Offshore Wet Bulk Logistics

Maritime Pickup and Delivery Routing of Bulk Cargo

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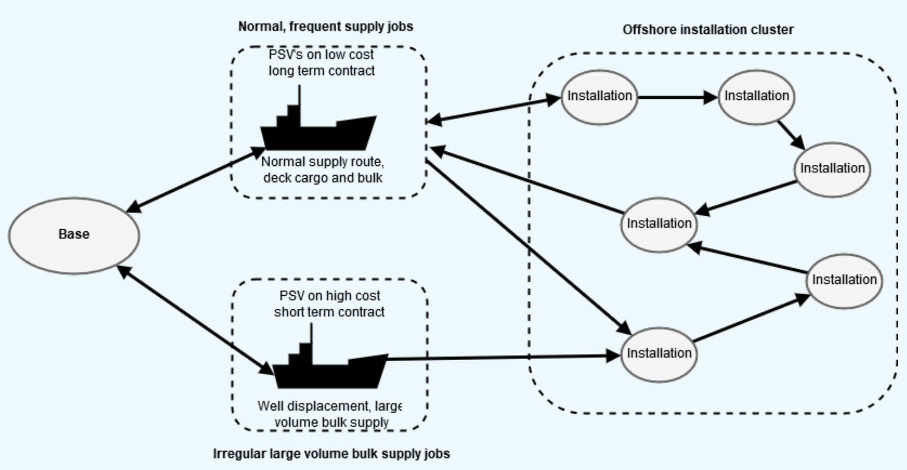
Introduction

An offshore installation's demand for wet bulk increases as a petroleum reservoir matures. Especially brine and chemicals are required to uphold the petroleum production. Platform supply vessels (PSV) transports the wet bulk out to the installations from onshore supply bases on pre-scheduled routes. When large or unexpected cargoes are required at the installations, the transport is often given to PSVs on the spot market at a high cost. This practice is due to insufficient wet bulk capacity on many PSVs in today's pre-scheduled fleet. As many reservoirs in the North Sea are old, the demand for wet bulk will increase further, and such incidents occur more often.

Objective and Scope of Work

The objective of this thesis is to investigate the effects of routing PSVs according to wet bulk demand with different tank configurations. Using an optimisation-based approach, a Maritime Pickup and Delivery Problem (MPDP) is constructed. A mixed integer problem (MIP) -solver provides the route which gives minimum waiting time on the offshore installations.

Current System



Mathematical Formulation

Objective function

$$minimise \quad z = \sum_{i \in N^C} y_i$$

Subject to the following constraints

$$\sum_{j \in N \setminus \{d\}} x_{oj} = 1$$

$$\sum_{i \in N^C} x_{ij} - \sum_{i \in N^C} x_{ji} = 0, \qquad j \in N^C$$

$$\sum_{i \in N \setminus \{o\}} x_{id} = 1$$

$$\sum_{j \in N} x_{ij} = 1, \qquad i \in N$$

$$x_{ij}(t_i + T^S_{ij} - t_j) \leq 0, \qquad (i,j) \in A$$

$$t_i - t_0 \geq 0, \qquad i \in N$$

$$t_N - t_i \geq 0, \qquad i \in N$$

$$t_i - D_i - y_i = 0, \qquad i \in N^C$$

$$x_{ij}(l_{is1} - Q_{js} - l_{js1}) = 0, \qquad i \in N \setminus \{d\}, j \in N^D, s \in$$

$$x_{ij}(l_{is2} - Q_{js} - l_{js2}) = 0, \qquad i \in N \setminus \{d\}, j \in N^P, s \in$$

$$x_{ij}(l_{is1} - l_{js1}) = 0, \qquad i \in N \setminus \{d\}, j \in N^P, s \in$$

$$x_{ij}(l_{is2} - l_{js2}) = 0, \qquad i \in N \setminus \{d\}, j \in N^D, s \in$$

$$h_{isc} - \frac{l_{isc}}{H^{CAP}} \geq 0, \qquad i \in N, s \in S, c \in C$$

$$\sum_{s \in S} \sum_{c \in C} h_{isc} \leq H, \qquad i \in N$$

$$x_{ij} = 1, \qquad S_{ij} = 0, i \in N_P, j \in N_D$$

$$x_{ij} = 0, \qquad S_{ij} = 0, i \in N_D, j \in N_P$$

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

$$h_{isc} \in \{0,1,...,H\}, \qquad i \in N, s \in S, c \in C$$

$$t_i \geq 0, \qquad i \in N$$

$$l_{isc} \geq 0, \qquad i \in N, s \in S, c \in C$$

$$y_i \geq 0, \qquad i \in N^C$$

Description

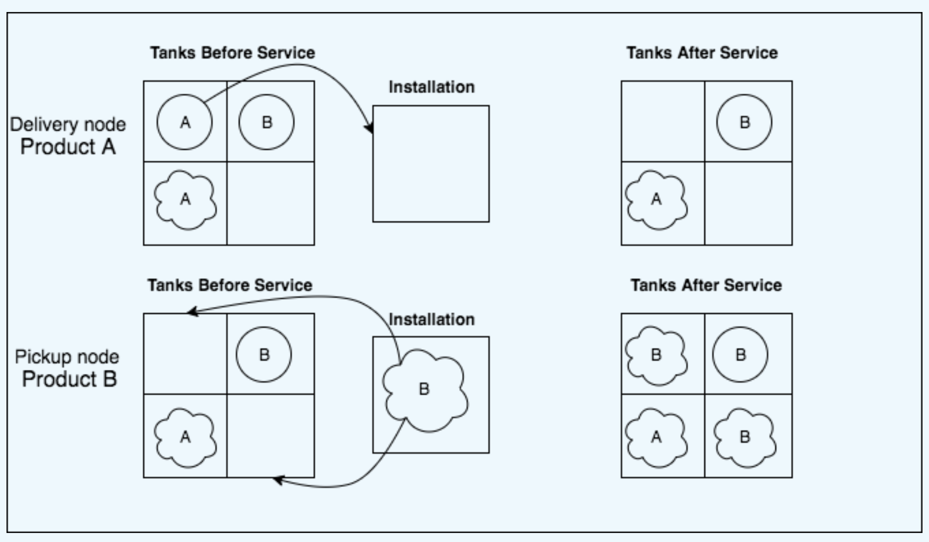
The problem is defined on an undirected graph $G =$ (N, A), where $N = \{0,1,..,n+1\}$ with indices i and j is the set of nodes, and $A =$ (i, j) is the set of all feasible arcs in the network. $N^C = \{1,2,...,n\}$ are the cargoes that are to be served in the network, which are divided into pickup cargoes $N^P \subset N$ and delivery cargoes $N^D \subset N$. Delivery cargoes are cargoes that the vessel *delivers* to a node, while pickup cargoes are cargoes that the vessel *picks up* from a node. Origin- and destination nodes o=0 and d=n+1 represents the same physical location. The cargoes are from different suppliers $S = \{0,1,...,k\}$ indexed by s, and have two conditions $C = \{clean, dirty\}$, or $\{1, 2\}$, indexed by c. Every cargo is described by Q_{is} which represents the amount of cargo from supplier s, and its node i. The initial load condition on the vessel is set as the sum of all delivery cargoes, thus let $L_{0s1} = \sum_{i \in N^P} Q_{is}$. The time the demand occurs at a node is denoted by D_i. Between all nodes there are sailing times S_{ij}. And the loading/unloading time for cargo i is determined by a rate R, which gives $U_i = \frac{\sum_{s \in S} Q_{is}}{R}$, where U_i is the loading/unloading time of cargo i.

Thus the time between two nodes is defined by letting $T_{ij} = U_i + E_i + S_{ij}$, where E_i is the time when leaving node i. The vessel's capacity is denoted by V^{CAP}. There are H number of tanks on the vessel of equal size, which is set to H^{CAP}.
The model is routing a vessel with binary variable x_{ij} equal to 1 if the vessel sails directly from node i to j. The time variable t_i determines the time before service in node $i \in$ N$\setminus$ d. Load variable l_{isc} keeps track of the load of condition c from supplier s after service in node i. h_{isc} is a variable that counts the number of tanks which are occupied in node $i \in$ N of cargo from supplier s in condition c. y_i is a time variable with the time between the demand occurs at node $i \in N^C$, and the time the vessel starts servicing it.

Problem Characteristics

The problem is restricted by several aspects, with the most significant listed and illustrated below.

- Wet bulk capacity on PSVs
- Do not mix different products
- Do not mix same product from different suppliers
- Costly operations rely on deliveries on time



Due to environmental legislations, products containing oil must be transported back onshore from the offshore installations to be recycled. Produced water and drilling mud are the main products that are brought back to base. The figure above shows how a tank configuration can manage its load when servicing two installations:

1. Product A is produced water and product B is drilling mud. Circular products are clean and cloudy products are dirty. First installation requires delivery of clean produced water, while second installation requires pickup of dirty drilling mud.
2. PSV delivers clean produced water and gains an empty tank.
3. PSV picks up dirty drilling mud equivalent to 1.5 tank size, which must be assigned to two tanks. The half full tank can now only contain dirty drilling mud from the same supplier.

This is treated in the mathematical model by letting the number of tanks assigned to a certain load type, h_{isc}, take a value equal to or higher than the required amount of tanks to keep the necessary products separated. The number of occupied tanks $\sum_{s \in S} \sum_{c \in C} h_{isc}$ can not exceed the amount of tanks on the PSV.

Results

The results presented in this thesis will contribute to the discussion regarding solutions for offshore wet bulk logistics. Is there a better way for the industry to manage their wet bulk demand which also is more cost effective for the offshore operators? Can suppliers who allow mixing their product with products from other suppliers experience a competitive advantage? Stay tuned, the results are yet to come.

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