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A fuzzy approach for container positioning considering sustainable profit optimization

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ABSTRACT

Liner companies are forced to operate efficiently due to regulatory and market competition patterns and requirements. Container positioning is a vital part of their strategy. Instead of minimizing costs of moving empty units as preferred in the literature, this paper presents a formulation that optimizes the trade-off between full and empty units. Paradoxically, carrying empty instead of full units in some cases leads to more profitable operations. This paper considers these as well as the derived CO_2 footprint aspects. Owing to the seasonality and incompleteness of data, a fuzzy optimization approach is chosen.

1. Introduction: statement of the problem

Undoubtedly, containers have revolutionized liner shipping, but the immense problem of equipment positioning has arisen. Different commodities have necessitated different container types, causing local imbalances of demand and supply of equipment. Theofanis and Boile (2009) estimate the number of unused stored containers to be 1.5 million TEU globally. These imbalances can be solved by repositioning the empty units. The process is described in detail in Rodrigue et al. (2013). Cheung and Chen (1998) and Choong et al. (2002) present models for repositioning, distinct from the transportation of full containers. Theofanis and Boile (2009) provide reasons for the imbalance of containers and analyze the logistical management and strategies of liner shipping companies, while Sherali and Suharko (1998) present an approach that deals with a related issue regarding the repositioning of empty rail cars. Most commonly, the problem of empty unit positioning is considered a mixed-integer linear programming (MILP) multi-commodity flow problem to evaluate the optimal cargo mixture with respect to all relevant costs and constraints (see Aversa et al. (2005), Meng and Wang (2011), and Shintani et al. (2007)).

In the present article, a pure linear programming (LP) approach is chosen in order to keep the calculation uncomplicated and fast. However, it is simple to extend this LP formulation to an MILP one, if necessary. Chang et al. (2015) uses a bi-level structure comprising an upper level for optimizing operational profits and a lower level for repositioning empty containers and minimizing transportation costs. Cheung and Chen (1998) and Choong et al. (2002) merely concentrate on minimizing the transit costs for a predefined, distributed number of empty containers.

Thus, most of the literature describes the overall problem as "static," i.e. all costs, parameters, and constraints are well defined and the cargo mixture is a priori determined. But in reality, the local demand and surplus for empty units are

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dynamic, as they depend on the flow of transported units. The cargo flow is chosen by the shipping companies on the basis of the so-called contribution margin (CM). The CM is defined as the difference between all variable revenues, such as the gross freight rate or bunker adjustment factor surcharge, as well as all variable costs, such as cargo handling or storage expenses. However, when shipping companies decide on the cargo flow of both full and empty units, the demand and the related cost of repositioning of the empty containers are practically unknown. Thus, the total variable costs cannot be estimated; hence, the derived CM is uncertain. In this paper, the CM is not regarded as a reliable indicator; it will be treated as a fuzzy variable (see Section 2.2).

In order to reduce this imbalance, some companies such as Maersk involve their clients in savings or extra costs for repositioning (MAERSK Line, 2015). However, to change the cargo flows in the preferred way, the companies need to know the exact reactions of clients and competitors, which is not always possible or a realistic assumption. Another approach is to block some capacity for empty units, which is not efficient either, due to the uncertain fluctuation of the market in terms of both prices and demand. Therefore, it is only possible to react a posteriori to imbalances of equipment.

In the short term, which means only one voyage, equipment imbalances are negligible. The algorithm that provides the optimal short-term solution is called *imbalanced* algorithm in this paper. For sustainable and efficient operations, it is necessary to generate an algorithm that maximizes the profit for longer periods, the so-called *balanced* algorithm. First, this might be regarded as the dual problem of the well-known LP of cost minimization. In this case, however, the costs would have been fixed, as mentioned in Choong et al. (2002) and Cheung and Chen (1998). This does not describe real-world conditions. As opposed to this conventional concept, the new approach takes a holistic view and regards the demand of repositioning empty units as a consequence of the imbalance of full-unit shipments. Consequently, changes in the cargo-flow of laden units directly alter the need for empty positioning. Therefore, the cargo flows of full units are optimized with respect not only to their revenues, but also to costs and capacity effects on empty positioning. In contrast to the rest of the literature known to the authors, in this work profit is optimized in a single holistic step.

Other essential parameters such as available cargo between ports or freight rates fluctuations are quite uncertain due to many external effects, namely dynamically changing market patterns. The effort to develop parametric programming to deal with the related uncertainty would be enormous. In contrast to Chang et al. (2015), who uses an LP formulation, in this work a crisp model is presented vis-á-vis the fuzzy linear optimization (FLP) approach, in order to highlight the benefits of fuzzification. Fuzzification is explained in the works of Xu and Zhou (2011) and Bojadziev and Bojadziev (2007). This innovative approach to position empty units with FLP is also a contribution of this work.

The conception presented is also in accordance with the considerations put forward in Kontovas (2014), where existing formulations of green ship routing and scheduling problems are recited. The implementation of repositioning empty units in his paper leads to a reduction in transportation effort and emission of CO_2. The same effect is shown in this paper.

The present paper is structured as follows: In the following Section 2, the crisp mathematical LP and the FLP models are presented. In the end of this section, the balancing constraint Eq. (11) is added to the model to expand the *imbalanced* short-term profit-maximizing LP or FLP model into a *balanced* mid- and long-term profit-maximizing model. In Section 3, a numerical example is introduced and solved by the fuzzy algorithm. Finally, a comparison is drawn between the *imbalanced* and the *balanced* algorithm. In Appendix A, the different results between the crisp and the fuzzy model are presented. Section 4 concludes the paper with a summary of the results.

2. Problem formulation

2.1. The crisp model

The problem of optimal cargo flows can be interpreted as a multi-commodity flow problem that can be solved by LP. The approach used in this work is developed from the original Dantzig–Wolfe decomposition method (Dantzig and Wolfe, 1960). The formulation of the crisp *imbalanced* problem is described below. The *imbalanced* algorithm solves the commonly considered problem of optimizing profit in the short term.

Objective function:

$$max\ P = \sum_{\forall o,d,t}\left[FR_{o,d,t}\cdot x_{o,d,t} - \left(SC + \sum_{\forall i,j,s} SF_{i,j,s}\cdot x^{i,j,s}_{o,d,t} + \sum_{\forall i} tv_i \cdot f_i + lc_o\cdot x_{o,d,t} + dc_d \cdot x_{o,d,t}\right)\right] \tag{1}$$

subject to:

$$TEUC_{i,j,s} \geqslant \sum_{o,d,t} x^{i,j,s}_{o,d,t}\cdot TEU_t \tag{2}$$

$$PlugC_{i,j,s} \geqslant \sum_{o,d,t} x^{i,j,s}_{o,d,t}\cdot PLUG_t \tag{3}$$

$$TONC_{i,j,s} \geqslant \sum_{o,d,t} x^{i,j,s}_{o,d,t}\cdot w_{o,d,t} \tag{4}$$