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Weather impact on containership routing in closed seas: A chance-constraint optimization approach

Konstantinos Kepaptsoglou [a,*], Grigorios Fountas [b], Matthew G. Karlaftis [b,1]

[a] School of Rural and Surveying Engineering, National Technical University of Athens, 9, Iroon Polytechniou str, 15770 Athens, Greece
[b] School of Civil Engineering, National Technical University of Athens, 5, Iroon Polytechniou str, 15773 Athens, Greece

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ABSTRACT

Weather conditions have a strong effect on the operation of vessels and unavoidably influence total time at sea and associated transportation costs. The velocity and direction of the wind in particular may considerably affect travel speed of vessels and therefore the reliability of scheduled maritime services. This paper considers weather effects in containership routing; a stochastic model is developed for determining optimal routes for a homogeneous fleet performing pick-ups and deliveries of containers between a hub and several spoke ports, while incorporating travel time uncertainties attributed to the weather. The problem is originally formulated as a chance-constrained variant of the vehicle routing problem with simultaneous pick-ups and deliveries and time constraints and solved using a genetic algorithm. The model is implemented to a network of island ports of the Aegean Sea. Results on the application of algorithm reveal that a small fleet is sufficient enough to serve network's islands, under the influence of minor delays. A sensitivity analysis based on alternative scenarios in the problem's parameters, leads to encouraging conclusions with respect to the efficiency and robustness of the algorithm.

1. Introduction

Reliability is an important challenge in shipping operations, since it guides shippers/consignees into arranging accordingly their production, transportation and distribution plans (Wang and Meng, 2012a). According to Vernimmen et al. (2007), vessels delays can be caused by factors beyond the control of shipping firms, such as weather conditions, port congestion and labor strikes. The adverse effect of weather conditions on the operation of commercial vessels has a significant influence on the total time at sea, affecting schedule reliability and increasing operational costs. In particular, the wind affects the performance of vessels by increasing both travel and service time at port and consequently the overall cost of transportation. The Aegean Sea is a case where weather and especially, wind and waves play a critical role for maritime activities (Mazarakis et al., 2012). In terms of freight shipping operations, maritime transportation between the islands of the Aegean Sea and the Greek mainland is classified as short sea shipping, where liner companies seek to minimize transportation time of cargo.

* Corresponding author. Tel.: +30 2107723167; fax: +30 210 7722404.
E-mail addresses: kkepap@central.ntua.gr (K. Kepaptsoglou), gregfoun@hotmail.com (G. Fountas), mgk@mail.ntua.gr (M.G. Karlaftis).
[1] Tel.: +30 2107721280; fax: +30 210 7722404.

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In order to establish a stable freight transport network, disengaged from the problems of Ro–Ro passenger liners, Sambracos et al. (2004) introduced the potential use of small containers for carrying freight to a network of Aegean islands and considered the associated vehicle routing problem (VRP) for planning a small containership service. Later, Karlaftis et al. (2009) investigated routing for a fleet of small containerships between hub-and-spoke ports of the Aegean Sea by additionally considering simultaneous pick-ups and deliveries and time deadlines. In this paper, we extend previous work by Karlaftis et al. (2009) on containership routing by introducing weather effects on travel times between ports. Indeed, uncertainty in weather conditions contributes to the stochastic nature of vessel's travel time and therefore incorporation of its impact in the routing process allows more realistic outcome.

The consideration of the stochastic nature of travel times variable (a) offers a better representation of the real problem conditions, (b) allows a better evaluation of whether vessels arrive within preset time deadlines or not (6) and (c) aids in a better estimation of possible delays and additional transportation cost for maritime companies. For this purpose, we adopt a chance-constrained programming model, in order to formulate the problem and to convert its stochastic nature to a deterministic form (Zhang et al., 2012). We also develop and implement a genetic algorithm, adopted to the requirements of the stochastic travel time vehicle routing problem with simultaneous pick-ups and deliveries and time deadlines (STT-VRPSPDTD). The proposed approach focuses on important aspects on the strategic design of a dedicated containership network in the Aegean Sea, and particularly the introduction of weather impacts on establishing service efficient vessel routes.

The paper is organized as follows. Section 2 discusses the background which deals with STT-VRPSPDTD and wind distributions in Aegean Sea. In Section 3, the problem is described in detail and the mathematical model is presented, while in Section 4 the solution process is described in detail, including the genetic algorithm details and the method used for the estimation of stochastic travel times. The computational results of the application to the Aegean Sea are reported in Section 5. Section 6 concludes our paper and discusses suggestion for future research.

2. Related work

In the maritime industry, three modes of shipping operations are mentioned: industrial, tramp and liner shipping (Lawrence, 1972). According to Sigurd et al. (2005), the transportation of containers via sea ways is considered as a part of liner shipping. Liner vessels follow a fixed route, according to a published itinerary (Christiansen et al., 2013). A number of reviews concerning research in maritime transportation have been published in the last 30 years (Ronen, 1983, 1993; Christiansen et al., 2004; Christiansen et al., 2007, 2013). In addition, Kjeldsen (2011) has investigated routing and scheduling of ships and cargo in liner shipping. Meng et al. (2013) prepared a review paper on containership routing and scheduling problems and Tran and Haasis (2013) surveyed work on container shipping and indicated three major planning problems on the topic: container routing, fleet management and network design.

A wide range of papers on liner shipping has been published in the last decade, mainly due to the increase in cargo containerization (Christiansen et al., 2013). According to Christiansen et al. (2013) the research on liner shipping operations can be categorized in four groups, depending on the type of the network design model exploited (see Table 1). The first group focuses on models with a single route or set of routes without transshipment. Among recent studies in this category, Sambracos et al. (2004) formulated a capacitated vehicle routing problem considering a network of 13 island of the Aegean Sea, in order to eliminate the dependence of freight transport from the passenger shipping. Shintani et al. (2007) investigated the design of containership routes taking into account the repositioning of empty containers and developed a genetic algorithm for this purpose. Karlaftis et al. (2009) extended the work of Sambracos et al. (2004) and proposed a genetic algorithm approach for routing of a containership service considering simultaneous pick-ups and deliveries at ports and time deadlines. Meng and Wang (2011a) developed a dynamic programming model in order to solve efficiently a multiperiod liner ship fleet programming problem. They created a scenario decision tree for determining the optimal fleet deployment plan. Chuang et al. (2010) constructed a fuzzy genetic algorithm in order to determine optimal containerships routes taking into account demand, travel and berthing time. The network models, in which all feeder ports are connected to a hub port, belong to the second group. Meng and Wang (2011b) considered an intermodal hub and spoke network and formulated a mathematical program with equilibrium constraints (MPEC), proposing a hybrid genetic algorithm for its solution. The third category concentrates on models where some ports of the network are considered as hub ports, without any restriction on the number of hub and non-hub ports a vessel can visit. In this context, Reinhardt and Pisinger (2012) investigated a network design problem in combination with a fleet assignment problem. The formulation of the problem allowed simple and butterfly routes with transshipment in the central port and a branch-and-cut method was adopted for the solution of the model. The last group consists of networks where the ports are neither classified as hub and non-hub. Imai et al. (2009) formulated one multi-port calling (MPC) network and one hub and spoke (H&S) network and examined the container management cost including empty container repositioning. For the first network they developed a genetic algorithm and for the H&S network a brute-force heuristic method was used. The joint optimization of vessel routing and deployment of fleet was investigated by Álvarez (2009). He formulated a mixed integer programming model, which considers multiple types of vessels reflecting differences in terms