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Operational planning of routes and schedules for a fleet of fuel supply vessels

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ABSTRACT

This paper considers a real operational problem of routing and scheduling a fleet of fuel supply vessels used to service customer ships anchored outside a major port. The problem can be formulated as a rich multi-trip vehicle routing problem, including constraints related to stowage and time-dependent sailing times. An arc-flow and a path-flow model are developed and compared. A computational study shows that the path-flow model is superior and can be used in real planning situations. We also discuss how the model can be used in a real-time setting when new orders arrive and deviations from the plan occur.

1. Introduction

Ocean shipping is the major transportation mode of the world trade today, and the volume carried by seaborne trade is growing (UNCTAD, 2014). Ships operate between ports for loading and unloading passengers and cargo, as well as for loading fresh water, supplies, and discharging waste. Another important task for ships in certain ports is fuel refilling. The problem studied in this paper regards the fuel supply business, where incoming customer ships are supplied with fuels by a given fleet of specialized fuel supply vessels. Even though fuel refilling is an important task for ships entering ports, the planning problem considered in this paper has, to the authors' knowledge, only been studied in one previous paper (Christiansen et al., 2015). As in that case study, we consider the problem of a Hellenic oil company operating in the broader area of Pireaus Port delivering fuel to customer ships, as illustrated in Fig. 1. The incoming customer ships anchor in a specified area outside the port waiting to be supplied by the company's fuel supply vessels. The supply vessels load at refineries in the inner part of the port area before supplying the customer ships. The refineries offer different types of fuel, and a given customer ship may require more than one type. Fuel transported to the customer ships must be allocated to compartments on board the supply vessels, and different fuel types cannot be mixed in the same compartment. Each customer ship needs to be serviced within a given agreed time window. The planning problem, which we denote as the Fuel Supply Vessel Routing Problem (FSVRP), consists of determining routes and schedules for the fleet of supply vessels such that costs are minimized and all customer ships are serviced within their time windows. The vessels can perform more than one voyage during the planning horizon. The problem also includes allocating the different types of fuel to separate compartments within the supply vessels, which adds

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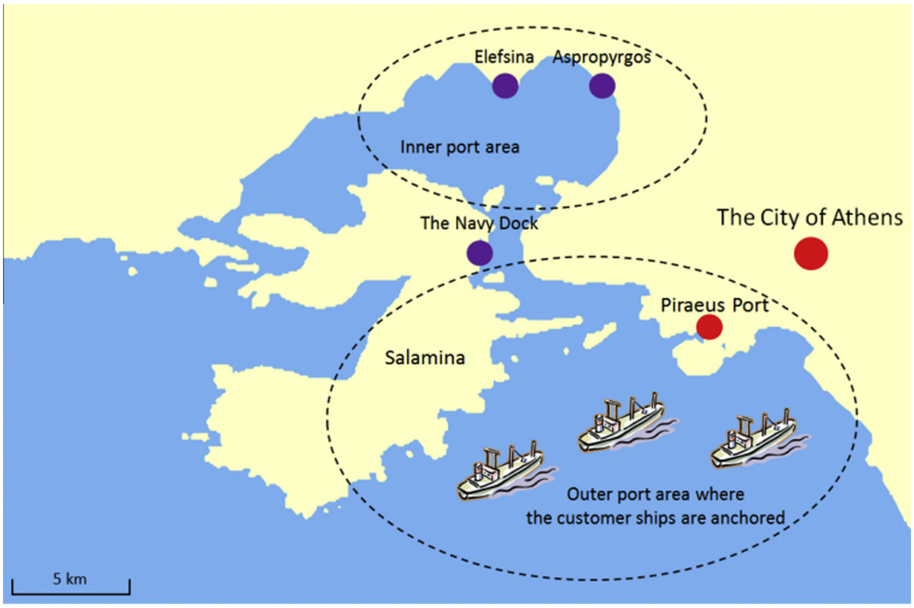

Fig. 1. Map of Piraeus Port area.

substantial complexity. The FSVRP can be considered as a rich version of the multi-trip vehicle routing problem with time windows, see for example Nguyen et al. (2013) and Cattaruzza et al. (2014).

The fuel supply business in Piraeus Port, as probably in most other ports, has long traditions, and the business is to a large extent characterized by manual efforts in determining routes and schedules for the fuel supply vessels. However, many complicating factors and the large amount of money involved increase the demand for good decision support systems in the fuel supply business.

Christiansen et al. (2015) presented an arc-flow model for the FSVRP with some additional elements related to the customer ships. It was assumed that all different orders for the same customer ships could be serviced by more than one fuel supply vessel and the orders were optional and not contracted. They also proposed some alternatives of how to simplify the model to make it easier to solve using a commercial solver. It was shown that the simplified version where one ensures that all orders for any customer ship are serviced by the same fuel supply vessel (i.e. without customer splitting) provided similar results as the one without this simplification (i.e. with customer splitting). This is also in correspondence with what is experienced in practice where customer splitting is rarely performed. Unfortunately, Christiansen et al. (2015) experienced that even the simplified model was extremely hard to solve for realistic instances, and large optimality gaps were reported even after 10,000 s of running time.

The objective of this paper is to describe the operational planning problem of designing routes and schedules for a fleet of fuel supply vessels providing fuel to customer ships. Furthermore, the contributions of this paper are an enhanced arc-flow model for the FSVRP where no customer splitting is allowed as well as a new path-flow model. We also show that the proposed path-flow model and corresponding solution method is superior to the arc-flow model in Christiansen et al. (2015) with regards to computational performance, and realistic instances are solved to optimality within reasonable solution times. The planners need to use the model when new orders appear during the day or other unforeseen deviations from the plan occur. Therefore, we provide a discussion on how the model can support decision-making in a real-time setting.

The outline of the remaining of the paper is as follows: Section 2 presents the FSVRP in more detail, while Section 3 surveys relevant literature. Section 4 presents the arc-flow and path-flow models for the problem, while the algorithm for generating the paths (i.e. feasible vessel voyages) is described in Section 5. A computational study is conducted in Section 6, while Section 7 discusses how the proposed models can be used as decision support in a real-time setting. Finally, concluding remarks are provided in Section 8.

2. Problem description

Here, we distinguish the fuel supply vessels from the cargo and passenger ships that enter the port area to receive fuel, by using the words *vessel* or *supply vessel* to denote the fuel supply vessels, and *ship* or *customer ship* to denote the ships that are serviced by the fuel supply company.

A given heterogeneous fleet of supply vessels is used to supply customer ships anchored in a port area. In the start of a planning horizon, some supply vessels may not be available for loading until some specified time since they may still be