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RESEARCH ON ONE-WAY CHANNEL CONVERSION STRATEGY OF COASTAL PORTS BASED ON SYSTEM SIMULATION

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ABSTRACT

The waterway is the necessary passage for ships to enter and leave the port. From the perspective of cost, many coastal port channels are one-way channels, it alternates as an inbound channel and an outbound channel. The one-way channel conversion strategy refers to when it is used as an inbound channel and when it is used as an outbound channel. By constructing a simulation model, this paper simulates the one-way channel conversion strategy that uses a fixed time period conversion, a conversion considering a certain number of outbound ships, and a conversion with the combination of time and number of outbound ships to achieve the best state of the port's overall operations. By comparing the port service level, traffic capacity of waterway, ships waiting time and other indicators, a one-way channel conversion strategy suitable for port operations is recommended.

Key words: One-way Channel, Conversion strategy, Port Operation, System Simulation.

1. INTRODUCTION

In recent years, with the development of economy and trade, port construction under high demand has gained a new development opportunity. At present, port construction is gradually becoming saturated. With gradually complete of port hardware facilities, under the new situation, the focus of port construction has shifted from whether infrastructure exists to how to improve the overall operation level of the port, and more attention has been paid to how to improve the port service level, throughput capacity of channel and other indicators. It brings new opportunities for port development.

At present, most of the research focuses on improving the level of port service, throughput capacity of channel, improving the navigation efficiency of ships, reducing waiting time and other indicators. Construct ship scheduling optimization model, or use system simulation method to simulate the whole process of ship entering or leaving the port under different conditions, and provide suggestions for the development of relevant waterways. On the construction of ship scheduling optimization model, Zheng(2018), aiming at minimizing the total waiting time of incoming ships, constructs a mixed integer linear programming model and designs a hybrid algorithm combining heuristic rules with simulated annealing algorithm to solve the problem. Wang(2014), designed a multi-objective genetic algorithm based on one-way channel ship scheduling optimization, which provides theoretical support and key technology for integrated scheduling of port ships. Zhang(2018), analyzed the difficulties of ship scheduling in one-way, two-way and compound channels, an optimization model of ship scheduling in one-way channel was established, which reduced the conversion of the channel and the total scheduling time. Xu(2009), based on the information provided by ship-borne AIS related to the safety of ships' passage, takes the main factors such as berth distance, ship size, ship type, draught and other sub-factors as the weights, and puts forward the optimal sequencing mode for ships entering and leaving ports in one-way waterway.

In the aspect of using system simulation method to construct ship port channel simulation model, Ning(2008), using arena simulation software, constructed a simulation system of port ship operation, comparing the throughput of port route theory with that of simulation. Zhang(2009), constructed the simulation model of the ship's inbound and outbound operation system of one-way channel in bulk port area based on different inbound and outbound rules, compared and analysed the effects of different rules on channel capacity under different conditions, and explored the contribution of different rules of inbound and outbound to throughput capacity of one-way channel. Liu (2014), analyzing the effects of first come first service rule, large vessel priority service rule and ship clustering navigation rule on port service level by using computer simulation technology and building a simulation model of ship navigation operation system. Song (2012), defined the weighted average of ship tonnage to port as the characteristic tonnage of ship type combinations, and the influence of ship type combinations on port channel capacity is studied. Guo (2011), Using Arena simulation software to build a model to study the influence of safe time interval on the passage capacity of coastal bulk port area under different conditions.

Most of the research focus on the optimization of ship scheduling and navigation rules, which improves the operation level of ports in one-way navigation environment. Most of the research on ship scheduling in one-way navigation channel are based on the construction of ship scheduling optimization model, which solves the

problem through optimization algorithm. The model of ship's inbound and outbound operation based on system simulation is built, and the influence of different navigation rules on channel capacity is obtained.

On the basis of the former research, this paper considers the ship scheduling problem under the conversion of one-way channel. Under the restriction of one-way channel, the ship entering and leaving port usually needs to consider how to convert the channel at a certain stage to make the ship's traffic flow smoothly. Under the changeable rules of ship arrival and departure, the port dispatcher is required to convert the channel reasonably. It is of great value to study how to convert one-way channel reasonably and efficiently, to ensure that ships arrival on time for loading and unloading, to arrange the next voyage on time for departure.

2. ANALYSIS ON THE PROCESS OF SHIP'S INBOUND AND OUTBOUND OPERATION AND EVALUATION INDEX UNDER ONE-WAY NAVIGATION

2.1 Analysis of ship's inbound and outbound operation process under one-way navigation

The process pf ship's inbound and outbound operation in one-way channel and operation in port can be divided into :ship's arrival, anchorage waiting, condition judgment for entry, navigation in channel, arrival berth, auxiliary operation, loading and unloading operation, departure operation and ship departure. There are differences in ship's tonnage, ship's type, cargo loading and unloading type, berth demand, ship's behavior characteristics and so on. It is necessary to conduct comprehensive and meticulous operation process analysis for different ships. After arrival, the ship waits for entry at the anchorage outside the harbour. In the process of waiting for anchorage, the weather conditions, tide level of ships, whether the channel is empty, whether it is in the one-way channel converting stage, whether it meets the safe time distance with the front ship and so on are judged respectively. After satisfying all the judgement conditions, the ship enters the channel, sails into the harbour and arrives at the berth. Carrying out loading and unloading operations, after the completion of loading and unloading operations to meet all similar conditions of departure before leaving, release berth, leave the port for the next voyage operation.

2.2 Evaluation index

Aiming at the impact of conversion strategy scheme on the whole port, this paper adopts port service level as an evaluation index. The port service level (AWT/AST) directly reflects the degree of service received by ships. AST indicates the average time of ships which required for loading and unloading in a port under normal conditions. The AWT indicates the average waiting time of the ships. AWT/AST reflects the proportion of waiting time to berth operation time. The better the service level of the port, the better the service of the ship and the reasonable utilization of the resources in the port.

Aiming at the influence of conversion strategy scheme on ships, this paper introduces the average waiting time of ships as an evaluation index. The average waiting time of ships is divided into waiting time of ships for waterway and waiting time of ships for berthing. The waiting time of ships for berthing refers to waiting time due to the lack of reliable berthing, which reflects the waiting time period. The matching relationship between the berth and the arriving ship shows that the longer the waiting time is, the more tense the berth is, the shorter the waiting time is, the lower the cost of the ship and the better of the economy. The longer the waiting time is, the more congestion the current traffic is. In this paper, the waiting time of large ships under the influence of conversion strategy is also considered, and the waiting time of large ships is introduced as one of the evaluation indexes.

3. ONE-WAY CHANNEL CONVERSION STRATEGY

In port operation, the ship dispatcher monitors the state of ships entering and leaving the port and the operation process in real time. Judging the flow direction of inbound and outbound channel ships, which gradually forms an empirical value for the work of converting the flow direction of inbound and outbound under the heavy workload. However, under the influence of uncertain factors, the conversion of one-way channel can not be achieved by relying on the empirical value alone, and unreasonable conversion strategy will make the waiting time of ships too long, the service level of the whole port decreases, and the throughput capacity of channel decreases. Based on the above problems, this paper proposes three conversion strategies for one-way channel.

3.1 Scheme 1: One-way channel conversion strategy according to fixed time

Converting the one-way channel according to the fixed number of hours. For port dispatchers, this conversion mode is based on the accumulated experience of a certain amount of work. When the law of ship's arrival is known According to the arrival time of ships, a reasonable fixed conversion time can be deduced as a method of converting one-way channel periodically to allow different traffic flows to carry on the traffic. Converting according to fixed time can make the port dispatching easy to manage. Under this converting decision, the number of ships in formation does not take into account the inbound or outbound flow direction. However, when the converting time is too long and the number of ships passing through the waterway is small, it is easy to form the situation that the waterway is idle and still open to navigation, resulting in the reduction of waterway utilization rate and the long waiting time of the opposite ships.

3.2 Scheme 2: One-way channel conversion strategy based on the number of outgoing vessels

Converting the one-way channel according to the number of ships coming out of port formation. This plan focuses on the number of ships coming out of the port formation. Under the navigable condition of ships with normal

inbound and outbound directions, when the ship's operation in the port has been completed and meets the conditions of departure and in the state of imminent departure, it will become one of the fleet ships to depart from the port. When the number of ships in the departure formation accumulates to a certain number, the converting channel is in the state of departure navigation. This scheme considers that in the case of limited resources in the harbour, ships that have completed berthing operations are still waiting for departure from the harbour, and excessively use of resources in the harbour results in unreasonable utilization of resources and delays caused by the inability of incoming vessels to obtain berthing resources in time. In order to improve the utilization rate of resources in port and enhance the function of port service, this paper adopts the rule of priority of departure for outgoing ships. Priority rules for departure form the core of this scheme. However, considering the idea of priority for ships leaving the port formation, in the case of extremely number of ships arriving at the port, the "critical value" of ships leaving the port formation is too small to form a single channel state for too long, resulting in large waiting time for ships to depart and unreasonable control of channel converting time in the continuous state of departure. The changeover of converting time is not fixed, which will affect the waiting time of ships and may result in poor overall navigation condition of waterway.

3.3 Scheme 3: One-way channel conversion strategy considering converting time and number of outgoing vessels

Under one-way navigation, the conversion strategy considering the combination of converting time and the number of fleets of ships leaving port is proposed. Based on the analysis of the two conversion strategies, considering the converting time or priority of departure, the number of ships leaving the port formation is slightly thin. Therefore, scheme 3 combines the number of ships leaving port with the converting time to form a comprehensive conversion strategy. Under this conversion strategy, we can simultaneously pay attention to the converting time and the number of fleets of ships which leave the port, and synthetically analyze the optimal converting strategy, so as to make the port and channel state optimally, make the waiting time of ships shortest, and improve the level of port service. Based on the above three decision-making schemes, the simulation models of ship's inbound and outbound and inbound operations are established by means of system simulation, and the one-way channel converting operation flow under the three decision-making schemes is simulated respectively.

4. ESTABLISHMENT OF SIMULATION MODEL FOR SHIP'S INBOUND AND OUTBOUND AND OPERATION IN PORT.

System simulation is widely used in various fields as a safe, economical, controllable and efficient technical means. Anylogic simulation software is used to build simulation models. Anylogic is a simulation tool for modeling discrete events, system dynamics, multi-agent and hybrid systems. Its object-oriented modeling characteristics and visual development are discussed. The environment makes the modeling operation convenient and concise. The channel simulation model in this study is based on discrete event simulation under anylogic system. The simulation model of ship's inbound and outbound and operation in port under one-way navigation based on anylogic system simulation is established.

The simulation model established in this paper can be divided into: ship generation sub-module, anchorage waiting sub-module, entry judgment sub-module, ship navigation sub-module, ship operation sub-module, departure judgment sub-module. Six sub-modules constitute the whole process of ship entry and exit and operation in port under one-way navigation.

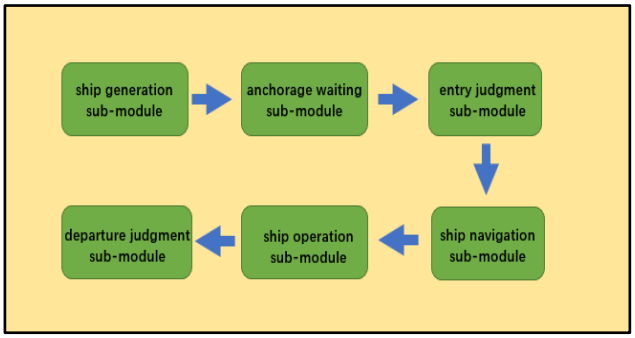

Figure 1. The whole process simulation sub-module of ship entry and exit and operation in port under one-way navigation

Ship Generation Sub-module: Generate ship entity resources, simulate ship's arrival process, and input ships' parameters in ship generation module, including: ship attributes, ship's arrival rules and other actual ship-related data.

Anchorage waiting sub-module: In order to allocate berth resources for the generated ship resources, berth allocation is carried out by flexible berthing, and berth resources are occupied by ships.

Entry judgment sub-module: Judgment of various conditions for ship resources, It is necessary to judge the wind, current and extreme weather before actual ships enter the harbour. For large ships or special ships, it is necessary to judge whether the tide level meets the requirements of the harbour entry. Based on the particularity of the ships which need to tide riding, the rule of tide priority is introduced into the sub-module. After satisfying the natural conditions, it is necessary to judge the phase of one-way channel converting. The three conversion decision-making schemes proposed above will be added to the judgment module for multiple simulations. When the ship is in the entry stage of one-way channel converting, it can enter the port. Otherwise, the ship should wait. Finally, the condition of collision avoidance is judged. The distance between the vessel and the front vessel must meet the safety distance before entering the channel.

Ship navigation and ship operation sub-module:

After satisfying the judgment of the entry conditions, the vessel sails in one-way channel according to the

corresponding navigation time and enters the corresponding berth in the port to carry out the loading and unloading operation.

Departure judgment sub-module: After the completion of berth operation, it is necessary to judge whether the berth meets the exit conditions before leaving the port. The judgment of the exit conditions is similar to the judgment of the entry conditions.

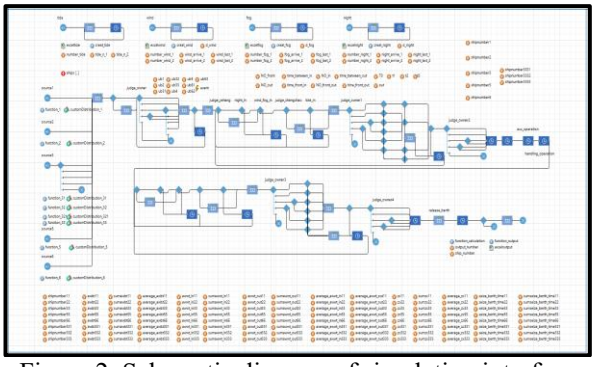

Figure 2. Schematic diagram of simulation interface

5. CASE STUDY

This paper chooses a coastal port and waterway as an analysis. The port area has multi-port and multi-junction points. Because of environmental restrictions and other factors, the one-way navigation rules are adopted. As shown in Figure, this paper establishes the whole process simulation of ship's inbound and outbound and operation in the port under one-way navigation. The conversion strategies are simulated separately, and the relevant evaluation indexes under the three conversion strategies are compared.

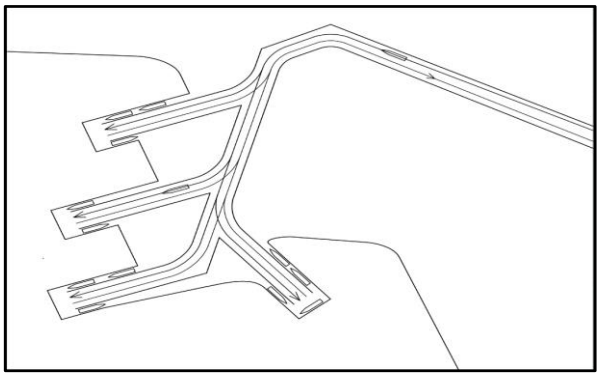

Figure 3. Schematic diagram of one-way traffic flow in a port area

5.1 Parameter selection

The data of a certain harbor basin is selected as input parameters and input into the model. The data include the number of ships arriving at the harbor, the types of ships arriving at the harbor, the speed of ships, the time of ships sailing and loading and unloading time, the time interval of ships arriving at the harbor which obeys Poisson distribution, etc. Input natural condition data, including extreme weather time and tidal value in the harbor. Input berth data, including berth attributes, berth number and so on. The rules of navigation, tide priority, ship departure priority and first come first serve should be determined.

Table 1. Simulation Model Input Parameters

Name of input parameters	Input parameter values
Ship's tonnage	The tonnage of ships is between 1,000 tons and 50,000 tons, and the ships are mostly around 10,000 tons.
Types of ship's cargo	All incoming goods are summarized in 8 categories , such as petroleum, natural gas and products, liquid chemical products, wood, mining materials, vehicles, containers and other goods.
Auxiliary, loading and unloading operation time	Calculate and select values in accordance with the specifications
Vessel Speed	8 knots.
Safety distance of ships	Calculating safety spacing value from 8 knots speed.
The tonnage of Berths	11 berths of 5000 tons, 6 berths of 30,000 tons, and 28 berths of 50,000 tons.
Waterway conditions	The main waterway is 29.8 km in length and has 3 branch waterways, 3 junctions.

Running simulation model 10 times, three one-way channel conversion strategies under one-way navigation are simulated respectively, and the optimal conversion decision quantification values under the scheme are obtained, and the optimal values of the three schemes are compared by using different evaluation indicators.

5.2 Impact of different schemes on port service level

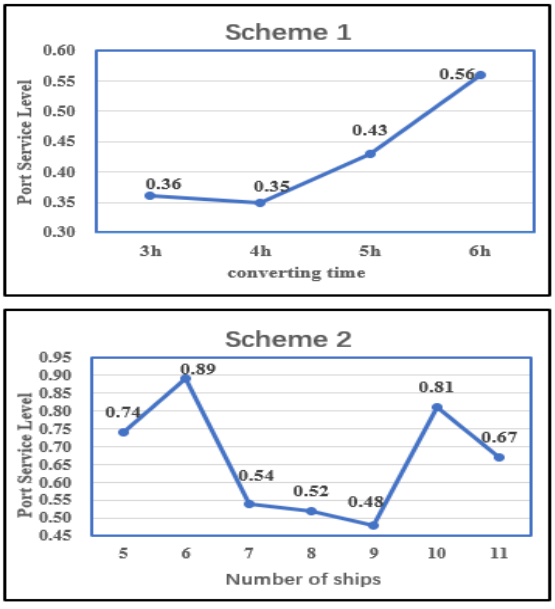

Figure 4. Port service level under different converting times or number of ships in departure formation

Scheme 1: Considering the reasonable one-way channel converting time, this paper takes 3 hours, 4 hours, 5 hours and 6 hours as one-way channel converting time, and carries out system simulation under four kinds of one-way channel converting time. As shown in Fig.4, scheme 1 shows that different one-way channel converting time has a significant impact on port service level, the port service level under four-hours converting one-way channel is lower and the port service level is better. Therefore, it is better to choose four-hour converting one-way channel as conversion strategy in scheme 1.

Scheme 2: Considering the distribution of the number of ships leaving the port, this paper takes 5-11 as the cumulative value of the number of ships leaving the port. Under normal navigation conditions, when the cumulative value of ships leaving the port is reached, the one-way channel is in the state of outgoing navigation., the port service level under scheme 2 is in the optimal state when nine ships are about to leave the port. Therefore, it is reasonable to select the one-way channel converting strategy when nine ships are about to leave the port

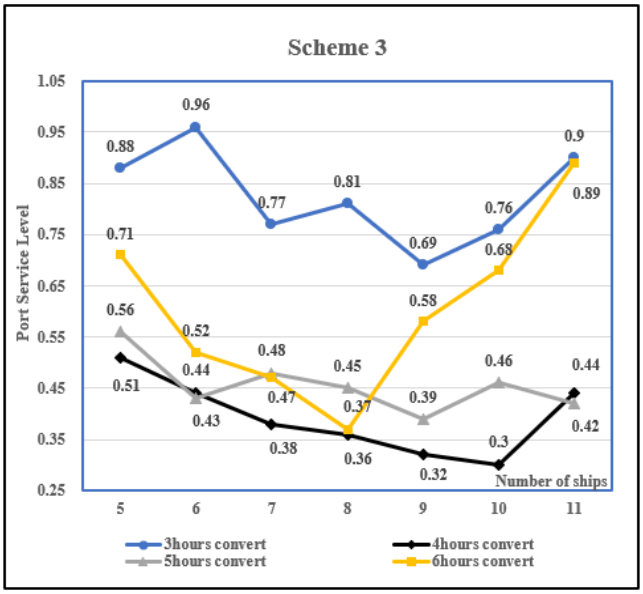

Figure 5. Port Service Level under Scheme 3

Scheme 3: Combining the converting time with the number of ships coming out of port, considering the rule of priority of departure, when any conditions of the converting time or the cumulative value of the number of ships in the departure formation are satisfied, the converting channel is in the state of outbound navigation. As shown in Fig.5, the port under scheme 3 is in the state of outbound navigation. The service level is in the optimum state when the converting time is 4 hours and the number of ships coming out of the port reaches 10 as the cumulative condition of the converting. Therefore, the combination of 4 hours converting and 10 ships coming out of the port is chosen as the one-way channel conversion strategy in the third scheme.

5.3 The influence of different schemes on the average waiting time of ships

Considering the obvious influence of one-way channel converting strategy on ships, this paper also selects the average waiting time of ships and the average waiting time of large ships as the evaluation index. A reasonable one-way channel converting strategy can reduce the waiting time of ships and make ships more efficient in entering and leaving ports and loading and unloading operations. Therefore, considering the effect of one-way channel converting strategy on the average waiting time of ships and large ships, this paper defines a ship which tonnage reaches 50,000 tons as a large ship.

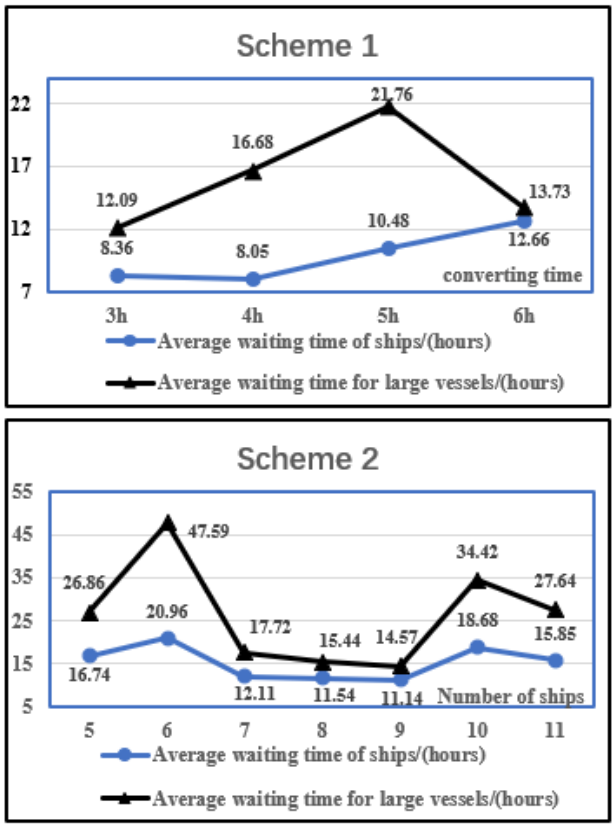

Figure 6. Average waiting time of ships under different converting times and number of ships in departure formation

Scheme 1: According to the reasonable one-way channel converting time, select 3, 4, 5, 6 hours as the time of converting one-way channel for system simulation, and compare the average waiting time of ships under different converting time. As shown in Fig.6, different converting time have obvious effects on the average waiting time of ships and large ships. It is more reasonable to choose 4 hours to convert one-way channel when considering the average waiting time of ships. It is more reasonable to choose 3 hours to convert one-way channel when considering the average waiting time of large ships. Therefore, when comparing the average waiting time of ships and large ships, different converting time are selected respectively. As a reasonable choice of scheme 1.

Scheme 2: According to the reasonable number of ships

leaving the port, 5-11 ships are taken as the cumulative value of the number of ships leaving the port. When the ships leaving the port reach the critical value, the one-way channel is in the state of departure and navigation., when the number of ships coming out of the port formation reaches 9, the one-way channel will be switched. At this time, the waiting time of ships and large ships can reach the shortest time. Therefore, when comparing the average waiting time of ships and the average waiting time of large ships, when the number of ships coming out of the port formation reaches 9, converting one-way channel is a reasonable choice for scheme 2

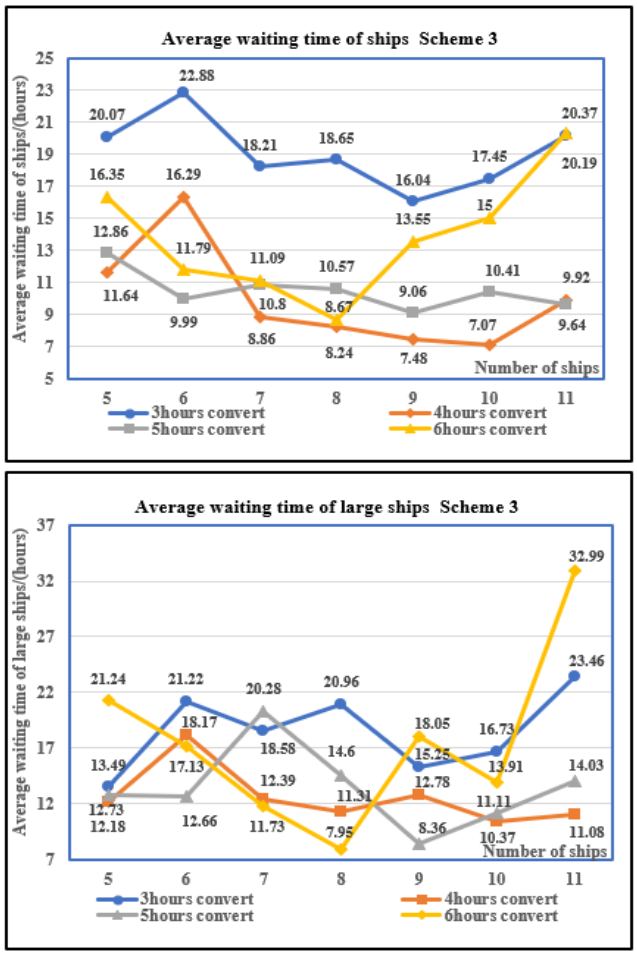

Figure 7. Average waiting time of ships and large ships in scheme 3

Scheme 3: Combining the converting time with the number of ships leaving port, considering the rule of priority of departure, referring to Figs.7, it can be analyzed. In Scheme 3, considering the average waiting time of ships and large ships, the converting time of 4 hours is chosen to be connected with the converting when the number of ships coming out of port formation reaches 10. Considering the average waiting time of large ships, it is more appropriate to choose a combination of 6 hours converting time and 8 ships in the port when the number of ships in the departure formation reaches 8. Therefore, when comparing the average waiting time of ships and the average waiting time of large ships, the best choice of scheme 3 can be obtained separately.

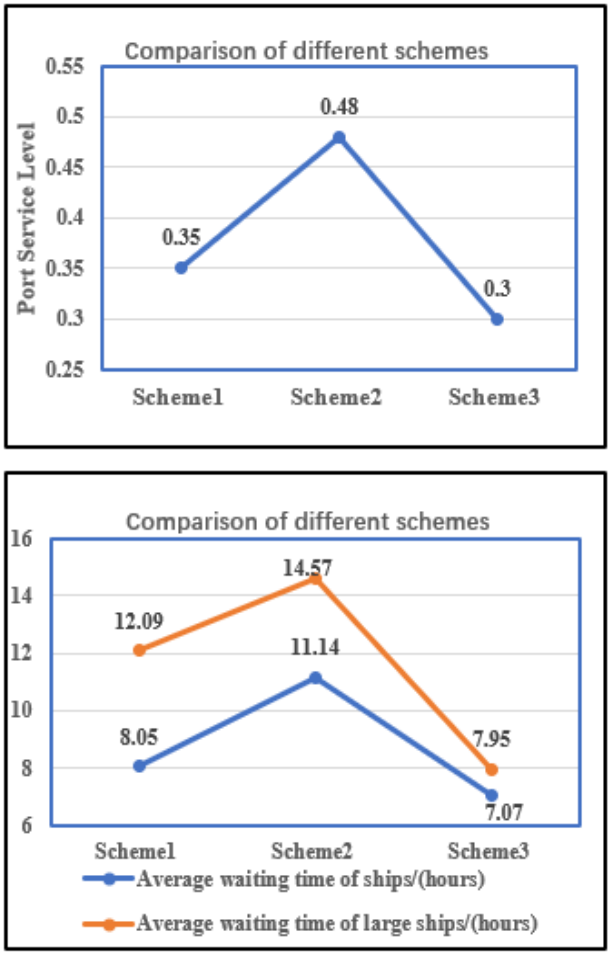

Figure 8. Average waiting time and port service level under different schemes

Considering the actual situation of the port and referring to Fig.8, we can conclude that under the same ship arrival distribution, the service level of the port under the one-way channel converting strategy of scheme 3 is better than that of the other two schemes, which shows that the one-way channel conversion strategy under scheme 3 is better for the whole port. It is more advantageous to upgrade the operation status. The average waiting time of the ships and the large ships under the one-way channel converting strategy of the third scheme is smaller than that of the other schemes, which proves that under the third scheme, the channel converting strategy can reduce the waiting time of ships and improve the efficiency of ships' entry and exit and operation in the harbor.

6. CONCLUSION

By putting forward three kinds of one-way channel conversion strategies, considering the influence of one-way channel conversion strategy on port service level, average waiting time of ships and specific large ships under the same ship-to-ship distribution, this paper uses system simulation method to input the same arrival data and analyses three different ways. The optimal situation of one-way channel conversion strategy is discussed, and

three kinds of one-way channel conversion strategies are compared according to different evaluation indexes. From the data of system simulation, it can be concluded that only considering the converting time of one-way channel or the number of ships coming out of port formation is too limited, whether it is all of scheme 1 or scheme 2. In this case, it is particularly necessary to consider the combination of converting time and the number of ships leaving the port. Based on this item, the third one-way channel conversion strategy under comprehensive consideration is put forward. Through simulation analysis and data comparison, the scheme is proposed. Three one-way channel conversion strategies have reached the best state in comparison of several schemes under several evaluation indexes. Therefore, considering the converting time and the number of ships coming out of the port formation, this one-way channel conversion strategy is the best conversion strategy for this certain port basin under the three schemes proposed in this paper.

At present, affected by the actual environment and navigation rules of the port channel, some ports still use one-way navigation mode. In order to ensure that the overall operation level of the port is in good condition and the operation efficiency of arriving ships reaches the best level, one-way channel conversion strategy is one of the most important factors. How to deal with the one-way channel conversion strategy is one of the most important factors. A reasonable planning of the conversion strategy of the one-way channel still needs to be further studied.

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