Project 2019-110, DTU Management, Collaborative Berth Planning in Liner Shipping ("CoPlan")

Final Report

The aim of the project was to identify the optimization potential of collaborative berth planning. Initially the project was planned as a 2-year period postdoc project. Thanks to the co-financing of the DTU Management department of DTU, the Danish Maritime Fond allowed the project to be extended to a 3-year PhD project.

On the 1st of December 2019 the CoPlan project kick started by the employment of Bernardo Martin Iradi as PhD student at DTU Management, under the supervision of Assoc. Prof. Dario Pacino and Prof. Stefan Røpke.

Identification of core feature

The project's initial task was a survey of the currently available literature. During the first phase of the project, meetings were held with PORTCHAIN (terminal digital service company), to identify the key components that a study should have to be of industrial relevance. The following components were identified as essential:

- berthing time of the vessels
- expected departure times
- berthing positions
- vessels' speed between port calls
- operating costs
- delay costs.

The literature survey identified the work of Venturini et al. (2017) as the only work that studied berth allocation planning over multiple ports; the so-called Multi-Port Berth Allocation Problem (MBAP). The classic Berth Allocation Problem (BAP) is the identification of berthing time and position for container vessels on a terminal. The planning problem is calculated over a period of several weeks. The MBAP extends this planning by including multiple terminals.

The work of Venturini et al. (2017) has demonstrated that the integrated planning of multiple terminals can result in a reduction of CO2 emissions, as vessels can better plan the sailing speeds between terminals, since berthing time are no longer restricted to specific time slots.

The discussion with PORTCHAIN, identified the need to better advocate the motivation for having such planning tools. A natural question that was raised was: "Since this planning methodology requires collaboration between terminals and carriers, will all the parties involved benefit from the collaboration?".

Analysis of the cooperation advantages

To answer the question from PORTCHAIN, a game theoretical approach was used. The first step was the implementation of a solution method that could find optimal solutions to the MBAP. The method published in Venturini et al. (2017) was not efficient enough to guarantee optimal solutions. A branch & price algorithm was developed. The algorithm was able to find optimal solutions to all relevant data instances and was thus a feasible approach for the game theoretical analysis.

The planning tool was tested with 3 types of coalitions: carriers only, terminals only, and a grand coalition of both carriers and terminals. The analysis shows that cost savings cannot be achieved unless both terminals and carriers collaborate. Hence a grand coalition is required.

Once a grand coalition is in place, cost savings need to be distributed among the partners of the coalition. We tested the system using two cost sharing methods: Equal Profit Method (EPM) and using Shapley values. The EPM minimizes the difference between the cost savings that each partner gets, while using the Shapely value we aim at giving cost savings proportional to the effort (e.g. changes in sailing speed) that each partner has put into the coalition. In both cases, it always pays off to be part of the coalition. In other words, standing outside of the coalition will be more costly.

The solution approach and the game theory analysis have been published in the INFORMS journal: Transportation Science, which is one of the very top journals in the field of transport optimization (Martin-Iradi et al., 2022a).

Extension to realistic problems

The MBAP definition used for the game theory analysis assumed fixed berthing positions. In such a case, the quay of a terminal is divided into discrete segments, each of which can hold one vessel. Though such a simplification is valid for general analysis, a more operational version of the planning tool needs to be more detailed.

The second phase of the project focused on relaxing this assumption, and thus effectively allowing the planning of vessel berthing anywhere on the quay.

The first line of work was the extension of the exact method previously developed. The introduction of a continuous berth space, however, has drastically increased the computational complexity of the planning problem. Thought several attempts were made, we were only able to provide solutions for small scale problems. The results of this study have been published in Martin-Iradi et al. (2022b).

To solve industrial scale instances, we moved our focus from mathematical modelling to customized heuristic algorithms. We developed an Adaptive Large Neighborhood Search (ALNS). This framework relies on an iterative destruction and re-construction principle that, given an initial solution, gradually improves its quality. Moreover, we also developed an alternative mathematical modelling formulation that could solve bigger problems than previously. Though an improvement, the mathematical model was not able to solve the large-scale instances. The model was, however, useful to validate the high-quality performance of the ALNS. A detailed description of the model, the algorithm, and the results has been published in Martin-Iradi et al. (2024).

Conclusions

The CoPlan project has successfully demonstrated that collaboration between terminals and carriers, when planning the berth scheduling of vessels, can result in cost savings. The question remains as to what form of collaboration is the best suited, the most likely to succeed and be accepted by all parties.

Companies such as PORTCHAIN could be seen as the impartial orchestrators of such collaborations. Other possibilities arise in companies such as Mærsk who own both vessels and terminals.

The project resulted in 3 international scientific journal publications. Furthermore, ongoing work, experimental results, and solution methods have been presented in several international conferences:

- 11th Triennial Symposium on Transportation Analysis
- 13th International Conference on Computational Logistics
- 32nd European Conference on Operational Research
- INFORMS Annual Meeting 2021
- 31st European Conference on Operational Research
- 5th AIRO Young Workshop
- 12th International Conference in Computational Logistics

The project has also contributed to the research field with two novel sets of data instances, which, it is our hope, will inspire more research in this area.

The PhD student Bernardo Martin-Iradi has completed his studies and successfully defended his thesis titled “Integration and collaboration in maritime logistics and other transportation areas” on the 14th of April 2023. As the thesis was deemed of high quality, it is now under consideration for the EDDA award. The EDDA award is given by the European Operational Research society (EURO) to the best PhD thesis in operations research.

Overall, we consider the CoPlan project to have been a success.

References

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