# Research on Construction and Application of Operation Efficiency Index of Inland Navigation Hub

**Xinyi Wu, Qiuwang Chen, Ruoxue Huang**
*Three Gorges on Yangtze River Navigation Administration, Yichang, Hubei, China*

**Abstract: The operation efficiency of inland navigation hub directly affects the transportation cost of water transport logistics. The traditional efficiency evaluation is based on the static data of freight rate and cost, which is difficult to realize the dynamic perception of the operation situation of navigation hub. Based on the dynamic data of inland river navigation operation, this paper constructs the inland river navigation operation efficiency index (TTEI), which includes four dimensions of ship dam-crossing efficiency, ship dam-crossing waiting time, dispatching plan execution and navigation capacity utilization, and carries out demonstration analysis with the actual navigation data. The study shows that the proposed operation efficiency index can effectively quantify the operation status of inland navigation hub, and provide a theoretical reference for navigation organization optimization, resource allocation and operation decision-making.**

**Keywords: Inland Navigation Hub; Waiting Time; Navigation Capacity; Operation Efficiency Index; Navigation Organization Optimization**

## 1. Introduction

Inland navigation hub is an important node of waterway transportation channel in inland river basin, and its operation efficiency is directly related to the economic and social development and logistics transportation cost along the inland river. Facing the development trend of ship traffic flow growth and strong transport demand, how to scientifically evaluate the operation status of inland navigation hub, identify the bottleneck of operation efficiency, and optimize the navigation scheduling organization has become the focus of the industry.

Around the transport efficiency evaluation and operation organization optimization, many researches have been carried out at home and abroad. Foreign researches mainly focus on ship operation efficiency and lock operation optimization. KALAJDŽIĆ M[1] The evaluation index system of ship energy efficiency is constructed, and the influence of water depth, velocity, draft and other factors on operation efficiency is analyzed. Milan Kalajdžić[2] By studying the navigation data of ship voyages and analyzing the actual navigation constraints of ships in each section, the inland river ship operation efficiency index (EEO) is proposed; GOLAK J[3] By collecting the AIS data of ships, the influence of the optimization of navigation hub dispatching organization on the operation efficiency is deeply analyzed. The research shows that the waiting time of ships passing through the lock can be effectively reduced by optimizing the navigation dispatching and the operation mode of ships passing through the lock. LIU J[4] Based on the fuzzy theory and data reasoning method, the safety of inland navigation ships is studied, and the safety evaluation model of inland navigation ships is constructed. Domestic research focuses more on the evaluation of the operational efficiency of navigation facilities. Jiang Jun[5] The comprehensive evaluation of the service level of inland navigation hub is carried out around the indicators of navigation service, reservation management and green low carbon, and the evaluation system of the service level of inland navigation hub under the reservation mode is constructed. Zhang Xiaorui[6] Wait, Wang Xuanshuang[7] Wait for Ling Yi[8] By using DEA model, three-stage DEA model and other methods, the efficiency evaluation of inland shipping and port operation is carried out, which provides a theoretical reference for the efficiency quantification of transportation system. Zheng Haotian[9] Based on the efficiency of overturning dam, the optimization of container multimodal transport scheme along the Yangtze River is studied, and the important influence of waiting time loss on transport efficiency is revealed. Qi Junlin[10] The navigation

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construction practice of the Three Gorges-Gezhouba cascade project is systematically summarized, which provides practical experience for the optimization of navigation organization and the improvement of navigation capacity of the project.

The existing studies provide a theoretical reference for the evaluation of the operation efficiency of inland navigation hub, but most of them focus on ports, shipping systems or single operation link, and lack of dynamic evaluation methods based on actual operation data. In view of the fact that the deviation of ship waiting time and dispatching plan implementation will directly affect the efficiency of ship turnover and increase the operation cost, this paper takes the inland waterway hub as the research object, and constructs the operation efficiency index of inland waterway hub from the aspects of ship efficiency, ship waiting time, dispatching plan implementation and navigation capacity, so as to realize the quantification of the operation status of inland waterway hub. And then provide a decision-making basis for that optimization of the ship dispatch organization.

## 2. Index Construction Method

### 2.1 Index Selection Principle

In the selection of operation efficiency index of inland navigation hub, the availability, representativeness and operability should be followed.

2.1.1 Accessibility

The selected index indicators shall be preferentially derived from the navigation dispatching management business system of the existing inland river navigation hub, such as the planned time for ships to pass through the dam, the actual time for ships to pass through the lock, etc., and it is necessary to ensure that the data sources of the selected index indicators are accurate, objective, complete and continuously updated, so as to reduce the workload of manual statistics.

2.1.2 Representativeness

The selected index can effectively reflect the core characteristics of the navigation efficiency of the inland river hub, focusing on the key links in the whole process of ship passing through the dam, and can reflect the operation status of the inland river hub from different dimensions. At the same time, a high degree of duplication or overlapping of information between indicators should be avoided.

2.1.3 Operability

On the premise of meeting the needs of index evaluation, we should try our best to control the number of index indicators, give priority to the selection of indicators with clear structure, simple calculation method and strong interpretation, and avoid building too complex index system. Considering the relatively limited sample size, the index system should have good operability.

### 2.2 Index System Construction

Combined with the operation characteristics of inland navigation hub and the availability of index data, the following four types of indicators are selected to construct the index system:

2.2.1 Dam passing efficiency index $E_1$

It is used to characterize the actual efficiency of ships passing through the hub, focusing on the matching degree between the time of ship scheduling plan and the actual time of ships passing through the dam. The dam-passing efficiency index can be established by measuring the actual dam-passing time, single gate passing time, planned time deviation rate and other indicators to reflect the matching degree between the ship dispatching plan time and the actual dam-passing time, which is defined as:

$$E_1 = \frac{T_{plan}}{T_{actual}} \tag{1}$$

The closer the index is to 1, the higher the efficiency of passing the dam is.

2.2.2 Wait Time Indicator $E_2$

It is used to characterize the congestion degree and delay level of navigation system, and reflect the time loss of ships in the process of waiting for the lock. Typical indicators include average latency, maximum latency, and latency dispersion. The waiting time index is established to reflect the waiting degree of the ship, and the average waiting time is transformed:

$$E_2 = \frac{1}{1+W} \tag{2}$$

Where W is the normalized average waiting time, and the longer the waiting time, the lower the index.

2.2.3 Plan implementation indicator $E_3$

It is used to characterize the consistency and stability of scheduling plan execution and reflect the deviation between the plan and the actual operation. It can be described by the planned fulfillment rate, time deviation and sequence deviation rate. Establish the plan implementation index, which is expressed by the plan fulfillment rate:

$$E_3 = \frac{N_{on-time}}{N_{total}} \tag{3}$$

This indicator reflects the stability of scheduling plan execution.

2.2.4 Navigation capacity utilization index $E_4$

It is used to characterize the utilization level of navigation resources and reflect the matching relationship between actual operation load and design capacity. It can be measured by the utilization rate of sluice chamber, the utilization coefficient of navigation capacity and the peak load rate. Establish a navigation capacity utilization index to reflect the utilization level of navigation resources:

$$E_4 = \frac{Q_{actual}}{Q_{capacity}} \tag{4}$$

### 2.3 Index Calculation Method

In order to realize the comprehensive evaluation of multiple indexes, the navigation operation efficiency index is constructed after the dimensionless treatment of each index:

$$TTEI = \sum_{i=1}^{4} W_i E_i \tag{5}$$

Where: $W_i$ Is the weight coefficient. Considering the importance of each index, the waiting time and dam-crossing efficiency directly reflect the navigation operation status and have a greater impact on the comprehensive efficiency, so they are given a higher weight. Plan execution and navigation capacity utilization mainly reflect dispatching management and resource utilization, and are given relatively low weights. Referring to the relevant research results of efficiency evaluation and combining with the practice of navigation management, it is determined that: $W_1 = 0.3, W_2 = 0.3, W_3 = 0.2, W_4 = 0.2$.

## 3. Empirical Analysis

### 3.1 Data Source and Sample Selection

The typical operation data of an inland river navigation hub is selected as the research sample, and the data comes from the navigation dispatching management system and operation statistical records. During the statistical period, 162 ships passed through the dam, which can fully reflect the daily operation status of the hub. In order to ensure the representativeness of the analysis results, the selected typical statistical days are free of equipment failure, bad weather, construction control and other special factors, and the operation process of the navigation hub can basically reflect the state under normal navigation conditions. According to the distribution of ship arrival time and the statistical results of navigation hub operation, the arrival of ships shows obvious characteristics of time aggregation, in which the arrival density is higher from 13:00 to 16:00, and the navigation pressure is relatively concentrated. In the rest of the period, the arrival of ships is more balanced. Therefore, the whole day is divided into non-peak hours (00: 00-12: 00, 16: 00-24: 00) and peak hours (13: 00-16: 00), and the indexes such as ship dam-crossing efficiency, ship dam-crossing waiting time, dispatching plan execution and navigation capacity are calculated respectively, and the navigation efficiency under different operation States is compared and analyzed.

### 3.2 Index Calculation Results

The statistical results of main indicators in each period are shown in Table 1:

**Table 1. Comparison of Typical Daily Peak and Flat Peak Navigation Operation Indexes**

| Time period | Average waiting time (min) | Planned fulfillment rate (%) | Capacity utilization (%) | Dam crossing efficiency Exponent E | Waiting time Exponent E E | Plan execution Exponent E | Capacity utilization Exponent E | TTEI |
|---|---|---|---|---|---|---|---|---|
| Ping Feng | 28 | 93 | 76 | 0.96 | 0.78 | 0.93 | 0.76 | 0.86 |
| Peak | 52 | 86 | 89 | 0.91 | 0.66 | 0.86 | 0.89 | 0.71 |

It can be seen from Table 1 that there are some differences among the indicators in different periods. During the peak period of inland navigation hub, the average waiting time of ships passing through the dam increases from 28 min to 52 min, an increase of about 86%, and the corresponding waiting time index of ships passing through the dam decreases from 0. 78 to 0. 66. The results show that the waiting time of ships passing through the dam is prolonged during the peak period. Influenced by the concentrated arrival of ships, the fulfillment rate of dispatching plan during peak hours decreased from 93% to 86%, the execution index of dispatching plan decreased by about 7%, and the deviation between the time of dispatching plan and the actual operation of ships increased. At the same time, the utilization rate of navigation capacity has increased from 76% to 89%, which shows that the navigation hub is in a high load operation state during peak hours. Influenced by the increase of ship waiting time and the

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increase of deviation in the implementation of dispatching plan, the operation efficiency index of inland navigation hub decreased from 0.86 to 0.71, a decrease of about 17%, reflecting that the operation efficiency of navigation hub in peak hours is lower than that in non-peak hours.

### 3.3 Analysis of Influencing Factors

In order to further analyze the impact of each index on the operation efficiency of inland navigation hub, the contribution rate is calculated according to the variation and weight of the index, and the results are shown in Table 2.

**Table 2. Analysis of the Contribution of Each Index to the Decline of the Operation Efficiency of the Inland Navigation Hub**

| Indicators | Exponential change | Weight | Weighted variation | Contribution rate (%) |
|---|---|---|---|---|
| Dam passing efficiency E | -0.05 | 0.3 | -0.015 | 23.1 |
| Waiting time E E | -0.12 | 0.3 | -0.036 | 55.4 |
| Plan to execute E | -0.07 | 0.2 | -0.014 | 21.5 |
| Ability to utilize E | 0.13 | 0.2 | 0.026 | — |

Note: The contribution rate is calculated according to the proportion of each negative weighted change to the total negative change.

It can be seen from Table 2 that the contribution rate of the decrease of the waiting time index of ships passing the dam to the decrease of the operation efficiency of the inland navigation hub is about 55.4%, which is the primary factor affecting the operation efficiency of the navigation hub. The contribution rates of dam-crossing efficiency and dispatching plan execution index are about 23. 1% and 21. 4%, respectively, indicating that the operation organization and dispatching plan execution also have a greater impact on the operation efficiency of the navigation hub. Although the utilization rate of navigation capacity during peak hours is high, its positive effect fails to offset the negative impact of the increase in waiting time.

On this basis, the mechanism of each influencing factor can be further analyzed:

(1) The waiting time of ships passing through the dam is the primary factor affecting the navigation efficiency. The waiting time index decreased the most, and the contribution rate to the decrease of the operation efficiency of the inland navigation hub reached 55. 4%, indicating that the operation efficiency of the inland navigation hub is highly sensitive to the change of congestion.

(2) The execution deviation of the scheduling plan has a magnifying effect. The contribution rate of plan execution index is 21.5%, although the decline is relatively limited, it will aggravate the imbalance of ship queuing, further prolong the waiting time of ship crossing the dam, and have a superimposed impact on the operation efficiency of inland navigation hub.

(3) The index of dam-crossing efficiency decreases by 0. 05, and the contribution rate to the decrease of the operation efficiency of the inland navigation hub is 23. 1%, which indicates that the efficiency of dam-crossing dispatching organization during peak hours is different from that during non-peak hours, and has a certain impact on the operation efficiency of the inland navigation hub.

(4) The utilization of the traffic capacity of the navigation hub has the characteristics of marginal decline. The utilization rate of navigation capacity of the navigation hub during peak hours has increased from 76% to 89%, indicating that the navigation resources have been fully utilized. However, from the change of the operation efficiency index of the inland navigation hub, the improvement of the utilization level of the capacity of the navigation hub can not offset the impact of the increase of the waiting time for ships to cross the dam and the expansion of the deviation in the implementation of the dispatching plan, and the operation efficiency index of the inland navigation hub still decreases by about 17%, indicating that under the condition of higher operation load, the improvement of the operation efficiency of the inland navigation hub is facing certain constraints.

## 4. Optimization Recommendations

Combined with the analysis results of the operation efficiency index of inland navigation hub, the optimization should focus on the key factors affecting the operation efficiency of navigation hub.

(1) Optimize the ship arrival structure. Combining with the law of ship arrival time and the ability to cross the dam, we should control the source of dispatching plan in advance, rationally compile the planning framework of

each period, reduce the phenomenon of centralized arrival of ships, and reduce the risk of congestion during peak periods.

(2) Strengthen the dynamic scheduling mechanism. Relying on the real-time operation data of inland river navigation hub gates, a rolling correction mechanism is established to dynamically adjust the dam-crossing plan, improve the consistency of plan implementation, and reduce the delay of fleet gear caused by the accumulation of deviation.

(3) Implement differentiated navigation organization. According to the characteristics of ship type, cargo type and operation, classified dispatch and hierarchical organization are implemented to improve the matching efficiency of navigation resources.

And (4) establish a waiting time monitor index. Taking waiting time as an important index for navigation efficiency evaluation, normal monitoring and analysis are carried out to find out operation bottlenecks in time and provide basis for dispatching decision-making.

## 5. Conclusion

(1) Based on the operation data of the inland waterway hub, the operation efficiency index model of the inland waterway hub is constructed, which covers four dimensions: ship dam-crossing efficiency, ship dam-crossing waiting time, dispatching plan execution and navigation capacity utilization, and realizes the quantitative evaluation of the operation status of the inland waterway hub.

(2) The analysis of typical operation days shows that the comprehensive efficiency index in peak hours is about 17% lower than that in non-peak hours, and the increase of waiting time and the expansion of plan execution deviation are the main reasons for the decline of efficiency.

(3) The operation efficiency index of inland river navigation hub can reflect the change of hidden time cost in the operation of navigation hub, and can be used as an important tool to evaluate the operation status of navigation hub, optimize the dispatching organization and assist decision-making.

(4) Based on the operation data of large samples of inland navigation hubs, the index weighting method such as entropy weight method can be used to further improve the index system and build a dynamic monitoring and early warning mechanism for the operation efficiency of inland navigation hubs.

## References

[1] KALAJDŽIĆ M, VASILEV M, MOMČILOVIĆ N. Evaluating an Inland Waterway Cargo Vessel's Energy Efficiency Indices. Pomorski zbornik, 2022, 61(1): 141-156.

[2] Milan Kalajdžić. Matija Vasilev. Inland Waterway Cargo Vessel Energy Efficiency in Operation. Brodogradnja, 2023, 74(3): 304-316.

[3] GOLAK J, GRIGORIEV A, VAN LENT F, et al. Optimizing Periodic Operations for Efficient Inland Waterway Lock Management.

[4] LIU J, JIANG X, HUANG W, et al. A Novel Approach for Navigational Safety Evaluation of Inland Waterway Ships under Uncertain Environment. Transportation Science and Economics, 2022, 5(1): 87-102.

[5] Jiang Jun, Li Huomei, Yin Hong, et al. Service Level Evaluation of Inland Navigation Hub Considering Carbon Emission under Reservation Mode . Water Transport Engineering, 2025.

[6] ZHang Xiao-rui, ZHENG Tian-bao, LIU Yang. Efficiency Evaluation and Promotion Strategy of Inland River Shipping Development in Anhui Province . Journal of Global Environmental Science, 2025, 29 (7): 1-15.

[7] Wang Xuanshuang, Liu Mingwu, Lin Gang. Research on the Efficiency of Inland River Container Port Based on Three-stage DEA . Port Science and Technology, 2021.

[8] Ling Yi. Evaluation of Inland River Shipping Efficiency in Guangdong Province Based on Three-stage DEA Model . Water Transport Management, 2022.

[9] ZHENG Haotian. Research on optimization of container multimodal transport scheme along the Yangtze River based on dam-turning efficiency. Integrated Transport, 2024.

[10]Qi Junlin, Chen Dongyuan, Li Ran. Innovation and Practice of High Quality Navigation of Three Gorges-Gezhouba Cascade Project in 20 Years. China Navigation, 2023 (7): 55-67.

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