Research on Flexible Transshipment Technology for River-Sea Intermodal Transport

Guoqing Huang, Jing Li

China Waterborne Transport Research Institute, Beijing 100088, China

Abstract

This study investigates transshipment technology schemes for river-sea intermodal transport of different cargo types in China, summarizes the characteristics and applicability of various transshipment technologies, and proposes a flexible technology scheme capable of responding to shocks from changes in cargo types and volumes as well as adapting to different vessel types. Furthermore, corresponding response strategies are proposed to mitigate disruptions arising from various external factors, including changes in transport volume, cargo types, and vessel types.

Keywords

River-sea intermodal transport, transshipment scheme, flexible handling technology, response strategy.

1. Introduction

In modern transportation systems, both maritime transport and inland waterway transport occupy crucial positions and play irreplaceable roles. As a major waterborne transportation country, China achieved an inland waterway freight volume of 4.95 billion tons in 2024, which was 2.2 times that of 2012, with a cargo turnover of 2.2 trillion ton-kilometers. Meanwhile, maritime transport completed a freight volume of 4.577 billion tons and a cargo turnover of 10.917898 trillion ton-kilometers. Among these figures, the river-sea intermodal transport volume of the Yangtze River trunk line reached 1.56 billion tons, accounting for approximately 40% of the total transport volume of the Yangtze River trunk line, indicating a steady growth trend in river-sea intermodal freight volume. Concurrently, China is optimizing and upgrading the national waterway network and accelerating the construction of a national comprehensive three-dimensional transportation network. Multiple canal projects are under planning and implementation, which will directly connect the inland waterway network with maritime shipping. Notably, the Pinglu Canal is expected to be fully navigable in September 2026.

2. Related Research on River-Sea Intermodal Transport Transshipment

Against this background, research on the layout and technology of river-sea intermodal transport has become a prominent focus in China in recent years. Yao Haiyuan et al. from the Planning and Research Institute of the Ministry of Transport comprehensively considered the river-sea intermodal transport volume of the Pinglu Canal, the port construction conditions and resource capacity of each port area in Beibu Gulf Port, as well as the utilization status of existing port resources. In accordance with the principle of "nearby transshipment and full utilization of existing resources", they proposed a cargo-specific layout of river-sea intermodal transport hubs tailored to local conditions and formulated a layout plan featuring matched capacities of large and small berths and efficient transportation organization. Li Xiaochong from CCCC Fourth Harbor Engineering Investigation and Design Institute Co., Ltd. conducted research on the layout optimization of river-sea intermodal transport in Qinzhou Port under the background of the Pinglu Canal. Liu Shengyou from Guangxi Beibu Gulf International Port

Group Co., Ltd. determined the main cargo types and flow directions of the Pinglu Canal based on an economic comparison of routes in various regions and predicted the river-sea intermodal transport volume during the planning period. Du Jian et al. from Dalian Jiaotong University conducted research on the path optimization of multimodal transport under dual uncertainties of transportation demand and time, suggesting that rail-water intermodal transport can enhance the robustness of the entire transportation scheme [1-4].

Although extensive research has predicted the future transport volume of the Pinglu Canal and carried out planning, layout, and process design for river-sea intermodal transport terminals, cargo types, volumes, and transportation time may change with macroeconomic policies, domestic and foreign market demand, industrial restructuring, and climate conditions, resulting in significant uncertainties[5]. When facing shocks from changes in cargo types and volumes, river-sea intermodal transport terminals should be equipped with flexible and adjustable handling technology schemes to respond effectively.

3. Application Cases of Domestic River-Sea Intermodal Transport Technologies

Provinces along China's coasts and rivers have formed their own characteristics and advantages in exploring river-sea intermodal transport development models and determining loading and unloading technologies, due to differences in transport volume, cargo types, routes, and port area layouts.

3.1. Cases of River-Sea Intermodal Transport in Nanjing

In Nanjing Xinshengwei Port Area, the river-sea intermodal transport mainly adopts two modes:

(a)Sea vessel berths and river vessel berths are adjacently arranged on the same side. After a sea vessel berths, a portal crane with a grab bucket is used for unloading, and the cargo is directly loaded onto river vessels via belt conveyors. This mode is mainly applicable to bulk cargo with low metering requirements that can be measured by ship draft, such as coal and iron ore. For cargo requiring more precise metering, an additional truck transshipment and weighing link is added. After weighing, the cargo is unloaded into the material pool of the river vessel terminal, and loading operations are then carried out from the pool, such as in the case of copper concentrate river-sea intermodal transport.

Fig. 1 Adjacent arrangement of river and sea berths on the same side, with transshipment via trucks before loading

Fig. 2 Non-adjacent arrangement of river and sea vessel berths, with loading and unloading connected via belt conveyors

(b)Sea vessel berths and river vessel berths are non-adjacently arranged on the same side. After a sea vessel berths, a portal crane with a grab bucket unloads the cargo, which is then directly transported to the river vessel berth via belt conveyors or into silos (or yards) before loading operations are conducted. This mode is mainly used for grain-related operations.

3.2. Cases of River-Sea Intermodal Transport in Zhejiang

Zhoushan Port Transit and Storage Co., Ltd. mainly handles bulk cargo such as iron ore, grain, and coal, with three main river-sea intermodal transport modes:

(a)Large-tonnage sea vessel berths and river-sea through vessel berths are arranged on both sides of the same terminal, adopting the "water-to-water" direct loading and unloading mode. This mode improves scheduling efficiency through expedited berthing and departure, allowing large ships to enter the river directly after unloading a certain volume of cargo.

(b)Large-tonnage sea vessel berths and river-sea through vessel berths are arranged on the same side of the terminal. After a sea vessel unloads, the cargo is transported to the river vessel berth via belt conveyors, and ship loaders are used for loading river vessels.

(c)After a sea vessel unloads, the cargo is directly transported to yards or silos via belt conveyors, and loading operations are arranged subsequently according to the schedule of river vessels.

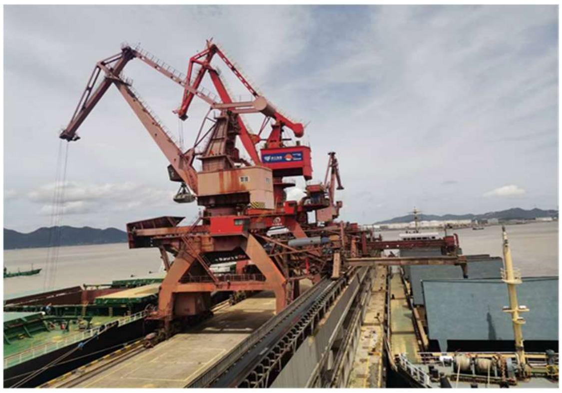

Fig. 3 Arrangement of river and sea berths on both sides, with direct loading and unloading

3.3. Cases of River-Sea Intermodal Transport in Guangzhou

As the world's largest fully automated terminal with a horizontal layout, Nansha Phase IV Terminal is capable of simultaneously operating 4 large ships and 16 barges, adapting to multimodal transport operation modes. In addition, the under-construction Nansha River-Sea Intermodal Transport Terminal is located in the river-sea intermodal transport operation area of the Nansha Port Area, as an independently planned and constructed barge area for river-sea intermodal transport. Its "transshipment from large ships to small ships" river-sea intermodal transport operations adopt an excavated basin layout, which increases the number of available berths.

Fig. 4 River and sea vessels berthing on the same side at Nansha Phase IV Fully Automated Terminal, with transshipment via the front yard

3.4. Other Cases of River-Sea Intermodal Transport

In some regions with backward terminal infrastructure, offshore transshipment technologies including transshipment platforms, floating crane transshipment, and ship-borne crane transshipment-are adopted to address issues such as insufficient water depth in river-sea unloading areas and inadequate port berths. Among these, large offshore transshipment platform ships are similar to offshore mobile terminals; after berthing, they can conduct continuous loading and unloading operations throughout the process without shifting or waiting. These platforms enable the transfer of bulk materials from sea vessels to river vessels via belt conveyor systems for inland transport, or from river vessels to sea vessels for ocean transport.

Fig. 5 Transshipment operation of large offshore transshipment platforms

4. Comparative Analysis on the Adaptability of River-Sea Intermodal Transport Technologies

River-sea intermodal transport cargo transshipment technologies can be categorized into three types based on operation location and whether they rely on a rear yard: offshore transshipment, terminal frontage transshipment, and rear-yard-based transshipment. Terminal frontage transshipment, essentially the "direct loading and unloading" mode, can be further divided into "double alongside berthing", "same-side alongshore berthing", and "both-side berthing".

Among these, double alongside berthing and both-side berthing can be directly operated using general loading and unloading equipment, while same-side alongshore berthing requires secondary transshipment via horizontal transportation. In contrast, rear-yard-based transshipment is more flexible: cargo is generally transported to the rear yard via mobile machinery or belt conveyors, and after storage and retrieval, it is transported back to the frontage for loading operations.

The "direct loading and unloading" mode, with fewer processes, is obviously superior to the "rear-yard-based transshipment" mode. However, when there is a significant difference in transport volume between large and small ships, efficient matching between unloading and loading is difficult due to the ship shifting times, which results in reduced efficiency when the transport volume difference between river and sea ships is substantial. In contrast, the "rear-yard-based transshipment" mode can utilize the yard as a buffer for large transport volumes; through efficient systematic or automated operations, it can complete the loading and unloading of large ships in the shortest possible time, thereby improving overall berth utilization.

Due to fewer equipment involved, the "double alongside berthing" and "both-side berthing" modes under the "direct loading and unloading" category have advantages in energy consumption and environmental protection. The same-side alongshore berthing mode under "direct loading and unloading" relies on belt conveyor or truck transshipment, which is prone to cargo damage and pollution. The "rear-yard-based transshipment" mode involves more horizontal and vertical transportation as well as additional transshipment links, leading to inevitably higher unit energy consumption and emissions.

Fig. 6 Container loading and unloading operation under "double alongside berthing"

"Both-side berthing" enables direct transshipment operations through the outward-extending arms of loading and unloading machinery on both sides, which is commonly used in the arrangement of both sides of pier terminals or terminals extending into deep-water areas. However, since some goods require customs clearance and inspection, this mode necessitates support from relevant management departments for import and export goods.

The "both-side berthing" with "rear-yard-based transshipment" mode can combine the efficient operation of "direct loading and unloading" with the buffer advantage of "rear-yard-based transshipment", making it an ideal process mode when terminal conditions permit.

5. Flexible Technology Scheme for River-Sea Intermodal Transport

5.1. Flexible Technology Responding to Changes in Transport volume

Based on the aforementioned technologies, a modular flexible technology can be established to address the uncertainty of transport volume changes. Combined with on-site resource conditions, actual cargo types, and transport volume, an economically reasonable flexible technology combination can be determined.

For example, when adopting berthing operations on both sides of the terminal, part of the materials can be stored in the rear yard, while the other part can be directly routed to the loading side for river vessel loading operations, by switching the material flow direction at the intermediate transfer station for diversion.

Under this condition, the combined technology of " grab ship unloader + belt conveyor + yard stacking and reclaiming + belt conveyor +mobile ship loader" can be adopted. Utilizing the yard as a buffer, this combination can handle large-flow river-sea intermodal transport operations, it can also support multimodal transport operations such as truck and train loading.

When the transport volume is properly matched and small ship scheduling is within a controllable range, the combined technology of " grab ship unloader + belt conveyor + transfer station process switching + multiple groups of mobile ship loaders " can be employed. In this scenario, goods are transported horizontally in reverse at the transfer station near the terminal, and materials are supplied to multiple ship loaders through multi-point unloading technologies such as plough unloaders, thereby achieving an approximate "direct loading and unloading" operation mode. When transport volume changes, switching between the two modes can be implemented.

Fig. 7 Flexible operation technology responding to changes in transport volume

5.2. Flexible Technology Responding to Changes in Cargo Types

Technologies with good compatibility for cargo type changes include grab ship unloading, belt conveyor transshipment, heavy truck transshipment, and mobile ship loading technology.

For instance, the technology combination of "portal crane grab unloading + environmental protection mobile hopper + electric truck transshipment with tire-type mobile ship loader" can effectively meet river-sea intermodal transport operations between different berths. After implementing effective environmental protection and spillage control measures, the mode of multiple parallel unloading/ loading groups can flexibly respond to various changes in cargo types.

When belt conveyors are used in river-sea intermodal transport to replace heavy truck transportation, the adaptability of belt conveyors to different cargo types must be considered. Particularly in the transfer link process, the design of the transfer station should be compatible with the material characteristics of different cargo types to ensure the normal operation of the conveyor system after material switching. When necessary, key operating parameters such as belt speed and transport volume should be controlled.

If the supply of a certain cargo is insufficient in the short term and periodic switching to another cargo is required, a fixed process flow should generally not be established; instead, a technology combination with good compatibility for cargo type changes should be adopted.

Fig. 8 Flexible operation technology responding to changes in cargo types

5.3. Flexible Technology Responding to Different Vessels

In addition, with the widespread application of bulk-to-container technology, bulk cargo can be transported not only in the "bulk-in-bulk-out (BIBO)" mode but also in the "bulk-in-container-out (BICO)" mode. The modular flexible technology can also accommodate operations involving both bulk carriers and container ships in river transport.

Fig. 9 Flexible operation technology responding to different vessels

For example, in bulk grain transportation, relying on the silo system, after sea vessel unloading and silo turnover, bulk grain can be simultaneously loaded onto ships and containers during external delivery. The corresponding technology combinations are as follows:

(a)"Pneumatic grain suction machine + air-cushion belt conveyor + silo system + swing-type ship loader", which realizes the "bulk-in-bulk-out" operation of unloading large sea vessels and loading small river vessels.

(b)"Pneumatic grain suction machine + air-cushion belt conveyor + silo system + bulk-to-container conversion + container trailer + rail gantry container loading", which realizes the "bulk-in-container-out" operation of unloading large sea vessels and loading small river vessels.

When inland goods need to be concentrated at seaports for loading large ships, the flexible technology combination of "multiple groups of belt-type portal cranes + belt conveyors + transfer station/yard + multiple groups of ship loaders" can be adopted. Since multiple loading and unloading equipment can operate in parallel on both the river and sea sides, and the involved port machinery can be flexibly deployed and transferred, this combination not only matches small river vessels well but also can specifically meet the loading and unloading requirements of large vessels.

6. Conclusion

One of the key advantages of river-sea intermodal transport is its integration of the low cost and large volume of inland waterway transport with the long distance and wide network of maritime transport, thereby optimizing transportation time and efficiency and realizing network coverage and regional linkage. As the core link connecting upstream and downstream, river-sea intermodal transshipment port areas must promptly respond and adjust to changes in upstream and downstream sectors, whether facing periodic changes caused by uncertain factor disturbances or related industrial adjustments. When planning the layout of river-sea intermodal transport, fully considering the flexible matching of loading and unloading technologies with factors such as transport volume, cargo types, and vessel types can enhance the reliability of the river-sea intermodal transport technology system in responding to uncertain risks.

Acknowledgments

The authors acknowledge support from the Guangxi Special Fund Project for Innovation-Driven Development (Grant No. Gui Science AA23062021).

References

[1] Yao, H., Li, L., Hu, Y., Chen, Z., Sun, P., Feng, H., & Jin, Z. (2024). Research on the river-sea intermodal transport scheme of Beibu Gulf Port for the Pinglu Canal. Port & Waterway Engineering, 2024(9), 14–19.

[2] Li, X. (2024). Layout optimization of river-sea intermodal transport in Qinzhou Port under the background of the Pinglu Canal. Port & Waterway Engineering, 2024(8), 21–25.

[3] Liu, S. (2025). Research on the volume prediction of river-sea intermodal transport of the Pinglu Canal. Pearl River Water Transport, 2025(6), 83–85.

[4] Ning, W. (2023). Discussion on the construction concept and scheme of the Pinglu Canal. Hydro-Science and Engineering, 2023(5), 162–168.

[5] Du, J., Yang, Y., Zhang, R., et al. (2026). Research on Multi-Modal Transport Path Optimization under Dual Uncertainties of Transportation Demand and Time. Journal of Dalian Jiaotong University, 2026(2), 26–37.