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Optimization model aimed for the aquaculture industry for fleet composition and routing of wellboats

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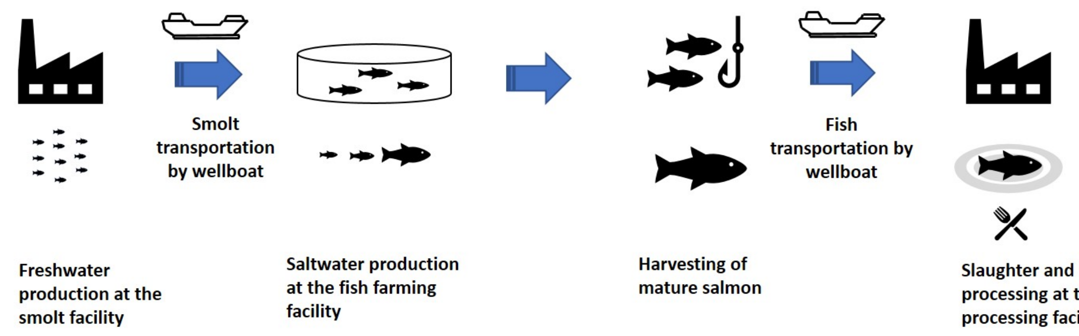
INTRODUCTION

The Norwegian aquaculture industry is continuously seeking further growth, and aims to almost fivefold today's salmon production within the year of 2050. In order to obtain such a strong expansion of the industry, Norway is today faced with multiple challenges. All depending on how these challenges are met and possibly solved, and the future development of the industry, a corresponding demand for wellboat operations is required. Stricter wellboat regulations, together with the possible future production volumes and tasks, are important aspects when evaluating the future size and composition of the fleet of wellboats. The underlying routing decisions are equally essential in order to enhance the fleet utilization. An optimization model aimed for this industry could be of high value as a decision making support tool to make and evaluate decisions regarding fleet composition and routing of wellboats in relation to the transportation demands and requirements.

Objective and Scope of Work: The main objective of this thesis is to propose an optimization model, which can be used for fleet composition and routing of wellboats in the aquaculture industry. The model shall be implemented in a commercial solver to test its performance and its applicability to solve real-life problems.

PROBLEM DESCRIPTION

The planning problem originates from the necessity to transport smolt out to the farming locations, harvest and transport the salmon to the processing facilities, as well as assisting the industry with lice treatment. The problem consists of several participants, including the farming locations, the smolt and processing facilities and a home port as a base for the wellboats. Between these facilities, wellboats of different sizes are used to execute the different operational tasks. Based on this size selection, an optimal combination of different sized wellboats can be obtained in order to meet the demand.



MATHEMATICAL MODEL

Sets and indices: Let N^T = {1,2....,n} be set of tasks indexed by *i*, and let N = {0,1,....,n+1} be the set of nodes also indexed by *i*. Task *i* is represented as a node which includes both the loading and the unloading locations of task *i*. This is illustrated in Figure **??**, where the loading and unloading locations of the different tasks *i* are assigned geographical nodes and are connected through a distance matrix in Excel. The geographical nodes are to be separated completely from the nodes mentioned in this model. Further, let V = {1,....,v} be the set of vessel types in the fleet indexed by *v*. o and d are two artificial nodes indexed by *v*, representing the origin and destination nodes of vessel type *v*, respectively. If a vessel is not used, then the vessel will go directly from $o(v)$ to $d(v)$. The number of tasks is *n*, while the total number of nodes is *n+2*, including both artificial nodes *i*=0 and *i*=n+1. The set and indices are summarized below.

Parameters: Let T_{ijv} represent the calculated operation time for vessel type *v* from arrival at the loading location for task *i* until the arrival at the loading location for task *j*. This parameter includes the sum of the time spent by vessel type *v* loading and unloading the demand at task *i*, the transit time between the geographical nodes related to task *i*, and transit time from the unloading location of task *i* to the loading location of task *j*. Also included in this time parameter is the time addition due to washing and disinfection when switching between different type of tasks. A time addition will also be included if it is found necessary to sail back to home base for refill of chemicals in relation to lice treatment. Let [T_{iv}^{MIN}, T_{iv}^{MAX}] denote the time window associated with the loading location of task *i*, related to all vessel types *v*. The parameter T_i^{MIN} represents the earliest time for start of service, while T_i^{MAX} is the latest time. If wanted, it is possible to change the number of each vessel type *v* to be included in the fleet of wellboats. The number of available vessels of vessel type *v* is given by V_v^A. The cost parameter denoted as C_{ijv} represent all the possible costs that are related to the operation of vessel type *v* between the tasks *i* and *j*.

Decision variables: In the mathematical formulation, the binary flow variable x_{ijv} determines which type of vessel services a particular task. The variable is equal to 1 if vessel type *v* services task *i* just before task *j*, and 0 otherwise. The time variable t_{iv} represents the time at which the service begins at the loading location of task *i* with vessel type *v*.

Objective function

$$minimize \quad z = \sum_{i\in N}\sum_{j\in N}\sum_{v\in V} C_{ijv}x_{ijv} \tag{1}$$

s.t.

$$\sum_{v\in V}\sum_{j\in N} x_{ijv} = 1, \qquad i \in N \tag{2}$$

$$\sum_{j\in N\setminus\{d(v)\}} x_{o(v)jv} = 1, \qquad v \in V \tag{3}$$

$$\sum_{i\in N} x_{ijv} - \sum_{i\in N} x_{jiv} = 0, \qquad j \in N\setminus\{o(v), d(v)\}, v \in V \tag{4}$$

$$\sum_{i\in N\setminus\{o(v)\}} x_{id(v)} = 1, \qquad v \in V \tag{5}$$

$$x_{ijv}(t_{iv} + T_{ijv} - t_{jv}) \leq 0, \qquad v \in V \tag{6}$$

$$T_{iv}^{MIN} - t_{iv} \leq 0, \qquad i \in N, v \in V \tag{7}$$

$$T_{iv}^{MAX} - t_{iv} \geq 0, \qquad i \in N, v \in V \tag{8}$$

$$x_{ijv} \in \{0,1\}, \qquad (i,j) \in N, v \in V \tag{9}$$

$$t_{iv} \geq 0, \qquad i \in N, v \in V \tag{10}$$

The objective function

The objective function (1) minimizes the costs related to operation of the available fleet of wellboats. This function only consists of one term, having gathered all the related costs into this term through calculations in Excel. The term multiplies all the included flow variables x_{ijv} by the associated cost coefficients, and sums it up to a value to be minimized.

The restrictions

Constraints (2) ensure that all tasks are serviced, while constraints (3)-(5) describe the flow along the sailing route used by vessel type *v*. Constraints (4) ensure node balance by requiring that all arcs in towards a node, also must leave this node. This accounts for all nodes except the artificial nodes $o(v)$ and $d(v)$. Constraints (3) ensure that vessel type *v* only services and leaves the artificial origin node once, while constraints (5) ensure that vessel type *v* only arrives and services the artificial destination node once. Constraints (6) describe the compatibility between routes and schedules. These constraints ensure that the time when arriving at task *j* must be greater or equal to the time the service starts at the previous task *i*, plus the time it takes to complete the service and then get from the the unloading location of task *i* to the loading location of task *j* with vessel type *v*.

The time-window constraints are given by constraints (7) and (8). The starting time t_{0v} for each vessel type *v* is set equal to zero. Finally, the mathematical formulation involves binary requirements on the flow variables (9), as well as non-negativity constraints for the time variables (10).

Not all constraints are listed and used directly in the model, but handled in the pre-processing phase in Excel. This accounts for the constraints regarding sufficient capacity of vessel type *v* to service the demand at task *i*. If applied directly in this model, a new variable had to be introduced controlling the amount of cargo onboard the vessel, and constraints requiring that the demand is no greater than the capacity.

RESULTS

The model will be tested with different demand scenarios and running of the model in the commercial software Mosel Xpress Optimizer. The results gives an indication of the applicability of the model.

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