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Review of the literature on tidal optimization by the Mike21 model

Lu Ping[1,2,*]

[1]*School of Merchant Shipping, Shanghai Maritime University, Shanghai, 201306, China*
[2]*Yangtze River Pilot Center, Jiangyin, Jiangsu, 214431, China*
201640111003@stu.shmtu.edu.cn
**Corresponding author*

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Abstract: The navigation environment of the Jiangsu section of the Yangtze River is complex, and the full utilization of port water depth resources is an important guarantee for navigation safety and a favorable condition for accurate tidal forecasting. Improving pilotage safety, tidal forecasting is crucial for ship navigation safety, port operation efficiency, and nearshore engineering. Tidal forecasting can help ensure the safe operation of large ports. At present, various numerical models used domestically and internationally only focus on the impact of tides and currents in coastal areas. There is little research on tidal optimization in narrow and curved long channels such as the Jiangsu section of the Yangtze River, and there are also few researchers using MIKE software to simulate and simulate tidal levels, flow velocities, and flow directions. This article provides a comprehensive study on tidal optimization models and algorithms, the current research status at home and abroad, the problems that need to be solved in tidal optimization, and Mike21.

1. Research background and significance

1.1 Implementation of National Strategy for the Integrated Development of the Yangtze River Delta

Jiangsu section of the Yangtze River in the Yangtze River Delta. The Yangtze River Delta is one of the regions with the most active economic development, the highest degree of openness and the strongest innovation ability in China, and plays an important role in the national economy. Keeping close to the integration development of the Yangtze River Delta is the key to the overall development of the Yangtze River Economic Belt and East China, which has greater regional drive and demonstration effect, forming regional fine clusters.

The Outline of Integrated Development Planning for the Yangtze River Delta Region was deliberated and approved by the Political Bureau of the CPC Central Committee in May 2019 and approved by the State Council in October 2019 as the Overall Plan for Eco-Green Integration Development Demonstration Zone in the Yangtze River Delta Region, which calls for the organic unification of green economy, high-quality life and sustainable development. It is an integral part of the overall planning for the demonstration area of ecological green integration development in the Yangtze River Delta, and the Overall Plan for the Demonstration Area of Ecological Green Integration Development in the Yangtze River Delta is the overall plan for the demonstration area of ecological green integration development in the Yangtze River Delta. This marks that the national strategy of integration development of the Yangtze River Delta has entered a comprehensive construction period, cross-administrative areas are jointly constructed and shared, and ecological civilization and economic and social development complement each other. The navigation capacity of the Jiangsu section of the Yangtze River has been significantly improved with both economic and social benefits.

At present, the trend of large-scale and standardization of world marine ships is becoming more and more obvious. The main standard ship types have exceeded 50,000 tons, and the important international seaports with a depth of 12.5 meters have become the mainstream seaports in the world.

1.2 Limited navigation capacity of the Jiangsu section of the Yangtze River

It can enter and exit 100,000-ton ships 24 hours a day and ultra-large ships between 200,000-300,000 tons at tides. Its advantages are self-evident compared with the unique deep water advantages of the coast.

After the completion of the 12.5m deep water channel [1] in the Jiangsu section of the Yangtze River, the two-way voyage with load reduction for 50,000-ton container ships (live draft < 11.5m) and other 50,000-ton ships will be raised from 105 m to 125,5m (the datum level is the local minimum theoretical tidal level in the lower reaches of Jiangyin), while the load reduction voyage takes into account 100,000-ton bulk carriers. According to statistics, a 12.5m deep water channel project under Nanjing of the Yangtze River has been built, which has effectively improved the navigation conditions of the lower reaches of Nanjing of the Yangtze River, enhanced the navigation capacity and significantly improved the economic and social benefits. In 2018, 50,000-ton, 100,000-ton, 200,000-ton and above ships arrived at port increased by 2.9 times, 3.4 times and 4.9 times respectively compared with 2011, and actual carrying capacity increased by 4.0 times, 7.6 times and 7.4 times respectively compared with 2011. The cargo throughput of Jiangsu ports along the river reached 1.78 billion tons, an increase of 15 times over 2011.

The national port throughput of goods reached 14.351 billion tons in 2018, an increase of 2.5% over the previous year. The coastal ports completed 9,463 million tons, an increase of 4.5%; Inland ports completed 4,888 million tons, a 1.3% reduction. The inland port has completed the national port cargo throughput of 34.06%.

Railway, airport and port groups are becoming more and more perfect, and world-class cities in the Yangtze River Delta are coming out. On May 13, 2019, the official website of the Ministry of Communications issued data on port cargo throughput above 2018 scale. Data show that the Yangtze River Delta Port occupies 3 of the top 10 ports in terms of cargo throughput in 2018, with Ningbo-Zhoushan Port, Shanghai Port and Suzhou Port ranking 1, 2 and 6 respectively. In 2018, the total cargo throughput of 16 ports in the Yangtze River Delta Group was 4,363 million tons, accounting for 30.4% of the total throughput of national ports.

1.3 Feasibility of Tidal Optimization in the Jiangsu Section of the Yangtze River

By optimizing the channel tides in the Jiangsu section of the Yangtze River, the function of the deep water channel in the Jiangsu section of the Yangtze River will be further developed, the navigation conditions will be improved and the navigation capacity will be enhanced.

The author intends to take Nantong Rugao Port as an example to study the optimization model and algorithm of tidal flow in Jiangsu section of the Yangtze River. Rugao Port of Nantong intends to normalize its approach to 12.0m ships after unloading on the basis of the early approach to restricted ships.

2. Research on the Current Situation and Dynamic Analysis at Home and Abroad

2.1 Current Status of Foreign Research Technology

Kelvin [2] of the United Kingdom devised a harmonic analysis method as early as 1868 based on tidal statics [3] and dynamics [4]. After years of development, many scholars Carter [5], Edden [6], W.H. Munk [7] have put forward new solutions for different situations, which make the harmonic analysis theory to be further improved. A large number of long-term tidal level observation data are required to obtain stable and long-term tidal prediction and an accurate model for harmonic analysis. For example, F. Mosetti and B. Mancaa[8] separated the celestial flood from the tidal level using a progressive approximation method and calculated the tidal composition harmonic constant based on the least square method. The most widely used tidal models in the world are POM[9] of University of Prinston, ECOM model [10], Hamsom model [11], DEFT3D model of Netherlands [12], MOHID[13] model of University of Georgia, FVCOM model of MIT, etc. And MIKE model [15].

POM (Princeton Ocean Model) is a numerical ocean model established by Blumberg and Moller of Princeton University in 1977, which is based on three-dimensional baroclinic primitive equation. POM is a widely applicable numerical model [16]. It uses SIGMA coordinates [17] which vary with the topography. It is used in estuaries, continental shelves, lakes, semi-enclosed sea areas and open oceans. It can also be coupled with wave models to simulate the tidal flat boundary. It has been widely used in scientific research and practical application. At present, it has a very wide range of applications and is a very wide numerical model in China.

ECOM model is a three-dimensional numerical model for shallow water, in which Blumberg[15] research team abandons the method of splitting operator and time filtering based on POM model and uses explicit format horizontal time difference, implicit format vertical time difference and semi-implicit format to calculate water level. The limitation of artificial space and time smoothing is excluded, but ECOM model cannot set the depth change of dry and wet grids and is unsuitable for use when simulating the smoothing of shallow or intertidal zone, and its attenuation nature limits the time and step of implicit format.

The HAMSOM model, which is considered by Backhaus et al., is mainly applicable to the 3-D baroclinic model of simulated marginal sea and continental shelf sea areas, including tidal action, wind field action, atmospheric pressure, heat flux, baroclinic gradient within the ocean, etc., and specially addresses the problems of continental shelf and ocean. A three-dimensional baroclinic model is developed specifically for the continental shelf and ocean problems.

DELFT3D developed by WLDELFTHYDRAULICS, Delft University, Netherlands, is mainly used in free surface water environment, which can simulate water flow, waves, water quality, ecology, sediment transport and bed bottom topography, as well as various two- and three-dimensional interactions.

Delft3D realizes the finite element method (FiniteElements) for users to choose, similar to the calculation format of TeleMac, and the system has its own abundant water quality ecological process library to realize seamless connection between the system and the geographic information system.

MOHID model is based on NEVES two-dimensional ocean model. More than 40 independent sub-modules are selected, or different modules are nested using transverse grid three-dimensional ocean model, or vertical grid of SIG coordinate system model or rectangular grid with discrete space is used. Therefore, the model can not well fit the boundary conditions to simulate complex island waters.

FVCOM (Finite Volume Coastal Ocean Model) was successfully established in 2000 by a research team led by Chen Changsheng of Massachusetts State University. The FVCOM model combines the advantages of finite difference and finite element models in existing marine studies and uses the finite volume method to discretize the equations. The FVCOM model is designed to save calculation time. By using the 2.5-order turbulent closing sub-model, the internal model of the external model is split and a closed control equation is formed.

MIKESOFTWARE is a mathematical simulation software developed by Danish Hydraulic Institute (DHI), which integrates physical, chemical and biological simulation functions, including rainfall runoff, groundwater, rivers and even marine and water pollutants. Its main modules include: MIKE11 (one-dimensional model), MIKE21 (two-dimensional model), MIKE3 (three-dimensional model), MIKEBASIN (watershed management model). MIKESHE (hydrological groundwater model), LITPACK (coastline dynamic model), MIKEURBAN (urban water supply and drainage network model), WEST (sewage treatment model), etc.

2.2 Current Situation of Domestic Research Technology

In terms of shallow-water tidal forecasting [18], domestic scholars have also done a lot of work. Considering the actual conditions of coastal areas in China, the tides are affected by many factors, such as tidal force, wind, pressure, coastal characteristics, precipitation, inclination of the lunar orbit and so on. Tidal changes show strong non-linearity and uncertainty. Therefore, a fixed forecasting model has been established for tidal forecasting in coastal areas of China. Specifically, In the work of tidal forecasting in coastal areas of our country and in the work of tidal forecasting in coastal areas of our country, our experts and scholars have made a great deal of improvements and Optimization in the work of tidal forecasting in coastal areas of our country on the basis of some advanced models abroad, which has made some scientific achievements in the work of tidal forecasting in many waters of our country and applied the improved models to the work of tidal forecasting. In-depth study and Research on tidal forecasting in coastal areas of China has enabled coastal areas of China to develop.

In order to solve the problem of discontinuous records existing in tides, Wang Ji and Fang Guohong [19] put forward the method of sub-sequencing, which makes the least squares method more widely used. Chen Manchun and Chu Yingjie [20] improved Wang Ji's method and adopted different harmonic terms, which significantly improved the forecast accuracy. Gao Huanshen [21] analyzed the results of celestial tides and non-linear related storm surges, provided an analytical table for increasing and decreasing water, and proposed a method to improve the accuracy of tidal forecasting. Liu Xiaobo et al. [22] When calculating the Taicang reach of the lower reaches of the Yangtze River, based on the POM model which fully reflects the changes of water level and flow rate of the reach, and combining the measured values, they established a better three-dimensional hydrodynamic model of the tidal reach. According to the time changes, they measured and calculated by POM model and calculated by POM model according to the time changes. Zhao Wanlu[23] Taking the cooling water arrangement scheme of the second phase project of Zhanjiang Power Plant as an example, based on Ecomsed model, carried out numerical simulation of the tidal current dynamic field and temperature field in the engineering water area, and compared the results of physical model test, analyzed and verified that the model was feasible to simulate the hydrothermal characteristics of the coastal water area, and expanded the application scope of Ecomsed model. Chen Qian and others [24] carried out numerical simulation of tides and tides in Zhejiang offshore area by using three-dimensional continental shelf sea model (HAMSOM). The original model was improved by using grid nesting and dynamic boundary technology to improve the calculation accuracy. In this way, the characteristics of tides and tides in the whole coastal area of Zhejiang Province were more comprehensively understood and better satisfied in calculation and measurement. Liu Dong [25] According to DEFLT3D simulation, analyzed the hydraulic values of the whole year 2011 from Xuliujing to the offshore areas of the Changjiang Estuary, and combined with the actual measurement of the annual tidal level data of Xuliujing Tidal Station, put forward the calculation method of the water surface gradient of the tidal reach, and obtained the hydrological and sediment characteristics of the Changjiang Estuary. Xu Peng [26] established a high-resolution FVCOM model for Xiangshan Port, which reproduces the main tidal characteristics of Xiangshan Port in terms of tidal level, tidal current simulation and structure of residual tidal flow field by comparing the measured data with previous results. Feng Jing [27] studied the application of MIKE21FM hydrodynamic model in the field of environmental impact assessment. The calculation results of this model can better reflect the process and characteristics of current movement in the simulated sea area, show the real flow field in the sea area, simulate the coincidence of the tidal level and the measured tidal level, and study Mike 21FM.

To sum up, there are few studies on the tidal utilization of narrow and long navigation channels such as Jiangsu Section of the Yangtze River at home and abroad. Various numerical models [28] focus only on the effects of tides and currents in coastal areas. Few researchers simulate and simulate the tides, flow rates and flow directions by MIKE software [29].

3. Objectives, research content, and solutions for key scientific issues in research

3.1 Research Objectives

The navigation environment of Jiangsu section of the Yangtze River is complicated, and the current direction near the dock, anchorage and navigation channel is complicated [30]. The flow rate is high and the maximum flood period can reach 6-7 sections. The pressure and challenge faced by the navigation safety of ships are more and more serious, because the functions of gold channel are fully exerted, the navigation density of ships is getting higher and higher, and the navigation environment is becoming more and more complicated. The trend of ship enlargement is obvious, and the current area of the ship is increasing continuously, which has more and more significant influence on ship handling and dock stabilization. Accurate tidal forecasting is beneficial to make full use of the water depth resources in the port and is an important guarantee for navigation safety. Improving navigation safety tidal forecasting [31] is critical to the navigation safety of ships, to the operational efficiency of ports and to the impact of offshore projects.

Accurate tidal forecasting is conducive to the full utilization of port water depth resources [32], and is an important guarantee for navigation safety. Tidal forecast is helpful for safe operation of large ports. The 12.5m deep water channel [33] in Jiangsu section of the Yangtze River has been perfected and the navigation environment has been improved. The 150,000-ton ships entering and leaving ports in Jiangsu section of the Yangtze River will normalize. In Jiangsu section of the Yangtze River, the theory of point-zone-surface tides is adopted and an algorithm is used to carry large heavy-duty ships into the river [34]. The traditional "China Coastal (Shanghai Port, Hangzhou Bay) Tidal Inducement Table" only shows the tidal height at each time point. Users can only estimate the size of the tides by the difference between adjacent time points and their personal experience. However, the information about the tides in a specific area, their size and direction, and the possibility of precise tides and directions can not be obtained after the tides have been optimized. Tidal forecasting provides reliable decision-making basis for pilots berthing and further improves the level of navigation operation in the access channel [35]. On the port side, in order to guarantee the tidal operation of long navigation channel [36] for 200,000-ton ships, the efficiency of ships entering and leaving the port has been greatly improved.

Through the study of navigation environment in Jiangsu section of the Yangtze River, the importance of tidal forecast to navigation process of ships is found, and the construction of tidal optimization model and algorithm are explored, so as to improve the navigation ability of ships berthing and leaving, optimize the entrance and exit routes of Cape type ships, and construct long-term and short-term model of navigation volume of the Yangtze River to validate the application of tidal optimization in navigation of the Yangtze River.

3.2 Research content

3.2.1. Building Tidal Optimization Models and Algorithms

Taking Tianshenggang Tidal Level Station in Jiangsu Section of the Yangtze River as an example, based on the measured River topographic data and relevant hydraulic structure information, the Tidal Optimization in Jiangsu Section of the Yangtze River is simulated and analyzed with MIKE21 hydrodynamic model [37], and the feasibility of the Tidal Optimization Model [38] is demonstrated. The calculation results of the model are reasonable and credible, which indicates that the MIKE21 model can be well applied in the tidal optimization demonstration calculation of the Jiangsu section of the Yangtze River.

3.2.2. Improving the Navigation Capacity of Ships Berthing and Departure

Navigation environment of restricted ships entering and leaving Jiangsu section of the Yangtze River, objective analysis and coping with various risks faced by restricted ships in the process of docking, among which tidal optimization is one of the important factors for successful docking. This paper demonstrates the optimization model and algorithm of tides by studying the berthing and departing of Ship Credibility 19 in order to improve the ship's ability of berthing and departing.

3.2.3. Optimizing the Entry and Exit Routes of Cape Ships

During the process of entering port, ships need to go through operation such as voyage, anchoring and berthing and so on. Large ships, especially restricted ships (over-draft ships), are restricted by water depth. Tidal optimization is indispensable for navigation, anchoring and berthing. The optimization of anchorage capacity model and berthing timing is particularly important. Tidal optimization model and algorithm are embodied in precise calculation of tides to maximize the utilization of water depth. Quantitative analysis is carried out on the existing data from docks, anchorages, entry and exit times, and on the basis of analysis of the existing route selection for Cape Ships under 12.5m deep water channel of the Yangtze River, the route selection is optimized to improve the voyage and departure benefits of Cape Ships on the Yangtze River.

3.2.4. Construction of Long and Short Cycle Models for Yangtze River Pilot Capacity

The trend of large-scale ships entering and leaving the Yangtze River is obvious. Tidal optimization is particularly important to navigation safety of restricted ships (especially over-draft ships). It is inevitable that ships entering and leaving the river will be restricted due to large-scale ships. By studying the period variation of navigation volume, the method of forecasting by neural network is put forward to study the long and short period variation of navigation volume of the Yangtze River and verify the application of tidal optimization in navigation of the Yangtze River. Based on the dynamic analysis of the navigation volume of the Yangtze River, the model of the long-term and short-period variation of the navigation volume of the Yangtze River is constructed by comparing the fitting value of regression with the empirical formula of BP neural network and the repeated training method, and the accuracy of BP neural network prediction is verified.

3.3 Key scientific issues to be addressed

3.3.1 Improving the accuracy of application model calculation

Tides are fluctuations in the earth's seawater caused by the gravitational forces of the moon and the sun. Because the sun is too far away from the earth, its effect on the tides is less pronounced than that of the moon. In both full and new months, the tides are the largest, called shuangwang. When looking at the tides, the "high" tides are very high and the "low" tides are very low [39]. When the sun and the moon are at right angles to the earth, small tides occur at this time - the period when the high and low tides are at their lowest. The area along the Jiangsu Section of the Yangtze River is mainly controlled by current, with two high tides occurring every day. It belongs to irregular half-day tides [40], and has the general characteristics of reciprocating flow in the estuary. Each tideway date is about 25 hours, during which two high tides and two low tides occur, with an average tidal difference of 200 cm, an average high tideway difference of 400 cm, and an average small tideway of 87 cm. The duration of average high tides and ebb tides are about 8 hours and 4 hours respectively. Flow direction is quite complex, and the flow speed in different areas varies greatly, which plays a great role in the navigation and docking of ships. The sun rises and sets at the same time on the same day of the lunar calendar every year, so the formation of tides has the same law. The rising time is the same on the same day of the lunar calendar every year and the rising law is the same. Since the tides are mostly influenced by the moon, the lunar month-day is used in the calculation. At the same time, the tidal cycle usually repeats about half a month, so it happens on the 1st, 16th, 2nd and 17th day of the lunar calendar. By analogy, the corresponding calculation start date is the first day and the start date is the sixteenth day.

The model and algorithm of tidal optimization in Jiangsu section of the Yangtze River are put forward to forecast and measure the tidal level at any point in the measuring area for general ports without tidal information[41]. The measurement accuracy is improved by combining the historical data of fixed-point stations in the measuring area and the measured data nearby.

3.3.2 Theoretical research and practical synchronization issues

The tidal reach of the Yangtze River covers an area about 620 km from Datong, Anhui Province to the estuary of the Yangtze River. The river will be subject to both runoff and tides in the tidal reach. The tidal boundary of the river is the longest reach that can be reached by the rising tides formed retrospectively along the river. When there is no rising trend above the tidal boundary, the tides can be reached on the tidal boundary. The important research content of land-sea interaction is the change of tidal boundary in tidal reach, which is of great significance to the study of tidal boundary.

Simultaneously transform the theoretical research results into the application methods needed by management practice, further improve the organization of vessel berthing and departing traffic in Rugao Port, and improve the management technology of vessel berthing and departing navigation.

4. Research Plan and Feasibility Analysis to be adopted

4.1 Research Technology and Technical Route

4.1.1 Test methods and means

Using MIKE software [42], a tidal calculation model is established and its rationality is verified by comparing the actual data of tidal level, flow direction and flow velocity with the calculated data. Taking the 12m ship Credit 19 in Rugao Port of Nantong as an example, the berthing windows of large ships [43] are studied from the aspects of tidal level, flow direction and flow velocity respectively to find out the boundary conditions of berthing and berthing requirements. Choose the optimum route to enable the restricted ships to navigate safely, break down and berth off the Changjiang River. Construct long-period and short-period models of Yangtze River navigation volume to verify the feasibility of the tidal optimization model and algorithm.

4.1.2 Technical methods

1) Graphical method. The research includes port cargo throughput, time difference between Wusong and each tidal station, intelligent buoy setting, tidal data collection, accuracy of tidal fitting curve and tidal curve map.

2) Review method. The model and algorithm of tidal optimization, the current situation of research technology at home and abroad, the problems to be solved in tidal optimization and Mike 21 are reviewed.

3) Construct model and algorithm. Modeling basic data and hydrodynamic model are built to form equations.

4) Real ship argumentation. To study the application of Tidal Optimization for the berthing and departing of Ship Chengxin 19.

5) Research on path selection optimization. The anchorage capacity model and berthing and departure timing are optimized.

6) Research on long and short period pilotage. To analyze the correlation between the outbreak and the Baltic index.

4.2 Feasibility Analysis

4.2.1 Feasibility of scientific issues

1) By calculating and demonstrating 150000 ton ships under different tide levels, flow directions, and flow velocities, it is concluded that the relevant requirements for berthing ships at Nantong Rugao Port are met.

2) By using the long channel to divide the tide and ride the tide, the berthing window time requirements for ships berthing at Nantong Rugao Port are obtained.

3) By analyzing the overall process of 150000 ton bulk cargo ships entering and berthing at Rugao Port, the risks and emergency measures for berthing at Rugao Port are proposed, and a relevant emergency system is constructed.

4) Optimize the route selection for open vessels entering and exiting the Jiangsu section of the Yangtze River.

To a certain extent, it is beneficial for further improving the navigation capacity and operational efficiency of deep water channels, and for improving the ore handling capacity of ports; For 150000 ton bulk cargo ships berthing at the port, the emergency support measures proposed can be referred to and implemented by the port and pilot departments; It can also serve as a reference for the maritime department to implement safety supervision work.

4.2.2 Guaranteed data sources

The data is sourced from the real ship data collection of the pilot ship, which has authenticity and traceability.

In the officially released "China Coastal Tide Measurement Table 2019" (Shanghai Port, Hangzhou Bay), the calculation of tides is authoritative.

The real-time measurement data of intelligent buoy with 2 anchors and 4 floats is real and effective.

The Yangtze River waterway information is sourced from the Yangtze River Waterway Map APP, official data, and updated in real-time.

5. Conclusion and Outlook

5.1 Conclusion

The numerical simulation system for refined tide prediction is a numerical simulation system that uses numerical simulation and harmonic analysis methods to establish a set of physical tide calculation models based on the laws of tide and tidal current movement and the measured data of existing tide level stations. It can quantitatively simulate the tide movement in different scenarios and calculate the tide level at any point at any time. The refined numerical simulation system for tidal forecasting can fully ensure the timeliness and effectiveness of hydrological information acquisition, significantly improving the efficiency and accuracy of hydrological forecasting.

The research achievement is to accurately predict the tides in the Jiangsu section of the Yangtze River and apply it to the pilotage practice process. Accurate tidal forecasting is beneficial for fully utilizing port water depth resources and is an important guarantee for navigation safety. The position of the Yangtze River tidal boundary under different runoff and tidal ranges is discussed using the MIKE21 hydrodynamic model. The calculation results of the model are reasonable and reliable, indicating that the MIKE21 model can be well applied in the tidal optimization calculation of the Jiangsu section of the Yangtze River.

5.2 Outlook

Tidal optimization models and algorithms can fully utilize tides for navigation, berthing, and unberthing of piloted ships. Some achievements have been made in the study of the actual berthing and unberthing of piloted ships, the use of anchorage, and the pilotage capacity of the Yangtze River. However, there are still shortcomings that need to be further deepened in the following aspects of learning in future work:

1) Further exploration of tidal currents in navigable environments. During piloting operations, wind speed and flow velocity are widely used. During berthing, the influence of water flow is greater than that of wind speed, leading to top flow berthing; On the contrary, the influence of wind speed is considered, and its application is less compared to that of tidal currents. In the future, further research will be conducted on the impact of tidal currents on ship pilotage operations.

2) Verify the actual ship berthing at full tide. The proposed concept of berthing at full tide has not been verified by actual ships. If berthing can be achieved during full tide, the significant improvement in the utilization efficiency of the dock will break the tidal limit. Overcoming the influence of weather factors, the adverse weather effects such as strong winds and fog have been significantly alleviated. After berthing at full tide, berthing operations can be organized as soon as

possible after severe weather such as fog or strong winds, to avoid situations where the dock cannot berth due to missing the tidal window due to adverse weather conditions; At the same time, in continuous foggy weather, it is possible to seize the time gap when the weather improves, quickly organize berthing operations, enhance berthing flexibility, and create more berthing opportunities; When working on water, timely organize berthing operations, strengthen berthing flexibility, create more production support needs for berthing docks, and relieve berthing pressure in the Jiangsu section of the Yangtze River. After berthing at full tide, while relieving the pressure of berthing at the wharf, effectively reducing the demurrage costs of port cargo owners and ship owners, and achieving win-win results, it has greatly guaranteed the demand for supply guarantee at the wharves in Jiangsu section of the Yangtze River, compressed the departure time of ships, and improved the efficiency of ship turnover.

3) The long-term period of the considered pilotage vessel quantity is 10 years, while the long-term period of shipping is generally 30 years. Due to the limited data collection of pilotage, the duration of the long-term period is limited. Further research will be conducted on the long-term and short-term periods of the pilotage vessel quantity in the future.

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