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Analysis on Optimal Allocation of Water Resources under the Background of Digital Twin

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Abstract: With the intensification of global climate change and human activities, water resources shortage, water pollution and water disasters are becoming increasingly prominent, which seriously threatens the survival and development of human beings. How to effectively manage and optimize the allocation of water resources has become a common challenge faced by all countries in the world. Traditional water resources management methods are often based on empirical judgment and historical data, which is difficult to accurately reflect the dynamic changes and complex relationships of water resources system. The emergence of digital twin technology provides new technical means and solutions for optimal allocation of water resources. Digital twin technology can realize comprehensive perception, dynamic simulation and intelligent decision of water resource system by constructing real-time interaction and mapping between physical entity and virtual model. With the help of digital twin technology, the quantity and quality of water resources can be monitored in real time, and the future demand and supply trend of water resources can be predicted, which provides a scientific basis for the optimal allocation of water resources. At the same time, digital twin technology can also simulate water resource allocation schemes under different scenarios, evaluate their economic, social and ecological benefits, and provide decision-makers with diversified optimization schemes. = Based on the introduction of digital twin technology and its application in the field of water resources management, this paper deeply analyzes the strategy and practice of optimal allocation of water resources under the background of digital twin. This paper introduces the concept, key technology and potential application value of digital twin technology in water resources management, and puts forward the optimal allocation strategy of water resources under the background of digital twin technology. Through the implementation of the strategy, the utilization efficiency and management level of water resources can be further improved, providing a strong guarantee for the sustainable development of economy and society.

1. Introduction

Water resource is one of the basic resources that human beings depend on for survival and development, and its optimal allocation is of great significance to ensure the sustainable development of economy and society. However, with the acceleration of population growth, economic development and urbanization, water resources shortage, water pollution and water disasters have become increasingly prominent, and water resource management has brought great challenges. Traditional water resources management methods are often based on empirical judgment and historical data, which is difficult to accurately reflect the dynamic changes and complex relationships of water resources systems, and it is difficult to meet the current demand for water resources management[1]. Therefore, it is necessary to introduce new technical means and solutions to realize the optimal allocation of water resources. As an important part of the new generation of information technology, digital twin technology provides new ideas and means for optimal allocation of water resources by constructing real-time interaction and mapping between physical entity and virtual model[2]. With the help of digital twin technology, the quantity and quality of water resources can be monitored in real time, and the future demand and supply trend of water resources can be predicted, which provides a scientific basis for the optimal allocation of water resources. At the same time, digital twin technology can also simulate water resource allocation schemes under different scenarios, evaluate their economic, social and ecological benefits, and provide decision-makers with diversified optimization schemes. Therefore, research on optimal allocation of water resources under the background of digital twin is of great significance to promote the modernization and intelligence of water resources management.

2. Overview of digital twin technology

2.1 Concept of digital twin technology

Digital Twin is a technology that closely integrates the physical world with the virtual world. By constructing a virtual model corresponding to the real world, it realizes the virtual mapping and simulation analysis of the real system. The basic principle of digital twin technology is to digitally model actual engineering projects, equipment and systems to form a virtual corresponding model[3-4]. This model can simulate the running state of the actual system and reflect its performance, state and behavior. Through the acquisition and transmission of real-time data, the virtual model and the real system can be synchronized in real time, so as to realize real-time monitoring, prediction and optimization.

Digital twin technology originated in the manufacturing field, with the rapid development of information technology, digital twin technology has gradually become a hot research and application in various industries, including water resources management. In the field of water resources management, digital twin technology is mainly used in water resources monitoring, simulation, prediction and optimization. For example, by establishing a digital twin basin or water system model, the quantity and quality of water resources can be monitored in real time and the future demand and supply trend of water resources can be predicted. The economic, social and ecological benefits can be evaluated by simulating water resource allocation schemes under different scenarios. Through optimization algorithms and intelligent decision support systems, optimal allocation and intelligent scheduling of water resources can be realized[5].

2.2 Key Technologies of digital twins

The application of digital twin technology depends on a series of key technologies, which

together build the core framework of digital twin system. It mainly includes the following technologies: First, modeling technology. It requires a highly accurate digital image to be built according to the complexity and uniqueness of the specific water resources allocation engineering system, which not only includes a fine description of the physical structure, but also involves an in-depth understanding and modeling of the system's internal operating mechanism, interaction relationship and external influencing factors, so as to ensure that the digital model can truly reflect the essential characteristics of the entity system[6]. The second is simulation technology. Through advanced algorithms and computing platforms, the dynamic behavior and performance of digital models under different conditions are simulated. In water resource allocation engineering, this means that engineers can predict the impact of different scheduling strategies, climate change or engineering transformation on water resource supply and demand balance, water quality safety and ecological environment with unprecedented accuracy, so as to achieve fine optimization of resource allocation schemes. Third, data integration and management technology. Faced with the flood of heterogeneous data from multiple sources, this technology realizes seamless integration and efficient management of data through data cleaning, format conversion, storage optimization and other means, which ensures the timeliness, accuracy and consistency of data, provides a reliable information basis for the digital twin model, and enables the model to continue iterative optimization and better serve practical applications. Fourth, real-time update technology. Through the comprehensive application of technologies such as the Internet of Things, big data analysis and cloud computing, real-time data collection, transmission and processing become possible, ensuring the instant synchronization between the virtual model and the physical system, which not only improves the accuracy of model prediction, but also enables the digital twin to maintain a high degree of adaptability in a rapidly changing environment and provide timely and effective support for decision making[7].

2.3 Application value of digital twin technology in water resources management

Digital twin technology has shown great application potential in the field of water resources management, and its core value is reflected in several dimensions:

(1) Improve the efficiency of water resources monitoring. By constructing a detailed digital twin basin or water system model, the distribution, flow, consumption and quality changes of water resources can be comprehensively and real-time monitored. This not only greatly improves the spatial and temporal resolution and accuracy of monitoring, but also reduces the human and material costs of traditional monitoring methods, providing strong support for the scientific management and protection of water resources[8].

(2) Optimize water resource allocation schemes. With the help of simulation technology, digital twins can simulate the effect of water resources allocation under various hypothetical scenarios, including water allocation under different seasons and different demands, water quality assurance and ecological water replenishment strategies[9]. This "virtual trial and error" approach helps decision makers evaluate the economic feasibility, social acceptance and environmental impact of resource allocation schemes from different angles, and promotes rational allocation and efficient use of resources.

(3) Improve water emergency response capacity. In the face of extreme weather events such as floods and droughts, digital twin technology can rapidly integrate multi-source data, predict the development trend of disasters, assess potential risks, and provide timely and accurate early warning information and decision-making basis for emergency management departments. This not only shortens the emergency response time, but also improves the effectiveness and pertinence of emergency measures.

(4) Modernize water resources management. As a product of the deep integration of information technology and water resources management, digital twin technology not only innovates the means and methods of water resources management, but also promotes the transformation of management concepts. It emphasizes data-driven and intelligent decision-making, promotes the development of water resources management in the direction of refinement, intelligence and sustainability, and provides a strong impetus for the realization of long-term safe and efficient utilization of water resources[10].

3. Strategies for optimal allocation of water resources in the context of digital twins

3.1 Data collection and integration

Data acquisition and integration are the basis of optimal allocation of underwater resources in digital twin background. In order to build an accurate digital twin model, it is necessary to collect a large amount of water resources related data, including hydrometeorological data, water quality data, and water conservancy project data. At the same time, this data needs to be integrated and processed to form a data set that can be used for model construction and simulation.

In terms of data acquisition, sensors, remote sensing technology, drones and other means can be used to achieve real-time monitoring and data acquisition of water resources systems. In terms of data integration, technical means such as data cleaning and data fusion can be used to integrate and process multi-source heterogeneous data to improve the accuracy and availability of data.

3.2 Model construction and simulation

Model construction and simulation are the core of optimal allocation of underwater resources in digital twin background. By constructing a digital twin basin or water system model, the comprehensive perception and dynamic simulation of water resources system can be realized. The model construction needs to consider the quantity and quality changes of water resources, the operation state of water conservancy projects, hydrometeorological conditions and other factors, and adopt appropriate mathematical methods and algorithms for modeling and simulation.

In terms of model construction, technical means such as physics-based modeling method, data-driven modeling method or hybrid modeling method can be adopted. In the aspect of simulation, high performance computing technology and parallel computing technology can be used to improve the efficiency and accuracy of simulation. At the same time, the model needs to be verified and calibrated to ensure the accuracy and reliability of the model (Table 1).

Table 1 Digital twin model construction and simulation

Model type	Construction method	Simulation tool
Physics-based model	Mathematical equation modeling	MATLAB/Simulink
A data-driven model	Machine learning algorithm	TensorFlow
Hybrid model	Comprehensive method	COMSOL

3.3 Real-time monitoring and early warning

Real-time monitoring and early warning is an important guarantee for optimal allocation of underwater resources under the background of digital twin. By monitoring the status change of water resources system in real time, potential problems and risks can be discovered and solved in

time. At the same time, through early warning systems, measures can be taken in advance to avoid or reduce the occurrence of water shortages, water pollution and water disasters (Table 2).

Table 2 Real-time monitoring and early warning system

Monitoring content	Simulation analysis	Application effect
Water level and discharge	Prediction of storage capacity change	The optimal flood discharge scheme is recommended
Water quality parameter	Variation trend of water quality	Early warning of potential risks
Dam safety	Safety condition monitoring	Provide maintenance advice

In terms of real-time monitoring, the sensor network, Internet of Things and other technical means can be used to achieve real-time monitoring and data collection of water resources system. In terms of early warning, an early warning system based on the digital twin model can be built, and through simulation and analysis of the model, the future water resource supply and demand trend and the probability and impact degree of water disasters and other emergencies can be predicted, so as to provide early warning information and decision support for decision makers.

3.4 Decision support and optimization

Decision support and optimization is the ultimate goal of optimal allocation of underwater resources in the background of digital twin. By constructing intelligent decision support system, we can provide scientific and reasonable optimization schemes and suggestions for decision makers. At the same time, through the optimization algorithm and intelligent scheduling system, the optimal allocation and intelligent scheduling of water resources can be realized.

In terms of decision support, technical means such as data mining and machine learning can be used to conduct in-depth analysis and mining of digital twin models, extract useful information and knowledge, and provide decision support for decision makers. In terms of optimization, genetic algorithm, particle swarm optimization algorithm and other optimization algorithms can be used to optimize and solve the water resources allocation scheme. At the same time, an intelligent scheduling system can be built to automatically adjust the running state of water conservancy projects and the allocation scheme of water resources according to real-time monitoring data and early warning information, so as to realize the optimal allocation and intelligent scheduling of water resources.

4. Conclusion

Digital twin technology provides a new idea and means for the optimal allocation of water resources. By constructing digital twin model, we can realize the comprehensive perception and dynamic simulation of water resources system, and provide scientific basis and technical support for water resources management. In the future, with the continuous progress of technology and the in-depth promotion of application, digital twin technology will play a more important role in water resources allocation engineering. In order to promote the wide application and development of digital twin technology in water resources allocation engineering, it needs the joint efforts of government, enterprises, scientific research institutions and other aspects.

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