A Variable Neighborhood Search Heuristic for Ship Scheduling

A Computational Study

Geir Brønmo*

Marielle Christiansen* Kjetil Fagerholt† Bjørn Nygreen*

*Section of Managerial Economics and Operations Research
Norwegian University of Science and Technology
N-7491 Trondheim, Norway
geir.bronmo@iot.ntnu.no

† Department of Marine Technology
Norwegian University of Science and Technology, Trondheim
and Pipelife Norway ASA, Surnadal, Norway

1 Introduction

In the last couple of decades we have witnessed a hard competition between shipping companies, where the profit margins are squeezed to a minimum. This means that it becomes harder to determine a good fleet schedule by simple planning methods. Further, the increasing competition in the shipping industry forces the companies to manage their fleet efficiently, simply to remain in business. These issues are some of the reasons for an increased need for optimization-based decision-support systems within ship scheduling, and this need will probably continue to increase in the future. In (Christiansen, Fagerholt and Ronen, 2004), some more explanations are given for the accelerating needs for and benefits from such systems.

The purpose of this paper is to present a heuristic method for a ship scheduling problem. The heuristic is a search method with variable neighborhoods. We compare the heuristic with a Set Partitioning method regarding computation time and solution quality. Decision-support tools for the tramp market are highly demanded, and this study will contribute in analyzing if a routing and scheduling tool based on the proposed approaches is valuable for the tramp shipping industry.

2 Problem description

The studied short-term ship scheduling problem for the tramp market corresponds to a pickup and delivery of bulk cargoes at maximum profit. A tramp shipping company often engages in *Contracts of Affreightment (COA)*. These are contracts to carry specified quantities of cargo between specified ports within a specific time frame for an agreed payment per ton. In addition, a tramp shipping company may take optional cargoes that will be picked up at a given loading port and delivered to a corresponding unloading port if the shipping company finds it profitable. A port can be visited several times by the same ship each planning period. One such visit is called a port call. Each cargo further consists of a specified quantity and a time window for the loading – and sometimes for the unloading - of the cargo. The revenue of carrying a cargo is normally the cargo quantity multiplied by a revenue rate.

Often, the ship capacities, the cargo type and quantities are such that the ships may carry multiple cargoes simultaneously. This means that a new loading port can still be visited with some cargoes onboard. We assume that the cargoes can be loaded onboard irrespective of the type of product already onboard.

The shipping company in the tramp market operates a heterogeneous fleet of ships with specific ship characteristics including different cost structures and load capacities. We are concerned with the operations of a given number of ships within the planning horizon. The fixed costs can be disregarded as they have no influence on the planning of optimal routes and schedules. The ships are charged port and channel tolls when visiting ports and passing channels and these costs depend on the size of the ship. The remaining variable sailing costs consist mainly of fuel and diesel oil costs, and depend usually on the ship size. Normally, tramp shipping companies seek to maximize the profit of their activity, so we use this objective when optimizing the ship schedules. A general mathematical programming model for ship scheduling problems corresponds to a multi vehicle pick-up and delivery problem with time windows, where the profit is maximized and some requests are optional.

3 A search Heuristic with multiple Neighborhoods

This section describes a neighborhood search heuristic for the ship scheduling problem described in the previous section. The heuristic is two-phased. First initial solutions are constructed by an insertion method. The resulting solutions are then improved by a neighborhood search. The search explores six different neighborhoods with user specified frequencies.

The insertion method has been used in several versions in other applications with some similarities to our ship scheduling problem. In (Madsen et al., 1995), it was applied on a Dial-A-Ride-Problem with Time Windows. The cargoes are sorted, and each cargo is processed in turn. The optimal insertion is found, given that the sequence of port calls from the cargoes already inserted is fixed. The insertion method is run three times with different initial sorting of the cargoes, to provide different starting points for the local search. The three sorting criteria are:

- time, i.e. increasingly by pick-up time window start
- quantity, decreasingly
- priority, here the cargoes are divided into two groups by quantity and each group is sorted by time

Local search variants are often seen in solving scheduling problems. In (Potvin and Rousseau, 1995) a hybrid local search algorithm is used for routing problems in general. (Toth and Vigo, 1997) present a tabu search method on solving the handicapped persons transportation problem, which is a special case of the Dial-A-Ride problem**.** Aldaihani and Dessouky (2003) and Cordeau and Laporte (2003) present tabu search heuristics, while Jung and Haghani (2000) present a genetic algorithm for the Dial-A-Ride problem. The Dial-A-Ride problem and the ship scheduling model presented in Section 2 are variants of the multi vehicle pickup and delivery problem with time windows (m-PDPTW). Nanry and Barnes (2000) present a reactive tabu search algorithm for the m-PDPTW.

Local search variants that are seen in the literature often combine relatively simple local search neighborhoods with some kind of mechanism to escape from local optima, for instance tabu search. Our approach is different. We use more complex neighborhoods, and to increase efficiency it is necessary to split the neighborhood and assign lower frequencies to the most complex ones. The search neighbourhood is a union of six different neighbourhoods that is a collection of *intra-route* and *inter-route* operators. The intra-route operators try to improve the schedule of one ship, while the inter-route operators look for improvements by moving cargoes between two or more ships. In one neighbourhood *round* all possible passes are tested and one or more improving feasible passes are chosen. Each neighborhood is assigned a user-specified frequency, so that computationally complex neighborhoods are performed less often than those less complex.

The resequence neighborhood. Here, one cargo is removed from the schedule of its ship. The cargo is then re-inserted in the schedule of the same ship at the best possible place, by considering all feasible insertions without altering the sequence of the other visits in the schedule.

The resequence two neighborhood. Two cargoes are removed from the schedule of one ship, and are then re-inserted into the schedule the best possible place.

The reassign neighborhood. One cargo is removed from the schedule of its original ship. Then the best insertion to each of the other ships is found. The cargo is then assigned to the ship that gave the best feasible insertion.

The interchange neighborhood. Two cargoes assigned to different ships are removed from the schedule. The two cargoes interchange ships, and the best insertion is found.

The triangle interchange neighborhood. Three cargoes are assigned to different ships. The three cargoes interchange ships, and the best insertion is found.

The reassign rejected neighborhood. This neighborhood is only activated if there is one or more rejected cargoes in the cargo list, i.e. cargoes for which the algorithm has not found any feasible insertion so far. One cargo is removed from the schedule of its ship. Then one *rejected* cargo is inserted into the schedule of the given ship. Then the best insertion of the removed cargo to each of the othter ships is found. The cargo is then assigned to the ship that gave the best feasible insertion.

The search is run completely for each start solution, and finally the best solution found is chosen.

4 Set Partitioning method

The problem presented in Section 2 can be solved by use of standard commercial optimization software for mixed integer linear programming. Due to its complexity, only small sized data instances can be solved to optimality. In order to establish real-life benchmarks for the heuristic, the model is formulated as a Set Partitioning problem instead with columns corresponding to feasible ship schedules. This is a solution approach that has been widely used for solving ship scheduling problems, see for instance (Brown et al., 1987) and (Christiansen and Fagerholt, 2002).

Here, the optimal schedule for all cargo combinations is generated a priori. The resulting Set Partitioning model is solved by standard commercial optimization software.

5 Computational results

The computational study was performed on seven test cases from the tramp shipping industry. The data are collected from four different shipping companies, and represent a great variety in size and complexity. The computational results are shown in the following table:

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Planning horizon in days	23	90	75	75	150	20	35
# of cargoes	18	66	9	17	50	30	15
# of ships	6	3	3	6	13	13	4
Column generation CPU (sec.)	6482	-	<1	9300	-	235	454
Set Part Running CPU (sec.)	5	-	<1	<1	-	91	4
Optimality gap (%)	0	-	1.42	1.93	-	0.48	0.22
Heur Running time (sec.)	6.1	1919	9	1.1	55	23.3	3.6

For five of the cases an optimal solution was found by the Set Partitioning method, and for all cases the heuristic was run several times with different parametrical settings. From the table it can be seen that the heuristic presents near optimal solutions. For Case 1, the heuristic found the optimal solution. The heuristic uses a very small amount of computation time compared with the Set Partitioning method, and hence it can be used to find good solutions to larger problems.

6 Conclusion

In this paper we have presented a heuristic for solving tramp ship scheduling problems. The heuristic is a local search based method where neighborhoods have different frequencies, and is implemented in the commercial decision support system TurboRouter described by Fagerholt (2002). In the computational study the heuristic is compared with a Set Partitioning method. The results show that the heuristic gives quick response, and provides near-optimal solutions for the cases that could be solved by the optimization method. Hence a decision support system based on the proposed heuristic can be a valuable tool for planners in the shipping industry.

References

M. Aldaihani and M. M. Dessouky, “Hybrid scheduling methods for paratransit operations”, *Computers & Industrial Engineering* 45, 75-96 (2003).

G. G. Brown, G. W. Graves and D. Ronen, “Scheduling ocean transportation of crude oil”, *Management Science* 33(3), 335-346 (1987).

M. Christiansen and K. Fagerholt, “Robust ship scheduling with multiple time windows”, *Naval Research Logistics* 49(6), 611-625 (2002).

M. Christiansen, K. Fagerholt and D. Ronen, “Ship Routing and Scheduling: Status and Perspectives”, *Transportation Science* 38(1), 1-18 (2004).

J.-F. Cordeau and G. Laporte, “A tabu search heuristic for the static multi-vehicle dial-a-ride problem”, *Transportation Research Part B* 37, 579-594 (2003).

K. Fagerholt, “A computer-based decision support system for vessel fleet scheduling - Experience and future research”, *Decision Support Systems* 37(1), 35-47 (2004).

S. Jung and A. Haghani, “Genetic algorithm for a pickup and delivery problem with time windows”, *Transportation Research Record* 1733, 1-7 (2000).

O. Madsen, H. Ravn and J.M. Rygaard, “A heuristic algorithm for a dial-a-ride problem with time windows, multiple capacities, and multiple objectives”, *Annals of Operations Research* 60, 193-208 (1995).

W.P. Nanry and J.W. Barnes, “Solving the pickup and delivery problem with time windows using reactive tabu search”, *Transportation Research Part B* 34, 107-121 (2000).

J.-Y. Potvin and J.M. Rousseau, “An exchange heuristic for routeing problems with time windows”, *Journal of the Operational Research Society* 46, 1433-1446 (1995).

P. Toth and D. Vigo, “Heuristic algorithms for the handicapped persons transportation problem”, *Transportation Science* 31(1), 60-71 (1997).