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Robust supply vessel routing and scheduling

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ABSTRACT

We solve the problem of tactical supply vessel planning arising in the upstream offshore petroleum logistics. Supply vessels deliver all the necessary materials and equipment to offshore installations from an onshore supply base according to a delivery schedule. The planning of supply vessels should be done so that their number is minimized and at the same time provide a reliable flow of supplies from the base. The execution of a weekly sailing plan is affected by weather conditions, especially in winter time. Harsh weather conditions increase the number of vessels required to perform the operations as well as the service times at the installations, and thus disrupt the schedule, leading to additional costs and reduced service level. We present a methodology for robust supply vessel planning enabling a trade-off analysis to be made between the schedules' service level and vessels' cost. The methodology involves the generation of multiple vessel schedules with different level of robustness using an adaptive large neighbourhood search metaheuristic and a subsequent discrete event simulation procedure for the assessment of the service level. To control the level of robustness we developed a concept of slacks and incorporated it into the metaheuristic algorithm.

1. Introduction

In the problem under study, encountered by many offshore oil and gas operators, a fleet of supply vessels performs deliveries to offshore installations on a regular basis from an onshore supply base. Deliveries take place according to a vessel sailing schedule constructed for a certain planning horizon. Supply vessels are the major cost contributor in offshore upstream logistics. To illustrate, the daily charter cost of a supply vessel is around 25,000 USD. The planners therefore always try to minimize the number of vessels required for servicing the installations. The execution of a schedule may be disrupted by harsh weather conditions which increase the duration of vessel operations and may lead to the use of extra vessels. Possible delays due to the uncertain weather conditions should therefore be taken into account during the construction of the vessels schedules. The impact of weather uncertainty on containership routing has already been studied by Kepaptsoglou et al. (2015). In our context, previous works dedicated to the construction of vessel schedules under weather uncertainty (Halvorsen-Weare and Fagerholt, 2011; Norlund et al., 2015) are applicable only for small and medium instances of non-realistic sizes. The purpose of this paper is to develop a methodology for the generation of robust supply vessel schedules for realistic large-size problem instances, taking into account the trade-off between service level and vessel costs.

1.1. Problem description

In the upstream oil and gas offshore supply, the delivery of equipment and material to offshore installations takes place from an

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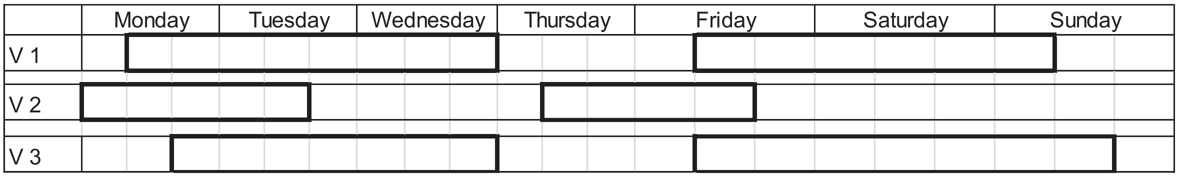

Fig. 1. Example of a weekly vessel schedule.

onshore supply base. Every supply base has its own set of offshore installations to serve and a fleet of supply vessels to deliver cargo to them. In this paper we focus on the problem of supply vessel scheduling which is commonly referred to as the Periodic Supply Vessel Planning Problem (PSVPP). In the PSVPP each installation is associated with a required number of deliveries per period (a week in this paper), a weekly cargo demand that is spread between departures, and an average service time for unloading operations performed by a vessel. Some installations may be closed at night and therefore have opening hours only during the day (for example, from 7:00 to 19:00). Each vessel is characterized by its cargo capacity, daily charter cost, sailing speed, fuel consumption rate, and turnaround time at the base (the time required for loading operations). The supply base has opening hours (for example, from 8:00 to 18:30), and vessel loading operations can be only performed in the time window (TW) during which the base is open. There is a set of possible departure times from the base for the vessels during the day. There are also practical restrictions such as the base capacity (maximum number of departures per day), and the delivery lead-time constraints defined by the maximum voyage duration and the maximum number of visits in a voyage. To ensure a steady supply and short lead-times, the departures of vessels on voyages that include a particular installation should be evenly spread throughout the week. Obviously, a vessel cannot start loading and unloading operations at the base until it has returned from the previous voyage.

The primary objective of the PSVPP is to construct a delivery schedule satisfying the installations' visit requirements so that the total vessel charter and fuel costs is minimized. A vessel delivery schedule is defined by a set of vessels used and by a set and sequence of voyages for each vessel. A vessel voyage is defined by a departure time from the base, a set of installations to be visited in a certain sequence starting and ending at the supply base, and a voyage duration. The distances between the installations and between the base and the installations are called voyage legs. Fig. 1 provides an example of a supply vessel schedule for a planning period of one week (a weekly vessel schedule). There are three vessels in this schedule (V1, V2 and V3), each of which has a set of voyages (marked with bold lines) with departure times assigned to the days of the planning period.

The weekly vessel schedule is normally fixed for a horizon of several weeks or several months, which ensures the stability and predictability of supplies to the installations. A new schedule may be constructed when the installations change their locations or when a change takes place in their activity (demand, required number of visits, etc.). In addition, seasonal changes of the schedule can be introduced in order to adapt it to weather conditions that effect its performance.

The PSVPP can be solved as a deterministic or as a stochastic problem. Deterministic planning implies that parameters values do not change dynamically over time and are not influenced by uncertain factors. In this study, we deal with supply vessel scheduling under uncertainty. The number of uncertain factors influencing supply vessel operations to some extent is large. Delayed cargo deliveries from suppliers to the base for a planned departure may cause uncertainty in the departure time from the base. The frequency of deliveries to the installations and the weekly volume of cargo to be delivered may vary from week to week due to specificities of the technological processes at the installations. On the Norwegian continental shelf, as in another nordic countries, the main uncertainty factor lies in weather conditions, which seriously impact sailing and service times. Weather conditions change over time, which means that the travel time on a voyage leg depends on the travel time on the previous leg. As a result, sailing and service times become time- and location-dependent uncertain parameters which are difficult to express analytically.

1.2. Literature review

There exist several studies dedicated to the PSVPP in its deterministic variant. Fagerholt and Lindstad (2002) formulated and solved a version of the problem in which several constraints were relaxed. Their work was followed by the paper of Halvorsen-Weare et al. (2012) who developed a two-phase algorithm for the PSVPP, which in a first phase constructs all shortest feasible voyages, and in a second phase uses the voyages as an input to a set covering model. Shyshou et al. (2012) developed a large neighbourhood search (LNS) heuristic capable of solving real-size instances of the PSVPP. Borthen et al. (2017) later proposed a very efficient genetic search-based heuristic for a simplified PSVPP with a homogeneous fleet of vessels, and did not consider time windows at the installations. Several known extensions of the problem have also been studied. Thus, Norlund and Gribkovskaia (2013) addressed the problem of emissions reduction in supply vessel planning. These authors incorporated several speed optimization strategies in the construction of vessel delivery schedules. Such strategies yielded a reduction of fuel consumption with no increase in the fleet size. Kisialiou et al. (2017) introduced a PSVPP with flexible departures and coupled vessels (PSVPP-FC). The original PSVPP assumes one possible departure option per day at a fixed time for a vessel. The authors extended the PSVPP by introducing a set of available departure options during the day. In addition, each vessel has a certain type, and vessels of the same type can swap their voyages in the subsequent week. These extensions may yield sailing and waiting time reductions and may also result in a fleet size reduction.

The PSVPP under weather uncertainty involves dynamic and interdependent travel times resulting from changing and uncertain weather conditions which are difficult or impossible to describe with any probability distributions. The only practical way to handle uncertainty in travel and service times in PSVPP is to generate robust solutions that remain feasible under the influence of uncertain