Digital Transformation Technology for Energy Enterprises Based on Intelligent Monitoring of Information in the Entire Business Domain Research and Applications

Yongqing Cheng[1,a,*], Yanan Cao[1,b], Ruofei Liu[2,c], Huayong Kong[2,d]

{328492092@qq.com[a,*], 16801001@ceic.com[b], 20049919@ceic.com[c], 11688110@ceic.com[d]}

GD Power Development Co., Ltd, Beijing, China[1]
CHN Energy Digital Intelligence Technology Development(Beijing) Co.,Ltd, Beijing, China[2]

Abstract. In order to implement the deployment of digital transformation and promote digital transformation, combined with the characteristics of large-scale energy enterprises, GD POWER DEVELOPMENT CO.,LTD has designed and realized an entire business domain. Based on the entire volume and real-time convergence of information in the whole business domain, through the research and application of digital transformation technologies such as big screen visualisation, intelligent voice interaction, and process automation, the system achieves data-driven management and control upgrading, and gradually realises intelligent operation. The system adopts the mode of "1+N+1", displaying various indexes in a panoramic view through the cockpit of the whole domain. Real-time supervision and control of the company's economic operation, equipment status, safety and environmental protection, business management, etc., is achieved through the function modules of statistical analysis, intelligent alarms, and benchmarking and assessment, with the assistance of the virtual duty officer.

Keywords: Digital transformation, Energy enterprise, Entire Business Domain, Intelligent monitoring.

1 Introduction

Digital transformation is a comprehensive organizational strategy aimed at incorporating digital technologies to fundamentally change business processes, operations, and customer experiences. It involves the integration of digital technology into all aspects of an organization, leading to fundamental shifts in how businesses operate and deliver value to customers. The momentum of digital transformation in today's dynamic business landscape has significantly quickened, with ongoing acceleration. This phenomenon is clearly demonstrated by digital transformation statistics, illustrating how businesses have not only maintained but often increased their value, including revenue, through digitization. The anticipated growth of the global digital transformation market is significant, with projections indicating substantial expansion. By 2025, it is expected to reach $1,009.8 billion from $469.8 billion in 2020, representing a Compound Annual Growth Rate (CAGR) of 16.5% during this period. Statista forecasts that worldwide spending on digital transformation will surge to $3.4 trillion by 2026, while Markets and Markets projects a CAGR of 19.1%, with the market size increasing from

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$521.5 billion in 2021 to $1,275 billion in 2026. This is illustrated in Figure 1. The World Economic Forum predicts that digital transformation will add $100 trillion to the global economy by 2025, with interactions facilitated by platforms contributing two-thirds of this value. The benefits of adopting a digital model is illustrtaed in Table 1. The digital economy is poised to represent over 20% of the Gross Domestic Product (GDP) by 2026. Additionally, between 2019 and 2025, the digital transformation market is projected to experience a Compound Annual Growth Rate (CAGR) of 23%, reaching $3.3 trillion. Looking further ahead, from 2022 to 2030, the global digital transformation market is expected to grow at a CAGR of 23.1%, reaching $3,810.05 billion by 2030. During the period of 2022-2027, the market is forecasted to grow at a CAGR of 21.1%, reaching $1,548.9 billion by 2027 from $594.5 billion in 2022. Companies encounter a lot of challenges that can hamper their digital transformation endeavors. These difficulties include workforce non-compliance, which can slow down initiatives and progress, the search for appropriate and well-suited skill sets throughout the organization, resistance to change, and difficulties in quantifying the company's Return on Investment (ROI).

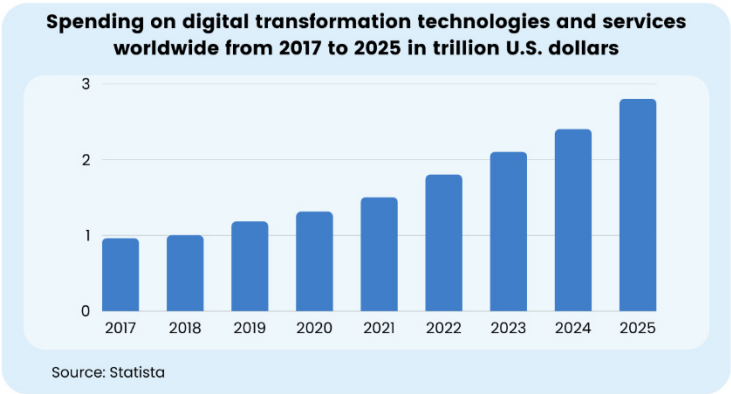


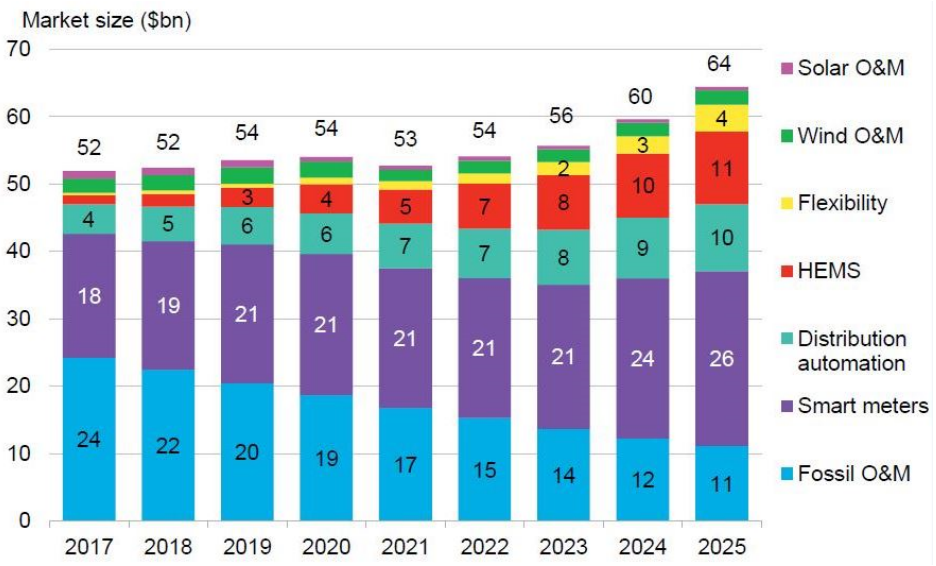
Fig. 1. Statistics of spending on digital transformation technologies and service worldwide [1]

Table 1. Top Benefits of adopting a digital transaformation

S. No	Benefits	Percentage (%)
1.	Improve operational efficiency	40
2.	Meet changing customer expectations	35
3.	Improve new product quality	26
4.	Increase design reuse	25
5.	Reduce product development costs	24
6.	Introduce new revenue streams	21
7.	Reduce the cost of poor quality	14
8.	Increase first pass yield	5

Here, the digital revolution within the energy sector is concentrated, given its early embrace of digital technologies. The inception of digital transformation trends in energy utilities dates back to the 1970s, with power utilities pioneering the use of technology to streamline grid management and operations. Subsequently, numerous companies transitioned to digital meters,

replacing traditional analog ones. In the field of Oil and Gas, technology innovations have been utilized to enhance decision-making in various facets, such as exploration and production assets, encompassing reservoirs and pipelines. According to the report "Digitalization of Energy Systems" by Bloomberg New Energy Finance (BNEF), significant transformations are expected in the culture of digital technologies employed in the energy sector from the present day until 2025. This is illustrated in Figure 2. Additionally, notable shifts are expected in the sectors of the energy system that will derive the greatest advantages from these technological advancements.



Source: Bloomberg New Energy Finance [2].

Fig. 2. The scale of the market for digital technologies within the energy sector

1.1 Research background

In the context of China's current "carbon neutrality" constraint, high-quality development of energy enterprises is a win-win situation for both economic development and carbon reduction, and digital transformation may accelerate the achievement of its goals [3]. Digital transformation is an ongoing process that is driven by the recent advances in digitalization [4]. The process of digital transformation has been accelerating, and new technologies have brought many challenges of uncertainty to enterprises while showing their advantages. In recent years, the regularity of industrial development has weakened significantly, and the complexity, randomness, and suddenness of the problem have increased. The simple superposition of digital technology and traditional industries can no longer meet the needs of conventional vertical industries, and the digital transformation of enterprises is entering "deep water".

Energy digital transformation is an effective approach to optimizing the energy allocation and improving the energy scheduling [5]. Compared with other industries, energy enterprises have both economic tasks and social responsibilities at the same time [6]. When a energy enterprise adopts digital transformation, it has higher operating efficiency, lower costs, and better

innovation success, resulting in better performance [7].The new round of scientific and technological innovation drives the convergence of the energy revolution and the digital revolution. In order to grasp the development opportunities, and drive the development of the whole energy industry, energy enterprises need to re-recognize the important role of scientific and technological innovation, attach importance to the improvement of their own scientific and technological innovation strengths, and strive to make greater breakthroughs in the development [8].

1.2 Overview of the research work

GD POWER DEVELOPMENT CO.,LTD's (for short: GD) business covers a wide range of four major industrial sectors, including thermal power, hydropower, new energy, and mining; it contains many grassroots units, and the situation of production units under the management calibre is complicated. At present, each energy enterprise has made significant progress in implementing the deployment of digital transformation and promoting the process of digital transformation, has carried out the construction work of data coherence, data platforms, application software development platforms, etc., and has initially completed the basic system construction. During the construction process, many vital issues have also been identified, such as information silos, data governance, and lack of convenience. The exposure of these problems requires continuous exploration and the search for corresponding technologies to solve them.

In order to implement the deployment of digital transformation, promote digital transformation, achieve data-driven business innovation and organisational change, prompt control upgrades, and gradually achieve the overall goal of intelligent operation, GD comprehensively launched the construction of intelligent control. As a part of the work, the entire business domain intelligent monitoring platform mainly realises the comprehensive control of the company's situation and production scheduling. It achieves the goals of accurate control of the production process , automatic release of abnormal alarms, and automatic generation of business statistics. It promotes the smooth flow of all kinds of information up and down the company and the efficient operation of production management.

The major contributions of this research work are:

- The article provides a comprehensive overview of digital transformation trends in the energy sector, highlighting the historical context, key drivers, and emerging technologies shaping the industry's digital evolution.
- Through a detailed case study of GD Power Development Co., Ltd, the research work offers valuable insights into the practical implementation of digital transformation initiatives within a large-scale energy enterprise. By examining GD's entire business domain intelligent monitoring platform, the manuscript elucidates the design, architecture, and key features of an integrated digital control system.
- The manuscript conducts an in-depth analysis of the key technology applications deployed within GD's intelligent monitoring platform.
- The paper presents an empirical analysis of the performance metrics of GD's digital transformation system over a five-year period. By examining key performance indicators such as system uptime, error rate, user satisfaction, and mean time to repair (MTTR), the

research work evaluates the effectiveness of GD's digital transformation efforts and identifies trends and improvements over time.

2 Design of the entire business domain intelligent monitoring platform

2.1 Overall Architecture Design

The entire business domain intelligent monitoring platform adopts the mode of "1+N+1", through the entire domain "cockpit" panoramic display of various indicators, with the assistance of a "virtual duty officer". Through "statistical analysis", "intelligent alarm", "benchmarking assessment" and other functional modules, it realizes real-time supervision and control of the company's economic operation, equipment status, safety and environmental protection, and business management. The overall system architecture design is shown in the Figure 3.

2.2 Application Module Design

The Cockpit Module is the main window of the intelligent monitoring platform of the entire business domain, reflecting the real state of the company in real-time in the dimensions of economic operation, equipment status, safety and environmental protection, and production operation, and maximizing the understanding, management, and control of the managers on the status of the company's whole business domain.

The Statistical Analysis Module is the integration and statistics of the company's various production and operation activities data, to achieve the centralized collection of information from different data sources, carry out comprehensive statistics, analysis, and comparison of the enterprise's data, and assist managers in the production and operation of decision-making analysis.

Intelligent Alarm Modules cover equipment anomalies, safety anomalies, operation index anomalies, environmental protection anomalies, natural disasters, and other aspects. The alarm information from multiple data sources is automatically analyzed, fused, filtered, refined, and displayed in a comprehensive, multi-level, and multi-angle manner visually. It promotes data circulation and sharing between upper and lower-level units and horizontal business departments, and improves the integration level of regulation and control.

The Emergency Command Module integrates the functions of the emergency plan, emergency drill, and emergency resources to achieve unified deployment of resources and sharing of emergency materials. In the event of emergencies, it can quickly activate the emergency plan, coordinate the forces of all parties, and ensure that the rescue work is carried out in an orderly manner.

The Intelligent Benchmarking Module is based on a unified benchmarking index system, with a benchmarking model as the core and analysis and evaluation as the goal, through the establishment of a benchmarking management index system that serves the characteristics of the business sector itself and the achievement of continuous improvement of the whole

process of benchmarking management around various benchmarking dimensions such as production and operation, key business points, and so on.

The Intelligent Report Module quickly implements customized reports by dragging, pulling, and dropping, and develops fixed reports, custom reports, and other reports. It is equipped with report drilling, report generation, multi-format export, and other functions. Support report query by date, organization and other conditions; generate internal analysis reports on a regular basis.

The Virtual Duty Officer Module adopts the AI intelligent dispatching robot as the voice assistant and auxiliary tool of the business system, providing the platform with intelligent query, linkage display, and voice broadcasting services of business data and assisting in improving the office efficiency of the duty officer. With the goal of improving work efficiency, based on artificial intelligence technology, combined with preset instructions, it forms a standardized management process through multi-sensory interactions such as voice, broadcasting, and information pushing, and improves the intelligent level of business management.

3 Key technology applications of the platform

3.1 Large Screen Visualization Technology

Data visualization is to express the intrinsic value of data in a more graphic way. Data visualization on the big screen is to take the big screen as the main display carrier to present the data, highly integrate the business application data, improve the efficiency of collaborative operation, assist in decision-making and deployment, and realize the overall value enhancement of collaborative operation and scheduling in the industry through the functions of synchronous rendering with ultra-high resolution, animation simulation and analysis, intelligent graphic chart, and roaming in the key scenes.

The system construction adopts flexible and configurable large-screen visualization technology. Daily editing of the scene, includes arbitrary drag and drop, free layout, automatic adsorption, flexible combinations of resources within the scene, saving and exporting the scene and other operations, adapting to different data access requirements , and supporting multi-source data access.

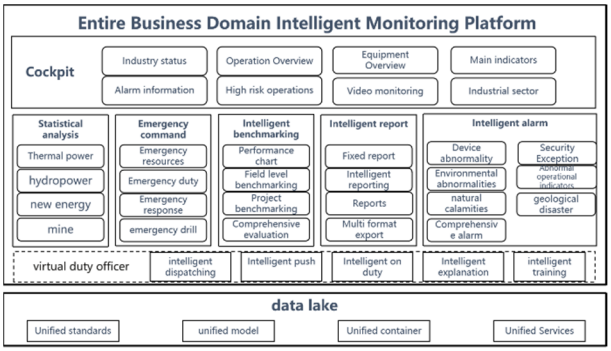


Fig. 3. Overall system architecture design diagram

3.2 Intelligent voice capability

The rise of artificial intelligence technology, especially the application of a series of artificial intelligence technologies such as speech recognition technology, has made significant theoretical innovation and application breakthroughs at home and abroad, which has helped to solve some problems in the field of distribution network regulation and operation [9,10]. The system adopts the AI intelligent scheduling robot as the voice assistant and auxiliary tool to provide intelligent query, linkage display, and voice broadcasting services for business data, and assist in enhancing the office efficiency of the duty officer.

In terms of audio acquisition and recognition, the new generation of speech recognition frameworks based on Encoder-Decoder reduces the loss of information caused by separate modelling of traditional frameworks, and improves the accuracy of reception through single-pass multi-speech enhancement technology and microphone array technology; in terms of linguistic analysis for natural language processing, based on the user's behaviors, it carries out Chinese word segmentation, linguistic annotation, and naming literate recognition of natural language. It locates the in terms of natural language processing linguistic analysis, based on user behaviors, it performs Chinese word segmentation, linguistic annotation, and naming recognition of natural language to locate the essential linguistic elements, eliminate ambiguities, and support accurate understanding of natural language. For natural language processing utterance analysis, the dependency relationship between words in a sentence is used to represent the syntactic structure information of words, and the tree structure is used to represent the structure of the whole sentence.

3.3 Process automation

RPA is a digital transformation tool that has demonstrated tremendous growth in research output as well as its application in the past decade [11,12]. In response, the dispatch watchman faces periodic repetitive tasks, including downloading attachments, editing daily reports, sending emails, sending SMS, receiving message notifications, and so on. In order to improve work efficiency, the system adopts RPA automation to handle these business logics. According to the actual business requirements, the process automation includes simulating mailbox login, capturing files in the specified directory and storing them locally, simulating login on the website, capturing files in the specified directory and storing them locally reading relevant local files and sending them via email, reading local files to get information about the duty leader, and sending SMS to remind them. Realizing these automated processes dramatically reduces the workload of the dispatch duty officer and improves work efficiency.

3.4 Data security and protection

Data security begins with well-known encryption protocols and access controls. Our platform employs state-of-the-art encryption algorithms to protect data both at rest and in transit. Access to sensitive information is restricted based on user roles and permissions, ensuring that only authorized personnel can access and manipulate data. To further enhance privacy protection, personally identifiable information (PII) is anonymized or pseudonymized wherever possible. This practice reduces the risk of unauthorized identification of individuals while still allowing for meaningful data analysis and insights. Our platform adheres to relevant data protection regulations and industry standards. Compliance with these regulations is

regularly audited, and any necessary adjustments are made to ensure ongoing adherence. Proactive monitoring and threat detection mechanisms are integral to our data security strategy. Real-time monitoring tools continuously scan for suspicious activities and anomalous behavior, enabling prompt detection and mitigation of potential security threats. Transparency and accountability are foundational principles guiding our approach to data security and privacy protection. Industry should be committed to fostering transparency by openly communicating our data handling practices and accountability by holding ourselves to the highest standards of integrity and compliance.

4. Core functional design of the platform

4.1 Cockpit module implementation design

The cockpit module is the main window of the platform, reflecting in real time the real status of the company's production operation, equipment status, economic operation, safety, and environmental protection in various dimensions. Through page drilling and data integration, the module achieves multi-scene and multi-level linkage analysis and display to meet the needs of the company's leaders and dispatchers for all-round and visualized monitoring of the business, and at the same time provides support for relevant units to visit the display.

Cockpit Overview is divided into seven areas as the interface for daily operation monitoring. The left area displays the company's operation overview and equipment overview, the right area displays the main indexes, alarm information, high-risk operations, and video surveillance, and the middle area displays the current situation of the industry in the form of a map. The Cockpit module supports visual display based on big screens, PCs and mobile devices, and the deployment architecture is shown in the Figure 4.

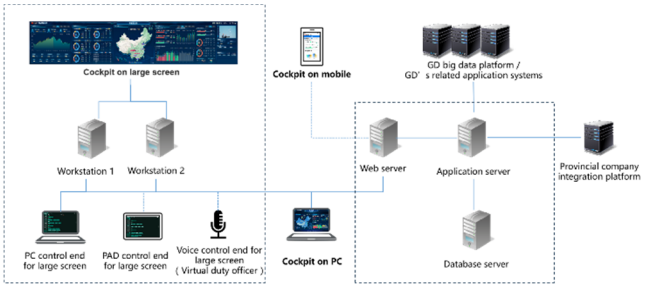


Fig. 4. Cockpit Deployment Architecture

4.2 Statistical analysis module implementation design

The statistical analysis module is based on the convergence of a large amount of data from multiple sources, establishes an intelligent integration and reasoning model, divides the functional pages into safety management, production and operation, power trading, ecological and environmental protection, production energy efficiency, unit overhaul, water usage, operation monitoring and so on according to the logic of the business, and achieves efficient and intuitive presentation of the results through a variety of illustrations and forms to support the business departments in carrying out a comprehensive statistical analysis of the data of the

enterprises and improve the integrated management capability. It supports business departments to carry out comprehensive statistics, analysis, and comparison of data from each enterprise, and improves the integrated management capability. At the same time, it has intelligent analysis of typical data scenarios, providing users with potential reasons and conclusions under the appearance of data, from seeing data to understanding data, reducing the complexity of the user's work and improving management efficiency.

The statistical analysis module needs to calculate and assemble the query data according to the business logic and return it to the user page. According to the data access required by each page, the complexity of the calculation, data sources, and other circumstances, there is a need for targeted development of data synchronization and offline calculation schemes. The timed data synchronization and calculation scheme are shown in the Figure 5.

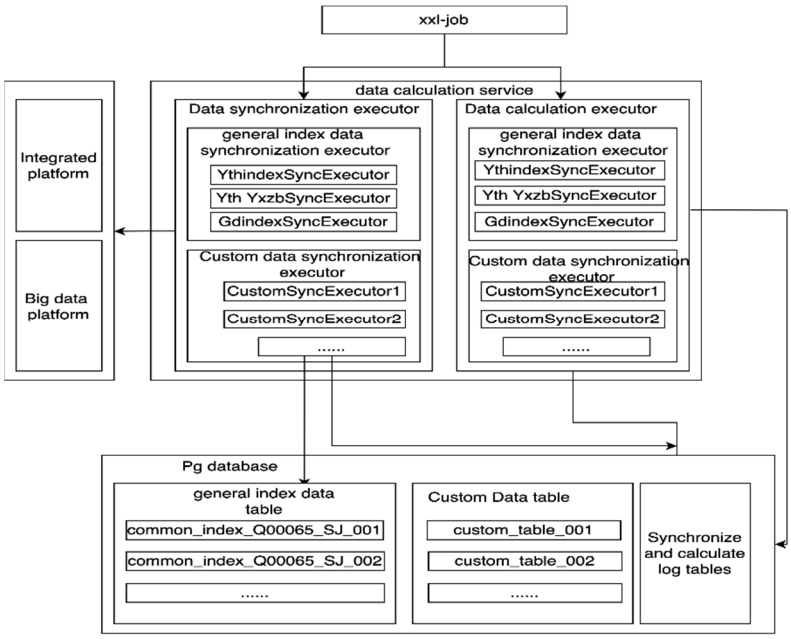


Fig. 5. Timing data synchronization and calculation scheme design

4.3 Intelligent benchmarking module implementation design

The Intelligent Benchmarking Module is a tool that uses artificial intelligence to analyses data, discover patterns, and provide decision support. When designing, the module is instrumentalized as much as possible while meeting the personalized needs of the business departments, so that it is fully scalable and can quickly support the benchmarking business through the application when other departments have relevant scenarios. The design idea of the module follows the working principle and working idea of benchmarking management, and completes the closed loop of benchmarking business through selecting benchmarks, establishing systems, collecting data, analyzing gaps, formulating countermeasures, making continuous improvements, and reviewing on a regular basis.

Small indicator competition function is the core function of the module, through the experiments on different operating conditions of the unit to derive the theoretical target value, for different units of the benchmarking conditions for personalized target setting, while supporting the configuration of different indicators of the scoring rules; monthly access to the unit's actual operating data, the system will automatically calculate the unit's total score and the scores of the indicators according to the scoring rules, and the monthly ranking of the group to show the competition. Results. The whole process does not require offline intervention. The logical design is shown in the Figure 6.

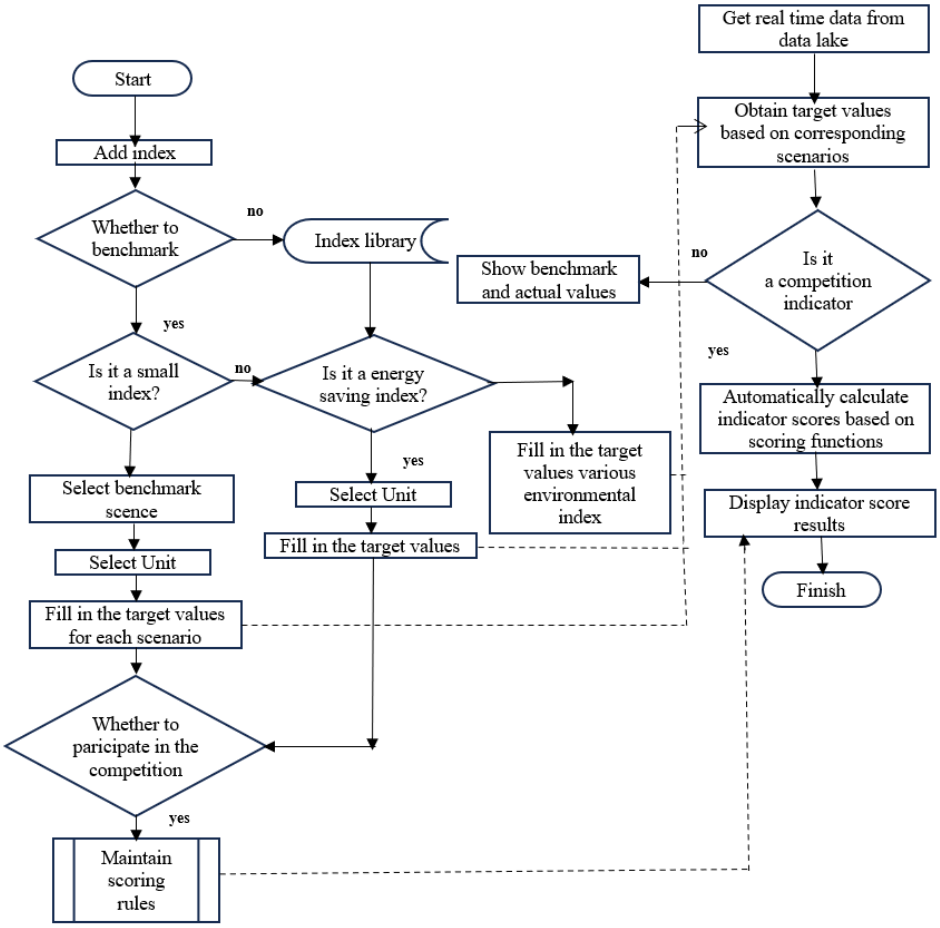


Fig. 6. Logic design of the small indicator contest function

4.4 Virtual Duty Officer Module Implementation Design

The main functions of the Virtual Duty Officer module include: the intelligent scheduling function, integrated with the digital big screen system, which can switch the big screen according to the instruction, drill down the indicator detail data, automatically extract the related indicators, and form an efficient linkage in terms of explaining the coherent display;

the intelligent push function, which can realize intelligent push reminders through the configuration of preset commands and automatic learning, and integrated with the intelligent alarm module; intelligent watchman function, which can assist the watchman to carry out duty through preset tasks and automatic learning. Through the preset duty tasks and automatic learning, it establishes intelligent duty mode, assists the duty officer to carry out duty, and records the events and operation records in the whole duty process, which is convenient for tracking and analyzing; Intelligent Explanation and Intelligent Training Function, through the technology of multi-sensory interaction and intelligent scheduling, combined with the content of the knowledge base, it achieves explanation and training.

The Virtual Duty Officer module links the control system through intelligent voice interaction robots, hardware terminals, etc., to realize the system linkage control function of terminal equipment such as PCs and digital big screens in a natural language interaction mode. The logical design is shown in the Figure 7.

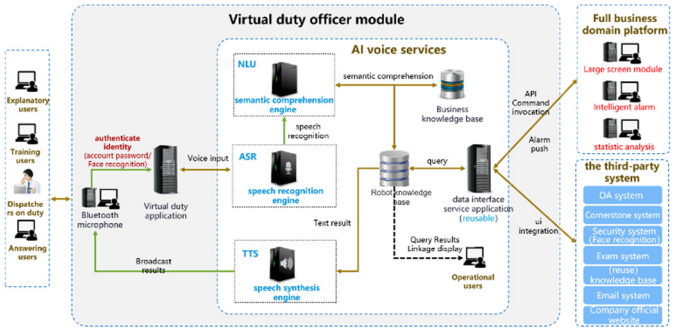


Fig. 7. Logical design of the Virtual Duty Officer module

5 Implementation and application effects of the platform

GD's Entire Business Domain Intelligent Control Platform is a data-based, comprehensive, cross-business domain intelligent management system. The construction of the platform covers the business of thermal power, hydropower, new energy, mining and other industrial sectors. By realizing the dual-wheel drive of business demand and business data, it promotes business innovation and mechanism change, and pushes forward the goal of intelligent operation.

By applying intelligent technology, the platform builds the function of "virtual duty officer", which can deeply participate in human-computer interaction, realize the analysis, control and prediction of key indexes of enterprise management and operation, and enhance the ability of supervision and risk pre-control of enterprise production and management activities. In addition, the platform also builds functional modules such as cockpit, statistical analysis, alarm management, benchmarking assessment, etc. It organically integrates real-time operation data and management data, so as to dynamically analyses production and operation activities, and deeply excavate and assist in operation decision-making. Through data insights, problems are identified, gaps are found, work is improved, and the operation and control functions of regional companies are effectively supported. It realizes the organic combination

of data from the unified system, self-built system and the production system of the grassroots units, and truly realizes the integrated management of control, operation and production.

To sum up, GD's Entire Business Domain Intelligent Control Platform is a highly integrated and intelligent platform with robust data analysis and intelligent support functions, and the successful application of the system will significantly enhance the operational efficiency and competitiveness of GD.

6 Experimental Analysis

For this experimentation, we conducted a study focusing on the performance metrics of a digital transformation system implemented by GD POWER DEVELOPMENT CO., LTD over the past five years. We collected data on four key performance indicators (KPIs): System Uptime, Error Rate, User Satisfaction, and Mean Time to Repair (MTTR). The data was gathered annually, spanning from 2019 to 2023.

System Uptime: The percentage of time the system was operational without interruptions. This is calculated using the following formula.

$$System\ Uptime\ (\%) = \frac{\text{Total time system is operational}}{Total\ Time} \times 100 \quad (1)$$

Error Rate: The percentage of operations resulting in errors or failures. This is computed using the formula.

$$Error\ rate\ (\%) = \frac{\text{Number of errors}}{Total\ number\ of\ operations} \times 100 \quad (2)$$

User Satisfaction: The rating given by users to evaluate their satisfaction with the system's performance.

MTTR: The average time taken to resolve system issues or failures. This is computed using the following formula

$$MTTR = \frac{Total\ downtime}{Number\ of\ failures} \quad (3)$$

We utilized the past data to examine the performance trends of the digital transformation system. The data was used to demonstrate improvements and trends over the specified five-year period. The empirical performance of the proposed system is illustrated in Figures 8-11.

The Figure 8 depicting system uptime over the past five years shows a consistent upward trend. This indicates that the system's operational stability has improved steadily over time. The inference drawn from this trend is that the organization has invested in maintenance and optimization efforts, resulting in increased system reliability and reduced downtime. The Figure 9 illustrating the reduction in the error rate demonstrates a consistent decline over the five-

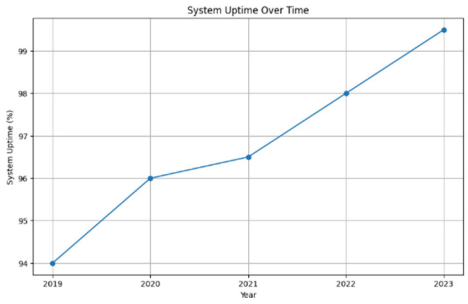


Figure 8. Empirical analysis on system uptime over time

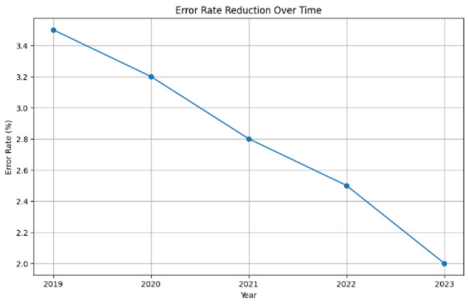


Figure 9. Empirical analysis on error reduction over time

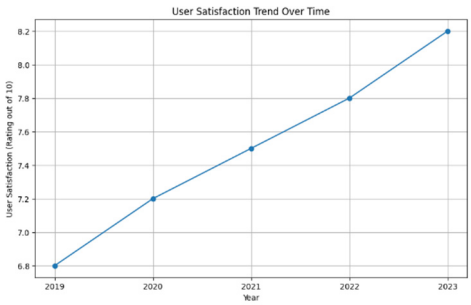


Figure 10. Empirical analysis on user satisfaction trend over time

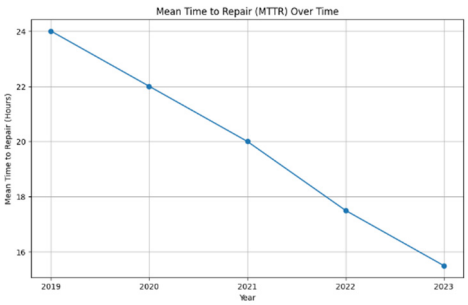


Figure 11. Empirical analysis on MTTR over time

year period. This downward trend suggests that the implementation of the digital transformation system has led to a reduction in errors and failures within the system. The inference is that the organization has effectively addressed issues and enhanced system performance through continuous improvement initiatives.

The user satisfaction trend in Figure 10 exhibits a positive line, with user satisfaction ratings increasing steadily over the past five years. This upward trend indicates that users have experienced improved system performance and usability over time. The inference drawn is that the organization has successfully met user expectations and requirements through enhancements to the digital transformation system. The Figure 11 reveals a consistent decrease in the average time taken to resolve system issues or failures over the specified period. This diminishing trend suggests that the organization has enhanced its problem-solving capabilities and response efficiency. The inference made is that the organization has implemented effective measures to minimize downtime and improve system reliability, resulting in faster issue resolution.

Overall, the empirical analysis indicates that the digital transformation efforts undertaken by GD Power Development Co., Ltd have resulted in concrete improvements in system performance, reliability, and user satisfaction over the past five years. The trends observed suggest that the organization's investments in technology maintenance and optimization have yielded positive outcomes, contributing to the overall success of the digital transformation initiative.

7. Conclusion

The research works provides a comprehensive and insightful exploration of digital transformation technology within energy enterprises. The study demonstrates the transformative potential of digital technologies such as big screen visualization, intelligent voice interaction, and process automation by focusing on the implementation of intelligent monitoring across the entire business domain. Through empirical analysis and the application of key performance indicators (KPIs), we highlighted the significant benefits and improvements resulting from digital transformation initiatives. From enhanced system uptime and reduced error rates to increased user satisfaction and faster issue resolution, the empirical data emphasize the positive impact of digital transformation on operational efficiency and organizational performance. Furthermore, the research work offers valuable insights into the design and implementation of the entire business domain intelligent monitoring platform. Energy enterprises can achieve data-driven management, decision-making, and control upgrades by making use of the technologies such as large screen visualization, intelligent voice capability, and process automation, ultimately driving intelligent operations and sustainable growth. In future, an effort will be taken to enhance the interoperability and adaptability.

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