Optimization of Three Gorges Ships' Trafficability Based on Anylogic

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Abstract: To improve the effective utilization rate of the Three Gorges ship lock and reduce ships' average waiting time, thereby improving ship lock service level, this paper first selects ship lock trafficability calculation methods, factors affecting ship lockage efficiency and ship lock service level indicators through literature survey. Adopting AnyLogic application simulation technology and taking probability distribution as the main idea, it constructs a discrete dynamic model on Three Gorges ship lockage using the relevant parameters of Three Gorges ship, anchorage and ship lock based on the actual operating data of the Three Gorges in 2013. Through multiple simulation tests and comparisons, it is concluded that removing passenger ships from the ship type combination can greatly improve trafficability of the Three Gorges ship lock and improve ship lock service level.

Keywords: three gorges; ship; ship lock service level; anylogic

1. Introduction

With the increasing demand for ship lockage in the Three Gorges, the limited ship lock trafficability has caused ship efficiency problems in passing dams, which restricts the transportation efficiency in the entire river basin. At the same time, the limited anchorage capacity also makes backlogging of ships near the dam in the Three Gorges become a norm. Therefore, how to alleviate pressure on the anchorage to be locked and improve the overall ship efficiency in crossing the dam has become an urgent problem for the navigation management department. Domestic Liu Jingxian et al. analyzed the characteristics of the channel system and ship entities, established a channel simulation model based on ship behavior, and input actual data from a seaport to conduct simulation experiments. Many scholars abroad have done a lot of researches on traffic based on simulation. Using computer simulation experiments, Kia M. et al. analyzed and proposed service standards and model parameters, as well as ways to increase trafficability.

This paper utilizes AnyLogic simulation software to virtualize the process for the ship to arrive at the front of the Three Gorges Dam and pass the Three Gorges Dam. Theory and simulation are combined in proposal of ship lockage program, which is to build a ship lockage efficiency optimization model and improve the service level of the Three Gorges, thereby bringing certain social and economic benefits.

2. Simulation Analysis on Trafficability of the Three Gorges Ship Lock

2.1 Ship Lock Trafficability Definition and Analysis

2.1.1 Ship lock trafficability definition

Ship lock trafficability refers to the annual amount of passable cargo for the ship lock under certain boundary conditions. It is not a fixed figure, but changes with the change of variable conditions.

China's current practice code "Overall Design Code for Ship locks" (JTJ305-2001) (hereinafter referred to as "the Code") has specific provisions for the calculation of ship lock trafficability, and its calculation method is as follows:

$$P_1 = \frac{\mathrm{n}}{2} NG \tag{1}$$

$$P_2 = \frac{1}{2}(\mathrm{n} - \mathrm{n}_0)\frac{NG\alpha}{\beta} \tag{2}$$

$$\mathrm{n} = \frac{\tau \times 60}{T} \tag{3}$$

In the formula: P1 is the total deadweight tonnage (t) of ships passing through the lock each year in one direction; P2 is the annual volume (t) of passengers and freight passing through the ship lock in one direction; n is the daily average times of lockage; n0 is the daily times of non-passenger and cargo ship lockage; N is the annual shipping days (d); G is the average deadweight tonnage (t) at one lockage; α is the ship loading factor; β is the non-equilibrium factor of traffic volume; τ is the daily working hour (h); T is time for one lockage (min).

2.1.2 Analysis on factors influencing ship lock trafficability

According to the above formulas, the influence factors of ship's ability can be divided into the following categories: Table 1.

2.1.3 Ship lock service level indicators

From the two perspectives of ship and ship lock, this paper analyzes ship lock trafficability using two ship lock service level indicators: average waiting time of the ship and effective utilization rate of ship lock.

Table 1. The factors influencing ship lock trafficability are as follows:

Factors	Specific indicators
2 intermediate parameters	Average tonnage for one lockage
	Average time of one lockage
Ship lock scale factor	Effective length
	Effective width of lock chamber
	Water depth of lock chamber on sill
Ship lock process factors	Lock opening time
	Lock closing time
	Irrigation time
	Weepage time
Ship lock layout factors	Approach channel layout form
	Distance between the area to be locked and the lock chamber
Composition factors of ships passing through the ship lock	Ship type design dimension
	Ship combination ratio
Key parameters of ship lock operation	Daily working hours
	Daily lockage times
	Annual shipping days
	Non-equilibrium factor of traffic volume
Ship performance and ship navigation safety requirements	Ship entry speed
	Safe distance (or interval time) for ship entry
	Ship exit speed
	Safety distance (or interval time) for ship exit
	Navigation speed of the ship between locks
Ship lock operation mode	One-way operation
	Bidirectional operation

(1) Average waiting time of the ship

Average waiting time of a ship refers to the average waiting time for the ship to leave the anchorage after arrival at the anchorage. It judges the ship lock service level from the perspective of ship lockage. Duration of average waiting time of a ship reflects the ship lock service level. A shorter duration means higher ship lock service level and a longer duration means lower ship lock service level.

(2) Effective utilization rate of ship lock

Effective utilization rate of ship lock refers to the ratio of the actual working hours of the ship lock in one year to its operable time in one year. A higher effective utilization rate of ship lock indicates busier ship lock, and it will take longer waiting time for ship lockage after its arrival, so ship lockage service level is lower. A lower effective utilization rate of ship lock indicates longer idle time of ship lock, so it will take shorter waiting time for ship lockage and ship lockage service level will be higher.

3. Case Analysis

3.1. Statistics and Analysis of Actual Operation Data of the Three Gorges Ship Lock in 2013

(1) Ship statistics by tonnage

The ship type is a major factor affecting the ship gate passing capacity. Table 2 shows the statistics of ship type collected in 2013.

(2) Dimension statistics on ships passing through ship lock

The ship scale is also a major factor affecting the three gorges ship gate passing capacity. Table 3 shows the ship scale statistics collected for 2013.

(3) Actual running time of relevant operating equipment of the Three Gorges Ship Lock

The Three Gorges Ship Lock is a five-grade ship lock, which generally runs in one-way operation mode. The process of a ship passing through the first lock chamber constitutes control condition of the ship's trafficability. Therefore, this study mainly focuses on this condition. Therefore, it is necessary to collect the actual operation schedule of the main equipment of the Three Gorges lock, as shown in Table 4.

(4)Analysis on ship entry time

The Three Gorges lock adopts two ship formations to enter the gate simultaneously to save the ship entry time. Table 5 shows the statistical method of entering the gate under the combination of different number of ships, and table 6 shows the statistical analysis of ship displacement.

(5) Analysis of ship shifting time

(6) Analysis on ship lockage time

Combined with Table 4, Table 5, Table 6, the ship crossing time is analyzed. The Three Gorges lockage mode is one-way lockage of double-line five-grade ship lock. Therefore, the lockage time for a fleet = the total running time for passing through a lock chamber + the total time for ship entry + the total time for ship berth (lock) shifting.Finally, the ship crossing time analysis of Table 7 is obtained.

Table 2. Classification statistics on ships passing through three gorges ship lock in 2013

Ship type	Ship tonnage	Ship number	Average deadweight ton (t)	Upward deadweight ton (t)	Ship type proportion
Cargo ship	500	853	584	583	1.83%
	1000	5431	1192	717	11.67%
	2000	8320	2090	1350	17.87%
	3000	8705	2976	2288	18.70%
	4000	6093	4077	3247	13.09%
	5000 and above	15211	5949	4110	32.67%
Passenger ship		1942			4.17%
Total		46555			
Average for Cargo Ships			3712	2641	

Table 3. Dimension statistical analysis on ships passing through the three gorges ship lock in 2013

Ship type	Ship tonnage (t)	Ship width (m)	Ship number	Average ship length (m)
Cargo ship	500	8	60	45.93
		9.2	125	47.07
		10	25	52.12
		11	45	57.64
		13	179	60.56
		16.3	289	85.5
		17.2	130	86.12
	1000	10	451	59.36
		11	2174	64.04
		13	2373	71.15
		15	17	81.5
		17.2	161	99.8
		19.2	255	107.59
	2000	11	838	70.5
		13	5445	76.93
		15	1824	84.5
		16.3	45	88
		17.2	54	112
		19.2	114	119.18
	3000	11	59	80.36
		13	3010	80.36
		15	5349	86.83
		16.3	235	88.69
		17.2	52	100
	4000	13	78	90.28
		15	2590	90.88
		16.3	2943	95.62
		17.2	482	104
	5000	15	489	91.29
		16.3	6062	100.74
		17.2	5686	106.47
		19.2	2974	110.56
Passenger ship		8	124	25.32
		9.2	4	46.98
		10	14	56.58
		11	461	69.7
		13	82	76.89
		15	198	87.24
		16.3	204	92.86
		17.2	348	103.09
		19.2	348	133.5
		25	128	150

Table 4. Actual operation schedule of the relevant equipment of the three gorges ship lock

	Actual operating parameters of Three Gorges Ship Lock (min)
Close the miter gate of the first lock	6.5
The first lock chamber leaks water	11~15
Open the miter gate of the second lock	3
Close the miter gate of the second lock	4
The first lock chamber fills water	10
Open the miter gate of the first lock	3.5
Total running time	38~42

Table 5. Analysis on ship entry time in three gorges

Ship number	Entry time (s)
2	(330+120)/0.35/60=21.43min
3	There are two groups, and the arrival time of the first group is 21.43min. At this time, the later group still needs to sail a safety distance of about 90m, 90/0.5/60=3min. So, the total time is about 21.43+3=24.43min
4	There are two groups, and the arrival time of the first group is 21.43min. At this time, the later group still needs to sail a safety distance of about 90m, 90/0.35/60=4.29min. So, the total time is about 21.43+4.29=25.72min
5	There are 3 groups, and the arrival time of the first 2 groups is 25.72min as calculated above. Group 3 (5th ship) still needs to sail a safe distance of 90m, 90/0.5/60=3min So, the total time is about 25.72+3=28.72min
6	There are 3 groups, and the arrival time of the first 2 groups is 25.72min as calculated above. Group 3 (5th ship) still needs to sail a safe distance of 90m, 90/0.35/60=4.29min So, the total time is about 25.72+4.29=30.01min

Table 6. Analysis on ship shifting time in three gorges

Ship number	Entry time (s)
2	320/0.3/60=17.78min
3	There are two groups, and the arrival time of the first group is:320/0.3/60=17.78min At this time, the later group still needs to sail a safety distance of about 90m, 90/0.4/60=3.75min. So, the total time is 17.78+3.75=21.53min.
4	There are two groups, and the arrival time of the first group is:320/0.3/60=17.78min At this time, the later group still needs to sail a safety distance of about 90m, 90/0.3/60=5min. So, the total time is 17.78+4.29=22.78min.
5	There are 3 groups, and the arrival time of the first 2 groups is: 22.78min Group 3 (5th ship) still needs to sail a safe distance of 90m, 90/0.4/60=3.75min The total time is 22.78+3.75=26.53
6	There are 3 groups, and the arrival time of the first 2 groups is:22.78min Group 3 (5th ship) still needs to sail a safe distance of 90m, 90/0.3/60=5min The total time is 22.78+5=27.78

4. Anylogic Simulation

4.1 Modeling Process and Diagram

A virtual scenario of the Three Gorges was established using AnyLgoc, and a series of ship parameters were set based on the collected statistical data. The probability was set based on the above ship distribution.Figure 1 is a modeling illustration.

Table 7. Analysis on ship lockage time

Ship number		Entry time (min)	Shifting time(min)	Total equipment operating time (min)			Interval of ship lock (min)	Daily average lockage times
				Fourth-grade water replenishment	Fifth-grade operation	Average running time		
2		21.43	17.78	42	38	39.07	78.28	18.40
3		24.43	21.53				85.03	16.94
4		25.72	22.78				87.57	16.44
5		28.72	26.53				94.32	15.27
6		30.01	27.78				96.86	14.87

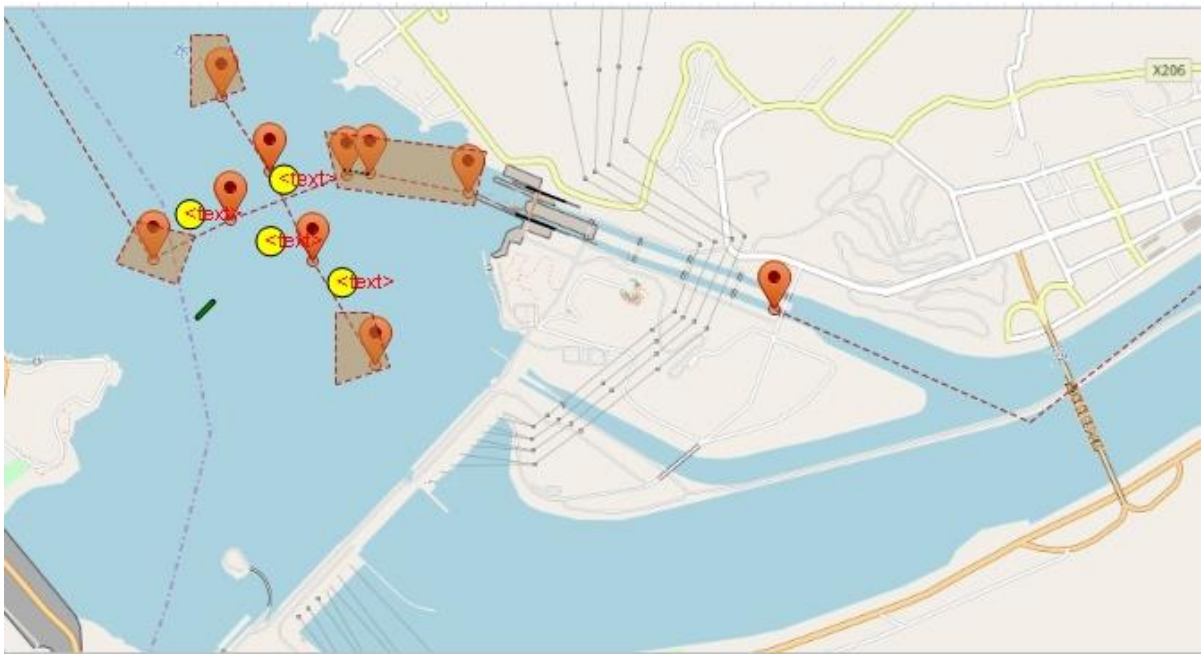

Figure 1. Anylogic simulation modeling diagram

4.2 Analysis of Results

4.2.1 Trafficability simulation test on combinations of ships passing through the ship lock in 2013

Three Gorges ship lockage process based on the random queue principle was simulated using AnyLogic software. Four groups of tests were designed for this simulation test, which were based on the actual ship type combination (including passenger ship) in 2013. 55 million tons, 60 million tons, 62.5 million tons, and 65 million tons were respectively input into the system, and the simulation results are shown in Table8.

Table 8. Combination data on ships passing through the three gorges ship lock in 2013

	Test 1	Test 2	Test 3	Test 4
Input cargo volume in the test (10,000 tons)	5500	6000	6250	6500
Actual cargo volume passing through the ship lock (10,000 tons)	5515	6014	6254	6460
Actual deadweight ton of cargo ship passing through the ship lock (10,000 tons)	7748	8449	8787	9077
Cargo ship's rated tonnage in one lockage (t)	16037	16573	1692	17312
Cargo ship's tonnage in one lockage (t)	11415	11767	1205	12321
Average number of ships in one lockage	4.51	4.66	4.75	4.86
Average time in one lockage (min)	90.60	91.80	91.98	92.40
Daily average times of ship lockage	14.34	15.13	15.41	15.56
Lock chamber utilization rate	0.717	0.741	0.757	0.774
Average waiting time of ship (h)	1.86	3.20	5.73	46.55
Effective utilization rate of ship lock	90.41%	95.61%	98.41%	100.00%

4.2.2 Analysis on the influence of passenger ship conditions on trafficability of the three gorges ship lock in 2013

According to the data, the actual ships passing through the ship lock in 2013 include about 4% of passenger ships. These passenger ships occupy the effective area of the lock chamber, which affects the ship lock's trafficability. To analyze the influence of passenger ships on trafficability of the Three Gorges ship lock, passenger ship is removed from the actual ship type combination, while the combination ratio of ships in each tonnage and size remains unchanged. The simulation test results are shown in Table 9 .

Table 9. Simulation test results

	Test 1	Test 2	Test 3	Test 4
Input cargo volume in the test (10,000 tons)	5500	6000	6250	6500
Actual cargo volume passing through the ship lock (10,000 tons)	5520	6010	6255	6504
Actual deadweight ton of cargo ship passing through the ship lock (10,000 tons)	7755	8443	8787	9137
Cargo ship's rated tonnage in one lockage (t)	16661	17066	17342	17692
Cargo ship's tonnage in one lockage (t)	11858	12148	12344	12593
Average number of ships in one lockage	4.49	4.6	4.67	4.77

Average time in one lockage (min)	90.72	91.26	91.62	92.04
Daily average times of ship lockage	13.81	14.68	15.04	15.32
Lock chamber utilization rate	0.71	0.727	0.739	0.754
Average waiting time of ship (h)	1.58	2.19	2.89	4.56
Effective utilization rate of ship lock	87.02%	93.02%	95.63%	97.95%

Excluding the influence of passenger ships, analysis of Table 9 found that in the limit trafficability simulation of Three Gorges ship lock in 2013, the actual volume of cargo passing through the ship lock is higher when there is no passenger ship.

To facilitate analysis on the influence of passenger ships on trafficability of the Three Gorges ship lock, the data are summarized into a comparative analysis table as shown in Tables 10 and 11.

Table 10. Comparative analysis on the influence of passenger ship conditions on trafficability of the three gorges ship lock in 2013

	Test considering passenger ship in 2013 (Test 4 in Table 3.2-9)	Test excluding passenger ship in 2013 (Test 6 in Table 3.2-11)
Actual cargo volume passing through the ship lock (10,000 tons)	6460	6794
Cargo ship's rated tonnage in one lockage (t)	17312	18238
Average number of ships in one lockage	4.86	4.91
Average time in one lockage (min)	92.40	92.70
Daily average times of ship lockage	15.56	15.53
Lock chamber utilization rate	0.774	0.777

Table 11. Comparative analysis on the influence of passenger ships on ship lock service level in 2013

Effectiveness Test	Average waiting time of ship (h)		Effective utilization rate of ship lock	
	Considering passenger ship	Excluding passenger ship	Considering passenger ship	Excluding passenger ship
Test 1	1.86	1.58	90.41%	87.02%
Test 2	3.20	2.19	95.61%	93.02%
Test 3	5.73	2.89	98.41%	95.63%
Test 4	46.55	4.56	100.00%	97.95%

As can be seen from the above table, if passenger ships are excluded, cargo ship's rated tonnage in one lockage, average number of ships in one lockage and lock chamber utilization rate have all been improved, thereby improving trafficability of the Three Gorges ship lock. From the perspective of average waiting time of the ship, the average waiting time is higher for combination with passenger ship. From the perspective of effective utilization rate of the ship lock, the effective utilization rate of the ship lock is higher for combination with passenger ship. Hence, properly removing passenger ships from fleet passing through the ship lock will help improve the ship lock service level (that is, the average waiting time of the ship and the effective utilization rate of the ship lock).

5. Conclusion

AnyLogic software was used to simulate and analyze the series of lockage data of the Three Gorges ships in 2013. The simulation test results show that if passenger ships are prohibited from passing through the Three Gorges ship lock, based on the type of cargo ships passing through the Three Gorges ship lock in 2013, the limit trafficability of the Three Gorges ship lock has increased by 5%. It indicates that this way greatly improves the trafficability of the Three Gorges ship lock, reduces the average waiting time of ships, and improves ship lock service level. However, there are some ideal hypotheses in the simulation and the research needs further optimization if necessary.

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