Reservoir Irrigation Operation Design Based on Dijkstra Algorithm Combined with ACO Algorithm

Baoping Jia
Engineering Management Department, Shanxi Conservancy Technical Institute, Taiyuan 030027, China
E-mail: jbp1027@163.com

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In response to the problems of low resource utilization efficiency and imprecise management in traditional reservoir irrigation operation systems, a reservoir irrigation operation system combining Dijkstra algorithm and ant colony optimization algorithm is proposed. In the study, the improved Dijkstra algorithm is first used to optimize the irrigation operation path of the reservoir. On this basis, a more comprehensive reservoir irrigation operation system model is constructed by further combining ant colony optimization algorithm and improved Dijkstra algorithm. The results showed that the data processing accuracy, recall rate, and F1 value of the irrigation operation system model are 95.06%, 89.68%, and 85.07%, respectively. The length of the optimal path is 21.93 meters, and the annual average irrigation water consumption is 131 million m3. The data processing ability and irrigation water consumption prediction ability are better than the comparison method. This indicates that through reasonable operation design, the system model can better balance the irrigation, power generation, and various other needs of the reservoir, improve the efficiency of water resource utilization, and promote the sustainable development of agriculture and energy.

Povzetek: Opisan je inovativni model za načrtovanje namakanja z uporabo rezervoarjev, ki združuje Dijkstrov algoritem in algoritem optimizacije s kolonijo mravelj. S tem prispeva k trajnostnemu razvoju kmetijstva in energetike.

1 Introduction

With the development of social economy and population growth, water resources have increasingly become an indispensable resource in human production and life. As an important facility for regulating water resources, the reservoir irrigation operation design is of great significance for improving water resource utilization efficiency, ensuring agricultural production and ecological balance. However, reservoir irrigation operation is a complex problem that requires consideration of various factors, such as reservoir storage, discharge, irrigation demand, power generation demand, etc. Traditional operation methods are often based on experience or simple mathematical models, making it difficult to cope with complex and ever-changing reservoir operating environments [1-3]. Therefore, studying better methods for reservoir irrigation operation has important practical significance and theoretical value. The Dijkstra algorithm is a classic shortest path algorithm mainly used to solve the shortest path problem in graphs with non negative weights [4-5]. Ant Colony Optimization (ACO) is an algorithm that simulates ants searching for food paths, using information exchange between ants to find the optimal path. The combination of Dijkstra algorithm and ACO algorithm can effectively solve the irrigation operation problem of reservoirs [6-7]. The study first utilizes the improved Dijkstra algorithm to optimize the irrigation operation path of the reservoir, and then combines the ACO algorithm and the improved Dijkstra algorithm to construct a model of the reservoir irrigation operation system based on the path optimization. The research aims to better address multi-objective and multi-constraint problems in reservoir irrigation operation, and provide better solutions for practical applications.

The first part of the study introduces the current research status of reservoir irrigation operation and machine learning in reservoir operation. The second part of the study utilizes the improved Dijkstra algorithm and ACO algorithm to construct a reservoir irrigation operation model. The third part verifies the performance of the constructed reservoir irrigation operation model through simulation experiments. The fourth part summarizes the experimental results and analyzes the advantages and disadvantages of the research methods used.

The design of reservoir irrigation operation is an important issue in the field of agricultural water conservancy, with the goal of rational allocation of water resources, meeting irrigation needs while maximizing water resource utilization efficiency. With the development of technology, more and more intelligent algorithms are being applied to the design of reservoir irrigation operation to solve its multi-objective and multi-constraint optimization problems. Therefore, numerous experts and scholars have conducted extensive research on reservoir irrigation operation. Bakanos and Katsifarakis conducted applied research on the urban water supply, irrigation, hydropower generation, flood control, and environmental flow protection of reservoirs based on the study of a multi-purpose reservoir operation system. The system simulated three different hydrological scenarios by optimizing genetic algorithms. The results showed that the system was able to successfully identify and quantify the increase in hydropower production, and pointed out the necessary changes in the reservoir operation rule curve [8]. Boluwade conducted water resource operation research using global precipitation measurement tasks and a comprehensive multi satellite inversion system to effectively estimate and schedule precipitation. The use of CHIRPS and TAMSAT systems was studied for seasonal forecasting, irrigation operation, and reservoir operation analysis. The results indicated that the system could provide more decision-making reference data for water resource managers and decision-makers [9]. Waluyadi et al. optimized the operation model of reservoirs by using multiple linear regression and stochastic models. A distribution probability modeling was conducted on the operation of inflow, irrigation, and raw water supply using a model. The results indicated that the reliability and elasticity of the model in reservoir operation had the highest benefits and performance [10].

Chek proposed a linear regression method based on Dijkstra algorithm to find the shortest path from the source node to the target node. This method could reduce computation time and memory consumption, and achieves decentralized task allocation path planning. The results indicated that this method could effectively avoid collisions and prevent the possibility of deadlock, and provide a better AGV route [11]. Li et al. proposed an exploration path planning method based on information entropy to improve the exploration efficiency and map creation performance of unknown scenes. The study first constructed an information entropy map and set boundaries, then used Dijkstra's algorithm to explore paths starting from boundary features, and finally drew a map based on the results of path exploration. The results indicated that the path planning algorithm constructed in the study not only achieved high detection efficiency, but also had an increased coverage range [12]. Wang et al. proposed a time sensitive network operation algorithm based on ACO algorithm to improve the timeliness and accuracy of operation in the industrial role. Research focused on end-to-end delay manipulation of time triggered flows in time sensitive networks to address errors in time triggered flows. The results indicated that the algorithm could significantly improve convergence speed and avoid the occurrence of local optimal solutions [13]. The summary of the relevant research conducted by the above-mentioned experts and scholars is shown in Table 1.

Table 1: Summary of research results by relevant experts and scholars

Literature	Proposed models/methods	Advantage	Shortcoming
Bakanos and Katsifarakis [8]	A multipurpose reservoir dispatching system based on genetic algorithm optimization	Suitable for multi-purpose reservoirs	High computational complexity
Boluwade [9]	A water resource scheduling model using global precipitation measurement tasks and integrated multi satellite inversion systems	Provided more decision-making reference data for water resource managers and decision-makers	Accuracy and coverage are limited
Waluyadi et al. [10]	Reservoir operation optimization model based on multiple linear regression and stochastic model	High reliability and elasticity demonstrated in reservoir scheduling	High model complexity
Chek [11]	Linear regression method based on Dijkstra algorithm for path planning	Plan task allocation and paths in reservoir scheduling	Possible inability to capture non-linear relationships
Li et al. [12]	Exploration of reservoir operation path planning method based on information entropy	Can directly optimize scheduling strategies	The calculation of information entropy involves a large amount of data processing
Wang et al. [13]	A time sensitive network scheduling algorithm based on aco algorithm	Can solve the errors in time triggered flow	The ACO algorithm is affected by parameter settings

In summary, it is of great significance to study the optimization of reservoir irrigation scheduling systems using Dijkstra algorithm and ACO algorithm. The study of integrating two algorithms can improve the reservoir irrigation scheduling system's ability to handle multi-objective and multi constraint scheduling problems. Meanwhile, it also can avoid the increased path planning time caused by the processing process, providing better solutions for practical applications.

2 Design of reservoir irrigation operation system combining dijkstra algorithm and ACO algorithm

The reservoir irrigation operation system is a complex system engineering that involves multiple issues such as optimal allocation of water resources and ecological environment protection. To achieve efficient and environmentally friendly reservoir irrigation operation, a new reservoir irrigation operation system model is constructed by combining Dijkstra algorithm with ACO algorithm. This system can dynamically adjust irrigation paths and resource allocation according to actual situations, improving irrigation efficiency and water resource utilization.

2.1 Reservoir irrigation operation path based on improved dijkstra algorithm

To ensure the sustainability and scientificity of reservoir irrigation operation, the process of reservoir resource operation is carried out on a periodic basis. Reservoir resource operation is a complex process involving multiple factors, including water demand, water quality conditions, climate factors, ecological balance, economic factors, regulatory policies, and social impacts. These factors need to be comprehensively considered, scientifically analyzed, and reasonable decisions made to achieve the rational allocation and sustainable utilization of reservoir resources. The main parameter variables involved in the process of reservoir resource operation include reservoir status, decision quantity, etc. [14-15]. Irrigation demand reflects the water demand of crops and is an important basis for irrigation operation. Decision variables are controllable factors in reservoir management, such as the outflow and flood discharge of the reservoir. When operate reservoir resources, it is necessary to determine the state variables of the reservoir, which can be represented by formula (1).

$$V_{t+1} = V_t + Q_t - q_t \quad (1)$$

In formula (1), V_{t+1} represents the state variable of the reservoir. V_t represents the water volume of the reservoir before the operation of the reservoir resources at moment t. Q_t represents the amount of water entering the reservoir at the moment t after the operation decision. q_t represents the discharge volume of the reservoir at moment t. Through the analysis of reservoir resources, it is found that in the process of irrigation operation, it is necessary to evaluate the benefits of irrigation operation, evaluate the actual effectiveness of irrigation operation schemes, compare the advantages and disadvantages of different schemes, and provide scientific basis for decision-makers. To effectively evaluate the operation efficiency, constraints are applied to both flood season and non-flood season, and the optimal objective function is obtained by combining recursive equations, as shown in formula (2).

$$E_{t+1}(V_t) = \max(f(V_t, Q_t, q_t) + E_t(V_t)) \quad (2)$$

In formula (2), $f(\cdot)$ represents the functional relationship. E_t represents the optimization strategy at t time. After completing the study of reservoir operation coefficients and objective functions, the selection of irrigation paths also has a direct impact on irrigation. This is because the location of the reservoir has the most direct impact on irrigation costs, so the study applies the Dijkstra algorithm to the path optimization of reservoir irrigation operation. The basic idea of the Dijkstra algorithm is to start from the starting point, gradually expand outward to adjacent nodes, and select the edge with the shortest distance to expand the node until it reaches the target node. The main feature of the algorithm is the use of greedy strategy, which selects the current shortest distance each time and updates the distance of all adjacent nodes.

In the application of Dijkstra algorithm, only the distance between nodes is usually considered. However, in actual path planning, it is more important to consider the time and cost required for transportation between different nodes. Therefore, the study conducts an in-depth analysis of the traditional Dijkstra algorithm and improves it to better apply it to the optimization problem of reservoir irrigation paths [16-17]. When using reservoir water resources for actual irrigation operation, the location of the reservoir is the main factor directly affecting operation. The study comprehensively considers labor costs, losses, etc., and improves the Dijkstra algorithm. The flowchart for improving the Dijkstra algorithm is shown in Figure 1.

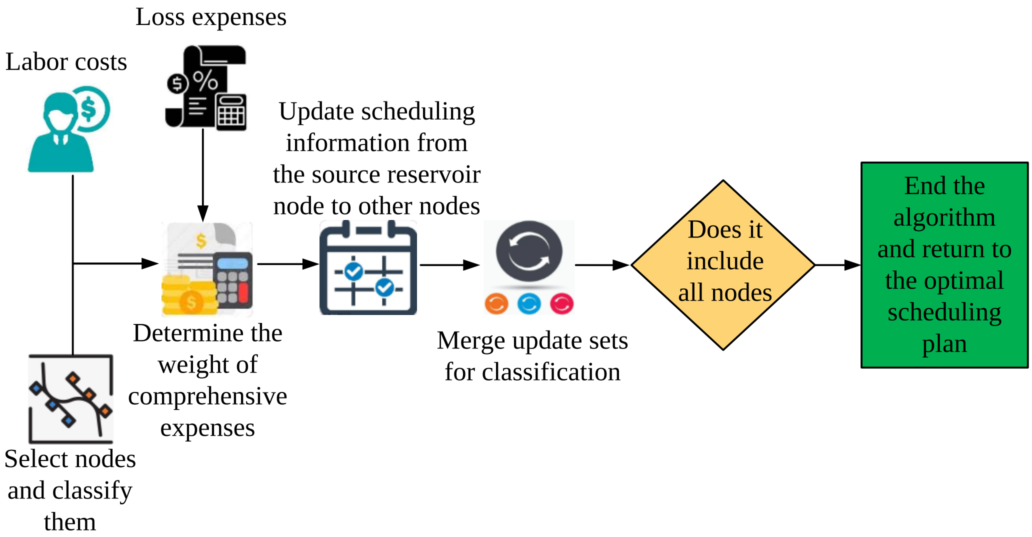


Figure 1: Flowchart for improving Dijkstra algorithm

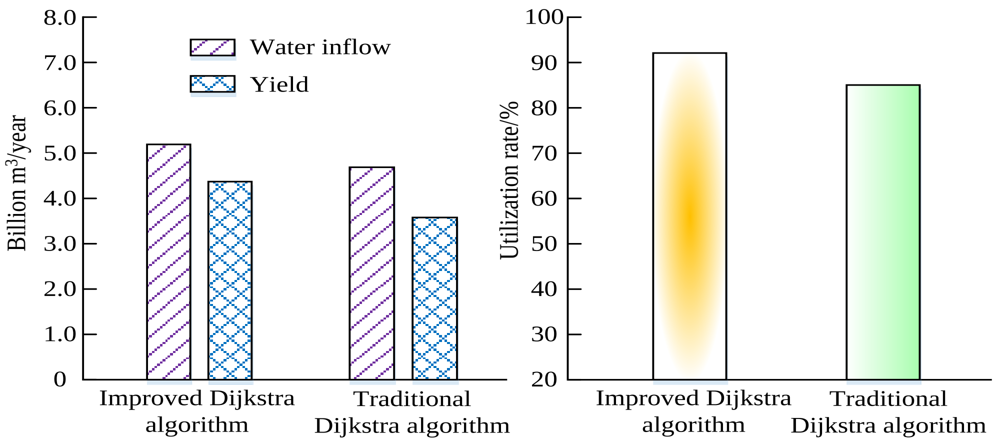
The study will improve the Dijkstra algorithm and apply it to actual reservoir irrigation operation. It is found that the time, manpower, and economic costs required for irrigation operation from Reservoir A to Reservoir B are not exactly the same as those required for operation from Reservoir B to Reservoir A. This is mainly because operation in two directions may face different geographical environments, hydrological conditions, traffic conditions, and other factors, all of which may have an impact on the time, manpower, and economic costs of operation. Based on this, to ensure the scientificity of the research, when using the improved Dijkstra algorithm for irrigation path planning, the average cost between reservoir nodes is taken as the standard cost value. At this point, the labor cost value can be calculated, which can be represented by formula (3).

$$C = C_1(\frac{C_1}{C_2} + C_1) + C_2(\frac{C_2}{C_1} + C_2) \quad (3)$$

In formula (3), C represents the average labor cost value. C_1 represents the labor cost value of A reservoir. C_2 represents the labor cost value of Reservoir B. After calculating the labor cost value, it is also necessary to calculate the final expenses, and the final total loss value can be calculated using formula (4).

$$R = S(W_1C_1(\frac{C_1}{C_2} + C_1) + W_2C_2(\frac{C_2}{C_1} + C_2)) + L \quad (4)$$

In formula (4), R represents the total loss value. S represents the distance between reservoirs. W_1 represents the water resource loss value of Reservoir A. W_2 represents the water resource loss value of Reservoir B. L represents other loss values during the operation process. The comparison results before and after optimizing the irrigation operation path are shown in Figure 2.



(a) Comparison results of inflow and outflow before and after optimizing irrigation scheduling paths

(b) Comparison results of inflow and outflow before and after optimizing irrigation scheduling paths

Figure 2: Comparison results of irrigation operation path optimization before and after

From Figure 2, after optimizing the irrigation path, the utilization of inflow and outflow of water resources in the reservoir has been significantly improved, and the utilization rate of water has also been significantly improved. This indicates that the optimization of reservoir irrigation operation paths based on the improved Dijkstra algorithm has a positive effect.

2.2 Improved Dijkstra algorithm combined with ACO algorithm for irrigation operation system model construction

Through the study of using the improved Dijkstra algorithm for reservoir irrigation operation, it is found that the Dijkstra algorithm mainly solves the single objective optimization problem, that is, finding the shortest path. However, there may be multiple conflicting objectives in irrigation operation, such as irrigation area, water consumption, energy consumption, etc. [18-19]. To address these issues, the ACO algorithm is introduced in the study. In the irrigation operation problem of reservoirs, the irrigation channel network can be abstracted as a graph model, where nodes represent reservoirs, pumping stations, irrigation areas, etc. The edge represents the water flow path, and the weight of the edge can represent the time, cost, or energy consumption required for the water flow to pass through this path. Then, the ACO algorithm is used to search for the optimal irrigation path from the starting reservoir to the target reservoir on the graph model. The flowchart of the ACO algorithm is shown in Figure 3.

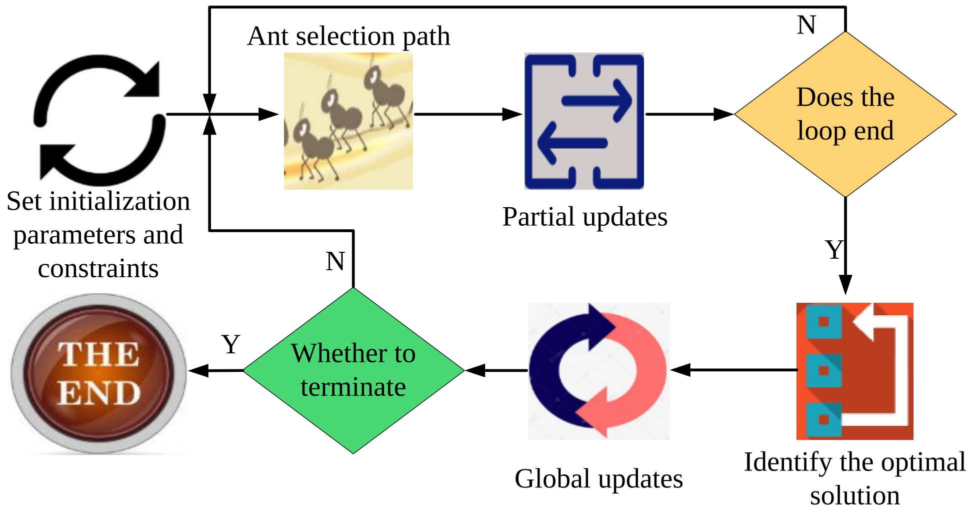


Figure 3: ACO algorithm flowchart

When integrating the ACO algorithm with the improved Dijkstra algorithm, the first step is to set the objective function of the operation system model, which can be represented by formula (5).

$$F = \min\left[R_{i,j}(t) - D(t)\right]^2 \quad (5)$$

In formula (5), $R_{i,j}(t)$ represents the expected probability value of the i th and j th nodes in the t period. $D(t)$ represents the actual probability value during the t period. At this point, the moderate function can be calculated using formula (6).

$$Fit^k = \sum_{i=1}\sum_{j=1}\frac{\left[R^k(t) - D(t)\right]^2}{D_{\max}(i)} + \frac{\left[R^k(t) - D(t)\right]^2}{D_{\max}(j)} \quad (6)$$

In formula (6), t represents the total amount of information obtained by k ants in the ant colony during the t period. $D_{\max}(i)$ represents the total amount of information on the path where node i is located. $D_{\max}(j)$ represents the total amount of information on the path where node j is located. Optimizing the objective function and moderate function can avoid the slow initial speed of the ACO algorithm, and state transition rules need to be considered in the process of using the ACO algorithm for path planning. To regulate the concentration of ants in searching paths, a harmonic parameter is added to the search rules to reduce the probability of ants deviating from the concentrated area and selecting paths. The transfer rule formula obtained by adding harmonic parameters is shown in formula (7).

$$p_{i,j}(t) = s\frac{G_{ij}(t)^a B_{ij}(t)^b}{\Sigma G_{ij}(t)^a B_{ij}(t)^b} \quad (7)$$

In formula (7), s represents a harmonic parameter with a range of values between [0,1] and a random number. $p_{i,j}(t)$ represents the probability value of state transition. $G_{ij}(t)$ represents the total amount of pheromones accumulated on paths i and j during the t period. $B_{ij}(t)$ represents the estimated moderate function value in the t period based on the objective function. a and b represent the parameters of different nodes, respectively. By applying new state transition rules, the probability of ants exploring redundant paths can be reduced, thereby improving the exploration efficiency of the algorithm and saving time. The flow chart of irrigation operation path optimization based on improved Dijkstra algorithm and ACO algorithm is shown in Figure 4.

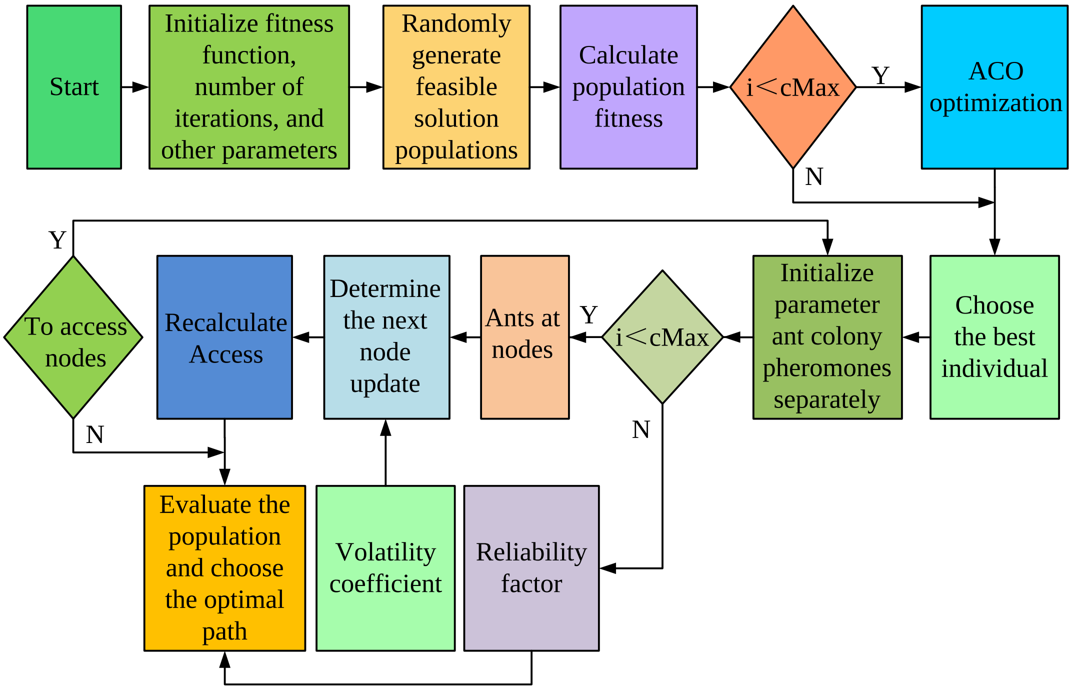


Figure 4: Irrigation operation path optimization flowchart based on improved Dijkstra algorithm and ACO algorithm

Through the optimization of irrigation operation paths, it is found that when using the ACO algorithm to optimize the path, the volatilization of pheromones is reduced, which can affect the accuracy of ants in path planning. Therefore, the study introduces a volatilization factor and improves the local and new rules to accelerate the convergence speed of the algorithm, thereby avoiding ants appearing on the same path during the convergence process. The improved local update rule can be represented by formula (8).

$$G_{ij}(t+1) \leftarrow (1-dis)G_{ij}(t) + dis\Delta(t,t+1) \quad (8)$$

In formula (8), $G_{ij}(t+1)$ represents the total amount of pheromones accumulated on paths i and j during the $t+1$ period. dis represents the volatility factor, which is a random number between [0,1]. $dis\Delta(t,t+1)$ represents the increase in pheromones at t and $t+1$ moments after introducing volatilization factors. After completing the local update, it is necessary to update the global path, which can improve the guidance weight of pheromones. By introducing global update coefficients, the concentration of pheromones can be increased, significantly improving the running speed of the algorithm. The global update rule can be represented by formula (9).

$$\Delta G_{i,j}(t,t+1) = \begin{cases} \frac{1}{ad * L_{i,j}}(i,l) \\ 0 \end{cases} \quad (9)$$

In formula (9), ad represents the global update coefficient, which is a random number between [0,1]. $L_{i,j}$ represents the length of the global path. After optimizing the irrigation operation path of the reservoir, the construction time and engineering standards of different reservoirs are different in the construction of the water resources network. The study introduces reliability parameters for coordination, which are comprehensively set based on the construction time and intensity of the reservoir. The longer the construction time, the worse the reliability. It is assumed that the lower the intensity, the worse the reliability [20-21]. Therefore, the study introduces a reliability coefficient in the selection of reservoir nodes to reduce the irrigation operation tasks of reservoirs with aging facilities and low storage capacity. The calculation formula for reliability coefficient can be represented by formula (10).

$$H = \frac{D}{T} * V \tag{10}$$

In formula (10), H represents the reliability coefficient value. After obtaining the reliability parameters, a new irrigation operation probability formula can be obtained, as shown in formula (11).

$$p_{i,j}(t) = H * s \frac{G_{ij}(t)^a B_{ij}(t)^b}{\Sigma G_{ij}(t)^a B_{ij}(t)^b} \tag{11}$$

Based on the above research, it is necessary to clarify the design principles before constructing a water resources operation system model. Firstly, it needs to meet the downstream urban living, industrial and agricultural water use, and urban ecological needs. Secondly, it needs to consider the water level difference between flood season and non flood season. Finally, hydrological data is stored and analyzed simultaneously for decision-making purposes [22]. After requirement analysis, the simulation system functions are divided into three parts: conventional operation, optimized operation, and manual operation. The flowchart of the irrigation operation system model combining the improved Dijkstra algorithm with the ACO algorithm is shown in Figure 5.

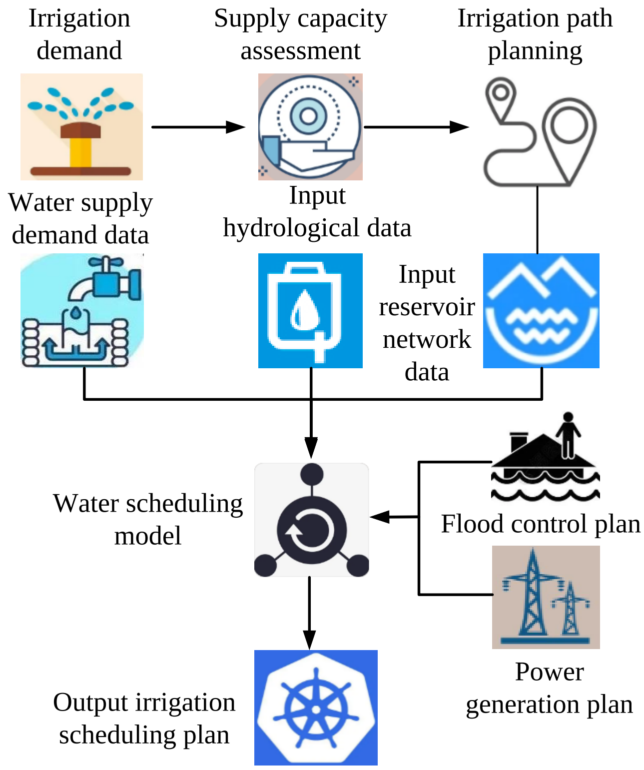


Figure 5: Flow chart of an improved irrigation operation system model combining Dijkstra algorithm with ACO algorithm

3 Performance analysis of irrigation operation system model based on Dijkstra and ACO

To verify the performance of the reservoir irrigation operation system model constructed based on Dijkstra algorithm and ACO algorithm, this study compared the Greedy Algorithm (GA), Particle Swarm Optimization (PSO), and Dijkstra+ACO algorithms. The accuracy, recall, F1 value, optimal path length, number of search nodes, and actual irrigation pre measurement in path planning data processing were used as validation indicators for performance verification.

3.1 Path and irrigation demand performance analysis of reservoir irrigation operation system model

To verify the path planning performance of the irrigation operation system model, simulation experiments were conducted using actual data from a certain reservoir. The reservoir had a regulating capacity of 780 million m3, an average annual runoff of 1.15 billion m3, a normal storage level of 85 meters, and a dead water level of 65 meters. The installed power generation capacity of the reservoir was 40MW, and the designed irrigation area was 65000hm2. The power generation guarantee rate was designed to be 85%, and the limited water supply during the designed irrigation failure period was reduced to 60% of the normal water supply. Simultaneously comparing GA, PSO, and Dijkstra+ACO algorithms could better evaluate the performance and effectiveness of the model. The comparison results of accuracy, recall, and F1 values of the three algorithms are shown in Figure 6.

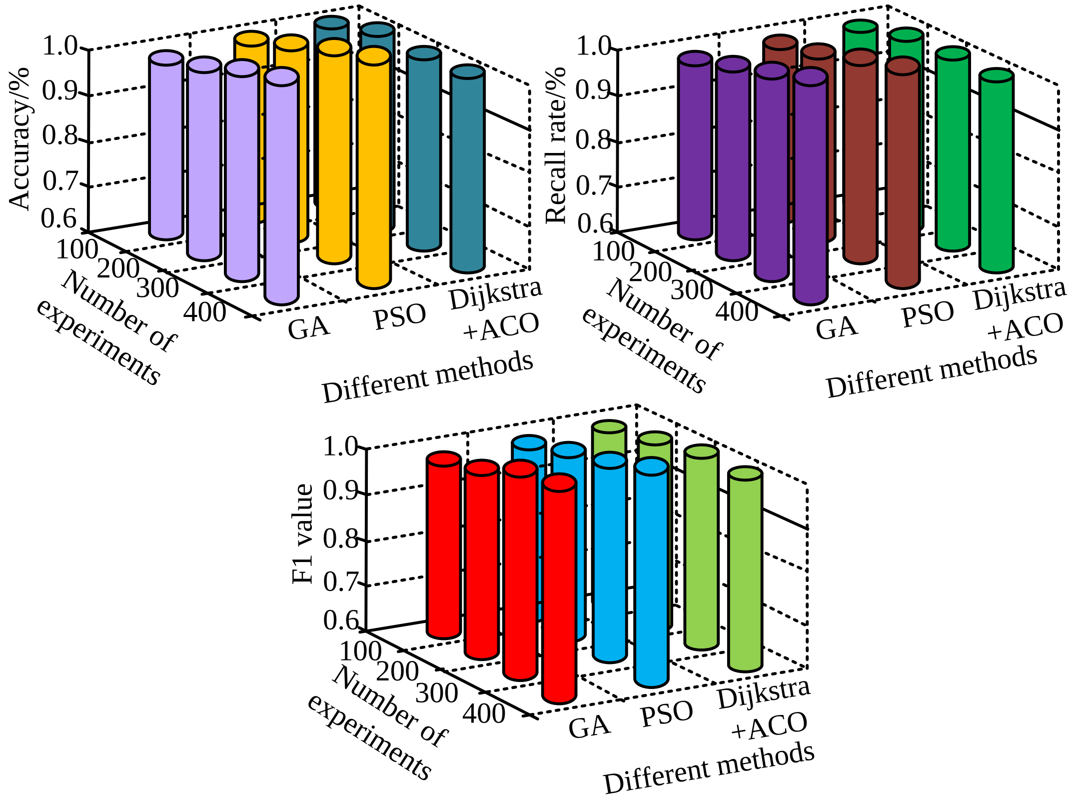


Figure 6: Comparison results of accuracy, recall, and F1 values of three algorithms

According to Figure 6, the data processing accuracy, recall, and F1 values of Dijkstra+ACO algorithm, PSO algorithm, and GA in irrigation operation path planning process were 95.06%, 89.68%, 85.07%, 96.27%, 90.16%, 88.29%, and 0.92, 0.86, and 0.83, respectively. The comparison showed that the irrigation operation system model constructed using Dijkstra+ACO algorithm had higher robustness and stability in the processing of irrigation path data. To analyze the temporal and spatial complexity of Dijkstra+ACO algorithm in reservoir scheduling, the study took the execution time and the size of memory required in the irrigation path planning process as the indicators of temporal and spatial complexity analysis. The results of the comparison of execution time and required memory of the three algorithms are shown in Table 2.

Table 2: Comparison results of execution time and memory required for three algorithms

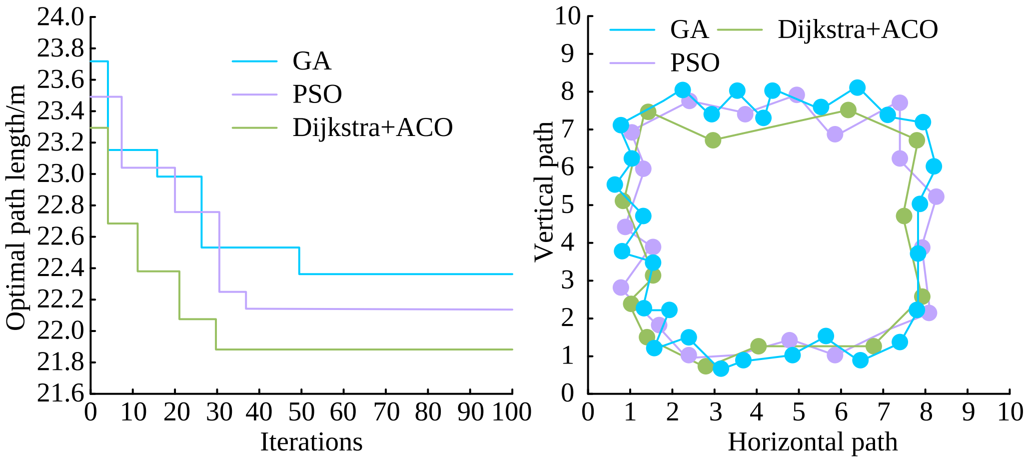
Arithmetic	Execution time/s	Memory size required/MB
GA	120.59	150.5
PSO	113.18	120.7
Dijkstra+ACO	92.63	108.5

As analyzed in Table 2, in the time complexity comparison, the execution time of the three algorithms had more obvious differences. The execution time of the Dijkstra+ACO algorithm was shorter than that of the GA and PSO algorithms by 20.55s and 27.96s, respectively. In the memory consumption of the path planning, the Dijkstra+ACO algorithm consumed 12.2MB and 42MB less memory than the GA and PSO algorithms, respectively. This indicated that the Dijkstra+ACO algorithm constructed in the study was able to find the optimal or near-optimal irrigation path planning scheme in a shorter period of time and complete the computational task with less memory consumption. To analyze the uncertainty and sensitivity of Dijkstra+ACO algorithm in reservoir scheduling, the ability to analyze unexpected irrigation demand (out of 10 points) and irrigation elasticity coefficient were used as validation indexes. The results of uncertainty and sensitivity analysis of the three algorithms are shown in Table 3.

Table 3: Uncertainty and sensitivity analysis results of the three algorithms

Arithmetic	Capacity to analyze unforeseen irrigation needs/points	Irrigation elasticity coefficient
GA	7.5	0.79
PSO	8.2	0.81
Dijkstra+ACO	8.9	0.85

From the analysis in Table 3, in the comparison of accidental irrigation demand analysis capability, the Dijkstra+ACO algorithm scored 8.9 for accidental irrigation demand analysis capability, while the PSO and GA scores were 8.2 and 7.5, respectively. The irrigation elasticity coefficients of the three algorithms of Dijkstra+ACO algorithm, PSO and GA had the values of 0.85, 0.81, and 0.79, respectively. This further validated the effectiveness and superiority of Dijkstra+ACO algorithm in the field of reservoir scheduling and provided a more efficient, stable, and flexible solution for reservoir scheduling. To further verify the performance of the irrigation operation system model in irrigation path planning, the optimal path length and path planning were studied as validation indicators. The comparison results of the optimal path length and path planning for three methods are shown in Figure 7.

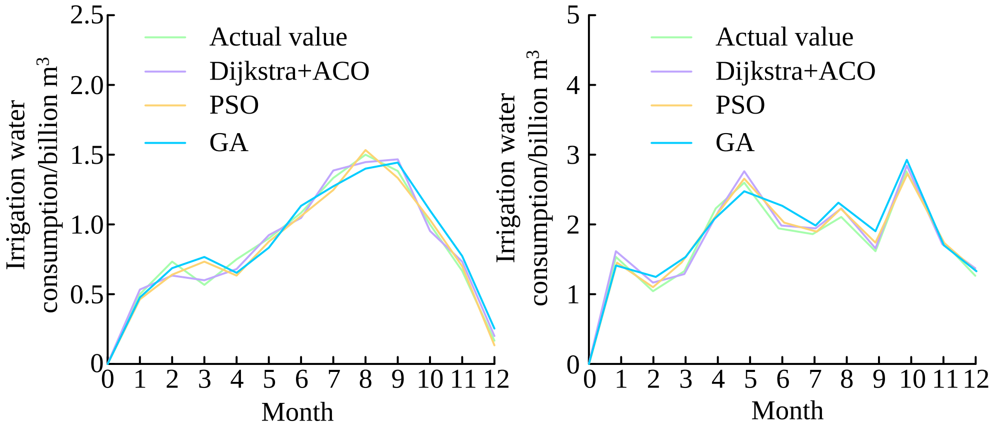


(a) Comparison results of the optimal path of three methods

(b) Comparison results of three optimal path planning methods

Figure 7: Comparison results of optimal path length and path planning using three methods

As shown in Figure 7 (a), during the irrigation operation, the Dijkstra+ACO algorithm completed the search and planning of the optimal path length in 32 iterations. The PSO algorithm and GA completed the optimal path length and planning when iterating 41 and 57 times, respectively. The optimal path lengths for Dijkstra+ACO algorithm, PSO algorithm, and GA were 21.93m, 22.15m, and 23.6m, respectively. As shown in Figure 7 (b), in the comparison results of optimal path planning, the number of path nodes in the Dijkstra+ACO algorithm was significantly less than that in the PSO algorithm and GA, indicating that the Dijkstra+ACO algorithm had better search ability and robustness in solving path planning problems. To verify the performance of the irrigation system model in irrigation operation requirements, the sensitivity analysis of reservoir capacity and precipitation on irrigation water consumption was studied as validation indicators for performance testing. The sensitivity analysis comparison results of three methods affected by reservoir capacity and precipitation are shown in Figure 8.



(a) Three methods for assessing reservoir capacitySensitivity analysis of impact

(b) Three methods for measuring precipitationSensitivity analysis of impact

Figure 8: Comparison of sensitivity analysis results of three methods affected by reservoir capacity and precipitation

As shown in Figure 8 (a), the actual irrigation water consumption also showed a significant change with the change of reservoir capacity, with an average annual irrigation water consumption of 126 million m3. The Dijkstra+ACO algorithm had the smallest difference with the actual irrigation value, with an average annual irrigation water consumption of 131 million m3. The average annual irrigation water consumption of PSO algorithm and GA was 137 million m3 and 141 million m3, respectively. From Figure 8 (b), when there was a change in precipitation, there would also be a significant change in irrigation water consumption. The curve showed significant fluctuations within the range of rainfall variation, indicating a high level of uncertainty in rainfall. With the increase of rainfall, the irrigation water consumption would also correspondingly increase to meet the water requirements of farmland. To further verify the performance of the irrigation system model in irrigation operation requirements, the study compared the actual irrigation demand with the irrigation demand predicted by three methods. The comparison results between the irrigation demand of three methods and the actual demand are shown in Figure 9.

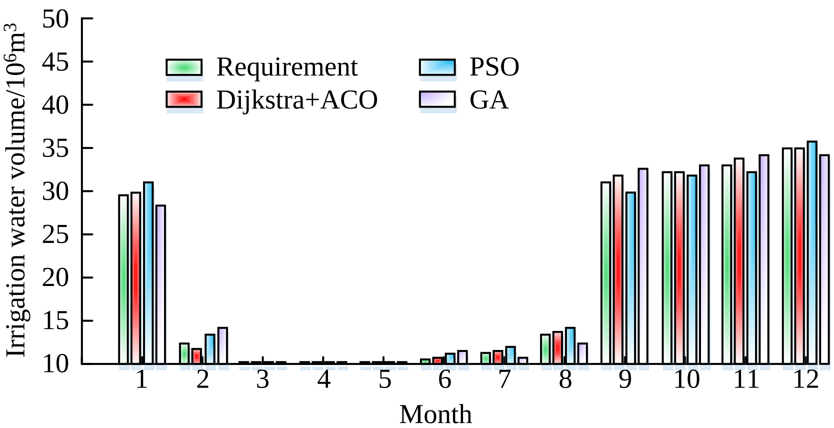


Figure 9: Comparison of irrigation demand and actual demand using three methods

As shown in Figure 9, there were significant differences in the demand for irrigation in different months of the year, which was directly related to rainfall and crop cultivation. Compared with the actual irrigation demand, the demand of Dijkstra+ACO algorithm could basically meet the irrigation demand. However, there was a certain gap between the irrigation demand of PSO algorithm and GA and the actual irrigation demand, which could not effectively meet the actual irrigation demand. This indicated that the study of using Dijkstra+ACO algorithm to construct a reservoir irrigation operation system model could meet real needs in irrigation path optimization and irrigation demand, and had higher practicality.

3.2 Application performance analysis of reservoir irrigation operation system model

To further verify the application performance of the reservoir irrigation operation system model, the study used the reservoir irrigation operation system model to predict the water demand hydrograph and compared it with the measured water demand hydrograph. The comparison results between the predicted and the actual measured water demand hydrographs are shown in Figure 10.

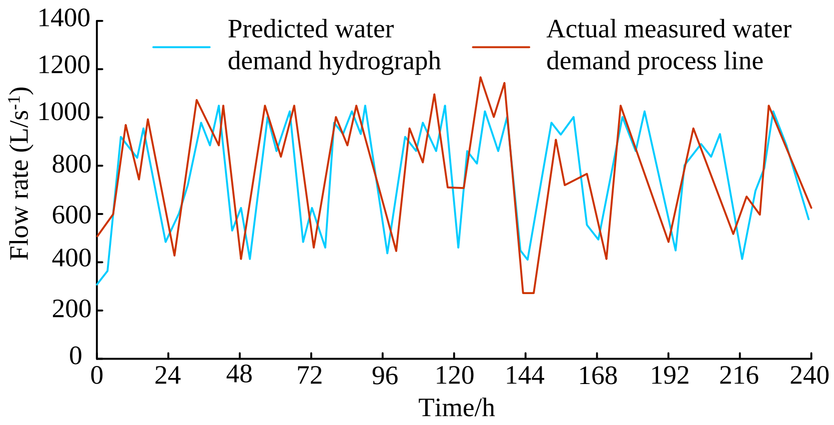


Figure 10: Comparison results between predicted and actual measured water demand hydrographs

From Figure 10, in the comparison of the 10-day water demand process lines, the average value of the actual measured water demand process lines was 786.3L/s-1, and the interval between the minimum and maximum values was [283.7,1195.8] L/s-1. The average value of the predicted water demand hydrograph was 801.6L/s-1, and the interval between the minimum and maximum values was [269.7,1089.2] L/s-1. The difference between the two was 15.3L/s-1, which had a relatively small impact on the practical application of the irrigation operation system model. This indicated that the reservoir irrigation operation system model constructed in the study could also achieve good application results in practical applications, and could further meet the needs of irrigation operation on the basis of optimizing the operation path. To verify the actual predictive performance of the irrigation operation system model, the study used irrigation restriction water supply line, irrigation anti damage line, irrigation comprehensive anti damage line, power generation comprehensive anti damage line, and anti water discharge line as indicators for performance verification. The calculation prediction curves for five validation indicators are shown in Figure 11.

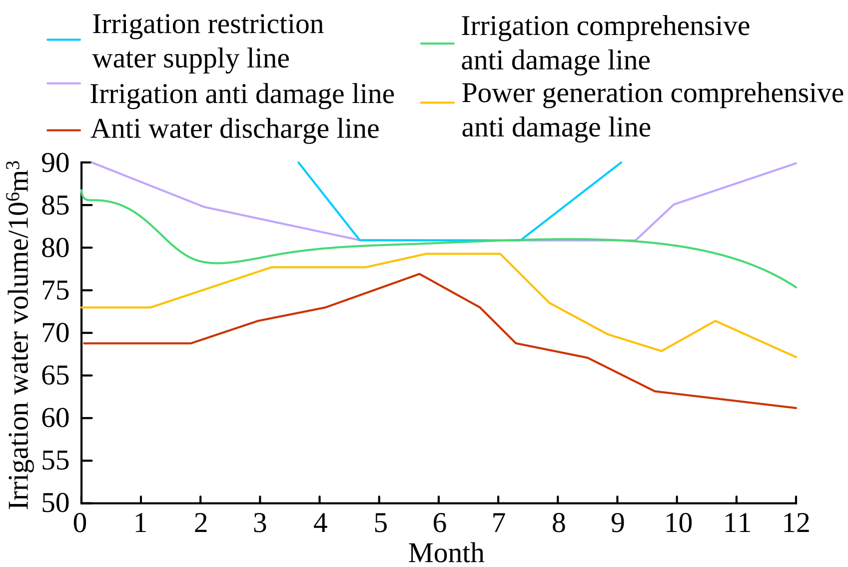


Figure 11: Calculation and prediction curve of five validation indicators

As shown in Figure 11, the irrigation operation system model could accurately predict the irrigation restriction water supply line, irrigation anti damage line, irrigation comprehensive anti damage line, power generation comprehensive anti damage line, and anti water discharge line in different months. The effective prediction of these five indicators could ensure the reasonable allocation of water supply, prevent damage to reservoirs, environment, and land, improve water supply efficiency, and comprehensively consider various factors to achieve sustainable development of irrigation. To verify the comprehensive operation performance of the reservoir irrigation operation system, the study used irrigation and power generation as indicators to verify the comprehensive operation performance. The comprehensive operation results of the reservoir irrigation operation system are shown in Table 4.

Table 4: Comprehensive operation results of reservoir irrigation operation system

Method of calculation	Irrigation water supply/billion m3	Annual irrigation guarantee rate/%	Water supply rate during the destruction period/%	Reducing water supply guarantee rate/%	Annual average power generation/(10000 kW·h)	Guaranteed power/(10000 kW·h)	Guaranteed power/kW	Power generation guarantee rate/%
Runoff regulation	4.15	85.32	62.37	/	10563	627	719	85
Comprehensive operation of irrigation and power generation	4.15	85.32	62.37	100	10867	71529	92564	85

According to Table 4, there was no significant difference between the two methods of runoff regulation and comprehensive operation of irrigation and power generation in terms of irrigation water supply, annual irrigation guarantee rate, water supply rate during the destruction period, and reducing water supply guarantee rate. But in terms of ensuring electricity, the comprehensive operation method of irrigation and power generation ensured a larger amount of electricity, and at the same time, the average annual power generation and guaranteed power were also higher. In addition, the average annual power generation of the comprehensive operation method for irrigation and power generation also slightly increased. This indicated that the reservoir irrigation operation system could allocate water and energy resources more reasonably, improve resource utilization efficiency, and achieve optimized resource allocation. At the same time, it could also reduce the phenomenon of reservoir water discharge and the negative impact on the environment. The study, to further validate the performance of the irrigation scheduling system model, took a reservoir in a hilly area as a case study. The reservoir was located in an irrigated agricultural area and was also tasked with power generation, so its irrigation scheduling design needs to take into account the dual demands of irrigation and power generation. The study first collected data on meteorological data, hydrological data, irrigation demand and power generation demand for the past five years for this reservoir. Then the irrigation water supply and average annual power generation were qualitatively evaluated. After the implementation of the new scheduling scheme, the irrigation water supply and power generation of the reservoir were 10.59 million m3 and 0.58 million kw, respectively, and the irrigation water supply and power generation without the new scheduling scheme were 9.96 million m3 and 0.53 million kw, respectively. After the use of the new scheduling scheme, the irrigation water supply and power generation of the reservoir increased by 0.63 million m3 and 0.05 million kw, respectively. This indicated that the Dijkstra algorithm combined with the ACO algorithm enables the model to find the optimal solution among many possible scheduling schemes, thus realizing the rational allocation and efficient utilization of water resources. In addition, the model also considered the dual demand of irrigation and power generation, and realized the synergistic benefits between them by coordinating the relationship between them.

4 Discussion

By summarizing and analyzing the above research content, this study explored the application of Dijkstra algorithm and ACO algorithm in reservoir irrigation scheduling design, and successfully constructed an irrigation scheduling system model that can handle multi-objective and multi constraint optimization problems. There are certain differences in the water demand process compared to actual cases, which can be attributed to multiple aspects. On the one hand, although the study combined Dijkstra algorithm and ACO algorithm for predicting water demand, changes in natural factors such as climate, soil conditions, and crop growth status may still have an impact on actual water demand, and the model fails to fully capture these dynamic changes. On the other hand, the parameter settings and algorithm optimization of the model may also have an impact on the prediction results. Therefore, future research can further explore how to optimize model parameters and algorithms to improve prediction accuracy. Secondly, the system model has achieved significant results in the comprehensive scheduling of irrigation and power generation. The system not only ensured agricultural irrigation water, but also fully considered the demand for power generation, achieving effective coordination between the two. However, research has also found that the operation and management of the system require professional technical personnel for operation and maintenance. Therefore, how to cultivate and introduce professional talents in related fields is one of the key to the successful operation of the system. The hybrid algorithm also explored the impacts of ecological and social factors, and in adapting to the ecological balance, it not only met the needs of agricultural production, but also provided the ecosystem with the necessary amount of water, which helps to maintain the balance of water ecology and biodiversity. In adapting to social impacts, by increasing the amount of water supplied for irrigation and the annual guaranteed rate of irrigation, it ensured stable agricultural production and meets the social demand for food and other agricultural products. Therefore, the development of the agricultural economy can be promoted to meet the demand for electricity in industry, commerce and services, and promote the overall development of the economy.

In summary, the combination of Dijkstra's algorithm and ACO algorithm in reservoir irrigation scheduling design has achieved remarkable results, but there are still some areas that need to be improved and optimized. Future research can further explore how to optimize the model parameters and algorithms to improve the prediction accuracy. Meanwhile, it is also necessary to pay attention to the coordination of irrigation and power generation demand, as well as the cultivation and introduction of talents in the operation and management of the system. Through continuous exploration and practice, the system will play a greater role in the sustainable development of agriculture and energy.

5 Conclusion

To solve the problems of low resource utilization efficiency in traditional reservoir irrigation operation systems, in-depth research was conducted on the combination of Dijkstra algorithm and ACO in reservoir irrigation operation design. By effectively combining these two algorithms, the constructed irrigation operation system model could better handle multi-objective and multi-constraint optimization problems. The results showed that in the application of the reservoir irrigation operation system model, the average predicted water demand hydrograph by the system was 801.6L/s-1, which was 15.3L/s-1 different from the actual water demand hydrograph. At the same time, in the system model, the comprehensive operation method for irrigation and power generation had an irrigation water supply of 415 million m3, an annual irrigation guarantee rate of 85.32%, a water supply rate during the destruction period of 62.37%, a reduced water supply guarantee rate of 100%, an average annual power generation of 108.67 million kW·h, and a guaranteed power quantity of 71.529 million kW·h. This indicated that the reservoir irrigation operation system placed more emphasis on the synergistic benefits of irrigation and power generation. The system not only focused on the rational allocation of water resources, but also focused on achieving the dual goals of agricultural production and power supply through optimized operation. It could achieve rational utilization of water resources and improve irrigation efficiency, providing strong support for sustainable development of agriculture and energy. Meanwhile, the practical impacts of hybrid methods in actual reservoir management scenarios were categorized into three aspects: efficiency, resource allocation, and accuracy. The first was the computational efficiency. Hybrid methods could generate a large number of feasible solutions in a short period of time, thus greatly speeding up the search and optimization process. In the actual reservoir management, the scheduler could get the scheduling solution faster, which improved the efficiency and response time. The second was resource allocation. Hybrid method could give multi-objective constraint analysis, which helped to reduce the waste of water resources and improved the utilization efficiency in practical applications. The last was prediction accuracy. In practical application, higher prediction accuracy could help dispatchers more accurately grasp the trend of changes in irrigation demand and power generation demand, which provided strong support for the development of scientific scheduling programs. Although the research achieved significant results, there are still certain shortcomings. The exploration of uncertainty factors in the process of reservoir irrigation operation is not yet sufficient for input, and the next step is to conduct in-depth comprehensive evaluation of the uncertainty factors to improve the performance of the system model.

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