INTEGRATED QUAY CRANE ASSIGNMENT AND SCHEDULING PROBLEM UNDER UNCERTAINTY: A REACTIVE APPROACH

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ABSTRACT - This study examines the integrated quay crane assignment and scheduling problem (QCASP) under uncertainty at container terminals. First, a mixed integer linear programming model is formulated to optimally assign and schedule quay cranes to multiple vessels simultaneously. The model derives a baseline schedule that minimises the cost of waiting and departure delays of vessels. However, different disruptions; delays in vessel arrivals and quay crane breakdowns may occur when implementing the baseline schedule. Therefore, a reactive strategy is formulated to generate a reactive reschedule that minimises delays from the baseline schedule when a disruption occurs. The reactive strategy takes the baseline schedule as a reference and derives the reactive schedule by rescheduling only quay cranes. Finally, the accuracy of the model is tested by running small-size problem instances.

Keywords: Container terminals; Quay crane assignment; Quay crane scheduling; Reactive strategy; Uncertainty

1. INTRODUCTION

Container terminals play a significant role in global containerized trade, and they can be defined as the main nodes responsible for connecting sea and land transportation. The average annual growth of containerized trade during 2024 and 2028 is predicted as over 3 percent [1]. Therefore, the optimization of container terminal operations can ensure the stability of global supply chains by streamlining the movement of goods across transportation networks and minimising delays. Quay Crane (QC) is the key equipment employed to perform the container loading and discharging operations of vessels and the performance of QC operations significantly affects the efficiency of the container terminal [2]. Quay Crane Assignment (QCA) and Quay Crane Scheduling (QCS) are the two main problems associated with the planning of QC operations and the decisions made when solving these problems are highly interrelated and have a significant impact on one another [3], [4]. Therefore, most of the recent studies have focused on integrated operations problems where two or more planning functions are connected [5]. Furthermore, the outcomes of operations problems are significantly impacted by uncertain parameters and uncertain events such as delays in vessel arrivals and QC breakdowns [6]. However, uncertainty has been rarely incorporated into the operations problems and there is a research gap in addressing integrated problems under uncertainty [5], [6]. Therefore, this study aims to fill this gap by proposing a reactive model to solve the integrated QCASP under uncertainty.

2. MATERIALS AND METHODS

A mixed integer linear programming (MILP) technique is used to develop a mathematical model to solve the integrated QCASP problem under uncertainty. The proposed conceptual framework to formulate the integrated model along with the reactive strategy is shown in Figure 1.

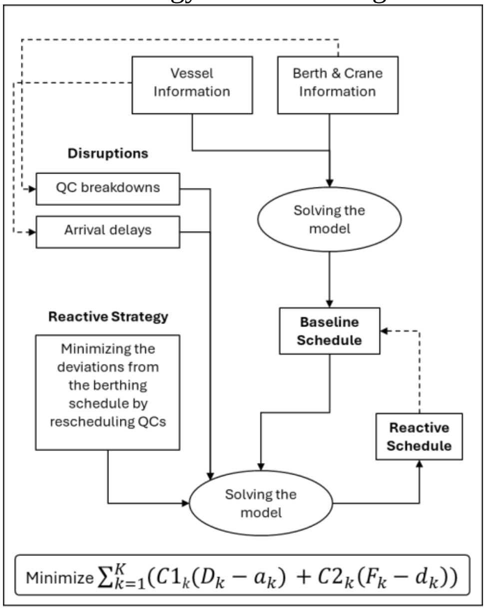

Figure 1. Conceptual framework

First, a MILP model which considers practical constraints such as the non-overlapping constraint and the safety distance between cranes is formulated to derive a baseline schedule. The baseline schedule contains a berthing schedule of vessels and a crane schedule that describes the sequence of tasks of QCs assigned to each vessel. This study assumes an approximated berthing schedule is determined in advance according to the service agreements between the terminal and shipping lines. The model uses this berthing schedule and vessel information as inputs and further, optimizes the berthing schedule by deriving the crane schedule by optimally assigning and scheduling QCs to multiple vessels simultaneously. The objective function of the model aims to minimize the total cost of waiting times and departure delays of vessels. To address the uncertainty, a reactive strategy is formulated to derive a reactive schedule when delays in vessel arrivals and QC breakdowns are realized at the time of implementation of the baseline schedule. The reactive strategy aims to generate a rescheduling plan that reduces deviations from the baseline berthing schedule after the realization of an uncertain event by only rescheduling QCs. Finally, numerical experiments for small-size problem instances are conducted to test the accuracy of the proposed model.

3. RESULTS AND DISCUSSION

The results of solving the model for a small-size problem instance are presented in Figure 2. In the small size problem instance, a total number of 6 vessels with 6 bays, 3 berthing positions and 7 QCs are considered and the minimum safety distance that should be maintained between two adjacent QCs is specified as 2 bays. The model has generated the optimal quay crane scheduling plan in a way that minimises the total cost of waiting and departure delays of vessels. As displayed in Figure 2, the specified safety distance is always maintained between adjacent QCs and the order of the QCs is maintained throughout the operation avoiding overlaps. Two uncertain scenarios; the breakdown of QC number 2 and the arrival delay of vessel number 2 are considered in the experiment. As shown in the figure, a reactive QC schedule is generated by rescheduling QCs to minimise the deviations of the baseline berthing schedule. Numerical experiments highlight the accuracy of the representation of practical constraints and the generation of optimal solutions for small-size problems. However, the applicability of the reactive strategy for large-size instances is yet to be analysed. This requires the combination of solution algorithms with the mathematical model to solve large-size instances.

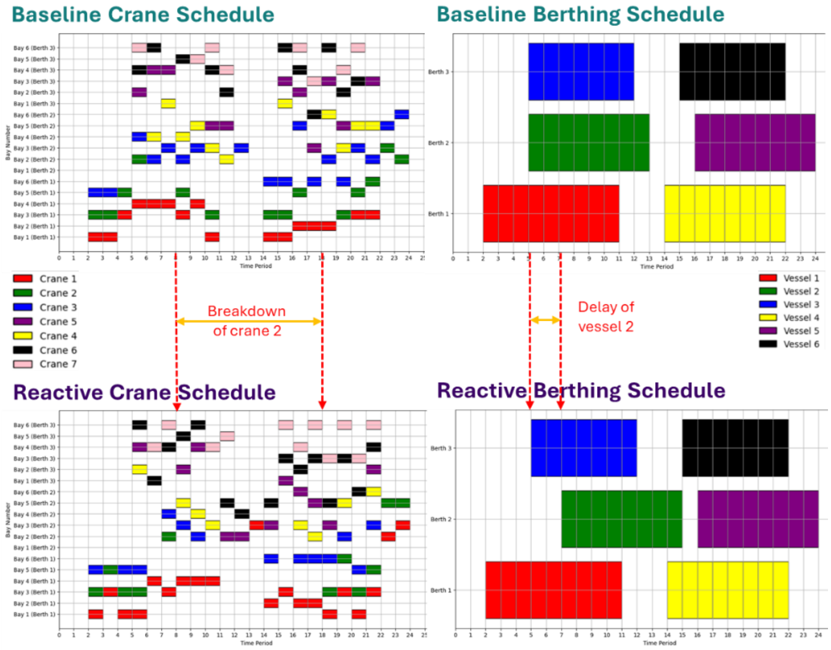

Figure 2. A numerical experiment of the problem

4. CONCLUSION

This study proposed a reactive approach to solve the integrated QCASP of container terminals under uncertainty. The significance of the study lies in solving the integrated model by incorporating practical constraints and using a reactive approach to deal with uncertainty. Future studies may focus on developing a solution algorithm using solution methods such as heuristics, metaheuristics or hybrid techniques to analyze the accuracy of the proposed model for large-scale problems.

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