Vehicle routing problems arising in servicing offshore oil installations

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The aim of this talk is to present two vehicle routing problems rooted in real-world applications faced by Statoil, the largest Norwegian offshore oil and gas operator. The first problem is motivated by Statoil supply operations performed by supply vessels from onshore bases to offshore installations, providing them with necessary supplies on a regular basis, and is further called a periodic supply vessel planning problem. The second problem arises in the transportation of personnel to and from offshore installations by helicopters and is aimed at minimizing transportation risk for passengers and pilots. However, these formulations are not limited to the specific problems faced by Statoil and have general applicability in maritime cargo and helicopter passenger transportation.

The periodic supply vessel planning problem consists of determining the optimal fleet of vessels needed to serve offshore installations from onshore bases assigned to them over a one week horizon, with simultaneous planning of vessels routes and schedules. Each installation has a weekly demand fulfilled by a given number of deliveries. To ensure uniform supply, the departures of cargo from the base to each installation should be evenly spread throughout the week. Each vessel can perform several voyages during a week. Each voyage is defined by a start day and a sequence of installations to visit, and can last several days. The total cost of a weekly schedule is comprised of vessel charter costs as a major component and sailing and service costs related to the voyages' fuel consumption. The objective is to find a fleet configuration and to schedule multiple voyages for each vessel so that installations' weekly requirements on the number of visits and the spread departures should be fulfilled at minimal cost. There are some added practical constraints that should be considered like opening hours at installations, vessels and base capacities, limits on voyage duration and on number of stops per voyage. Bases add specific restrictions on the fixed time for departures and no departures during week-ends. The periodic supply vessel problem may be regarded as a two-level bin packing problem where first-level items (installations' visits) are packed into second-level items (voyages) with a certain weight each (sailing and service cost). The second level items (voyages) have to be packed in a number of bins (vessels) with their weights (charter costs) so that the resulting packing is best with respect to the total sum of bins and second-level items weights.

We will present a heuristic for a single-base problem and its extension to the multi-base case. To diversify the search, the heuristic is applied from a number of restarts. At each restart an initial feasible solution is randomly generated and a number of large neighbourhood search (LNS) iterations are performed. Each iteration consists of visit removal and visit insertion loops with added local improvement procedures involving reassignments of voyages to other vessels and visit relocations. The heuristic was evaluated on real instances with up to 12 installations provided by Statoil. Results demonstrate that it is quite efficient for the instances considered and can be used to solve large instances within reasonable time. The multi-base approach relies on a version of the LNS heuristic for a single-base problem. The main idea of the multi-base approach is aimed at a reduction of the number of vessels serving installations in the neighbouring oil fields, and is based on sharing vessels between bases. Such vessels perform inter-base voyages starting from one base and finishing at another base. Computational tests indicate that the multi-base approach is helpful in identifying such synergies.

The second problem is a helicopter routing problem with an objective of minimizing transportation risk for passengers and pilots. In the offshore oil industry, helicopters are used as a major mode of transportation for personnel to and from offshore installations. For offshore employees and pilots, helicopter transportation represents one of the major risks. To improve transportation safety, we suggest minimizing the expected number of fatalities when planning helicopter routes. We decompose the risk of helicopter transportation into take-off and landing risk and cruise risk. In air transportation a flight may consist of several connected flight stages, where each stage is the operation of an aircraft from a take-off to its next landing. Take-off and landing risk for a flight depends on the total number of person take-off and landings defined as a summation of persons exposed to pairs of take-off and landings over all flight stages. Flight cruise risk is dependent on the total person flight hours given by summation over all flight stages the products of number of persons on board and corresponding flight hours. In offshore helicopter passenger transportation, each installation receives a delivery originating at a heliport and sends a pickup quantity to the heliport which makes the problem a multi-vehicle one-to-many-to-one pickup and delivery problem (VRPPD) with combined demands. In this talk we present a new objective for the VRPPD consisting of two parts: passenger risk and pilot risk, where risk is a weighted sum of person take-off and landings and person flight hours.

Three routing policies were considered: a direct service policy, a Hamiltonian solution policy, and a general solution policy. Under the direct service policy, each installation is served directly from the heliport so that the number of flights is equal to the number of installations. The term “Hamiltonian” refers to the fact that each installation is visited exactly once for the combined pickup and delivery within a Hamiltonian tour. In a general solution, each installation is allowed to be visited twice, once for delivery and once for pickup, and these visits may take place in two different flights. Under the direct service policy the risk for passengers is minimized, but it may not be realistic to serve each installation directly with limited fleet size or time. We used a tabu search heuristic to generate solutions under each routing policy in order to study the trade-offs between cost and risk under the same operating rules.

Computational experiments were conducted on 120 instances derived from real geographical data for two offshore operational regions in the North Sea. To ensure fair comparisons between the various routing policies in each instance we used the minimum number of routes required as determined by generated demands. Results of comparative analysis show that when minimizing passenger risks, the flights become longer with fewer passengers on board, because the major impact on passenger risk (up to 75%) comes from number of person take-offs and landings. Hamiltonian routing policy with cost objective is the best for pilots. But when minimizing risk, the passenger risk goes down by 5% on average and the pilot risk goes up by 1.5%. The reduced (up to 8%) average number of passengers on board guarantees a similar reduction in the number of person take-off and landing, while person flight hours may both increase or decrease. In these solutions passenger risk is on average 8 times higher than pilot risk. In solutions with passenger risk objective, the number of installations visited during each flight becomes more evenly distributed. Under a general strategy with passenger risk minimization helicopters visit installations twice performing all deliveries first, while with total risk minimization services are often performed simultaneously. In the first case risk for passengers reduces by 20% and significantly increases (by 80%) for pilots as compared with least cost solutions. The total risk minimization reduces pilot risk remarkably without deteriorating passenger risk. The average number of passengers on board goes down by 57%, and person take-offs and landings are reduced up to 27%. The passenger risk is on average 4 to 5 times higher than pilot risk under the general strategy. We propose also a penalty mechanism to achieve an equitable distribution of risk between passengers and pilots, given that pilots fly much more frequently than passengers.