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A barge fleet composition for an industrial dry bulk transportation: operating between river wharf and coastal floating transshipment platform

Boyu Jin

SHANGHAI MARITIME UNIVERSITY

WORLD MARITIME UNIVERSITY

Shanghai, China

A BARGE FLEET COMPOSITION FOR AN INDUSTRIAL DRY BULK TRANSPORTATION

Operating between river wharf and coastal floating transshipment platform

By

JIN BOYU

China

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DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

Jin Boyu

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Supervised by

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ABSTRACT

Title of research paper: **Barge Fleet Composition for An Industrial Dry Bulk Transportation -- Operating Between River Wharf and Coastal Floating Transshipment Platform**

Degree :**Master of Science in International Transport and Logistics**

The problem I am trying to solve in this paper is to find out a optimal barge fleet composition which meet the technical feasibility, required transport capacity and the cost should be relatively lower than other schemes. The barge fleet will service for a industrial dry bulk transportation from Africa to China, and due to the restrictions on the natural environment and infrastructure, a coastal floating transshipment platform(FTS) will be the terminal of this barge fleet. And the TEDS (technical and economical demonstration of ship) method was employed to solve this fleet composition problem.

In the second chapter I did the technical demonstration by analyzing the natural conditions, the operating of floating transshipment platform(FTS), the general operation modes of barge fleet, the types of connection between pusher and dumb barges, and show the final choice of different type of barge fleet operating modes according to the natural or technical condition.

Then I done economical demonstration with four steps: The first step is to determine the target of this industrial shipping system and determine the restrictions both natural and technical. Such as annual transportation mission and loading/ discharging rate of both ends. The second step, list the schemes for comparison according to the situation of inland waterway draft, current shipbuilding technique, and the suggestion from some experienced captain, shipping company manager and Ship Design Institute. The third step is reject the schemes which failed to complete the transportation mission. The fourth step is to choose the lowest cost fleet composition solution among the feasible schemes.

As the result, in order to complete the annual transportation volume of 10million tons bauxite, the optimal barge fleet composition is using six 12000DWT self propelled barge with a service speed of 8 kn/h laden and 9 kn/h ballast.

KEYWORDS: Technical and Economical Demonstration of Ship, barge operating model , fleet composition

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List of Abbreviations

ROI:	Rate of return on investment(ROI）
FTS:	Floating Transshipment Ship
C/E:	Chief engineer
VALE:	Companhia Vale do Rio Doce, Brazil mining company
VALEMAX:	Valemax ship
VLOC:	Very Large Ore Carrier
CAPE :	Cape size ship
PANAMAX:	Panamax size ship
SUPRA:	Supra size ship
HANDY:	Handy size ship
COA:	Contract of Affreightment
TC:	Time charter
VC:	Voyage charter
FO:	Fuel oil
DO:	Diesel oil
LO:	Lubricating oil
LOA:	Length Over All
M/V:	Motor Vessel
Kn:	nm/h, knots
Nm:	Nautical miles
OPEX:	Operating cost
DWT:	Deadweight
HP:	Horse power

Chapter 1 Introduction

1.1 Back ground and problem description

Generally, maritime dry bulk transportation is to serve the unbalanced geographical distribution of the supply and demand of the raw material. Under the background of globalization, manufacturers always face a geography gap between mining and proceeding. This geography gap brings a demand for transportation, therefore, benefiting shipping industry, especially dry bulk market. For example, China production of primary aluminum was 3100 thousand metric ton, which means more than a half (54%) of primary aluminum of the world was produced by China (<<MINERAL COMMODITY SUMMARIES>>, 2017), but according to an interview with the president of Asia’s largest refractory mineral processing company in 2015, because of the government's strict control of domestic bauxite production, bauxite supply in the market is very tight. From 2010 to 2013, China's dependence on overseas bauxite were 48.6%, 61.7%, 49.5% and 75.4%, more than 60% of imported bauxite was from Indonesia. In 2014, the Indonesian government introduced a ban on the export of raw ore, in order to increase the added value and create more job opportunities. Since the implementation of this policy, China aluminum smelter had to import more bauxite from Australia and Africa.

Africa accounted for 32 percent of world Bauxite resources, for example, especially the Guinea, a Africa country located on west coast of Africa, haing the largest bauxite reserves in the world (7,400,00 thousand metric dry ton). This massive resources attracted many Chinese importers to invest in mining.
Where there is demand, there is market. These investments in overseas mining enterprises in China have brought enormous transport demand. Recently, a china Aluminum company intends to invest in a mining area in Guinea.The first phase of the development will start from the area close to the coast, whose output is expected to reach 10 million tons .The bauxite will be transported to a north port of China, supporting the company’s electrolytic aluminum factory. Now, this Alumina manufacturing company intends to outscore the transportation process to a shipping company.

At present, after preliminary consideration of local natural conditions and infrastructure, this company already has a general idea of how to operating this whole transportation. That is, using a barge fleet to transport bauxite to a floating transshipment platform, and transfer bauxite to large bulk carriers, such as VLCC or CAPE, through the floating transshipment platform.

The whole transportation can be divided in to two parts： river-sea transportation part and cross-ocean transportation part. The second part is to transport bulk cargo from the floating transshipment platform which mooring in an anchorage near the river mouth, to a north port in China. The distance of this leg is long enough, so according to the economies of scale theory, the larger the carrier employed, the less the unite transportation cost. Up to yet, there are many papers already have done the technical and economic analysis for the large bulk carrier. The result become a common sense: theeconomies of scale works when there is no natural and /or policy limitations. In this case, there is no draft limitation for Cape at the floating loading platform because she is mooring in the sea. So is the discharging port — the destination is a mature port with a dredged bulk terminal. However, This market of this leg is very mature, even if the company does not have its own private fleet, through the COA contract and TC, or even VC can also complete the transportation mission.

But, within the first leg, –whether the fleet could complete this river-sea transportation strictly depended onthe hydrographic conditions of the river and other technical conditions. So, this paper will focus on this part, and try to use the TEDS(technical and economical demonstration of ship) method to find an optimized barge fleet composition which can minimize the cost and ensure the completion of the transportation task (10 million tons per year).

1.2 Propose of research

The main purpose of this article is to provide an optimized fleet composition scheme for the shipping company reference.

At the same time, this industrial transshipment transportation in Africa, Southeast Asia and other areas which exporting raw materials but restricted by infrastructure construction (such as wharf-front draft)have significant advantages. There are bound to be many companies also face barge fleet composition problem. So this paper can provide an idea on the barge fleet composition comparison,

Moreover, with in this paper, the data of barge building price, maintenance cost, management cost, etc. are experience data from captains, C/Es, ship yard, and shipping companies, which certainly have reference value.

1.3 Methodology

Ship is a complicated, large investment which has a long service life. Due caution should be exercised before design and construction. Through investigation and research, this paper summarizes the existing barge fleet operation technology and cost experience.Through the comparative analysis of technology and economic indicators of each barge fleet composition scheme, this paper finds out the technically feasible, capacity feasible and economic reasonable barge fleet composition scheme.

The first step in technical and economic analysis is the investigation of raw data. The purpose of investigation is to find out the requirements and conditions for the use of the barge. The scope of the investigation includes:

(i) The type and quantity of the goods.

(ii) The transportation distance, channel depth, hydrographic data, navigation area meteorological data and so on.

(iii) Handling efficiency of both ends.

(iv) The technique, operation mode, and other information of the existing barge fleet.

The second step is to establish a feasible comparison scheme. The key of this step is to make clear the restrictions on natural conditions and technical conditions when selecting ship forms and fleet operating models. Then establish a number of reasonable fleet composition scheme.

The third step is to select the technical feasible plan to complete the transportation task and have a certain safety margin.

The fourth step is to select the most economical one from the last step by calculating and comparing the cost of each scheme.

1.4 Literature review

In 2010, Yang Qiuping , Xie Xinlian and Zhao Jiabao analyzed the main task of fleet planning and basic objectives. They summed up the research progress in this field, reviewed and summarized the using of linear programming, integer programming, dynamic programming, simulation and other research methods on fleet composition. They also pointed out that the current research on Fleet Planning of large industrial materials transportation is relatively mature, the research object will be transferred to the container liner and the tramp market; they believe that the develop of new optimization model and algorithm is still the focus of future research; uncertain rules under the condition of fleet programming is the future research direction and the application of fleet composition decision support system is the inevitable trend of the development of shipping industry. Also Pantuso, Fagerholt and Hvattum examined many scientific literature on the maritime fleet size and mix problem in 2014. They found that the most research were focus on initial composition of the fleet and operations research played an important role in the solving of fleet composition problem. Zhao Gang& Xu Zhengyan has analyzed the shortcomings of the traditional ship demonstration method, and a new proof method -- the optimum scheme direct search method (Simplex algorithm is used in the search process.) is put forward in 1991. Simplex algorithm is used in the search process. After the introduction of this method, the design of computer software has been carried out. At last, the authors use this software to solve a real case, and the best fleet composition of Beilun - Baoshan iron ore transportation line has been proved.

This paper describes the procedure and method of technical economic evaluation of transportation ship includes: (i) investigation data; (ii) the establishment of demonstration program; (iii) calculating ship type demonstration technology program, and economic operation; (iv) evaluation for ship index and select the optimal scheme; (v) preparation ship design specification. In this paper, the method of operation and economic calculation, the evaluation index of ship type and the selection of optimum scheme are emphasized.

For barge fleet composition problem, Hu Yunchang, from Department of ocean and naval engineering of Tianjin University, introduced the sea-going pusher barge fleet. The sea-going pusher barge fleet is a combination of pusher and barge, pusher and barge connected by a connecting device. Compared with the ordinary self-propelled barge, the pusher-barge model has the advantages of high efficiency of the host machine and the possibility of carrying out the cyclic transportation, so the pusher-barge model has higher economic benefit than the self-propelled barge on some routes. In his paper, An optimum composition of barge fleet is proved and calculated by the optimization method, the economy of the pushing barge fleet also be evaluated.Fadillah, A., Saito, K., & Prasodjo, B. S. also have studied on Pusher Barge System in the Indonesia Coal Transportation market. About 20 years ago, Indonesia's electricity consumption has rapidly increased, with an annual rate of about 15% to 20%, and as a result, Indonesia's vast coal reserves will be mined to meet the growing domestic demand. And a coal transportation system is needed.The economic feasibility of pusher barge system for coal transportation in Indonesia has been studied and it was showed that this system is the most economical form of transportation. In this paper, the authors investigated the optimal size of the barge cargo capacity for coal transportation in Indonesia. The objective is to minimize the economic cost of transport (ECT) and the problem is solved using the Excel solver. Constraints in the system include power plant demand, river restriction, ship speed and loading or unloading capacity in coal terminal.(Fadillah, A., Saito, K., & Prasodjo, B. S. ,2003)

The book <<Techniques for pushing transportation of integrated barge fleet>> is written in 2001 by Liu Hengmao and Chen Qihua, published by China Communications Press. This book considers pushing barge transportation is the development direction of the inland water transportation, this paper also introduced the development and application of barge transportation at China and other country. The pushing barge transportation technology and operation management mode also be introduced, and the economy of pushing barge transportation has been proved in the last chapter. Honestly, this book has been a great help to me.

Chapter 2 Technical demonstration

2.1 Route hydrologic condition

The average depth of river and the depth of estuary sandbar area is two important factors and limiting the ship type selection. At present, the main types in several international design are based on the height of the width and depth of bridge on the river and the maximum allowable value through design, such as the Suez size, Panamax and the Lake bulk carrier.The depth of the river often determines the maximum draft depth of a ship.

In addition to the depth below the water, buildings above the river - such as the bridge - are also a factor in limiting the choice of ship types. This factor determines the height of the superstructure of the ship. However, the ship can lower the airdraft by filling ballast water.

In this case, the mainly restriction is that the depth of the river is 6 meters. Thus, the draft (including the safety margin) can be no more than 6 meters.

Table 1- Ship particulars of main bulk carriers

	DWT(t)	LOA(m)	Beam(m)	Depth(m)	Draft(m)
VLOC	>200000	>330	>55	>29	
CAPESIZE	13~180000	274.32~330	41~45	22.3~24.6	17.2~17.8
PANAMAX	6~70000	222.5~274.32	32.2	18.0~19.2	13.0~14.0
SUPERMAX	5~60000	<222.5	<32.2	<16.6	11.5~13.5
HANDYMAX	4~50000	<222.5	<32.2	<16.6	
HANDYSIZE	2~50000	<222.5	<32.2	<16.6	11.5~12

Source: <<Ship Principle >> , Shanghai Jiao Tong University press, 2003

So, as shown above, even the minimum size of vessel of current common bulk carriers is unfit for the requirement.

But, as early as the 1950s, the experts in our country began to study the possibility of river and sea direct transportation. In the 90s, the study increased gradually. By twenty-first Century, with the implementation of relevant government policies, the direct transportation between the rivers and seas gradually flourished. At present, on Yangtze River, the biggest barge which leads to the open sea has reached 45000 tonnage (ATB barge), which is the world's largest river-sea sailing barge.

The requirement of river-sea sailing are shallow draft and good sea-keeping ability, but these are two contradictory directions in ship designing. So this is a “trade off“ on ship form.

Table below represents three types of river-sea sailing ship form of the Yangtze River .

Table 2- Ship particulars of river-sea sailing barges in Yangtze River:

DW	LOA	Beam	Depth	Draft
5000	95	17	7.7	4.7
7000	100	20	11.5	4.78
12000	108	19.5.0	8	4.98

Source: Xilan,H. & Lizheng,W. (2001) Determination of the Main Ship Form of inland barges. *Ship Standardization and Quality,* (2), 27-30.

As above we can see, barge fleet is more suitable for this situation.

2.2 Technical condition of floating bulk transshipment platform(ship)

2.2.1 Introduction of the "floating terminal"

Floating dry bulk transfer system, so called "floating terminal", is using a floating transfer-platform to complete the bulk cargo transshipment from a ship to another ship on the water. The floating transfer-platform usually is a rebuild-vessel: using a ship as a rebuilding-foundation and equip her with loading and discharging equipment， enabling it to handling cargo form a ship alongside to another ship on another side. The floating can be self-propelled or pushed by auxiliary tug to the operating area (usually is an offshore anchorage).

In recent years, with the coal and iron ore transportation demand continues to increase and the bulk carrier upsizing trend intensified, the capacity of a CAPE can be exceed 200 thousand ton; the largest iron ore carrier- Valemax's loading capacity has reached 400 thousand ton. These large bulk carriers put higher requirements for the navigable depth of the channel, depth of wharf-frontage and berth capacity of the port. Port managers typically chose the way of dredging the channel and upgrading the wharf structure to meet the needs of large bulk cargo ship berthing requirements. Offshore floating bulk transferring system has become an effective option facing the limitations of wharf-frontage depth and wharf handing capacity,because of its flexiblity and low price.

In some raw-material exporting areas, due to the high price of construction material, low construction capacity (local constructive ability is restricted), the huge amount of exporting volume, and the urgency of transportation demand, the cost of building a large traditional bulk terminal could be very high, accordingly the ROI will be very low. While offshore floating bulk transshipment system with its features of flexibility and comparatively lower overall investment, has been applied to a number of cases.

The floating dry bulk cargo transshipment system has the following characteristics:

(i) Customization: customized systemcan be provided according to specific conditions such as cargo type, barge size and the type of big bulk carrier;

(ii) Flexible operation: platform can be quickly moved to another service areas.

(iii)The construction cost is low: the rebuilding time is short, the overall investment is low, and the ROI is high;

(iv) The total transportation cost is low: transshipment between barge and big bulk carrier(water to water) can skip the yard part and reduce the storage and management cost.

The comparison of floating bulk transshipment-platform and traditional land bulk terminal:

Table 3- Comparison between Floating bulk transshipment platform and traditional land bulk terminal

	Floating bulk transshipment-platform	Traditional land bulk terminal
Land occupied area	No requisition	Land shall be requested for yard
Environment effects	Dust escaping may exist during the transshipment process,if not controlled well, it will directly affect the marine environment	Also exist dust escaping, and the windbreak net or closed material yard measures should be adopted in the yard area, otherwise, the land and marine environment will be affected simultaneously
Requirements for management	Need to be circumspect on transferring fleet scheduling organization, and the overall logistics management requirements are very high	Operating time are determined by ships' arriving time, so the overall logistics management requirements are more relaxed

Building cost	Comparably Low	Comparably High
Additional function	The holds can only be used as temporary storage, can not provide further processing function	Have the function of storage and further processing

Source: own presentation.

2.2.2 Two types of floating bulk transshipment-platform system

2.2.2.1 The coastal floating bulk transshipment system

Southeast Asia and South America, the world's major exporters of coal and iron ore, have large amounts of coal, iron ore and other bulk exported every year. But due to limited construction material, and insufficient construction ability, the construction cost of large fixed professional bulk terminal's cost in these areas is very high. Moreover, there are many mines in these areas, especially in Southeast Asia, but the annual output of ore is only 1 million ~ 2 million ton or even lower. Thus,the ROI of fixed terminal investment is very low.

Therefore, these areas generally adopt following approaches:

1, Constructing inland barge terminal and shipping bulk cargo by barge;

2, Barge fleet sailing to an anchorage nearby, and transshipping the bulk cargo to bulk carrier through the FTS;

3, Using these bulk carriers to transport bulk cargo to the port of destination.

Currently the world's most famous company operating this system is

Coeclerici(an Italy logistics company). Their FTSs were distributed in Philippines, Indonesia, India, Venezuela, Chile and other places, to provide customers with the best location of bulk cargo transshipment and transportation services.

2.2.2.2 The offshore floating bulk transshipment system

The offshore floating bulk transfer system mainly refers to a platform which have a large tonnage of the original ship form (usually is a big bulk carriers such as Capesize). Because of its strong stability (can survive strong wind and rough sea), it can adapt to offshore operation conditions. One side rail of the ship (platform also) is equipped with numbers of ship loader (bridge or fixed), corresponding receiving and delivering systems and auxiliary equipment, the other side of the rail equipped with discharging machine. The full transshipment capacity can reach 2 000 ~ 7 000 t/h.

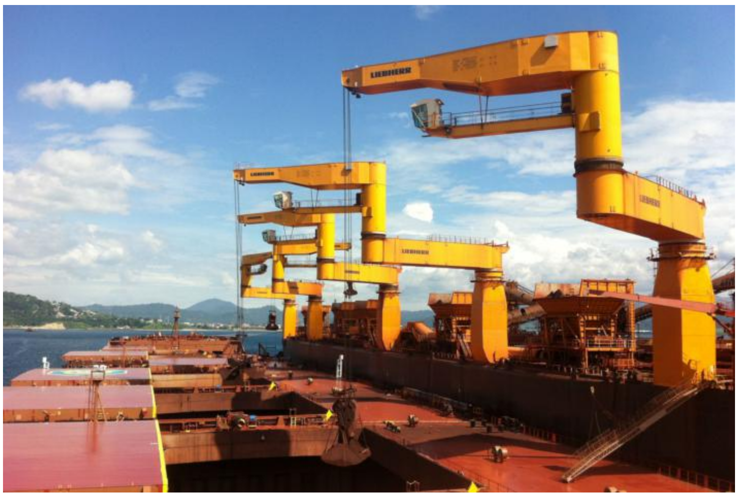

Figure 1- Discharging equipment on FTS
Source: LIEBHERR official website(www.liebherr.com)

The system integrates 3 functions: handling (loading and discharging), storage and transshipment, and has self-propelled ability. The system is mainly applicable to the areas where the water depth of the channel is restricted or the berthing condition is limited, and the operation of "discharging a part of cargo from big vessel " + "transshipment" or "totally discharging the big vessel" +"transshipment"is carried out offshore. Bulk cargo which originally carried by Cape and VLCC will move to Handy and Supra through this transshipment system, then shipped to the port of destination.

In 2011, Vale rebuilt a 280 thousand DWT bulk carrier "ore -F" into a floating transport ship(FTS).This modification has opened up the same type of ship modification in the world. The platform has the characteristics of large tonnage, advanced system and high efficiency. It also integrates 3 functions of loading and unloading, storage and navigation. "Ore -F" LOA 322.1 m, beam56 m, depth 31.4 m, 280 thousand DWT, equipped with 5 sets of double rotary crane (LIEBHERR brand, each capacity of 1 400 t/h), 5 hopper, 5 belt machines and 1 sets of mobile loading machine (capacity of 7 000 t/h) , hold cleaner and other necessary auxiliary equipment, loading machine rail across both sides of the hatch.

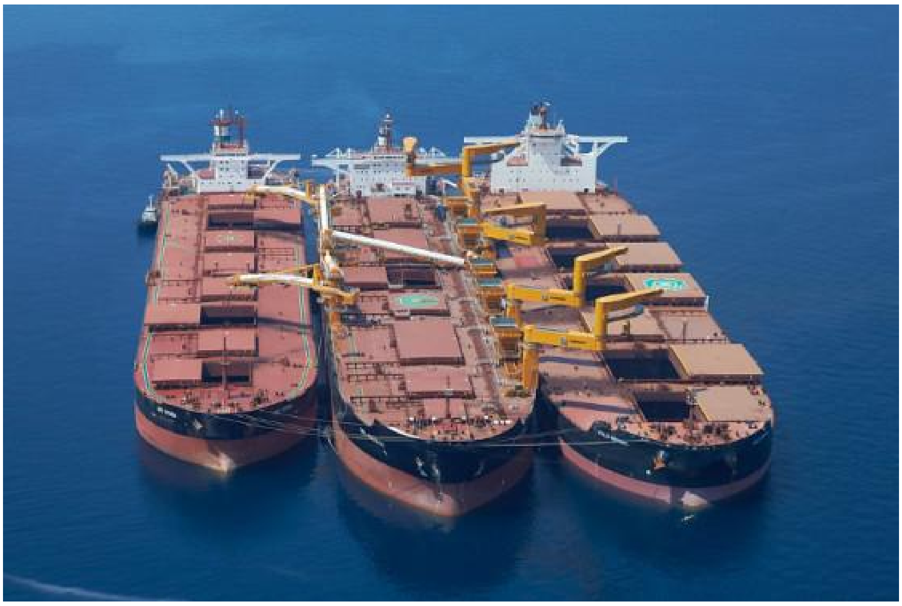

Figure 2- FTS in transshipment working
Source: LIEBHERR official website(www.liebherr.com)

Vale’s FTS has been put into use in Subic Bay in the Philippines Sea, her starboard can discharging VLCC and port side can load Capesize. The system through the FTS transshipment cargo from VLCC to Capesize and then use the Capesize to carry the cargo to the port of destination, effectively solving the problem some ports have due to limited navigable water depth and unfit wharf structure (it cannot meet the 400 thousand DWT ore carrier’s navigation and berthing).

In that time, China does not allow the 400 thousand DWT super large iron ore ship (Valemax)to directly berth in China’s ports, but the Valemax type bulk carrier was right designed for the Chinese market, so Vale have to employ this system.

2.2.3 Comparison of two types

Table 4- Comparison of the coastal FTS and offshore FTS

	The coastal floating bulk transshipment system	The offshore floating bulk transshipment system
Basic ship	Barge	Cape or VLOC
Operating area	Coastal	Offshore
Vessel-to-load	Panamax or Cape	Supra or Cape
Vessel-to-discharge	Barge	VLOC or Cape
Transshipment capacity (t/h)	1000~3000	3000~7000
Navigation ability	Self-propelled or non	Self-propelled
Application area	Yangze River mouth, Subic bay (Vale)	Southeast Asia, South America, Africa

Source: own calculation and presentation

Through the above introduction and comparison, the coastal floating bulk transshipment system is obviously suitable for this Africa industrial bulk transportation.

2.4 Analysis of barge transport mode

2.4.1 Different operation modes of dumb barges fleet

There are two main operation modes of dumb barges: pushing and towing. The general selection principle is that when the sailing distance is long, it is advisable to choose the towing way; when the channel is narrow and complicated, the better choice is pushing.

Under the background of this case, it is easy to make the fleet sway when pushing , and the turning radius of the pushing at the bend of the river is larger, which influences the navigation of other ships. Moreover, the disturbance of the propeller of the tugboat will increase the sailing resistance of the rear barge.

Figure 3- Towing barge fleet in Yangtze River

Source : Own shooting

But at the same time pushing has the following advantages:

(i) Low transport costs. The cost of pushing is 10 - 30% lower than that of tow,because pushing can reduce water resistance and save fuel;

(ii) High operating speed. During the operating, pushing speed is 15 - 20% higher than the towing transport;

(iii) Good manoeuvre performance. Pushing model’s manoeuvre performance is better than towing model, the transport efficiency is higher.

So, from the end of the 19th Century, pushing model was applied in many countries. Since 1950s, the United States has taken the lead in developing the coastal push transportation. In 1975, the United States built the world's first offshore pushing barge fleet---consisting with pushing tug and 40 thousand DWT oil barge.

Compare the same tonnage, same main engine power of pushing barge fleet and general ship,the pushing barge fleet ‘s speed and ability to resist wind and waves is less than general ship, and the building cost may not be cheaper, But in barge operating model, the pusher tug and the barge can be separated, if there is a lower loading and discharging efficiency and shorter voyage situation, the operating turn over time of pusher tug is higher than dumb barge, so it can complete more voyages and service more barge to the utilization ratio of the propulsion power. Moreover, the pushing barge fleet has low requirement for crew technical level and low requirement for crew number, so the total transportation cost will be reduced.

Under the background of this case, the voyage leg is natural waterway, the width and draft is limited, and the tug is needed in order to assist barge berthing to FTS. This distance from the river mouth to the anchorage is 21 admiralty miles, and the sea-sailing conditions are good(wind 3.3m/s ,wave 1.2m), according to the above analysis, the pushing transportation mode will be employed.

2.4.2 Different connection model between pusher and barge

The operation of pushing mode in inner water transportation is very mature, when the barge fleet sailing off the coast,they could occur large waves, in this time the connection model between tug and barge is the crucial point.

The coupling device type application in the sea-sailing pushing barge fleet of many classification methods are different all over the world, usually divided into non integral, integral and half integral according to the relative motion between pusher and dumb barge.

Among three connection above, the most suitable model for this river-sea transportation is the integral connection model.The integral connection is to link the boat and the barge to the full rigid, and the movement of the six degrees of freedom is completely manipulated, like one ship. Therefore, its ability to withstand wind and waves is similar to that of a self propelled cargo ship. There are several types of integral connection, wedge groove type. Also known as "T.B.S" type, and other “three-pin-fix”type, “ABC”type, “Murvicker” type and so on. Their common features are: the stern of the barge has a deep groove, and the shape of the barge matches with the front of the pusher. The pusher is wedged into the barge and is firmly locked with an oil pressure, and a buffer rubber is arranged between the contact surfaces. This connection is complicated in structure and inconvenient in operation. It is necessary to adjust the boat and barge to the right place to wedge in. But under the river-sea transportation, the seaworthiness of barge fleet should be the most important consideration, and this connection model can maintain steady sailing under the condition of 6 m waves.

Chapter 3 Economical demonstration

3.1 Scheme for comparison

In order to calculate the fleet size required by different speed, different tonnage, different type (self-propelled and non self-propelled) barges to complete the transportation capacity of 7 million tons of bauxite per year, the following experimental scheme was designed.

Each scheme contains 3 sets of factors: speed, barge type and tonnage, fleet size as shown in Table 5 ~ Table 7.

Table 5- Service speed schemes

	Speed scheme 1	Speed scheme 2	Speed scheme 3	Speed scheme 4
Loaded speed	8 kn	7 kn	6 kn	5 kn
Ballast speed	9 kn	8 kn	7 kn	6 kn

Source: own setting

Table 6- Barge tonnage and type schemes

Barge Type	Barge Tonnage
non self-propelled	10000DWT
	12000DWT
	15000DWT
self-propelled	10000DWT
	12000DWT
	15000DWT

Source: own setting

Table 7- Barge number schemes

Barge Type	Barge Number
non self-propelled	4
	6
	8
	10
self-propelled	4
	6
	8
	10

Source: own setting

Table 7- Barge particular and new building price

ship type	DWT/POWER	LOA	Beam	Depth	Laden draft	Unite price
self-propelled barge	10000DWT	114	24.2	7.3	5.1	48.51
self-propelled barge	12000DWT	119	26.5	8.2	5.45	57.33

self-propelled barge	15000DWT	130	29	8.6	5.65	67.62
barge	10000DWT	107	25.5	6.9	4.9	23.08
tug	3600HP					27.93
barge	12000DWT	108	29.5	7.3	4.98	27.93
tug	4800HP					33.08
barge	15000DWT	118	35	8	4.98	35.28
barge	6800HP					43.95

Source: own presentation, data from capt.JIN and Shanghai shipping Research Institution.

3.2 Search for the feasible schemes

According to the previous section, we obtained 96 contrasting schemes. Now we are going to pick out the schemes that can complete the transportation mission.

To accomplish this, we need to calculate the annual volume of each scheme：

$$Q = N_B W_0 K_{PB} \tag{3.1}$$

Where, Q = quantity of annual transportation(mt)

N_B= the number of barges

W_0= deadweight of each barge

K_{PB}= annual voyage times

The annual voyage times(K_{PB}) is the number of voyages a barge can complete within one year,

$$K_{PB} = [A/(M/24V_1 + M/24V_2)] \times f_B \tag{3.2}$$

Where, A= operating days per year

M= sailing distance (one direction)(kn)

V_1=loaded sailing speed (heading for anchorage)(kn)

V_2=ballast sailing speed (heading for loading port)(kn)

f_B=sailing rate

Sailing rate is the ratio of actual sailing time to operating time. Operating time consist by actual sailing time, loading time, discharging time, departure time, berthing time, tally time, hold inspecting time, ballasting time and other non productive times.

Sailing rate can be calculated by formula below:

$$f_B = (M/24V_1 + M/24V_2)/(M/24V_1 + M/24V_2 + t_0 + t_1 + t_2) \tag{3.3}$$

Where, M= sailing distance (one direction)(kn)

V_1=loaded sailing speed (heading for anchorage)(kn)

V_2=ballast sailing speed (heading for loading port)(kn)

t_0 =time for loading and discharging (h)

t_1 = time for berthing and unberthing(h)

t_2 = time for connecting the pusher/tug and barge(h)

The average time for berthing and unberthing of each barge is 1.5 h, according to the captions' experience.

The loading and discharging time (t_0)can be calculated by DWT of barge and the loading / discharging rate of dock / transfer platform, which is 2500mt per hour and 1850mt per hour respectively.

$$t_0 = \frac{W_0}{R_L} + \frac{W_0}{R_D} \tag{3.4}$$

Where W_0 = Deadweight of barge

R_L = Rate of loading at dock(mt/h)

R_D = Rate of discharging at transfer platform(mt/h)

By put-in the comparison schemes and functional relation into Excel, we can test if a scheme can complete the transportation mission.

As the Appendix A: "Comparison schemes " and Table 8- Capable schemes list shows: under the restriction of this case, the mission cannot be achieved by any four non self-propelled barge schemes, and same for six 10000DWT barge fleet.

For the six 12000DWT barge schemes, only they service speed at 7kn laden /

8kn ballast, can they complete the transportation mission.

For the six15000DWT barge schemes, due to the holds capacity, if their service speed over or at laden 5kn and ballast 6kn, they can always complete the transportation mission.

For the eight barge schemes, due to the fleet size, they can complete the transportation mission with each size of barge but for 1000DWT barge fleet they can not complete the mission under the speed of laden 5kn and ballast 6kn.

In the part of self-propelled barge schemes, the transportation mission cannot be achieved by any four self-propelled barge schemes as well.

For the six 1200DWT self-propelled barge schemes, they can complete the transportation mission if their speed higher than laden 7kn/h and ballast 8kn/h. For For the six 1500DWT self-propelled barge schemes, if their speed slower than laden 7kn/h and ballast 8kn/h, they can not complete the transportation mission.

The following list shows the fleet composition schemes capable for annual transport 10,000,000mt bauxite per year.

Table 8- Capable schemes list

Barge type A: non self-propelled barge B: self-propelled barge		Number	Speed (laden / ballast)		Annual transport volume(mt)	Coefficient of affluence (compare to10,000,000 mt per year)
A	12000DWT	6	8	9	11037024	10.37%
A	12000DWT	6	7	8	10134885	1.35%
A	15000DWT	6	8	9	12933017	29.33%
A	15000DWT	6	7	8	11936955	19.37%
A	15000DWT	6	6	7	10841086	8.41%
A	10000DWT	8	8	9	12834484	28.34%
A	10000DWT	8	7	8	11740732	17.41%
A	10000DWT	8	6	7	10559627	5.60%
A	12000DWT	8	8	9	14716032	47.16%
A	12000DWT	8	7	8	13513179	35.13%
A	12000DWT	8	6	7	12203935	22.04%
A	12000DWT	8	5	6	10772554	7.73%
A	15000DWT	8	8	9	17244023	72.44%
A	15000DWT	8	7	8	15915940	59.16%
A	15000DWT	8	6	7	14454782	44.55%
A	15000DWT	8	5	6	12838383	28.38%

A	10000DWT	10	8	9	16043105	60.43%
A	10000DWT	10	7	8	14675915	46.76%
A	10000DWT	10	6	7	13199534	32.00%
A	10000DWT	10	5	6	11599252	15.99%
A	12000DWT	10	8	9	18395040	83.95%
A	12000DWT	10	7	8	16891474	68.91%
A	12000DWT	10	6	7	15254918	52.55%
A	12000DWT	10	5	6	13465692	34.66%
A	15000DWT	10	8	9	21555029	115.55%
A	15000DWT	10	7	8	19894926	98.95%
A	15000DWT	10	6	7	18068477	80.68%
A	15000DWT	10	5	6	16047979	60.48%
B	12000DWT	6	8	9	11037024	10.37%
B	12000DWT	6	7	8	10134885	1.35%
B	15000DWT	6	8	9	12933017	29.33%
B	15000DWT	6	7	8	11936955	19.37%
B	15000DWT	6	6	7	10841086	8.41%
B	10000DWT	8	8	9	12834484	28.34%
B	10000DWT	8	7	8	11740732	17.41%
B	10000D	8	6	7	10559627	5.60%

	WT					
B	12000D WT	8	8	9	14716032	47.16%
B	12000D WT	8	7	8	13513179	35.13%
B	12000D WT	8	6	7	12203935	22.04%
B	12000D WT	8	5	6	10772554	7.73%
B	15000D WT	8	8	9	17244023	72.44%
B	15000D WT	8	7	8	15915940	59.16%
B	15000D WT	8	6	7	14454782	44.55%
B	15000D WT	8	5	6	12838383	28.38%
B	10000D WT	10	8	9	16043105	60.43%
B	10000D WT	10	7	8	14675915	46.76%
B	10000D WT	10	6	7	13199534	32.00%
B	10000D WT	10	5	6	11599252	15.99%
B	12000D WT	10	8	9	18395040	83.95%
B	12000D WT	10	7	8	16891474	68.91%
B	12000D WT	10	6	7	15254918	52.55%
B	12000D WT	10	5	6	13465692	34.66%
B	15000D WT	10	8	9	21555029	115.55%
B	15000D WT	10	7	8	19894926	98.95%
B	15000D WT	10	6	7	18068477	80.68%

B	15000DWT	10	5	6	16047979	60.48%

Source: own calculation

3.3 Chose the most economical scheme

3.3.1 Safety affluence

In order to pick out the most economical scheme, we reject the scheme which Coefficient of affluence higher than 50%. Because high Coefficient of affluence lead to a “over capacity”, which is a waste.

Also reject the schemes which Coefficient of affluence lower than 10%, because the operating area is located in tropical rain forest climate zone, the abundant precipitation in rainy season may affect the transport operation. So over than 10% Coefficient of affluence for safety is needed.

3.3.2 Total cost estimate

The total cost is the sum of all costs of operating a ship on an established route, including capital costs and shipping costs. The annual shipping cost of a ship is the sum of the expenses of each ship in a year, and basically consists of five major items: the cost of ship, the crew salary, FO/DO/LO consume, port charge and other charges.

3.3.2.1 Capital costs

Capital costs include the loans to banks(purchase of new vessels), annual repayment of principal and interest.

$$\text{capital cost} = \mathrm{P}_1(\frac{1+\mathrm{i}N}{N})$$

Where, P_1 = Loan value

i = Loaning rate

N = Shipping operation period(year)

In this case, i = 0.06, and we assume each barge will serve 15 years, so N=15.

3.3.2.2 Depreciation

The vessel is gradually lost since she was built, in order to compensate for the loss of the ship, a fee is charged annually at depreciation rate for a given period of time.

$$Y_1 = \frac{P - \Delta P}{N_1}$$

Where, $Y_1 =$ Depreciation charge per year

P = Ship building price

$\Delta P =$ The residual value to the planned vessel service years

$N_2 =$ The ship service years before her recycling

For the planned vessel service years, according to Chinese standards and regulation , the general service years of main ships are as follow:

Table 9- Allowable ship service years under Chinese regulation

Chemical tanker, dangerous goods carrier, LNG, LPG	18 ~ 20 years
Bulk carrier, RO RO and container ship	20 ~ 22 years
General Cargo ships and multi-purpose ship	25 years
Inland water tankers and barges	20 years
Passenger and cargo ships, cruise ships, and motor barge	24 years
Push integrated barge ship	22 years
High-speed passenger ship and glass-steel-body ship	10 ~ 15 years

Source:Ministry of Communications of the People's Republic of China, 1997

So we set the service years of our barge fleet as 20 years.

3.3.2.3 Maintenance

Ship maintenance cost is the annual share of various repair costs, according to a certain percentage of the ship price. The fee is also referred as repair fund. The ship maintenance including repairs , annual inspection and special inspection etc.. The maintenance drawing rate of ocean going vessels is 2.5%, coastal ships is 3.5%, inland water vessels is 4.5%. The maintenance cost also according to the actual conditions of ships.

3.3.2.4 Insurance

Insurance premiums are paid to insurance companies for insurance and are generally estimated by the following formula.

Annual insurance premium = Insurance rate * P

Where，P = ship building price

The insured value is usually put forward by the insurance company according to the condition of the ship, and the insured value is not equal to the ship price, but the transportation cost estimate can be assumed to be equal to the ship price.

The annual premium rate, usually 0.45~0.75%, depends on the ship's age, sizes, voyage distance, cargo type, navigation area conditions, etc.. If the ship sails in the war zone, the premium rate will be high. Generally, the insurance rate for the bulk cargo ship is about 0.55%, and about 0.7% for the tanker.

The following table shows three rates related to the price of the ship. The data are collected from shipping companies.

Table 10- Depreciation,Maintenance and Insurance cost rates related to new building price

Sailing area	Vessel type	Depreciation	Maintenance	Insurance	Total
Ocean	Bulk carrier，general	3.6%	2.5%	0.55%	6.55%

	cargo carrier， tug				
	Tanker	6%	2.5%	0.7%	9.2%
Coastal	Bulk carrier，general cargo carrier， tug， barge	3%	3.5%	0.6%	7.1%
	Tanker	4.5%	3.5%	0.8%	8.8%
Inland water	Bulk carrier，general cargo carrier， tug， barge	2.57%	4.5%	0.6%	7.67%
	Tanker	3.6%	4.5%	0.8%	8.9%

Source: data collected from many shipping managers

3.3.2.5 Crew costs

Crew costs, that is, the annual payment for crews. Crew costs are divided into basic wages, auxiliary wages, meals, sailing allowances, bonuses and wage surcharges. Crew costs account for about 46% of the operating costs. This paper refers to the historical data of COSCO Shipping Group when estimating the operating cost.

3.3.2.6 FO/DO/LO consumption

The cost will be estimated by the power and unit consumption of the main engine, marine auxiliary machinery and boiler, as well as the operating time and the price of fuel and lubricant.

In the calculation process, it should be divided into two situations： sailing and mooring. The engine power when sailing is about 80~85% of its maximum sustained power ; marine auxiliary machinery power in navigation and ship equipment (such as ship crane) during working are about 80% of their maximum sustained power, or 70% if ship is mooring; for crude oil tanker or oil barge, consider the need to warm the oil, the boiler should be take an other estimate.

FO is thicker and cheaper than DO, so FO is the major fuel when ship's sailing. In inland water navigation, DO is added to fuel to obtain better maneuverability.

The consumption of LO can be calculated separately according to the actual needs of the main engine and the marine auxiliary machinery. In estimation, LO cons presented as a percentage of the fuel cost:

For the ship sailing along coast: 7~10%

For the ship sailing in inland waterway : 17%

3.3.2.6 Port charges

Port charges including all of royalties and expenses when ships in the port , but in this case, the entire transportation system is a industrial transportation, so the loading dock facility is a also pier investing in this project. The owner of dock is also the owner of barge fleet, so this part of cost can be slip in the process of schemes' cost comparison temporarily.

3.3.2.7 other expenses

Other expenses refer to the integration of miscellaneous expenses for ships, including fleet management fees, entertainment expenses, bills printing fees, staff training fees, publicity fees, conference cost, communication fees, office supplies and so on.

Other costs generally make up about 15% of total annual costs.

3.3.3 Cost comparison results

According to The Hypothetical price of ship, ship forms and the prediction methods of various costs given in the previous section, the various costs of each ship type per year can be calculated by excel:

Table 11- annual cost for each type of barge(in million$)

ship type	DWT	unite price	crew cost	depreciation	maintenance	fuel cons	LO cons	insurance	management cost
self-propelled barge	10000DWT	48.51	19.30	4.85	1.91	11.43	0.37	0.89	9.35
self-propelled barge	12000DWT	57.33	19.30	5.73	1.91	12.00	0.40	0.90	9.35
self-propelled barge	15000DWT	67.62	19.30	6.76	1.91	12.37	0.44	0.98	10.25
barge	10000DWT	23.08	0.00	2.31	0.41	0.00	0.00	0.00	0.00

tug	3600HP	27.93	19.30	2.79	1.32	13.82	0.37	0.98	9.35
barge	12000DWT	27.93	0.00	2.79	0.44	0.00	0.00	0.00	0.00
tug	4800HP	33.08	19.30	3.31	1.47	19.65	0.40	1.10	11.51
barge	15000DWT	35.28	0.00	3.53	0.47	0.00	0.00	0.00	0.00
barge	6800HP	43.95	19.30	4.40	2.06	26.95	0.49	1.32	13.40

Source: own calculation

Based on the data given above, we can calculate the total cost of each feasible plan, including the shipping price. (As space is limited, costs details are in appendix B: "costs details of each feasible scheme")

Table 12- Total cost of each feasible scheme

Barge type A: non self-propelled barge B: self-propelled barge		Number	Speed (laden / ballast)		Coefficient of affluence (compare to10,000,000 mt per year)	TTL fleet price	Total cost
B	12000DWT	6	7	8	1.35%	23400	43247
B	**12000DWT**	**6**	**8**	**9**	**10.37%**	**23400**	**43247**
B	15000DWT	6	6	7	8.41%	27600	48500
B	15000DWT	6	7	8	19.37%	27600	48500
B	15000DWT	6	8	9	29.33%	27600	48500
A	12000DWT	6	7	8	1.35%	24900	49212
A	12000DWT	6	8	9	10.37%	24900	49212
B	10000DWT	8	6	7	5.60%	26400	52886
B	10000DWT	8	7	8	17.41%	26400	52886

B	10000DWT	8	8	9	28.34%	15200	41686

Source: own calculation

Through this table, we can quickly find the best solution(the second column), which has a relatively adequate security margin, but also more economical than other programs.

So far, we've worked out the best fleet composition by calculating the cost of the fleet each year. that is, using six 12000DWT self-propelled barge with 8 kn laden speed and 9 kn ballast speed to transport 10,000,000mt per year and have 1,037,034mt security margin.

Chapter 4 Summary and Further Discuss

4.1 Summary

4.1.1 Research process

In this paper, the composition of the fleet was fixed in four steps.

The first step is to determine the target of this industrial shipping system and determine the restrictions both natural and technical.

Transportation mission:

10 million tons of bauxite should be transport from a river port nearby mining area to the transfer-platform in the open sea anchorage each year.

Main restrictions:

Operating days: In consideration of the local climate (Each year there are3-month wet-season, heavy rainfall will affect the normal loading/discharging and transshipping.At the same time, the arrival of the flood season will affect the safety of sailing), the maintenance time of various equipment / facilities and the annual inspection / dry-docking time of vessels. So the whole transport system can be operated for 270 days per year.

Voyage distance: total voyage distance is 64km, including 40km inland waterway, 24km from the coast to open sea anchorage (transfer-platform).

Loading / discharging rate: There are two berths in loading port along the river: two barge berths are arranged in inland water, each berth have a belt conveyor (designed convey rate is 4000t/h). The average carrying efficiency of each berth per barge shall be 2500t/h.

The transfer platform has six ship cranes (designed working capability: 1000t/h) and can discharg 2 barges at same time ,the discharging rate shall be 1850t/h each barge.

The second step is listing the schemes for comparison according to the inland waterway draft (six meters), current shipbuilding technique, and the suggestion from some experienced captains, shipping company managers and Ship Design Institute.

The third step is to reject the schemes which failed to complete the transportation mission.

The fourth step is to choose the fleet composition solution with the lowest cost in the feasible schemes.

4.1.2 Research result

So far, we found the optimal barge fleet composition:

Table 13- The optimal barge fleet composition

Barge type A: non self-propelled barge B: self-propelled barge		Number	Speed (laden / ballast)		Coefficient of affluence (compare to10,000,000 mt per year)	TTL fleet price	Total cost
B	**12000DWT**	**6**	**8**	**9**	**10.37%**	**23400**	**43247**

Source: own calculation

That is using six 12000DWT self propelled barges with a service speed of 8/9 laden/ballast to complete the annual transportation volume of 10million tons bauxite.

4.2.3 Shortcomings

First of all, the contrast scheme of this paper is not enough. Ship fleet is a large investment.Before making a decision and signing a contract with shipyard, sufficient investigation should be done. But due to the limited knowledge of the author's own way, some barge transportation models such as Japan's new coastal barge technology remain to be discussed.

In the limited information which the author has consulted, the new type barges on the coast of Japan have large capacity, large wave resistance and more suitable for the sea and river combined transport. But because of this new type of vessel's building price is much higher, and maintenance cost is great, the application of suge barge needs further discussion.

According to other information the author consulted, on Miami coast of the United States, some container are also operated by barge fleet.The fleet operates mainly in towing, but I did not find the fleet's information, and, according to shipping manager and caption's experience, towing model in the Yangtze River is gradually faded from the field of vision, due to its drawbacks of maneuverability and safety.

Second, in the cost comparison process, almost all costs, including the cost of the ship, are roughly estimated. For example, when calculating crew costs, I ignored different requirements for manning between different ship types, but use the same crew cost for each ship.

When calculating fuel consumption, I can only estimate by empirical proportion because of my insufficient engineering knowledge. At the same time, I didn't forecast the fluctuation of fuel oil price for the next year, but the fact is that the price of fuel is changing every day. If anyone want to make accurate cost estimates, a reasonable forecasts of fuel prices should be done.

Moreover, in reality, the unite price of ship is different between build one ship and a fleet. The larger the tonnage, the lower the unit cost; the more the number of mass construction, the lower the cost of a single ship As the cost is reduced, ships are allowed higher speed,.

4.2 Further discuss： If the loading/discharging efficiency improved

4.2.1 Problem proposition

In the main part of this paper, the loading and discharging rate of the dock and the transfer-platform are fixed for the sake of calculation.Compared to the large investment and long construction period of the dredging river, improving the efficiency of -loading and unloading rate is not only cheaper, but also more likely to change in the future.

In this section, I will research on the possibility to reduce the logistics cost of whole transportation system by further improving the loading and discharging efficiency of both ends, as well as which end deserves more investment.

4.2.2 Analysis methods

On the basis of the comparison scheme of the original barge fleet information, we raise the loading and discharging efficiency of the dock side and the platform side respectively. By comparing the corresponding changes(margin) in the total annual transportation volume, the possibility of the realization of the loading and unloading system is proved in combination with the actual situation.

With in the previous model, I changed the loading and discharging rate from the original figure to (2500t/h), 3000t/h, 3500t/h,4000t/h respectively and a "slop function"(regress the two sets of data) was implied in Excel to calculate the degree of the change of annual transportation volume.

4.2.3 Model calculation result

Because of the limited space, please refer to the Appendix B for the full results form.

The most notable finding is that the greater the DWT of barges, the greater the cost reduction by improve loading and discharging efficiency.

Over all, the average slop(degree of change)of changing discharging rate (263) is higher than changing loading rate(243). So, Increasing the unloading efficiency of the barge on the transshipment platform will be more conducive to reducing the overall transport cost.

4.2.4 Summary

After the calculations above, it is theoretically feasible to reduce a barge by increasing the L/D efficiency. If reducing the number of 1~2 barge barges, the depreciation, and related management costs can be reduced, the preliminary estimates, each reduction of 1 barges, the annual cost reduction of about 2 million US dollar.

After the calculations above, it is theoretically feasible to reduce a barge by increasing the efficiency of handling. Reduce the number of 1~2 barge barges, depreciation, and related personnel management costs can be reduced, the preliminary estimates, each reduction of 1 barges, the annual cost reduction of about 2,813,900 dollar.

But, enhance the efficiency of loading and discharging will also bring technical problems and cost (if terminal machine, yard conveyor and transportation equipment ability increased, the corresponding cost will increased), and, for 10 thousand tons of barge loading capacity of 4000 tons, the original should be said has been great, to further improve the L/D rate will bring greater security risks, which is not conducive to safety operation.

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Appendix A: The list of Comparison schemes

Barge type A: non self-propelled barge B: self-propelled barge		Number	Speed (laden / ballast)		Coefficient of affluence (compare to10,000,000 mt per year)	TTL fleet price	Total cost
B	12000DWT	6	7	8	1.35%	23400	43247
B	**12000DWT**	**6**	**8**	**9**	**10.37%**	**23400**	**43247**
B	15000DWT	6	6	7	8.41%	27600	48500
B	15000DWT	6	7	8	19.37%	27600	48500
B	15000DWT	6	8	9	29.33%	27600	48500
A	12000DWT	6	7	8	1.35%	24900	49212
A	12000DWT	6	8	9	10.37%	24900	49212
B	10000DWT	8	6	7	5.60%	26400	52886
B	10000DWT	8	7	8	17.41%	26400	52886
B	10000DWT	8	8	9	28.34%	15200	41686
A	10000DWT	8	6	7	5.60%	27760	55128
A	10000DWT	8	7	8	17.41%	27760	55128
A	10000DWT	8	8	9	28.34%	27760	55128
B	12000DWT	8	5	6	7.73%	31200	57663
B	12000DWT	8	6	7	22.04%	31200	57663
B	12000DWT	8	7	8	35.13%	31200	57663
B	12000DWT	8	8	9	47.16%	31200	57663
A	15000DWT	6	6	7	8.41%	32340	61488
A	15000DWT	6	7	8	19.37%	32340	61488

A	15000DWT	6	8	9	29.33%	32340	61488
B	15000DWT	8	5	6	28.38%	36800	64667
B	15000DWT	8	6	7	44.55%	36800	64667
A	12000DWT	8	5	6	7.73%	33200	65616
A	12000DWT	8	6	7	22.04%	33200	65616
A	12000DWT	8	7	8	35.13%	33200	65616
A	12000DWT	8	8	9	47.16%	33200	65616
B	10000DWT	10	5	6	15.99%	33000	66107
B	10000DWT	10	6	7	32.00%	33000	66107
B	10000DWT	10	7	8	46.76%	33000	66107
A	10000DWT	10	5	6	15.99%	34700	68910
A	10000DWT	10	6	7	32.00%	34700	68910
A	10000DWT	10	7	8	46.76%	34700	68910
B	12000DWT	10	5	6	34.66%	39000	72079
A	15000DWT	8	5	6	28.38%	43120	81984
A	15000DWT	8	6	7	44.55%	43120	81984
A	12000DWT	10	5	6	34.66%	41500	82020

Appendix B: Costs details of each feasible scheme

total	43,247	43,247	48,500	48,500	48,500	49,212
management	3,815	3,815	4,183	4,183	4,183	4,697
insurance	368	368	402	402	402	448
fuel cons	4,666	4,666	4,897	4,897	4,897	8,020
tug maintenance	0	0	0	0	0	600
barge maintenance	780	780	780	780	780	180
tug depreciation	0	0	0	0	0	1,350
barge depreciation	2,340	2,340	2,760	2,760	2,760	1,140
Crew cost	7,878	7,878	7,878	7,878	7,878	7,878
ttl fleet price	23,400	23,400	27,600	27,600	27,600	24,900
Tug price	0	0	0	0	0	13,500
Barge price	23,400	23,400	27,600	27,600	27,600	11,400
Coefficient of affluence (compare	1. 35%	10. 37%	8. 41%	19. 37%	29. 33%	1. 35%
Annual transport volume (mt)	10, 134, 885	11, 037, 024	10, 841, 086	11, 936, 955	12, 933, 017	10,134,885
Speed (laden / ballast)	8	9	7	8	9	8
	7	8	6	7	8	7
Number	6	6	6	6	6	6
Barge type A: non self-propell B: self-propell	12000DWT	12000DWT	15000DWT	15000DWT	15000DWT	12000DWT
	B	B	B	B	B	A

49,212	52,886	52,886	41,686	55,128	55,128	55,128	57,663	57,663	57,663
4,697	5,087	5,087	5,087	5,087	5,087	5,087	5,087	5,087	5,087
448	482	482	482	534	534	534	490	490	490
8,020	6,733	6,733	6,733	7,523	7,523	7,523	6,222	6,222	6,222
600	0	0	0	720	720	720	0	0	0
180	1,040	1,040	1,040	224	224	224	1,040	1,040	1,040
1,350	0	0	0	1,520	1,520	1,520	0	0	0
1,140	2,640	2,640	2,640	1,256	1,256	1,256	3,120	3,120	3,120
7,878	10,504	10,504	10,504	10,504	10,504	10,504	10,504	10,504	10,504
24,900	26,400	26,400	15,200	27,760	27,760	27,760	31,200	31,200	31,200
13,500	0	0	0	15,200	15,200	15,200	0	0	0
11,400	26,400	26,400	15,200	12,560	12,560	12,560	31,200	31,200	31,200
10. 37%	5. 60%	17. 41%	28. 34%	5. 60%	17. 41%	28. 34%	7. 73%	22. 04%	35. 13%
11,037,024	10, 559, 627	11, 740, 732	12, 834, 484	10, 559, 627	11, 740, 732	12, 834, 484	10, 772, 554	12, 203, 935	13, 513, 179
9	7	8	9	7	8	9	6	7	8
8	6	7	8	6	7	8	5	6	7
6	8	8	8	8	8	8	8	8	8
12000DWT	10000DWT	10000DWT	10000DWT	10000DWT	10000DWT	10000DWT	12000DWT	12000DWT	12000DWT
A	B	B	B	A	A	A	B	B	B

57,663	61,488	61,488	61,488	64,667	64,667	65,616	65,616	65,616	65,616
5,087	5,469	5,469	5,469	5,577	5,577	6,262	6,262	6,262	6,262
490	537	537	537	536	536	597	597	597	597
6,222	10,998	10,998	10,998	6,529	6,529	10,693	10,693	10,693	10,693
0	840	840	840	0	0	800	800	800	800
1,040	192	192	192	1,040	1,040	240	240	240	240
0	1,794	1,794	1,794	0	0	1,800	1,800	1,800	1,800
3,120	1,440	1,440	1,440	3,680	3,680	1,520	1,520	1,520	1,520
10,504	7,878	7,878	7,878	10,504	10,504	10,504	10,504	10,504	10,504
31,200	32,340	32,340	32,340	36,800	36,800	33,200	33,200	33,200	33,200
0	17,940	17,940	17,940	0	0	18,000	18,000	18,000	18,000
31,200	14,400	14,400	14,400	36,800	36,800	15,200	15,200	15,200	15,200
47. 16%	8. 41%	19. 37%	29. 33%	28. 38%	44. 55%	7. 73%	22. 04%	35. 13%	47. 16%
14, 716, 032	10,841,086	11,936,955	12,933,017	12, 838, 383	14, 454, 782	10, 772, 554	12, 203, 935	13, 513, 179	14, 716, 032
9	7	8	9	6	7	6	7	8	9
8	6	7	8	5	6	5	6	7	8
8	6	6	6	8	8	8	8	8	8
12000DWT	15000DWT	15000DWT	15000DWT	15000DWT	15000DWT	12000DWT	12000DWT	12000DWT	12000DWT
B	A	A	A	B	B	A	A	A	A

66,107	66,107	66,107	68,910	68,910	68,910	72,079	81,984	81,984	82,020
6,359	6,359	6,359	6,359	6,359	6,359	6,359	7,292	7,292	7,828
603	603	603	667	667	667	613	716	716	746
8,416	8,416	8,416	9,404	9,404	9,404	7,777	14,664	14,664	13,366
0	0	0	900	900	900	0	1,120	1,120	1,000
1,300	1,300	1,300	280	280	280	1,300	256	256	300
0	0	0	1,900	1,900	1,900	0	2,392	2,392	2,250
3,300	3,300	3,300	1,570	1,570	1,570	3,900	1,920	1,920	1,900
13,130	13,130	13,130	13,130	13,130	13,130	13,130	10,504	10,504	13,130
33,000	33,000	33,000	34,700	34,700	34,700	39,000	43,120	43,120	41,500
0	0	0	19,000	19,000	19,000	0	23,920	23,920	22,500
33,000	33,000	33,000	15,700	15,700	15,700	39,000	19,200	19,200	19,000
15.99%	32.00%	46.76%	15.99%	32.00%	46.76%	34.66%	28.38%	44.55%	34.66%
11,599,252	13,199,534	14,675,915	11,599,252	13,199,534	14,675,915	13,465,692	12,838,383	14,454,782	13,465,692
6	7	8	6	7	8	6	6	7	6
5	6	7	5	6	7	5	5	6	5
10	10	10	10	10	10	10	8	8	10
10000DWT	10000DWT	10000DWT	10000DWT	10000DWT	10000DWT	12000DWT	15000DWT	15000DWT	12000DWT
B	B	B	A	A	A	B	A	A	A

Appendix C: The effect of increasing handling efficiency of both ends on annual transportation volume

loaded spd	ballast spd	DWT barge	no.of barge	no.of pusher	DWT self-propelled barge	no. of self-propelled barge	Q=	Q=	Q=	Q=	Q=	slope	Q=	Q=	Q=	Q=	Q=	Q=	slope
Vl=	Vb=	W0=	Nb=	Np=	W1=	Na=	2500	3000	3500	4000	5000		1850	2500	3000	3500	4000	5000	
5	6	0	0	0	10000	4	4639701	4695737	4736598	4767714	4811970	67	4639701	4759433	4818417	4861451	4894235	4940882	71
5	6	10000	4	4	0	0	4639701	4695737	4736598	4767714	4811970	67	4639701	4759433	4818417	4861451	4894235	4940882	71
6	7	0	0	0	10000	4	5279813	5352499	5405655	5446220	5504044	88	5279813	5435416	5512481	5568878	5611940	5673357	93
6	7	10000	4	4	0	0	5279813	5352499	5405655	5446220	5504044	88	5279813	5435416	5512481	5568878	5611940	5673357	93
5	6	0	0	0	12000	4	5386277	5461944	5517307	5559572	5619842	91	5386277	5548315	5628637	5687449	5732371	5796468	97
5	6	12000	4	4	0	0	5386277	5461944	5517307	5559572	5619842	91	5386277	5548315	5628637	5687449	5732371	5796468	97
5	6	0	0	0	10000	6	6959551	7043605	7104898	7151572	7217955	101	6959551	7139150	7227626	7292177	7341353	7411323	106
5	6	10000	6	6	0	0	6959551	7043605	7104898	7151572	7217955	101	6959551	7139150	7227626	7292177	7341353	7411323	106
7	8	0	0	0	10000	4	5870366	5960359	6026349	6076807	6148886	109	5870366	6063361	6159417	6229913	6283854	6360959	116
7	8	10000	4	4	0	0	5870366	5960359	6026349	6076807	6148886	109	5870366	6063361	6159417	6229913	6283854	6360959	116
6	7	0	0	0	12000	4	6101967	6199261	6270677	6325329	6403462	118	6101967	6310761	6414884	6491386	6549970	6633788	126

6	7	12000	4	4	0	0	6101967	6199261	6270677	6325329	6403462	118	6101967	6310761	6414884	6491386	6549970	6633788	126
8	9	0	0	0	10000	4	6417242	6524938	6604103	6664750	6751550	131	6417242	6648578	6764249	6849366	6914622	7008099	141
8	9	10000	4	4	0	0	6417242	6524938	6604103	6664750	6751550	131	6417242	6648578	6764249	6849366	6914622	7008099	141
5	6	0	0	0	15000	4	6419192	6526953	6606168	6666852	6753708	131	6419192	6650671	6766415	6851587	6916886	7010424	141
5	6	15000	4	4	0	0	6419192	6526953	6606168	6666852	6753708	131	6419192	6650671	6766415	6851587	6916886	7010424	141
6	7	0	0	0	10000	6	7919720	8028749	8108482	8169330	8256067	131	7919720	8153125	8268721	8353318	8417910	8510035	140
6	7	10000	6	6	0	0	7919720	8028749	8108482	8169330	8256067	131	7919720	8153125	8268721	8353318	8417910	8510035	140
5	6	0	0	0	10000	8	9279401	9391474	9473197	9535429	9623940	135	9279401	9518866	9636834	9722903	9788470	9881764	142
5	6	10000	8	8	0	0	9279401	9391474	9473197	9535429	9623940	135	9279401	9518866	9636834	9722903	9788470	9881764	142
5	6	0	0	0	12000	6	8079415	8192917	8275961	8339358	8429763	137	8079415	8322472	8442956	8531174	8598557	8694701	146
5	6	12000	6	6	0	0	8079415	8192917	8275961	8339358	8429763	137	8079415	8322472	8442956	8531174	8598557	8694701	146
7	8	0	0	0	12000	4	6756590	6876083	6964056	7031527	7128213	145	6756590	7013529	7142370	7237335	7310234	7414794	157
7	8	12000	4	4	0	0	6756590	6876083	6964056	7031527	7128213	145	6756590	7013529	7142370	7237335	7310234	7414794	157
7	8	0	0	0	10000	6	8805549	8940539	9039523	9115211	9223329	163	8805549	9095041	9239126	9344870	9425781	9541439	175
7	8	10000	6	6	0	0	8805549	8940539	9039523	9115211	9223329	163	8805549	9095041	9239126	9344870	9425781	9541439	175
6	7	0	0	0	15000	4	7227391	7364285	7465286	7542873	7654245	167	7227391	7522166	7670570	7780209	7864517	7985666	181
6	7	15000	4	4	0	0	7227391	7364285	7465286	7542873	7654245	167	7227391	7522166	7670570	7780209	7864517	7985666	181
5	6	0	0	0	10000	10	11599252	11739342	11841496	11919286	12029925	168	11599252	11898583	12046043	12153629	12235588	12352206	177

5	6	10000	10	10	0	0	11599252	11739342	11841496	11919286	12029925	168	11599252	11898583	12046043	12153629	12235588	12352206	177
8	9	0	0	0	12000	4	7358016	7499952	7604735	7685263	7800911	173	7358016	7663768	7817869	7931790	8019434	8145441	188
8	9	12000	4	4	0	0	7358016	7499952	7604735	7685263	7800911	173	7358016	7663768	7817869	7931790	8019434	8145441	188
6	7	0	0	0	10000	8	10559627	10704998	10811310	10892440	11008089	175	10559627	10870833	11024962	11137757	11223880	11346713	186
6	7	10000	8	8	0	0	10559627	10704998	10811310	10892440	11008089	175	10559627	10870833	11024962	11137757	11223880	11346713	186
6	7	0	0	0	12000	6	9152951	9298891	9406016	9487994	9605193	177	9152951	9466142	9622326	9737079	9824955	9950682	189
6	7	12000	6	6	0	0	9152951	9298891	9406016	9487994	9605193	177	9152951	9466142	9622326	9737079	9824955	9950682	189
5	6	0	0	0	12000	8	10772554	10923889	11034615	11119144	11239684	183	10772554	11096629	11257275	11374899	11464743	11592935	194
5	6	12000	8	8	0	0	10772554	10923889	11034615	11119144	11239684	183	10772554	11096629	11257275	11374899	11464743	11592935	194
8	9	0	0	0	10000	6	9625863	9787407	9906155	9997124	10127325	196	9625863	9972868	10146373	10274048	10371934	10512149	211
8	9	10000	6	6	0	0	9625863	9787407	9906155	9997124	10127325	196	9625863	9972868	10146373	10274048	10371934	10512149	211
5	6	0	0	0	15000	6	9628787	9790430	9909252	10000279	10130562	196	9628787	9976006	10149622	10277380	10375329	10515636	211
5	6	15000	6	6	0	0	9628787	9790430	9909252	10000279	10130562	196	9628787	9976006	10149622	10277380	10375329	10515636	211
7	8	0	0	0	15000	4	7957970	8124258	8247354	8342152	8478590	204	7957970	8316832	8498626	8633422	8737359	8887147	223
7	8	15000	4	4	0	0	7957970	8124258	8247354	8342152	8478590	204	7957970	8316832	8498626	8633422	8737359	8887147	223
7	8	0	0	0	10000	8	11740732	11920719	12052697	12153615	12297772	218	11740732	12126721	12318834	12459827	12567708	12721918	233
7	8	10000	8	8	0	0	11740732	11920719	12052697	12153615	12297772	218	11740732	12126721	12318834	12459827	12567708	12721918	233
7	8	0	0	0	12000	6	10134885	10314124	10446083	10547290	10692320	218	10134885	10520294	10713555	10856003	10965351	11122190	235

7	8	12000	6	6	0	0	10134885	10314124	10446083	10547290	10692320	218	10134885	10520294	10713555	10856003	10965351	11122190	235
6	7	0	0	0	10000	10	13199534	13381248	13514137	13615550	13760111	219	13199534	13588541	13781202	13922196	14029850	14183392	233
6	7	10000	10	10	0	0	13199534	13381248	13514137	13615550	13760111	219	13199534	13588541	13781202	13922196	14029850	14183392	233
5	6	0	0	0	12000	10	13465692	13654861	13793269	13898930	14049605	228	13465692	13870787	14071593	14218624	14330928	14491169	243
5	6	12000	10	10	0	0	13465692	13654861	13793269	13898930	14049605	228	13465692	13870787	14071593	14218624	14330928	14491169	243
6	7	0	0	0	12000	8	12203935	12398521	12541355	12650659	12806924	236	12203935	12621523	12829768	12982771	13099941	13267576	253
6	7	12000	8	8	0	0	12203935	12398521	12541355	12650659	12806924	236	12203935	12621523	12829768	12982771	13099941	13267576	253
8	9	0	0	0	15000	4	8622011	8817549	8962738	9074807	9236496	241	8622011	9044852	9260279	9420546	9544435	9723457	266
8	9	15000	4	4	0	0	8622011	8817549	8962738	9074807	9236496	241	8622011	9044852	9260279	9420546	9544435	9723457	266
6	7	0	0	0	15000	6	10841086	11046428	11197929	11314309	11481367	250	10841086	11283249	11505855	11670313	11796776	11978498	272
6	7	15000	6	6	0	0	10841086	11046428	11197929	11314309	11481367	250	10841086	11283249	11505855	11670313	11796776	11978498	272
8	9	0	0	0	12000	6	11037024	11249928	11407102	11527895	11701367	260	11037024	11495653	11726804	11897686	12029152	12218162	283
8	9	12000	6	6	0	0	11037024	11249928	11407102	11527895	11701367	260	11037024	11495653	11726804	11897686	12029152	12218162	283
8	9	0	0	0	10000	8	12834484	13049876	13208207	13329499	13503100	261	12834484	13297157	13528498	13698731	13829245	14016198	281
8	9	10000	8	8	0	0	12834484	13049876	13208207	13329499	13503100	261	12834484	13297157	13528498	13698731	13829245	14016198	281
5	6	0	0	0	15000	8	12838383	13053907	13212336	13333705	13507416	262	12838383	13301342	13532830	13703173	13833772	14020849	281
5	6	15000	8	8	0	0	12838383	13053907	13212336	13333705	13507416	262	12838383	13301342	13532830	13703173	13833772	14020849	281
7	8	0	0	0	10000	10	14675915	14900899	15065871	15192018	15372215	272	14675915	15158401	15398543	15574784	15709635	15902398	291

7	8	10000	10	10	0	0	14675915	14900899	15065871	15192018	15372215	272	14675915	15158401	15398543	15574784	15709635	15902398	291
7	8	0	0	0	12000	8	13513179	13752165	13928111	14063054	14256427	291	13513179	14027058	14284740	14474671	14620467	14829587	314
7	8	12000	8	8	0	0	13513179	13752165	13928111	14063054	14256427	291	13513179	14027058	14284740	14474671	14620467	14829587	314
6	7	0	0	0	12000	10	15254918	15498152	15676694	15813323	16008655	295	15254918	15776904	16037210	16228464	16374926	16584470	316
6	7	12000	10	10	0	0	15254918	15498152	15676694	15813323	16008655	295	15254918	15776904	16037210	16228464	16374926	16584470	316
7	8	0	0	0	15000	6	11936955	12186387	12371031	12513228	12717886	306	11936955	12475248	12747939	12950133	13106039	13330721	335
7	8	15000	6	6	0	0	11936955	12186387	12371031	12513228	12717886	306	11936955	12475248	12747939	12950133	13106039	13330721	335
8	9	0	0	0	10000	10	16043105	16312345	16510258	16661874	16878875	327	16043105	16621446	16910622	17123414	17286556	17520248	352
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5	6	0	0	0	15000	10	16047979	16317383	16515420	16667131	16884270	327	16047979	16626677	16916037	17128966	17292215	17526061	352
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