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Research on optimizing liner routing schedule of ZhongGu Shipping Company

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Research on Optimizing Liner Routing and Schedule of ZhongGu Shipping Company

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DECLARATION

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

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

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ABSTRACT

Title of research paper:

Research on optimizing liner routing and schedule of ZhongGu Shipping Company

Degree: MSc

Abstract: The liner shipping service network design problem aims to determine which candidate shipping line should be chosen, what ship deployment plan should be used to serve a chosen shipping line, how many laden containers each deployed ship should carry on a segment and how to reposition the empty containers, with the objective of minimizing the total operating cost, which means ports of call, call sequence, ship type and deployment, and service frequency and sailing speed. These are the main factors to affect the strategy decision and service schedule. I work in ZhongGu Shipping Company and want to help it redesigning and optimizing the liner routing and schedule. Thus, this paper uses a three-stage optimization method to deal with the data related to the factors and combines all the issues to formulate this liner routing optimal schedule problem as a mixed integer programming model with the objective to minimize the total cost incurred from the liner routing on the schedule, including ship related costs, fuel consumption costs, port related costs, laden containers and empty container inventory-in-transition costs. A solution algorithm, combined with a primal heuristic obtains promising bounds, is then proposed. Finally, a numerical example and sensitive analysis are used to evaluate the performance of the proposed model and solution algorithm.

KEYWORDS: Liner routing, Schedule, optimization, ZhongGu Shipping Company

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1. Introduction

1.1 Research backgrounds

During the last two decades, hub-and-spoke network design problems have received increasing attention in a wide range of application areas such as transportation, telecommunications, computer networks, postal delivery, less-than-truck loading (LTL) and supply chain management. The economy of scale offered by hub-and-spoke network structures for transferring origin–destination (O–D) flows is exploited by concentrating flow on fewer links and by avoiding underutilized connections.

In order to maximize the benefits of the shipping company, especially the liner shipping company, the company has to analyze the both conditions of market and itself and design the most suitable liner routes for it. How to establish the schedule is base on several factors about which a lot of research on liner route designing has been done.

1.2 Literature review

The shipping market is affected by the world economy and the directly obvious reflection is freight rate changes. Shipping market cycles can be described as the overlapping of three different cycles (Stopford, 2009): 1, long-term cycles, typically driven by major changes in the industries of seaborne commodities; 2, short-term cycles, which mainly follow the evolution of the world economy; and 3, seasonal cycles, characteristic of many seaborne commodity trades. Shipping companies operate in such an uncertain and changeable environment, and a crucial strategic decision is that of designing an optimal fleet of ships. Giovanni Pantuso, Kjetil Fagerholt and Lars Magnus Hvattum (2013) think that deciding how many ships of each type to use in order to meet the demand is typically to minimize the total cost of setting up and operating a fleet of ships and usually the problem includes ship routing or deployment decisions to support the tonnage estimation.

Capacity utilization of a liner ship route is a reflection of the percentage of utilized ship slots. It is one of the main determinants of a liner shipping company's profitability (Agarwal and Ergun, 2008). Compared with other possible indicators such as total cost and revenue, capacity utilization is simple and easily obtainable in shipping industry while the total cost/revenue has a number of components and is subject to a number of unpredictable factors, such as changes in port calling charges, fluctuations in bunker price, and variation of currency exchange rates. About capacity utilization of a liner ship route, Shuaian Wang, Qiang Meng and Michael G.H. Bell (2012) formulate it as a linear programming model and a min–max model, respectively and they assess two fundamental properties of the min–max model to develop two e-optimal global optimization algorithms for solving the min–max model, which find a globally ε-optimal solution by iteratively cutting off the bounded polyhedral container shipment demand set with a cut.

To guide the optimal deployment of the ships, a single vessel round trip is considered by minimizing operational costs and flowing the best paying demand under commercially driven constraints. Christian E.M.Plum, DavidPisinger, Juan-José Salazar-González and Mikkel M.Sigurd (2013) use two novel models of the Single Liner Shipping Service Design Problem and a Branch-and-Cut-and-Price solution method for solving the problem. The algorithm can solve instances with up to 25 ports to optimality, a very promising result as real-world vessel round trips seldom involve more than 20 ports.

In a short-term liner ship fleet planning, Qiang Meng, Tingsong Wang and Shuaian Wang (2012) take into account container transshipment and uncertain container shipment demand, which is affected by some unpredictable and uncontrollable factors. To characterize the uncertainty, they first assume that the number of containers transported from an origin port to a destination port is a random variable. With this random container shipment demand, the proposed problem can be formulated as a two-stage stochastic integer programming model, with the objective of maximizing the expected value of the total profit, and then, a solution algorithm integrating the sample average approximation method and a dual decomposition and Lagrangian relaxation approach will be developed.

In a single liner long-haul service route designing, the problem includes route structure design, ship deployment and empty container repositioning. Dong-Ping Song and Jing-Xin Dong (2013) minimize the total cost incurred from a liner long-haul service route, including ship related costs, fuel consumption costs, port related costs, laden containers and empty container inventory-in-transition costs. A three-stage optimization is used to takes advantage of the characteristics of the existing route structures and can solve the service route design problems effectively from the practical perspective. In addition, the established relationships between the load factors and the route structure provide useful insights into ship utilization and route structure choice.

Given a set of port-to-port container shipment demands with delivery deadlines, the liner shipping company aims to design itineraries of port calls, deploy ships on these itineraries and determine how to transport containers with the deployed ships in order to maximize its total profit. Shuaian Wang and QiangMeng (2013) develop an optimization model and design a tangible solution algorithm for the liner shipping network design problem with deadlines. They formulate the proposed problem as amixed-integer non-linear non-convex programming model. A column generation based heuristic method is proposed for solving this problem.

Container routing determines how to transport containers from their origins to their destinations in a liner shipping network. Container routing needs to be solved a number of times as a subproblem in tactical-level decision planning of liner shipping operations. Shuaian Wang (2013) proposes a novel hybrid-link-based model that nests the existing origin-link-based and destination-link-based models as special cases, which compared with the origin-to-destination-link-based, origin-link-based and destination-link-based models.

Besides, the local cargo demands and inland transport efficiency determine the port selection. Existing methods for liner shipping network design mainly deal with port-to-port demand but most of the demand has inland origins and/or destinations. Zhiyuan Liu, Qiang Meng , Shuaian Wang and Zhuo Sun (2013) think it is necessary to cope with inland origin–destination pairs involving a change in transport mode from inland transportation to maritime shipping. They provide a comprehensive methodology for the problem of global intermodal liner shipping network design, in which inland transportation costs, port handling costs and seaborne shipping costs are all considered and a destination-based optimization model for quantitatively evaluating any set of liner shipping networks to refine the ship routes and design new ship routes.

Liner container shipping companies are transporting more containers than before due to the ever-increasing container shipment demand. So they deploy large ships sailing among hub ports to benefit the economies of scale. The increase in ship size and shipment demand also leads to a shift of the ship deployment strategy from multi-port-calling (MPC) to combined hub-and-spoke (H&S) and MPC especially for global liner container shipping companies such as Maersk (2010). Qiang Meng and Shuaian Wang (2011) do the research on liner shipping service network design with combined H&S and MPC operations and empty container repositioning and develop a mixed-integer linear programming model for the proposed liner shipping service network design problem, which can be efficiently solved by commonly used optimization solvers such as CPLEX. As a result, the combined network dominates pure H&S and pure MPC networks in the sense that the combined one has the lowest operating cost. Numerical results demonstrate that large cost-savings can be expected by incorporating the empty container repositioning issue at the network design stage.

Shahin Gelareh and David Pisinger (2011) do the study on the simultaneous design of network and fleet deployment of a deep-sea liner service provider which is based on a 4-index (5-index by considering capacity type) formulation of the hub location problem which are known for their tightness. They then propose a primal decomposition method to solve instances of the problem to optimality and determine the quality of the solution by boxing the optimal value between a lower and upper bound, even when stopped before proving optimality.

Most studies on optimization of liner shipping operations usually assume that the port time is fixed or is a linear function of the number of containers handled. Shuaian Wang and Qiang Meng (2012) take port congestion and port time variability into account. They examine the design of liner ship route schedules that can hedge against the uncertainties in port operations, which include the uncertain wait time due to port congestion and uncertain container handling time by formulating a mixed-integer nonlinear stochastic programming model.

Nowadays, the environment problem is a very important issue in the world and the shipping industry is one of the main sources of environment pollution. Speed reduction can reducing CO2 emissions for the container shipping industry in achieving its environmental sustainability (Psaraftis, H.N., Kontovas,C.A., Kakalis, M.P., 2009). Xiangtong Qi and Dong-Ping Song (2012) attempt to fill research gap with the stochastic aspect of the systems. They focuses on designing an optimal vessel schedule in a given shipping route with the aim to minimize the total fuel consumption (or emissions) by considering uncertain port times at each port-of-call and the frequency requirements on the liner schedule. Meanwhile, by introducing the penalty of being late, they design an optimal vessel schedule with reasonably high service levels.

An increasing bunker price in container shipping, especially in the short term, is only partially compensated through surcharges and will therefore affect earnings negatively. Theo E. Notteboom and Bert Vernimmen (2009) assess how shipping lines have adapted their liner service schedules (in terms of commercial speed, number of vessels deployed per loop, etc.) to deal with increased bunker costs and set up a cost model to simulate the impact of bunker cost changes on the operational costs of liner services. The model shows shipping lines are reacting quite late to higher bunker costs. The reasons that explain the late adaptation of liner services relate to inertia, transit time concerns, increasing costs associated with fixing schedule integrity problems and fleet management issues.

Fagerholt, K., Laporte, G. and Norstad, I. (2010) minimize vessel fuel consumption on a single route while satisfying port time windows by determining optimal sailing speed for each voyage leg. Judith Mulder and Rommert Dekker (2013) consider that the optimal sailing speed has to be determined for each ship route. A ship route is a sequence of ports that are visited by a ship and the ship routes are cyclic and consist of a westbound and an eastbound trip.

Kang Chen, Zhongzhen Yang and Theo Notteboom (2013) present a New Coastal Liner Route Design Model (NCLRDM) for coastal intermodal networks based on the user equilibrium assignment model with the objective of minimizing state subsidies for coastal shipping operators under a given carbon emission reduction target for the entire intermodal network. A network-topology method (Temporal–Spatial Expansion) captures differences in traffic assignment between waterway and highway networks.

Each port is usually called at no more than twice along one string, although a single port may be called at several times on different strings. The size of string dictates the number of vessels required to offer a given frequency of service. Groups of Liner Service Providers sometimes make a short term agreement to merge some of their service routes (in a certain region) into one main ocean going rotation and sub-feeder rotations. Shahin Gelareh, Nelson Maculan , Philippe Mahey and Rahimeh Neamatian Monemi (2012) propose a mixed integer linear programming model of the network design, and an allocation of proper capacity size and frequency setting for every rotation and propose a Lagrangian decomposition approach which uses a heuristic procedure and is capable of obtaining practical and high quality solutions in reasonable times.

In conclusion, A route in this context is a result of three major decisions: (1) which ports to visit and in what sequence, (2) how often to visit the ports, and (3) the size and speed of the ships to use, which determines ports of call, call sequence, ship type and service frequency or sailing speed simultaneously.

1.3 Objective and contribution

This paper aims to optimize the liner schedule of ZhongGu Shipping Company with the ports of call, call sequence, ship type and deployment, and service frequency and sailing speed. Firstly, a three-stage optimization method is used to analyze all the influence factors, determining the port rotation of a liner service route, deploying the ships in terms of size and number of ships, assigning laden containers, and regulating service frequency and sailing speed. Secondly, we assume that the price regulated by the company is equal to average price in the market and the orders of demand are related with the market occupancy of the company.

Combined with the above analysis, a mixed integer programming formulation is proposed for maximizing the benefit value of the company, and in another words, for minimizing the total cost incurred from the liner routing on the schedule, including ship related costs, fuel consumption costs, port related costs, laden containers and empty container inventory-in-transition costs. Finally, through a solution algorithm, combined with a primal heuristic obtains promising bounds, we get the best optimal solution and establish the liner schedule for the company, and give the recommends by comparing it with the former schedule.

This dissertation uses a three-stage solution procedure to deal with the influence factors. At the first stage, we focus on route structure design by narrowing down the route structure solution space into a manageable target set. At the second stage, we develop an efficient port selection algorithm by making use of the characteristics of the container flow pattern with respect to the route topologic structure. At the third stage, the number of deployed ships and their type and speed and service frequency are determined. The interrelations between three groups of decisions are appropriately modeled. Then a mixed integer programming model with the objective to minimize the total cost is proposed for the schedule design and a numerical example is used to evaluate the performance of the proposed model and solution algorithm.

2. Three -stage analysis method for influence factors

This section presents a three-stage analysis procedure to do some research on the influence factors of shipping line design. At the first stage, we focus on route structure design by using the way of narrowing down the route structure solution space into a manageable target set. At the second stage, we develop the relationship between port selection and line routing design and know how the port selection influence the result of routing strategy. At the third stage, the number of deployed ships with appropriate capacity and service frequency are determined. The interrelations between three groups of decisions are appropriately modeled.

The importance of developing a reasonable port selection algorithm can be explained from two perspectives. Firstly, it affects the computational performance because it is the basis of each route structure decision at the first stage (from which we maybe get a huge number of results due to the nature of the combinatorial optimization even after applying the topological structure of the service routes). Secondly, it affects the total costs and the third stage analysis because it imposes constraints to the ship deployment and service frequency. In addition, it should be pointed out that all three stages of analysis are interrelated. On the one hand, the later stage analysis depends on the earlier stage analysis. On the other hand, the first stage decisions cannot be optimized without iteratively evaluating analysis results at the second and third stages because the overall cost relies on all three stage decisions. The analysis procedure is outlined as follows.

The three-stage analysis procedure

Stage 1: route structure design

(1-i) Assume the target set for the line service route structure based on the route topological structure and the knowledge of container flows and the limits of port geographical environment.

(1-ii) Select one candidate route structure from the target set.

Stage 2: port selection

(2-i) Assign the port-to-port demands onto the selected service route and evaluate the laden rate of containers on the target line route.

(2-ii) Focus on the dominant leg with the highest laden container amount among all legs in a round-trip.

Stage 3: ship deployment and service frequency

(3-i) Evaluate the total container demands (including both laden and empty containers) at each leg in a round-trip according to the provided data and market environment.

(3-ii) Select the candidate set of ship types to satisfy the required shipping capacity based on the container flow amount.

(3-iii) Calculate the port time to identify the feasible number of ships to be deployed in the route to provide a weekly service.

(3-iv) For a given number of ships, the ship sailing speed (s) is implied. Then, the service frequency can be determined

To sum up, the objection of three-stage analysis is to know how the major influence factors to affect the routing decisions and how we can optimize the line routes with minimizing the total cost incurred from the liner routing on the schedule.

2.1 Route structure design

To find the optimal route structure, meta-heuristic optimisation methods such as genetic algorithms can be applied to deal with the problem (Shintani et al., 2007). However, meta-heuristic methods are usually time-consuming and the results are difficult to explain.

Wang and Meng (2013) propose the concept of reversing port rotation direction, which is to develop the performance of an existing shipping network by altering the port rotation direction in some line routes, such as from clockwise to counter-clockwise, or vice versa. This is a special concept and is practically more applicable since reversing port rotation would require much less operational and managerial effort than redesigning the existing shipping networks. It should be pointed out that Wang and Meng (2013) deal with a shipping network with multiple service routes. But in this paper, we focus on an individual service route because we should select one candidate route structure from the target set.

Another relevant concept is port-call swapping. Brouer et al. (2013) explain the rationale and effect of port-call swapping in a liner service, which is considered as one of the important measures to improve the ship schedule when disruption. It focuses on the decisions at the operational level rather than at the tactical level.

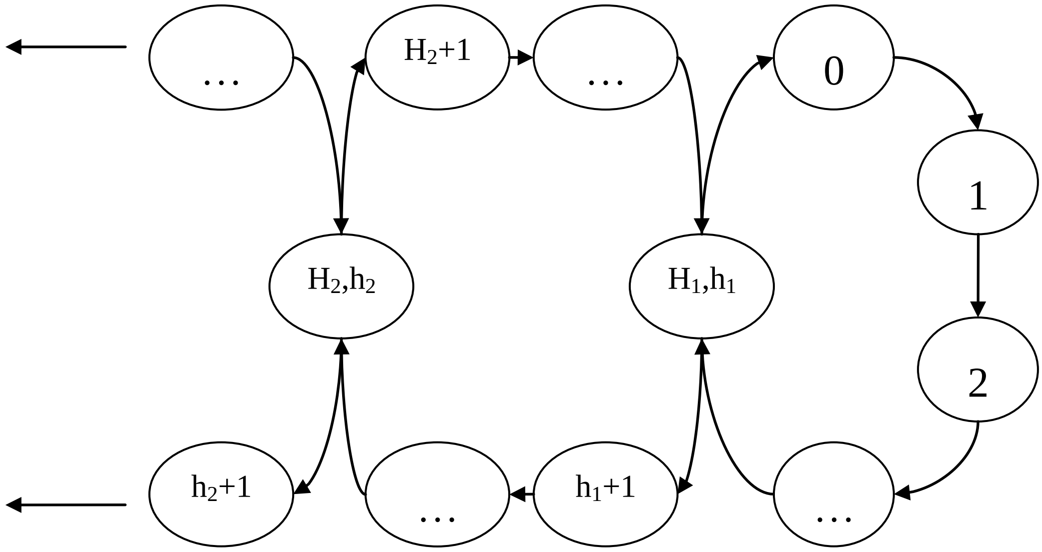

Fig. 1 The part of a generic shipping service route

The concept of reversing port rotation direction can be extended to this paper to form another new route structure design problem by allowing adjusting the port rotation direction in each cycle in the route. We take the generic shipping line service route in Fig. 1 as an example. For the first cycle on the rightmost side, we could reverse the direction to be $H_1 \rightarrow H_1-1 \rightarrow \ldots \rightarrow 1 \rightarrow 0 \rightarrow H_1$. For the second cycle, we could reverse both segments of port-calls and then swap them between outbound and inbound trips. Namely, reverse $H_2 \rightarrow H_2+1 \rightarrow \ldots \rightarrow H_1-1 \rightarrow H_1$ to be $H_1 \rightarrow H_1-1 \rightarrow \ldots \rightarrow H_2+1 \rightarrow H_2$ and let it to be part of the inbound trip; reverse $h_1 \rightarrow h_1+1 \rightarrow \ldots \rightarrow h_2-1 \rightarrow h_2$ to be $h_2 \rightarrow h_2-1 \rightarrow \ldots \rightarrow h_1+1 \rightarrow h_1$ and let it to be part of the outbound trip. Similar operations can be applied to other cycles in the service route, but if there are only two ports in a cycle, then there is no need to reverse them.

Suppose there are n cycles in the existing service route. The size of the solution space which consists of all alternatives with possibly reversing port rotation direction is not greater than $1+C_n^1+C_n^2+\ldots+C_n^n$. The first term indicates that no cycle is reversed and the second term represents only one cycle will be reversed. For the case with three cycles, the size of the solution space is 8, which is significantly limited and can be easily solved. In fact, over 80% of service routes have no more than three cycles.

2.2 Port selection

Table 1.Classification of shipping service routes in three major trade lanes (CI(2009))

Cycles	No. of routes	%	No. of ships	%	Capacity(TEU)	%	Ave. capacity (TEU)
1	68	44.51	398	36.04	1627709	31.09	4079
2	32	20.43	212	19.83	1186054	22.69	5620
3	24	15.23	174	16.02	990158	18.83	5626
4	10	6.84	76	6.88	322089	6.26	4354
5	7	5.09	82	7.67	424202	8.1	5051
6	5	2.71	51	4.51	220929	4.23	4507
7	3	1.29	24	2.28	116991	2.23	4680
8	4	3.15	63	5.69	275646	5.28	4446
9	1	0.75	12	1.1	68028	1.3	5668

The number of simple directed cycles involved in liner service route is rather small in practice. Based on the data of three major trade lines (Asia–Europe, Asia–North

America, Europe–North America) with total 154 long-haul shipping service routes in 2008 (CI, 2009), all of them can be properly classified according to the number of simple directed cycles they have (see Table 1). The majority of them consist of only one to three directed cycles. This indicates that liner shipping route design problem can be greatly simplified to use the concept of n directed cycles for maximizing the company's benefits from the practical perspective.

Obviously, the number of directed cycles in the liner shipping service route has a significant impact on its container flows and the ship utilization, thus when selecting ports, we should take the container demands and loading/discharging efficiency of the quay into account. Actually, we can establish the relationships between the container-flow patterns and the route topological structure, the result of which may provide us some ideas about how much ships should be utilized and also enables us to work out an efficient heuristic algorithm to select ports.

We assume that we will select ports in two regions: A and B, and create all possibilities of port choice in region A and region B. In region A, there is 2^K-1 possibilities of port choice, while in region B, it is 2^T-1, so there are (2^K-1)*(2^T-1) possible solutions for port selection in both regions in all.

With each solution of port choice, we enumerate all possible sequences of port calls. A port call order in a region is a permutation of selected ports. Assuming that in a particular state, we select x ports in region A and y ports in region B. We can get x!*y! solutions for ship voyage in this particular state.

Then, we will define loading and discharging port for shipments from a huge set of port choice and port call order by an optimal idea. With each state of port choice and port call order created by the former two steps, there are two cost components in total cost we can get: one is total ship cost when sailing, and the other is total port due, which are defined. Totally, there are 7 sub-components left which have not been defined. Our tactic in this algorithm is not to try to minimize total of these undefined costs but only five of them by using an optimal model (Table 2). This optimal model aims to find a suitable loading and discharging ports for all container flow in order to minimize total five of undefined cost: total handling cost, total inland transportation cost and total inventory cost (both in inland transport and sailing).

Table 2.Components of total cost

NO.	Component	Sub-component
1	Total ship cost	Port time
2		Sailing time
3	Total port tariff	Port due
4		Handling cost
5	Total inland transportation cost	Origin to loading port
6		Unloading port to destination
7	Total inventory cost	Port time
8		Sailing time
9		Inland time

This optimal idea comes from an observation that we can create a positive linear relationship between the target total cost and total handling cost, inland transportation cost and inventory cost (both in inland transport and sailing) of each shipment. The optimal strategy is determined by that of each shipment. Thus, instead of solving a complex problem with all shipments, we should only work with smaller ones, each related with a separate shipment which is much simpler than the former.

We assume that cargo from i to j will be loaded by port s, discharged by port d. We call the total of inland transportation costs from inland i to port s and port d to inland j, handling costs in port s and d, and inventory costs (both in inland transport and sailing) as an optimal cost. With each pair of ports, the optimal cost is different. Therefore, we calculate this target cost for all pairs and select a pair (s,d) as loading and discharge ports for container flow from i to j if it has minimum optimal cost.

After the previous step, we have got a list of loading and discharging ports for all shipments. It is possible that the container demand carried by a ship will exceed her capacity in some ports. Thus, we will re-arrange some shipments in these ports to satisfy two necessary constraints. Supposed in port s, carried container exceed ship capacity, there are two ways to adjust excessive volume: one is that some laden containers in port s will be changed to other ports in the same region called by a vessel later than port s. The other is some shipments will be unloaded earlier in port s instead of later in other ports in the same region.

Finally, we can calculate the total cost for all shipments with the company's information, based on the ports on a shipping route, the sequence of port call, loading and discharging ports of each transport route from inland i to inland j we have got before.

2.3 Ship deployment and service frequency

As we mentioned before, some parts of the ship deployment decisions can be determined immediately after knowing laden container flow and demands. This will exclude those ship types with insufficient capacity among the candidate set of ship types. For each ship type in the candidate set, we need to determine the rest of ship deployment decisions, such as the number of ships and the sailing speed.

$$t_p(i) = t_i^a + t_i^d + \sum_{j=0}^{N-1}(x_{ij} + x_{ji}) / h_i \qquad (1)$$

$$t_p = \sum_i t_p(i) \qquad (2)$$

$$\frac{\sum_{i=0}^{N-1} d_i / S_{\max} + t_p}{7*24} \le n_v \le \frac{\sum_{i=0}^{N-1} d_i / S_{\min} + t_p}{7*24} \qquad (3)$$

$$t_s = 7*24*n_v - t_p \qquad (4)$$

$$S_{\min} \le s \le S_{\max} \qquad (5)$$

$$s = \sum_i d_i / t_s \qquad (6)$$

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d_i -the distance from port i to the next port in the shipping route

h_i -the handling rate at port i in TEU per hour

n_v -the number of ships (type v) to be deployed in the shipping route

s -the sailing speed of ships at sea (per hour), the value of which should be between the minimum speed $S_{\min}$ and the maximum speed $S_{\max}$

t_i^a -the ship approach and docking time (hour) into port i when it arrives

t_i^d -the ship exit time (hour) from port i when it departs

t_p -the total time (hour) that a ship spends at the ports in a round-trip, $t_p(i)$ means the time that a ship spends at port i

t_s -the total time (hour) that a ship spends at sea in a round-trip

x_{ij} -the weekly laden containers which are loaded onto a ship from port i and designated to port j

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According to Eqs (1) and (2), we can calculate the total port time (t_p) which means how much a ship needs to spend at the ports in a round-trip. Combined with Eqs (4)-(6), the number of ships (n_v) to be deployed in the shipping route should be an integer in Eqs. (3). Thus, it is easy to for us to find the best n_v, which becomes a one-dimensional parameter optimization problem, because Eqs. (3) limits the solutions into a few discrete choices. After making a decision about the number of ships, the ship sailing speed (s) can be determined by using Eqs. (4) and (6).

Up to now, we deal with the liner shipping route design problem in a generic way, but we have not discussed the exact formula or model for the cost functions and how to calculate the target cost and all of the cost components. In the following section, we try to establish the model based on above analysis and apply the algorithm to optimize the pointed company's liner schedule.

3. Model and algorithm research

In our problem, we deal only with the import/export cargo between two separated regions. Each region is divided into some hinterland areas and several main ports. Flows of import/export containers between a hinterland area in A and another in B have been classified. There are some ports in both regions which can be used to serve mainline ships. Our task is to organize a cargo transportation network, which involves sea transportation, considering inland transportation.

3.1 Problem description

Considering a liner shipping company aiming to redesign a long-haul service route to serve pointed ports located in at least two different regions, which is denoted by a set of ports {P}. Without loss of generality, it is assumed that (i) the redesigned long-haul service route maintains a weekly or more often service frequency; (ii) the weekly laden container demand in terms of 20- foot equivalent units (TEUs) from port x to port y allocated on the service route is given by the container demand according to the local market; (iii) ships deployed on the service route are of the same type and ship size in a specific period of time is predetermined; (iv) laden containers are not allowed to be transhipped within the designed long-haul liner service route, and in a round voyage, a ship only calls a port maximum one time; (v) ships sail at a constant speed during the voyage; (vi) the freight rate is equal to the average market price.

It is also defined that (i) the topological structure of a redesigned service route is defined by the number of directed cycles in the service route (termed as n directed cycles route); (ii) the net import of a port is the difference between total laden containers that flow into the port and out of the port. If the value is positive, the port is called surplus port, otherwise, it is called a deficit port. (iii) A ship's total load factor is defined as the ratio of the number of total containers on board to the ship capacity
in terms of TEU. A ship's laden load factor is defined as the ratio of the number of

laden containers on board to the ship capacity in terms of TEU. Two empty containers is equal to one laden container when loading in terms of TEU.

Though using the model, the questions which will be settled in this paper are (i) which ports should be included in the itinerary of mainline ships among candidate ports in each region? (ii) What is the sequence of port calls along a ship's route? (iii) For a cargo transportation demand (from a hinterland area in A to another in B or vice versa), which ports should be loading and unloading ports? (iv) which type of ships should be deployed on the pointed liner route? Because we assume that the freight rate is equal to the average market price, in order to maximize the benefits of the company, we establish the model with the objective to minimize total transportation cost (sea cost and inland cost), port tariff (port due and handling charge) and inventory cost of cargo, to optimize the schedule with above questions.

3.2 Model formulation

Firstly, we should decide model variables according to the objective of minimizing the total cost, including input variables, decision variables, intermediate variables (which are calculated based on variables in the former two groups), time variables and cost variables.

Input variables:

N,M	number of hinterland areas in regions A and B. Hinterland areas in A are numbered from 1 to N, areas in B from N+1 to N+M.
r_i	if r_i=1, area i belongs to region A. If r_i =0, area i belongs to region B.
K, T	number of candidate ports in regions A and B. Ports in A are numbered from 1 to K, ports in B from K+1 to K+T.

p_i if p_i=1, port i belongs to region A. If p_i=0, port i belongs to region B.

$Q_{i,j}$ number of TEUs from area i to area j in a specific period of time.

$box_{i,j}$ number of containers from i to j in a specific period of time.

$v_{i,j}$ average inventory cost per day per TEU for cargo from i to j (USD).

OD set of cargo flow. OD={(i, j), $Q_{i,j}$ > 0}.

ship_size the capacity of ship (TEUs).

voyage_N number of round voyage in a specific period of time.

fuel_price the price per tonne of HFO (USD per tonne).

$port\_due_i$ port due (ship due, pilotage, towage...) per ship call in port i(USD/ship).

THC_i terminal handling charge in port i (USD per move).

$handling_i$ % handling rate in port i (moves per hour).

pre_dwell_i minimum dwell time of cargo before ship operation (hours).

$post\_dwell_i$ minimum dwell time of cargo after ship operation (hours).

MT_i manoeuvring time per entry/exit in port i (hours).

$distance_{i,j}$ the distance between port i and port j (miles).

$inland\_cost_{i,s}$ inland transportation cost per TEU between area i and port s (USD per TEU).

$inland\_time_{i,s}$ inland transportation time between area i and port s (hours).

ship_cost cost per day for ship operation during sailing time and port time (USD per day).

speed ship speed (knots per hour).

Decision variables:

$load_{i,j,s}$ if $load_{i,j,s}$ =1, a shipment from i to j will be loaded by port s, or else $load_{i,j,s}$=0

$unload_{i,j,d}$ if $unload_{i,j,d}$=1, a shipment from i to j will be unloaded by port d, or else unloadi,j,d ¼ 0

$select_i$ if $select_i$=1, port i is selected in ship's route, or else $select_i$=0.

$next_{i,j}$ if $next_{i,j}$ =1, after port i, port j will be the next call in ship's round voyage, or else $next_{i,j}$=0.

Intermediate variables

hubA set of selected hub port in region A; hubA={i: p_i=1, $select_i$=1}

hubB set of selected hub port in region B; hubB={i: p_i=0, $select_i$=1}

hub set of selected hub port in both region; hub= hubA ∪ hubB.

ExpA Total loading cargo in region A per voyage (TEUs).

ExpB Total loading cargo in region B per voyage (TEUs).

$$ExpA = \frac{\sum_{i=1}^{N} \sum_{j=N+1}^{N+M} Q_{i,j}}{voyage\_N} \qquad ExpB = \frac{\sum_{j=N+1}^{N+M} \sum_{i=1}^{N} Q_{j,i}}{voyage\_N}$$

Time variables

$port\_time_t$ total time ship spends in port t, includes manoeuvring time and unloading and loading time (hours).

$$port\_time_t = 2 * MT_t + \frac{\sum_{(i,j)\in OD} box_{i,j} * load_{i,j,t} + \sum_{(i,j)\in OD} box_{i,j} * unload_{i,j,t}}{handling_i \% * voyage\_N}$$

$sailing\_time_{s,d}$ total time a ship spend at sea when sailing from port s to port d (hours).

$$sailing\_time_{s,d} = \sum_{i\in R_{s,d}} \sum_{j\in R_{s,d}} \frac{distance_{i,j} * next_{i,j}}{speed}$$

$R_{s,d}$ set of port in the voyage from s to d.

$mainline\_time_{s,d}$ time from a ship arrives port s until it leaves port d. It includes the sailing time between the ports as well as the time a ship spends in ports on the voyage from port s to port d (hours).

$$mainline\_time_{s,d} = sailing\_time_{s,d} + \sum_{i \in R_{s,d}} port\_time_i$$

$time_{i,j}$ total time for a shipment, from cargo leaves area i until arriving area j (hours).

$$\begin{aligned} time_{i,j} = & \sum_{s \in hub} inland\_time_{i,s} * load_{i,j,s} + \sum_{s \in hub} pre\_dwell_s * load_{i,j,s} \\ & + \sum_{s \in hub} \sum_{d \in hub} mainline\_time_{s,d} * load_{i,j,s} * unload_{i,j,d} \\ & + \sum_{d \in hub} post\_dwell_d * unload_{i,j,d} \\ & + \sum_{d \in hub} inland\_time_{j,d} * unload_{i,j,d} \end{aligned}$$

voyage_time total time for a round voyage. It includes time a ship spends at sea and turnaround time in port.

$$voyage\_time = \sum_{i \in hub} \sum_{j \in hub} \frac{sailing\_time_{i,j} * next_{i,j}}{2} + \sum_{i \in hub} port\_time_i$$

cost variables

$total\_inland\_cost_{i,j}$ inland transportation cost for cargo flow from i to j, which means inland cost from area i to loading port s, and from unloading port d to area j (USD).

$$total\_inland\_cost_{i,j} = Q_{i,j} * (\sum_{s \in hub} inland\_cost_{i,s} * load_{i,j,s} + \sum_{d \in hub} inland\_cost_{i,d} * load_{i,j,d})$$

$tariff_t$ port tariff in port t per ship call. It includes port dues for ship and handling cost for cargo (USD).

$$tariff_t = port\_due_t + \frac{\sum_{(i,j)\in OD} box_{i,j} * load_{i,j,t} + \sum_{(i,j)\in OD} box_{i,j} * unload_{i,j,t}}{voyage\_N} * THC_t$$

TSC total ship cost in a voyage and at port (USD). TSC=ship_cost* voyage_time

TPC total port tariff in a voyage (USD). $TPC = \sum_{t \in hub} tariff_t$

TLC total inland transportation cost for all shipments to port and from port serving for a voyage (USD).

$$TLC = \frac{\sum_{(i,j)\in OD} total\_inland\_cost_{i,j}}{voyage\_N}$$

TIC total inventory cost for all shipments in a voyage (USD).

$$TIC = \frac{\sum_{(i,j)\in OD} Q_{i,j} * v_{i,j} * time_{i,j}}{24 * voyage\_N}$$

So, we get the final formulation with the objective to minimize the total cost:

$$TC = ship\_cost * voyage\_time + \sum_{t \in hub} tariff_t$$

$$+ \frac{\sum_{(i,j)\in OD} total\_inland\_cost_{i,j}}{voyage\_N} + \frac{\sum_{(i,j)\in OD} Q_{i,j} * v_{i,j} * time_{i,j}}{24 * voyage\_N}$$

Subject to

$$\sum_{i=1..k} select_i \geq 1, \sum_{i=K+1..K+T} select_i \geq 1 \qquad (7)$$

$$\sum_{j=hub} next_{i,j} = 1, \forall i \in hub, \sum_{i=hub} next_{i,j} = 1, \forall j \in hub \qquad (8)$$

$$\sum_{i\in hubA} \sum_{j \in hubA} next_{i,j} = \sum_{i \in hubA} select_i - 1 \qquad (9)$$

$$\sum_{i\in hubB} \sum_{j \in hubB} next_{i,j} = \sum_{i \in hubB} select_i - 1 \qquad (10)$$

$$\sum_{s \in hub} load_{i,j,s} = 1, \forall (i,j) \in OD \qquad (11)$$

$$\sum_{d \in hub} unload_{i,j,d} = 1, \forall (i,j) \in OD \qquad (12)$$

$$\sum_{s \in hub} load_{i,j,s} * (1 - |r_i - p_s|) = 1, \forall (i,j) \in OD \qquad (13)$$

$$\sum_{d \in hub} unload_{i,j,d} * (1 - |r_j - p_d|) = 1, \forall (i,j) \in OD \qquad (14)$$

$$\sum_{s \notin hub} load_{i,j,s} = 0, \sum_{d \notin hub} unload_{i,j,d} = 0, \forall (i,j) \in OD \qquad (15)$$

$$\sum_{s=1..K+T} load_{i,j,s} = 0, \sum_{d=1..K+T} unload_{i,j,d} = 0, \forall (i,j) \notin OD \tag{16}$$

$$ExpB + \sum_{s \in hub_k} \left(\frac{\sum_{(i,j)\in OD} Q_{i,j} * load_{i,j,s}}{voyage\_N} - \frac{\sum_{(i,j)\in OD} Q_{i,j} * unload_{i,j,s}}{voyage\_N} \right) \le ship\_size, \forall k \in hubA \tag{17}$$

$$ExpA + \sum_{s \in hub_k} \left(\frac{\sum_{(i,j)\in OD} Q_{i,j} * load_{i,j,d}}{voyage\_N} - \frac{\sum_{(i,j)\in OD} Q_{i,j} * unload_{i,j,d}}{voyage\_N} \right) \le ship\_size, \forall k \in hubB \tag{18}$$

3.3 Algorithm research

It is obviously to see that the model we get is non-linear programming model, and our problem belongs to the nondeterministic polynomial class which has no efficient algorithm. So we decide to use a straightforward method in this optimization problem. This method is rather simple to implement, though the number of possible results is very large and increases exponentially with the number of decision variables. We try to use a heuristic approach to find a good solution. The result may not be the optimality but it can be acceptable and feasible to be found. In routing design, heuristic method is one of the most popular ways scholars use to solve problems.

The key of our optimization problem is how to select ports in the regions. Once we decide to define some ports as loading or unloading port and the port call order, the ship deployment and service frequency will be easy to be solved. In our model, there are four components and nine sub-components. Base on the analysis of section two, we classify the total cost into two parts: one is total ship cost, and another is total port due (including inland transportation cost). Thus, our tactic is first to force on the total port due by using a target model to select ports, rather than finding a minimum cost of all sub-components. Then, the ship size and speed can be determined by the total cost model.

Through observation and simple calculation, we find that there is a positive linear relationship between the total port due and total handling cost, inland transportation cost, inventory cost (happening during inland transport and sailing time) of each shipment. So, we establish the target model = total handling cost + total inland transportation cost (origin to loading port and unloading port to destination) + total inventory cost (during inland transport and sailing time).

Instead of solving a big problem with all shipments, we use this target model to work with smaller ones to find suitable loading and unloading ports for all cargo flow to minimize the target cost, which is concerned with each separate shipment we can easily deal with. Obviously, ship cost and inventory cost during time ship in port is outside the new model, because the time a ship speed in the port is affected by lots of factors such as weather, traffic situation and berth equipment. If we do not take them out of the target model, the big problem can not be divided into smaller and simpler ones, and the algorithm will become much more complex.

Target cost:

$$C_{i,j,s,d} = (inland\_\cos t_{i,s} + inland\_\cos t_{j,d}) * \frac{Q_{i,j}}{voyage\_N}$$
$$+ t_{i,j,s,d} * v_{i,j} * \frac{Q_{i,j}}{voyage\_N} + (handling\_\cos t_s + handling\_\cos t_d) * \frac{box_{i,j}}{voyage\_N}$$

Now we can create the target cost formulation to solve the problem. We assumed that cargo from i to j will be loaded in port s, and unloaded in port d. Then, we calculate and regard the total inland transportation costs from area i to port s, port d to area j, handling costs in port s and d, and inventory costs (during sailing time and inland transport time) as the target cost. With each pair of ports, the target cost is different. After we calculating all cost for possible pairs, a pair (s,d) will be selected as loading and unloading ports for shipping service from i to j if it has minimum target cost.

Finally, considering that the cargo demand carried by one ship will exceed her capacity in some ports, we will re-arrange and adjust some shipments in some ports to satisfy model constraint (17) and (18). Here we apply three ways to adjust excessive volume and meet the cargo transport demand: (i) to add ships or take place of the small ship or increase service frequency; (ii) to increase the cargo flow to the problem port and make the ship call this port as the extra port; (iii) to transfer the excessive volume to other ports in the same region called by a ship later than the problem port.

4. Application study

4.1 Brief introduction of ZhongGu Shipping Company

ZhongGu Shipping Company is the third biggest shipping company in China and professionally supplies container transport service in domestic trade. With the development of the company, the shipping business has expanded to all the main cities and ports, with the strategy to cover all coastal areas in the future. ZhongGu has its own fleet of ships, and else hires about 45 ships with voyage charter and time charter. According to the cargo demand and VIP clients' needs, the company sets up approximately 50 agencies along the coast. In the following part, I will briefly introduce the basic situation of the company with agencies, operating fleet of ships, and competitive service product.

Fig. 2 All the main agencies of ZhongGu in China

It is seen from Fig.2 that the company can provide the transport service in almost coastal cities and move the cargo to meet client's needs. Once the cargo flow is regulate and enough to full a ship, the company will consider to establish a new agency in local port. Now XiaoLan Agency (Xiao Lan is an area near GuangZhou) is being set up because of local market and large cargo flow. Besides, the company can also supply inland transport service if clients want to sign a contract under the Door-or -Door term. Although ZhongGu has no own truck team, it makes the contracts with local inland transportation companies and get agreements with their truck teams to transport containers.

Due to the character of domestic trade: short voyage, high service frequency and fierce competition, the company creates its own fleet of container ships by purchasing and bareboat chartering. Now there are 13 ships in the fleet: HAISHUNFA, XINHAIWANG, XINHAIYUE are operated in branch lines in the north of China, with dwt 5820t, 5144t and 8000t respectively, while the ships run in main lines are XINHAIXIN, XIHHAIMING, XINHAIXIU which are operated in north of China, with dwt 10255t, 10530t, 8952t respectively, HAILANZHONGGU 6, HAILANZHONGGU 8, HAILANZHONGGU 18, ZHONGGUTAISHAN which are arranged in south of China, and HAILANZHONGGU 3, HAILANZHONGGU 9, HAILANZHONGGU 16 which run on the north-south routing. All the series of HAILANZHONGGU ships have the capacity of dwt 28768t. With the increasing shares of the market, the company has designed and invested to build four container ships with dwt 40000t and will be delivered next year.

In additional, ZhongGu has its own fuel oil sub-company to supply the energy to ships. The fuel cost covers the most of total operating cost in shipping, so ZhongGu can get cheaper fuel oil provided by its own sub-company to control and decrease the total shipping cost and become more competitive compared with other shipping company. Another core competence is its ShangHai to GuangZhou shipping line named “VIP line”. On this routing, ZhongGu arranges several large ships to make scale of economy and reach agreements with both ports to allow its ships call the berth at first time when they arrive. Because of the advantage of high service frequency and regular transport on time, this shipping service product attracts more and more clients to do the business with ZhongGu shipping company.

4.2 Data collection

4.2.1 Cargo flow

The objective of this paper is to optimize the routing and schedule of ZhongGu, so we deal with container flows between any two cities where the company has the agency and can supply the service on the domestic trade route. The initial data are provided by ZhongGu shipping company which includes all seaborne trade profiles between any two target regions and describe the actual volume of freight traffic in April, 2014. Each profile has basic information about origin, destination, number of containers, TEUs, loading and discharging ports, and number of voyage (Table 3). Information about origin/destination is our bases to divide the business into five main zones: the north of China (YingKou, JinZhou, DanDong, DaLian), the north-east of China (LongKou, QingDao, TianJin, RiZhao), the east of China (Shanghai, TaiCang, JiangYin, NingBo), the south-east of China (XiaMen, ShanTou, FuZhou, QuanZhou) and the south of China (GuangZhou, HuangPu, HuMen, ShenZhen, ZhuHai). The Yangtze River zone is the branch line and not included. Some ports are not shown in the Table 3 because the volumes of their shipment are small and counted into other ports in the same region such as RiZhao into QingDao.

Table 3.Summary of cargo flow between any two target regions

origin	destination	voyage number	containers	TEUs
YingKou	ShangHai	8	2646	3173.0
	TaiCang	4	2952	3298.0
JinZhou	ShangHai	3	965	1069.0
DaLian	TaiCang	2	398	490.0
	NingBO	3	597	757.0
	ShangHai	4	1214	1505.0

DaDong	ShangHai	2	323	368.0
TianJin	NingBO	7	1669	2061.0
	ShangHai	7	2482	3163.5
	XiaMen	2	1150	1476.0
QingDao	GuangZhou	6	5610	7071.0
	XiaMen	6	4700	6085.0
LongKou	ShangHai	4	619	684.0
JiangYin	XiaMen	7	1492	1821.0
TaiCang	GuangZhou	3	3178	4036.0
	QuanZhou/ZhuHai	2	368	439.0
	HuMen	4	1431	1884.0
	XiaMen	11	3152	3872.0
	TianJin	2	938	1057.0
	DaLian	1	79	94.0
	YingKou	4	2725	2215.0
ShangHai	XiaMen	11	3239	4075.0
	GuangZhou	8	8377	10572.0
	ShenZhen	6	1306	1765.5
	DaLian/LongKou	4	703	532.0
	YingKou	8	2921	2843.0
	DaLian	5	1414	1216.5
	DanDong	2	419	134.0
	JinZhou	3	1101	298.0
	TianJin	7	2809	3441.0
NingBo	HuangPu	5	1077	1193.5
	DaLian	3	623	288.0

	TianJin	8	1870	1074.0
XiaMen	ShangHai	11	3067	4274.0
	JiangYin	6	1273	1518.0
	TaiCang	8	2137	2851.0
	QingDao	5	3451	4214.0
	GuangZhou	8	1450	1546.0
	TianJin/TaiCang	2	1299	1450.0
ShenZhen	ShangHai	5	1112	1491.5
HuMen	TaiCang	3	1097	1463.0
GuangZhou	TaiCang	4	4080	5128.5
	ShangHai	7	7487	9218.5
	NingBO	3	647	829.5
	QingDao	6	6123	7718.0
	XiaMen	6	1004	1021.0
ZhuHai	TaiCang	2	376	436.0

Source: from the ZhongGu Shipping Company

The number of containers and TEUs includes the quantity of empty business container shipment, and one empty container is calculated into a half TEU. This is the reason of why the number of TEUs on some routing such as TianJin to ShangHai is not an integer. In additional, the company often repositions some own containers to the pointed ports where the containers are not enough to satisfied the transport needs, but the volume of empty container repositioning is not calculated into the TEUs of shipment. So on some routing, the number of TEUs is smaller than that of containers such as NingBo to TianJin.

The number of hinterland areas is according to the agreement with local truck team to decide whether the company can provide the inland transport service. To sum up, all the Door- or -Door term transports surround nineteen ports selected as candidate ports in running the application: YingKou, JinZhou, DanDong, DaLian (the north region); LongKou, QingDao, TianJin (the north-east region); ShangHai, TaiCang, JiangYin, NingBo (the east region); XiaMen, ShanTou, QuanZhou (the south-east region) and GuangZhou, HuangPu, HuMen, ShenZhen, ZhuHai (the south region) These are main ports along the coast of China. In our specific data, containers going through these ports occupy nearly 95% of the total cargo shipment of ZhongGu Shipping Company.

Between all candidate ports and inland points, we use the transportation modes of railroad and truck. The mode of railroad is used for transportation in some specific port equipped with the railway such as YingKou and the company needs to make a contract with local Railway Administration for cargo transport. Between the east region and the Yangtze River region and among the ports in the south region, feeder services will be used in the transportation model to carry containers. In these regions, there are many branch lines, so such ports can function as feeder ports and the company can control and decrease the total cost of transportation by rationally choosing the mode. However, in the scope of this research, it is very difficult for us to choose the mode of transportation because we do not know what price the company will get in the contract with local truck team and Railway Administration through negotiations in the future. So we assumed that all containers will be moved by truck or railway in all regions during the inland time except JinZhou, DanDong, RiZhao, and the south region where the feeder service is available. The feeder ports will be mainly selected among ports of ZhongShan, XiaoLan, HuMen, QinZhou, YangPu based on the smallest total cost of transportation and inventory for a shipment between origin/destination and transhipment port in the south region.

4.2.2 Sea and inland distance

Sailing distances between ports are retrieved from the database of the ZhongGu Shipping Company (according to the ship's log). Inland distances and transport times between hinterland areas and candidate ports are calculated in proportion according to the quotation sheets (which are not shown in the paper because of business factors, so I assume the reference distance base on the average of the quotation).

4.2.3 Voyage number and port time

Base on the shipping record in April of the ZhongGu Shipping Company, we classify the data by ship size and sum up the number of voyage, container and TEU (see Table 4).

Table 4.Summary of computational results

ship size	voyage number	containers	TEUs
5000t(300TEU)	30	5262	5160
6000t(410TEU)	64	13705	16100.5
7000t(480TEU)	8	2030	2648
8000t(530TEU)	7	1629	1514
9000t(620TEU)	41	13714	15977.5
10000t(740TEU)	13	4594	4714
11000t(800TEU)	16	6146	7557
16000t(1130TEU)	9	4790	5691

22000t(1600TEU)	8	5677	5513
28000t(1750TEU)	42	41603	52335

Source: calculated by the author

The ship utilization of each size is around 72% by calculation. In all ports, mainline vessels are served by two or three gantry cranes with productivity 25 moves per hour (in some port, there are only three gantry cranes such as XiaMen port and it is impossible to allocate all the cranes to one ship). For the entry and exit in each port, 2 hours per call is taken (the average based on all the ports' geographical conditions and regulations). About minimum dwell time before loading or after discharging, our own ships do not need to wait for the berth, but the rest of the company's fleet usually speed 12 hours dwell time, not considering weather, accident and waiting for cargo. These data originate from the actual ship operating record of ZhongGu.

4.2.4 Port tariff

Each port has a different tariff table, but the cost always includes ship dues, towage, mooring/unmooring, pilotage, hatch moving cost and other costs of such as commission and communication.

Ship dues: 0.06 RMB per net tonnage

Towage: 0.36*horsepower*time(hour) per tug, a mainline ship use one tug per entry/exit and feeder ships do not need tugs. A tug ordinarily has 3500 horsepower and work for one hour, so the towage is totally 2520 RMB per call.

Mooring/unmooring: 140*2 RMB per call

Pilotage: except in Yangtze River region, there is almost no pilotage on most lines. If the port imposes a pilotage, the company should pay 0.005*net tonnage per call.

Hatch moving: 45 RMB per hatch per open/close

Other costs assessed at 5% of the total port tariff.

4.2.5 Ship cost

The total ship cost includes three parts: hire cost, fuel cost and management cost (such as crew's salary).

Hire cost: in the domestic market, a ship with 5000t is about 400,000 RMB per month; 8000t is around 680,000 RMB per month; 10000t is approximately 800,000 RMB per month (the time charter rate is achieved from the market in April and in order to simplify the calculation, the rate of other ships with different deadweight ton will increase or decrease in proportion).

Fuel cost: total fuel cost includes heavy oil cost and light oil cost. A ship with 5000t spends 4.5t heavy oil and 0.3t light oil per day; 8000t spends 7.8t and 0.5t; 10000t spends 11t and 0.8t. FC= heavy oil price* volume per day* sailing_time+ light oil price* volume per day* voyage_time. (We get the price per ton of heavy oil 4500 RMB per tonand light oil 7550 RMB per ton from the fuel oil sub-company during April. 2014.)

Management cost: like hire cost, a ship with 5000t is about 300,000 RMB per month; 8000t is around 500,000 RMB per month; 10000t is approximately 600,000 RMB per month.

4.2.6 Inland transportation cost

Base on the above analysis of section 4.1, Inland transport in our case is simplified just by road mode, except that in YingKou port, we use the both models of road and rail. Hence, the cost of inland transportation will be divided into two parts based on the ratio of cargo carried between two transportation modes. In YingKou, from the latest figures in 2013, the ratio of ton-km goods transport by road and by rail is 3.3:1.2. Because the "sea-rail multimodal transport" is still a new service item in the customer's view, many clients trend to use the traditional model of road to finish the transportation and the ratio of by road and by rail is still high. The road cost by statistics = 800+ 10 per km in most ports (RMB/TEU). The rail cost in YingKou = 2200+ 5.5 per km (RMB/TEU), so the inland transportation cost in Yingkou = (800*3.3+2200*1.2)/4.5+ (10*3.3+5.5*1.2)/4.5 per km =1173.3+ 8.8 per km (RMB /TEU).

4.2.7 Inventory cost of cargo

Notteboom (2006) assessed that one day delay of cargo delivering would result in two following costs: opportunity cost (3%-4% per year), economic depreciation (10-30% per year). So we assume inventory cost in our case is 28% per year (approximately 0.065% per day) including 3% opportunity cost because of bad domestic trading market and 25% economic depreciation.

4.3. Model instantiation

In our model, the decision variables are $load_{i,j,s}$, $unload_{i,j,d}$, $select_i$ and $next_{i,j}$. These variables are obviously not quantized in the formulation and cannot be work out in the model. So in the first step, we should transform and apply new variables which can be quantized to take place of them.

The key of optimization problem is to get the results of ship deployment, which is related to ship size and speed, and port selection, which is related to distance of sailing. Besides, in section 4.2, the most of data has a relationship with net tonnage of the ship. Thus, we ought to establish the relationship between ship size and net tonnage, ship size and speed, ship size and hatch number, ship size and hire price, and use the distance between two ports to indicate which ports we will select.

Table 5.Data of net tonnage and ship size of the company's fleet

number	net tonnage	ship size (TEU)
1	2290	351
2	3190	529
3	4500	296
4	10805	1746
5	1537	198
6	4585	133
7	2470	402
8	3515	596
9	2087	315
10	2699	401
11	1679	250
12	1570	218
13	1830	265
14	1676	266
15	4544	686
16	4545	686

17	2528	441
18	4250	616
19	1979	290
20	2410	410
21	3146	480
22	2256	443
23	2098	318
24	4336	671
25	2470	402
26	1642	265
27	2410	396
28	4608	738
29	6832	1131
30	2347	411
31	1658	265
32	2470	396
33	9470	1599
34	1662	240
35	4879	802
36	4874	802
37	2491	410
38	4339	672
39	1575	205
40	2483	410
41	4150	688
42	1679	282

43	2470	399
44	6341	872
45	1537	186
46	1642	265

Source: from ZhongGu and cut out the ship names

Table 5 shows the data of net tonnage and ship size of the ships by hiring in the fleet. We here use the method of linear regression to deal with above data by EXCEL. The objective is to describe the net tonnage with ship size, which stands for the ship size. From Table 6, we can see that R square and adjusted R square are both 0.88 more than 0.36, which means that the results are available and there is a strongly positive linear relationship between the net tonnage and ship size because of the high R square. So the formulation is that net tonnage= 451.94+ 5.68* ship size.

Table 6.Results of the linear regression between net tonnage and ship size

SUMMARY OUTPUT						
Regression statistics						
Multiple R	0.94069052					
R Square	0.884898655					
Adjusted R Square	0.882282715					
Standard error	686.6317471					
Observation	46					
Variance analysis						
	df	SS	MS	F	Significance F	
Regression analysis	1	159482696.8	1.59E+08	338.2718	2.8E-22	
residual error	44	20744378.87	471463.2			
total	45	180227075.7				
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	451.9367142	183.7780874	2.459144	0.01793	81.55632	822.3171
X Variable 1	5.680729814	0.3088668	18.39217	2.8E-22	5.05825	6.30321

Using the same method, we set up the relationship between ship size and hatch number, and the relationship between ship size and sailing speed. The results of linear regression are shown in Table 7 and Table 8. The R squares and adjusted R squares of both are more than 0.36. So the formulation between hatch number and ship size is that hatch number = 7.33+ 0.01* ship size.

Table 7.Results of the linear regression between hatch number and ship size

SUMMARY OUTPUT						
Regression statistics						
Multiple R	0.978473226					
R Square	0.957409855					
Adjusted R Square	0.956441897					
Standard error	0.716737095					
Observation	46					
Variance analysis						
	df	SS	MS	F	Significance F	
Regression analysis	1	508.1140605	508.1141	989.1028	8.54E-32	
residual error	44	22.60333078	0.513712			
total	45	530.7173913				
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	7.334289421	0.191835832	38.23211	2.14E-35	6.94767	7.720909
X Variable 1	0.010139767	0.000322409	31.45001	8.54E-32	0.00949	0.01079

Table 8.Results of the linear regression between sailing speed and ship size

SUMMARY OUTPUT						
Regression statistics						
Multiple R	0.985363819					
R Square	0.970941855					
Adjusted R Square	0.967309587					
Standard error	0.28091106					
Observation	10					
Variance analysis						
	df	SS	MS	F	Significance F	
Regression analysis	1	21.09371181	21.09371	267.3101	1.97E-07	
residual error	8	0.631288191	0.078911			
total	9	21.725				
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	8.491331533	0.179951247	47.18684	4.5E-11	8.076363	8.9063
X Variable 1	0.003060608	0.000187198	16.34962	1.97E-07	0.002629	0.003492

About the relationship between sailing speed and ship size, because there is not a large number of observations, we decide to apply the method of trend lines, including logarithm, polynomial, power and exponential line, and compare the R squares of them. After calculation, we find that the power trend line has the highest R square (0.9799, see Fig 3), which is bigger than that of linear regression. So the formulation between sailing speed and ship size is that speed = 2.3438* ship size ^ 0.2345. Then, we get the formulation between hire cost and ship size with the same way.

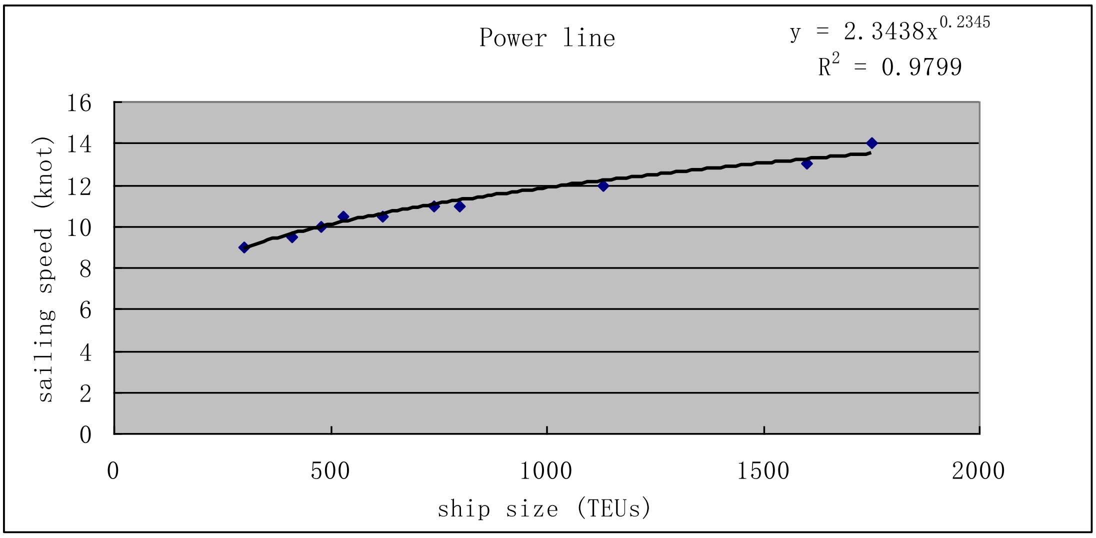

Fig 3.The result with power trend line between sailing speed and ship size

Now through the above formulations, we can set up the relationships between the ship size and most costs (RMB):

Ship dues = 0.06* (451.94+ 5.68* ship size);

Pilotage = 0.005* (451.94+ 5.68* ship size);

Hatch moving cost = 45*2* (7.33+ 0.01* ship size);

Sailing_time = distance/ (2.3438* ship size ^ 0.2345);

Hire cost =4639.3* ship size ^ 0.7854;

Fuel cost = 4500 * (0.015* ship size +0.04)* distance/ (2.3438* ship size ^ 0.2345)+ 7550* (0.0011* ship size -0.0592)* [distance/ (2.3438* ship size ^ 0.2345)+1];

Management cost = 684.79* ship size + 108293

Related to port selection, we consider doing research on the relationship between the number of trading TEUs and the distance of sailing, and establishing the formulation. Based on the analysis of section 3.3, we can see from Table 4 that the number of 9000t ships' voyage in April is the largest, so the ship size of 9000t is assumed as the typical size in the target model with the objective to temporarily ignore the ship deployment and focus on the port selection solution. In Table 9, the data have been handled and the results of linear regression about the number of trading TEUs per voyage and the sailing distance are shown in Table 10.

Table 9.The data for calculation (ship size: 9000t)

voyage number	boxes	TEUs	TEUs/voyage number	distance(mile)
4	1186	1407.0	351.75	688
4	1214	1505.0	376.25	556
4	1428	1831.0	457.75	720
2	727	928.5	464.25	701
1	327	404.0	404.00	691
4	1415	1708.0	427.00	664
1	340	395.0	395.00	644

1	351	404.0	404.00	654
4	1134	956.0	239.00	588
5	1414	1216.5	243.30	556
1	326	435.0	435.00	700
3	1266	1549.0	516.33	715
3	1217	1457.0	485.67	711
1	343	454.5	454.50	654
3	1026	1327.0	442.33	664

Source: from ZhongGu Shipping Company

Table 10.Results of linear regression about trading TEUs per voyage and distance

SUMMARY OUTPUT						
Regression statistics						
Multiple R	0.78512282					
R Square	0.616417843					
Adjusted R Square	0.586911523					
Standard error	50.91604279					
Observation	15					
Variance analysis						
	df	SS	MS	F	Significance F	
Regression analysis	1	54158.8511	54158.85	20.89104	0.000525	
residual error	13	33701.76438	2592.443			
total	14	87860.61548				
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-348.6961743	165.7288115	-2.10402	0.055407	-706.732	9.339155
X Variable 1	1.143405607	0.250161366	4.570672	0.000525	0.602965	1.683846

Because R square > 0.36, the formulation we get about cargo flow and distance is that trading TEUs per voyage = 1.14*sailing distance – 348.696 and by the same method, the formulation between the handling boxes and sailing distance is calculated that handling containers per voyage = 0.52* sailing distance – 2.208 with the available R square.

Having the formulations related to port selection and ship deployment, in the second step, we can use the new decision variables to make the model instantiation and transform the target cost model.

Table 11.Results of linear regression about boxes per voyage and distance

SUMMARY OUTPUT						
Regression statistics						
Multiple R	0.70661541					
R Square	0.499305338					
Adjusted R Square	0.460790364					
Standard error	29.27614838					
Observation	15					
Variance analysis						
	df	SS	MS	F	Significance F	
Regression analysis	1	11111.28991	11111.29	12.96393	0.003228	
residual error	13	11142.20723	857.0929			
total	14	22253.49715				
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-2.208231518	95.29219106	-0.02317	0.981864	-208.074	203.658
X Variable 1	0.517902296	0.143839954	3.600545	0.003228	0.207155	0.82865

In the target cost model of section 3.3, the inland cost is related with how far the containers should be delivered and we assume that the distance is 25 km and the inland time is 0.5 day (which is the average of transport distance under Door- or –Door term in the contracts during company operation). Here we only use the mode of road unless the YingKou port is selected. About inventory cost, we calculate the expenses of stockpiling in yard and port, approximately 220 RMB per day (including yard fee 150 RMB and moving fee 70 RMB) and the hire price of a container is 0.58 USD= 4 RMB per day (according to the domestic market price in April.2014). The prices of stockpiling have a little difference among the candidate ports, but it is not great. Like the inventory cost, the handling cost per TEU is the same in all candidate port, 170 RMB for 20-foot container and 255 RMB for 40-foot container (before April 1st, the handling prices are 150 RMB for 20-foot container and 225 RMB for 40-foot container).

Finally, combined with all above calculation and analysis, we take the new variables into the target cost model with some assumes about input variables and get the transformed formulation: $C_{i,j,s,d}$=2300* (1.14* distance- 348.696)+ (1+ distance/ 10.5) *230* (1.14* distance -348.696)+ 340* (0.52* distance- 2.208).

4.4 Model solution

4.4.1 Port selection

After having done the model instantiation, we use the EXCEL to draw a diagram to describe the new target formulation and find the most optimal point in order to decide the way of selecting ports (the optimal point may be the lowest point which means the minimum total cost).

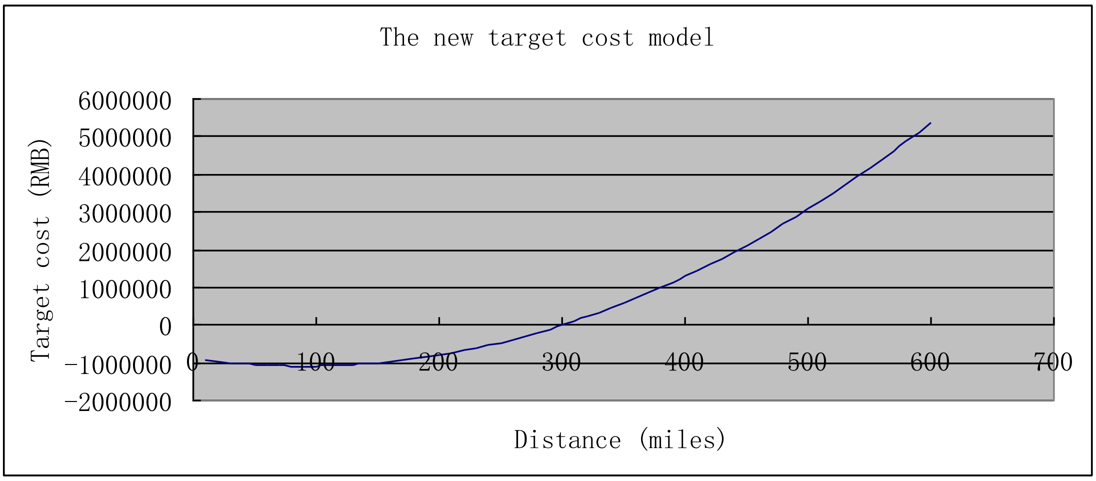

Fig 4.The diagram about the relationship between target cost and sailing distance

It is seen from Fig 4 that the lowest point is around 100 miles, but the target cost is below zero which is not normal and unaccepted. So the relationship between target cost and sailing distance should follow the function shown in the diagram and has a positive linear trend when the distance >= 300 miles. In order to control the minimum total cost, we consider the point round 300 miles as the optimal point.

The result of polynomial line diagram indicates that controlling the sailing distance around 300 miles, the company can minimize the target cost and finally minimize the total cost. Nineteen candidate ports are classified as five regions: the north, the north-east, the east, the south-east and the south. According to the different sea distances, the optimal distance of 300 miles means we can only choose two ports on one routing except the special situation such as to call extra port because of not enough cargo, and in the same region, two ports cannot be selected at the same time because the distance is short.

If we select three or more ports in the same region, though the total distance can more than 300 mile, the service frequency will be low and calling several ports will increase the happening rate of negative influence factors such as traffic jam and berth equipment accidence. This operating model is not what the company wants in present fierce domestic competitive market. What the company pursues is that through increasing service frequency and enhancing transportation on time, more and more customers will be attracted by our high-quality service products. So only selecting two ports as possible as we can to design routing is the optimal method for ZhongGu in the domestic market.

Table 12.Candidate ports in five regions

North	North-east	East	South-east	South
YingKou	LongKou	ShangHai	XiaMen	GuangZhou
JinZhou	QingDao	TaiCang	ShanTou	HuangPu
DanDong	TianJin	JiangYin	QuanZhou	HuMen
DaLian		NingBo		ShenZhen
				ZhuHai

Based on the principle of port selection, we create all possibilities of port choice in five regions, and there are 4*3+4*4+4*3+4*5+3*4+3*3+3*5+4*3+4*5+3*5 =143 schemes in total. Then, we use the result of the target cost model to optimize the schemes and 39 routings are cut out which are too short and regarded as branch lines.

In order to accurately select the ports on the routing, we apply the data and new decision variables into the total cost model. Because of massive calculation, we show the part about selecting ports between the north region and the east region and all possibilities to be chosen are listed in Table 13.

Table 13.All schemes of routing between the north and the east region

Scheme	Operating routing			Distance
1	YingKou-	ShangHai-	YingKou	688
2	YingKou-	TaiCang-	YingKou	698
3	YingKou-	JiangYin-	YingKou	774
4	YingKou-	NingBo-	YingKou	750
5	JinZhou-	ShangHai-	JinZhou	713
6	JinZhou-	TaiCang-	JinZhou	723

7	JinZhou-	JiangYin-	JinZhou	799
8	JinZhou-	NingBo-	JinZhou	747
9	DanDong-	ShangHai-	DanDong	630
10	DanDong-	TaiCang-	DanDong	640
11	DanDong-	JiangYin-	DanDong	716
12	DanDong-	NingBo-	DanDong	712
13	DaLian-	ShangHai-	DaLian	556
14	DaLian-	TaiCang-	DaLian	566
15	DaLian-	JiangYin-	DaLian	622
16	DaLian-	NingBo-	DaLian	647

The total cost includes four parts: total ship cost, total port cost, total inland transport cost and total inventory cost.

In total ship cost, there are hire cost (=4639.3* ship size ^ 0.7854/ 30), fuel cost (=4500 * (0.015* ship size +0.04)* distance/ (2.3438* ship size ^ 0.2345)/24+ 7550* (0.0011* ship size -0.0592)* [distance/ (2.3438* ship size ^ 0.2345)/24+1]), and management cost (= (684.79* ship size + 108293(/30).

Total port cost is divided into port dues, which include ship dues (=0.06* (451.94+ 5.68* ship size)), towage cost (=2520 RMB per voyage), mooring/unmooring cost (=280 RMB per voyage), hatch moving cost (=45*2* (7.33+ 0.01* ship size)) and other costs (=5% total port cost), and handling cost (=170*2*(0.52* sailing distance – 2.208)).

In total inland transport cost, the average of inland distance is 27 km in the north region and 25 km in the east region. So the inland cost per TEU = (800+ 10*27)+ (800+ 10*25). In YingKou, the inland cost = (1173.3+ 8.8*27)+ (800+ 10*25). The number of TEUs per voyage is related to sailing distance according to the section 4.3. the cargo during inland transport is 5% of the total cargo flow.

The inventory cost includes yard fee 150 RMB, moving fee 70 RMB, hire cost per TEU 4 RMB and opportunity and economic cost (28% of total inventory cost). The total time is made up of sailing time (=distance / speed, which is related with ship size), inland time in both areas (total one day), and pre/post dwell time (total one day).

The freight rate is assumed at 1200 RMB per TEU, which is the average of the market price on these routings. So the benefits = 1200* ship size – total cost. The results of calculation about the profits with different distances are seen in Table 14.

Table 14.The results of calculation (ship size: 9000t)

	Distance	Revenue	Total cost	Profit
1	400	744000	421596.216	322403.784
2	405	744000	433125.172	310874.8276
3	410	744000	444784.974	299215.0263
4	415	744000	456576.404	287423.5959
5	420	744000	468500.248	275499.752
6	425	744000	480557.29	263442.7104
7	430	744000	492748.313	251251.6869
8	435	744000	505074.103	238925.8971
9	440	744000	517535.443	226464.5567

10	445	744000	530133.118	213866.8815
11	450	744000	542867.913	201132.0873
12	455	744000	555740.61	188259.3896
13	460	744000	568751.996	175248.0043
14	465	744000	581902.853	162097.1471
15	470	744000	595193.966	148806.0337
16	475	744000	608626.12	135373.8798
17	480	744000	622200.099	121799.9011
18	485	744000	635916.687	108083.3134
19	490	744000	649776.668	94223.33242
20	495	744000	663780.826	80219.17382
21	500	744000	677929.947	66070.05335
22	505	744000	692224.813	51775.18673
23	510	744000	706666.21	37333.78969
24	515	744000	721254.922	22745.07795
25	520	744000	735991.733	8008.267224
26	525	744000	750877.427	-6877.42675
27	530	744000	765912.788	-21912.7883
28	535	744000	781098.602	-37098.6016
29	540	744000	796435.651	-52435.651
30	545	744000	811924.721	-67924.7208
31	550	744000	827566.595	-83566.5952
32	555	744000	843362.059	-99362.0585
33	560	744000	859311.895	-115311.895
34	565	744000	875416.889	-131416.889
35	570	744000	891677.825	-147677.825

36	575	744000	908095.487	-164095.487
37	580	744000	924670.659	-180670.659
38	585	744000	941404.125	-197404.125
39	590	744000	958296.671	-214296.671
40	595	744000	975349.08	-231349.08

It is shown from Table 14 that the profits become negative number until the distance is 525 miles, which means the ships with 9000t are not suitable to be arranged on these sixteen routings between the north and the east region, because the sailing distances of these sixteen schemes are all more than 530 miles. Since there are cargo flows on these routings, for making profits by operation, the company should apply the principle of economies of scale to increase ship size, the result of which is decreasing the cost per TEU, or arrange more ships.

According to the present situation of the company's fleet, we choose the ship size of 16000t and the largest 28000t to calculate the profits again respectively and draw the diagram based on the results (Fig. 5).

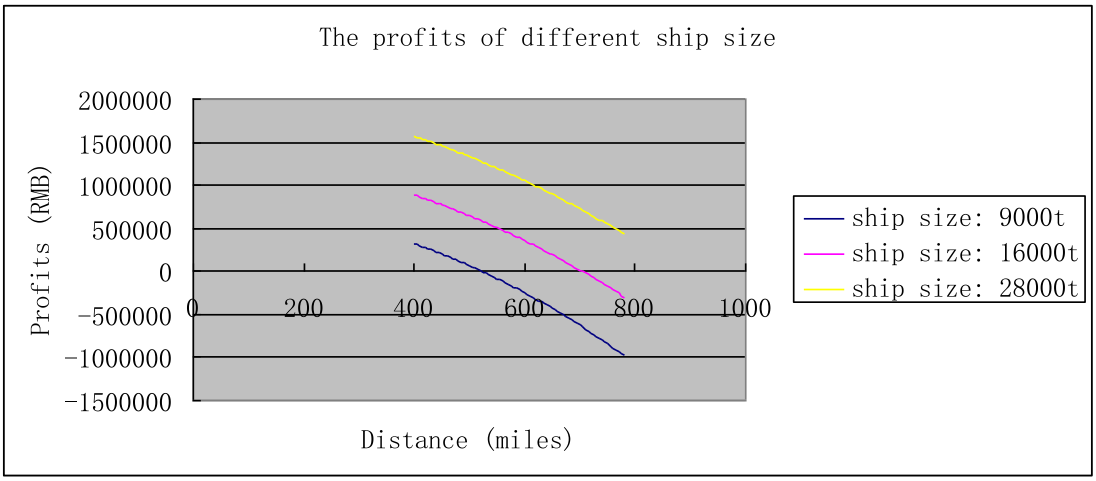

Fig 5.The results of calculation about profits with

After increasing the ship size, the company is able to make profits on these routings, but the cargo flow has a limit and not enough to fill a large ship in some scheme such as the routing of JinZhou- JiangYin- JinZhou. Besides, the number of 28000t ships in the fleet has also a limit and there are only six ships. So we finally cut out the uneconomic and unprofitable schemes, including scheme 3, scheme 4, scheme 7, scheme 8, scheme 11, scheme 15 and finish the optimization of port selection between the north region and the east region.

Following the steps of above calculation for optimization about port selection, we complete the calculation of optimal port selection in the rest pairs of regions and summarize the results in Table 15.

Table 15.Summary of port selection and routing design

	operating routing		
1	YingKou-	TaiCang-	YingKou
2	YingKou-	ShangHai-	YingKou
3	JinZhou-	TaiCang-	JinZhou
4	JinZhou-	ShangHai-	JinZhou
5	DanDong-	TaiCang-	DanDong
6	DanDong-	ShangHai-	DanDong
7	DanDong-	NingBo-	DanDong
8	DaLian-	TaiCang-	DaLian
9	DaLian-	ShangHai-	DaLian
10	DaLian-	NingBo-	DaLian

11	TianJin-	ShangHai-	TianJin
12	TianJin-	NingBo-	TianJin
13	TianJin-	XiaMen-	TianJin
14	TianJin-	GuangZhou-	TianJin
15	TianJin-	TaiCang-	TianJin
16	QingDao-	ShangHai-	QingDao
17	QingDao-	TaiCang-	QingDao
18	QingDao-	XiaMen-	QingDao
19	QingDao-	GuangZhou-	QingDao
20	LongKou-	ShangHai-	LongKou
21	JiangYin-	TianJin-	JiangYin
22	JiangYin-	XiaMen-	JiangYin
23	TaiCang-	XiaMen-	TaiCang
24	TaiCang-	GuangZhou-	TaiCang
25	TaiCang-	HuMen-	TaiCang
26	TaiCang-	ZhuHai-	TaiCang
27	ShangHai-	ShenZhen-	ShangHai
28	ShangHai-	XiaMen-	ShangHai
29	ShangHai-	ShanTou-	ShangHai
30	ShangHai-	GuangZhou-	ShangHai
31	ShangHai-	ZhuHai-	ShangHai
32	NingBo-	GuangZhou-	NingBo
33	NingBo-	HuangPu-	NingBo
34	XiaMen-	HuangPu-	XiaMen
35	XiaMen-	GuangZhou-	XiaMen
36	QuanZhou-	ShenZhen-	QuanZhou

4.4.2 Ship deployment and sailing speed

Economies of scale in ship size have been proved in the former section as well as in many other studies. Total cost per TEU will decrease when we deploy a larger vessel. However, the cost per TEU during sailing, which decreases because of economies of scale and results in the average cost of one TEU decreasing, is only a part of total cost per TEU. Its savings do not automatically lead to general benefit because the total cost at port increases with the ship size, which is the other part of total cost. So there is a limit in economies of scale and the most important thing we consider is how to minimize total cost and keep the decision variables subject to the constraints, rather than focusing on the cost of an individual process.

In a whole process, the change of any aspect possibly has a negative effect on both total cost and other aspects. The most economic ship size is only fully understood when we put it in the correlation with other influence factors. The marginal cost at sea is falling while the total cost at port is increasing with ship size enlargement. So the benefit of operating large container vessels is only marginal.

In our case, for ships of more than 16000t, its deployment will become scale diseconomies if the cargo flow is not enough to fill the ship such as on the routing with LongKou, which cause higher total cost. The reason explaining the uneconomic deployment of large vessels in our problem can come from the short voyage distance (DaLian- QingDao- DaLian) which can not make full use of the ship cost advantage of these ships.

To overcome this matter, we made a simulation considering sea distance as the given part to survey their efficiency. In longer distances, it appears to be more beneficial with using large vessels. We will assess the impact of ship size to total cost by concentrating on three cost groups. The first is transport and inventory cost during inland and feeder process (total inland and inventory cost). The second includes ship cost and inventory cost during sailing time (cost at sea). The third is the cost in port: ship cost and inventory cost during time in port and port tariff. The formulations of TSC, TPC, TLC and TIC are taken to consider the correlations between these groups and ship size (Fig. 6).

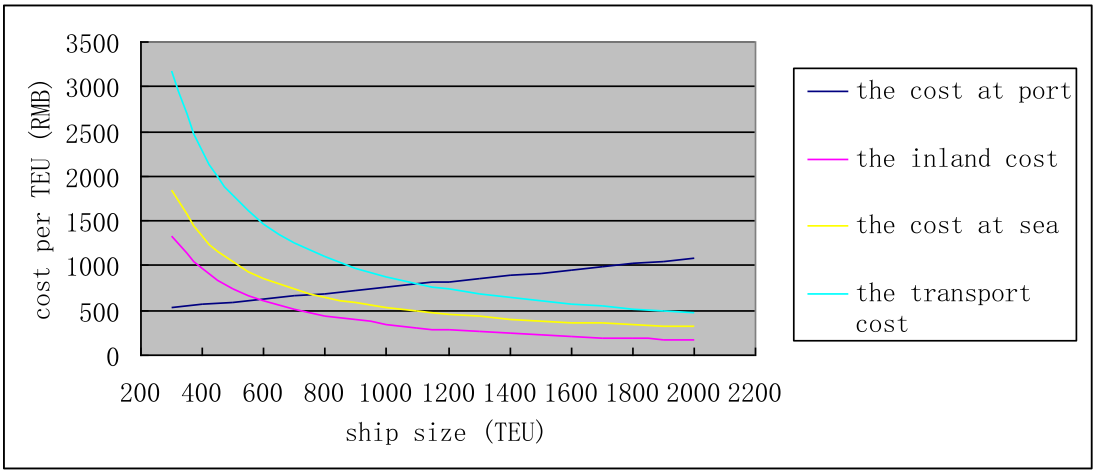

Fig 6.The several costs when the distance is 600 miles

Controlling the distance unchangeable and assumed as 600 miles, we use four cost formulations of section 3 to calculated and get the above diagram. From Fig. 6, we can see that the inland/feeder cost tends to decline with larger vessels and it helps to reduce the transport cost between loading/unloading ports and hinterland destinations. Economies of ship size are also expressed very clearly in the part of sea cost with closed relationship between sea cost and ship size. So we combine both costs as the total transport cost and add its trend line into the diagram.

Unlike two first groups, the third, cost in port, increases together with ship size. It can be explained from the fact that more ports in ship’s voyage leads to higher port tariff. But in our case, the principle of port selection is to choose only two ports on one routing as possible as we can. So port tariff is only a minor reason and the main reason stays on the side of ship cost and inventory cost during time in port. With higher volumes of cargo, large ships must spend more time in ports for loading and discharging.

Besides, there are three reasons for the most of ships why the time spent in port will increases. The first one is that the accidents or bad weather such as heavy fog or strong wind happen. It is act of God and cannot be avoided to increase the ships’ staying time at port and make the ships delay leaving the port, with the extra cost such as the extra light oil cost. The second is that because of the depressed domestic shipping market, some ships have to waiting for the cargo in port to keep having no broken stowage, which can be avoided by reasonably operating and arranging the inland transportation. The third is that the ship has arrived at the port but no berth is available because the ships of many shipping companies reach the port at the same time and the berths are not enough for loading and unloading. This situation cannot be avoided to some extent, but we can avoid our ships arriving at the same port together by ship deployment and routing design.

It is known from Fig. 6 that the point of intersection of two lines, the transport cost line and the cost at port line, means that the total cost has the minimum value at that point and when the distance is 600 miles, the ship with the capacity of 1100 TEU (16000t) is the most economic. Then, we calculate other distances of the routings we redesigned before based on the above analysis. Fig. 7 and Fig. 8 show the results of the optimal point of total cost with the distance of 500 miles and 700 miles.

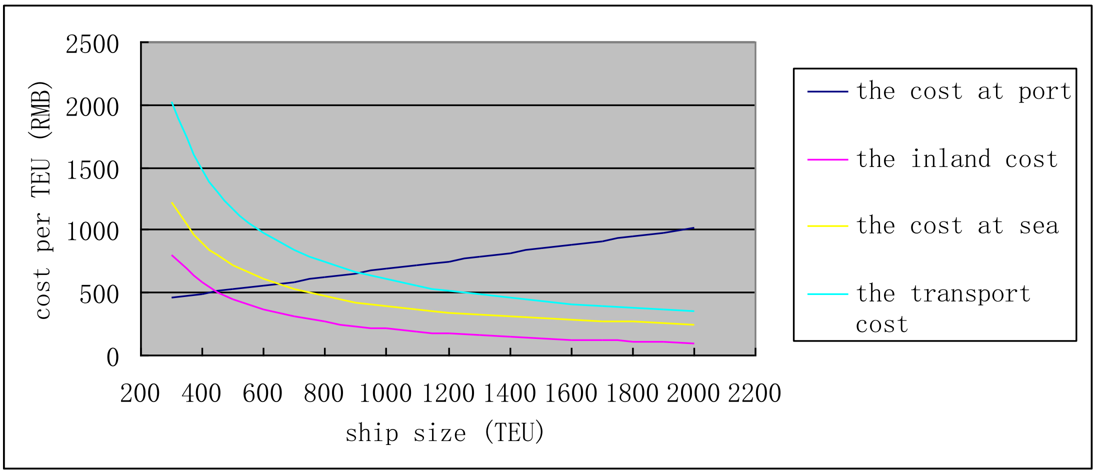

Fig 7.The several costs when the distance is 500 miles

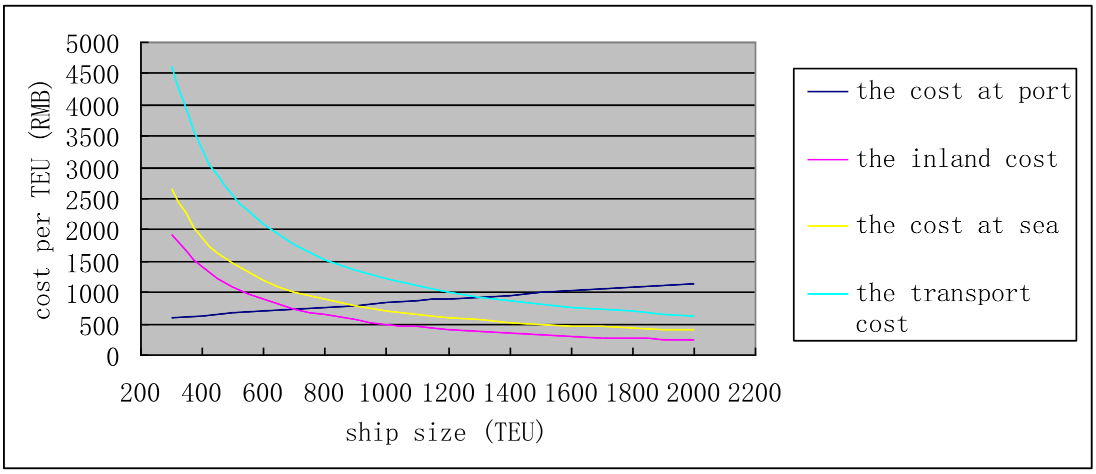

Fig 8.The several costs when the distance is 700 miles

From above two diagrams, we can get the answers that the ships with the capacity of 900 TEU (13000t) should be deployed on the shipping routing of 500 miles, while the ships with the capacity of 1300 TEU (18000t) are better to be allocate to the routing of 700 miles. Through such calculation and analysis, we can assess all of 34 schemes we redesign in section 4.4.1 and find the most suitable ship size for each routing to deploy ships. We ought to make full use of our own ships and the hired ships in our fleet now, unless our fleet cannot provide the ship we need and we are not able to take place of it. Once the ship deployment is determined, the speed can be calculated by the formulation speed = 2.3438* ship size ^ 0.2345.

4.5 Sensitive analysis

Having deployed the ships and selecting the ports for all schemes, we will assess the impact of ship size and sailing distance to the total cost in the company's operation in this section.

Savings of smaller ship cost, decreasing inventory cost or port tariff when we shorten the routine sometimes can not make up for considerable increase of inland/feeder cost, which constitutes a high percentage in total cost because the time spent during inland transportation occupy a big proportion of total time. Operation in fewer ports is beneficial when we can control inland/feeder process, especially inland transport.

In our study, inland cost with the model of road plays more than 95% in cargo transport cost between ports and origins/destinations of shipments. The hub and spoke system is only competitive when a substantial percentage of cargo are not transformed to other ports but generated in the hubs. We clarify that it is only feasible when large volumes of cargo demand come from the hinterlands approaching to transshipment ports. Hinterland accessibility can be considered as an important element which influence significantly to port attractiveness. Thus, inland connection is emphasized as an advantage for upstream ports to compete with downstream ports which has better conveniences about ship accessibilities and closeness to mainline. The inland distances between a shipment's position and a port is one of the most influential factors in the assignment of a shipment to a particular port, which confirms the importance of inland transportation to port selection.

Here we use the method of sensitive analysis to assess the redesigned schemes according to the impact of ship size and sailing distance to the total cost. From Table 16, the results of sensitive analysis about ship size to total cost show that the ship size has a little great impact on the total cost and under the distance of 600 miles, the ship size with 800 TEU is the boundary, having the minimum total cost.

Table 16.The sensitive analysis about ship size and total cost

distance	600	miles
ship size	620	TEU
formulation	¥992,562.14	
	¥992,562.14	
300	1062102.716	RMB
410	1022676.753	
480	1008157.544	
530	1000926.914	
620	992562.1359	
740	987831.2276	
800	987397.5853	
1130	998560.1698	
1600	1034012.552	
1750	1047632.743	

As the same as the above sensitive analysis, we can see that the impact of distance on the total cost is great and after 750 miles, the amount of increase of the total cost is larger and larger. From both tables, we think the distance is more sensitive than the ship size reflected on the total cost.

Table 17.The sensitive analysis about distance and total cost

distance	600	miles
ship size	620	TEU
formulation	¥992,562.14	
	¥992,562.14	
400	421596.216	RMB
450	542867.9127	
500	677929.9467	
550	827566.5952	
600	992562.1359	
650	1173700.846	
700	1371767.004	
750	1587544.886	
800	1821818.77	
850	2075372.933	

Finally, we combine two sensitive analysis tables and make Table 18 to analyze the impact of sensitive analysis results to the routing and schedule design.

Table 18.Summary of impact of ship size and distance to total cost

distance	600	miles					
ship size	620	TEU					
formulation	¥992,562.14						
¥992,562.14	500	550	600	650	700	750	800
300	698649	870425	1062103	1274784	1509571	1767566	2049872
410	682828	843867	1022677	1220208	1437413	1675243	1934652
480	678707	835033	1008158	1198965	1408340	1637167	1886330
530	677513	831109	1000927	1187811	1392605	1616154	1859301
620	677930	827567	992562	1173701	1371767	1587545	1821819
740	681987	827682	987831	1163157	1354382	1562226	1787412
800	685053	829186	987398	1160383	1348839	1553461	1774944
1130	709006	847502	998560	1162773	1340732	1533030	1740257
1600	752826	887787	1034013	1192005	1362267	1545301	1741611
1750	767851	902260	1047633	1204451	1373197	1554353	1748400

According to the above results, we should redesign ship deployment and shipping routing with the principle of distance of the routing prior to ship size to be considered in the process of establishing ZhongGu's shipping schedule. Having determined the sailing distance, we should deploy the larger vessel as possible as we can because though the total cost is the same or similar, the company can make more profits based on economies of scale. Of course, it is necessary for us to make use of now available ships in the fleet during the process of ship deployment.

5. Conclusion and recommendation

In this paper, we use the cost model to design routing and ship deployment from a logistics perspective. We concern not only sea transport factors but also inland transport. The model has been applied in a real case, container transportation of ZhongGu Shipping Company in domestic market, and solved by computational programs. Results from computational programs and sensitive analyses have provided us with some in-depth views about liner network matters.

Firstly, shipping is only an element in the whole logistics network. The optimal network does not depend only on shipping but also other elements. Ship cost or port tariff plays a large part in the total cost of cargo transportation but is not the unique one. In our calculations, when we miss other elements, the results will deviate from the optimality. The lack of inventory cost at port and sea can dim the negative effect of mega vessels. Without inland transport, we can not fully understand the benefit of the direct call in liner services.

Then, the deployment of larger vessels does not mean that the total cost must fall down because of economies of scale, on the contrary, it trends to increase. The decrease in the number of port calls can give the advantage of lower ship cost, inventory cost and port tariff, but we must pay a higher inland/feeder transport cost. The extra inland/feeder transport cost is an obstacle to reduce ports in ship's voyage as well as the use of hub and spoke system as well. When put in an entire network, mega vessels are not as beneficial as desired. Their benefit is only marginal. The main bottle neck is the extra cost in the port which causes a longer time the ship and cargo spent in port, consequently, a higher ship cost and inventory cost occurring.

Finally, we redesign the shipping schedule of ZhongGu Shipping Company in Table 19 based on all results of calculation and analysis in this paper (we assume the cargo start to be loaded on June 1st and try to avoid the ships arriving at the same port at the same time).

Table 19.The redesigned shipping schedule

Routing	Ship size	operating routing			ETD of each port		
1	22000t	YingKou-	TaiCang-	YingKou	6/1	6/4	6/7
2	16000t	YingKou-	ShangHai-	YingKou	6/2	6/5	6/8
3	16000t	JinZhou-	TaiCang-	JinZhou	6/3	6/6	6/9
4	16000t	JinZhou-	ShangHai-	JinZhou	6/5	6/8	6/11
5	11000t	DanDong-	TaiCang-	DanDong	6/3	6/7	6/11
6	11000t	DanDong-	ShangHai-	DanDong	6/6	6/9	6/12
7	11000t	DanDong-	NingBo-	DanDong	6/4	6/7	6/10
8	10000t	DaLian-	TaiCang-	DaLian	6/5	6/8	6/11
9	10000t	DaLian-	ShangHai-	DaLian	6/7	6/10	6/13
10	10000t	DaLian-	NingBo-	DaLian	6/6	6/9	6/12
11	11000t	TianJin-	ShangHai-	TianJin	6/8	6/11	6/14
12	9000t	TianJin-	NingBo-	TianJin	6/7	6/10	6/13
13	16000t	TianJin-	XiaMen-	TianJin	6/6	6/12	6/18
14	22000t	TianJin-	GuangZhou-	TianJin	6/5	6/11	6/17
15	11000t	TianJin-	TaiCang-	TianJin	6/9	6/12	6/15
16	9000t	QingDao-	ShangHai-	QingDao	6/9	6/12	6/15
17	9000t	QingDao-	TaiCang-	QingDao	6/10	6/13	6/16
18	28000t	QingDao-	XiaMen-	QingDao	6/11	6/17	6/23
19	28000t	QingDao-	GuangZhou-	QingDao	6/12	6/18	6/24
20	11000t	LongKou-	ShangHai-	LongKou	6/10	6/13	6/16

21	11000t	JiangYin-	TianJin-	JiangYin	6/1	6/5	6/9
22	11000t	JiangYin-	XiaMen-	JiangYin	6/3	6/7	6/11
23	10000t	TaiCang-	XiaMen-	TaiCang	6/1	6/4	6/7
24	28000t	TaiCang-	GuangZhou-	TaiCang	6/2	6/5	6/8
25	10000t	TaiCang-	HuMen-	TaiCang	6/3	6/7	6/11
26	11000t	TaiCang-	ZhuHai-	TaiCang	6/5	6/9	6/13
27	9000t	ShangHai-	ShenZhen-	ShangHai	6/1	6/4	6/7
28	16000t	ShangHai-	XiaMen-	ShangHai	6/2	6/5	6/8
29	8000t	ShangHai-	ShanTou-	ShangHai	6/3	6/6	6/9
30	28000t	ShangHai-	GuangZhou-	ShangHai	6/4	6/7	6/10
31	9000t	ShangHai-	ZhuHai-	ShangHai	6/6	6/10	6/14
32	11000t	NingBo-	GuangZhou-	NingBo	6/1	6/4	6/7
33	11000t	NingBo-	HuangPu-	NingBo	6/3	6/6	6/9
34	8000t	XiaMen-	HuangPu-	XiaMen	6/2	6/5	6/8
35	8000t	XiaMen-	GuangZhou-	XiaMen	6/6	6/9	6/12
36	8000t	QuanZhou-	ShenZhen-	QuanZhou	6/1	6/3	6/5

The recommendations we give the company are that more large vessels, especially with the ship size of 11000t and 16000t, should be hired to take place of the small ships such as 5000t and 6000t vessels, while the number of port calls and vessels on one routing should be decreased. More direct ships can help the company to improve the quality of service product and punctuality and attract more customers in competitive domestic shipping market.

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