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Studying the Best Way to Control Cluster Reactors more Effectively while Haiyang Nuclear Power Plant Undergoes Digital Transformation

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Abstract

This study explores a specific case of Haiyang Nuclear Power Plant (HNPP) to increase the effectiveness of group reactor management through information technology in the process of digital transformation. Haiyang NPP has implemented several programs, including 12-week rolling plan management, real-time on-site monitoring system, electronic work package mechanism, big data analytics platform, joint production regular meeting mechanism, emergency response, and integrated command, to achieve efficient management and maintenance. The following key performance indicators have seen significant improvements as a result of these programs, according to quantitative analysis: the average operation response time has decreased by 55.56%, the troubleshooting time has decreased by 66.67%, the operation plan completion rate has increased to 90% on time, the equipment failure rate has decreased by 50%, and the personnel satisfaction rate has increased to 92%. Furthermore, there was a 10% reduction in total operating expenses and a 95% operational compliance rate. The findings demonstrate that putting information technology management into practice successfully not only improves worker productivity and safety but also offers substantial support for nuclear power facilities' long-term viability.

Keywords: nuclear power plants, digital transformation, cluster stack management, information technology, big data analytics, operational efficiency

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1 Introduction

Against the background of expanding worldwide energy demand, nuclear power, as a clean and efficient kind of energy, is rapidly becoming an essential part of the energy policy of numerous countries [1]. How to increase nuclear power plant management effectiveness and guarantee their safe and stable operation, however, has emerged as one of the industry's major difficulties as the number and scale of nuclear power plants continue to rise. Particularly in China, the dual responsibilities of energy production and technology innovation fall to the top nuclear power plant in China, Haiyang. Haiyang NPP is actively supporting digital transformation to improve the efficacy of its cluster reactor management in light of the ongoing advancements in digital technology. However, in this process, there are still many technical and management problems, which pose new issues on how to further improve the complete management competence of nuclear power plants [2, 3].

Digital transformation has emerged as a major effort to boost management effectiveness and productivity across a range of businesses in recent years. Digitalization in the nuclear power sector refers, first and foremost, to the extensive monitoring and optimization of the entire operation process using information technology, rather than just the automation of equipment upgrades [4]. With the

DNMC operation management center serving as the system's core, Haiyang NPP has established a group reactor management system. This system uses a wireless network, a large visualization screen, and mobile terminals to transmit real-time information about the status of the equipment on site as well as operation scenarios back to the management center, enabling comprehensive monitoring and fault diagnosis of the operation site. In addition, Haiyang NPP has greatly increased equipment reliability and operating efficiency using a range of techniques including deep-level cause analysis, online expert help, and maintenance strategy optimization [5].

Nevertheless, it is impossible to overlook the complexity of managing group reactors or the variety of issues they encounter. Haiyang Nuclear Power Plant requires the synchronized operation and management of many nuclear power units, and there are intricate system correlations between the units, so any one point of failure may pose systematic safety hazards [6]. Thus, reducing human error in the operation process, optimizing resource allocation, and enhancing the effectiveness of group reactor management through digital methods have emerged as critical issues that require resolution.

Even if the openness and responsiveness of operations management have greatly improved thanks to digital means, there are still a number of issues with the cluster stack management process at Haiyang NPP [7]. The first and most crucial problem is how to continue optimizing the operating procedure while guaranteeing the nuclear power plant operates safely. For instance, there is still substantial space for development in the capacity to integrate and analyze multi-dimensional data in real time under complicated operation situations, even though the current wireless network and video system cover the whole plant area. Second, even though operational documents are electronically converted through handheld terminals, in reality, delays in data transfer and incompatibilities among various systems frequently impair the effectiveness of managerial decision-making because of the need to coordinate and schedule resources among several departments [8, 9].

Furthermore, the point inspection system, which is the central mechanism for managing nuclear power equipment, has been essential to Haiyang NPP's operation. However, as the number of equipments and system complexity increase, point inspection engineers are under a lot of pressure to handle cross-field and multitasking issues. Currently, there is a significant issue in further optimizing the point inspection system's operation mechanism to make it more effective in handling complicated situations.

Currently, nuclear power plants both domestically and internationally are concentrating their management effectiveness improvement strategies on three main areas:

1. enhancing the visualization management of equipment status through informatization;
2. enhancing the operation process's real-time monitoring capability through data integration and analysis; and
3. optimizing the fault diagnosis and maintenance strategies through expert systems. Nonetheless, there are still a number of issues with the particular implementation procedure [10, 11].

First, despite the fact that the majority of nuclear power plants have set up platforms for data integration, the problem of data silos between various systems persists. In addition to limiting thorough analysis and in-depth mining of operational data, this system isolation also has an impact on the precise assessment of equipment state [12]. Second, while dealing with complicated and multi-dimensional defects, the current fault detection system has low diagnostic efficiency since it lacks an intelligent diagnosis model based on big data and mostly depends on the experience judgment of engineers. The daily management of nuclear power plants has also made extensive use of a variety of wireless networks, video surveillance, electronic work packages, and other informatization tools; however, the synergistic effect between these technologies has not yet been fully developed, and there is still a greater amount of manual labor and repetitive tasks, which limits the improvement of overall management effectiveness [13].

This study presents an optimization technique for whole-process group pile management based on the task management center, with the aim of addressing the aforementioned issues. In order to create an intelligent management platform backed by big data, this article first suggests realizing the complete real-time gathering and feedback of operation information through wireless networks, video monitoring, handheld terminals, and other instruments. Through big data analysis and failure prediction models, the platform can not only achieve cross-system data integration but also increase the precision and effectiveness of problem diagnosis.

Second, by fusing machine learning algorithms with expert expertise, this article suggests introducing an intelligent decision support system and an expert system into the group stack management process. This increases the automation level of operation management. Based on this, this study also suggests a new point inspection system operation mode that uses a multi-level, stage-by-stage point inspection mechanism to achieve precise management of the equipment's whole life cycle. The implementation process of operation planning, fault diagnosis, and maintenance strategy is also adjusted to further improve management effectiveness by fortifying the synergy between the inspection staff and the operation management center.

This paper also suggests a new optimization scheme for operation process management, which aims to improve the digitization of the workflow by establishing an electronic work package and an electronic pick-up and return ticket mechanism, and to lessen the reliance on paper documents and manual operation. This study achieves lean management of the operation process and efficiently minimizes information lag in cross-departmental communication and resource scheduling by streamlining the operation preparation process.

2 Overview of the Operations Management Center

In order to reduce the work interface and enable inspection engineers to perform real-time monitoring of on-site operations, comprehensive troubleshooting, online expert support, deep-level cause analysis, and continuous optimization of maintenance strategy, among other tasks, the DNMC operation management center prioritizes on-site equipment and operations. To this end, it employs advanced information technology, including wireless networks, large visualization screens, mobile terminals, etc., to transmit the status of on-site equipment and operation scenes back to the operation management center in real time. This results in fewer work interfaces, quicker reaction times to unit problems, more productivity, better maintenance quality, and more dependable equipment.

2.1 Composition of the organization

The majority of the OMC staff are inspection specialists, with the addition of workweek teams (weekly managers, planning engineers, segregation managers, and professional coordinators) and inspection engineers. Inspection specialists are professional engineers under the inspection system, responsible for all the technical issues related to a functional area of the heap (such as the field of refrigeration, diesel engine field, etc.), and also set up under the first and second level of inspection engineers responsible for specific systems and equipment. The work week team, which is primarily in charge of group heap, performs the support role of operation process control. Setting up the operation strategy, coordinating the resources, and other tasks.

2.2 Facilities and technical support

The center construction site of the plant has office buildings; the first floor of the office building is all through; in accordance with the need to re-divide the pattern, the design is divided into the center of the hall, the deputy hall, the Zhizhen conference room, and satellite office area of the four major parts. This allows for the maximum utilization of the resources already available in the power plant and reduces unnecessary expenses.

The main office space is the lobby and sub-hall, which is equipped with a huge screen wall that can be arranged to fit any screen division and is set up with the appropriate server and software to enable audio and video access and interaction. Spot check experts in this field are able to accomplish remote communication with each plant's primary control and the scene. Multi-point high-definition video conferencing is made possible by the Zhizhen conference room's use of contemporary video conferencing technology. Distributed staff members from each plant can participate in the meeting remotely thanks to this system, which is a crucial information tool for the operation management center's group pile management.

The work week team's office, known as the "satellite office," was initially assigned to each plant. Its purpose is to coordinate the operations of the three plants and six piles of field operation plans in order to provide process control for the center's operations. The center additionally uses the following technical tools to support the above components' regular operation:

1. Wireless network: The entire plant is covered by a wireless 4G network that serves as an information highway linking the main control room, management center, and on-site operations. Real-time uploads of audio and video and

operation process data are possible over this network.

2. Video system: a fixed camera system with over 700 cameras throughout the plant that records full-coverage footage continuously for 24 hours, as well as a mobile camera system (head-mounted camera system + handheld recorder) that is used to operate the specifics of dynamic real-time image uploading and recording.

3. As the standard tool for field workers, the handheld terminal replaces paper work documents, fully electronic work instructions, permits, work procedures, and drawings. It also has a number of additional features, including wireless connectivity, defect reports, inspection records, personnel positioning, equipment scanning code identification, audio and video recording and communication, etc., essentially realizing the goal of "a machine in the hand, the whole of information." The idea of "one machine in hand, all information is available" is essentially realized. For information interoperability at the workplace, it is a crucial tool.

4. Electronic signage: Field equipment is arranged in the form of a two-dimensional code called a "identity card." A handheld terminal can be used to scan codes that correspond to the name of the equipment, the unit, the location, and other details. By comparing database data at the worksite with the code information, it is possible to intelligently prevent human error and effectively avoid making mistakes such as going to the incorrect power plant or equipment location.

The program management and control platform is specifically designed to integrate the data that was originally distributed in the work ticket system (Systems Applications and Products in Data Processing, a type of Enterprise Resource Planning Management Software, or SAP for short), the planning system (Primavera 6, a type of Project Planning Management Software, or P6), the work order time system (Daya bayTime Management System, or DTMS), and other information systems related to the work process. This is because group stack management has higher requirements for the overall coordination ability of the program. A complete work process information chain is formed by capturing and integrating data from Primavera 6, a type of project plan management software (also known as P6), work order time management system (also known as Daya bay Time Management System, or DTMS), and other work process related information systems. This increases information about work execution feedback, work process information, and reminders of plan changes. In order to support the main office and deputy office staff in effectively understanding the operation process information and subsequently taking flexible and prompt appropriate countermeasures based on that information to meet the center's goal of a timely and effective response to the crew's needs, push, work implementation feedback, pre-work risk tips, and other functions have been added [14].

2.3 Principal mechanisms of operation

The Total Productive Maintenance (TPM) system, which is based on the point inspection system, is the primary operating mechanism of the DNMC operation management center. It breaks down the barriers between the power plants and specialties and reorganizes the roles of coordination engineers, preparation engineers, spare parts engineers, executive supervisors, and work leaders that were previously scattered throughout the operation process. The point inspection engineer is in charge of the sub-system equipment, and the point inspection expert is in charge of the field equipment, forming a tree topology [15].

In this mechanism, the engineers and inspection specialists are the equipment masters; the entire equipment life cycle process is managed, along with the problem analysis, strategy formulation, work coordination, work preparation, work execution, spare parts management, experience feedback, document upgrading, and other equipment-related tasks. These tasks are assigned to the appropriate personnel based on the inspection system. The process in question has three distinct degrees of inspection: daily, full-time, and precision. Equipment operators are accountable for conducting daily inspections to easily identify surface signs of failure; professional inspection engineers are accountable for conducting full-time inspections to easily identify hidden faults and failure trends; and inspection specialists are accountable for performing precision inspections to easily identify the failure's root cause and potential solutions. We are able to "prevent failure before it occurs" and preserve the high stability of equipment performance by building equipment defensive lines at all levels.

2.4 Assistance for the working mechanisms

Mechanism for joint production meetings. The Zhizhen conference system allowed the three power plants to hold joint meetings for the planning meeting, the SRT (Screen Review Team, new work application review organization) and the routine morning meeting. From the three power plants, "three sets of people" changed to a set of personnel playing "a game of chess!"The daily production management program hosts the combined morning meeting. The business managers in charge of each department attend the joint morning meeting, which is facilitated by the daily production management project manager. The goals of the meeting are to reduce the number of levels of information transmission, strengthen response to problems and promote their effect, accomplish the goal of integrating resources and improving efficiency, and directly coordinate and solve problems across power plants and fields. In order to coordinate the review of the new work applications of the three power plants' priorities and the planned work arrangements of the three power plants, the joint SRT and planning meeting is a regular event in which the work week manager, planning engineer, coordination engineer, safety engineer, and other team members participate.

12-week planning mechanism: To ensure that the work is well-prepared and completed on time, DNMC uses an internationally cutting-edge 12-week rolling plan management mechanism. This mechanism tracks the preparations for the work starting 12 weeks in advance of its execution and sets up positioning at key nodes, such as 8 weeks, 5 weeks, and 2 weeks in advance. In the operation management center's satellite office, the planning engineers from the three plants collaborate to achieve cross-power plant and cross-discipline planning and coordination.

Electronic system for retrieving and returning tickets. Adopting information technology entails solving the issues of operating staff having to expend energy distributing paper permits, the person in charge of the work of the time-consuming, inefficient transfer of information, etc., and reallocating limited resources to the important work to enhance work efficiency for the management of the group heap. It also means that over 70% of the work with low risk is realized by the person in charge of the work of the local electronic ticket, and that they do not need to travel to the main control or isolation office to hold a pre-work meeting and receive paper permits. Group pile management improves work efficiency.

Work package mechanism that is electronic. The entire work preparation process is paperless, which significantly increases process efficiency and is a required information technology tool for group stack management. There is also no need to submit prepared instructions, procedures, drawings, and other work materials to the planning and operation departments in the form of paper work packages.

Additional steps for process optimization. Apart from the aforementioned methods, DNMC has implemented other optimization techniques aimed at enhancing the process management's lean and informatization level and ensuring the management of group stacks. For instance, DNMC has implemented the NG (Notification General) notification classification mechanism to optimize the management of certain low-risk workflows; the one-vote system to optimize the management of work permits; and the Work Order and Working Hour Management System (DTMS) to optimize the management of standard working hours, among other measures. The computerized version of manufacturing forms reflects the widely utilized approval method, which has significantly increased job efficiency.

3 Overview of Job Management Center-Based Group Heap Management Functions

The primary cluster stack management process at Haiyang Nuclear Power Plant's digital transformation is depicted in Figure 1, where intelligent informatization tools and systems effectively and cooperatively manage each process node and information flow.

Operation Plan Management: The cluster stack management activities are prearranged and coordinated across power plants, based on the 12-week rolling plan method. This guarantees the efficient execution of operation plans and the sensible distribution of resources.

Implementing operations on-site: Data is gathered on-site and sent back to the operation management center via a 4G wireless network, mobile terminals, and other information technologies. This allows for remote monitoring and technical help to enhance operational efficiency and safety.

Operation Process Monitoring and Feedback: The operation management center obtains the operation status of the site through the real-time video monitoring screen, and accurately analyzes the

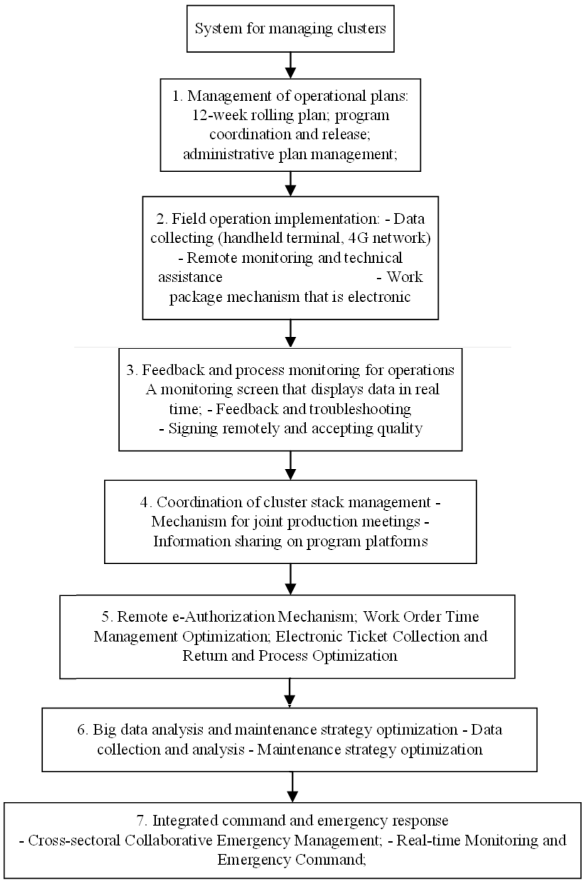

Figure 1. Cluster management system at Haiyang Nuclear Power Plant, detailing the seven-step process for operational optimization and emergency response

problems through the troubleshooting tool and provides real-time feedback to the operators to improve the efficiency of troubleshooting.

Coordination of group reactor management: Information is transferred in real time between various power plants and specialties through the system of joint regular meetings, ensuring smooth coordination and effective management of group reactor production activities.

Electronic Ticket Collection and Return and Process Optimization: Utilize electronic methods to streamline the process of collecting tickets and work permits during operations, minimize operational errors caused by humans, and enhance the organization of chemical orders and the documentation of working hours.

Utilizing gathered historical data for big data analysis, maintenance techniques can be optimized to increase equipment reliability and management effectiveness.

Emergency Response and All-encompassing Command: To guarantee the safe operation of the cluster piles during an emergency, the Operations Management Center promptly deploys resources for emergency response using real-time data and the command system.

4 Formulation of Mathematical Models

A mathematical model to assess the advantages of process optimization is built in order to quantitatively study the improvement of group stack management efficiency. We can calculate it using the system queuing theory and probability model, assuming that the processing and reaction times of each stage of operation plan management, field operation implementation, and operation feedback have a significant influence on the total effectiveness. Assume:

1. T_s the entire time needed to finish the plan (the rate at which a task is completed in a given amount of time).
2. λ the pace at which assignments (or homework requests) are received in a certain amount of time.
3. μ the speed at which homework is processed at each level (the task's processing capacity) .
4. T_{delay} work delay duration, encompassing equipment malfunctions, task authorization, and resource planning.
5. T_opt optimum use of information technologies during homework time.

The M/M/1 queuing model, in which the job management system handles job requests as a single server, can be used to analyze the efficiency of job processing. Formula for the queuing model: Average waiting time W:

$$W = \frac{1}{\mu - \lambda}. \tag{1}$$

Among these are the total number of tasks in the system L, the arrival rate of job requests (λ), and the operating system's processing rate (μ) per unit of time: Total amount of work in system L:

$$L = \frac{\lambda}{\mu - \lambda}. \tag{2}$$

According to this calculation, waiting times will rise sharply when more job requests are sent through the system and processing speed becomes inadequate.

Optimized model: Assuming that the processing speed of the optimized system is improved to$\mu_{opt} = \mu +$

$\Delta\mu$, the homework management center's information process optimization results in an optimal homework waiting time of W_{opt}.

$$W_{opt} = \frac{1}{\mu_{opt} - \lambda} = \frac{1}{(\mu + \Delta\mu) - \lambda}. \quad (3)$$

Among these, the increase in processing efficiency resulting from information technology advancements is represented by $\Delta\mu$. Efficiency improvement: The difference between the processing times prior to and following optimization is what we refer to as efficiency improvement η.

$$\eta = \frac{W - W_{opt}}{W} = 1 - \frac{W_{opt}}{W}. \quad (4)$$

By changing the formula for the queuing model, we can get

$$\eta = 1 - \frac{\mu - \lambda}{\mu + \Delta\mu - \lambda}. \quad (5)$$

This calculation shows that the efficiency improvement η will increase greatly when information technology significantly increases the system processing speed μ.

1. Remote monitoring/signing. The center hall can be used for remote monitoring and signing points through a 4G private network, handheld terminals, and head-mounted audio and video equipment. This lowers the need for on-site monitoring staff, particularly for work in areas with high industrial safety or radiation risks, which lowers the risk of worker injuries. Additionally, the monitoring staff in the hall can simultaneously monitor the key operational points of multiple power plants and sites, greatly increasing work efficiency.

2. Expert technical support provided remotely. Point check specialists are senior technical experts in a variety of fields who can assume more fully the role of experts in the center hall. They can do this by utilizing information technology to connect seamlessly with the field operation points, guiding the site's primary technical difficulties, helping to analyze anomalous situations, and making timely technical decisions. The center office houses a concentration of experts from different fields, making it simple and quick to initiate multi-disciplinary consultation when faced with cross-disciplinary and cross-field problems. This greatly increases the productivity and efficiency of the group pile's production work [16–19].

3. Acceptance of work quality. You can use the point inspection system to remotely accept personnel responsible for quality control after equipment overhauls. For similar functions, such as re-identifying the need for maintenance, operation, and other departments to cooperate on-site with the acceptance of start-stop equipment, you can fully utilize the operations management center's multi-party audio and video interaction, which allows all parties to accept the equipment "zero distance" through a variety of wireless network devices.

5 Case Study

In order to improve group reactor management performance, Haiyang Nuclear Power Plant (HNPP) has implemented digital transformation using a number of cutting-edge information technologies and management techniques. Through the use of intricate numerical tables, this case study will examine the implementation effects of several programs and highlight how each performance has been improved.

Table 1 lists the primary implementation programs, which are as follows: 12-week rolling plan management; electronic work package mechanism; big data analysis platform; on-site real-time monitoring system; emergency response; joint production regular meeting mechanism; and integrated command.

Table 1 illustrates how the average work response time improved by 55.68%, from 4.5 hours to 2.0 hours, demonstrating the critical role that the real-time monitoring system plays in problem detection and response. The troubleshooting time was improved by 66.85%, from 3.0 hours to 1.5 hours, demonstrating the effectiveness of expert remote support and knowledge sharing. The operating plan's on-time completion rate improved by 29.85%, from 70% to 80%, demonstrating the efficacy and adaptability of the 12-week rolling plan management. By implementing big data analysis and preventative maintenance procedures, the equipment failure rate was down to six times per month, a 50% decrease. The maintenance plan was effectively optimized as evidenced by the reduction in average maintenance time from 8 hours to 4 hours. A 30.88% boost in cross-departmental collaboration efficiency, from 66% to 86%, suggests that the method of regular joint production meetings was successfully implemented. Haiyang NPP has effectively achieved a general increase in the efficiency of group reactor management by using various IT technologies and undergoing digital transformation. Enhancing a range

Targets	Prior to execution (starting point)	Post-implementation	Enhancement	Program Applications
Hours Per Task Response on Average	4.5	2.	55.68%	Real-time monitoring system on-site
Hours spent troubleshooting	3	1.5	66.85%	Real-time monitoring on-site and remote professional assistance
Operational plan completion rate on time (%)	70%	80%	29.85%	12-week rolling schedule administration
Field Operator Contentment (%)	76%	94%	55.68%	Work package mechanism in electronic form with data feedback in real time
Failure rate of equipment (times/month)	12	6	52%	Preventive maintenance plan and big data analytics platform
Hours of average maintenance	9	5	55%	Big Data Analytics and Optimizing Maintenance Strategies
Cross-sectoral collaboration's efficiency (%)	66%	86%	30.88%	Procedure for holding frequent joint production meetings
Speed of emergency response in minutes	30	10	66.78%	Response to emergencies and integrated command
Openness in production scheduling (rating)	3.5/5	4/5	55%	Digital work packages and instantaneous information exchange
Equipment utilization (%)	82%	92%	11.86%	Real-time monitoring and preventative maintenance
Contentment with employee education (%)	75%	85%	29.5%	Electronic-learning platform
Total Operating Expenses ($ million year)	5000	4500	12%	Process optimization and electronic work packages

Table 1. Analysis of performance improvement

of metrics not only boosts operational effectiveness and security but also offers substantial backing for further enhancements in the future. For other nuclear power companies undergoing digital transformation, this case offers invaluable guidance and inspiration.

6 Conclusion

The case of Haiyang Nuclear Power Plant (HNPP), which has considerably increased the efficacy of cluster reactor management through a number of IT solutions in the process of digital transformation, is thoroughly examined in this paper. Numerous key performance indicators have significantly improved as a result of the implemented measures, which include emergency response and integrated command, 12-week rolling plan management, real-time site monitoring system, electronic work package mechanism, big data analytics platform, joint production regular meeting mechanism, and more. First off, the notable reduction in fault diagnosis and operation response times demonstrates the effectiveness of the real-time monitoring and expert assistance system, which ensures that issues are resolved promptly. Second, the improvement in field operators' satisfaction and the operation plans' on-time completion rate demonstrate the critical role information management technologies play in streamlining processes and enhancing employee engagement. In the meantime, the decrease in the average repair time and equipment failure rate indicates that big data analysis and preventative maintenance techniques work well together to greatly increase equipment reliability.

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