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Stochastic resource allocation for containerized cargo transportation networks when capacities are uncertain

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ABSTRACT

We consider the stochastic resource allocation problem for containerized cargo transportation with uncertain capacities and network effects, in which a freight operator needs to allocate a certain amount of capacity to each product to maximize the expected profit. We formulate the problem as a constrained stochastic programming model and provide theoretical results that completely characterize the optimal solution to the model under a special case. Under a general case, we build an approximation model of the problem and propose a sampling based algorithm to solve the approximation model. A number of numerical experiments are offered to test the algorithm.

1. Introduction

Containerized cargo transportation provides a favorable transport mode to shippers who desire cargo to be transported for a long distance to receivers across regions, nations, or even continents using standardized load units. With standardized units, the shipments undergo smooth transitions without a need to handle the cargo themselves in the units during the transportation process. The most widely seen load units are 20-ft containers (Twenty-foot equivalent units, or TEUs), 40-ft containers (Forty-foot equivalent units, or FEUs), and standard pallets.

We consider a *freight operator* who sells transport services to shippers (or freight forwarders) for a containerized cargo transportation network and utilizes various resources, such as equipment, crews, and vehicles, to accomplish cargo transporting. A freight operator could be an ocean shipping line that operates on a network of voyages, an intermodal operator that provides customers with integrated transport services of multiple modes, an alliance formed between a group of carriers that operates over the grand network of all carriers, and it could also be a freight forwarder who purchases services from carriers on a network and sells the services to shippers for that network. As has been observed in Crainic (2009), the rail freight transport industry has recently been experiencing an evolution from traditional "go-when-full" operations to fully planned and scheduled operating policies, under which services are provided based on published schedules of modes of operations. Liner shipping companies have long been known as operating on the so-called once-a-week schedule (Wang and Meng, 2012). We are thus interested in the market where a freight operator offers services during a given *service period* (e.g., a day or week) according to a predetermined timetable and the services are periodically repeated – like the operations in public transit and liner shipping systems. The use of standard units and planned schedules makes containerized cargo transport services particularly suitable for spot markets (Gorman, 2015). We limit the scope of the paper to freight operators who operate periodically repeated services in spot markets.

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1.1. Resource and product

We now define the network resources owned by the freight operator and the products that the operator offers to the market. A *leg* refers to the vehicle service that operates from a specific origin to a specific destination without stopping in the middle (but possibly with cargo loading/unloading services at the origin/destination) and departs at a specific time point within a service period. The freight operator owns various *resources* on legs, such as general container slots or reefer container slots on trains/vessels. The resources are capacity-constrained subject to the physical operating constraints of equipments, vehicles, and crews.

A shipper requests a booking of the service from the freight operator to deliver one or a group of shipments from a specific origin to a specific destination. In response to the request, the freight operator sells a *product* to the shipper. The product specifies the information of the service in three dimensions: (i) the origin-destination (O–D) pair, (ii) the *itinerary*, and (iii) the total price charged for delivering the shipments. The itinerary defines the sequence of legs that the shipments would travel through, the departure time, arrival time, and the travel times on the legs. The price is quoted depending on the number of shipments and the type of the service requested, such as, if it is the transport of general-purpose containers, reefers (i.e., refrigerated containers for the transport of temperature sensitive cargo such as frozen meat) or a mix of containers of different kinds, and if it is a standard delivery or premium delivery. Within a spot market, one of the easiest ways of managing booking prices is to maintain a price lookup table for all types of products. For a real-world instance, Chinese railway companies sell container transport services based on a fixed price table; see (CRRC, 2012), where the rate (Chinese Yuan) for transporting one 20-ft container is calculated as: $337.5 + 1.4 \times$ travel distance in kilometers. In this instance, the rate for transporting one 20-ft container is fixed for any given O–D pair with a fixed travel distance. Thus, a product (or product type) can be thought of as a combination of *O–D pair*, *itinerary*, *and price*.

As we defined, a product has an itinerary specified to traverse a sequence of legs. Thus, each product consumes a series of resources associated with the legs on the itinerary of the product. When a shipper requests to transport a group of shipments, e.g., 100 containers, through the same itinerary to enjoy a discounted total price resulting from the economies of scale, such a request will show up as a group booking of a product that is specified with the discounted price. Note that the discounted price may also depend on the weight and the type of the containerized cargo.

Fig. 1 illustrates the network resources and products, in which a freight operator operates daily services with four nodes, two tuck legs, and one rail leg. The two numbers in the parenthesis along each leg, from the left to the right, represent the id and capacity of the resource associated with the leg. We could have the following three different products:

Product 1: node 1 $\overset{\text{leg 1}}{\rightarrow}$ node 2 $\overset{\text{leg 3}}{\rightarrow}$ node 4 with leg 1 departing at 8:00 am, leg 3 departing at 4:00 pm, and the total price \$100,

Product 2: node 1 $\overset{\text{leg 1}}{\rightarrow}$ node 2 $\overset{\text{leg 3}}{\rightarrow}$ node 4 with leg 1 departing at 8:00 am, leg 3 departing at 4:00 pm, and the total price \$500 (for delivering a reefer),

Product 3: node 1 $\overset{\text{leg 1}}{\rightarrow}$ node 2 $\overset{\text{leg 3}}{\rightarrow}$ node 4 with leg 1 departing at 2:00 pm, leg 3 departing at 4:00 pm, and the total price \$500 (for a premium delivery).

As mentioned, each leg may include possible cargo loading/unloading processes at the origin/destination. Another perspective is to consider each node (especially, the container transfer terminals such as dry ports or sea ports) as one type of resources to represent the cargo transfer processes. Our model can easily be tailored to accommodate such a consideration through re-defining itineraries as including the nodes it traverses.

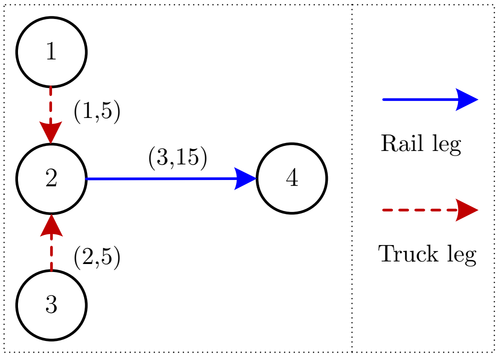

Fig. 1. Illustrations of network resources and products.