Routing and fleet sizing for offshore supply vessels

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In this talk we address the supply vessel planning problems arising in the servicing of oil and gas offshore installations on the Norwegian continental shelf. Supply vessels provide offshore installations with necessary supplies on periodic basis from an onshore supply base according to the weekly sailing schedules. A schedule is usually valid for a finite number of weeks before another schedule is developed due to the changes in installations' locations or their activities. We present four speed optimization strategies for the generation of green vessel schedules, and the simulation-based tool for the evaluation of strategies under the weather uncertainty. The second study is related to the annual supply vessel fleet sizing with discrete-event simulation. Rerouting and other operational strategies improving robustness of schedule are also studied.

Supply vessel planning on a weekly basis is a fleet mix and periodic vehicle routing and scheduling problem. Each installation requires one or more visits per week, and vessels sail one or more voyages during a week. Vessels departures from the supply base are planned at a fixed times and should be evenly spread throughout the week. Some of the installations are closed at night, yielding multiple time windows. To generate a minimal cost and green weekly schedules, a two stage optimization procedure is applied. In the first stage, a multi-period TSP with multiple time windows is solved with a constant speed to generate a shortest duration voyage for each vessel and each set of installations. Then, we apply speed optimization strategies to find optimized speed on each voyage leg by utilizing waiting time within the voyage. The speed optimized voyages are then used as an input to a set covering model that determines the vessels' voyages to use in the weekly schedules by assigning voyages to start days. A cost minimization objective including vessel charter and voyage fuel costs is used to achieve a weekly schedule with low emissions and a minimal number of vessels. The tests of applying speed strategies during weekly schedule generation show up to 25% less emissions on Statoil instances with 5 to 10 installations. Speed optimization applied a posteriori only on voyages from the optimal weekly schedule yield similar or slightly worse results. One of the strategies currently implemented by the largest Norwegian oil and gas operator Statoil yields around 10% fuel consumption reduction, resulting in 900 tons less CO_2 emissions for a single vessel per year.

Weather conditions are a main uncertainty factor in supply vessel planning since sailing time and service duration at offshore installations are weather dependent. To evaluate the performance of the speed optimization strategies, each speed optimized voyage is simulated accounting for sailing speed reduction and increase in service duration based on the generated weather data. The output of simulation yields a discrete distribution of voyage duration and corresponding average fuel consumption. The optimization model is then solved for a number of runs with different input sets of voyages randomly selected with respect to voyage duration distributions. Test results demonstrate that by taking weather uncertainty into account in speed optimization it is possible to achieve up to 22% less emissions. Application of some speed optimization strategies with weather simulation show even larger emissions reduction compared with the deterministic green schedule planning. Output analysis from schedule simulation under stochastic weather conditions allows for schedule local improvement by voyage rerouting and reassignment of voyages.

The number of vessels operating from a supply base varies during the year according to summer and winter schedules. The company hires two types of vessels to perform supplies to installations; time-charter vessels are hired in advance and have a long-term commitment period, while spot vessels are hired on an ad hoc basis. The daily rates for spot vessels may be significantly higher than for time-charter vessels. The optimal number of time-charter vessels to be hired for a year has a strong economic effect on the total annual vessel costs as supply vessels are rather expensive. The dependence of supply vessels' operations on weather conditions makes the fleet sizing problem highly stochastic. Due to impossibility to describe and model the stochastic phenomena analytically, a discrete-event simulation model is developed to evaluate alternative fleet size configurations for an annual time horizon taking into consideration uncertainty in weather conditions and future spot rates. The model simulates a sequence of voyages planned in the annual vessel schedule. The execution of the voyages depends on weather conditions which influence voyage duration. Because of the bad weather duration of a voyage scheduled for a vessel may be longer than allowed, so that this vessel cannot return to the base in time to start its next planned voyage. The voyage is then performed by another vessel, either an available time-charter vessel or a spot vessel. The system state of the model is characterized by the number of vessels being used offshore. Events changing the state of the system are considered to be voyage start events and voyage end events. By experimenting with various numbers of time-charter vessels and examining total annual vessel costs, the optimal number of time-charter vessels minimizing total annual vessel costs is determined. Significant wave height is used as a measure to quantify stochastic weather conditions influencing on possibility and duration of vessel's service at installations, and significant wave height and mean wave direction represent measures to quantify vessel's sailing speed reduction. The model is validated and tested on a real instance with 22 installations provided by the company. The simulation results confirmed the cost-efficient number of time-charter vessels employed by the company in reality.

The weekly vessel schedule is robust if all installations on planned voyages are visited. Adverse weather conditions decrease the robustness of the schedule. In practice, for each voyage a sequence of visits to the installations is adjusted according to the operational weather forecast. The problem is then to evaluate the robustness of the schedules with the simulation model and to analyze how operational rerouting against bad weather conditions restores the schedule robustness. The model simulates voyages as sequences of visits to installations as stated in the schedule. Rerouting is used to generate for each scheduled voyage a sequence with maximum possible number of installations visits within planned voyage duration. The system state of the model is characterized by the number of unperformed visits to installations. Events changing the state of the system are considered to be visits not performed in voyages. The performance measure is the percentage of completed visits, the experimental design factor is the fixed number of time-charter vessels. The simulation model is validated and tested on real summer and winter vessel schedules. The application of the rerouting module increases the number of completed visits by at least 56%.

Some installations visits may not be performed as planned due to bad weather conditions. Several operational strategies (insertion of visits into next planned voyage, scheduling ad hoc voyages to visit several installations with not performed visits, scheduling ad hoc single installation voyages) are developed in order to maximize the number of these visits to be performed later within a lead time at minimal cost. The discrete-event simulation models are developed to implement the strategies. The experimental design factor is the number of time-charter vessels hired for a year, the performance measures are the percentage of visits completed and the total annual vessel costs. A comparative analysis of the simulation outputs is conducted on a real instance.