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# Schedule design for sustainable container supply chain networks with port time windows ☆

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ABSTRACT

This paper studies a practical liner shipping schedule design problem with port time windows for container supply chain networks. A mixed-integer nonlinear non-convex model that incorporates the availability of ports is proposed to minimize the sum of ship cost and fuel cost (and thereby pollutant emission). In view of the structure of the problem, we reformulate it as an integer linear optimization model and propose an iterative optimization approach. The proposed solution method is applied to two liner networks operated by a global shipping line.



## 1. Introduction

As reported by UNCTAD [15], the world gross domestic product in 2012 grew by 2.2% with the reorientation in global production. In the meantime, the international trade grew by 1.8%, reaching 18.3 trillion USD in merchandize export. Maritime transportation is the backbone of international trade. For several decades, containerized trade has been the fastest growing shipping segment. It accounted for over 16% of global seaborne trade by volume in 2012 and more than half by value in 2007. In 2012, containerized trade volume expanded to 155 million twenty-foot equivalent units (TEUs) [15].

Containers are transported by global liner companies on regularly scheduled ship routes. A large variety of general cargos are containerized, such as manufactured products, food, and garment. Liner shipping services have fixed sequences of ports of call and fixed schedules, i.e., arrival and departure times at each port of call. Liner services are announced in advance to attract potential customers. For example, Fig. 1 shows a liner service – Singapore West Asia Express (SWX) – operated by American President Lines (APL) [1]. The ports of call and schedule are announced in the website of APL. Customers can arrange the delivery of their cargo based on the available date of the cargo at the origin port and the expected arrival date at the destination port [14]. Therefore, container liner shipping is of significant importance to the global supply chain network.

A container liner shipping network consists of many ship routes, and a shipping line has to determine the schedule for each ship route. Schedule design for a liner ship route is a tactical-level planning decision that is made every three to six months. To design the schedule of a ship route, the first factor to consider is the service availability of the ports. Since a port has limited berths and needs to provide services for a number of liner shipping companies and a number of ships, it cannot guarantee the availability of services whenever a ship arrives. We use the term "port time window" to refer to the time in a week that berths at the port can provide services to ships. A schedule designed without considering the availability of ports may be infeasible in reality.

Different schedules mean different sailing times between ports, which dictate different sailing speeds. It is known in the shipping industry that the daily fuel consumption of ships increases approximately proportional to the sailing speed cubed. Therefore, schedule design affects the bunker fuel consumption and thereby air pollutant emission. Reducing the fuel consumption will also improve the sustainability of the global container transportation network.

Container shipping lines provide weekly services for transporting containers, which means that the rotation time in terms of weeks for visiting all ports of call on a ship route is equal to the number of ships deployed. As a consequence, each port of call has a ship departure on the same day every week. When the speed

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of ships is higher, the rotation time is shorter, and hence fewer ships are required to maintain the weekly frequency.

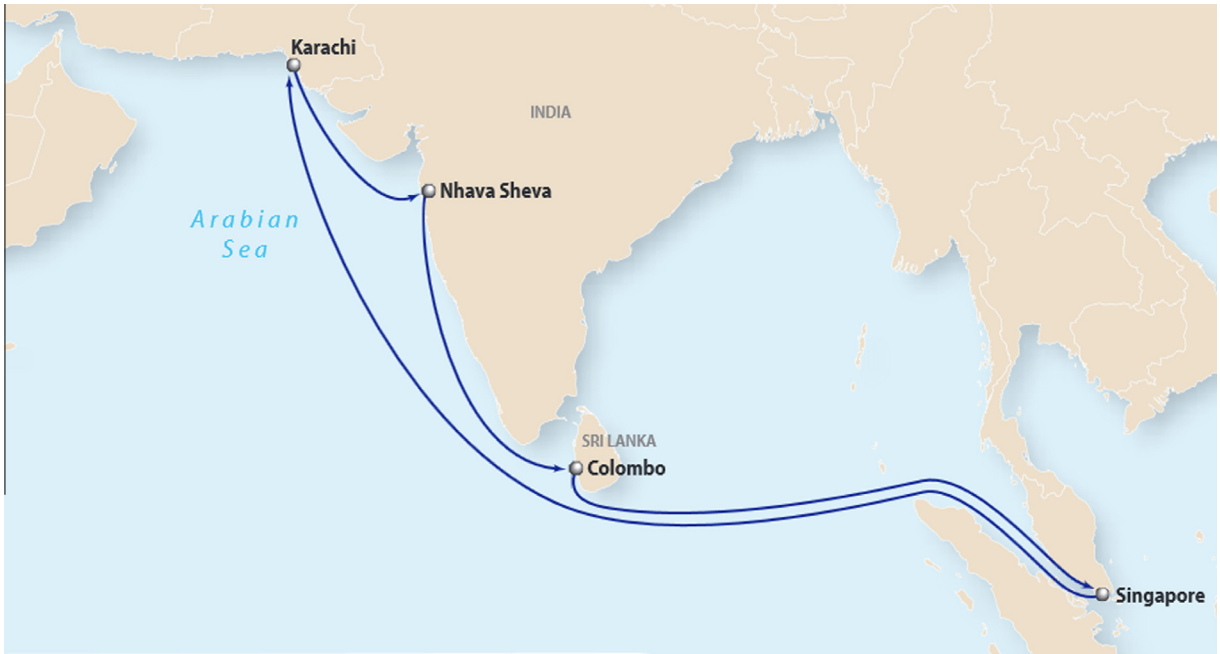
The objective of this paper is to design the schedule for each ship route in a container liner shipping network. The aim is to minimize the sum of ship cost and fuel cost, while ensuring that ports are available to serve the ships on the planned days. The main contribution of the paper to the state-of-the-art literature and practice is that it takes the initiative to address a practical liner shipping network schedule design problem with port time windows (NSDPTW). The designed schedules are preferable as the sum of ship cost and fuel cost is minimized. The schedules are feasible because the availability of berths at each port on each day is explicitly considered in the model. The results from the model need no or very little modification before put to use. Hence, this study provides a useful decision-support tool for liner shipping companies to plan their services.

The remainder of the paper is organized as follows. Section 2 is the literature review. Section 3 describes the problem and formulates a mathematical model. Section 4 proposes a tailored solution approach to address the problem. Section 5 reports case studies based on a network consisting of three service routes. Section 6 concludes and points out future research directions.

## 2. Literature review

There is not much research on schedule design for container liner shipping networks, see e.g. Christiansen et al. [5], Meng et al. [10] for reviews. The first category of relevant works is on schedule design at the tactical planning level. Wang and Meng [18] investigated the schedule design and container routing problem in a general liner shipping network with many ports and many ship routes with fixed sailing speed. Qi and Song [11] designed an optimal schedule for a liner ship route to minimize the total expected fuel cost. The port time is random, and a certain level of service, which is the probability that the containership would arrive at a port no later than the announced arrival time, has to be maintained in the model. Wang and Meng [20] designed a robust schedule for a liner ship route in which uncertainties in port operations and schedule recovery by fast steaming were captured endogenously. They assumed that ships are able to catch up the delayed schedule after a long leg that transverses an ocean. Wang and Meng [19] extended the work of Wang and Meng [18] by incorporating the optimization of speed, the uncertainty at port and the uncertainty at sea. None of the above four studies have considered the port time windows in schedule design. Wang et al. [17] developed a dynamic programming approach to design a schedule for a single ship route with port time windows. However, they assumed that each port on the ship route can only be visited once, whereas in reality many ship routes have ports that are visited twice. Wang et al. [16] extended the previous work by allowing a port to be visited twice on a ship route. Still, they focus on a single ship route, rather than a liner shipping network with many ship routes.

For the operational-level schedule adjustment, Yan et al. [21] developed a container routing model from the perspective of a




**Port Rotation**

| Port | City | Transit Day | Arrive | Transit Day | Depart |
|---|---|---|---|---|---|
| SIN | Singapore | 00 | Tue | 02 | Thu |
| KHI | Karachi | 09 | Thu | 11 | Sat |
| NS9 | Nhava Sheva | 12 | Sun | 13 | Mon |
| CMB | Colombo | 16 | Thu | 17 | Fri |
| SIN | Singapore | 21 | Tue | – | – |

**Fig. 1.** SWX service operated by APL [1].

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