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Hub Port Positioning and Route Planning of Feeder Lines for Regional Transportation Network

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***Abstract*—**In this paper, we seek to determine one reasonable local hub port and optimal routes for a containership fleet, performing pick-ups and deliveries, between the hub and spoke ports in a same region. The relationship between a hub port, and traffic in feeder lines is analyzed. A new network planning method is proposed, an integrated hub port location and route design, a capacitated vehicle routing problem with pick-ups, deliveries and time deadlines are formulated and solved using an improved genetic algorithm for positioning the hub port and establishing routes for a containership fleet. Results on the performance of the algorithm and the feasibility of the approach show that a relatively small fleet of containerships could provide efficient services within deadlines.

***Keywords*—**Route planning, Hub port location, Container feeder service.

I. Introduction

IN this paper we investigate hub port position and route scheduling for a fleet of containerships performing short-distance pickups and deliveries between hub-and-spoke ports, under time deadline constraints. Our motive stems from the real problem faced in transporting goods within the Bohai Bay Port Cluster. According to the statistics of China Ports Year Book 2012 [1], the feeder line throughput was up to 10,355,000 TEU of ports, an increase of 20.6%, along the coast of China in 2012. As a supporting transport around the hub port, a regional transportation network is an important guarantee for the shipping network's effective operation. However, due to the similar functions or the crossed hinterland of the ports, the existing regional transportation network is problematic, the function of ports are not clearly state. Excessive competition among ports will inevitably cause, the international competitiveness of a regional hub port to be weakened, and resources unnecessarily wasted. Therefore, positioning the hub port scientifically, and creating optimized ship routes in a region, is value for the efficient operation of the branch network.

Currently, there are few studies on regional shipping network construction, and also treated hub port positioning and route design as two separate issues, ignoring the relationship between hub port and ship routes. Identified research is on route design problems, mainly in maritime trunk transportation network (see [2], [3]). Most of the different network design models published during the last decade can be grouped into the following categories, as in [3]: (1) Models with a single route or sets of routes without transshipment [4], [5]. (2) Hub and feeder route models where each feeder port is connected to a single hub port [6], [7]. (3) Models where some ports are classified as hub ports without any constraints on the number of hub and non-hub ports a route may visit [8], [9]. (4) Multi route models without any separation of hub and non-hub ports [10].

The study on hub port positioning problem, mostly adopts the principal component analysis [11], the fuzzy clustering analysis method [12], and some other qualitative methods. But, there is no more mature quantitative analysis. Some research in China [13], [14] aimed at constructing container shipping feeder lines network, all assumed the local hub port was known. In fact, the positioning of hub port and routes allocation influences one another. Therefore, in this paper, a new network planning method, that takes hub port location and optimal routes into consideration jointly, is proposed.

II. Problem Description

In this study, a hub-and-spoke maritime network is considered to provide freight shipping services between two continents or regions separated by a major ocean. A fundamental hub-and-spoke maritime network considered in this study is shown in Fig. 1 [15]. This study based on the situation that freight between feeder ports on one feeder line at origin region (e.g., ports p1 and p2) and hub portsat the destination region (e.g., ports p5 and p6), are shipped through the local hub port, at origin region (i.e. shipped via hub port, p3, by routing the feeder line, *s*:*p1, p2, p3, p1*, and then the main line, *h*: *p3, p4, p5, p6,p5, p4, p3*).

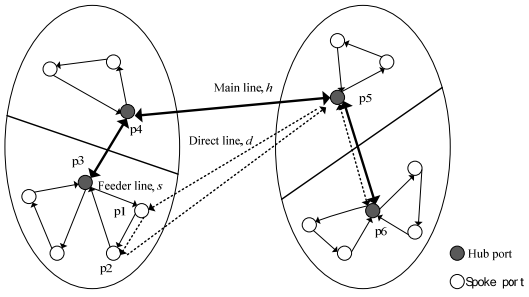

Fig. 1 The fundamental hub-and-spoke maritime network

This study explores decision-making on which port should be selected as a local hub port in a region based on location and freight shipping demands, and optimizing routes of small feeder ships between local hub port and its spoke ports in the

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same region, under capacity and time deadline constrains.

The problem considered is that of designing the network of routes for the containerships of a dedicated homogeneous fleet. A fleet of homogeneous containerships with a fixed capacity, starting from a central port, would deliver goods to a number of its spoke ports, at minimum travel cost. A ship approaching a port is assumed to perform both operations-pick-ups and deliveries-at the same time. Finally, the ship goes back to the central port. Therefore, liner shipping companies design fixed schedules and routes as a weekly service, which are kept in place for a relatively long time, e.g., for a few months or for a year. The shipping companies estimate potential cargo demand at each calling port on a weekly basis and try to construct service routes or networks by explicitly taking into consideration incurred costs during a specified planning horizon. The other assumptions are as follows:

1) Ships sail in ideal state, the average speed and port handling efficiency are known. Handling time of each spoke port is determined by containers loaded and unloaded and quay crane operating efficiency.
2) Each ship and the compatibility of ports, navigation channels and container type are known (such as draft, headroom, dangerous goods, etc.)

A.Model Formulation

The problem of deciding an optimal route (i.e., choosing an optimal set of calling ports and associated calling sequence of ports) and a reasonable hub port, can be formulated as follows:

Let:

$$X_{ijk}=\begin{cases}1 & \text{if ship } k \text{ uses arc}(i,j)\\ 0 & \text{otherwise}\end{cases}$$

$$Z_r=\begin{cases}1 & \text{if port } r \text{ is the hub port}, r\in G\\ 0 & \text{otherwise}\end{cases}$$

$$\text{minimize} \quad f(x)=C(X_{ijk}) \tag{1}$$

Subject to

1) Containership routes and number of hub port constrains

$$\sum_{k\in V}\sum_{i\in G}X_{ijk}=1,\ \forall j\in G \tag{2}$$

$$\sum_{k\in V}\sum_{j\in G}X_{ijk}=1,\ \forall i\in G \tag{3}$$

$$\sum_{i\in G}X_{ipk}-\sum_{j\in G}X_{pjk}=0,\ \forall k\in V, p\in G \tag{4}$$

$$\sum_{r\in G}\sum_{j\in G}X_{rjk}\le 1,\ \forall k\in V \tag{5}$$

$$\sum_{k\in V}\sum_{j\in G}X_{rik}-Z_r\ge 0,\ \forall r\in G \tag{6}$$

$$\sum_{j\in G}X_{rjk}-Z_r\le 0,\ \forall k\in V, r\in G \tag{7}$$

where G is the set of ports; V is the set of ships; i, j, p,r are nodes belonging to G; k is the ship belonging to V.

The objective function (1) minimizes total cost. The detailed cost functions are illustrated at Section II *B* in this paper. Constraints (2) and (3) ensure that every demand node is served by exactly one ship. Constraint (4) guarantees that a ship exits the demand node it enters, and constraint (5) ensures the ship k start's from hub ports; the purpose of constraints (6) and (7) is to guarantee that a ship start from one hub port and only one hub.

2) Demand and supply constraints for simultaneous pick-ups and deliveries

$$l_{rk}=\sum_{i\in G}\sum_{j\in G}d_jX_{ijk},\ \forall k\in V,\ r\in G\ when\ Z_r=1 \tag{8}$$

$$l_{jk}\ge l_{rk}-d_j+p_j-M(1-X_{rjk}),\ \forall j\in G, k\in V \tag{9}$$

$$l_{jk}\ge l_{ik}-d_j+p_j-M(1-\sum_{k\in V}X_{ijk}),\ \forall i\in G, j\in G, i\ne j \tag{10}$$

$$l_{rk}\le Q_k,\ \forall k\in V, r\in G, Z_r=1 \tag{11}$$

$$l_{jk}\le Q_k,\ \forall k\in V, j\in G \tag{12}$$

where d_i is the demand for node i; pj is the pick-up load in port j; l_{rk} is the load for ship k when leaving the mainland port; $l_{jk}$is the load for ship k after leaving port j; M is the arbitrarily large number. Q_k is the capacity for ship k.

Equation (8) determines initial ship loads. Constraints (9) and (10) correspond to ship loads for the first and successive nodes. Finally, constraints (11) and (12) ensure that ship capacity is not exceeded.

Constrains related to time

$$T_j\ge T_i+S_{ik}+t_{ijk}-(1-X_{ijk})\cdot T_k,\ \forall i,j\in G, k\in V \tag{13}$$

$$T_j\ge T_i+S_{ik}+t_{ijk}+(1-X_{ijk})\cdot T_k,\ \forall i,j\in G, k\in V \tag{14}$$

$$T_r=0,\ r\in G, when\ Z_r=1 \tag{15}$$

$$\sum_{i\in G}S_{ik}\sum_{j\in G}X_{ijk}+\sum_{i\in G}\sum_{j\in G}t_{ijk}\cdot X_{ijk}\le T_k,\ \forall k\in V \tag{16}$$

$$T_j\le L_j,\ \forall j\in G \tag{17}$$

where T_i, T_j are the arrival times at ports i, j; t_{ijk} is the time to traverse arc (i, j) by ship k; S_{ik} is the necessary time to serve node i by ship k; T_k is maximum route travel time for ship k; L_j is latest arrival time at port j.

Constraints (13) and (14) ensure successive arrival times between ports while constraint (16) handles maximum allowable travel time. Constraint (17) restricts arrival times to be prior to latest arrival times. The set of (1)-(17) represent the mathematical formulation for solving the routing of

containerships with time deadlines, pick-ups and deliveries.

B. Shipping Cost Function

Shipping costs are made up of two components: operating and capital costs ([16]). In general, the capital cost includes the cost regarding the ship itself, while the operating cost includes the costs of fuel, lubricant and port entry. These costs are defined as below:

$$C = CS + CP ,$$

where *CS* is ship related costs; *CP* is port related costs.

(1) Ship Related Costs CS

$$CS = C^C + C^F$$

where C^F is fuel and its related cost; C^C is ship's other costs, which are not incurred in proportion to the cruse distance ($C^C = C^M + C^D + C^R + C^I + C^P$); C^M is crew cost, C^D is ship's depreciation cost, C^R is interest, C^I is insurance cost, C^P is repair and maintenance cost.

The market report [17] investigates ship related costs (actually the time-charter cost) by various ship sizes. As a result of a regression analysis that was performed based on the above cost data, we obtained the following linear cost ($US per day) model using the Q_k (twenty-foot equivalent unit) capacity as the independent variable:

$$C^{CD} = 6.54 * Q_k + 1422.52. \quad (20)$$

This regression model provides a good prediction, since its coefficient of determination (R2) is 0.9972.

Given the number of voyages offered yearly, which is easily calculated as it is based on round trip duration, the total cost is the product of the cost per voyage and the cost of a deployed ship. This enables us to concentrate only on the evaluation of the voyage cost per ship. The ship's other costs, C^C, are computed from the multiplication of the ship's other daily costs, C^{CD}, and the time duration of the voyage, (*DIST*/(24**v*))+*IDLE*:

$$C^C = C^{CD}(\frac{DIST}{24*v} + IDLE),$$
$$IDLE = \sum_{i\in S}\left\{\sum_{j\in S}(s_j + s_i)(q_{ij}) + f_i + f_i'\right\} \Big/ 24,$$
$$DIST = \sum_{i\in S}\sum_{j\in S}\sum_{k\in V} X_{ijk}\cdot d_{ij},$$

where *IDLE* is stay time at port (days), which is associated with a given group of calling ports; S_i is handling time (loading or unloading) per container at port *i*; q_{ij} is the number of containers carried from ports *j* to *i*; f_i, f_i' is standby times for departure and arrival at port *i*; d_{ij} is cruising distance from ports *i* to *j* (nautical miles); *v* is cruising speed (*knots*).

The fuel cost C^F of a voyage, which in this case includes also lubricant cost, is defined by the following equation:

$$C^F = \frac{(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub})\cdot DS^{\frac{2}{3}}\cdot v^2 \cdot DIST}{A}$$

where C^{Fuel} is fuel cost; R^{Fuel} is fuel consumption; C^{Lub} is lubricant cost; R^{Lub} is lubricant consumption; *DS* is displacement; A is admiralty coefficient (a parameter used for the naval architecture. See [18].

The overall ship related cost *CS* is:

$$CS = C^{CD}(\frac{DIST}{24*v} + IDLE) + \frac{(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub})\cdot DS^{\frac{2}{3}}\cdot v^2 \cdot DIST}{A} \quad (21)$$

If we take a partial derivative of (21) by cruising speed *v* and set the resulting equation as zero as follows, then the optimal cruising speed *v** is defined by (22).

$$\frac{\partial CS}{\partial v} = -\frac{C^{CD}\cdot DIST}{24*v^2} + \frac{2*(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub})\cdot DS^{\frac{2}{3}}\cdot v\cdot DIST}{A} = 0$$
$$-C^{CD}\cdot A + 48*(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub})\cdot DS^{\frac{2}{3}}\cdot v^3 = 0$$
$$v^* = \left\{\frac{C^{CD}\cdot A}{48*(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub})\cdot DS^{\frac{2}{3}}}\right\}^{\frac{1}{3}} \quad (22)$$

The cost at the optimal speed and those at different speeds around the optimal one are plotted in Fig. 2.

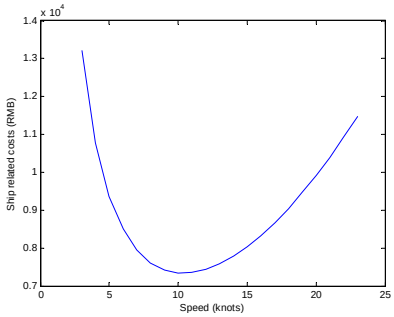

Fig. 2 Ship related costs at various speeds

(2) Port Related Costs CP

$$CP = C^E + C^H ,$$
$$C^E = \sum_{i\in S}\sum_{j\in S} C_{qi}X_{ijk}$$
$$C^H = \sum_{i\in G} H_i(q_i + d_i) ,$$

where C^E is the port entry cost; C^H is the cargo handling cost; C_{qi} is the entry cost per call at port *i*, note that a selected arc associates two calling ports *i* and *j*, however only one of them should be counted in the entire voyage. H_i is the handling cost per container (TEU) at port *i*.

$$CP = \sum_{i\in S}\sum_{j\in S} C_{qi}X_{ij} + \sum_{i\in G} H_i(q_i + d_i)\cdot$$

The total cost is:

$$f(x) = C(X_{ijk}) = C^{CD}\left(\frac{DIST}{24*v} + IDLE\right) + \frac{(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub}) \cdot DS^{\frac{2}{3}} \cdot v^2 \cdot DIST}{A} + \sum_{i\in S}\sum_{j\in S} C_{qi}X_{ij} + \sum_{i\in G} H_i(q_i + d_i) \quad (23)$$

III. Algorithmic Approach

For reasons that (1) the combinatorial and NP-Hard character of the VRP variants; (2) their wide applicability for solving VRPTWs, GAs are selected to solve the problem at hand.

Genetic algorithms were first introduced by J. Holland (1975) [19] and are described as search techniques based on the process of natural evolution. When applied in optimization, genetic algorithms start with a set of possible solutions called a population. Every possible solution is encoded into a string (or chromosome) representing it, according to a specific structure called a schema. A string is composed of genes, each gene actually corresponding to a decision variable of the initial problem. Strings evolve through a series of iterations called generations. During each generation, every string is evaluated using a fitness measure. According to their fitness measure, strings are selected for the next generation which is constructed by applying three basic genetic operators: selection of parents, crossover and mutation. Parents are selected probabilistically and can be crossed over by exchanging pieces with each other and/or mutate randomly or be transferred unaltered to the next generation; this process is repeated until a termination sequence (such as convergence) is reached [20].

The proposed GA has some distinct features: each generated string is evaluated by an external process ensuring that capacity constraints are exhausted but not violated in any case. On the other hand, time deadlines are considered as soft constraints, implying that delays are penalized even when a solution exists. Such an approach may lead to a minimum number of vessels operating at maximum capacity, but at the possible expense of relatively increased delays. However, since investing and operating additional vessels is of considerable cost compared to the gains of fully eliminating delays, we adopt such an approach. Careful selection of vessel capacity could lead to a good compromise and acceptable delay tolerance; such a decision can be supported by the proposed algorithm.

A.GA Characteristics

(1) Genetic Representation

Considering using real-coded schema will generate meaningless solution, we use a string which is represented as a sequence (permutation) of n nodes, without trip delimiters. This representation can be interpreted as the order in which a containership must visit all ports, if the same containership performs all trips one by one. For example, for a set of 8 ports, port 1 is the hub port, the original order of port is R0: [1 2 3 4 5 6 7 8], and a possible string would be (1 5 4 6 2 3 8 7). A containership start from port 1, then delete port 1 in R0 in the first place, get R1:[2 3 4 5 6 7 8]. The ship comes to port 5, then delete port 5 in R1 in the fourth place, get R2: [2 3 4 6 7 8]. The ship comes to port 4 in order, then delete port 4 in R2 in the third place, get R3:[2 3 6 7 8]. Until all the ports are visited, encoding with the place number of every port in line. Eventually, the string (1 5 4 6 2 3 8 7) is encoded as (1 4 3 3 1 1 2 1). Accordingly, an encoded string (1 7 4 3 2 1 2 1) can be decoded into (1 8 5 4 3 2 7 6).

The absence of trip delimiters aids in applying typical operators such as crossover and mutation. Trips are cut sequentially, beginning from the first node, according to a heuristic described later. The heuristic examines capacity constraints and pick-ups and deliveries and extracts routes from a string. The representation scheme allows for the extraction of the optimal number of routes and, therefore, determines the number of necessary containerships. As noted earlier, such an approach focuses on exhausting capacity of vessels at the expense of delays, an acceptable policy in ship transportation practice because of the high costs for investing and operating additional vessels.

(2) Crossover and Mutation Operators

A Single-Point Crossover is Applied:

Single point crossover partitions the chromosome only at one point over the length of the chromosome. The crossover point randomly generated, in the range of [1,Nvar-1], where Nvar is the length of the chromosome. The point as demarcation and the chromosome cross each other.

An example of the crossover method used is the following:

Parent 1:(1 2 3 4 5 6 7 8) coding (1 1 1 1 |1 1 1 1) Crossover

Parent.2:(1 3 5 6 4 2 7 8) (1 2 3 3 |2 1 1 1)

(1 1 1 1 2 1 1 1)decoding Child 1：(1 2 3 4 6 5 7 8)

(1 2 3 3 1 1 1 1) Child 2：(1 3 5 6 2 4 7 8)

A swapping mutation method is selected, and two genes in each string are randomly selected and swapped. The mutation rate is, in the case of a permutation the probability that a string is selected for that operation (Holland, 1975).An example of the mutation method used is the following:

(1 3 5 |6 2 4 |7 8)mutation (1 3 4 6 2 5 7 8)

(3) Selection

A selection criterion is used for choosing two parents to apply the crossover operator. We adopt a roulette-wheel selection method.

(4) Fitness function

The total cost is the fitness measure for evaluating a string. The objective is to achieve the smallest possible value of that measure.

A penalty is imposed for time delays (approaching an island out of the limit time window [ET_i, LT_i]). The penalty function

is:

$$f(t) = z_1 \sum_{i \in G} \max[(ET_i - T_i), 0] + z_2 \sum_{i \in G} \max[(T_i - LT_i), 0] \quad (24)$$

where z_1 is the opportunity cost per unit time ship waiting in port; z_2 is the penalty coefficient when the ship later than the time deadline. If the ship arrives before ET_i , the cost is $z_1(ET_i - T_i)$; if the ship approaching an island later than LT_i, the penalty cost is z_2 $(T_i - LT_i)$;if the reaching time between $[ET_i, LT_i]$, the penalty cost is zero.

The fitness function becomes:

$$F = C^{CD}\left(\frac{DIST}{24*v} + IDLE\right) + \frac{(C^{Fuel}R^{Fuel} + C^{Lub}R^{Lub}) \cdot DS^{\frac{2}{3}} \cdot v^2 \cdot DIST}{A}$$
$$+ \sum_{i \in S}\sum_{j \in S} C_{qi} X_{ij} + \sum_{i \in G} H_i(q_i + d_i) + z_1 \sum_{i \in G} \max[(ET_i - T_i), 0] + z_2 \sum_{i \in G} \max[(T_i - LT_i), 0]$$

B.Route Extraction Algorithm

Since no trip delimiters exist, an algorithm is necessary for extracting feasible routes (in terms of capacity) from each string. Pick-ups and deliveries must be considered, so a process is devised for extracting each route and calculating total travel and service cost; this proceeds as follows:

Step 1. Initiation. The first gene in a string sequence is selected. Each gene corresponds to a port.

Step 2. Route construction. The next port (gene) is added to the route. Capacity constraints exist (a) for the link between the mainland port and the first island port, (b) for the link between the next and the preceding island port, (c) for the link between the next port and the mainland port (when a containership returns to the mainland port). All these constraints exist since pick-ups may exceed deliveries in a port. Therefore, loads for cases (a), (b) and (c) are calculated. This is repeated for each node in the string sequentially.

Step 3. Route termination. If capacity constraints in a port are NOT exceeded, the port is added to the route and the algorithm returns to Step 1, selecting the next port as the first node. Otherwise, the algorithm returns to Step 1 setting this port as the initial port.

Step 4. Algorithm termination. When all ports are included in routes, the algorithm is terminated. An example of the algorithm's operation is given in Fig. 3. The numbers on the nodes representing ports are the port ID numbers. The numbers next to the links are loads for each link while the numbers in parentheses next to each port are delivery and pick-up loads for that port. Assuming that a ship has a capacity of 50 containers, the first link has a load of 30 containers, the second link has a load of 30-10+1=21 containers and the third link has a load of 21-10+1=12 containers. If the ship from port 3 returns to the mainland (port 0) its load for that link (3->0) would be 12-10+40=42 containers. On the other hand, if the ship continued to node 4, its load after port 4 will be 42-10+30=62 containers, which exceeds ship capacity. The example shows that, in that case, the critical link for a route containing port 3 is the return route to the mainland port, since the amount of pick-ups is very high in that port.

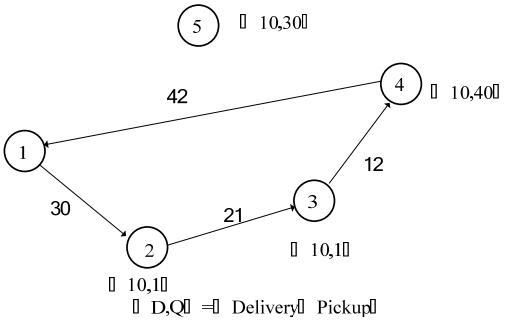

Fig. 3 Example of applying the route extraction algorithm

IV. Application

TABLE I
Distances between Ports in Nautical Miles

Distance	Dalian	Yingkou	Dan dong	Jinzhou	Tianjin	Qinhuangdao	Tangshan	Huanghuagang	Yantai	Weihai	Qingdao	Rizhao
Dalian	0	226	159	226	216	168	162	209	90	94	278	345
Yingkou	226	0	330	61	266	135	189	201	219	199	422	385
Dandong	159	330	0	383	373	315	321	368	215	195	346	412
Jinzhou	226	61	383	0	244	154	167	242	202	208	350	400
Tianjin	216	266	373	244	0	134	61	49	203	272	430	430
QinHuang-dao	168	135	315	154	134	0	72	153	172	193	400	385
Tangshan	162	189	321	167	61	72	0	82	154	188	305	369
Huang-huagang	209	201	368	242	49	153	82	0	179	220	346	413
Yantai	90	219	215	202	203	172	154	179	0	47	171	195
Weihai	94	199	195	208	272	193	188	220	47	0	128	195
Qingdao	278	422	346	350	430	400	305	346	171	128	0	68
Rizhao	345	385	412	400	430	385	369	413	195	195	68	0

The proposed algorithm is applied for routing a freight vessel fleet around 12 ports in the Bohai region, China. Table I shows the distances between the islands and the mainland in nautical miles. Table II summarizes demand and supply for each island. Demand and supply for each island (in containers data has been provided by the China Ports Year Book). Greek authorities have established a time deadline of 35-40 h after departure for supplying an island with goods [21]; we adopt here a 40h time deadline. Port handling efficiency is 0.042 h/TEU. Furthermore, homogeneous vessels with a capacity of 450 small containers and average speeds of 11 knots are considered.

TABLE II
WEEKLY THROUGHPUT AT PORTS (TEU)

Destination	Demand	Supply
Dalian	12462	6692
Yingkou	1200	692
Dandong	23	0
Jinzhou	300	162
Tianjin	4962	2377
Qinhuangda	2192	969
Tangshan	46	23
Huanghuagang	0	0
Yantai	2238	1108
Weihai	4777	2400
Qiangdao	18508	9231
Rizhao	600	254

A.GA Parameters and Fine Tuning

Since our application examines 12 islands, the string will have 12 genes and therefore the population size to be examined will be 12. Alternatively, a population of 24 is examined. Values of crossover rates to be applied are 0.2, 0.4 and 0.6 and mutation rates 0.01, 0.05, 0.10 and 0.15, respectively. The GA is terminated when there is no significant improvement to the fitness function value (<1%) for a number of 150 generations.

B.Results and Algorithmic Performance

Table III shows results for the above combinations of GA parameters (fitness function value, algorithm running time, necessary vehicles). The algorithm's running time on a 2.6 GHz computer with 4G of RAM ranges from 65-90 seconds.

Best results are obtained, with a population of 12, a crossover rate of 0.2 and a mutation rate of 0.01. For all combinations of GA operators, fitness function values do not differ significantly (about 5% at most). The solution for the best fitness function values is shown in Fig. 2. As can be seen in Table IV, Dalian Port, Tangshan Port, and Qinhuangdao Port are in one route; Qingdao Port and Huanghuagang Port are in a route. Dalian Port and Qingdao Port both have large container throughput, the container throughput ofTangshan Port, Qinhuangdao Port and Huanghuagang Port is small, relatively. This can be intuitively attributed to the algorithm's structure, which practically constructs routes, so that it minimizes total travel distances from the central port.

It turned out that Tianjin Port can be the central port in Bohai region, and total cost is 617492 RMB, the lowest. The cost of Dalian Port as the central port is compared, shown in Fig. 4.

TABLE III
RESULTS FOR DIFFERENT GA PARAMETERS COMBINATION

Population size	Crossover rate	Mutation rate	Fitness function value	Algorithm Running time (s)	Number of Routes- vehicles
12	0.2	0.01	617491.76	68.31	4
12	0.2	0.05	628030.04	71.26	4
12	0.2	0.1	621353.11	87.20	4
12	0.2	0.15	639292.33	67.92	4
12	0.4	0.01	621192.22	76.15	4
12	0.4	0.05	629799.83	74.22	4
12	0.4	0.1	628995.38	70.89	4
12	0.4	0.15	647497.71	79.83	4
12	0.6	0.01	618537.54	73.19	4
12	0.6	0.05	624564.32	81.36	4
12	0.6	0.1	621753.25	68.31	4
12	0.6	0.15	639131.44	71.26	4
24	0.2	0.01	627453.26	74.96	4
24	0.2	0.05	628232.39	80.43	4
24	0.2	0.1	624623.61	78.74	4
24	0.2	0.15	643262.83	76.27	4
24	0.4	0.01	630831.52	81.40	4
24	0.4	0.05	639769.82	80.05	4
24	0.4	0.1	628959.78	81.11	4
24	0.4	0.15	646393.71	82.66	4
24	0.6	0.01	617732.48	74.96	4
24	0.6	0.05	626334.79	80.43	4
24	0.6	0.1	624383.18	78.74	4
24	0.6	0.15	649081.13	76.27	4

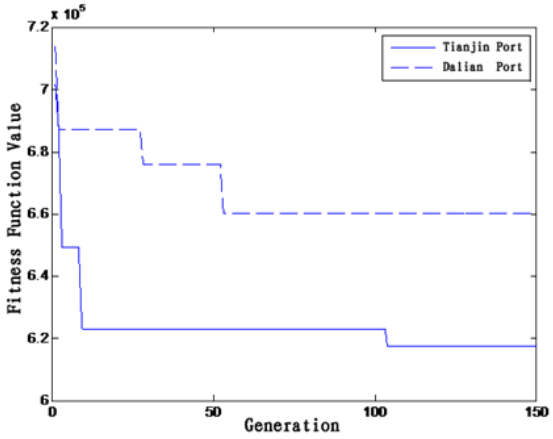

Fig. 4 Total cost of different hub port

As can be seen, the total cost of Dalian Port as a hub port is 661275 RMB, more than Tianjin Port. Therefore, in this paper Tianjin Port as the hub port, the branch network in Bohai sea region is constructed. Four routes are designed; route optimization results are shown in Table IV. Fig. 5 summarizes the best set of routes derived by the algorithm.

TABLE IV
ROUTE OPTIMIZATION RESULT

Routes	Ports
1	Tianjin—Tangshan—Qinhuangdao—Dalian—Tianjin
2	Tianjin—Jinzhou—Yingkou—Dandong—Tianjin
3	Tianjin—Weihai—Yantai—Rizhao—Tianjin
4	Tianjin—Huanghua—Qingdao—Tianjin

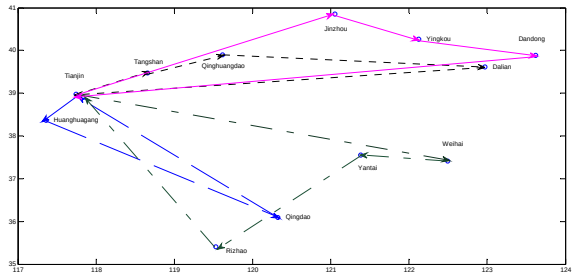

Fig. 5 Route optimization result

Sensitivity analysis is carried out for vessel capacity (the GA parameters that provide best results are kept). Fig. 6 shows the fitness function values, the number of routes and average delays per route for different vessel capacities (200, 250, 300, 350, 400, 450, 500, 550, 600, 650 and 700 containers).

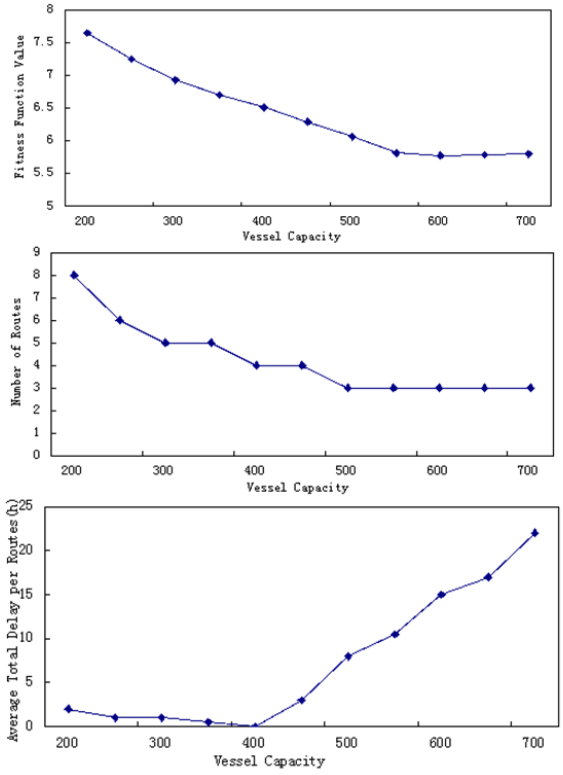

Fig. 6 Aspect of the ship size

As expected, when capacity increases, the number of routes decreases (since the algorithm tends to exhaust capacities of vessels). On the other hand, a smaller number of routes leads to considerably larger delays since routes are unavoidably longer, this is because the algorithm relies on a hard capacity constraint, used to guide route construction and a soft constraint on time deadlines. While the later can be violated some extent, capacities cannot. Penalizing for delays, leads to constructing routes that have minimized delays but not always eliminated; this is a shortcoming of the GA, but given increased uncertainties in maritime transportation these delays are considered tolerable. Of course, in practice, by properly selecting vessel capacities, the number of routes can be increased and travel times decreased.

V. CONCLUSIONS

In this paper we investigated the construction of a containership transportation branch network on strategic planning level, a new network planning method that integrated hub port location and route designing was proposed, examined routing of a containership service, with pick-ups, deliveries and time deadlines, developed a genetic algorithm for this purpose and implemented if by routing a container fleet in the Bohai Sea.

Results show that a relative fleet of 8-9 containerships with capacities of 450 containers is adequate for carrying out freight transportation in the Bohai sea region, without significant delays. Use of larger vessels (600 and 700 containers) could lead to an even smaller fleet at the expense of longer routes and potentially some delays, while at least seven smaller vessels with a capacity of 400 containers would be able to carry the same task. Moreover, results are adequately robust to changes in the algorithm's parameters and sensitivity analyses of the problem's parameters indicate consistency of the results to various changes. Finally, the algorithm's reasonable execution time (60-90 seconds) can ensure multiple runs for refining routing results under real life operational conditions.

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