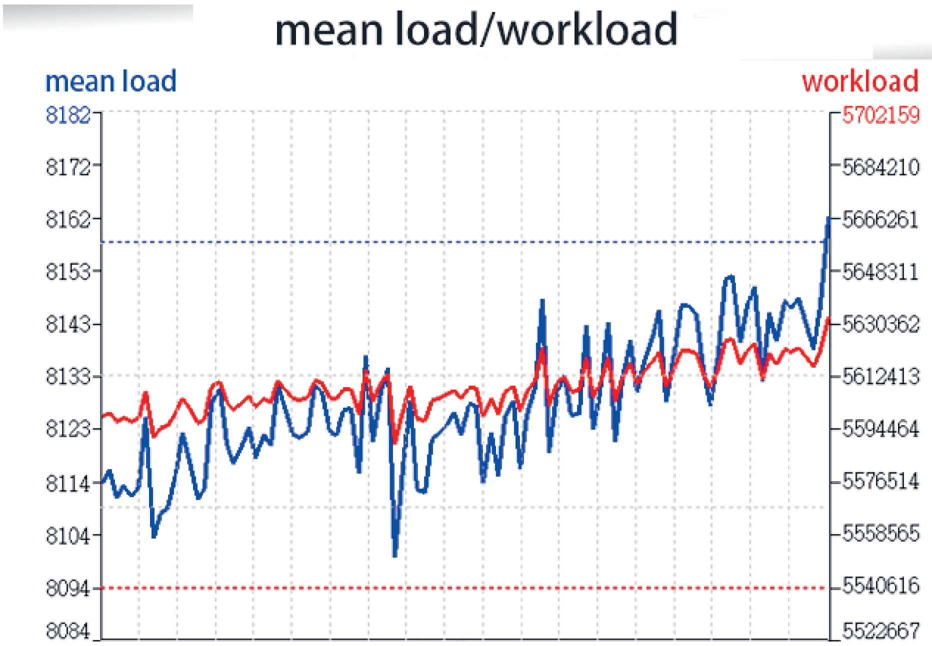


Figure 4-7-6 –Tool diagnosis interface *Copyright: Mitsubishi*

The figure below is the visual interface for vibration monitoring of rotating equipment. Through FFT analysis, it is possible to visualise vibration data. Anomalies can be detected by performing FFT analysis after processing the time axis waveform (original waveform) with digital filters and envelopes.

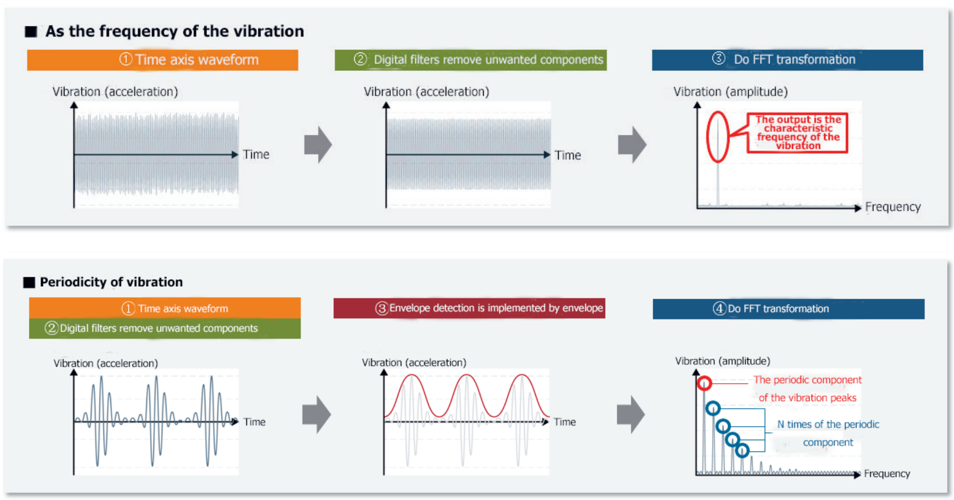


Figure 4-7-7 –Rotating equipment vibration monitoring interface

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
CNC machine tools	cutting tools	tool wear	spindle current	sensor
			usage times	counter
	bearing	bearing fault	vibration, temperature	sensor
			speed, load	PLC
		rotor eccentricity	speed, current, voltage	PLC
		stator winding insulation degradation	speed, current, voltage	PLC
		rotor demagnetisation / winding fault	speed, current, voltage	PLC
		rotor bar broken	vibration	sensor
			speed, current	PLC
	spindle	spindle bending	vibration	sensor
		spindle erosion	vibration	sensor
	leadscrews	screw rotation distance	running distance	counter

Table 4-7-2 – Data requirements of scenarios

Scenario 8: Condition monitoring for wind turbine blades –BLADEcontrol®

Overview

BLADE control®, the condition monitoring system for wind turbine blades, was developed by Weidmüller Interface (Shanghai) Co. Ltd. (Weidmüller) and has been successfully applied to more than 3,000 sets of wind turbines of various types.

With the continuous development of the scale and technology of wind power generation, the trend for large-scale wind turbines is becoming more and more apparent and the size of wind turbine blades is also increasing.

The increase in blade length increases the efficiency of wind energy capture and, at the same time, increases the probability of blade breakage and damage. Generally, the main reasons for blade breakage include poor process control during the production process, reduced strength and rigidity caused by incomplete resin curing in the partial area of the blade root, excessive wind speed, wind turbine stall, electrical failure and lightning strikes. As the years of operation increase, the current lack of monitoring of the state of wind turbine blades has caused their operation and maintenance levels to fall far behind, making blade failure unpredictable. An inability to achieve standard efficiency in production has resulted in a loss of power generation and degradation of safety performance.

Regardless of safety or economic benefits, research into monitoring the operating state of blades is vital. The platform's position in the production system architecture is shown in the figure below, covering Level 0, Level 1 and Level 2.

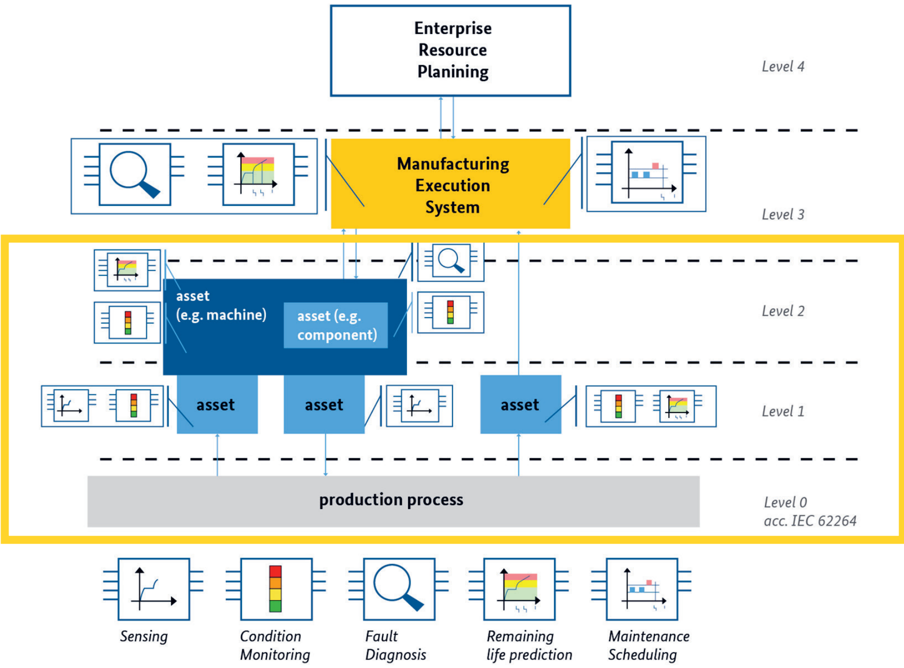


Figure 4-8-1 – System level diagram for BLADEcontrol®

The platform can realise functions such as vibration sensing, status evaluation, fault diagnosis, status trend prediction, maintenance and management of wind turbine blades, as shown below.

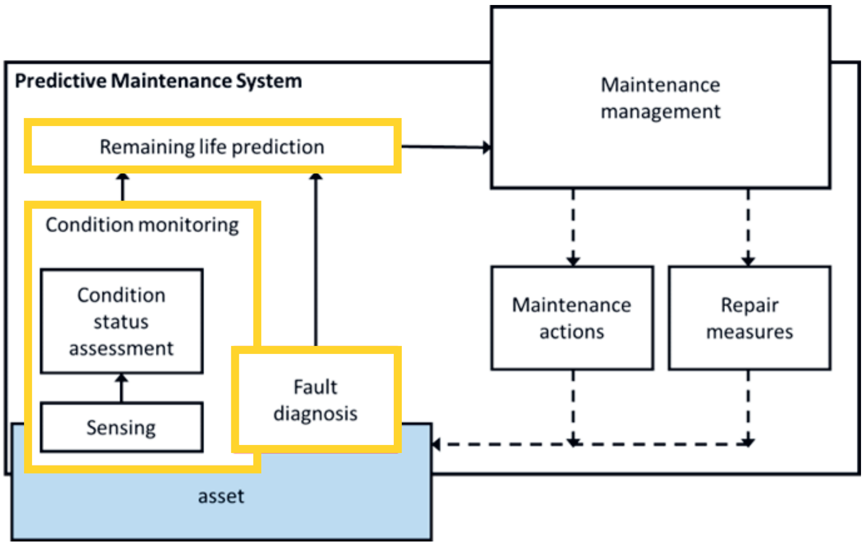


Figure 4-8-2 – System function diagram for BLADEcontrol®

Roles

The implementation model for this case is that Weidmüller cooperates with wind turbine manufacturers to apply predictive maintenance solutions and perform predictive analysis and maintenance in the condition monitoring system for wind turbine blades. Weidmüller mainly provides condition monitoring, implementation plans and data model and algorithm support; the role of the complete machine manufacturer is the system integration engineer, who is primarily responsible for connecting the system monitoring functions to the hardware and software of the wind turbine in order to achieve seamless system integration.

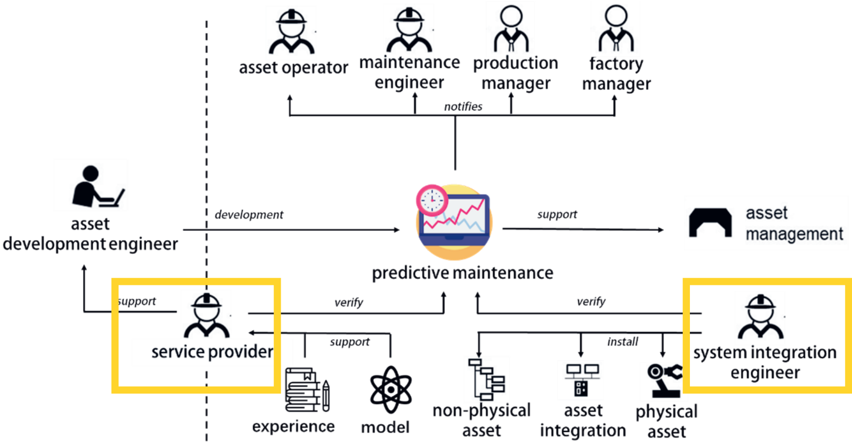


Figure 4-8-3 – Implementation role diagram

System architecture

The figure below shows the architecture of the BLADEcontrol® platform for the wind turbine blade condition monitoring system. The hardware mainly includes high-precision acceleration sensors, data acquisition and measurement units, wireless access points and data evaluation servers in the cabin. The software mainly includes a condition monitoring and health management system, as well as an alarm system for abnormal blade status.

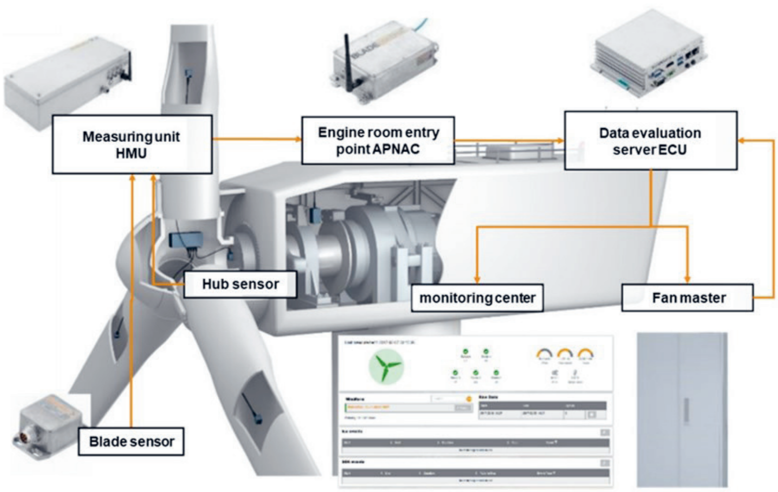


Figure 4-8-4 – Platform architecture diagram for BLADEcontrol®

Functions and methods

The blade condition monitoring system uses high-precision acceleration sensors to collect the vibration signals of the blade swing and swing direction and then determines the natural frequency model of the blade through artificial intelligence-specific algorithms and data models. After the blade vibration model is established, the blade online state monitoring system performs real-time collection, calculation and analysis and gives warning or alarm signals for the abnormal state of the blade.

Through this blade condition monitoring system, it is possible to identify in good time any external damage to the blade, lightning damage, internal structural damage, dynamic imbalance or other problems with the blade itself. At the same time, the system can accurately detect the icing condition of the blade in winter to achieve precise start and stop, increase production efficiency and reduce safety risks.

Feature highlights

The outstanding features of the BLADEcontrol® wind turbine blade condition monitoring system are as follows:

- Abnormal status detection: according to each device's daily operational status data, the system can for the first time detect any abnormal condition with the fan blade.
- Abnormal situation location: after identifying the abnormal situation, the system can quickly locate the fault point and cause of the fault, reducing troubleshooting time and narrowing the scope of troubleshooting.
- Predictive maintenance: it can predict failures in advance, avoid unexpected shutdowns and significantly improve the availability of wind turbine equipment.
- Predictable quality control: it can continuously monitor the quality of fan blades and their quality deviation trends, avoid a lot of product testing work and reduce wastage of raw materials, which is convenient for predicting inventory management for the blades.
- Energy analysis: it can continuously monitor the power generation status of the wind turbine, provide optimisation suggestions, reduce costs by reducing load fluctuations and avoid load imbalances. At the same time, predictive maintenance can significantly increase the life expectancy of the wind turbine and blades, thereby further reducing the cost of electricity.

Visualisation

The software-level interface uses legends to clearly and simply indicate each sensor's installation position and direction on the blade. When the system sounds an alarm, the faulty blade and alarm information are precisely shown, straightforward to view and simple to analyse.

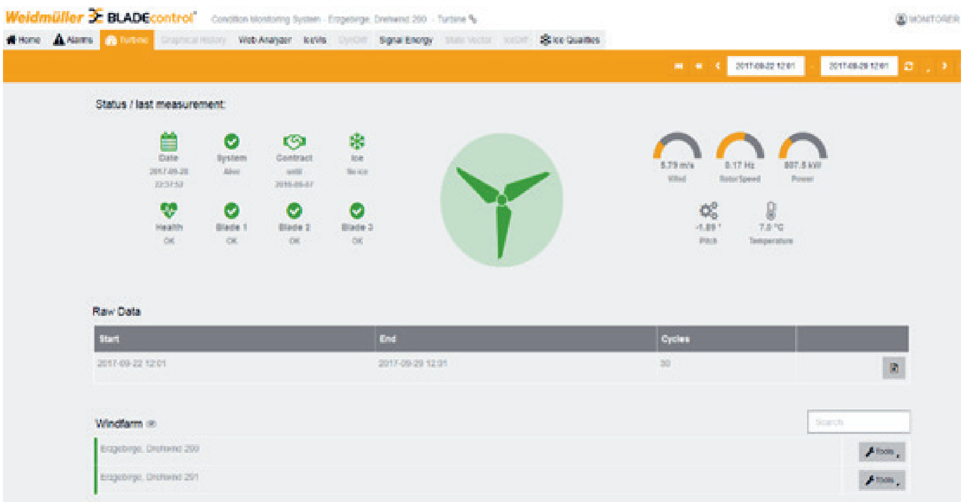


Figure 4-8-5 –BLADEcontrol® platform interface for fan blade condition monitoring system *Copyright:Weidmüller*

The blade condition monitoring and analysis software is installed on the wind farm site server. The software has a user-friendly human-computer interaction platform interface, powerful analysis and diagnosis capabilities and expert functions. This software mainly includes a monitoring module and the fans' status database. The background data management module needs to continuously receive and save status signals (vibration data, unit working condition data, etc.), statistics and other information from the measuring points of each unit. This information includes characteristic values for vibration measuring points, time-domain waveforms and other data, enabling the user to call up test data for graphical analysis at any time.

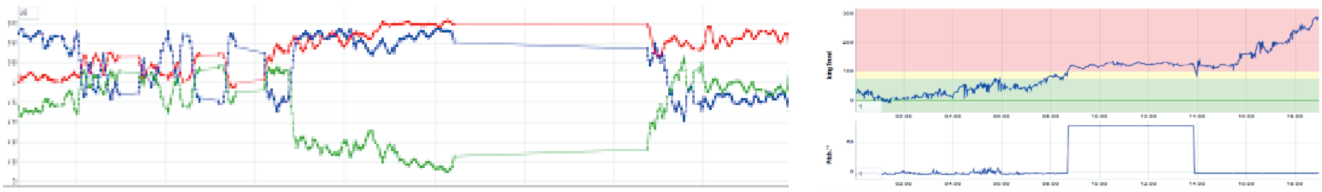


Figure 4-8-6 – BLADE control® platform data interface for wind turbine blade condition monitoring system

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
wind turbine	blade	icing on the blade	frequency/temperature/power/wind speed/pitch angle	acceleration sensors
		cracks on the blade	frequency/temperature/power/wind speed/pitch angle	acceleration sensors
		tip split-off due to lightning strike	frequency/temperature/power/wind speed/pitch angle	acceleration sensors
		structural damage	frequency/temperature/power/wind speed/pitch angle	acceleration sensors
		delamination of the blade	frequency/temperature/power/wind speed/pitch angle	acceleration sensors

Table 4-8-1 – Data requirements of scenarios

Scenario 9: Predictive maintenance for axial and centrifugal compressors

Overview

The purpose of this document is to introduce the application of Bently Nevada transducers and protection and monitoring systems on axial and centrifugal compressors with fluid film bearings – classified as critical machines. The American Petroleum Institute (API) 617-style compressors are typically found in refinery and petrochemical applications. Bently strongly recommends continuously collecting, trending and analysing the radial vibration, axial position and temperature data using a machinery management system such as System 1* software. The use of these tools will enhance the ability to diagnose problems and analyse the performance of compressors. Bently's various sensors, the 3500 machine condition monitoring & protection system, System 1*software, Thermodynamic performance software and Automated Machinery Diagnostic Functionality RulePak implement condition monitoring, diagnostic performance analysis and remaining life prediction for the compressors, which covers layers of Level 0, Level 1, Level 2 and Level 3.

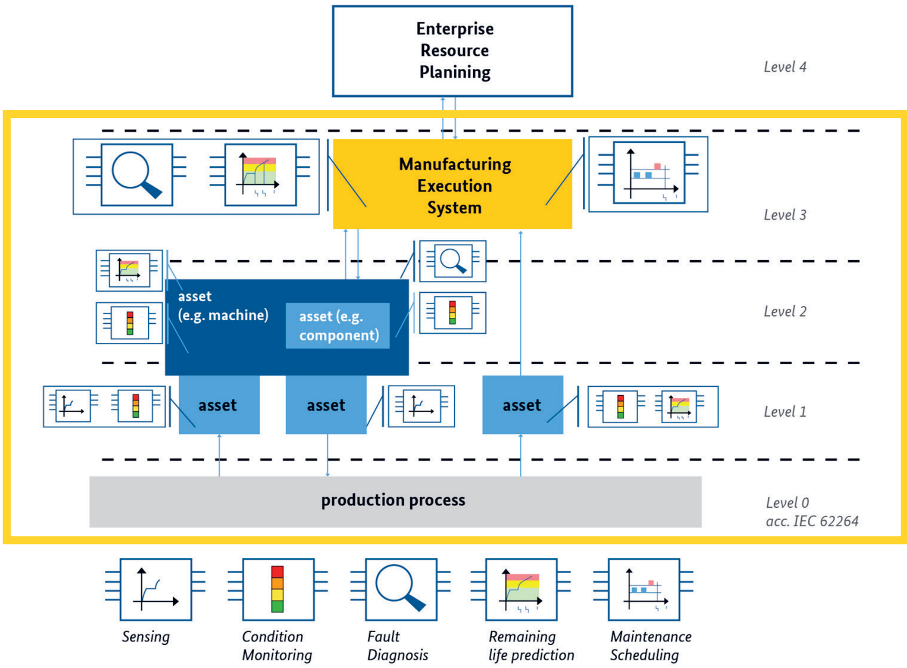


Figure 4-9-1 – System level diagram

Bently's Condition Monitoring, Diagnostics & Predictive Maintenance system for axial and centrifugal compressors deploys transducers for vibration, speed, pressure, flow, temperature etc., and implements sensing, condition monitoring, diagnostics and predictive maintenance functions, which are shown as follows:

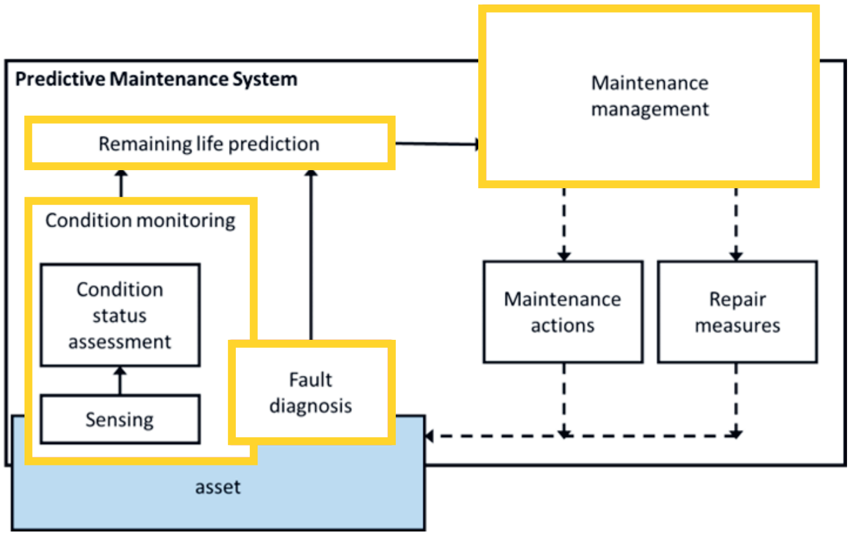


Figure 4-9-2 – System function diagram

Roles

There are various predictive maintenance technologies. Bently is the service provider that provides predictive maintenance HW/SW, architecture, data/modelling, and the system integrator who connects predictive maintenance functions with the HW/SW to implement system integration.

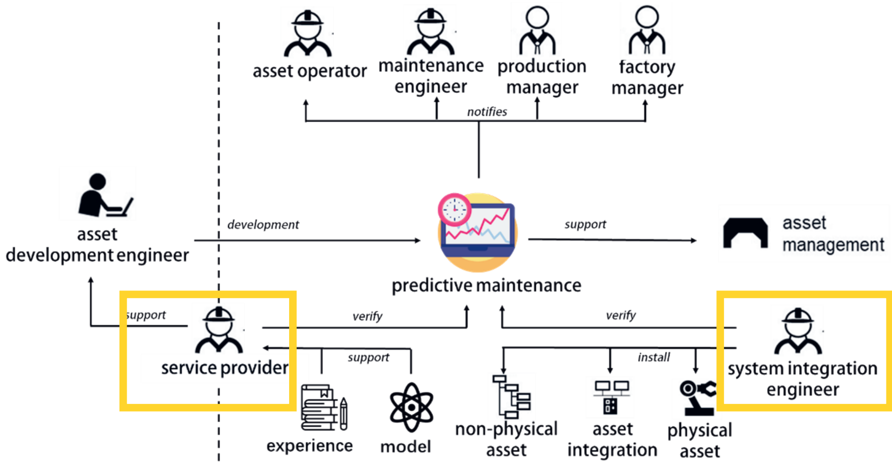


Figure 4-9-3 – Implementation role diagram

System architecture

The system architecture for Bently's Condition Monitoring, Diagnostics & Predictive Maintenance system for axial and centrifugal compressors is as follows:

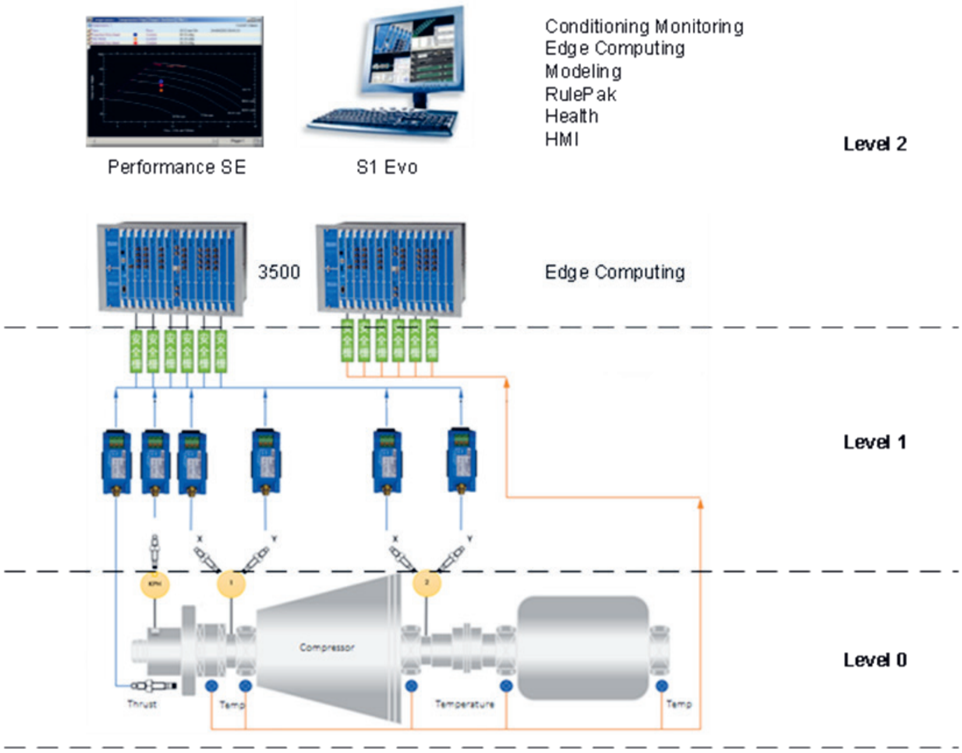


Figure 4-9-4 –System architecture diagram

These transducers deployed for vibrations, speed, pressure, flow and temperature are used to implement condition monitoring, modelling, edge computing, performance analysis and health management.

Functions and methods

Bently's Condition Monitoring, Diagnostics & Predictive Maintenance system for axial and centrifugal compressors implements sensing, condition monitoring, failure diagnostics, asset health and predictive maintenance functions.

- IoT management and edge computing management: perform edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management, etc.
- Big data service and cloud platform management: mainly realise the construction of the operating environment for the predictive maintenance algorithm model, data centre data analysis and processing, including process management, model management, equipment management, access service, data service, system management and other modules.
- Performance analysis: improve overall production capability, control costs through optimised maintenance activities, improve diagnostics and decision-making, automate data analysis and advisories, provide fast and easy combustion problem diagnostics.
- Modelling and asset health evaluation: Rulepak implements the compressor failure mode and anomaly detection process within the machinery management system and provides continuous asset health prediction.

Feature highlights

Bently's Condition Monitoring, Diagnostics & Predictive Maintenance system for axial and centrifugal compressors has the following features:

- Reliable data acquisition from 3500.
- Accurate failure diagnostics for compressor surge, compressor stall, unbalance, electrostatic discharge, misalignment, rubs, etc.
- System 1 software's ability for plant personnel to quickly identify important events, evaluate the situation and respond results in

increased asset availability, enhanced reliability and reduced maintenance costs.

- PERFORMANCE* SE* software providing online, continuous real-time calculation of machinery performance parameters helps to improve overall production capability, control costs through optimised maintenance activities, improve diagnostics and decision-making, automate data analysis and advisories, and provide fast and easy combustion problem diagnostics.
- Pre-configured diagnostic RulePaks automate the compressor failure mode and anomaly detection process within the machinery management system. The real-time analysis provides continuous asset health feedback to the user.

Visualisation

Bently's Condition Monitoring, Diagnostics & Predictive Maintenance system for axial and centrifugal compressors can handle diagnostics failures accurately for compressor surge, compressor stall, unbalance, electrostatic discharge, misalignment, rubs, etc. Below is a visualisation for the compressor stall.

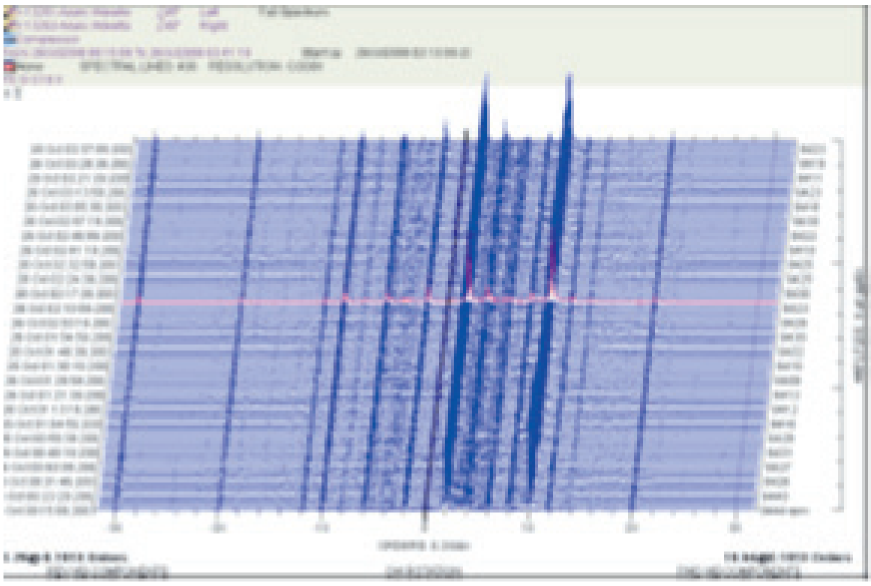


Figure 4-9-5 – Subsynchronous component at approximately 0.2X and accompanied orbit/timebase plot, caused by stall in the stationary channels

Copyright: Bently

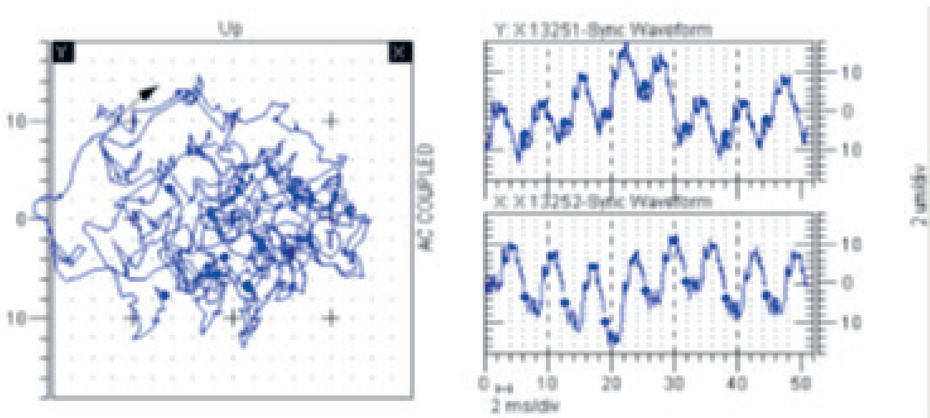


Figure 4-9-6 – Full size sample orbit for stationary channel (diffuser) stall *Copyright: Bently*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
axial flow and centrifugal compressors	compressor inboard	surge stall unbalance electrostatic discharge misalignment rubs	KeyPhasor	3300XL proximity probe, 3500/25 monitor
			radial vibration	3300XL proximity probe, 3500/40 or /42 monitor
			axial thrust position	3300XL proximity probe, 3500/40 or /42 monitor
			temperature	RTD/TC sensor, 3500/60 or 61 monitor
	compressor outboard		radial vibration	3300XL proximity probe, 3500/40 or /42 monitor
			axial thrust position	3300XL proximity probe, 3500/40 or /42 monitor
			temperature	RTD/TC sensor, 3500/60 or 61 monitor

Table 4-9-1 – Data requirements of scenarios

Scenario 10: Predictive maintenance for supercritical large power units

Overview

MUMBAI, Maharashtra, India-Tata Power is one of the largest integrated power companies in India and has important international influence. Tata Power is looking for a solution to implement group-wide monitoring and diagnostic procedures to continuously monitor the operating status and performance of all power plant equipment and convert its data into real-time monitoring for active maintenance and more efficient operations, through early warning of equipment problems to prevent unplanned shutdowns and forced shutdowns.

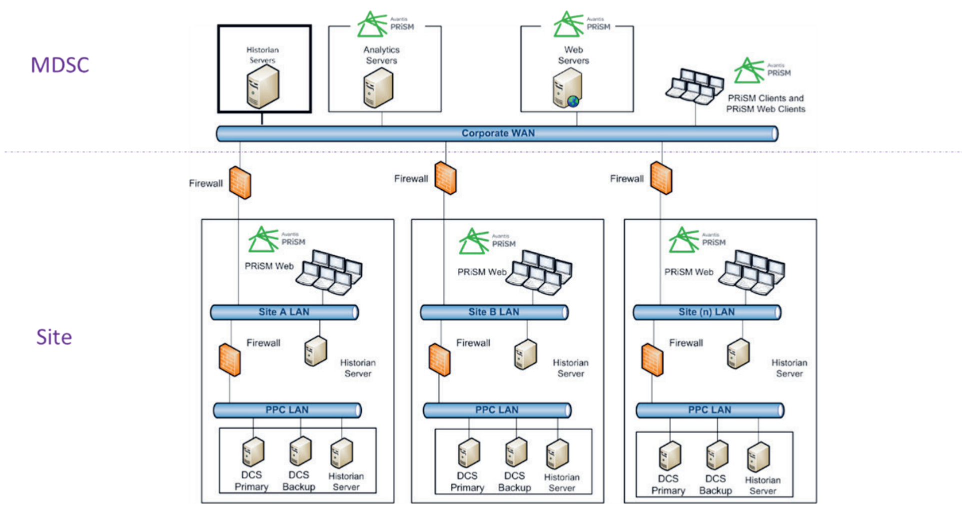


Figure 4-10-1 –Monitoring and diagnostic program solutions

Tata Power Company chose AVEVA PRiSM predictive asset analysis software as a key tool for its remote monitoring and diagnosis centre, and set three stages for the PRiSM predictive asset analysis of its supercritical large power project (CGPL-MUMPP). The first in the phase, AVEVA's Maintenance, Diagnosis and Service Centre is used for model building, adjustment and training. The second phase will cover the other three units at Mundra and two units at Trombay.

The predictive maintenance project for supercritical large-scale units has built a software and hardware system to realise predictive maintenance for critical large-scale units. The project has carried out condition monitoring, fault diagnosis and life prediction in the system architecture, as shown in the figure below, covering Level 0, Level 1 and Level 2.

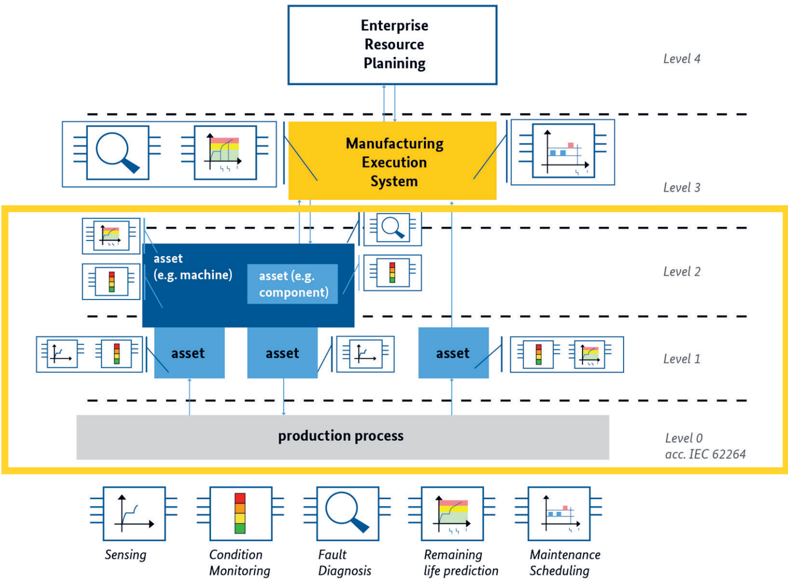


Figure 4-10-2 – System level diagram

The predictive maintenance system for supercritical large-scale units performs the functions of sensing, condition assessment, fault diagnosis and life prediction for supercritical large-scale units, as shown in the figure below:

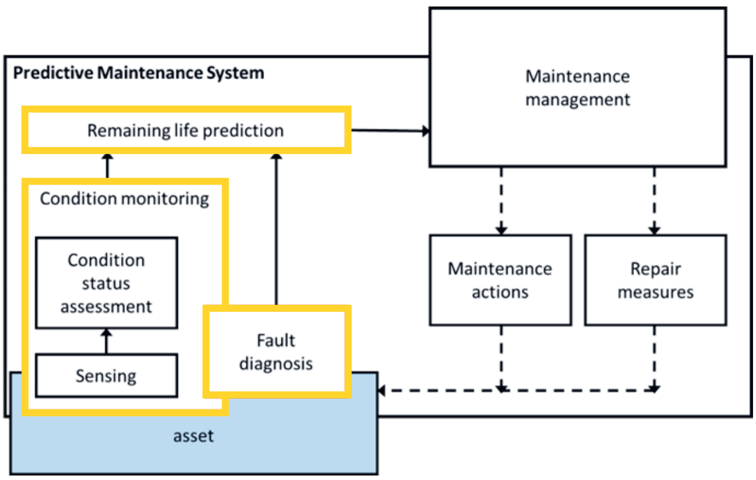


Figure 4-10-3 – System function diagram

Roles

In the construction of the predictive maintenance system for supercritical large-scale units, AVEVA plays the role of both service provider and system integration engineer, mainly responsible for providing predictive maintenance technology, system construction solutions, system integration and data/model support.

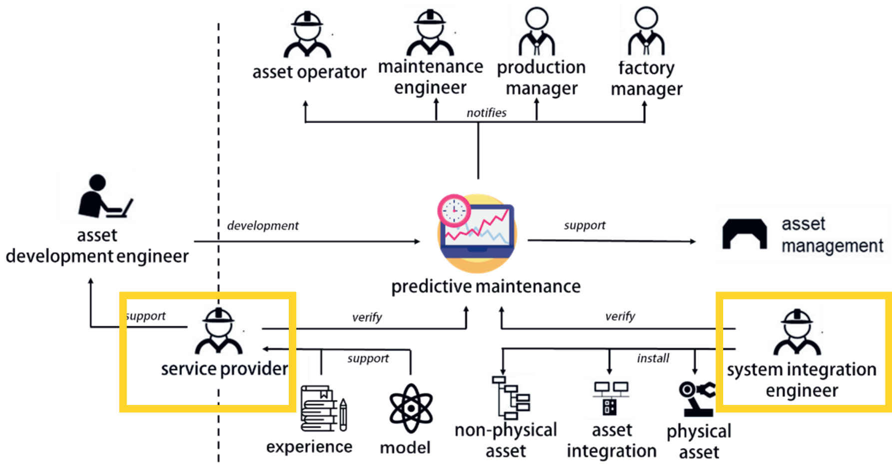


Figure 4-10-4 – Implementation role diagram

The functional architecture of the system is shown in the figure below:

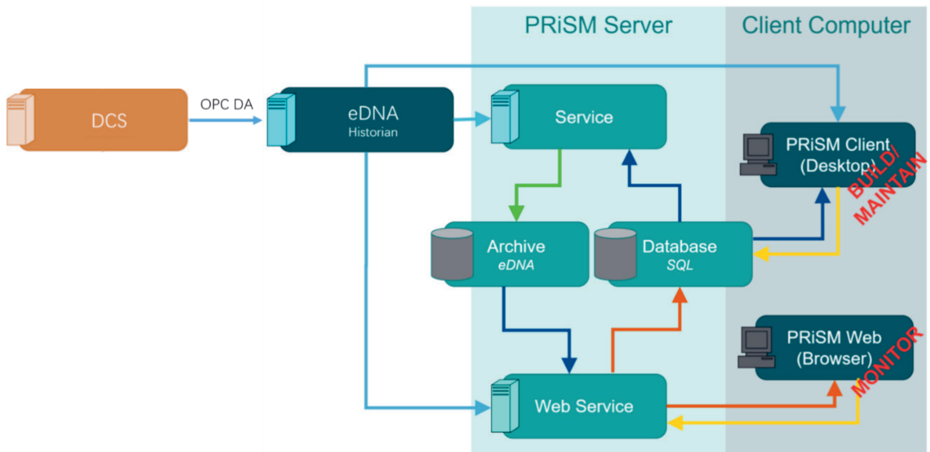


Figure 4-10-5 – System architecture diagram

- PRiSM Service——Process PRiSM analysis model.
- PRiSM Archive eDNA——PRiSM has a built-in high-performance real-time database, which stores the sensor-related data passed from the PIMS data source and the calculation data of the PRiSM calculation module.
- PRiSM Database SQL database – model database, storing all model configuration attributes, alarm records, training data sets, etc.
- PRiSM Web Service – an advanced web-based application that allows users to interact with and analyse the results of PRiSM.
- PRiSM Client software – a client program for

software configuration and management. The PRiSM client is an application used to build and deploy models.
- PRiSM Web Client – with the help of a web browser, you can monitor equipment alarms, browse alarm information, analyse data and perform other operations.

Functions and methods

Overview of AVEVA PRiSM features:

- online equipment status monitoring;
- based on advanced pattern recognition technology;
- solutions focused on asset health monitoring;
- data-driven model;
- early warning monitoring of upcoming equipment problems and/or failures;
- advanced problem analysis and diagnosis capabilities.

The system adopts the AVEVA PRiSM predictive asset analysis solution to monitor the key assets of the whole group and carry out the continuous improvement and maintenance plan:

- AVEVA PRiSM enables personnel to reduce the time spent manually collecting and analysing data, so that engineers and experts can perform higher-value tasks and create more time for initiative;
- AVEVA PRiSM predictive asset analysis has been configured to send alerts and related reports to the appropriate personnel at the appropriate time, so as to share information among various stakeholders before making decisions.
- AVEVA PRiSM predictive asset analysis also equips Tata Power Company with a knowledge capture function, which helps to detect operation and maintenance problems in a timely manner and standardises detection and resolution procedures.

Feature highlights

In addition to predictive analysis solutions, AVEVA also provides asset strategy optimisation solutions to achieve continuous improvement of asset lifecycle management. The AVEVA asset strategy optimisation software solution is a stand-alone application that has all common EAM system interfaces. It is a powerful and comprehensive support tool that helps maintenance engineers and reliability engineers design, manage and optimise maintenance strategies.

AVEVA asset strategy optimises the use of intelligent APM technology to improve the insight into operational performance with less effort, and more time to generate value. The software enables users to create and analyse the impact of different asset management strategies, providing clear insights into the consequences, results and benefits related to asset availability, productivity and profitability.

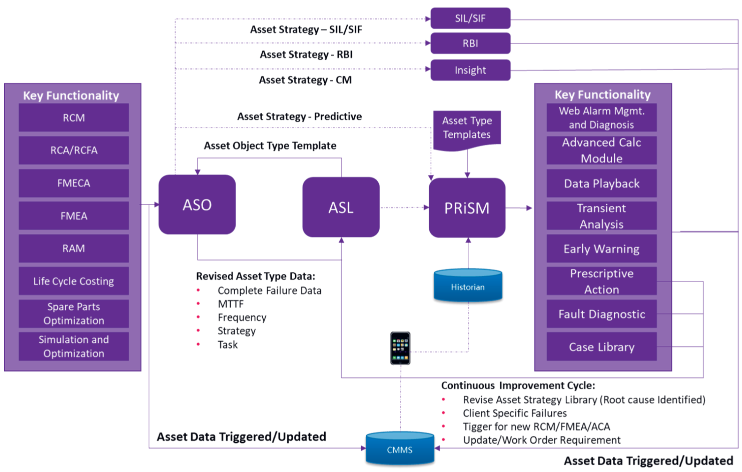


Figure 4-10-6 – APM closed loop continuous improvement cycle

Visualisation

The system deployed more than 300 models in the first phase, which provide regular monitoring and diagnosis for mechanical failures, performance deviations and transients. The interface is shown in the figure below.

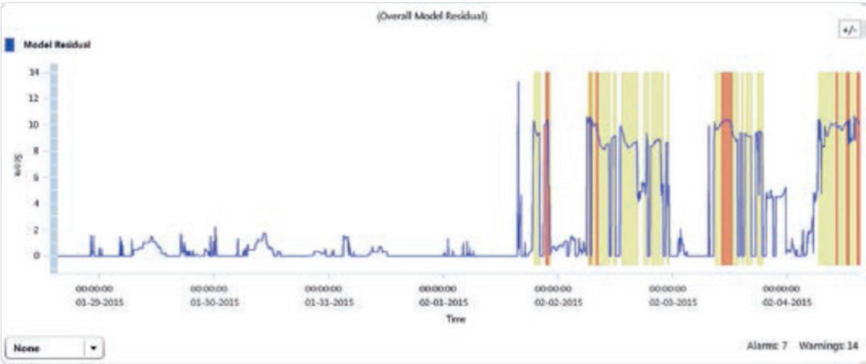


Figure 4-10-7 –Overall model deviation interface *Copyright: AVEVA*

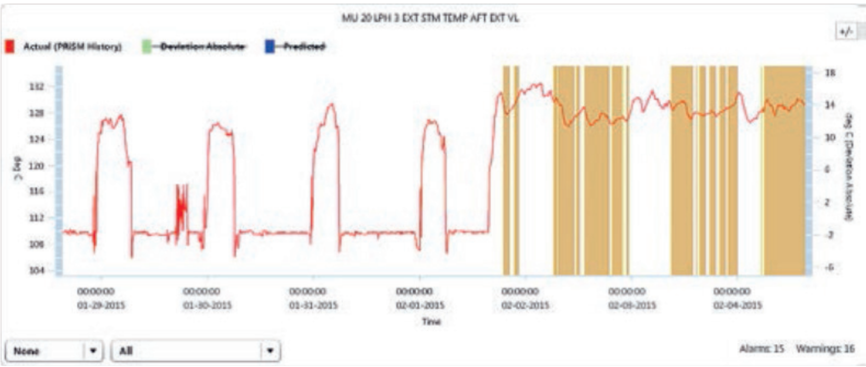


Figure 4-10-8 –Low-pressure heater extraction temperature trend interface *Copyright: AVEVA*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
power unit	boiler	overheating, blockage, leakage, coking	steam pressure, steam temperature, flow, load, liquid level, pressure	sensor
	turbine	mechanical fault	vibration, displacement, speed, teperature, load, lubricating oil temperature/pressure	sensor
		thermal fault	temperature, pressure, flow	sensor
	generator	mechanical fault	vibration, displacement, speed, temperature, load, lubricating oil temperature/pressure	sensor
		electrical fault	voltage, current, phase, vibration	sensor

Table 4-9-1 – Data requirements of scenarios

Scenario 11: Predictive maintenance for compressor

Overview

Compressors are important pieces of equipment in the process industry. In the daily operation and maintenance process, the response to anomalies or failures usually depends on the preset chain control mechanism in the unit monitoring system. In addition, the upper and lower limit settings of each measuring point in the conventional monitoring system and the configuration of the interlocking mechanism are highly dependent on the operating experience of equipment manufacturers and users. There is also a lack of analysis and prediction of actual operating conditions for the changed units.

Schneider Electric (China) Co., Ltd's (Schneider) predictive maintenance system PRiSM, as a functional module for predictive analysis in the system platform, analyses the relationship between equipment operating parameters, establishes a compressor normal operating state model, predicts its degradation trend, provides early compressor failure warnings and can diagnose faults according to the diagnosis rule base in the system analysis.

Predictive maintenance as a functional module in the system platform is shown in the figure below, covering Level 0, Level 1 and Level 2.

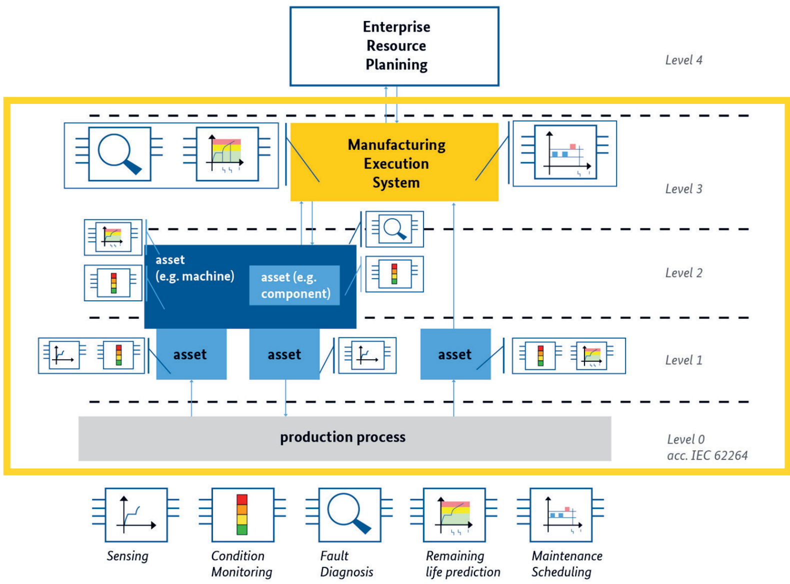


Figure 4-11-1 – System level diagram

The PRiSM predictive maintenance system supports standard connections with various real-time databases eDNA, PI, Wonderware Historian, IP.21. It provides data interfaces such as OPC UA, ODBC, SQL, etc., so it can easily operate remotely from the user's existing equipment. The VCenter system platform obtains data for compressor shaft vibration, shell vibration, displacement, speed, temperature, pressure and other data, as well as real-time operational data from each measuring point in the auxiliary system. This efficiently utilises existing measuring point resources and avoids duplicated sensor and transmission hardware investment, such as links.

Once the PRiSM predictive maintenance system is connected to existing real-time database data, it uses machine learning algorithms to establish a predictive analysis model to monitor the deviation between actual compressor operating status and model prediction results in real-time. The built-in alarm response management tool opens up response measures, including discovery of equipment abnormalities, equipment failure diagnosis, as well as tracking maintenance processes. It realises functions including compressor health evaluation, early failure warning, failure identification and cause analysis, alarms, as well as case management. The correlation between each part is shown in the figure below.

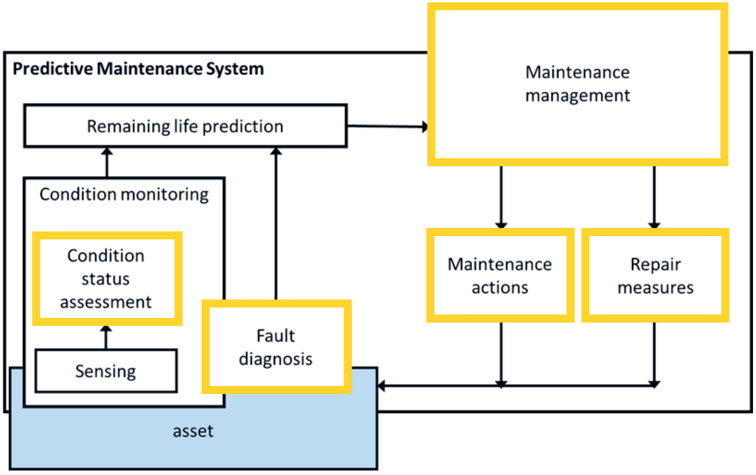


Figure 4-11-2 – System function diagram

Roles

The application mode of predictive maintenance technology can adapt to the needs of different stages of project implementation. In constructing the predictive maintenance system for compressors, Schneider plays a role as service provider, mainly providing predictive maintenance software, construction plans, data access, templates and models and training. As an asset operator, the user assists the service provider in establishing a compressor model and receiving training during system construction and is responsible for optimising the model, monitoring and responding to alarms and developing other types of equipment models once the system is online.

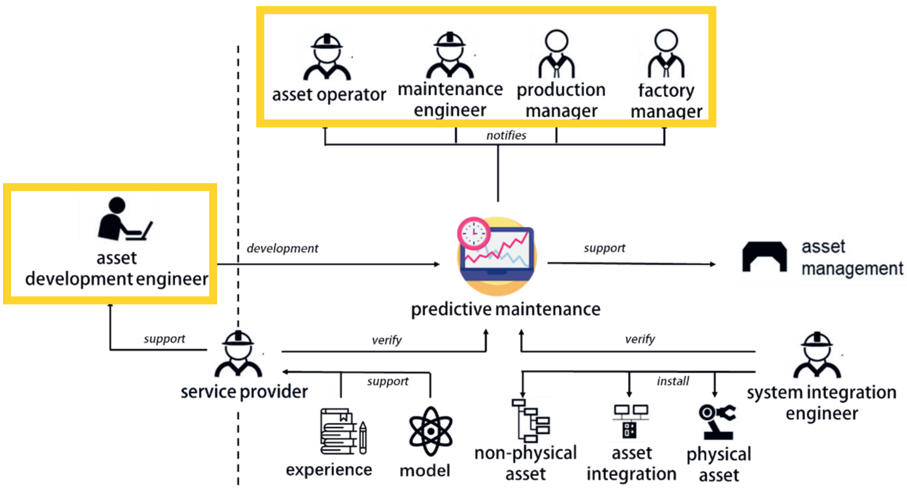


Figure 4-11-3 – Implementation role diagram

Once the PRiSM system is notified or the user regularly checks alarm information, the user can create a case in the PRiSM system or complete a new work order in the asset management system (EAM), and dispatch this to on-site maintenance personnel to perform inspections, repairs and other operations. Among other things, cases in the PRiSM system can easily be used to track the trend of failure and deterioration, record and update maintenance progress and collaborate with different professions. Once on-site maintenance work has been completed, the user evaluates the value of the case based on feedback information and closes the PRiSM system case or work order in EAM. If there has been consumption of spare parts, this must be tracked in the EAM work order. The PRiSM system case evaluation process can promote greater knowledge sharing between different teams, accumulate fault diagnosis rules and update and optimise the PRiSM model. All these factors will facilitate a timely resolution of similar problems in the future.

System architecture

The architecture diagram for the predictive maintenance system for compressors is shown in the figure below:

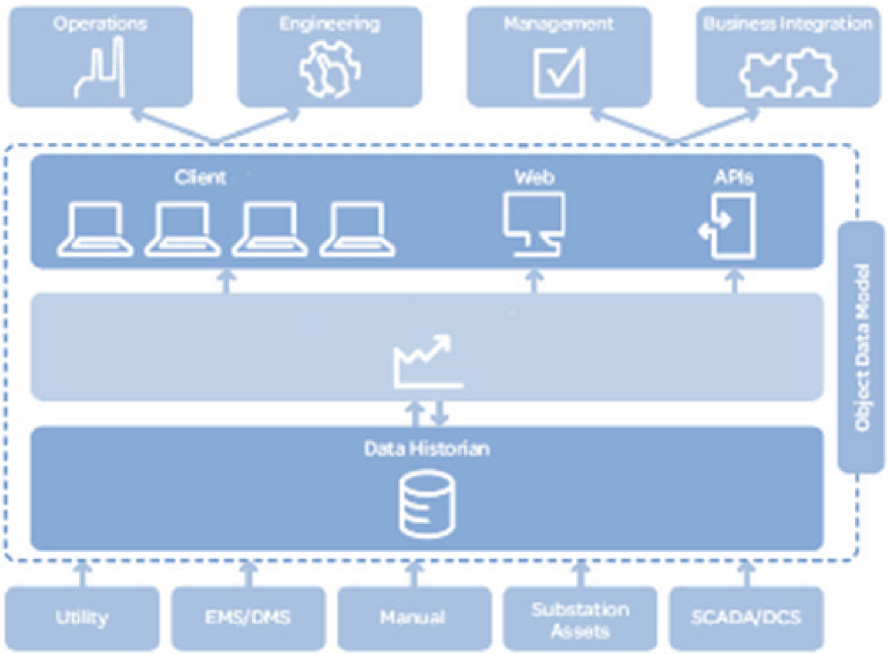


Figure 4-11-4 – System architecture diagram

PRiSM Server – stores real-time/historical data and PRiSM calculation data obtained from various data sources, and stores configuration attributes, alarm records, case information, etc. for all models.

PRiSM Client – configuration software. The user can build, verify, adjust and deploy the model in the graphical operation interface according to concise guidance steps.

PRiSM Web – based on web-based functions such as status, trend browsing, alarm management and notification services, users can not only perform operations such as view alarm information, analyse data and trends and manage alarms and cases via the browser, they can also publish analysis results to the system platform for information integration through Webservice and API interfaces.

Functions and methods

The PRiSM predictive maintenance system can effectively help users find early failures in critical equipment such as compressors and assist in analysing the causes of failures, mainly to achieve the following functions:

Build an equipment model

- Establish a predictive analysis model based on the equipment's historical operating data, verify the effectiveness of the model through data back-testing, and quickly add a rolling optimisation model for the training data set to improve its accuracy.

Equipment health rating

- PRiSM uses model prediction deviations to evaluate equipment health under different operating conditions over a period. At the same time, combined with the critical level of equipment to prompt users to intervene in advance, it is convenient for users to implement group management for scenes with many types and large numbers of equipment.

Analysis of the cause of the failure

- Trace the predicted value/actual value/deviation value trend for each variable in the model and identify the fault type and similarity with the help of the diagnosis rules defined in the system template.

Predictive alarm response management

- Users can efficiently manage various alarms in the PRiSM system on the web side, track the development trend for equipment failures and record response measures, and open up the entire process of equipment failures from discovery and confirmation to resolution over a long period.

As a predictive analysis function module of the system platform

- PRiSM uses the user's existing real-time database as the data source. Once the equipment operating data has been analysed, it can be used in the system and used as a predictive analysis module to output results to the system platform for information integration or for other functional modules to call.

Feature highlights

The main innovations of the PRiSM predictive maintenance system:

- It applies big data analysis techniques and machine learning algorithms to study the correlation between multi-dimensional equipment operating parameters, establish a compressor model and predict equipment degradation trends.
- It summarises historical failure cases in compressors, establishes a diagnostic rule base and uses pattern recognition technology to perform a cause analysis for equipment failures.
- It applies precise diagnosis technology to study the quantitative characterisation of progressive failures in rotating equipment, develops an index system for judging the state of equipment failures and carries out accurate diagnosis of equipment failures.
- It learns from the successful experience of compressor modelling, e.g. where users have successfully customised other types of equipment templates, such as steam turbines, expanders, pumps, motors, etc. The newly created device model, as an example, can inherit all the attributes of the template. When a certain attribute of the template is modified, the system automatically updates all device models that reference the template.

Visualisation

The PRiSM predictive maintenance system is based on the B/S architecture, making it convenient for users to view equipment status on the web side at the equipment, device, factory, or customised level. The equipment status is distinguished by green (normal), yellow (alert), and red (alarm). Click the equipment or warning event to link to each measuring point's predicted value/actual value/deviation value trend within the set period. The interface is shown in the figure below:

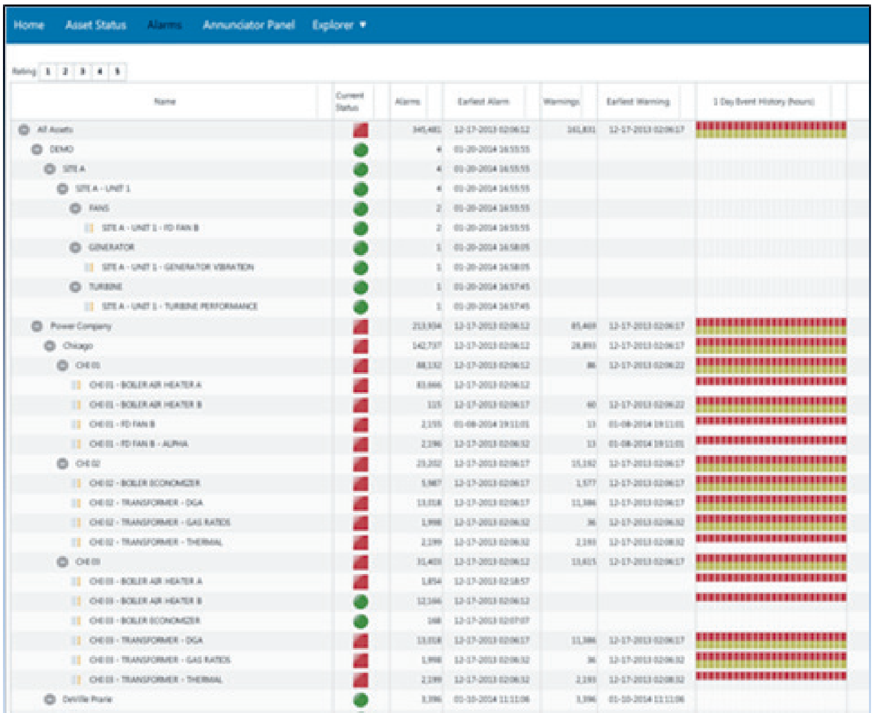


Figure 4-11-5 –Compressor predictive maintenance system interface *Copyright: Schneider*

The PRiSM system fault diagnosis function integrates the diagnosis rule library of known fault conditions for the compressor, which can assist with analysing the fault cause. Moreover, considering that a fault may have multiple fault features, the system also calculates the similarity of fault feature matching.

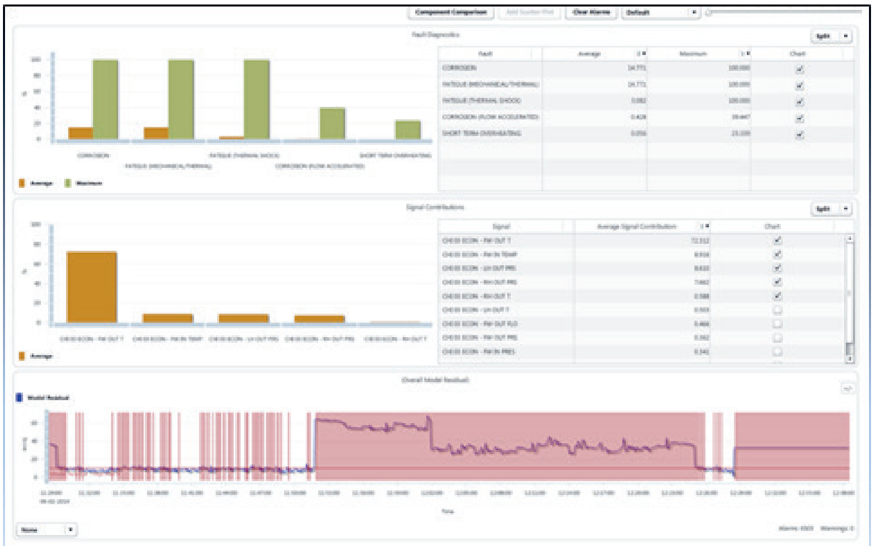


Figure 4-11-6 –Compressor predictive maintenance system failure analysis interface *Copyright: Schneider*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
compressor	bearing	bearing fault (looseness, wear)	vibration, displacement, temperature, load, lubricating oil temperature/pressure	sensor
	rotor	rotor fault (unbalance, misalignment, bending, friction)	vibration, displacement, speed, temperature, load	sensor
	gearbox	gear defects (wear, fracture)	vibration, displacement, speed, temperature, load, lubricating oil temperature/pressure	sensor
	heat exchanger	performance deterioration (blockage, leakage)	temperature, pressure, flow	sensor

Table 4-11-1 – Data requirements of scenarios

Scenario 12: Predictive maintenance for CNC machine cutting tools

Overview

As core equipment in the production line, the functional stability of CNC machine tools is a key factor in production efficiency and quality. As the key component in guaranteeing the high-precision production of CNC machine tools, the cutting tool has high requirements in terms of performance and state. These are affected by many factors: material, speed, time, temperature, production accuracy, pressure and structural performance changes. With the change of processing material, speed and other factors, particularly when the structure of CNC machine tools is damaged, tool performance will decline rapidly. It is necessary to monitor its durability, reliability, chip breaking and chip removal performance in real time, and predict the remaining life of the tool.

Delta, a Beijing intelligent technology company, jointly built a predictive maintenance system for CNC machine cutting tools with another company. The system integrates equipment information and real-time monitoring data to perform real-time state monitoring and acquisition, predict the running state of CNC machine tools, anomaly detection, remaining life prediction, health state monitoring and to provide maintenance strategies. The system level is shown in the figure below, covering Level 0, Level 1 and Level 2.

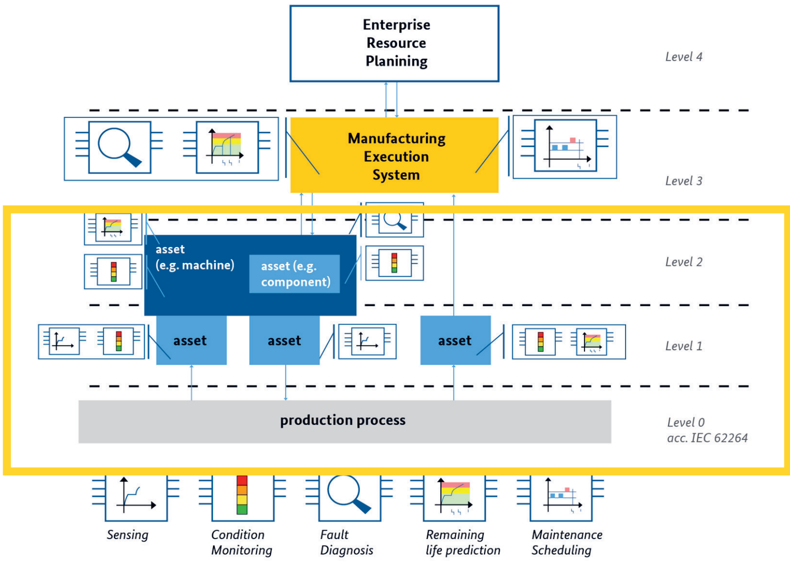


Figure 4-12-1 – System level diagram

The CNC machine tools realises data acquisition by connecting with the internal controller and installing sensors externally. By analysing the worn condition photo of the computer numerical controlled (CNC) machine tool's milling cutter, machining accuracy, load change of spindle controller and relevant signals generated during tool processing, the CNC machine tools operation status evaluation, fault diagnosis, anomaly detection, remaining life prediction health status monitoring are implemented, as shown in the figure below.

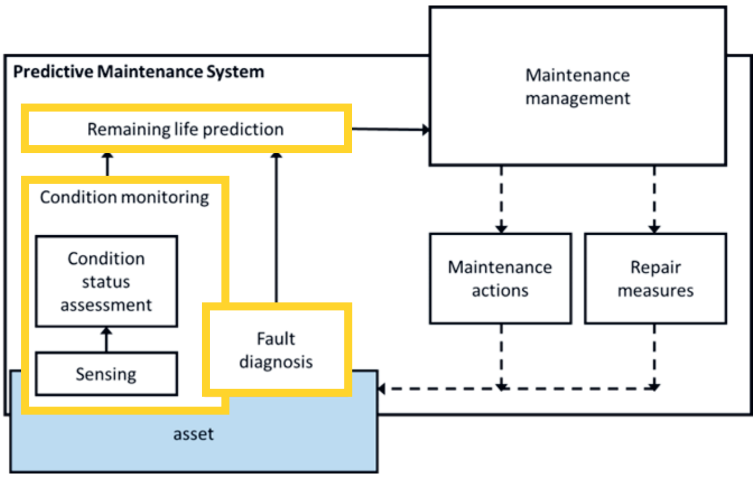


Figure 4-12-2 – System function diagram

Roles

In establishing a predictive maintenance system for CNC machine tools, the partner plays the role of asset operator and Delta is the service provider, mainly providing predictive maintenance technology, system construction scheme and data/model support, as shown in the figure below.

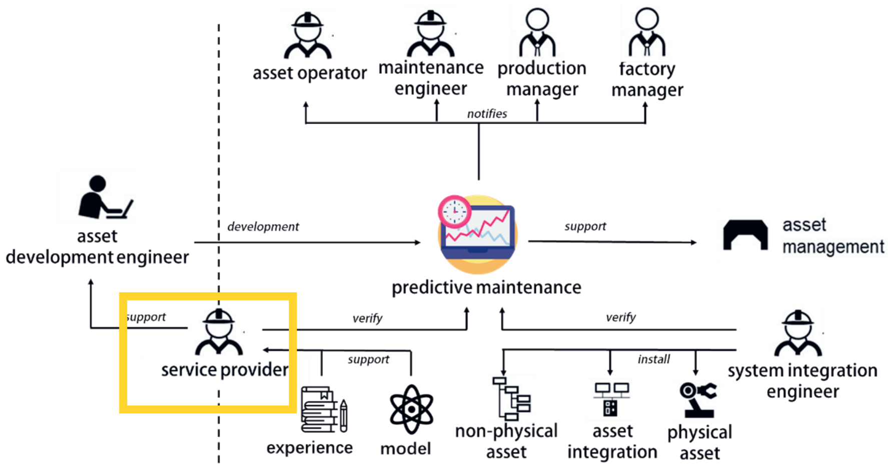


Figure 4-12-3 – Implementation role diagram

System architecture

The architecture of the predictive maintenance system for CNC machine tools is shown in the figure below. The relevant signals, which are generated from the vibrations and machining of cutting tools as well as the load change monitored by the spindle controller, can be received by adding sensors. PLC/IPC related information is collected synchronously. The information is transmitted to the data integration acquisition system and edge calculation management device to realise edge end calculation management, state evaluation, fault diagnosis, anomaly detection, remaining life prediction and health status monitoring.

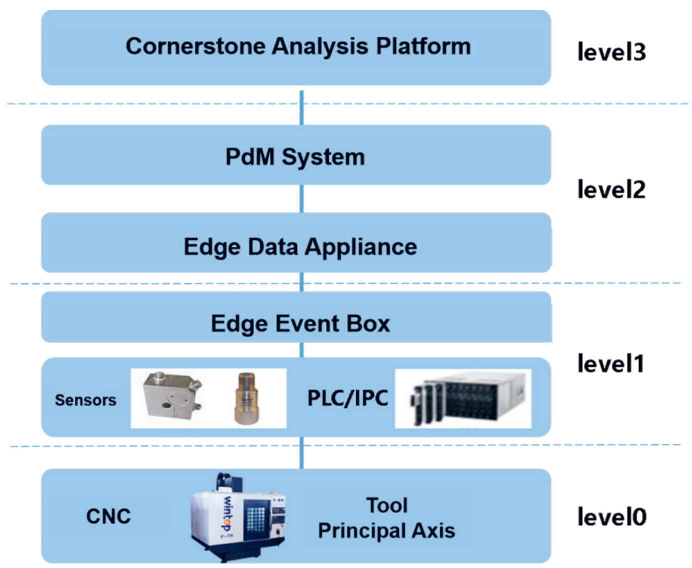


Figure 4-12-4 – System architecture diagram

Functions and methods

The functions performed by the predictive maintenance system for CNC machine tools include:

- Edge computing management device: this performs edge data acquisition and analysis and data security, which is used for data governance and AI program deployment; it quickly adapts to various application systems, simplifies the process of 'data to value', arranges background applications at the edge, processes data at the edge, then uploads the data required by cloud/central applications to the cloud and adopts safe channel to protect data security.
- Data acquisition and integration system: this collects equipment data, pre-processes the original data and transmits valuable data to the edge computing management device for diagnosis, analysis and prediction.
- Intelligent modelling and model verification: this mainly carries out development, iterative optimisation and model verification for the predictive maintenance model, establishes the algorithm life cycle management model library and improves the accuracy and generalisation ability of the model.
- Condition monitoring and health evaluation: this carries out data collection and condition monitoring for CNC machine tools, evaluates equipment health status and predicts the remaining service life of the equipment through the training model; it provides a visual representation of equipment health status, current trend analysis, vibration trend analysis, vibration spectrum analysis, speed characteristic analysis, remaining service life, etc.

Feature highlights

The prominent features of the predictive maintenance system for CNC machine tools are as follows:

- Digital knowledge base: establish, iterate and optimise the mathematical model for CNC machine tools through the data analysis platform, effectively manage and accumulate solutions for the same type of equipment and provide customers with a subscription service and model updates.
- PLC and sensor fusion acquisition: collect the spindle signal and three-axis sensor signal on the CNC machine tools, and synchronously record the signals from different sources inside and outside the machine tool to diagnose the state of the tool in all aspects.
- Cloud and edge end collaborative data processing: carry out data storage, processing and analysis based on the edge end, quickly collect data from the edge, then upload data required by the upper layer to improve the efficiency of data acquisition and decision-making, ensure data security, improve process response ability and reduce network load.

Visualisation

The predictive maintenance system for this case can realise the visual display of a CNC machine tool's cutting tool operation status, operation history status, health trend, real-time current and speed, real-time monitoring and early warning of equipment status. It can also detect equipment abnormalities in good time. The interface is shown in the following figure:

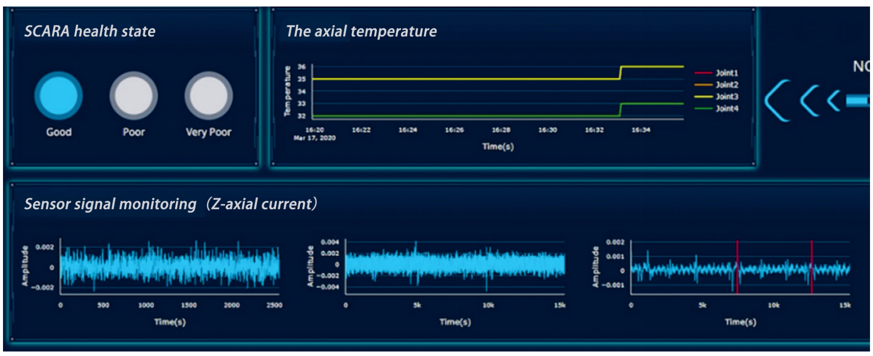


Figure 4-12-5 –Predictive maintenance interface

Copyright: Delta

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
CNC machine tools	cutting tools	cutting tools wear/ break	vibration	sensor
			speed, current, voltage	PLC
			cumulative machining distance	PLC
			cumulative processing quantity	PLC

Table 4-12-1 – Data requirements of scenarios

Scenario 13: Predictive maintenance for horizontal robots

Overview

The performance level of horizontal robots – a common piece of equipment in industrial manufacturing – will affect product quality and productivity. As key components in horizontal robots, performance of the reduction gear and belt will affect the robot's operational accuracy. Especially under poor working conditions, the gear is prone to damage and deformation, ball wear, oil leakage and other phenomena. These bring great challenges to the operation of horizontal robots. For these reasons, there is an urgent need to carry out predictive maintenance on horizontal robots, monitor their running state in real time and comprehensively analyse their state in order to carry out prediction and early warning.

Delta has deployed a predictive maintenance system for horizontal robots in one enterprise. The system carries out predictive maintenance for horizontal robots by monitoring whether operation is normal and diagnosing any damage or abnormality to their internal parts. The predictive maintenance system performs monitoring, diagnosis and life prediction, as shown in the figure below, covering Level 0, Level 1 and Level 2 in the system architecture.

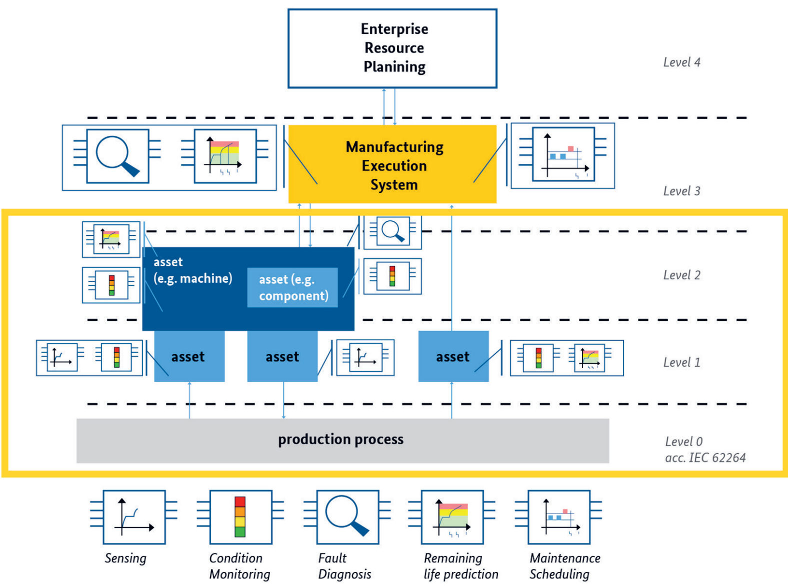


Figure 4-13-1 – System level diagram

The system mainly conducts real-time monitoring and collection, anomaly detection, remaining life prediction, health status monitoring through the vibration, sound and other information concerning operation of the monitor and provides maintenance strategies.

The system monitors the vibration value during operation, the events on the time series are automatically cut by the algorithm and compared with the long-term accumulated data signals in the knowledge base to assess the state of the horizontal robot arm.

By installing acceleration sensors on the robot and monitoring whether operation is normal, any damage to or abnormality with internal parts is diagnosed. The functions of sensing, state evaluation, fault diagnosis and life prediction are performed mainly through vibration, sound and other monitor information, as shown in the figure below.

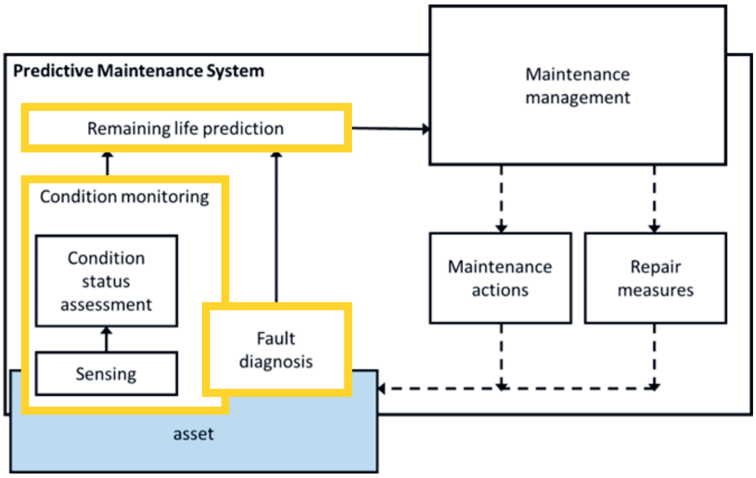


Figure 4-13-2 – System function diagram

Roles

In construction of the predictive maintenance system for horizontal robots, a certain enterprise plays the role of asset operator, and Delta is service provider and system integrator, mainly responsible for providing predictive maintenance technology, the system construction scheme, system integration and data/model support.

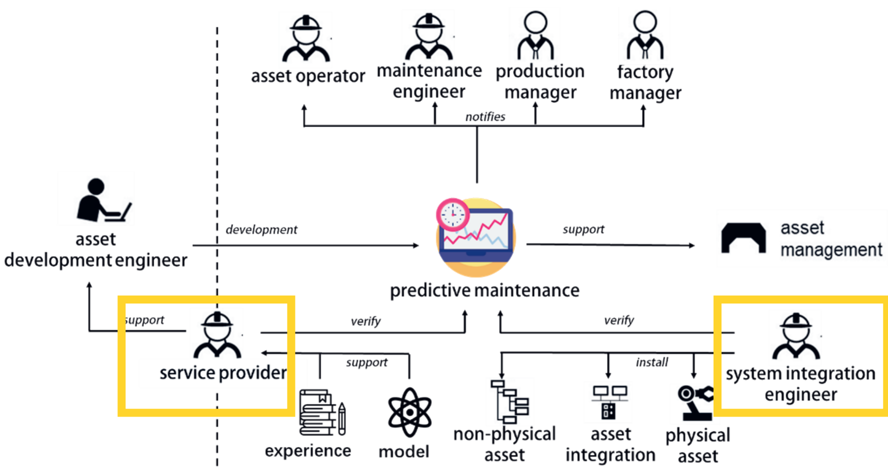


Figure 4-13-3 – Implementation role diagram

System architecture

The system architecture of the predictive maintenance system for horizontal robots is shown in the figure below. For predictive maintenance of horizontal robots, acceleration sensors are deployed in the reduction gears and belts to monitor their operation action status in real time, mainly through the collection of vibration, sound and other information of operation; synchronously collecting PLC/IPC-related information, this information is transmitted to the data integration and collection system, edge computing management device and data analysis platform, in order to achieve edge-side computing management, condition evaluation, fault diagnosis, abnormality detection, remaining life prediction and health status monitoring.

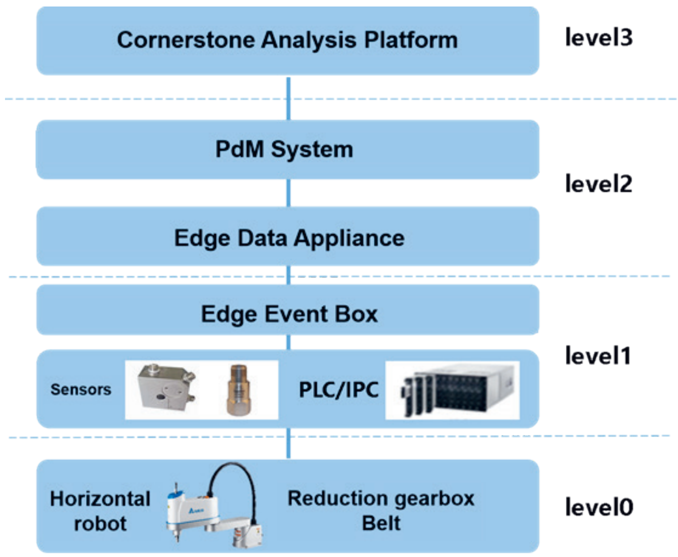


Figure 4-13-4 – System architecture diagram

Functions and methods

The functions of the predictive maintenance system for horizontal robots are as follows:

- Data acquisition and integration: collect equipment data, pre-process the original data, and transmit valuable data to the edge computing management device for diagnosis, analysis and prediction.
- Edge computing management device: perform data acquisition and analysis and data security at the edge end, which is used for data governance and AI program deployment; quickly adapt to various application systems, simplify the 'data to value' process, arrange background applications at the edge end, process data at the edge end and protect data security by using secure channels.
- Data analysis platform: realise the development, iterative optimisation and model verification of the predictive maintenance model, establish the algorithm life cycle management model library and improve accuracy and generalisation of the model.
- Condition monitoring and health assessment: this mainly performs data acquisition, condition analysis, fault diagnosis, condition prediction and early warning for horizontal robots. It also predicts the remaining life of equipment.

Feature highlights

The prominent features of the predictive maintenance system for horizontal robots are as follows:

- Digital knowledge base: establish a mathematical model for equipment through the data analysis platform; iterate and optimise, manage and accumulate solutions for the same type of equipment, provide customers with a subscription service for updating the model.

- Controller and sensor fusion acquisition: synchronously record information from different sources via the acquisition equipment controller signal and sensor signal, so as to diagnose the health state holistically.
- Multi-monitoring means fusion analysis: signal fusion, analysis, real-time monitoring, fault type diagnosis and life prediction of process parameters, accelerator and controller current.
- Health prediction: real-time dynamic analysis of multivariable and multi rules is carried out based on the equipment health model and deterioration model. The health prediction function of CNC machine tools or robots is carried out, thus laying a foundation for implementing predictive maintenance for the equipment.
- Cloud and edge end collaborative data processing: carry out data storage, processing and analysis based on the edge end; quickly collect, process and analyse data at the edge end, then upload the data to improve efficiency of data collection and decision-making, ensure data security, improve process response ability and reduce network load.

Visualisation

The predictive maintenance system for horizontal robots performs the collection of robot operation information, real-time state monitoring, fault diagnosis, state prediction and early warning and display. The interface is shown in the following figure:

Figure 4-13-5 –Predictive maintenance interface *Copyright: Delta*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
horizontal robot	RV reducer	wear	vibration	sensor
			angle, current, temperature	PLC

Table 4-13-1 – Data requirements of scenarios

Scenario 14: Predictive maintenance for intelligent slitting machine's micro-milling cutter

Overview

The micro-milling cutter is one of the core components in a milling cutter type slitter. Its state and performance determine operational accuracy, especially when the plate slitter is in high intensity, poor industrial control and work overload for a long period of time. Its performance wear is important for monitoring the milling cutter condition and life prediction. This may not only prevent cutting without warning, but also avoid unnecessary asset loss resulting from tool change ahead of time.

Delta and a cooperating factory have built a predictive maintenance system for the intelligent slitting machine's micro-milling cutter. The predictive maintenance system performs monitoring, diagnosis and life prediction, as shown in the figure below, covering Level 0, Level 1 and Level 2.

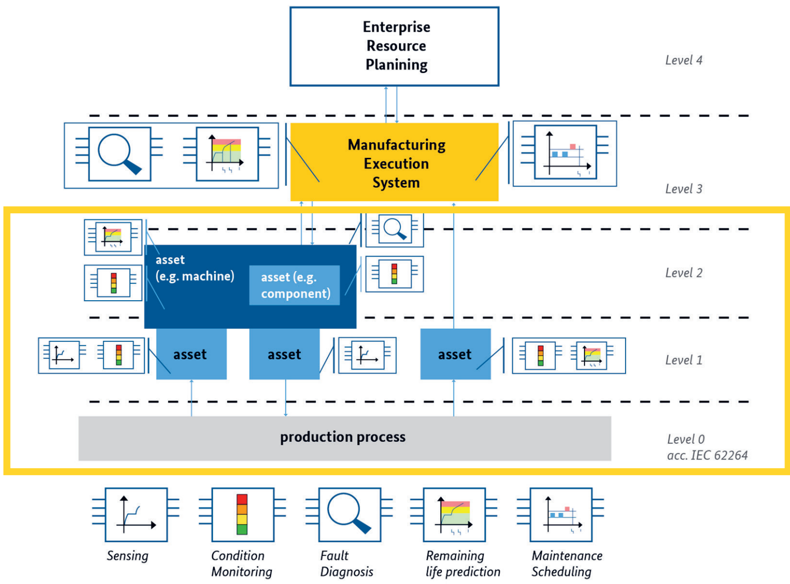


Figure 4-14-1 – System level diagram

The predictive maintenance system for the intelligent slitting machine's micro-milling cutter performs a state evaluation, fault diagnosis and life prediction by monitoring the spindle current load and signal/parameters during micro milling, and by extracting multiple signal fusion features through signal processing, as shown in the figure below.

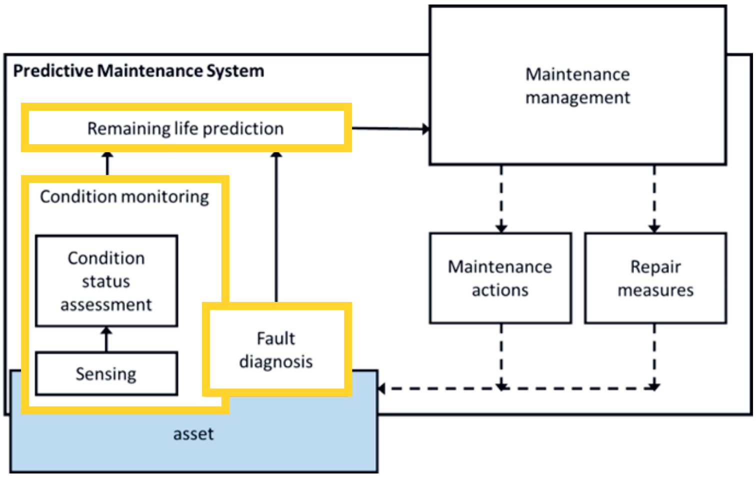


Figure 4-14-2 – System function diagram

Roles

In construction of the predictive maintenance system, Delta plays the role of asset operator. As a service provider and system integrator, Delta is mainly responsible for providing predictive maintenance technology, the system construction scheme, system integration and data/model support.

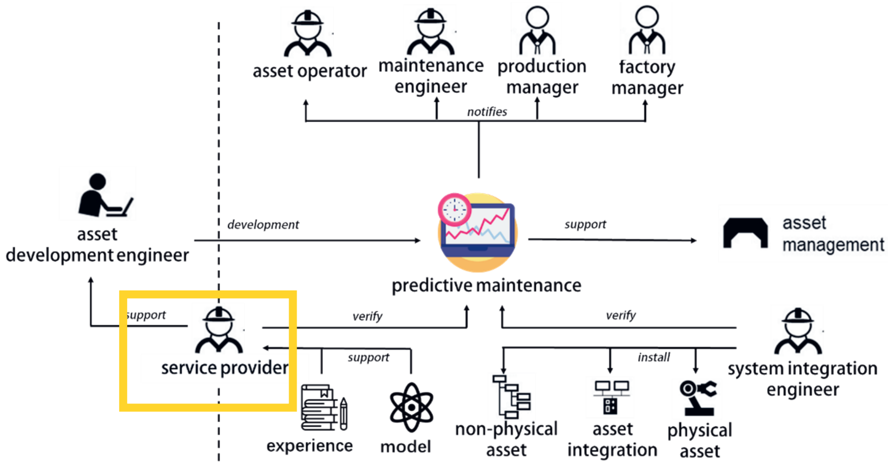


Figure 4-14-3 – Implementation role diagram

System architecture

The architecture of the predictive maintenance system is shown in the figure below. An IPC monitoring signal, spindle current load and signal/parameters during processing are detected for the spindle motor of the micro-milling cutter. The information is then transmitted to the data integration acquisition system, edge calculation management device and data analysis platform to carry out the functions of edge end calculation management, fault diagnosis, anomaly detection, residual life prediction, etc.

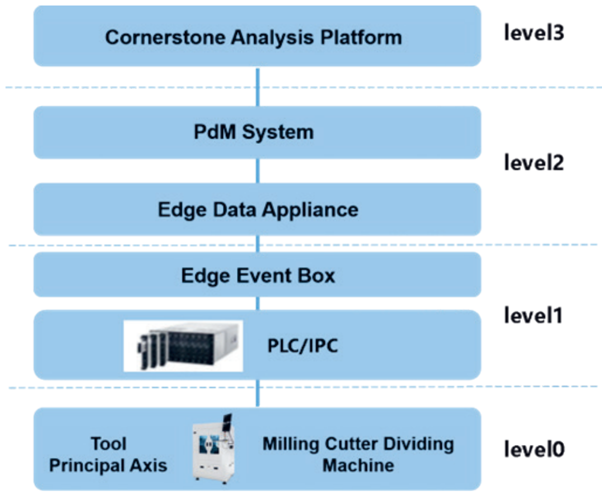


Figure 4-14-4 – System architecture diagram

Functions and methods

The predictive maintenance system for the intelligent slitting machine's micro-milling cutter mainly has the following functions:

- Data acquisition and integration system: collect, pre-process the original equipment data and transmit valuable data to the edge computing management device for diagnosis, analysis and prediction.
- Edge computing management device: perform data acquisition and analysis and security at the edge end, which is used for data governance and AI program deployment. Quickly adapt to various application systems, simplify the process of 'data to value', arrange background applications, process data at the edge end and protect data security by using secure channels.
- Intelligent modelling and model verification: carry out the development, iterative optimisation and verification of the predictive maintenance model; establish the algorithm life cycle management model library; improve accuracy and generalisation of the model.
- Condition monitoring and health assessment: this mainly performs data acquisition, condition analysis, fault diagnosis, condition prediction, early warning and the remaining life prediction for micro-milling cutter operation.

Feature highlights

The prominent features of the predictive maintenance system for the intelligent slitting machine's micro-milling cutter are as follows:

- Digital knowledge base: establish, iterate and optimise the mathematical model for CNC machine tools through a data analysis platform; effectively manage and accumulate domain knowledge of micro-milling cutter equipment status; provide customers with a subscription service for updating model.
- Fusion analysis of multiple monitoring means: real-time condition monitoring, fault type diagnosis and life prediction are achieved by collecting the spindle load signal and fusion analysis with the manufacturing parameter signal.
- Cloud and edge end collaborative data processing: quickly collect data at the edge end, store, process and analyse it; then upload the data required by the upper layer to improve the efficiency of data acquisition and decision-making, ensure data security, improve process response ability and reduce network load.

Visualisation

The predictive maintenance system performs the real-time visual display of tool equipment information, operation history, current status, collected parameters and the health trend. The interface is shown in the following figure.

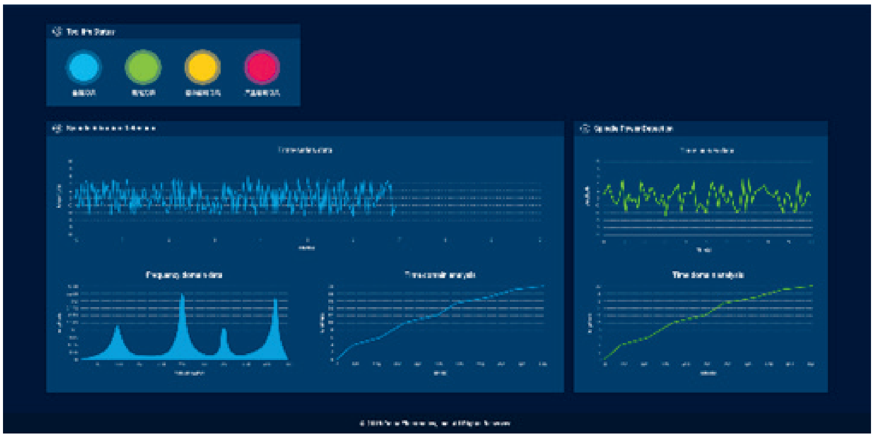


Figure 4-14-5 –Predictive maintenance interface *Copyright: Delta*

Data requirements

Table 4-14-1 – Data requirements of scenarios

Equipment	Part	Failure mode	Data requirements	Monitoring measures
plate slitting machine	cutting tools	cutting tools wear/ break	vibration	sensor
			speed, current, voltage	PLC
			cumulative machining distance	PLC
			cumulative processing quantity	PLC

Scenario 15: Predictive maintenance for servo welding guns in automotive manufacturing

Overview

Resistance spot welding is widely used in automobile manufacturing as a joining process. The resistance spot welding process usually requires a servo welding gun, and the servo drive system is the core component of the servo welding gun. The reliability of this component has a significant impact on whether the process can be executed in a stable and reliable manner. For this reason, developing an abnormal diagnosis method for the drive unit in the servo welding gun can effectively avoid product welding quality defects, reduce unexpected shutdowns, reduce costs, and improve economic benefits.

The welding workshop of SAIC-GM South Plant cooperated with Shanghai Manulism Technology Co., Ltd. to carry out a predictive maintenance project for servo welding guns and developed a software and hardware system to realise predictive maintenance for servo welding guns. The project has performed condition monitoring, abnormal diagnosis and life prediction in the system architecture, as shown in the figure below, covering Level 0, Level 1 and Level 2.

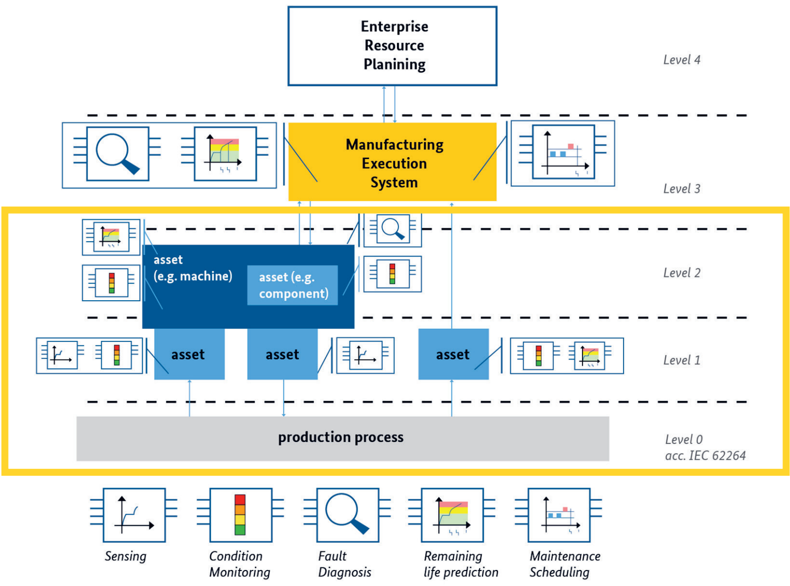


Figure 4-15-1 – System level diagram

This project collects signals for aspects such as current, torque, encoder position, temperature, program number, etc., and carries out status monitoring, fault diagnosis, life prediction, maintenance order triggering, maintenance management and other functions of the servo welding gun, as shown in the figure below.

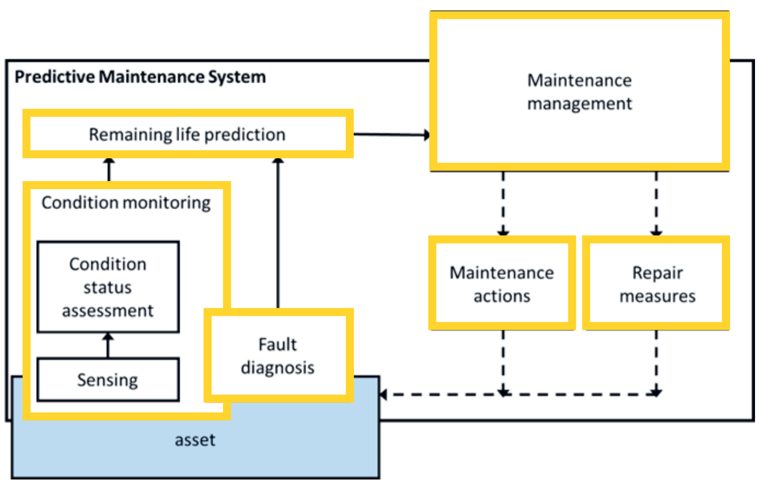


Figure 4-15-2 – System function diagram

Roles

In the predictive maintenance project for servo welding guns, the welding workshop of SAIC General Motors South Plant is the asset operator, maintenance engineer and product manager; Manulism plays the role of service provider, mainly responsible for providing the predictive maintenance software and hardware equipment, construction plan and data/model. In an emergency, the welding gun predictive maintenance system can promptly notify the maintenance team (maintenance engineer) in the welding workshop at SAIC General Motors South Plant of the equipment status and early warning information.

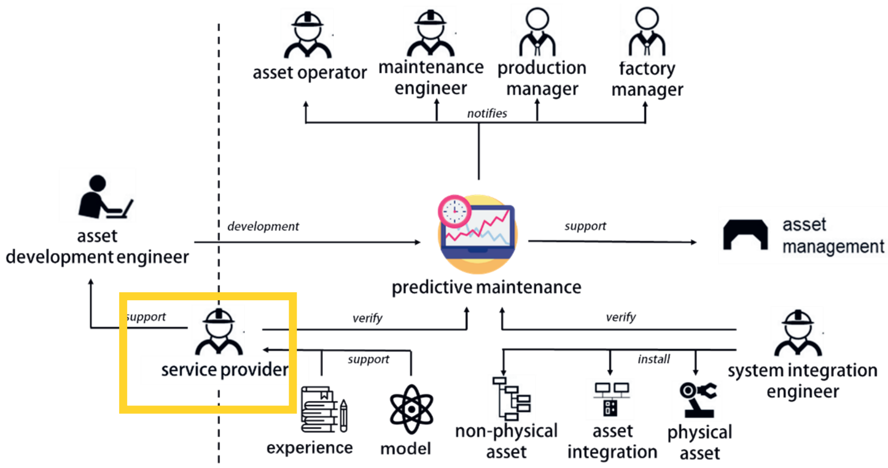


Figure 4-15-3 – Implementation role diagram

System architecture

The system architecture for the servo welding gun predictive maintenance project is shown in the figure. The current, torque, encoder and other signals from the servo welding gun perform the functions of condition monitoring, abnormal diagnosis, life prediction, single maintenance trigger and operation and maintenance management.

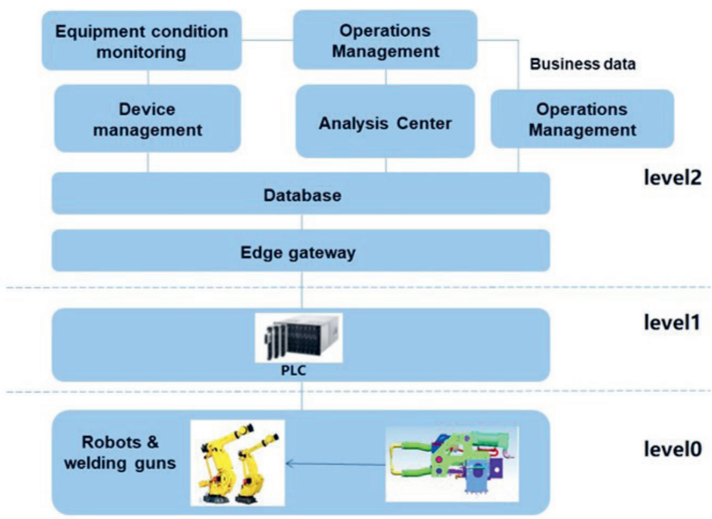


Figure 4-15-4 – System architecture diagram

Functions and methods

The main functions realised by the predictive maintenance project for the servo welding gun are:

- Edge gateway: collect data and upload, including management and configuration of data collection items.
- Equipment management: a digital twin of the production line is created by constructing a production system model, including equipment status, hardware management, alarm settings and system management.
- Equipment status monitoring: monitor real-time data and perform historical data query, comparison, statistics and analysis; generate corresponding reports.

- Analysis Centre: The big data analysis algorithm realises the operation and display of the predictive maintenance algorithm model. The system is divided into two modules: abnormal diagnosis and life prediction. The main functions include model management, model training and model settings.
- Operation and maintenance management: This mainly carries out centralised management of equipment inspection, emergency repair and maintenance. In addition, the results of the big data analysis model can trigger maintenance orders.

Feature highlights

The outstanding features of servo welding gun maintenance test items are as follows:

- Multi-monitoring method fusion analysis: position accuracy error analysis, fault diagnosis and life prediction functions are achieved by collecting sensor signals from the equipment itself, such as current, torque and encoder from the welding torch, fusing them with welding control signals, such as robot program numbers and place signals, and combining them with environmental information such as temperature and humidity for analysis.
- Application of machine learning algorithms: the application of cutting-edge machine learning algorithms, such as hypothesis testing, decision trees, support vector machines and isolated forests, combined with industry knowledge and experience in welding, optimises the prediction accuracy and universality of the model.
- Abnormal diagnosis: the system judges the status of the welding torch drive unit in real time through one-dimensional or multi-dimensional data. If the working state of the welding torch deviates greatly from the normal state, an abnormal prompt or a maintenance order will be triggered according to set maintenance rules.
- Damage prediction: multi-variable and multi-rule analysis of equipment or component degradation models based on the cumulative damage principle performs the component damage prediction function, laying a foundation for implementing predictive maintenance on the intelligent robot machine and robot tool side.

Visualisation

The predictive maintenance project for the servo welding gun can carry out a real-time visual display of equipment information, real-time monitoring, historical data, acquisition parameters, abnormal diagnosis and damage development for the servo welding gun. Green and orange, respectively, indicate the two states of normal and abnormal equipment. The interface is shown in the figure below:

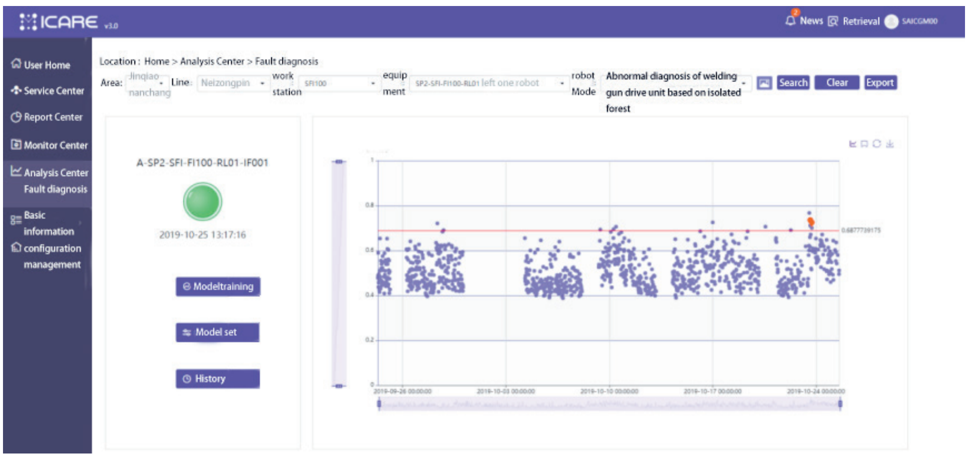


Figure 4-15-5 –Servo welding gun predictive maintenance system interface *Copyright: Manulism*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures (Data source)
servo welding gun	motor	lubrication deteriorated	torque, current, encoder, flag	PLC, servo welding gun
		overload	torque, current, encoder, flag	PLC, servo welding gun
		wear, welding slag accumulation	torque, current, encoder, flag	PLC, servo welding gun
	lead screw	block	move tip wear, fix tip wear, encoder, flag	PLC, servo welding gun
	electrode stem	misalignment	move tip wear, fix tip wear, encoder, flag	PLC, servo welding gun
	shaft and electrode	loosen	move tip wear, fix tip wear, encoder, flag	PLC, servo welding gun
tip dresser	blade	wear	move tip wear, fix tip wear, gun motor current, flag	PLC, tip dresser, servo welding gun, welding timer
		obstruction	move tip wear, fix tip wear, gun motor current, flag	PLC, tip dresser, servo welding gun, welding timer
robot	motor	lubrication deteriorated	torque, current, encoder, flag, load	PLC, robot
		overload	torque, current, encoder, flag, load	PLC, robot
	reducer	lubrication deteriorated	torque, current, encoder, flag, load	PLC, robot
		wear	torque, current, encoder, flag, load, time	PLC, robot

Table 4-15-1 – Data requirements of scenarios

Scenario 16: Predictive maintenance for machine and pump

Overview

As key equipment in chemical production, the operation status of a mechanical pump directly determines whether production equipment can operate safely and stably and the enterprise can achieve profitable production. The mechanical pump mechanism has a precise structure, fine dimensions, complex system working conditions and harsh environmental conditions. Normal operation of pumps has brought great challenges. It is vital to carry out condition monitoring and life prediction for pumps and to establish a complete predictive maintenance system.

Anhui Ronds Science & Technology Incorporated Company (Ronds) has cooperated with domestic petrochemical, petroleum, coal chemical, metallurgical, cement, water conservancy and other industries to implement a number of predictive maintenance systems for pump groups and build the hardware and software systems that perform predictive maintenance of key pumps in different industries. The pump predictive maintenance system carries out operational data monitoring, diagnosis analysis and life prediction in the system architecture. Its location is shown in the figure below:

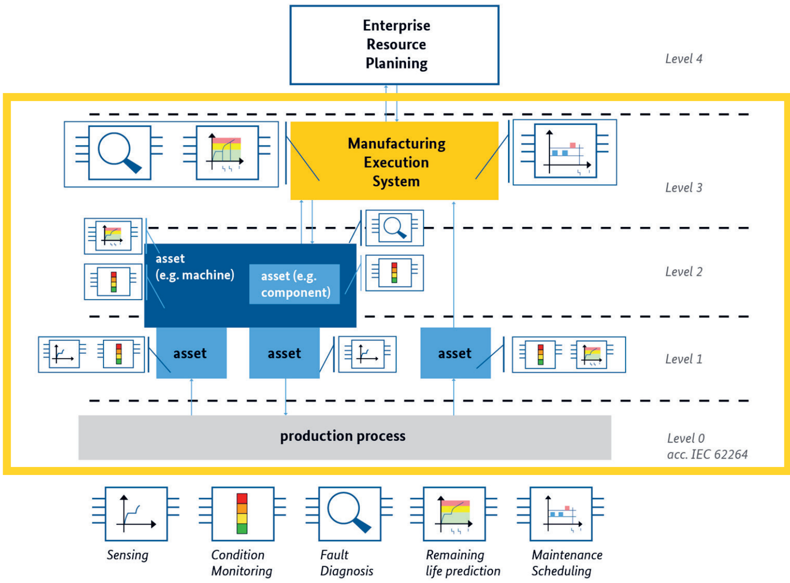


Figure 4-16-1 – System level diagram

The predictive maintenance system for the pump group deploys intelligent wireless vibration-temperature integrated sensors with edge computing in the corresponding parts of the monitoring equipment, and the platform deploys intelligent algorithm models to perform the functions of data collection, condition status assessment, fault diagnosis and life prediction during equipment operation, as shown in the figure below.

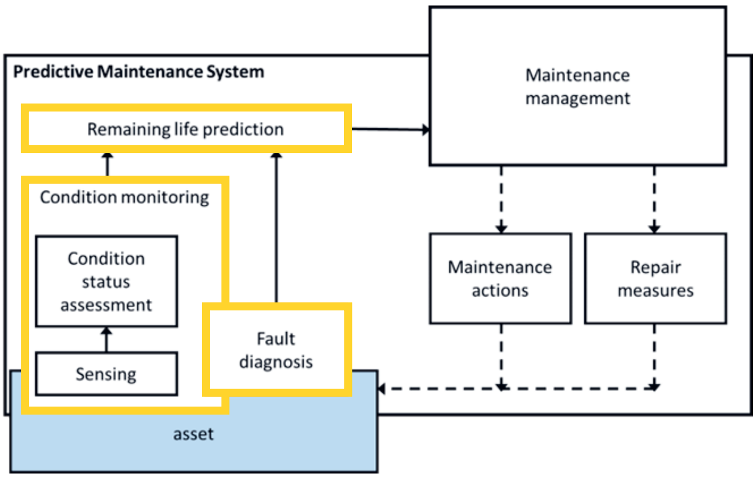


Figure 4-16-2 – System function diagram

Roles

In the construction system for the predictive maintenance platform for the pump group, Ronds is responsible for establishing different industries and multi-scenario solutions, and in line with actual needs, for developing and producing core software and hardware products such as sensors and acquisition stations, constructing big data platforms, establishing algorithm models, in addition to providing remote nursing services according to the needs of customers.

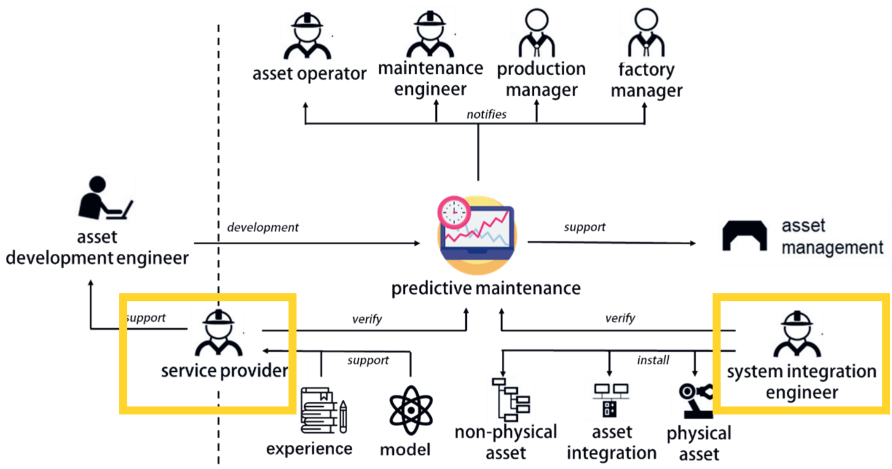


Figure 4-16-3 – Implementation role diagram

System architecture

The predictive maintenance system architecture for the pump group is shown in the figure below. The intelligent sensor and collection station are arranged according to the specific structure of the pump group, and the sensor signals and PLC signals are collected synchronously so as to perform the functions of edge computing management, condition monitoring and health management.

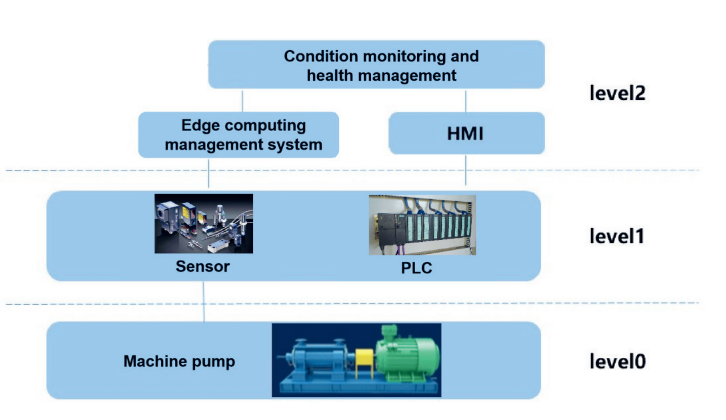


Figure 4-16-4 – System architecture diagram

Functions and methods

The predictive maintenance system for pumps performs the functions of data collection, condition monitoring, fault diagnosis and life prediction of the equipment. The main functions it realises are:

- IoT and edge computing management: carry out edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management, etc.
- Big data service and cloud platform management: mainly construct the operating environment for the predictive maintenance algorithm model, data centre data analysis and processing, including process management, model management, equipment management, access service, data service, system management and other modules.
- Intelligent modelling and model verification: mainly to realise the development, iterative optimisation and model verification of predictive maintenance models, establish the algorithm life cycle management model library and improve the capacity of the model for accuracy and generalisation.
- Condition monitoring and health evaluation: this mainly performs the visual analysis and cluster management functions for pump status and prediction results, including health status display, fault type display, fault trend display, vibration RMS value trend analysis, time domain waveform analysis, spectrum analysis, multi-time domain analysis, multi-spectrum analysis, multi-trend analysis, long waveform analysis, cepstrum analysis, envelope demodulation spectrum analysis and other modules.

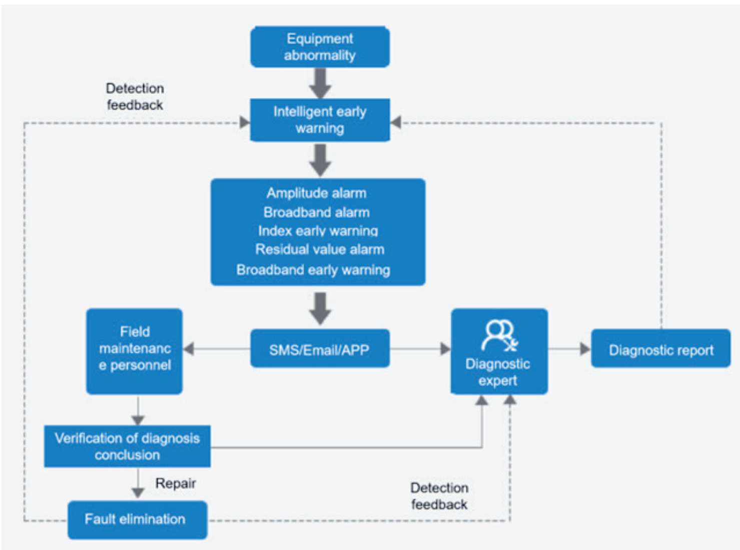


Figure 4-16-5 – System function flow chart

Feature highlights

The outstanding features of the pump predictive maintenance system are as follows:

- Multi-monitoring method fusion analysis: through the acquisition of machine pump operating parameters, comprehensive time-domain waveform, spectrum, multi-time domain, multi-spectrum, multi-trend, long waveform, cepstrum, envelope demodulation spectrum, temperature, current, voltage, load, etc. Sensor signal fusion analysis performs the functions of position accuracy error positioning, fault diagnosis and life prediction.
- Application of machine learning algorithms:

operating equipment mechanism + massive equipment operating data + high-quality data + case data + AI algorithm + advanced model of expert experience, continuous iteration of algorithm models, optimisation of prediction accuracy and model practicability.

- Health prediction: based on the equipment health model and deterioration model, multi-variable and multi-rule real-time dynamic analysis is carried out to perform the health prediction function of the pump, which lays the foundation for the industrialisation of intelligent in-depth diagnosis and comprehensive implementation of predictive maintenance.

Visualisation

The mechanical pump predictive maintenance system can realise a real-time visual display of basic equipment information, operating history status, current status, acquisition parameters, health trend, historical events, typical cases and stage health status for the mechanical pump. The actual status of the equipment is fully reflected through the operating status of the four alarms. Green, blue, orange, purple, and red respectively indicate the pump's five states of normal, notice, warning, alarm and danger. The visual interface is shown in the figure below:

Figure 4-16-6 –Mechanical pump predictive maintenance system interface *Copyright: Ronds*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
pump	bearing	bearing fault	vibration, temperature	sensor
			speed, load	PLC
	gear	gear fault	vibration, temperature	sensor
			speed, load	PLC
	motor	rotor eccentricity	vibration	sensor
			speed, current, voltage	PLC
		stator eccentricity	vibration	sensor
			speed, current, voltage	PLC
		stator winding insulation deterioration	speed, current, voltage	PLC
		stator winding is loose	vibration	sensor
			speed, current, voltage	PLC
		rotor loss of magnetism/winding failure	speed, current, voltage	PLC
		rotor bar broken	vibration	sensor
			speed, current	PLC
		phase failure (loose connector)	vibration	sensor
			current, voltage	PLC
		cooling fan failure	vibration	sensor
	pump body	base loose	vibration	sensor
		insufficient structural stiffness	vibration	sensor
		rotation loosening/ mating loosening	vibration	sensor
		misalignment	vibration	sensor
	impeller	cavitation/evacuation/insufficient flow/ surge	vibration	sensor
			flow, current, voltage	PLC
		impeller corrosion/loose	vibration	sensor
			speed, current, voltage	PLC
	choma	choma wear	vibration	sensor
	coupler	coupler fault	vibration	sensor
	seal	seal leakage	image, temperature	sensor
	cooling system	cooling system fault	temperature	sensor
	lubricating oil	insufficient lubrication	vibration, oil	sensor
	hinge	rotor bow	vibration	sensor
		rotor imbalance	vibration	sensor
		rotor eccentricity	vibration	sensor
		rotor wear	vibration	sensor

Table 4-16-1 – Data requirements of scenarios

Scenario 17: Predictive maintenance for power transformer

Overview

The power transformer is one of the core pieces of equipment in a power system. Its safe and stable operation is a key element in determining the operation status of a power grid. The asset management unit attaches great importance to its operational condition status assessment, latent fault diagnosis and maintenance strategy formulation. Due to the sophisticated structure of the power transformer, it runs in a closed, high-voltage, strong electromagnetic environment, and it is difficult to perform condition monitoring and diagnostic analysis on its operation.

Wuhan NARI Co Ltd., State Grid Electric Power Research Institute (Nari) has built a predictive maintenance test bed for power transmission and transformation equipment. The hardware and software system developed by the company has carried out predictive maintenance on power transformers. The predictive maintenance test bed for power transformers carries out condition monitoring and evaluation, fault diagnosis, life prediction, and maintenance decision-making in the system architecture. The location is shown in the figure below, covering Level 0, Level 1 and Level 2.

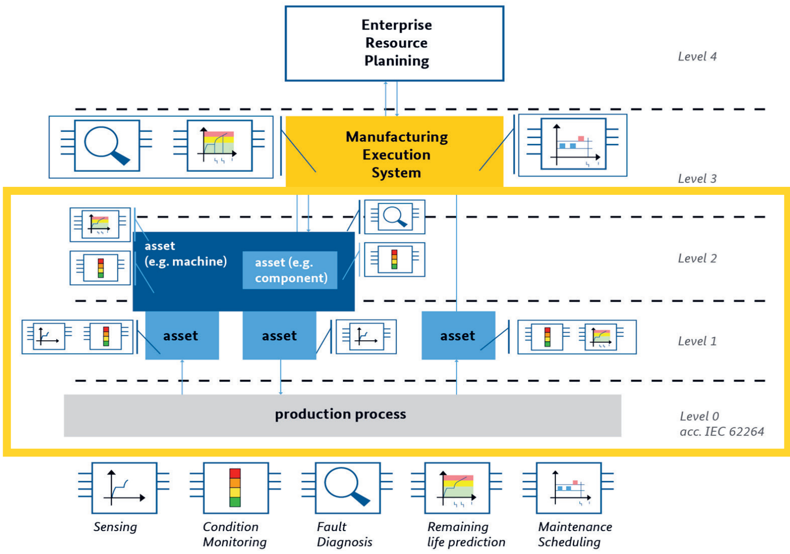


Figure 4-17-1 – System level diagram

The predictive maintenance test bed for power transformers performs the sensing, condition status assessment, fault diagnosis and remaining life prediction of power transformers by collecting operating data such as patrols, defects, fault trips, online monitoring and live detection, combined with equipment account and maintenance test information. The functions of forecasting and maintenance decision-making are shown in the figure below.

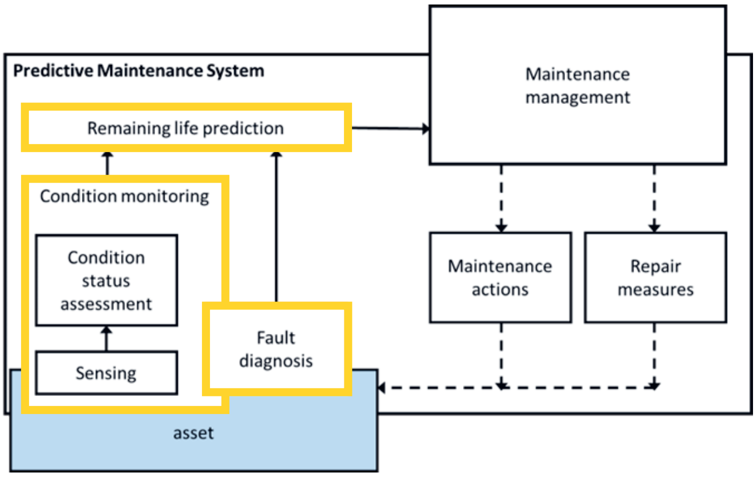


Figure 4-17-2 – System function diagram

Roles

In the construction of the predictive maintenance test bed for power transformers, Nari plays the role of service provider, mainly responsible for providing predictive maintenance software and hardware equipment, construction plans, and data/models; power grid companies and power supply companies play the role of asset operators. In an emergency, the test bed predictive maintenance system can promptly notify the asset operator about equipment status and early warning information.

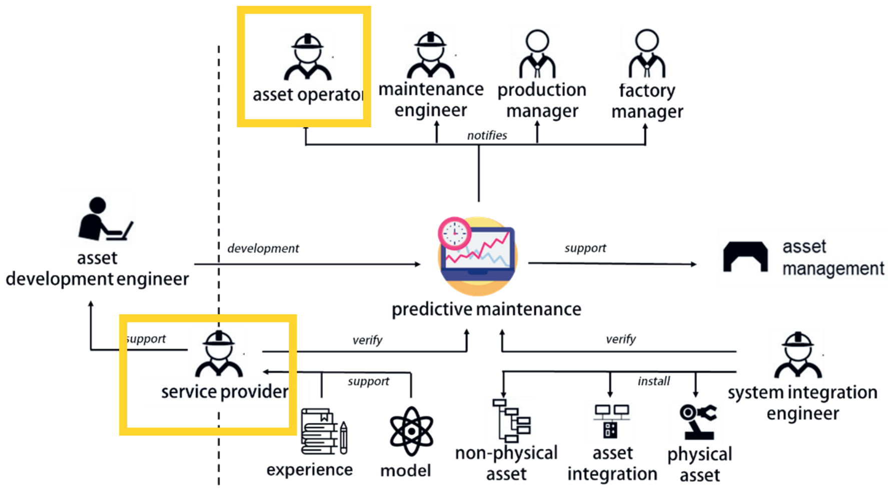


Figure 4-17-3 – Implementation role diagram

System architecture

The system architecture for the power transformer predictive maintenance test bed is shown in the figure below. Among them, devices such as oil chromatography online monitoring, partial discharge online monitoring, iron core grounding current online monitoring and other devices deployed on the power transformer test bed, synchronously collect mobile operation terminals and live detection data, realise the functions of edge calculation management, condition monitoring and fault diagnosis, etc.

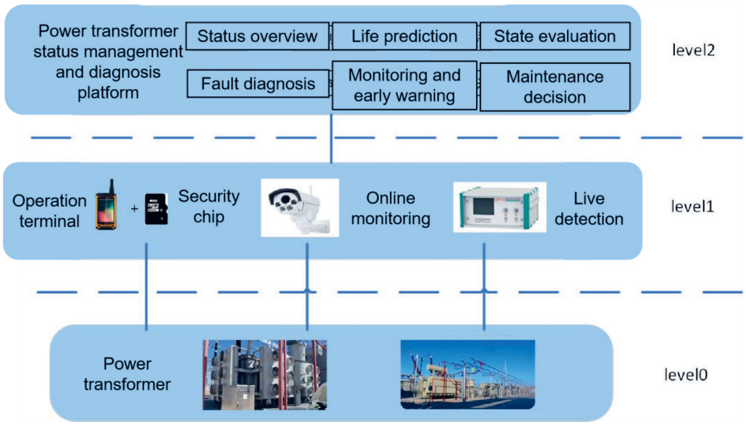


Figure 4-17-4 – System architecture diagram

Functions and methods

The predictive maintenance test bed for power transformers mainly carries out data collection, condition monitoring, status evaluation, fault diagnosis, life prediction and further training decision-making of power transformers. The main functions it realises are as follows:

- IoT and edge computing management: perform edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management, etc.
- Status overview: mainly realise the summary and display of online monitoring data, test data, inspection data, equipment history records and other related information, and provide data support for platform equipment status monitoring and diagnosis.
- Monitoring and early warning: this mainly analyses connected real-time data and releases early warning information for the monitoring volume indicators that exceed the early warning value, so as to achieve prompt early warning of the poor state of the equipment.
- State evaluation: this mainly carries out analysis of the overall and sub-component operating state of the transformer equipment, including normal state, attention state, abnormal state and serious state.
- Fault diagnosis: this mainly carries out analysis and diagnosis of faulty equipment and performs the automation of equipment fault diagnosis and visualisation of the whole process of fault diagnosis through fault diagnosis methods such as fault tree, expert system and big data analysis.
- Life prediction: this mainly performs real-time data and historical data analysis of equipment and applies big data and artificial intelligence analysis methods to carry out equipment state prediction and life management in the short, medium and long term.
- Maintenance decision: mainly carries out dynamic adjustments to the equipment operation and maintenance strategy based on the status evaluation, fault diagnosis, and life prediction conclusions, and formulates the maintenance strategy for the next stage.

Feature highlights

The outstanding features of the predictive maintenance test bed for power transformers are as follows:

- Multi-monitoring method fusion analysis: perform equipment status analysis, fault diagnosis and life prediction functions and make maintenance decision plans for the next step by collecting pre-operation information (ledger, acceptance records, drawings, etc.), operating information (patrol, defect records, fault tripping, online monitoring, live detection, poor working conditions, etc.), and maintenance tests of power transformers multi-source data of information (routine test report, professional inspection report, maintenance report, etc.) and other information (human, financial, material, etc.).

- Application of big data and edge algorithms: further optimise the prediction accuracy and universality of the model by applying small samples, random forest, FMECA, bayesian network and other cutting-edge big data analysis and machine learning algorithms, combined with the edge computing function of the on-site ubiquitous IoT device.

Visualisation

The predictive maintenance test bed for transformers enables equipment information, operational data and collected condition data to be used for condition evaluation, fault diagnosis, life prediction and other modules, respectively, to visually display current operating status of the equipment (normal, attention, abnormal, serious) and future equipment status prediction (low risk, medium risk, high risk). The visual interface is shown in the figure below.

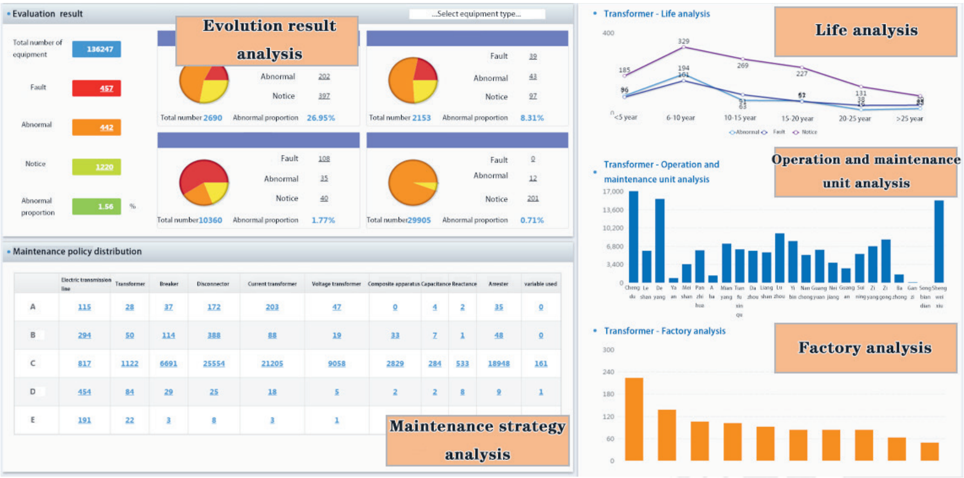


Figure 4-17-5 –Transformer system architecture diagram *Copyright: Nari*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
transformer	winding	short circuit fault	oil temperature, dissolved gas in oil	sensor (internal)
		open circuit fault	DC resistance, dissolved gas in oil	sensor
		winding overheating	furfural, dissolved gas in oil, DC resistance	sensor
		winding deformation	frequency response curve	sensor
	iron core	multipoint grounding	insulation resistance, dissolved gas in oil, vibration	sensor
		poor contact	dielectric loss, dissolved gas in oil, partial discharge	sensor

Equipment	Part	Failure mode	Data requirements	Monitoring measures
transformer	bushing	oil-leakage	oil position	sensor (internal)
		porcelain bushing flashover	pollution degree	sensor
		bushing heating	temperature, dissolved gas in oil	sensor
		insulation damp	micro-moisture content, dielectric loss	sensor

Table 4-17-1 – Data requirements of scenarios

Scenario 18: Condition monitoring and fault pre-warning for escalators

Overview

Microcyber Corporation Co., Ltd. (Microcyber) established a condition monitoring and fault warning system for escalators and built a software and hardware system to establish a condition monitoring and fault early warning system for escalators. The condition monitoring and fault early warning system for escalators performs monitoring, diagnosis and life prediction in the system architecture. The location is shown in the figure below, covering Level 0, Level 1 and Level 2.

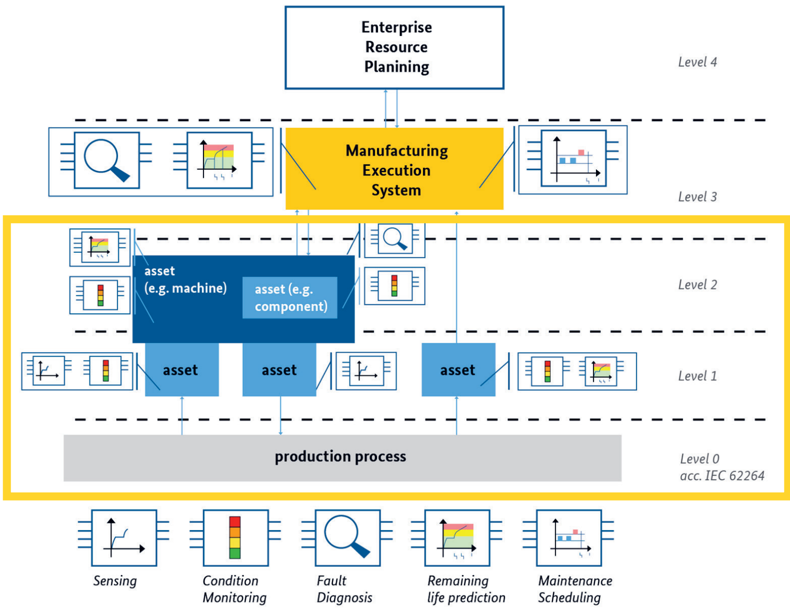


Figure 4-18-1 – System level diagram

Condition monitoring and fault warning from escalator vibration sensors, noise sensors, displacement sensors, temperature sensors and other sensing terminals are deployed on escalators to perform the functions of sensing, condition status assessment, fault diagnosis and life prediction for escalator equipment, as shown below:

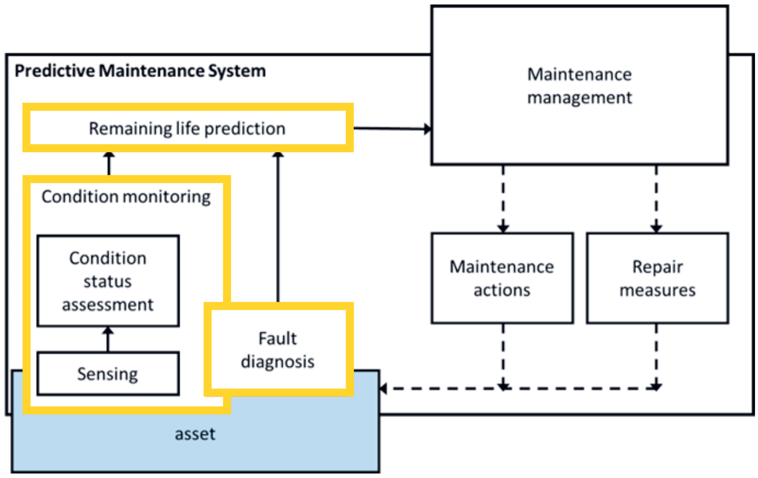


Figure 4-18-2 – System function diagram

Roles

In constructing the condition monitoring and fault early warning system for escalators, Guangzhou Guangri Elevator Industry Co., Ltd. (Guangri) plays the role of asset operator, and Microcyber plays the role of service provider, mainly responsible for providing software for escalator condition monitoring and fault early warning systems, hardware equipment, construction plans, data/model. In an emergency, the condition monitoring and fault warning system for escalators can promptly notify Guangri (asset operator) about equipment status and fault warning information.

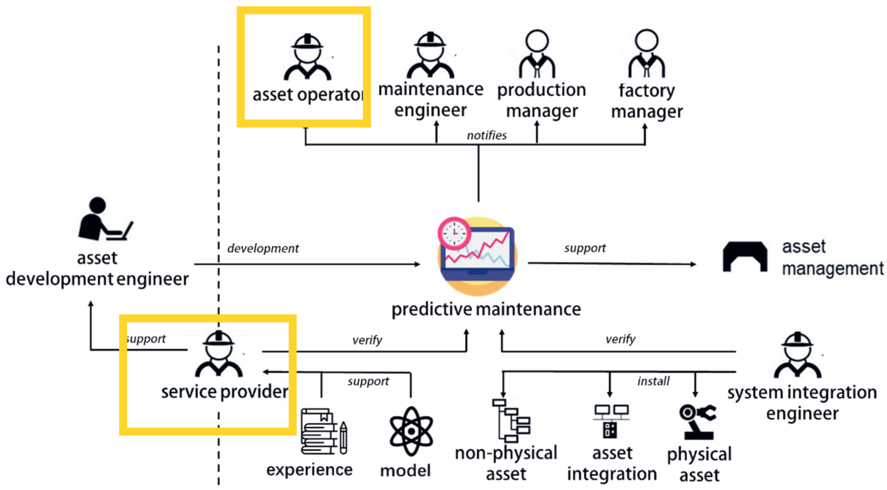


Figure 4-18-3 – Implementation role diagram

System architecture

The condition monitoring and fault early warning system for escalators is aimed at deploying and installing vibration, displacement, temperature, noise and other sensors in the escalator equipment, synchronously collecting sensor signals and performing functions such as edge computing management, condition monitoring and fault warning. The system architecture is shown in the figure below:

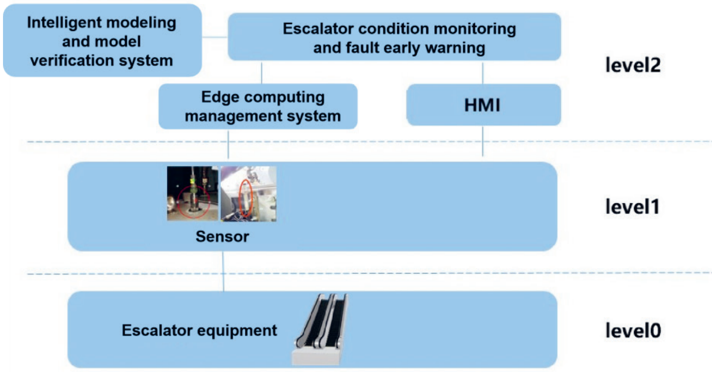


Figure 4-18-4 – System architecture diagram

Functions and methods

The condition monitoring and fault early warning system for escalators mainly performs data collection, condition monitoring and fault early warning functions for the escalator equipment. The functions performed mainly include:

- IoT and edge computing management: carry out edge data collection and analysis functions, including escalator equipment status, hardware management, alarm management, diagnostic parameter management, data communication, etc.
- Big data service and cloud platform management: this mainly carries out construction of the operating environment for the failure warning algorithm model, analysis and processing of data from the data centre, including process management, model management, equipment management, access services, data services, system configuration management and other modules.
- Intelligent modelling and model verification; this mainly carries out the development, iterative optimisation and model verification of fault early warning models, establishes a full life cycle management model library of algorithms, and improves the model's capacity for accuracy and generalisation.
- Condition monitoring and fault warning: this mainly performs the visual analysis of escalator status and fault warning results and cluster management functions, including health display, temperature trend analysis, noise trend analysis, displacement trend analysis, vibration trend analysis, vibration spectrum analysis, vibration time domain analysis, vibration cepstrum analysis, vibration envelope spectrum analysis and other modules.

Feature highlights

The outstanding features of the escalator's condition monitoring and fault early warning system are as follows:

- Multi-monitoring method fusion analysis: the fault warning function of the escalator equipment is performed by collecting data from the built-in controller of the escalator, and fusing and analysing sensor signals such as vibration, temperature, displacement, noise, etc.
- Application of machine learning algorithms: branched convolutional network BCNN, long and short-term memory network LSTM, AP nearest neighbour propagation clustering, federated learning and other machine learning and deep learning algorithms are used to improve the accuracy and robustness of predictions and reduce the number of algorithm calculations.
- Failure early warning analysis: multi-variable and multi-rule real-time dynamic analysis based on the equipment health model and degradation model has implemented the escalator's fault early warning function, laying the foundation for implementing predictive maintenance for the escalator.

Visualisation

The condition monitoring and fault warning system for the escalator can create a real-time visual display of the escalator's equipment information, operating history status, current status, collection parameters and health trend. Green, yellow and red indicate the three states of equipment normal, equipment abnormal and equipment failure respectively. The visual interface is shown in the figure below:

Figure 4-18-5 –Escalator condition monitoring and fault early warning system interface *Copyright: Microcyber*

Figure 4-18-6 –Escalator data analysis *Copyright: Microcyber*

Figure 4-18-7 –Escalator real-time warning interface *Copyright: Microcyber*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
escalator	electric motor	rotor eccentricity	vibration	vibration sensor
		bearing fault		
	retarder	gear fault	vibration	vibration sensor
		bearing fault		
		oil temperature fault	temperature	temperature sensor
	drive base	loose fault	vibration	vibration sensor
	main drive wheel	bearing fault	vibration	vibration sensor
	step chain tensioning wheel	bearing fault	vibration	vibration sensor
	main drive chain	noise fault	noise	noise sensor
	step chain	displacement fault	displacement	displacement sensor
		noise fault	noise	noise sensor
	handrail	handrail temperature fault	temperature	temperature sensor

Table 4-17-1 – Data requirements of scenarios

Scenario 19: Predictive maintenance for cement equipment based on IoT lubricant monitoring

Overview

The effective production capacity of the cement industry is very dependent on the normal operation of production line equipment. Industrial lubricants are equivalent to the blood supply in industrial equipment. According to data, online oil monitoring can detect potential equipment failures earlier, especially in large-scale cement production line equipment containing hydraulic systems and gearbox systems.

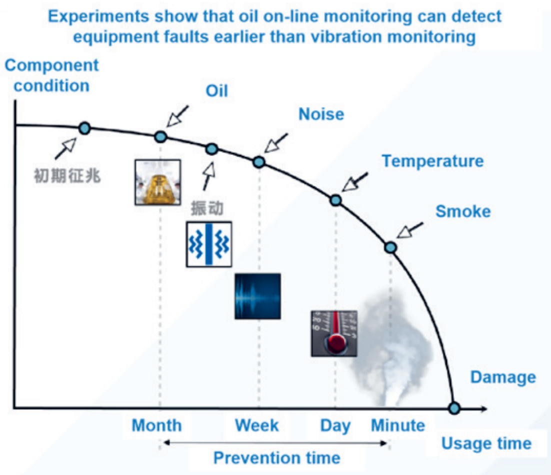


Figure 4-19-1 –Development stage and characterisation of equipment failure

In this case, combined with the existing field service network and cutting-edge predictive maintenance technology, the predictive maintenance platform for cement equipment based on IoT lubricant monitoring has developed a predictive maintenance closed-loop solution to ensure the reliable operation and maintenance of key equipment in the cement industry. The predictive maintenance platform for cement equipment based on IoT lubricant monitoring carries out condition monitoring, abnormal diagnosis and life prediction in the system architecture. The location is shown in the figure below, covering Level 0, Level 1 and Level 2.

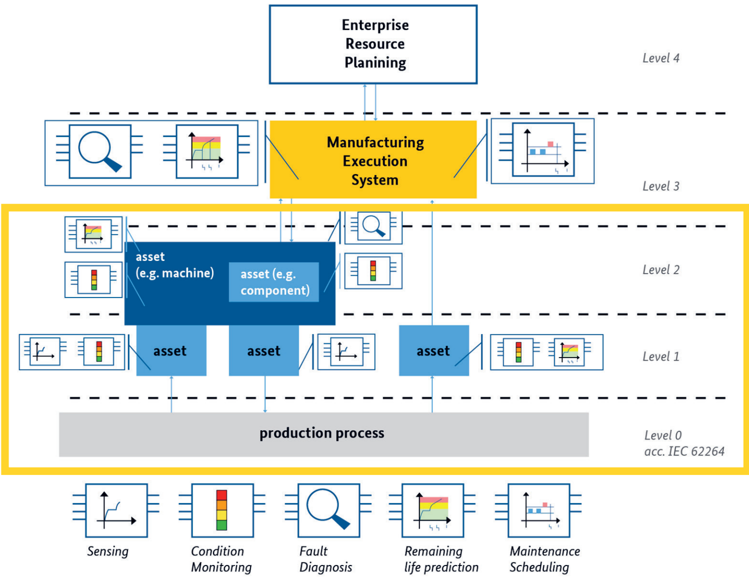


Figure 4-19-2 – System level diagram

The predictive maintenance platform for cement equipment based on IoT lubricant monitoring collects signals such as kinematic viscosity, lubricating oil temperature, oil quality (dielectric constant), oil pollution particle size, ferromagnetic/non-ferromagnetic particles, etc., and performs the functions of condition monitoring, fault diagnosis, life prediction and maintenance management in cement equipment, as shown in the figure below:

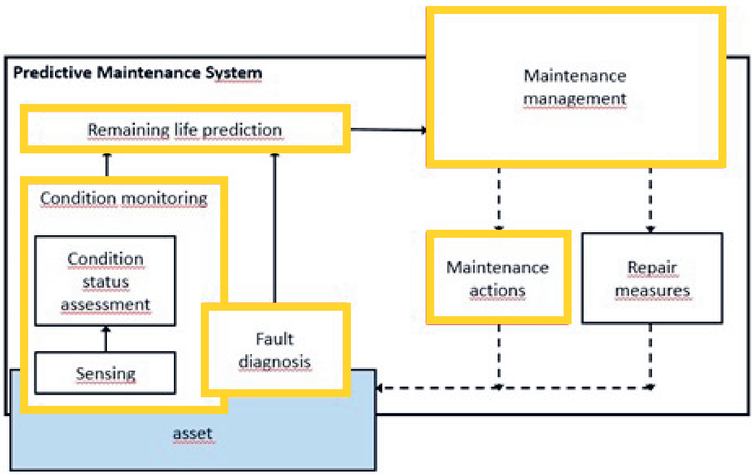


Figure 4-19-3 – System function diagram

Roles

The implementation mode in this case includes three roles: equipment user (equipment management personnel for cement production line), service platform operator, maintenance service implementer. The role of ZKH Industrial Supply Co., Ltd. (ZKH) Intelligent Internet of Things Division is the service platform operator, mainly providing IoT and predictive maintenance technology, platform construction solutions and data/model support; the synergistic network of service providers expanded by the existing team at ZKH is the implementation side of the on-site maintenance support service, including practical operation and training support such as oil change, cleaning and filtration.

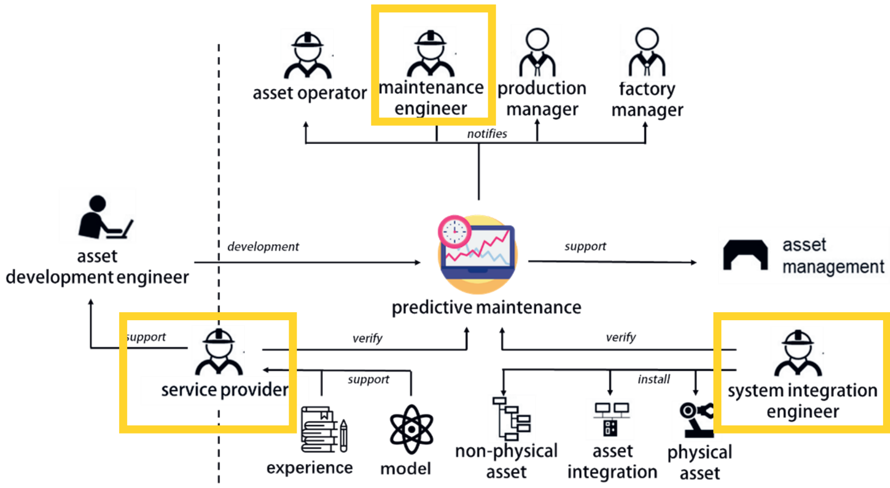


Figure 4-19-4 – Implementation role diagram

System architecture

The architecture of the predictive maintenance platform for cement equipment based on IoT lubricant monitoring is as follows. The hardware mainly consists of grate coolers, cement mills and other equipment in the cement production line, as well as integrated monitoring hardware composed of special sensors for aspects such as moisture content, quality and micro water. The software mainly includes systems such as an intelligent hardware management system, equipment operation and maintenance brain and a digital management field service network.

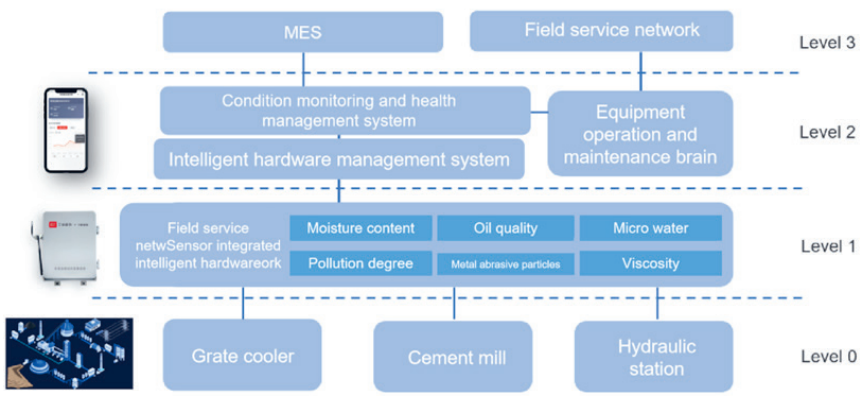


Figure 4-19-5 – System architecture diagram

Functions and methods

The main functions of the predictive maintenance platform for cement equipment based on IoT lubricant monitoring include three modules, as shown below.

Figure 4-19-6 – System function module

Feature highlights

The outstanding features of the predictive maintenance platform for cement equipment based on IoT lubricant monitoring are as follows:

- Lubrication sensor IoT capabilities: the integrated intelligent monitoring hardware launched by ZKH closely covers a variety of common lubrication monitoring requirements, does not require intrusive installation and adopts loop installation.
- Leading lubrication big data accumulation and analysis technology: ZKH has a number of patents and nearly 50,000 oil analysis data reports, leading in technology.
- A strong offline service network covering the whole country: ZKH can provide nationwide service coverage, spare parts supply and on-site service support capabilities to minimise the impact of unplanned equipment shutdowns.

Visualisation

The predictive maintenance platform for cement equipment based on IoT lubricant monitoring uses small programs and SaaS software as the carrier to provide equipment users and equipment service providers with monitoring, analysis and on-site services. The software supports historical data trend viewing to fully understand the lubrication running status; and supports comparative viewing of data indicators, highlighting the value of data analysis. The interface is shown in the figure below:

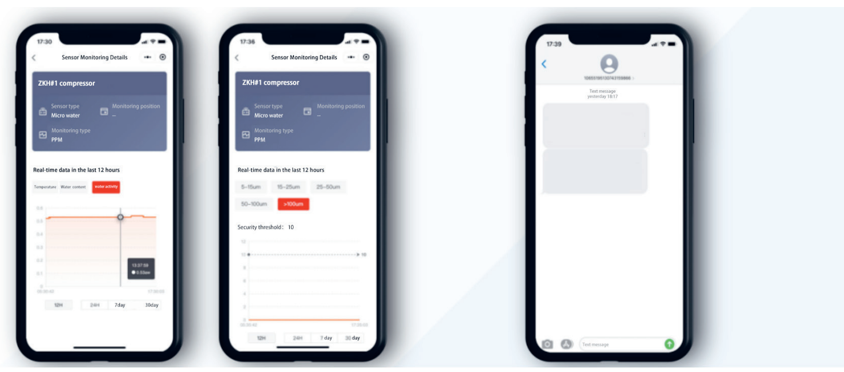


Figure 4-19-7 –Mini program interface of predictive maintenance platform for cement

Copyright: ZKH

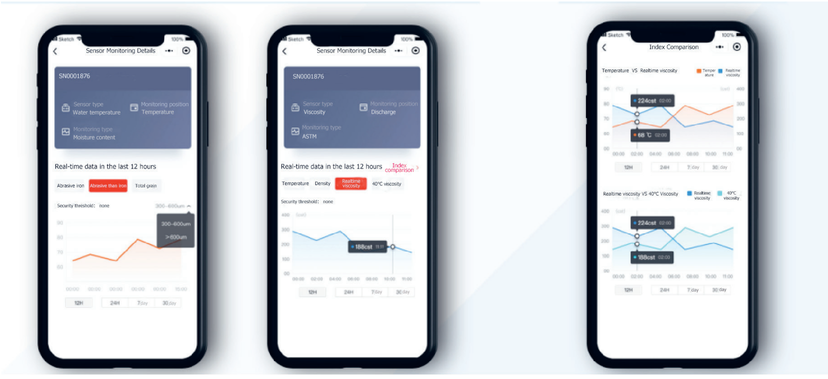


Figure 4-19-8 –Cement equipment predictive maintenance platform applet data analysis interface *Copyright: ZKH*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
rotary kiln	motor	bearing fault	vibration, temperature, current, voltage	sensor
		rotor fault	vibration, temperature, current, voltage	sensor
		stator fault	vibration, temperature, current, voltage	sensor
		coupling fault	vibration, tempera-ture	sensor
	gearbox	bearing fault	vibration, oil (metal wear, viscosity)	sensor
		rear fault	vibration, oil (metal wear, viscosity)	sensor
		shaft fault	vibration	sensor
	gear rim	bearing fault	vibration, temperature	sensor
		rear fault	vibration, temperature	sensor
		foundation loosen	vibration	sensor
grate cooler	hydraulic system	water ingress	oil (clearness, water contamination)	sensor
		valve jamming	oil (clearness, water contamination)	sensor
	motor	bearing fault	vibration, temperature, current, voltage	sensor
		rotor fault	vibration, temperature, current, voltage	sensor
		stator fault	vibration, temperature current, voltage	sensor
		coupling fault	vibration, tempera-ture	sensor

Table 4-19-1 – Data requirements of scenarios

Scenario 20: Predictive maintenance for fan in petrochemical factory

Overview

Fan shutdowns in petrochemical plants will cause huge losses. Predictive maintenance, early maintenance, early intervention and early diagnosis of important equipment in the plant are of great significance to ensuring the health of the equipment and stability of the production line. NOVA is mainly responsible for building a predictive maintenance system to achieve predictive maintenance for wind turbines in the plant. The position of the predictive maintenance system in the system hierarchy is shown in the figure below, covering Level 0, Level 1 and Level 2.

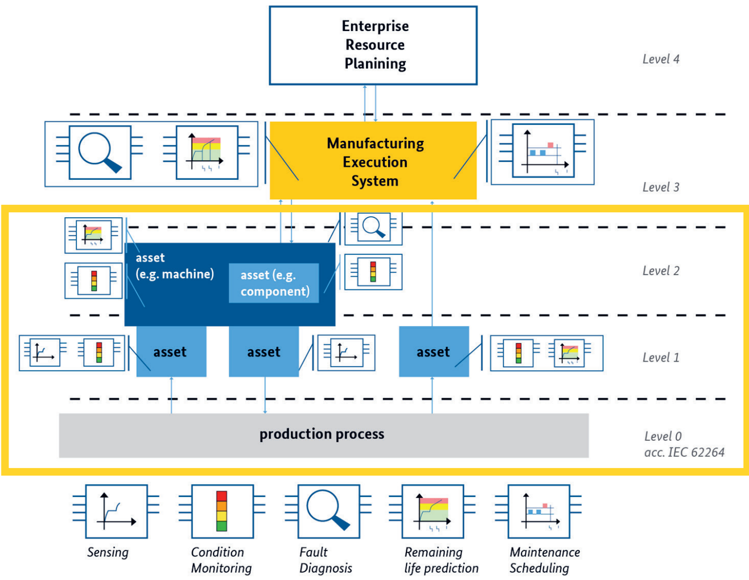


Figure 4-20-1 – System level diagram

The predictive maintenance system for wind turbines in petrochemical plants can perform the functions of sensing, condition status assessment and fault diagnosis of wind turbines, as shown in the figure below.

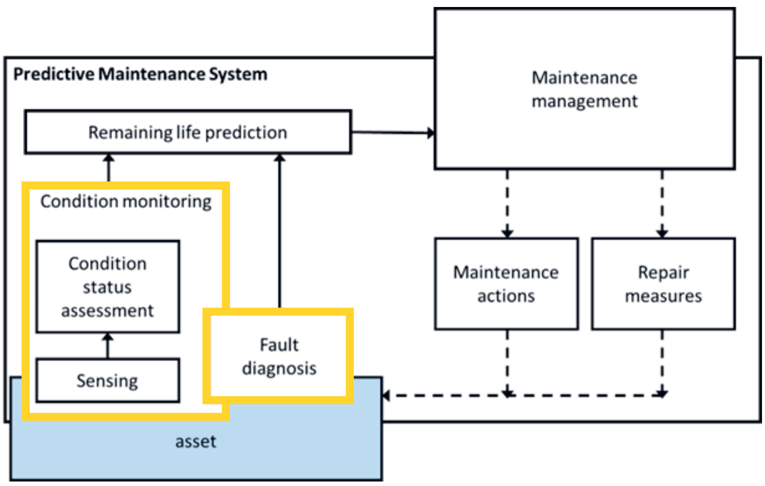


Figure 4-20-2 – System function diagram

Roles

This case uses a smart online monitoring system and the implementation model is that of a service provider working with a system integrator to develop a predictive maintenance system. In this case, NOVA's role is as service provider, mainly providing predictive maintenance technology, platform construction solutions and data/model support; at the same time, NOVA is also the system integration engineer, responsible for connecting the predictive maintenance function with the manufacturer's hardware and software to realise system integration.

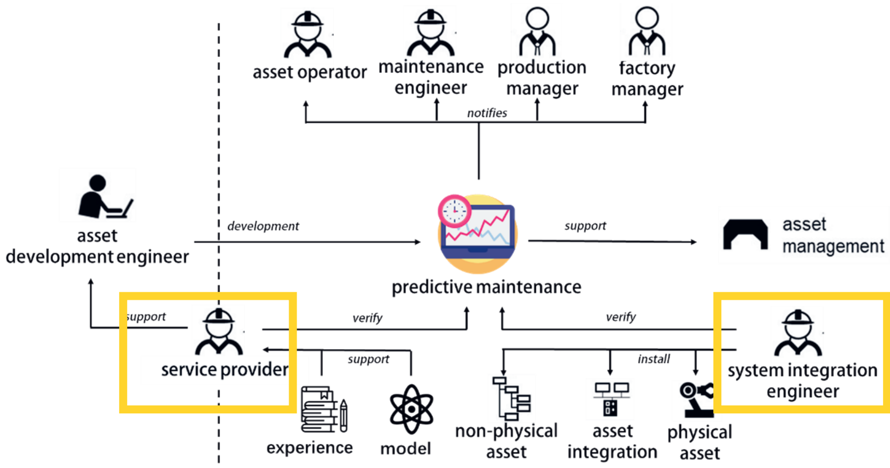


Figure 4-20-3 – Implementation role diagram

System architecture

In terms of vibration monitoring, analysis and measurement, NOVA provides a set of solutions for equipment vibration status monitoring, including data collection, wireless sensor (Sensor), a vibration monitoring system and data analysis for fans in the workshop.

Figure 4-20-4 – System architecture diagram

Methods

NOVA sets up monitoring points on the tension end of the fan, the free end of the fan, the load end of the motor and the free end of the motor. Sensors are installed at four measurement points, the data is collected through the data acquisition module and uploaded to the monitoring system to complete intelligent data screening and analysis:

- Data collection at multiple measuring points: continuous and intensive vibration data monitoring of equipment via the predictive maintenance system. Examples of collection points:

Equipment	Measuring point	Detection time	Detection value	Unit
Motor	Free end horizontal	2020/12/29 17:31	7.2826	mm/s
	Free end vertical	2020/12/29 17:32	3.8627	mm/s
	Load end tension direction	2020/12/29 17:32	4.6347	mm/s
	Tension at load end + 90°	2020/12/29 17:33	6.7047	mm/s
	Load end axial	2020/12/29 17:33	3.8286	mm/s
Fan	Tension end horizontal	2020/12/29 17:34	2.6732	mm/s
	Horizontal direction of tension end + 90°	2020/12/29 17:34	3.2896	mm/s
	Tension end axial	2020/12/29 17:35	1.9852	mm/s
	Free end horizontal	2020/12/29 17:36	1.9179	mm/s
	Free end vertical	2020/12/29 17:36	3.1761	mm/s
	Free end axial	2020/12/29 17:37	2.0844	mm/s

Figure 4-20-5 – Examples of monitoring points

- Accurate fault location: causes of abnormal vibration can be analysed based on spectrogram analysis and other means; the location of the fault and its cause can be accurately located.
- Predictive maintenance based on expert experience: diagnosis and analysis based on the experience of industry experts and on the basis of state data spectrum analysis and other means to ensure the accuracy of diagnosis results.

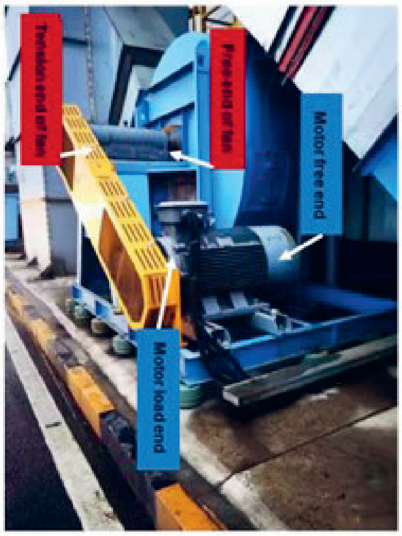


Figure 4-20-6 – Schematic diagram of monitoring location

Feature highlights

NOVA's predictive maintenance system can perform condition monitoring and fault diagnosis of wind turbines in the workshop. The main functions are:

- Complete solution: according to different needs, restrictions and customer budgets, provide predictive maintenance system options from the most basic to the most comprehensive.
- Transmission method: in view of varying local environmental restrictions, the system can provide limited, wireless, semi-wireless and other solutions.
- Edge computing management: perform edge data collection and analysis functions, including equipment status, trend analysis, hardware management, alarm management, system management and other modules.
- Predictive maintenance cloud platform: mainly realises the construction of the operating environment for the predictive maintenance algorithm model, analysis and processing of data from the data centre, including access services, data services, system management and other modules.
- Condition monitoring and health assessment: mainly carries out visual analysis of equipment status and prediction results, including temperature trend analysis, current trend analysis, vibration RMS value trend analysis, vibration spectrum analysis, RUL value display and other modules.

Visualisation

Predictive maintenance software can implement the visual display of parameters, including temperature, current, speed and other parameters, as well as state parameters such as vibration acceleration and effective value. The colours green, yellow and red indicate the three states of equipment normal, equipment abnormal, and equipment failure respectively, providing visual display and early warning. The visual interface is shown in the figure below:

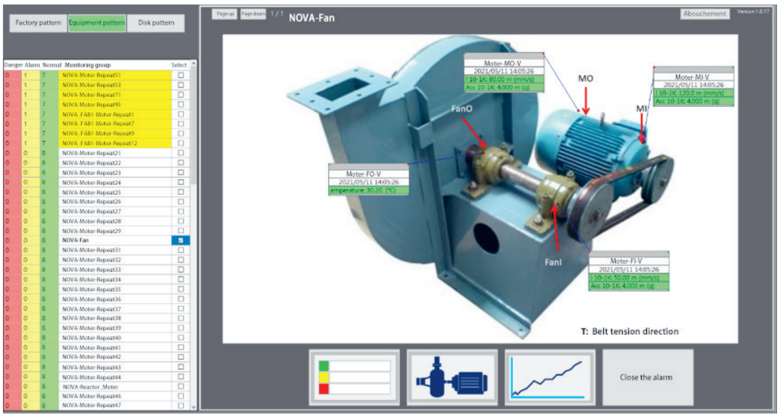


Figure 4-20-7 – Predictive maintenance system interface *Copyright: NOVA*

Data requirements

Equipment	Part	Failure mode	Data requirements	Monitoring measures
fan	bearing	bearing bending / wear	vibration	sensor
		ball wear	vibration	sensor
		maintainer deviation	vibration	sensor
		inner ring / outer ring damage	vibration	sensor
	motor	rotor eccentricity	vibration	sensor
		electrofusion abnormal sound	vibration	sensor
		base instability	vibration	sensor

Table 4-20-1 – Data requirements of scenarios

Scenario 21: Predictive maintenance for power distribution room

Overview

Agorae DR-EMS, an industrial IoT platform based on intelligent edge computing, proposed a predictive operation and maintenance management plan for power distribution rooms, which integrates core capabilities of network, computing, storage and application. Taking power distribution equipment and terminal load as models, the edge computing centre with the multiscale deployed measuring equipment is built to perform comprehensive monitoring and real-time perception of transmission and distribution equipment, which enhances the ability of the power distribution network, including advance warning, rapid detection and reaction and system evaluation. These support network reliability and energy optimisation and promote the digitalisation and transparency of power distribution equipment and load equipment for users. The position of the platform in the production system architecture is shown in the figure below, covering Level 0, Level 1 and Level 2.

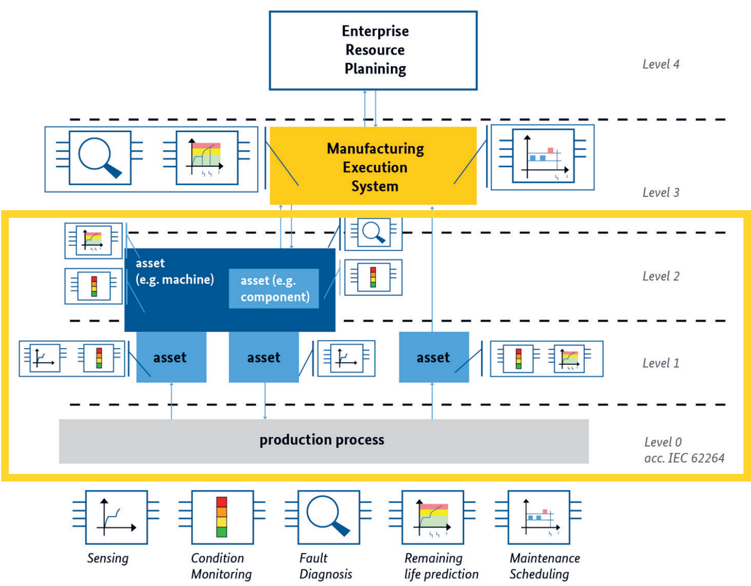


Figure 4-21-1 – System level diagram

The industrial IoT platform based on intelligent edge computing can perform functions such as sensing, condition status assessment, fault diagnosis, remaining life prediction, maintenance management, etc. as shown in Figure 4-21-2.

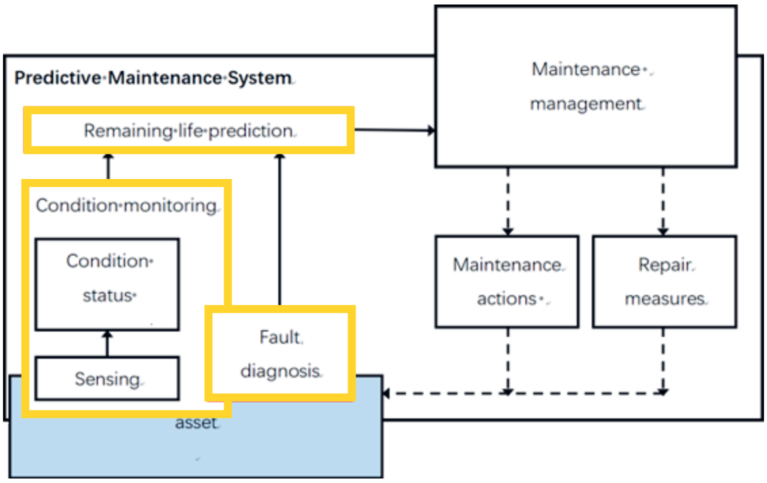


Figure 4-21-2 – System function diagram

Roles

In the construction of the predictive operation and maintenance platform for the power distribution room, Fujian Akuu Electrical Data Technology Co., Ltd. (AKUU) has the role of overall solution provider, mainly providing predictive maintenance technology, platform construction plans, data analysis and mechanism model support.

High-end manufacturing, commercial buildings, data centres, charging industry users such as stations and process industries are users, who are mainly responsible for using predictive maintenance technology to realise enterprise energy consumption monitoring, equipment failure operation and maintenance inspection and other functions.

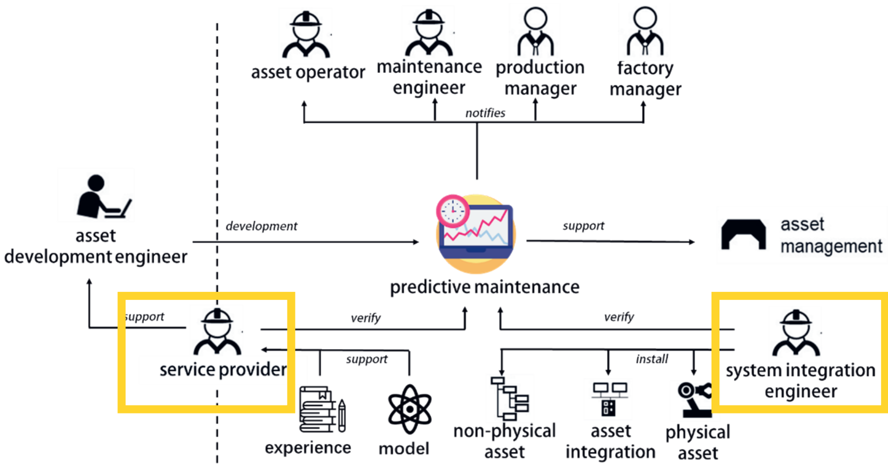


Figure 4-21-3 – Implementation role diagram

System architecture

This case uses the RAMEV A8 multi-channel intelligent data acquisition sensing measurement terminal, RAMEV X1 edge data smart box, RAMEV X5 edge data smart cabinet and other equipment, combined with the Agorae DR-EMS power distribution reliability and energy efficiency management platform to achieve interoperability within the entire intercommunication system.

Functions and methods

Operation monitoring management system

- Power distribution monitoring: 24 hours unattended, real-time monitoring of operating information, such as electrical equipment and environment.
- Load monitoring: monitor the full power parameters of the load and access the load operation and energy consumption in real time.
- Electrical safety monitoring: monitor the temperature and energy consumption of electrical safety facilities to ensure that energy efficiency indicators are reached; improve the reliability of electrical safety.
- Automatic alarm: real-time perception of power system conditions; automatic multi-channel push of alarm information in case of abnormalities or failures.
- Reliability analysis: transformer loss; transformer load factor; switch and circuit analysis.
- Power quality: harmonic monitoring; voltage qualification rate statistics; three-phase unbalance analysis.
- Operation and maintenance management system.
- The operation and maintenance management system can realise the creation and process traceability of inspection work orders, test work orders, trouble work orders and manufacturer maintenance work orders.
- Work order management: work order custom SLA service, automatic allocation and other management; users can follow the trouble ticket trend in real time via the mobile terminal.
- Equipment inspection: customise content format, then optimise equipment by inspecting it to ensure reliable operation.
- Equipment management: manage the whole life cycle of equipment and manage equipment files.
- Equipment analysis: analyse the multi-dimensional type of equipment and other information.
- Smart Energy Efficiency Management System.
- Full energy coverage: real-time dynamic monitoring of water, electricity, gas (steam), heat and other energy consumption.
- Energy consumption monitoring: real-time online classification, branch road, sub-item and sub-regional monitoring of enterprise energy consumption, and energy flow diagram.
- Energy consumption statistics: support the statistics and queries about historical energy consumption data for enterprise energy consumption units; optimise the energy consumption structure through statistical analysis.
- Energy efficiency analysis: analyse related data such as electricity, electricity bills, energy efficiency, etc.; this can help with calculating peak and valley multi-rate calculations of the electricity bill, and with calculating capacity and demand of the basic electricity bill.
- Cost control: data analysis and control management for basic electricity consumption, equipment life cycle, asset performance optimisation, etc.
- Report function: rich report function of the system, support personalised customisation and real-time download.

Feature highlights

- Leading cloud-side collaborative edge computing capabilities, support for seamless connection of nearly a hundred protocols and agreements, and two-way adjustable sampling frequency.
- Flexible microservice architecture, componentised application deployment, multi-scenario zero-code configuration, support process customisation/object customisation.
- Powerful alarm policy rules, threshold/frequency/time and other multi-dimensional

alarm convergence, which greatly reduces the false alarm rate.
- Integrated management and control of source network load based on digital twin, from system and equipment reliability to global energy efficiency management, (including business chain, energy chain, data chain and value chain) can be seen, managed and well used.
- The mobile APP, mini program, official account and PC are all-in-one, which meets the flexible configuration requirements of multi-role subjects with different organisations, different objects and different permissions.
- It provides safe services for companies in the whole factory area, including malfunction repairs, regular inspection and consumable material application. By applying the intelligent work order system in the AgoraeDR-EMS platform and applying good industrial APP on the code, the entire process is simple and efficient. Service optimisation of the link.
- Safe and worry-free, safe power operation, safe equipment operation, etc., through the AgoraeDR-EMS platform multi-source data fusion, aggregation and display, to achieve centralised safety supervision guarantee. Each subsystem is responsible for monitoring, recording, analysis and management, which is conducive to detecting hidden dangers, remedying faults, clarifying facts, restoring the truth, distinguishing responsibilities and summing up experience.
- Improved energy efficiency, thanks to the powerful power distribution data fusion capability of the Agorae industrial Internet platform DR-EMS and full-link all-weather operational data monitoring and analysis, combined with the platform's powerful industrial big data analysis capabilities, efficient analysis and insight into the energy consumption and leakage of various equipment. This provides a decision-making basis for further energy-saving optimisation.

Visualisation

Line power resource management, system registration and management of electrical line node switches (parameters such as rated current, breaking capacity, etc.), cables (parameters such as wire diameter, current-carrying, etc.) and load equipment (parameters such as power, rated current, rated voltage, etc.). It can also automatically generate the routing topology of electrical circuits, show operation parameters of the monitoring station in real time and provide warning of abnormal situations. The interface is shown in the figure below:

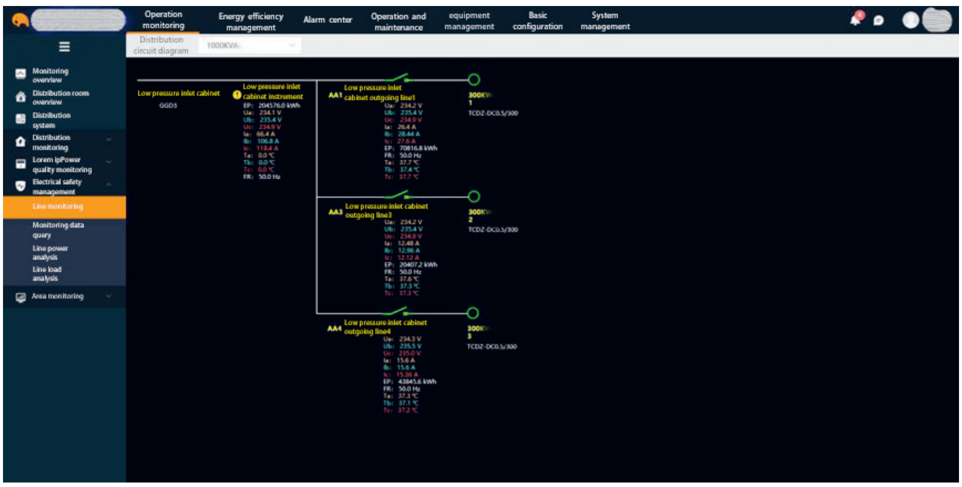


Figure 4-21-4 – Electrical circuit monitoring interface

Copyright: AKUU

Users can query data of the monitoring stations, including the real-time operational parameters of each monitoring station. Users can also easily query historical data curves to find potential faults early. The interface is shown in the figure below:

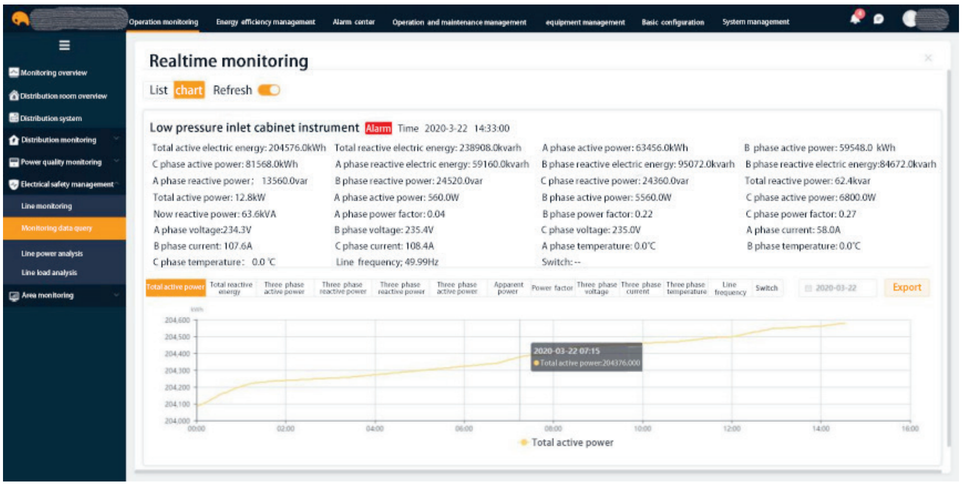


Figure 4-21-5 – Monitoring point data query interface Copyright: AKUU

By analysing changes in power and load of each node it is possible to identify any abnormal power consumption. The interface is shown in the figures below:

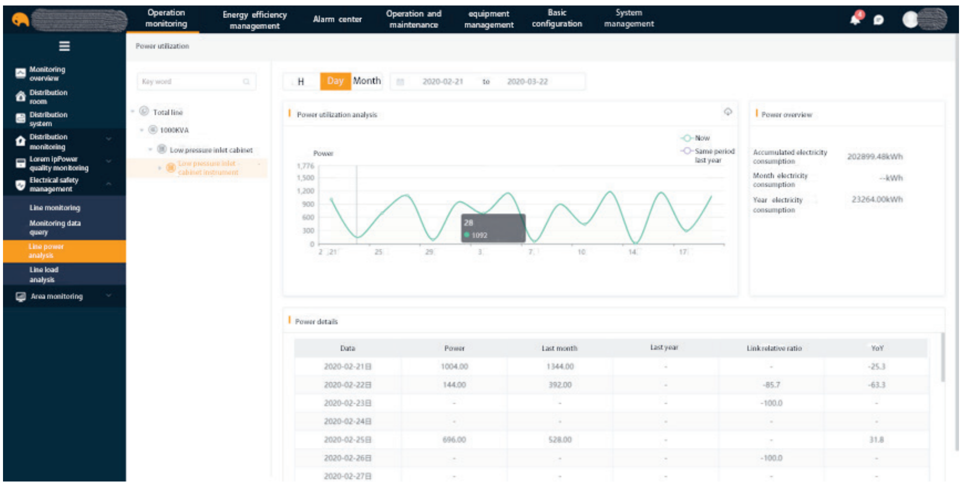


Figure 4-21-6 – Power analysis interface Copyright: AKUU

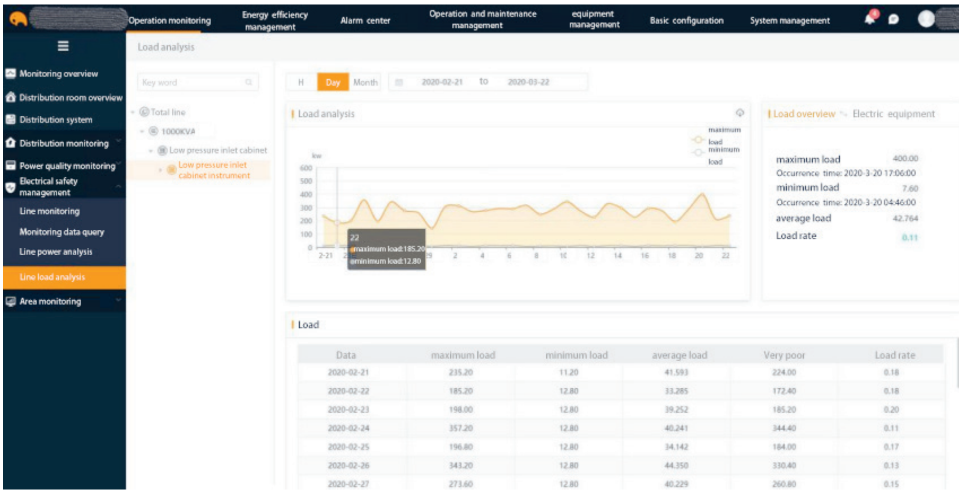


Figure 4-21-7 – Load analysis interface *Copyright: AKUU*

The alarm centre sets alarm rules and thresholds for each monitoring point through the alarm centre. Data abnormalities trigger early warnings and alarms. At the same time, you can view the alarm types and number of alarms, analyse hidden dangers and dispatch work orders. The interface is shown in the figure below:

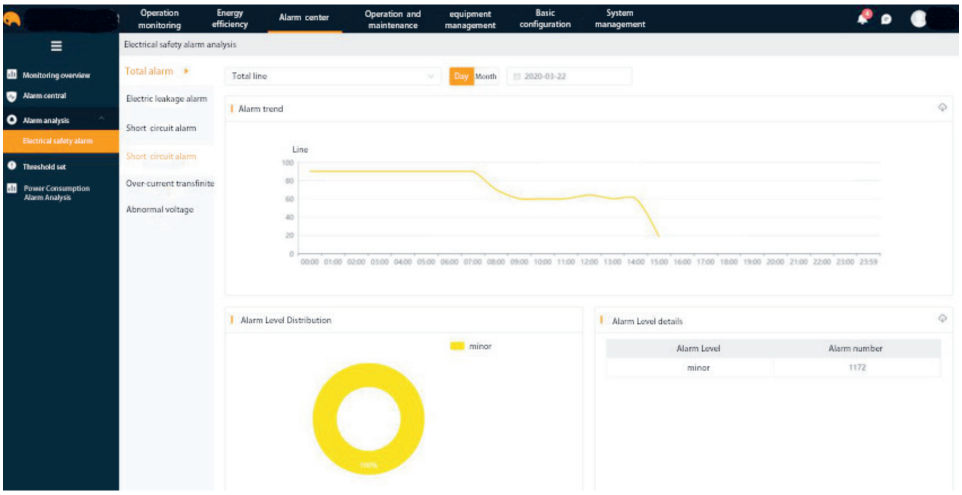


Figure 4-21-8 –Alarm analysis interface *Copyright: AKUU*

Data requirements

Equipment	Failure mode	Data requirements	Monitoring measures
oil-immersed transformer	voice disorder	harmonic, voltage, current	sensor (internal)
		current	sensor (internal)
		current	sensor (internal)
		vibration	sensor (internal)
		voice	sensor (internal)
		current	sensor (internal)
	under normal load and normal cooling mode, the oil temperature of the transformer increases continuously	temperature, current	sensor (internal)
		current, temperature	sensor (internal)
	three-phase voltage unbalance	voltage	sensor (internal)
		voltage	sensor (internal)
		voltage, current	sensor (internal)
dry type transformer	insulation resistance drop	voltage, current	sensor (internal)
	transformer core multi-point grounding	current	sensor (internal)
	transformer protection trip fault	current	sensor (internal)
		voltage, current	sensor (internal)
		voltage, current	sensor (internal)
	winding overheating	temperature, current	sensor (internal)

Table 4-21-1 – Data requirements of scenarios

Scenario 22: Predictive maintenance for city street lighting system

Overview

Predictive operation and maintenance solutions for urban street lighting systems, performing 24-hour real-time monitoring and diagnosis of street lighting systems, making timely operation and maintenance decisions, improving digitalisation and intelligence of terminal loads and lighting systems, and improving operational situation awareness of municipal lighting system equipment and the ability to actively control it.

Figure 4-22-1 –Schematic diagram of urban street lighting

The predictive maintenance system for the urban street lighting system performs monitoring and diagnosis in the system architecture. The location is shown in the figure below, covering the Level 0, Level 1 and Level 2.

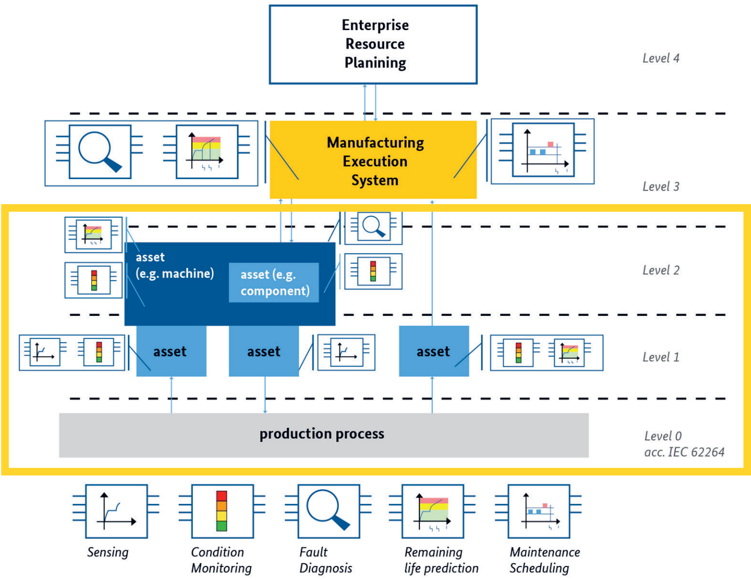


Figure 4-22-2 – System level diagram

The predictive maintenance platform for the street lighting system carries out the sensing, condition status assessment and fault diagnosis of the streetlamp, as shown in the figure below:

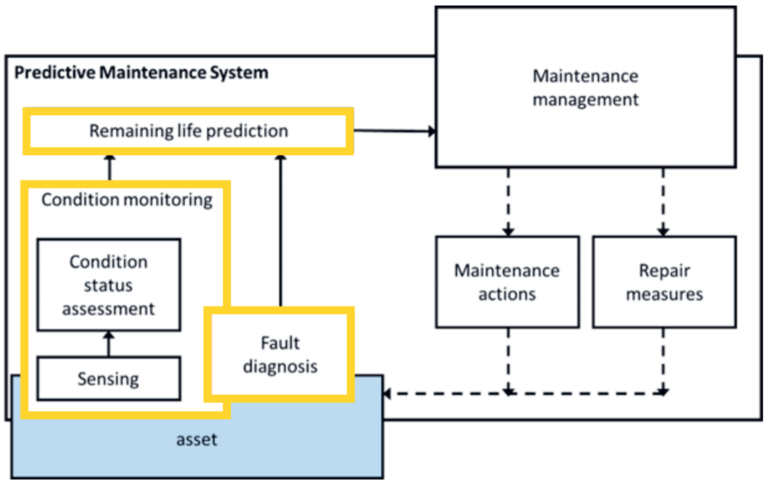


Figure 4-21-3 – System function diagram

Roles

In the construction of the predictive maintenance platform for street lighting systems, the role of AKUU is as overall solution provider, mainly providing predictive maintenance technology, platform construction plan, data analysis and mechanism model support. The manager is the street lighting office, which takes responsibility for municipal administration and urban investment. Any third party (such as a contract energy company) is the user. Through the platform's big data analysis and machine learning-based artificial intelligence algorithms, it can perform predictive maintenance for the electrical safety of the street lighting system and improve its digital and intelligent aspects.

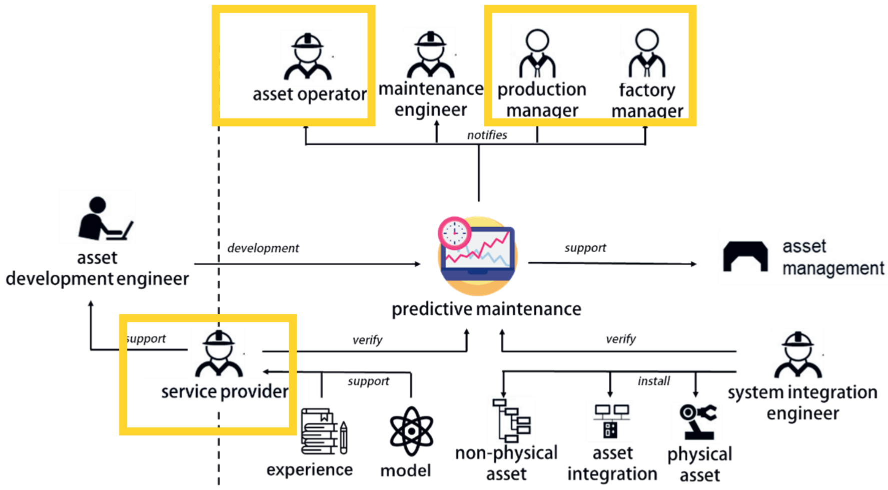


Figure 4-22-4 – Implementation role diagram

System architecture

The architecture of the test operation and maintenance solution for urban street lighting systems is shown in the figure. The city's public infrastructure neural network is developed by deploying edge multi-channel intelligent data collection, perception and measurement terminals, smart node safe power consumption fusion terminals, combined with smart city lighting infrastructure management platforms and mobile terminals.

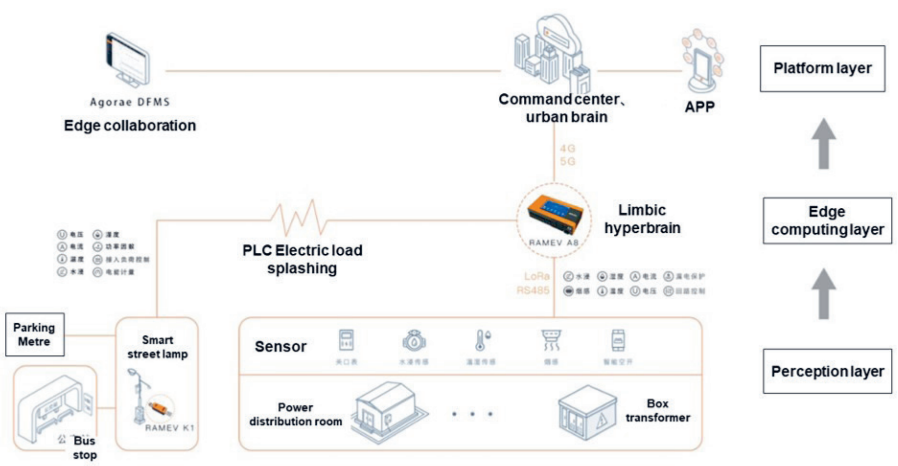


Figure 4-22-5 – System architecture diagram

Functions and methods

The test operation and maintenance solution for urban street lighting systems can improve lighting system reliability, asset life cycle management, operation and maintenance management, energy efficiency management, etc. The main functions are:

1. Operation monitoring: including street light box change, circuit, single lamp real-time monitoring of all electric parameters, load monitoring, etc.
2. Fault early warning: including real-time monitoring of equipment operating parameters, threshold setting, opening alarm for inspection openings, light pole immersion alarms, etc.
3. Safe use of electricity: including leakage protection, line monitoring, fault alarm, load monitoring, access control, etc.
4. Refined management: including energy consumption analysis, street light asset management, one-click repair report, load access management, work order service evaluation, etc.
5. Open sharing: open the load access point of the street lighting system and build the city's infrastructure neural network, so that the city has the characteristics of intelligent collaboration, resource sharing, interconnection and interoperability and ubiquitous perception.

Feature highlights

The outstanding features of the system test operation and maintenance solution for urban street lighting systems are as follows:

1. Effectively improve operation and maintenance efficiency and the safety and reliability coefficient of the street light system, from static analysis to dynamic perception, post-event analysis to pre-prevention and single-point prevention and control to global joint defence.
2. Effectively reduce the construction cost of pole combination transformation; flexibly support the mounting of personalised smart terminals.
3. Powerful edge computing capabilities; accurate fault research and judgment on the causes of switch tripping, such as overload, short circuit and maloperation; shorten the repair time and improve the reliability of the street lighting system.
4. The identification of living organisms based on artificial intelligence effectively solves the hidden dangers of electric leakage and the risk of electric shock under the influence of harsh environments, confined spaces and multi-variable environments, and greatly improves the safety of urban lighting systems.
5. Based on big data analysis, full life-cycle asset performance optimisation, using the operational life, real-time operating status, fault maintenance records of core lighting assets such as lamps, poles, cables, and switches, combined with multi-dimensional big data analysis such as weather and environment; automatically and accurately formulate maintenance strategies such as operation and maintenance, overhaul and replacement, thereby effectively avoiding the cost of excessive maintenance and blind replacement of equipment, as well as the unnecessary waste of manual vehicle shifts, and achieving the comprehensive goal of reducing costs, increasing efficiency and improving quality control and safety.

Visualisation

The smart city lighting infrastructure management platform uses smart street light boxes as edge computing nodes and smart light poles as edge connection nodes to conduct comprehensive detection, real-time perception, leakage alarm, as well as loop control of the transformation and distribution equipment and branch circuits of the municipal lighting system, load access management, dynamic environment monitoring, asset life cycle management, work order services, etc.

Figure 4-22-6 – Smart city lighting infrastructure management platform *Copyright: AKUU*

Figure 4-22-7 – Street lamp monitoring interface *Copyright: AKUU*

Data requirements

Equipment	Failure mode	Data requirements	Monitoring measures
high and low pressure tank	insulation fault	voltage, current	sensor (internal)
	operating mechanism failure	voltage, current	sensor (internal)
	failure caused by improper selection of protective components	voltage, current	sensor (internal)
	faults caused by environ-mental changes	voltage, current, temperature	sensor (internal)
	overcurrent and overload faults	voltage, current	sensor (internal)

Table 4-22-1 – Data requirements of scenarios

Summary

The emergence and application of predictive maintenance technology has a history of nearly 50 years. Whether it is traditional application at asset level, or application at factory level under the background of intelligent manufacturing and industry 4.0, the technical system involving condition monitoring, fault diagnosis, life prediction and maintenance management as the core function has basically formed a consensus. However, there are still many difficulties in the practical application process. These mainly include:

(1) Consistency of concept. The concept includes predictive maintenance, the relationships between preventive maintenance, PHM, corrective maintenance, time-based maintenance and state-based maintenance, as well as mapping between different technical and functional systems. With the establishment of IEC/SC65E WG12 on Predictive Maintenance and standard development, there will be a consensus among stakeholders on understanding and use of the concept. The main content of this document can also prove the above point.

(2) Data requirement. Data has always been an important issue plaguing industry. Sometimes it may not simply be a technical issue, but rather a policy issue. However, regardless of whether the data is open or not, stakeholders of predictive maintenance should first recognise the data requirement and possible collection methods needed to carry out predictive maintenance, in order to evaluate whether the current solution can achieve its purpose. It is, of course, hard to standardise data requirement; standardised data may sometimes affect innovation. This document provides multiple use cases with data requirements, which it is hoped will encourage stakeholders to innovate on this basis.

(3) Performance evaluation. Although prediction brings uncertainty, during the process of practical application users will always show concern for the accuracy of prediction, and other stakeholders will also pay attention to this. The current lack of quantifiable predictive maintenance indicators or levels, such as SIL levels in functional safety field, leads to a distrust for solutions. We are trying to build test evaluation systems to improve predictive maintenance performance, even though this may be a difficult process.

This document, which provides basic reference and guidance for the implementation of predictive maintenance, was completed under the joint efforts of Chinese and German experts over a period of three years. The collection of use cases is open and regularly updated. We hope that stakeholders will also regularly update predictive maintenance solutions.

Annex A. List of abbreviations

No.	Abbreviation	Full name
1	CM	condition monitoring
2	PM	predictive maintenance
3	ITEI	Instrumentation Technology & Economy Institute, PR China
4	TEG PM	Predictive Maintenance Working Group of the Sino-German Standardisation Cooperation Commission
5	VBS	value-based service
6	WFF	adaptable factory
7	DDA	seamless and dynamic engineering of plants
8	Mitsubishi	Mitsubishi Electric Automation (China) Ltd.
9	IPC	industrial personal computer
10	SFAE	Siemens Factory Automation Engineering Co., Ltd
11	CMS	Siemens state monitoring system
12	BBAC	Beijing Benz Automotive Co., Ltd.
13	Delta	Delta Electronics (Beijing) Co., Ltd
14	CSSC	China Shipbuilding NDRI Engineering Co., Ltd.
15	CUP	China University of Petroleum (Beijing)
16	NOVA	NOVA TEST EQUIPMENT Co., Ltd.
17	MSB	manufacturing service bus
18	TVOE	total value of engineering
19	LCC	life cycle cost
20	TBM	time-based management
21	CBM	condition-based management
22	RDA	real-time data analysis
23	FFT	Fast Fourier Transform
24	API	American Petroleum Institute
25	Manulism	Shanghai Manulism Technology Co., Ltd.
26	Weidmülle	Weidmüller Interface (Shanghai) Co. Ltd.
27	Ronds	Anhui Ronds Science & Technology Incorporated Company
28	Nari	Wuhan NARI Co Ltd., State Grid Electric Power Research Institute
29	Guangri	Guangzhou Guangri Elevator Industry Co., Ltd.
30	AKUU	Fujian Akuu Electrical Data Technology Co., Ltd.

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SHI Zhe, Foxconn Technology Group
ZHU Guoliang, Siemens Ltd. China
GUO Dongdong, Beijing Benz Automotive Co., Ltd.
GAO Shanqing, Mitsubishi Electric Automation (China) Ltd.
GUO Yun, Shanghai Manulism Technology Co., Ltd

Companies

Standardization Council Industrie 4.0
Instrumentation Technology & Economy Institute
Siemens Ltd. China
Beijing Benz Automotive Co., Ltd.
Mitsubishi Electric Automation (China) Ltd.
Shanghai Manulism Technology Co., Ltd.
Schneider Electric (China) Co., Ltd.
Baker Hughes Inspection & Control Technology (Shanghai) Co. Ltd.
Weidmüller Interface (Shanghai) Co. Ltd.
Delta Electronics (Beijing) Co., Ltd.
Anhui Ronds Science & Technology Incorporated Company
Wuhan NARI Co Ltd., State Grid Electric Power Research Institute
China University of Petroleum (Beijing)
China Shipbuilding NDRI Engineering Co., Ltd.
Microcyber Corporation Co., Ltd.
AVEVA Solutions (Shanghai) Co., Ltd.
NOVA TEST EQUIPMENT Co., Ltd.
ZKH Industrial Supply Co., Ltd.
Fujian Akuu Electrical Data Technology Co., Ltd.