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Abstract

This study aims to improve the efficiency of design technique for intermodal shipping network design, by virtue of parallel computing system. The existing methods for maritime liner shipping network design are mainly dealing with port-to-port demand. However, a big portion of the customers of a liner shipping company locate in the inland part. Thus, a holistic analysis is necessary to deal with the inland OD pairs, where the transport mode-change from inland transportation to maritime shipping is involved. This paper first reviews a solution method for the conversion of inland OD demand to port-to-port demand. Due to the size of the global shipping network, the computational burden of solving this method is quite intensive. Hence, this paper proposes a framework for parallel computing approaches to accelerate the computation speed.

Keywords

method, computing, intermodal, parallel, design, shipping, network

Disciplines

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PARALLEL COMPUTING METHOD FOR INTERMODAL SHIPPING NETWORK DESIGN

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ABSTRACT

This study aims to improve the efficiency of design technique for intermodal shipping network design, by virtue of parallel computing system. The existing methods for maritime liner shipping network design are mainly dealing with port-to-port demand. However, a big portion of the customers of a liner shipping company locate in the inland part. Thus, a holistic analysis is necessary to deal with the inland OD pairs, where the transport mode-change from inland transportation to maritime shipping is involved. This paper first reviews a solution method for the conversion of inland OD demand to port-to-port demand. Due to the size of the global shipping network, the computational burden of solving this method is quite intensive. Hence, this paper proposes a framework for parallel computing approaches to accelerate the computation speed.

Keywords: liner shipping network design; large-scale global network; inland transport; parallel computing

INTRODUCTION

The intermodal shipping network for a global liner shipping company comprises two components: a maritime liner shipping service network and an inland transportation network

[1]. Herein, the inland transportation network is also taken into consideration because most of the customer demand are originated from and/or destined to an inland location. Thus, apart from operating the regular maritime liner shipping services rotating at the sea ports, the shipping company should also account for transporting the inland demand from its origin to a corresponding import port and from export port to the inland destination. Due to the rapid change of demand caused by fast economic growth, the shipping company should re-design their transportation network around every six months [2]. Such a transportation network design by taking into consideration both maritime and inland network is termed as intermodal shipping network design.

Compared with designing the maritime liner service network alone based on estimated port-to-port demand [2], intermodal shipping network design can better suit the practical conditions and is thus more reasonable. Such a comprehensive liner shipping network design is still an open question in the literature due to its strong NP-hardness. Thus, this topic has considerable theoretical contributions with practical significance. However, since multiple inland origin/destination locations are usually attached to one sea port, the total number of inland locations is much higher than that of sea ports. When it comes to origin-destination (OD) pairs, the overall OD pair of intermodal shipping network design is much larger than that of the maritime liner service network alone, which geometrically increases the cost of storage and computation. Thus, based on a solution method for intermodal shipping network design, this paper aims to propose a parallel computing approach to partition the workload of this solution method and then concurrently solve the workload of each part, which can inherently improve the computational speed of the solution method. The techniques of parallel computing have been widely used to solving transportation problems, see, e.g., [3], [4], [5]. The methodology of these previous studies can be easily employed for solving the addressed problem.

Previous studies for liner shipping network design problem mostly deal with port-to-port demand, i.e., the origin and destination of each OD pair are both sea ports [6], [7], [8]. However, in practice, the customers of shipping service are in the inland part, which cannot be directly served by container ships. Since the liner shipping companies provide door-to-door service, the inland transportation from an inland EQSP (equipment supply point) to its export or import port should be determined.

For the annual OD demand of a liner shipping company, most of the demands are from inland OD pairs. Herein, the term “inland OD pairs” means the origin or destination (or both) of one OD pair is an inland EQSP. Therefore, it is necessary to convert these inland OD demand to port-to-port demand, such that the existing shipping network design method [2] can be

invoked. A holistic methodology was proposed in [9] for this conversion, which is briefly reviewed in the following two sections.

PROBLEM DESCRIPTION

In order to convert the inland OD demand to port-to-port demand, for each inland OD pair, we should find its loading port and discharge port. Such a problem is termed as Gate Port Allocation (GPA) for the ease of presentation. For a liner shipping company, two concerns should be account for the GPA problem: transit time and transport cost. The liner shipping company aims to search for a transport route with minimal cost and also fulfilling the transit time constraints. The transit time and transport cost here cover both the inland part and seaborne part. Note that inland transportation is usually faster and more expensive than maritime transportation, thus the liner shipping company should balance the trade-off between these two parts. A holistic analysis that can cover the entire cost and time from inland origin to destination is thus necessary. Hence, in this study, we intend to find the most cost-efficient path from origin to destination and also satisfy the transit time constraint. The demand of each inland OD pair is then converted to the loading port and discharge port on this path. Before introducing the method for GPA, the networks for inland and maritime transportation are first presented as follows.

The inland network is built based on existing multi-modal transportation systems, which includes three travel modes: rail, truck and barge. The cargos from one inland EQSP to its gate port can be transported by more than one mode or by a combination of these three modes. This network should be built based on the historical data of the liner shipping company.

For maritime network, each two sea ports are supposed to be directly connected, and the transit time and transport cost between any two ports can be estimated based on historical data or obtained from the historical data.

Combining the inland and transportation network, we then have a comprehensive transportation network for global shipping network design. Let N denote the set of nodes on the global network, where these nodes include the inland EQSPs \bar{N} , sea ports \hat{N} as well as inland transfer nodes \mathcal{N}^0 . These transfer nodes allow the intermodal or intra-modal transfer at any inland location. For instance, transporting cargo from Lanzhou, China to its export port in Shanghai may first take rail system from Lanzhou to Wuhan, and then take barge from Wuhan to Shanghai; herein, Wuhan is taken as an intermodal transfer node. There may be more than one transportation services between each two nodes. Let A denote the set of links, and A consists of two subset: inland link set \bar{A} and maritime link set \hat{A} . Each

link $a \in A$ is marked by its transit time t_a and transport cost c_a . The values of t_a and c_a are positive constants. For each inland link $a \in \bar{A}$, its travel mode is also recorded, and the capacity of each inland link is not considered.

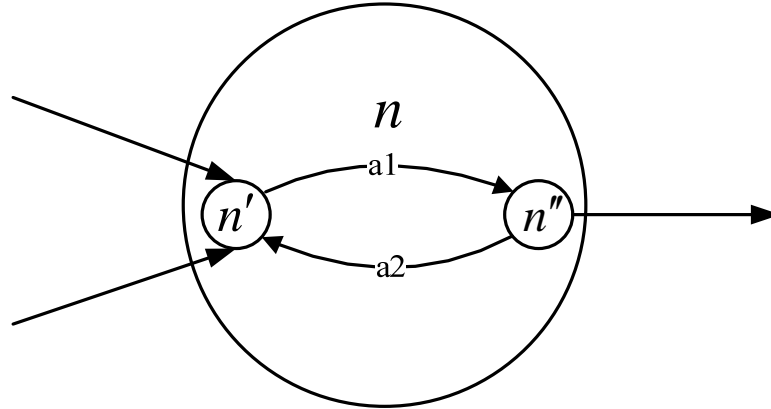


Figure 1. Network Representation for Sea Port n

Other than the inland transportation cost and maritime shipping cost, there is another cost involved in the container transportation, which is the handling cost at each sea port. In order to cope with the handling cost, a network representation is carried out for each sea port: each sea port node $n \in \hat{N}$ is replaced by an export node n' and an import node n'' , as shown by Figure 1. Between n' and n'' , two links $a1$ and $a2$ are also defined, as shown in Figure 1, $a1$ is the export link and $a2$ represents the import link. These two types of links $a1$ and $a2$ are also grouped in the link set A . The values of t_a and c_a on the import (export) link are taken as the time and cost used for discharging (loading) one container.

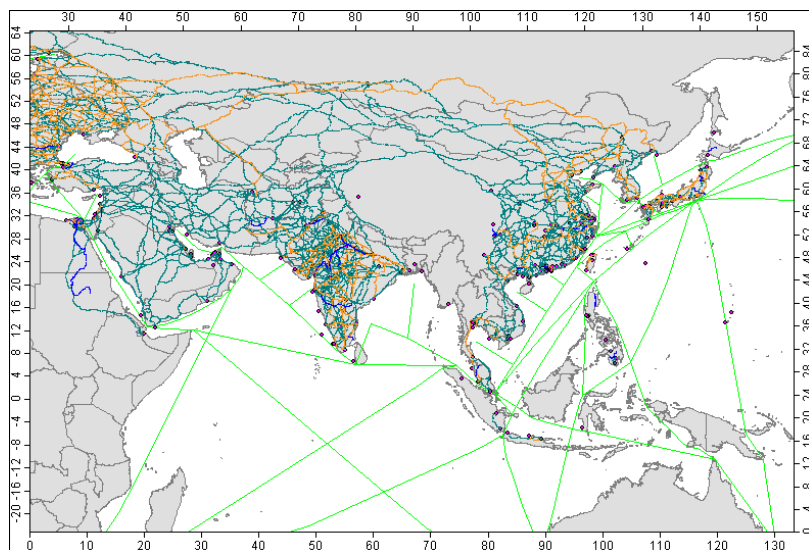


Figure 2. Global Transportation Network

Figure 2 indicates a global transportation network, with inland transport system and maritime transport system. Based on such a network we can then search for the optimal route for each inland OD pair, which can minimize the total transport cost whilst satisfying the transit time constraint.

GATE PORT ALLOCATION

Based on the global network, a methodology is proposed by [9] to find the loading port and discharge port for each inland OD pair, via solving a shortest path problem with transit time constraints. For each inland OD pair $(o, d) \in W$, such a shortest path problem can be formulated as the following integer model:

$$\sum_{a \in A} c_a x_a \quad (1)$$

Subject to

$$x_a \text{ is a binary variable} \quad (2)$$

$$\sum_{a \in A_n^+} x_a - \sum_{a \in A_n^-} x_a = \begin{cases} 1, & \text{if } n = o \\ -1, & \text{if } n = d \\ 0, & \text{otherwise} \end{cases}, n \in N \quad (3)$$

$$\sum_{a \in A} t_a x_a \leq \hat{T}_{od} \quad (4)$$

Where A_n^+ (A_n^-) denotes the set of all the links originating from (heading to) node $n \in N$.

Eq. (3) is the conservation equation, and eq. (4) represents the transit time constraints, where \hat{T}_{od} is the maximal allowable transit time for OD pair $(o, d) \in W$.

An efficient method is used in [9] to solve the constraint shortest path problem: first, for each inland EQSP $n \in \bar{N}$, we can build two path sets, inbound path set R_n^{in} and outbound path set R_n^{out} . Each path in the inbound path set originates from a import port and ends at the inland EQSP n , while each path in the outbound path set connects n to a export port. Second, for any inland OD pair $(n, m) \in W$, suppose m is also an inland EQSP, the paths from n to m can be enumerated by listing all the possible combinations of path set R_n^{out}

and R_m^{in} . Suppose one path use outbound path k_1 from set R_n^{out} and path k_2 from set R_m^{in} , the export port on k_1 is n_1 and the import port on k_2 is n_2 . Then the overall cost (time) on this path equals to the summation of five portions: transport cost (time) on path k_1 ; loading cost (time) at export port n_1 ; shipping cost (time) from port n_1 to n_2 ; discharge cost (time) at import n_2 ; transport cost (time) on path k_2 . Accordingly, we can compare the cost of all the enumerated paths, and choose the most cost-efficient one that can fulfill the transit time constraint.

It should be noted that if one EQSP is a sea port, then its loading port and discharge port should be itself. When solving the shortest path problem, another hurdle is encountered; that is, since the inland transport network is built based on the historical data of the liner shipping company, thus some newly added inland EQSPs are isolated from the inland network, and it is not connected to any sea port by any travel mode. For instance, suppose the inland transport network of China is indicated by the road map in Figure 3, the city Jingzhou is isolated, thus there is no inbound or outbound path between Jingzhou and any sea port.



Figure 3. An Isolated Inland EQSP

Due to the incompleteness of historical data, the problem addressed by Figure 3 would occur each time the liner shipping company expand its business when a new inland EQSP is added. To cope with this problem, another methodology is proposed in [9], which is reviewed in the following section. It provides an alternative loading/discharge port for each inland EQSP before solving the shortest path problem.

ALTERNATIVE GATE PORT

Based on the longitude and latitude of each EQSP (including the inland EQSP and sea ports), we can easily get the distance between each two EQSPs. Let L_{ij} denote the distance between EQSP i and j . Then, for each inland EQSP, it is quite straightforward to find the 5 closest sea ports. Denoted by P_n , the 5 nearest sea port of inland EQSP $n \in \bar{N}$ are grouped in this set.

Then, for each inland OD pair $(n, m) \in W$, an alternative gate port (loading or discharge port) can be determined purely based on the distance. We can enumerating all the combinations of selecting one port from set P_n and set P_m , and then find the path with minimal cost. The cost here comprises two parts: the total distance (including distance from origin to loading port, from loading port to discharge port, and from discharge port to destination) as well as the handling cost at loading and discharge port.

This alternative gate port allocation method based on distance has avoided the aforementioned problem caused by incompleteness of transport network data. Each inland OD pair would be inevitably assigned a loading port and discharge port. However, compared with the method presented in the section above, the results of alternative gate port are much inferior. This is because the setting of 5 nearest sea ports to each inland EQSP has restricted the usage of any other sea ports. For example, for the inland EQSP in Chicago, the top 5 nearest sea ports are all in the eastern coast of US, thus for any demand coming for East or Southeast Asia, it is enforced to use these sea ports in the eastern coast rather than using the sea ports in western coast (say, San Pedro) which are much cost-efficient. Hence, after the calculation for alternative gate ports, the GPA problem should be further modified by using the method in the previous section based on the global transportation network.

FRAMEWORK FOR PARALLEL COMPUTING

Another problem should be addressed here is the size of the problem. For the global shipping network design, the number of OD pairs is usually tens of thousands. The large size of global network has largely increased the burden and time in solving the global network design problem. Thus, in this paper, we aim to accelerate the computation speed of the proposed solution methods by virtue of the parallel computing system.

Based on a parallel computing system, if the total computation task can be partitioned into independent parts, then it would be quite convenient to harness a large number of processors to solve each part concurrently. In such case, the computational speed would be accelerated for tens of even hundreds of times. Thanks to the rapid development of computer hardware, it is not a big decision for any research institute to build a parallel computing system with distributed memory using local area network to connect desktop computers.

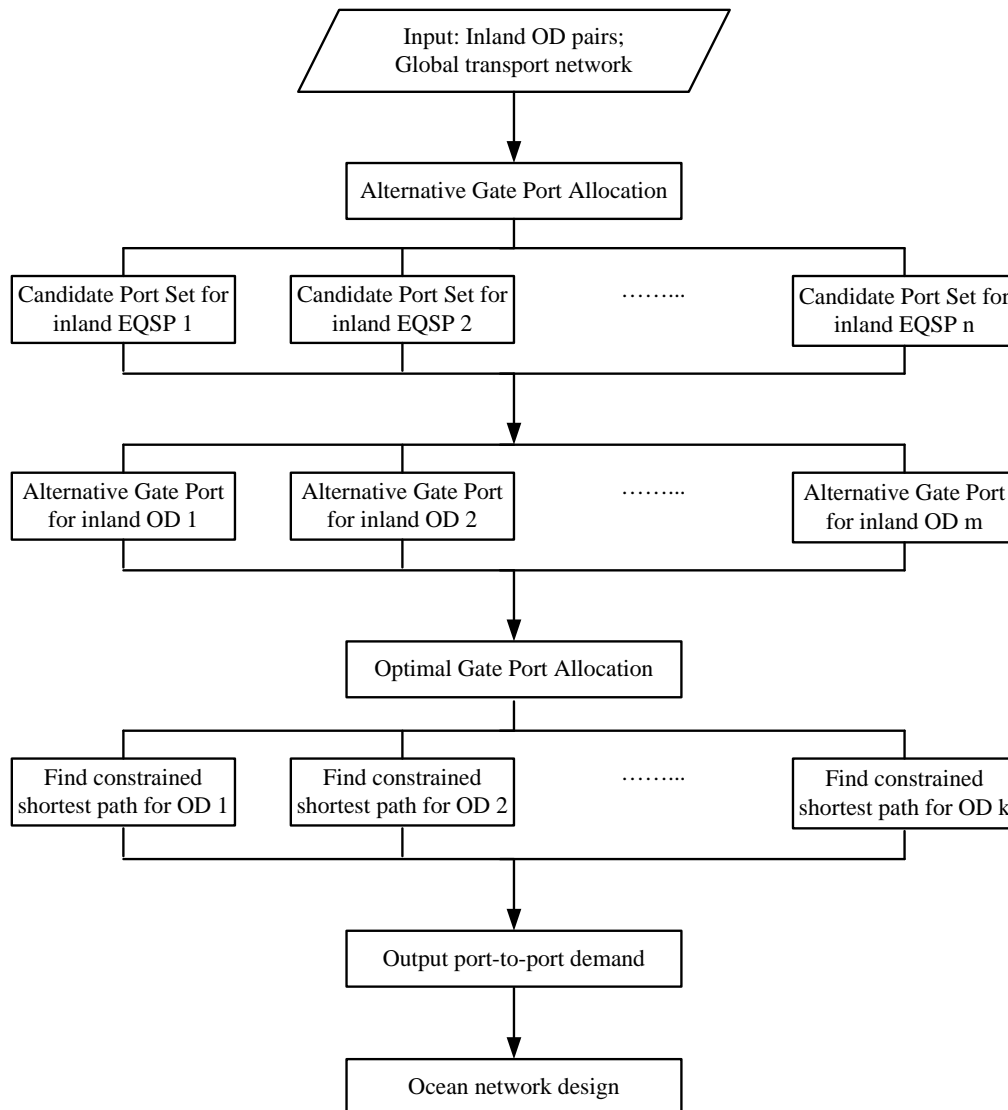


Figure 4. Flowchart for the Parallel Computing Method

Thus, the main task of proposing a parallel computing method is the workload partition of the solution method for global shipping network design. As presented above, the computation task of global shipping network design consists of two parts: conversion of inland OD demand to port-to-port demand, i.e., Gate Port Allocation; and then invoke the ocean

shipping network design. As shown in [2], the solution method for ocean shipping network design is an integrated one; namely, each process of the algorithm is sequentially conducted and it is impossible to carry out any two processes in parallel. For instance, the Ship Route Alternation should be performed after the Network Refinement [2]. However, the first part, GPA (Gate Port Allocation), is an ideal topic for parallel computing.

The GPA problem mainly solves a shortest path problem for each OD pair. Since the travel cost is set to be fixed, the allocation results of each OD pair would not influence the calculation of other OD pairs. Thus, it is straightforward to separate the calculation for different OD pairs and then send each OD pair to different processors in the parallel computing system for calculation. On the other hand, for each OD pair, the shortest path problem itself is a well studied topic for parallel computing, see [3], [4]. Hence, the following framework is proposed for the parallel computing, as shown in Figure 4. This parallel computing method is used for solving the GPA problem.

It can be seen from Figure 4 that three portions of the solution method are carried out by the parallel computing system: generating the candidate port set for each inland EQSP; calculating the alternative port for each inland OD pair; and solving the constrained shortest path problem for each inland OD pair. By using the parallel computing system, the computation speed of solving this problem would be inherently increased.

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