Large Scale Robust Optimization of Bulk Port Operations

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1. Introduction

Maritime transportation is a major channel of international sea trade which has increased significantly over the past few decades. The proper planning and management of port operations in view of the ever growing demand represents a big challenge. From the past research, it is well established that operations research methods and techniques can be successfully used to optimize port operations and enhance terminal efficiency. While significant contributions have been made in the field of container terminal management, almost no attention has been directed to bulk port operations. A key difference between bulk ports and container terminals is that it is necessary to explicitly account for the cargo type on the vessels in bulk terminals. In a container terminal, all cargo is packed into containers, and thus there is no need for any specialized equipment to handle any particular type of cargo. In contrast in bulk ports, depending on the vessel requirements and cargo properties, a wide variety of equipment is used for discharging or loading operations. For example, liquid bulk is generally discharged using pipelines which are installed at only certain sections along the quay. Similarly, a vessel may require the conveyor facility to load cargo from a nearby factory outlet to the vessel.

To our knowledge, large scale operations research problems have not been investigated thus far in the context of bulk port terminals. Moreover in general, literature on robust optimization algorithms in context of port operations and dynamic algorithms to optimize port operations in real time is also relatively scarce. In this work, we present two exact solution approaches and a heuristic approach to model and solve the dynamic, hybrid berth allocation problem (BAP) in bulk port terminals that explicitly take into account the cargo type on the vessel. Results inspired by real port data show that the problem is complex and general purpose solvers fail to produce good solutions as soon as the problem size increases. The exact solution approach based on generalized set partitioning and the heuristic approach based on the principle of squeaky wheel optimization significantly outperform the mixed integer programming approach and can be used to obtain near-optimal solutions of larger instances. We have also developed a robust berth scheduling algorithm that makes our berth allocation model for bulk ports more robust by using a dynamic recovery algorithm that solves the BAP in real time. Furthermore, we have formulated a mixed integer programming model for the integrated berth allocation and yard assignment in bulk ports. The model is implemented and solved using an exact solution algorithm based on column generation in which the master problem is formulated as a set-partitioning model.

2. Research Objectives

Integrated planning of port operations and robust solutions can help reduce congestion, lower delay costs and enhance efficiency of bulk port terminals. In particular, we focus on two crucial optimization problems of *Berth Allocation* and *Yard Assignment*. To our knowledge, these problems have not been investigated thus far in the context of bulk port terminals. On the one hand, we aim to identify similarities, and understand to what extent existing models on container terminals can be extended to bulk ports; on the other hand, our objective is to identify specific issues and bottlenecks for bulk terminal operations and devise specific solutions for bulk ports.

The main objectives of this research are two-fold. One, is to perform a comparitivie analysis between hierarchial and integrated optimization approaches, and experimentally analyze the impact of integration in terms of quality of solution and added complexity in context of bulk ports. From the past OR literature on terminal operations, it can be seen that significant contribution has been made in the field of large scale optimization and integrated planning of operations in container terminals by Park and Kim (2003) [1], Meisel and Bierwirth (2006) [2], Giallombardo *et al.* (2010) [3] and few others.

The second objective is to study the potential benefits of robust solutions in planning operations, and the added value of robustness in terms of system reliability and cost reduction. In the context of container terminals, robust planning methods have been used by Gao *et al.* (2010) [4] by considering stochasticity in vessel arrivals and by Han *et al.*(2010) [5] by considering stochasticity in both vessel arrival times and handling times.

3. Results and Conclusions

The berth allocation problem in bulk ports has many similarities but also few differences with that in container terminals. The main point of difference is that it is necessary to account for the fixed specialized equipment facilities such as conveyors and pipelines in bulk ports. We have formulated and implemented three different formulations to solve the dynamic, hybrid BAP in bulk port terminals that explicitly take into account the cargo type on the vessel. Results inspired by port data show that the problem is complex. The exact solution approach based on mixed integer linear programming (MILP) fails to produce optimal results for even medium sized instances in the CPLEX time limit. We propose an alternate exact solution approach based on generalized set partitioning (GSPP) in which all feasible assignments for a given planning horizon are generated a priori by data pre-processing and provided as an input to the optimization model. Each feasible assignment represents the assignment of a single vessel to a specific set of sections as determined from the discretization of the quay and a specific time interval as determined from the handling time of the vessel which is dependent on the berthing location of the vessel along the quay. For example, if a vessel that needs the conveyor facility is assigned to a set of sections that does not have this facility, the handling time may be extremely large. The model was able to solve all tested instances containing upto 40 vessels and 30 sections along the quay to optimality. However, the growth in the number of variables and constraints in the GSPP model is very fast with increase in the instance size, and the CPLEX solver runs out of memory for very large instances. To obtain near-optimal solutions of large sized instances in reasonable time, we have proposed a heuristic approach based on the principle of squeaky wheel optimization. In the proposed heuristic, solutions are successively updated by identifying the weak performing vessels and allocating them to sections where the handling time of the vessel is minimized. For example, if a vessel is carrying coal, its handling time may be minimized if it is assigned to the set of sections which are at close physical proximity to the yard location where coal is stored. For the tested instances, the heuristic produces sub-optimal results with less than 16 percent gap with respect to GSPP solution, and in much less computation time for larger instances as compared to GSPP approach.

We have also developed a dynamic recovery algorithm to solve the berth allocation problem in real time for a given baseline berthing schedule. The main idea is to solve the deterministic BAP, and obtain the robust formulation of the problem, and compare their performance in terms of loss of revenue at the planning stage and recovery savings in the event of disruptions. From the preliminary results we have obtained, it is clear that robust berth scheduling can lead to potential savings in the long run.

We have further formulated a mixed integer linear programming model to account for the integrated planning of berth and yard space allocation. In addition to the berthing assignment of vessels along the quay, the assignment of cargo locations on the yard to specific cargo types and vessels are also decision variables in this model. These decisions concern the storage location and the routing of materials in bulk ports. Unlike in container terminals where all cargo is packed into containers, in bulk ports there are also additional constraints for two or more cargo types that cannot be stored at adjacent locations. We are currently working on implementing the model using column generation method. In our framework, the master problem is formulated as a set partitioning model where each column represents the feasible assignment of a single vessel to a specific set of sections for a specific time interval and specific assignment of yard locations to the vessel.

To the best of our knowledge, this is the first paper that deals with large scale operations research problems and robust planning methods in context of bulk ports. From the research work done so far, it can be concluded, that while there are many similarities between bulk ports and container terminal operations, there are also several points of difference which necessitate the need to devise solution algorithms specific to bulk ports.

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