Digital twin model of equipment maintenance management in modern enterprises

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Abstract. With the development of science and technology, modern enterprise equipment is more and more complex and widely distributed. The requirement of “accuracy” of equipment maintenance management is higher and higher. Accurate equipment maintenance management is of great significance for accurate support of modern enterprise. By analyzing the current problems faced by modern enterprise equipment maintenance management, the digital twin technology is introduced into the field of equipment maintenance management, and the idea of modern enterprise equipment maintenance management based on digital twin is proposed. From the physical layer, twin layer, application layer and connection layer, the equipment model based on digital twin is established, the operation of the model is analyzed, and the application method of the model is prospected.

1. Introduction
With the continuous development of modern enterprise equipment towards large-scale, high-speed, distributed, automatic and complex direction, the requirements for continuity and stability of production equipment are constantly improving [1]. In the face of increasingly fierce market competition, the enterprise must effectively manage the equipment to create maximum benefits for the enterprise, reduce the cost of equipment maintenance support, and save the enterprise production funds, which puts forward new requirements for the equipment management mode [2].

Domestic and foreign scholars’ research on enterprise equipment management is mainly based on the analysis of single machine support, and less on the analysis of equipment group composed of a variety of equipment. In modern enterprises, there are many types of equipment and miscellaneous specifications of spare parts. The same type of equipment is scattered in different regions, and different types of equipment have the same replaceable units, so the demand for maintenance support is complex. At the same time, in order to meet the personalized needs of customers, the equipment operation time is greatly increased, the use of complex and harsh environmental conditions. Due to different tasks, the maintenance support requirements of the same type of equipment will vary greatly. Therefore, the original mathematical model of batch forecasting demand method cannot achieve the best effect, the existing research results are difficult to solve the problem of modern enterprise equipment maintenance management.

In recent years, digital twin technology has been fully developed. Its research originates from life cycle management, and has great matching and many advantages in the field of equipment maintenance support. Digital twin can be defined as the replication of a real physical system with a
digital model, which uses a large amount of data from the physical system to optimize, monitor, diagnose and forecast the system by integrating artificial intelligence, machine learning and software analysis \[3\]. The idea of digital twin was first proposed by Professor Grieves in the course of product lifecycle management around 2003 \[4\]. In 2010, NASA formally put forward the term "Digital Twin" in its technical report, and defined it as "a system or aircraft simulation process integrating multiple physical quantities, scales and probabilities" \[5\].

Using digital twin technology, we can accurately and comprehensively grasp the current status and historical status of the equipment, study the support demand based on the equipment status, optimize the maintenance support mode, repair the equipment when it is about to fail, give full play to the equipment performance, reduce the spare parts inventory and maintenance waiting time, and improve the efficiency of equipment use and maintenance support.

2. Analysis of equipment maintenance management in modern enterprises

2.1. Raising of the problem
Modern enterprises have many types of equipment, high degree of integration and wide geographical distribution. The same type of equipment is scattered in different regions, and different types of equipment may have the same replaceable units. There are many types, models and quantities of equipment. Taking an enterprise as an example, the enterprise is equipped with electric welding machine, cutting machine, lathe, milling machine, planer, grinder and other kinds of equipment, each type of equipment has multiple models, and can be divided into multiple subsystems according to its composition. Different types and models of equipment contain different subsystems, such as CNC lathe contains host system, driving device, CNC device and other subsystems. The subsystem consists of several replaceable units, including series system, parallel system, hybrid system, voting system and so on. Suppose that there are \(n\) types of A-class equipment in an enterprise (I, II, III...) equipped with the same system \(\alpha\), the number of the \(i\)-th equipment is \(a(i)\) \((1 \leq i \leq n)\), the \(\alpha\) system is a series system composed of \(m\) different replaceable units, and the number of the \(j\)-th unit is \(b(j)\) \((1 \leq j \leq m)\), then the A-class equipment group has a total of

\[
y = \sum_{i=1}^{n} \sum_{j=1}^{m} a(i)b(j)
\]

replaceable units. The operation of the same unit on different types of equipment is different. Even on the same type of equipment, different equipment will perform different tasks, resulting in different maintenance support requirements, which are complex.

Modern enterprises implement two modes of equipment maintenance: self-support and after-sale service. Among them, the self-support is completed by the enterprise itself, which uses the method of replacement repair to complete the task of maintenance support for simple failures. It is necessary to forecast the demand of spare parts in advance and reserve them in advance, to ensure timely maintenance in case of equipment failure. When the spare parts are in stock, the damaged equipment can be replaced immediately. The replacement time is short and the impact on the equipment is small. If the spare parts are not in stock, it is necessary to stop the machine and wait for the spare parts to be replenished for repair, which will affect the work of the equipment. The enterprise cooperates with the manufacturer to replenish the spare parts once a year, usually at the beginning of the year. If the spare parts are consumed within a year, they need to be replenished temporarily.

In the face of the complex maintenance support needs of modern enterprises, if we continue to manage according to the original batch support mode, it is easy to cause the shortage and overstock of spare parts and reduce the efficiency of maintenance support, so we need a new equipment maintenance management method to adapt to it.

2.2. The general idea of solving the problem
In view of the low accuracy of the traditional batch support mode, which cannot meet the needs of modern enterprises, the new equipment maintenance management ideas needs to analyze the current
status and tasks of each equipment. The application of digital twin technology can solve this problem well.

Equipment maintenance management model based on digital twin, the digital twin model is established for single equipment and each replaceable unit to grasp the actual operation status of the equipment in real time by using the digital twin technology, so as to guide the management decision-making. Taking spare parts demand management as an example, through the analysis of the sensitivity of the spare parts demand of each replaceable unit in the task and operation environment, the sensitivity coefficient system of the spare parts demand of replaceable unit is established to the external environment. Using the advantages of digital twin model, the sensitivity coefficient with high reliability can be obtained by using the collected data to train the sensitivity coefficient during the operation of physical equipment and digital twin model. By analyzing the equipment status, and inputting the annual tasks and operation conditions in the model, and using the unit sensitivity coefficient to forecast the demand of spare parts accurately, the goal of "accurate support" can be achieved, and the problems of shortage and overstock of some spare parts caused by the original support mode can be prevented.

2.3. The basic assumptions of the research
In order to carry out the research, the following basic assumptions are made:
(1) The maintenance tasks completed by enterprises are relatively simple, and the replacement time is relatively short, which can be ignored;
(2) Due to the short repair time, the queuing problem is not considered, that is, the equipment failure can be repaired immediately;
(3) The equipment runs in stable period, which conforms to relevant reliability law;
(4) When ordering spare parts, regular replenishment can be mass produced and quickly replenished with low cost, while temporary replenishment requires remote deployment or small batch production with high cost.

3. Establishment of digital twin model
The digital twin model of equipment is to realize the interactive integration of physical equipment, virtual equipment, data connection and information service through the bidirectional real-time mapping and quasi real-time interaction between physical equipment and virtual equipment by using information technology [6]. To establish the digital twin model of equipment, it is necessary to establish the digital twin for single equipment and divide it into each replaceable unit of each system. The digital twin model of equipment can be divided into physical layer, twin layer, application layer and connection layer, as shown in Figure 1.
3.1. Physical layer
The physical layer refers to the entity elements of the equipment and the entity data generated by them. It is the entity basis of the digital twin model of the equipment and the primary premise of the establishment of the digital twin model.

Entity elements mainly include entity equipment, subsystems, replaceable units, sensors, measuring tools used in equipment data collection, equipment operators, etc.

Entity data is mainly the data that has an impact on the equipment, which is in the periphery of the equipment, including task data, monitoring data, environmental data, support data, operator data, etc., as shown in Figure 2.

![Figure 2 Schematic diagram of entity data](image)

3.2. Twin layer
The twin layer is a virtual model and its twin data, which can realize the real-time and accurate mapping of entity elements. It is the key element of digital twin model establishment.

Virtual model is a virtual model of entity elements drawn by modeling software, which takes single equipment as the basic object, divides it into each replaceable unit of each system, and distinguishes different equipment by different twin data.

Twin data is mainly the data inherent in the equipment and generated by operation, including equipment parameters, replaceable unit data, operation data, test data, historical data, etc., as shown in Figure 3.

Using twin data, with the support of knowledge base, experience base and constraint base, twin equipment can be fused and provided to the application layer.

![Figure 3 Schematic diagram of twin data](image)
3.3. Application layer
The application layer is a software system based on the model data processing, which assists the equipment management personnel to monitor the equipment status, analyze the operation status, early warn the failure, and forecast the spare parts demand. It is a way for the digital twin model to output the operation results and realize the function of the model.

The software system mainly includes equipment condition monitoring subsystem, equipment operation condition analysis subsystem, unit operation condition analysis subsystem, failure early warning subsystem, spare parts demand forecasting subsystem, etc.

3.4. Connection layer
The connection layer is a collection of hardware, software and protocols used in the communication among the physical layer, twin layer and application layer of the digital twin model, as well as the communication between the model and the external model. It is an important bridge of the digital twin model. Through the connection layer, the physical layer, twin layer and application layer are closely linked and mapped to each other, and data can be shared between models to provide basis.

Internally, through the connection layer, the physical layer, twin layer and application layer can collect and share the required data in time, so as to achieve accurate description, analysis and forecast of the equipment. Externally, through the connection layer, it can be connected with the twin model of superior equipment group, the twin model of other equipment at the same level, the equipment maintenance support model and the warehouse management model based on digital twin, so as to obtain external information in time and make correct analysis and decision.

4. Operation and application of digital twin model

4.1. Operation of digital twin model
In the process of equipment operation, the physical layer continuously transmits real-time data such as temperature and vibration to the twin layer through sensors, and inputs data such as equipment actual use status and maintenance data into the twin layer. The twin layer provides data support for the application layer through data collection and processing, and uses the processing results to guide the operation of entities in the physical layer. The application layer uses the data given by the twin layer to provide application services for equipment managers, assist equipment maintenance support decision-making, and act on the physical layer. At the same time, it modifies the virtual model based on the data processing results to achieve accurate description of the equipment. The connection layer provides ways to transfer data between layers.

It can be seen from the operation that one of the important functions of digital twin model is the feedback training of the model. Through the analysis of twin data, using big data analysis, data mining and other methods, fitting coefficient and modifying the model can realize the accurate description of the equipment.

For example, when the digital twin model is used to forecast the demand of spare parts, the basic demand model of replaceable units based on life distribution is introduced, and the sensitivity coefficient system of replaceable units to operation and environment is constructed. The digital twin model is used to train the sensitivity coefficient, and the reliable demand law of spare parts is obtained.

4.2. Application of digital twin model
Through the above operation process, we can accurately grasp the real-time health status of each equipment and unit, and can modify the model parameters in real time to realize the accurate description of the equipment. Combined with different application requirements, the application layer can realize the functions of equipment operation status monitoring, health status assessment, key unit fault warning, spare parts demand forecasting and other functions by using data from digital twin model, big data processing, mathematical model and intelligent algorithm. Therefore, effective forecasting and timely maintenance can be carried out on the eve of equipment failure, to avoid the
phenomenon of "excessive maintenance" and "insufficient maintenance", improve the utilization rate of equipment parts, reduce the cost of equipment maintenance support, and improve the efficiency of equipment maintenance support.

According to this method, the digital twin model of all equipment owned by the enterprise is established, and the accurate support of enterprise equipment can be realized.

5. Conclusions

Digital twin technology provides a good technology for solving the problem of accurate support of equipment. This paper establishes a digital twin model for the equipment belonging to the enterprise from the physical layer, twin layer, application layer and connection layer. The operation of the model is analyzed, and the application method of the model is described.

By establishing the digital twin model of equipment maintenance management in modern enterprises and using the digital twin model to feedback and train the various rules of their own coefficients, we can get the rules of equipment operation and failure with high reliability to accurately grasp the operation situation and support demand of each equipment, so that the modern enterprise spare parts can support the equipment maintenance needs, improve the inventory utilization rate, reduce the inventory of spare parts, so as to improve the overall efficiency of enterprise maintenance support, and adapt to the requirements of accurate equipment support.

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References

[1] Xuan C, Song G, & Zhu Y. (2020). Necessity of equipment management system construction. Equipment Management and Maintenance, 2020 (07), 7-8.
[2] Ma J, & Guan T. (2021). The practice of TPM management mode in helping enterprises reduce equipment maintenance costs. China Plant Engineering, 2021 (04), 55-56.
[3] Prof. Rajratna Kharat, Bavane V, Jadhao S, & Prof. Marode R. (2018). Digital Twin: Manufacturing Excellence Through Virtual Factory Replication. Global Journal of Engineering Science and Researches, (NC-Rase 18), 6-15.
[4] Tao F, Zhang M, Cheng J, & Qi Q. (2017). Digital twin workshop: a new paradigm for future workshop. Computer Integrated Manufacturing Systems, 23 (01), 1-9.
[5] Glaessgen E, & Stargel D. (2012). The digital twin paradigm for future NASA and U.S. air force vehicles. 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conf, New York. American Institute of Aeronautics and Astronautics.
[6] Wu Y, Yao L, Xiong H, Zhuang C, Zhao H, & Liu J. (2019). Quality control method of complex product assembly process based on digital twin technology. Computer Integrated Manufacturing Systems, 25 (06), 1568-1575.