Offshore Supply Planning in a Rolling Time Horizon

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Abstract. This paper presents a real transportation problem stemming from offshore oil and gas logistics and shows how optimization models used in a rolling horizon simulation framework can be very valuable to assess and improve the operation's performance. With this aim, we study how the Order Selection Problem (OSP), a problem that helps the logistics provider decide which orders to carry to and from the platforms and which to postpone, and the *Vessel Routing Problem with Selective Pickups and Deliveries* (VRPSPD), that in addition to the order selection also routes the vessels carrying the orders, can be used in a practical planning setting. To quantify and justify the benefits of using the VRPSPD and OSP models in a real planning situation, an industry case based on real data was simulated in a rolling horizon framework and solved for an entire year. In addition to the traditional cost metric used, the focus of this paper lies on the implication these have on other important aspects that are often neglected in traditional optimization models; regularity and level of service. Several strategies for overbooking and postponing orders were also evaluated with respect to their cost, regularity, and level of service.

Keywords: Vehicle routing; Pickup and delivery; Rolling horizon; Simulation; Offshore supply

1 Introduction

The upstream offshore oil and gas supply logistics deals with the transportation of equipment and supplies used at offshore platforms. The main bulk of this transport work is performed by supply vessels. Several studies have shown that using advanced optimization methods can yield large benefits in the planning and organizing of offshore supply logistics, see for example Gribkovskaia et al. [8], Halvorsen-Weare et al. [9], Fernández-Cuesta et al. [4], and Norlund et al. [11]. On the other hand, improvements resulting from the use of optimization tools sometimes result in frequent re-design of established sailing patterns or the relaxing of the regularity of the platform visits and other requirements that can be important for the planners. The challenge when designing optimization models is therefore often to model the problems in such way that improvements can be made, but at the same time keep changes on a level that can be realistically implemented.

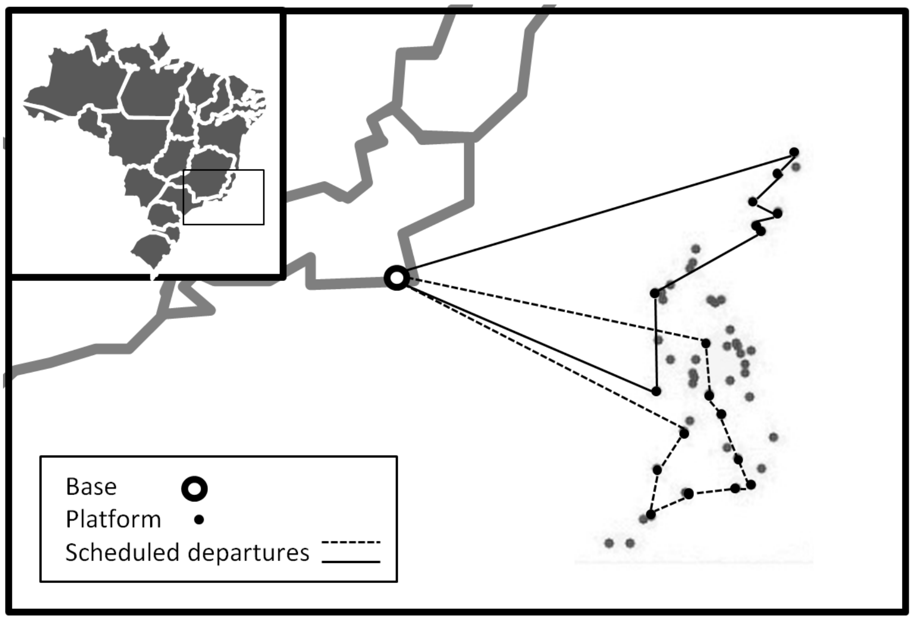

Fig. 1. Offshore supply layout with two scheduled departures.

Figure 1 shows the layout for an offshore oil and gas logistic network off the Brazilian coast, which is the case studied in this paper. The platforms place new order requests throughout the year. The requests include both pickup orders destined from the platforms back to the base and delivery orders destined out to the platforms from an onshore base. The resulting planning problem faced by the logistics provider consists of transporting the requested orders to and from the platforms so that these can produce oil and gas without any disturbances.

For practical purposes, the transportation is organized into *scheduled departures* that are repeated on a weekly basis throughout the year, see the examples in Figure 1. Each scheduled departure is associated with a voyage termed *regular voyage* that has a predetermined starting time and follows a predetermined route. The transportation of the orders is performed by a supply vessel sailing the regular voyage along the predetermined route while delivering and picking up orders. If the supply vessel performing the regular voyage has insufficient capacity to carry all orders for the platforms visited on a scheduled departure, these are normally transferred to the order pool of the subsequent scheduled departure that visits the corresponding platform. For every scheduled departure the planner therefore has an Order Selection Problem (OSP) where it has to decide which orders to carry and which to postpone for later. The exception to this is that some orders are *urgent* and should not be postponed. In this case, an *express voyage* is requested to carry the order instead. An express voyage requires a crew working outside their regular working hours.

The overall planning problem can therefore be seen as a number of consecutive OSPs that consist of selecting the subset of available orders to carry and to postpone. Even though each OSP can be considered as a static problem, the overall problem is dynamic because the decision of which orders to carry and postpone influences the consecutive problems. This interdependency between the different OSPs for the scheduled departures is in this paper modeled in a rolling horizon simulation framework where the information about the available order requests is revealed as time passes. Subsequent departures are dependent on the new order arrivals as well as the previous decisions made. Early implementations of a rolling horizon approach can be found in Sethi and Sorger [12]. General literature and classification on the combination of simulation and optimization can be found in Fu [5] and Gosavi [6].

The problem of order selection for offshore supply logistics in a rolling horizon framework was formulated by Andersson et al. [1]. However, it is clear that sailing the same historical route on the regular voyage week after week can be suboptimal. Instead, routing and order selection could be performed jointly. The *Vessel Routing Problem with Selective Pickups and Deliveries* (VRPSPD) is a pickup and delivery problem (PDP) with optional pickup and delivery orders where both the order selection and routing of the regular voyage is decided after the available orders become known. The VRPSPD was introduced by Fernández-Cuesta et al. [4] and belongs to a class of general *Pickup and Delivery Problems* (PDPs), see for example the classification schemes suggested by Berbeglia et al. [3] and Battarra et al. [2]. The class of PDPs to which the VRPSPD is most closely related to is the *One-to-Many-to-One Vehicle Pickup and Delivery Problem* (1-M-1 PDP), which is described in Gribkovskaia and Laporte [7]. The expression 1-M-1 refers to the fact that all supplies destined to the set of customers originate from the depot and all orders picked up at the customer locations must be returned to the depot. There exist also a few practical applications for the 1-M-1 PDP in the upstream offshore petroleum industry, see for example Gribkovskaia et al. [8] and Fernández-Cuesta et al. [4].

The purpose of this paper is to show through a rolling horizon simulation study how the practical planning of a real problem arising from offshore oil and gas logistics can benefit from solving the VRPSPD and OSP. Furthermore, we estimate the consequences this will have on platform visiting regularity and level of service in terms of the number of platform calls. An additional purpose is to test different strategies for selecting and postponing orders and to analyse their impact on the transportation system.

The remainder of this paper is organized as follows: Section 2 describes the transportation problem faced by the company and how the OSP and VRPSPD relate to this. Section 3 presents the mathematical models that correspond to the current industry practice (OSP) and the VRPSPD. Section 4 presents the case study on which the VRPSPD has been tested, followed by conclusions in Section 5.

2 Problem Description

The planning problem faced by the logistics provider originates from the necessity to transport supplies in the form of maintenance and production equipment (delivery orders) to offshore platforms and collect waste and redundant or depleted equipment (pickup orders) destined for the onshore base. The pickup and delivery orders are placed throughout the course of the year by the platforms. These orders cannot be split into smaller orders. The order arrival process for a platform is illustrated in Figure 2. Every time a new order arrives it is added to the order pool from which the orders to be carried are selected. The order pool for a given departure consists of all the pickup and delivery orders originating from or destined for one of the platforms scheduled to be visited on that departure. In addition, some order requests are *urgent*. It is the platforms who decide whether an order is urgent or not. Urgent orders cannot be postponed. Therefore, if the regular voyage is unable to carry all the urgent orders, an express voyage is requested to carry the remaining ones. A regular order can be postponed to the next departure for that platform, but becomes urgent after it has been postponed once.

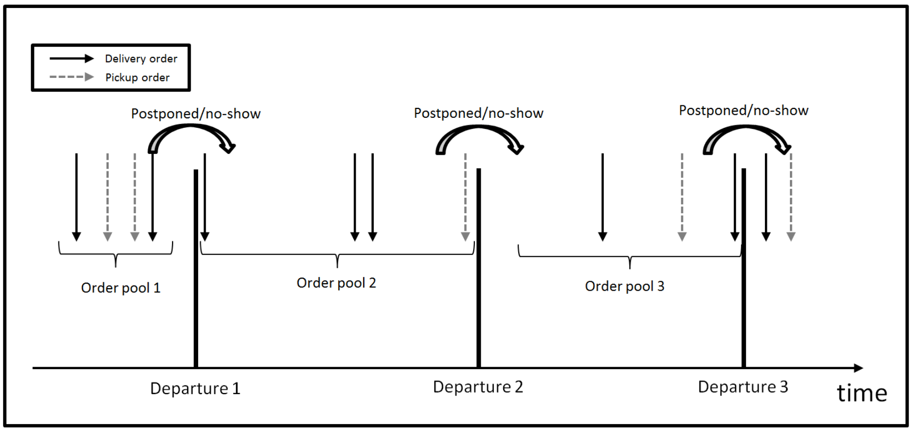

Fig. 2. The order arrivals are simulated in a rolling horizon where arriving orders are added to the order pool as time increases and carried at each departure point while missing (no-show) and postponed orders are transferred to the order pool of the following schedule visiting the same platform.

All materials are stored in a warehouse at a separate location away from the onshore base from which all orders are transported to the platforms and where the fleet is located. There is limited storage space at the harbor front of the base, so orders planned on a scheduled departure are transported to the harbor front and directly onto the vessel sailing the voyage. Due to congestion issues between the warehouse and the harbor front and issues with orders not being available at the warehouse as expected, some delivery orders may not be available for the departure in which they are planned. An order that does not show up at the harbor front at the determined departure time is termed a *no-show*. No-shows are transferred to the following departure just as the postponed ones. This means that an urgent order will be transferred to the order pool of the following departure if it becomes a no-show.

Based on the orders available in the order pool for a given departure, the orders to carry and the ones to postpone (if any) have to be decided based on their importance. The orders are therefore sorted according to their utility. In general, the utility for an urgent order is higher than for regular orders and higher for delivery orders than for pickup orders. The latter is because the imbalance between the quantity of delivery and pickup orders makes the former more constraining on the vessel capacity. The decision of which orders to carry is made by either solving the OSP or the VRPSPD.

Prior to every departure an initial set of orders to carry is decided and a request to transport the orders from the warehouse to the harbor front is placed. At this point, whether an order is a no-show is unknown. At the point of loading the orders on the vessel, the no-shows become known. To reduce the negative effects of the no-show orders, an overbooking policy can be implemented. This basically means that more orders are planned on the regular voyage than the vessel's capacity. If the initial plan reveals that there is insufficient capacity on the regular voyage to carry all the urgent orders, an additional express voyage has to be requested. The order selection for the express voyage is the same as for the regular voyage but with the reduced order pool consisting of the orders left behind by the regular voyage.

For the transportation of the orders the planner has a homogeneous fleet of specialized supply vessels at its disposal. The fleet is chartered on an annual basis so the charter costs are considered sunk. In the case study considered here, a schedule of 13 departures (routes/voyages) with a weekly regularity has been designed by the company a priori using historic knowledge about the expected demand of the platforms. There are 52 platforms that are serviced in total. Most platforms are visited twice per week, although some are serviced only once per week. Each scheduled departure is carried out by one of the available vessels on a regular voyage and visits each platform in a predetermined subset of the platforms exactly once according to the schedule. Under the current industry planning practice, the only way a regular voyage will deviate from the historical route is when a platform does not have any pickup or delivery orders. In this case the platform is skipped and the voyage continues to the next platform along the route.

An alternative to using the historic routes is to route the vessel solving the VRPSPD. Then, the route of the regular voyage will change from one scheduled departure to the next depending on the set of orders available. Based on the number of working hours of the crew, each regular voyage has a four day limit on its duration.

Whenever the vessel sailing the regular voyage has insufficient capacity to carry all the urgent orders or if there are overbooked orders left at the harbor front an express voyage has to be requested to carry the surplus. However, using an express voyage is expensive as it entails using a crew outside their ordinary working hours. Since the crew requires additional time to assemble, the express voyage is planned (routed) sequentially after the regular voyage using the VRPSPD. The express voyage has a two day maximum duration. For both regular and express voyages, the vessels require half a day turnaround time in the base before being ready to sail a new voyage.

3 Mathematical Formulations

In this section we formulate the mathematical models for the two versions of the planning problem. The OSP, which assumes given routes, is presented in Section 3.1. This is used to represent the current planning practice and is a variation of the model presented by Andersson et al. [1]. The VRPSPD, which considers the integrated routing and order selection problem is presented in Section 3.2 and is a variation of the model presented in Fernández-Cuesta et al. [4].

3.1 Order Selection Problem

The current practice is modeled through an order selection model that determines which orders from the order pool to service on the next given departure (route) and which to postpone and transfer to the subsequent order pools. Let $\mathcal{N}$ be the set of all nodes corresponding to platforms to be visited on a given scheduled departure and $\mathcal{O}^{Pool}$ be the set of all non-splitable pickup and delivery orders available in the order pool of the scheduled departure. Nodes that are scheduled for a visit but have no pickup or delivery orders are removed from $\mathcal{N}$. In addition, let o be an order in the set $\mathcal{O}_i$ for node/platform $i \in \mathcal{N}$. There may be several delivery or pickup orders at each node.

The binary variable u_o is 1 if order o is carried, and 0 if it is postponed. Let the time it takes to pickup or deliver o be T_o and its size be S_o. In the OSP we let S_o be negative for delivery orders and positive for pickup orders. The capacity of the vessel is given by Q. Let the variable l_i represent the total load on the vessel when leaving node i. In addition, let T^r be the given sailing time for the scheduled departure/route after the nodes without orders have been removed. T^r includes the time for visiting the platforms (i.e. mooring etc.), but excludes the time for loading/unloading. Let T^L be the maximum allowed scheduled time for the departure. Let $n(t)$ be a function that returns the order in which the nodes are visited, so that $n(t)$ is the t^{th} node that is visited according to the schedule. The set $\mathcal{O}^{Post}$ represents the subset of the orders in $\mathcal{O}^{Pool}$ that are postponed in a given solution. Finally, we define the objective function $U(\mathcal{O}^{Post})$ to represent the loss in utility postponed orders $\mathcal{O}^{Post}$. This yields the following compact order selection model, denoted the OSP.

$$\text{Minimize} \qquad U(\mathcal{O}^{Post}) \tag{1}$$

subject to

$$l_i \leq Q \qquad i \in \mathcal{N} \tag{2}$$

$$l_0 = \sum_{i \in \mathcal{N}} \sum_{o \in \mathcal{O}_i | S_o < 0} -S_o u_o \tag{3}$$

$$l_{n(t)} - l_{n(t-1)} = \sum_{o \in \mathcal{O}_{n(t)}} S_o u_o \qquad t = 1, .., |\mathcal{N}| \tag{4}$$

$$T^r + \sum_{o \in \mathcal{O}_i} T_o u_o \leq T^L \tag{5}$$

$$u_o \in \{0, 1\} \qquad i \in \mathcal{N}, o \in \mathcal{O}_i \tag{6}$$

$$l_i \geq 0 \qquad i \in \mathcal{N}, \tag{7}$$

The objective (1) minimizes the loss in utility of the postponed orders. Constraints (2) ensure that the capacity of the vessel is not violated, whereas constraints (3) and (4) control the start load and load continuity, respectively. The total duration is controlled by constraint (5). The domain of the variables are defined through constraints (6) and (7).

3.2 Vessel Routing Problem with Selective Pickups and Deliveries

The VRPSPD is an extension to the OSP where routing is included. For this we let $\mathcal{N} = \{\mathcal{N}^P, \mathcal{N}^D\}$ be the set of all nodes with orders on a given scheduled departure where $\mathcal{N}^P$ is the set of pickup locations and $\mathcal{N}^D$ is the set of delivery locations. Note that this means that a node no longer corresponds to a platform as in the OSP. Instead, each platform in the set of all platforms $\mathcal{P}$ is therefore represented by at most two nodes corresponding to the pickup and delivery node, respectively. Let sets $\mathcal{O}^{Pool}$ and $\mathcal{O}_i$ be as defined for the OSP. The vessel starts in the depot node 0 and ends in the depot node $|\mathcal{N}| + 1$.

Let v_i be a binary variable that controls whether node i is visited, and let variable l_i from the OSP be split into l_i^P and l_i^D for the pickup and delivery loads on the vessel immediately after leaving i, respectively. This eliminates the need for subtour elimination constraints (see for example Hoff et al. [10]). The binary variable u_o is 1 if order o is carried, and 0 otherwise, like before. The size of order o is given by S_o as in the OSP, although the delivery quantities are no longer defined as negative. Furthermore, let the set of arcs in the network be $\mathcal{A}$. This set consists of the arcs between all nodes in the network, except for the ones from the pickup to the delivery nodes for the same platform. For the arc between nodes i and j, the travel time is given as T_{ij} and the cost of traversing it as C_{ij}. The binary variable x_{ij} is 1 if the arc from i to j is used, and 0 otherwise. The time it takes to visit a node consists of a fixed time T^F (for mooring etc.) and a variable time for loading or unloading each unit of order o denoted (as before) by T_o. The duration of each voyage is limited by T^L as for the OSP. Then VRPSPD can be formulated as

$$\text{Minimize} \sum_{(i,j)\in\mathcal{A}} C_{ij}x_{ij} + U(\mathcal{O}^{Post}) \tag{8}$$

subject to

$$\sum_{(0,j)\in\mathcal{A}} x_{0j} = 1 \tag{9}$$

$$\sum_{(i,|\mathcal{N}|+1)\in\mathcal{A}} x_{i,|\mathcal{N}|+1} = 1 \tag{10}$$

$$\sum_{j\in\mathcal{N}} x_{ij} = v_i \qquad i\in\mathcal{N} \tag{11}$$

$$\sum_{i\in\mathcal{N}} x_{ij} = v_j \qquad j\in\mathcal{N} \tag{12}$$

$$v_i \geq u_o \qquad i\in\mathcal{N}, o\in\mathcal{O}_i \tag{13}$$

$$0 \leq l_i^P + l_i^D \leq Q \qquad i\in\mathcal{N} \tag{14}$$

$$l_0^D = \sum_{i\in\mathcal{N}^D}\sum_{o\in\mathcal{O}_i} S_o u_o \tag{15}$$

$$l_j^D \geq l_i^D - \sum_{o\in O_j} S_o u_o - Q(1-x_{ij}) \qquad i\in\mathcal{N}, j\in\mathcal{N}^D \tag{16}$$

$$l_j^D \geq l_i^D - Q(1-x_{ij}) \qquad i\in\mathcal{N}, j\in\mathcal{N}^P \tag{17}$$

$$l_j^P \geq l_i^P + \sum_{o\in O_j} S_o u_o - Q(1-x_{ij}) \qquad i\in\mathcal{N}, j\in\mathcal{N}^P \tag{18}$$

$$l_j^P \geq l_i^P - Q(1-x_{ij}) \qquad i\in\mathcal{N}, j\in\mathcal{N}^D \tag{19}$$

$$\sum_{(i,j)\in\mathcal{A}} T_{ij}x_{ij} + \sum_{i\in\mathcal{N}} T^F v_i + \sum_{i\in\mathcal{N}}\sum_{o\in O_i} T_o u_o \leq T^L \tag{20}$$

$$x_{ij}\in\{0,1\} \qquad (i,j)\in\mathcal{A} \tag{21}$$

$$l_i^P \geq 0 \qquad i\in\mathcal{N} \tag{22}$$

$$l_i^D \geq 0 \qquad i\in\mathcal{N} \tag{23}$$

$$u_o\in\{0,1\} \qquad i\in\mathcal{N}, o\in\mathcal{O}_i \tag{24}$$

$$v_i\in\{0,1\} \qquad i\in\mathcal{N} \tag{25}$$

The objective function (8) minimizes the travel cost plus the loss in utility for not handling orders. Constraints (9)–(10) ensure that the vessel starts and ends at the depot, whereas constraints (11) and (12) express that all visited nodes have one inbound and one outbound arc, respectively. Constraints (13) state that only orders from visited nodes can be handled. The capacity of the vessels is respected through constraints (14). The start delivery loads on the vessel is controlled by constraints (15), whereas constraints (16) and (18) together with constraints (17) and (19) ensure continuity in the pickup and delivery load aboard the vessel, respectively. Finally, constraint (20) limits the total travel time of the vessel, and constraints (21)–(25) define the domain of the variables.

It can be noted that by fixing variables v_i and x_{ij} corresponding to the scheduled departures (routes), the VRPSPD and OSP become equivalent.

4 Computational Study

The purpose of the computational study is to solve the VRPSPD and compare the results with a benchmark provided by the current industry practice represented by solving the OSP in a rolling horizon simulation framework corresponding to a full year of logistics operations. An additional purpose is to evaluate and analyze other strategies for improving the transportation system. Section 4.1 describes the case study, while Section 4.2 presents and discusses the computational results.

4.1 Case Study Setup

The case study is based on historical data from the Brazilian offshore oil and gas industry. The case company serves 52 platforms and other production/drilling units. A homogeneous fleet of eight supply vessels sailing 13 scheduled weekly departures is available during the course of a year. A sketch showing the layout of the platforms and two of the scheduled departures was shown in Figure 1. 47 of the 52 platforms are visited twice per week whereas the remaining five are visited once per week. There are 98 platform calls per week and in total there are 676 scheduled departures in a year. There are roughly 8 000 delivery and 5 000 pickup orders totalling 350 000 m^2 of cargo to be transported over that period. On average there are 380 m^2 of delivery orders and 150 m^2 of pickup orders on each scheduled departures. The vessels in the fleet all have a capacity of 620 m^2. The charter cost of the fleet is based on a regular charter contract in the offshore supply industry and is considered sunk over the planning period. The operational costs for the routing are calculated based on an estimate of the bunker price, the fuel consumption at the service speed for the vessel and an estimate of the crew costs.

Order Arrival Each platform is modeled with its own independent order arrival process as a homogeneous Poisson process. The inter-arrival time between two orders to a platform i is given by $(\lambda_i^{delivery})^{-1}$ and $(\lambda_i^{pickup})^{-1}$ for pickup and delivery orders, respectively. The inter-arrival time is estimated from historical data and the order sizes are calculated so that the total expected load for a given platform is proportional to the number of times the platform is visited. On average each platform that is visited twice per week has 3.2 delivery and 2.1 pickup requests per week. Pickup and delivery order requests have a 10% and 50% chance of being *urgent*, respectively. In addition, every delivery order has a 25% chance of being a no-show (to mimic the real operation). Both the no-show and urgent probabilities are approximated based on the data provided by the case company. The order arrival process for the entire year is drawn a priori and is therefore identical across all the runs.

Order Selection Based on the orders available in the order pool for a given departure, the orders to carry and the orders to postpone are decided, either by solving the OSP or the VRPSPD. To represent the utility of carrying the orders each order o is associated with an artificial penalty C_o for not being carried so that

$$U(\mathcal{O}^{Post}) = \sum_{i \in \mathcal{N}} \sum_{o \in \mathcal{O}_i} C_o(1 - u_o) \tag{26}$$

For the VRPSPD, the artificial penalty for not carrying an order is set higher than the operational cost $\overline{C}$ of visiting and returning from the most distant platform. $\overline{C}$ is set to zero for the OSP. C_o also scales with the size of the order compared to $\overline{S}$, which is the size of the largest order available. For every departure t an order is postponed the penalty is increased by a factor 4 so that

$$C_o(t) = F_o^{Base} \cdot 4^t \left(\overline{C} + \frac{S_o}{\overline{S}} \right) \tag{27}$$

where the factor F_o^{Base} is

$$F_o^{Base} = \begin{cases} 1 & o \in O^P \\ 2 & o \in O^D \\ 4 & o \in O^{Urgent} \end{cases}$$

All express voyages are routed with the VRPSPD using the same penalties as for the regular voyage.

Strategies and setup To evaluate the transportation system, several different strategies and setups have been tested. These are referred to as *settings*. The basic setting that corresponds to the current practice is termed **Base**. In this, the no-show probability is set to 25% for delivery orders and there is no overbooking policy in place. The order penalties are set so that the vessels are filled up as much as possible. To see if the vessel utilization can be improved, several overbooking settings (**OB**) ranging from 5% to 25% have also been tested. Since the 25% no-show rate leads to reduced vessel capacity utilization, the setting

Ideal using a no-show probability of 0% is implemented to quantify the consequences. Lastly, we have also tested the **Opportunistic** setting where we allow postponing regular orders by two departures instead of one before they become urgent. In addition, the factor F_o^{Base} is replaced by a new factor F_o^{Opp} that is defined

$$F_o^{Opp} = \begin{cases} 0.25 & o \in O^P \\ 1 & o \in O^D \\ 4 & o \in O^{Urgent} \end{cases}$$

Opportunistic is run with 0% overbooking and 25% no-show as in the **Base** setting. Either setting can be solved using both the OSP and the VRPSPD.

4.2 Case Results

The simulation results regarding delays and costs for the different settings run over a 360 day rolling horizon are summarized in Table 1. Delays are measured in the number of departures an order is postponed or weighted with the size (in m^2) of the order. The results for **Base**-OSP are given in absolute numbers. All other results are in percent using the **Base**-OSP as comparison except the results where **Base**-OSP is zero. These results are given in absolute numbers. Note that the first and last week (26 departures) have been cleaned from the results to allow the rolling horizon to be in a steady state. The level of service (LoS) is measured in number of platform calls during the period. Regularity is calculated for each of the 98 weekly departures for each platform and is measured as the difference in hours between the actual visiting time and the average visiting time from the start of the scheduled departure. The total regularity is then averaged across all platforms. In the following we discuss each of the settings to evaluate the VRPSPD and the transportation system. All VRPSPD runs were performed with Gurobi 6.0 running on a 2.4 GHZ 4-core computer with 16GB of RAM.

VRPSPD vs. OSP By comparing the results for the **Base** setting in Table 1 for the OSP and VRPSPD models we see that it is possible to reduce the total cost by improving the routing when solving the VRPSPD by 8.3%. Part of these savings stem from the reduction in express sailings by 21.7% (from 23 to 17). We also see that the number of one-departure delays stays roughly the same (-0.3%) whereas the number of two-departure delays has increased by 24.6%. This seems substantial but is an increase from 118 to 147 orders out of a total of 2 049 delayed orders. Since two-departure delays are not planned but rather only happen by chance if a previously postponed order happens to be a no-show the two-departure delay increase can be considered insignificant. Note that because of the no-shows, there are also 1 015 urgent one-departure delays. As expected, the primary advantage of using the historical routes is that they lead to more regular visits to the platforms as can be seen from the regularity in Table 1. In **Base**-OSP the average visiting deviation was five hours, whereas this average

Table 1. Results for settings **Base**, **OB** (Overbooking 5% - 25%), **Ideal**, for both the OSP and the VRPSPD. **Opportunistic** (Opp.) setting for VRPSPD only. Results from one-year run using **Base**-OSP as the baseline [±%]. Results where baseline is 0 are shown in absolute numbers. 1-dpt = one departure delay etc., NS = no-show, OB = overbooking, LoS = Level of Service [# platform calls]

			OSP							VRPSPD							
				Overbooking [%]							Overbooking [%]						
			Base	5	10	15	20	25	Ideal	Base	5	10	15	20	25	Ideal	Opp.
Delays	Regular	# of 1-dpt	1 326	-3.3	-10.9	-15.1	-18.6	-20.0	-89.2	-0.3	-4.4	-11.3	-15.1	-17.9	-19.8	-89.7	3.8
		# of 2-dpt	118	-13.6	-38.1	-60.2	-84.7	-87.3	-100.0	24.6	-6.8	-37.3	-67.8	-80.5	-90.7	-100.0	122.9
		# of 3-dpt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16
		Sum	1 444	-4.2	-13.1	-18.8	-24.0	-25.5	-90.1	1.7	-4.6	-13.4	-19.4	-23.0	-25.6	-90.6	14.6
	Urgent	# of 1-dpt	1 015	0.0	0.0	0.0	0.0	0.0	-100.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0	0.0
		# of 2-dpt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Sum	1 015	0.0	0.0	0.0	0.0	0.0	-100.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0	0.0
	Total	# delays	2 459	-2.4	-7.7	-11.0	-14.1	-15.0	-94.2	1.0	-2.7	-7.9	-11.4	-13.5	-15.0	-94.5	8.6
		delay dpt	2 577	-2.9	-9.1	-13.3	-17.3	-18.3	-94.5	2.1	-2.9	-9.2	-14.0	-16.6	-18.5	-94.7	15.1
		Size [m2]	77 736	-2.5	-7.6	-11.1	-14.1	-15.0	-94.3	1.0	-2.8	-7.9	-11.4	-13.4	-15.0	-94.6	8.4
		Size·dpt	81 437	-2.9	-9.0	-13.3	-17.4	-18.3	-94.6	2.1	-3.1	-9.2	-14.0	-16.4	-18.5	-94.8	15.2
Costs [MUSD]	Regular	Operational	66.5	-0.1	-0.1	-0.2	-0.2	-0.2	-0.5	-12.7	-12.7	-12.6	-12.7	-12.7	-12.6	-12.8	-13.3
		Charter	43.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Total	109.7	-0.1	-0.1	-0.1	-0.1	-0.1	-0.3	-7.7	-7.7	-7.6	-7.7	-7.7	-7.7	-7.7	-8.0
	Express	Fuel	2.0	-44.7	-36.6	-37.0	1.1	4.0	-96.0	-22.2	-49.7	-39.9	-38.1	-5.6	2.6	-96.0	-66.1
		Crew	2.6	-44.4	-36.1	-36.4	4.3	6.4	-95.9	-22.1	-49.2	-38.6	-36.1	-3.0	5.3	-95.9	-65.8
		Total	4.6	-44.5	-36.3	-36.7	2.9	5.4	-95.9	-22.1	-49.4	-39.2	-36.9	-4.1	4.1	-95.9	-65.9
		TOTAL	114.3	-1.9	-1.5	-1.6	0.0	0.1	-4.2	-8.3	-9.4	-8.9	-8.8	-7.5	-7.2	-11.3	-10.4
Departures		Scheduled	650	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Express	23	-43.5	-34.8	-34.8	13.0	13.0	-95.7	-21.7	-47.8	-34.8	-30.4	4.3	13.0	-95.7	-65.2
		# with OB	0	4	9	12	25	25	0	0	2	10	12	22	25	0	0
		# with NS	613	0.2	0.2	0.0	0.0	0.0	-100.0	0.0	0.3	0.2	0.2	0.0	0.0	-100.0	0.2
Orders		# of OB	0	4	12	17	31	37	0	0	2	13	15	29	38	0	0
		# of NS	2 049	0.0	0.0	0.0	0.0	0.0	-100.0	0.0	0.0	0.0	0.0	0.0	0.0	-100.0	0.0
		# carried	13 218	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vessels		# used	8	0.0	0.0	0.0	0.0	0.0	-12.5	0.0	0.0	-12.5	-12.5	-12.5	-12.5	-12.5	-12.5
		Utilization	58.9	-1.1	-0.9	-1.0	-0.2	-0.2	-2.8	0.0	-6.5	-6.7	-6.5	-5.9	-5.7	-8.2	-7.4
		LoS	4 699	-1.4	-1.7	-1.9	-1.6	-1.7	-3.7	-0.7	-1.6	-2.0	-2.1	-2.0	-1.9	-3.9	-2.4
		Regularity	5.0	0.0	0.0	0.0	1.2	1.2	1.0	178	176	176	176	178	178	180	174

was increased by +178% to over 13 hours for the VRPSPD. On the other hand, the level of service (LoS) in the form of total number of platform calls is slightly reduced (-0.7%) to 4 659 from 4 699 annual calls for the VRPSPD. Considering that the initial annual schedule has 4 900 platform calls it is hard to argue that the use of the VRPSPD would have a notable adverse impact on the service level.

Overbooking In Table 1 the results from overbooking from 5% to 25% are presented for both the OSP and VRPSPD. The total cost and delay (# delayed departures · size) is also presented in Figure 3. From this we see that it is beneficial to plan with overbooking up until a certain point. Because there is no way of storing the surplus overbooked orders, these will require an additional express voyage. The lowest total cost for the system was achieved by overbooking with 5% for both the OSP and the VRPSPD. From Figure 3 it is clear that if minimizing the number of order delays is the only concern of the logistics provider, it is better to overbook as much as possible. For the OSP at 25% overbooking there is a total of 2 091 delay orders. When considering that 2 049 of these are no-shows it means that only 42 orders were postponed voluntarily. However, 26 express voyages would be required in the 25% overbooking setting.

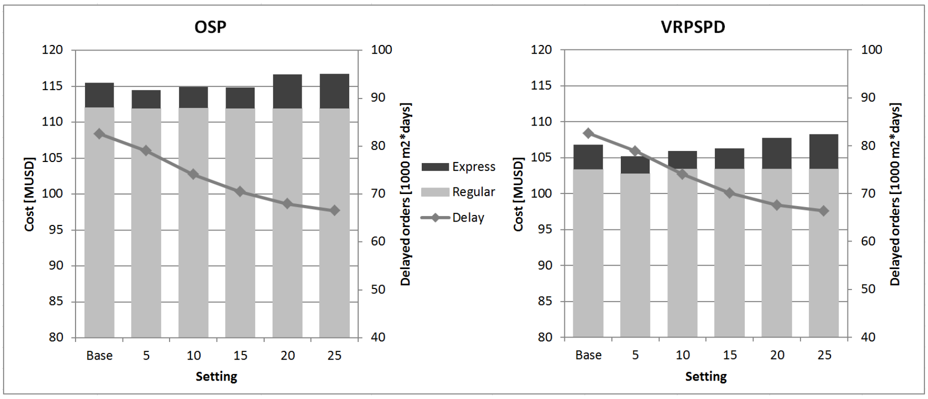

Fig. 3. Comparison of the cost and delays with varying levels of overbooking for the OSP and the VRPSPD.

Relaxing delay requirements In the **Opportunistic** setting we measure the consequence of allowing regular orders to be postponed twice and use the penalty factor F_o^{Opp} instead of F_o^{Base}. The results are presented in Table 1 in the **Opportunistic** setting for the VRPSPD. Note that we do not run the **Opportunistic** setting for the OSP as there are limited gains from postponing orders if the platforms are visited anyway. The results show that this setting would reduce the cost by 10.4% with respect to the **Base**-OSP. This corresponds to 2.3% of savings compared with the **Base**-VRPSPD. This is achieved by increasing the number of delays and thereby reducing the routing cost and also reducing the number of express voyages to seven. We also note that this setting has more than double the number of two-departure delays (+122.9%) and 16 three-departure delays due to no-shows. Note also that in addition to the savings in operational costs, an additional 12.5% savings in charter costs could be obtained because the number of vessels used is reduced from eight to seven. Both the regularity and level of service is comparable with the other VRPSPD settings.

Cost of no-shows The presence of no-shows in the logistic system is an important cost driver as it leads to reduced vessel capacity utilization on the voyages. From the **Ideal** setting in Table 1 the obtainable benefits by removing no-shows in the system can be seen. The results show that it would be possible to remove all urgent delays and reduce the number of regular one-departure delays by around 89% for both the OSP and the VRPSPSD. In addition, savings in routing costs in the magnitude of 4.2% for the OSP and 11.3% for the VRPSPD were obtained. The number of express voyages was reduced to only one for both the OSP and VRPSPD models. On top of this, potential savings of 12.5% of the charter costs stemming from the reduction in fleet size from eight to seven vessels are not accounted for in Table 1. This suggests that the initial focus for the logistics provider should be on the warehouse and land transportation to reduce the amount of no-shows.

5 Concluding Remarks

We have applied the Vessel Routing Problem with Selective Pickups and Deliveries (VRPSPD) and the Order Selection Problem (OSP) on a real logistics planning problem from offshore oil and gas supply logistics and suggested some strategic improvements. This was comprehensively tested in a simulated rolling horizon over a full year of operation based on historical data. The settings tested showed that savings of over 8% would be attainable by leaving the fixed route policy without having a large impact on the level of service provided, and still maintain the original scheduled departures and corresponding platform visits. However, doing this will lead to an decrease in the regularity as seen from the platforms. In addition, strategies for overbooking were found to be useful in reducing the overall cost up on to a certain point where the trade-off between the increased vessel utilization on the regular voyages was offset by the increase in express voyages. Relaxing the delay requirements was also analyzed and found to have a savings potential although at the cost of increased number of order delays. Lastly, an estimate of the cost of no-shows in the system was provided and potential savings of over 4% under the current planning and over 11% when using the VRPSPD could be attainable by improving the logistics and information systems.

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