Cyprus University of Technology

Faculty of Engineering and Technology

Doctoral Dissertation

COMPUTATIONAL INTELLIGENCE APPROACHES FOR OPTIMIZING SEASIDE OPERATIONS IN SMART PORTS

Sheraz Aslam

Limassol, October 2022

CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING, COMPUTER ENGINEERING AND INFORMATICS

Doctoral Dissertation

COMPUTATIONAL INTELLIGENCE APPROACHES FOR OPTIMIZING SEASIDE OPERATIONS IN SMART PORTS

Sheraz Aslam

Limassol, October 2022

Approval Form

Doctoral Dissertation

COMPUTATIONAL INTELLIGENCE APPROACHES FOR OPTIMIZING SEASIDE OPERATIONS IN SMART PORTS

Presented by

Sheraz Aslam

Supervisor: Herodotos Herodotou, Assistant Professor

Signature____

Member of the committee: Mikael Lind, Professor

Signature____

Member of the committee: Andreas Andreou, Professor

Signature____

Cyprus University of Technology

Limassol, October 2022

Copyrights

Acknowledgements

First and foremost, I would like to thank Allah Almighty for giving me the strength and confidence to complete this dissertation. Then, I would like to express my deepest appreciation to my research advisors Dr. Herodotos Herodotou and Michalis P. Michaelides for their continuous support throughout my my PhD. and related research. I believe that this dissertation could not have been completed without the support and encouragement of my supervisors. Also, thanks to the invaluable support and patience of Dr. Herodotou, I have become much more comfortable to the new environment. I am deeply indebted to him for his knowledge, thoughts and friendship.

I also gratefully acknowledge the support of the Cyprus University of Technology and the funding source that made my PhD. possible. I was funded by the STEAM project.

I would like to thank my parents and my wife Kainat Mustafa for their constant support, understanding and help whenever I needed it during my PhD studies and research work. I would also like to thank my brothers Shahzad Aslam and Shahbaz Aslam, and my loving sister Arshia Sana. I believe that without their motivation it is not possible to succeed in my life. I am always grateful to them for their encouragement and support.

Finally, I would also like to express my gratitude to my advisor during my Masters studies in COMSATS University Islamabad, Pakistan. He is now a good friend, Professor Dr. Nadeem Javaid. He was the mentor who set me on the research and academia path, and without his advice and support, my career decisions would have been very different.

Sheraz Aslam

Dedicated

To my Parrents Muhammad Aslam and Raj Baigum.

To my wife Kainat Mustafa and my daughter Aizal Fatima.

ABSTRACT

Over the last couple of decades, demand for seaborne containerized trade has increased significantly and it is expected to continue growing over the coming years. As an important node in the maritime industry, a marine container terminal (MCT) should be able to tackle the growing demand for international sea trade. The increasing number of ships and containers creates several challenges to MCTs, such as congestion, long waiting times before ships dock, delayed departures, and high service costs. The berth allocation problem (BAP) and the quay crane assignment problem (QCAP) are two of the most important optimization problems in container terminals at ports worldwide. A BAP concerns allocating berthing positions to arriving ships to reduce total service cost, waiting times, and delays in vessels' departures. The latter concerns assigning optimal number of quay cranes to docked vessels. From both the port operator's and the shipping lines' point of view, minimizing the time a vessel spends at berth and minimizing the total cost of berth operations are considered fundamental objectives with respect to terminal operations.

This dissertation initially focuses on the BAP, with the objective of reducing the total service cost, which includes waiting cost, handling cost, and several penalties, such as a penalty for late departure and a penalty for non-optimal berth allocation. First, the BAP is formulated as a mixed-integer linear programming (MILP) model. Since BAP is an NP-hard problem and cannot be solved by exact optimization methods in a reasonable time, a metaheuristic approach, namely, a cuckoo search algorithm (CSA), is proposed to solve the BAP. To validate the performance of the proposed CSA-based method, we use two benchmark approaches, namely, the genetic algorithm (GA) and the optimal MILP solution. Next, we conduct several experiments using a benchmark data set as well as a randomly-generated larger data set. Simulation results show that the proposed CSA algorithm has higher efficiency in allocating berths within a reasonable computation time than its counterparts.

Furthermore, we extend the study of BAP, which considers a single quay (straight line) for berthing ships, to multiple quays, as found in many ports around the globe. Multi-quay BAP (MQ-BAP) adds the additional dimension of assigning a preferred quay to each arriving ship, rather than just specifying the berthing position and time. Here, we address MQ-BAP with the objective of minimizing the total service cost, which includes minimizing the waiting times and delays in the departure of ships. MQ-BAP is first formulated as a MILP and then solved using three computational intelligence (CI)-based approaches, namely, CSA, GA, and particle swarm optimization (PSO). In addition, the exact MILP method is also implemented for comparison purposes. Several experiments are conducted using real data from the Port of Limassol, Cyprus, which has five quays serving commercial vessel traffic. The comparative analysis and experimental results show that the CSA-based method outperforms the other CI-based methods, while achieving near-optimal results in affordable time for all considered scenarios.

Eventually, this dissertation investigates, for the first time, multi-quay combined BAP and QCAP, and solves it using CI approaches. First, a mathematical model has been developed based on a real port scenario and real constraints. Then, based on the developed model, we solve multi quay combined BAP and QCAP using exact method and CI approaches, i.e., CSA, GA, and PSO. Validation and performance evaluation of the developed modeling framework and the proposed methods are performed through extensive experiments with real data. The real dataset is collected from the Port of Limassol, Cyprus. In addition, the dataset contains data for multiple quays (five), two of which are container terminals and the other three are passenger or general cargo terminals. The experimental results reveal that the exact method can solve the problem only when one week dataset is used; however, our newly adopted CI-based methods for MQ combined (BAP and QCAP) problem are able to solve large instances (i.e., one month) with small computation time.

To summarize, this dissertation develops several CI based methodologies for several BAP formulations (stand-alone BAP, MQ-BAP, and MQ combined BAP and QCAP) in real world environments with several practical constraints. The proposed methods have been tested and evaluated extensively using real data against benchmark approaches. Numerical findings from experiments confirm the effectiveness of the proposed solutions. Therefore, the proposed CI-based methods can serve as promising decision support tools and assist terminal operators while developing berth allocation plans. The latter (MQ combined BAP and QCAP) will also assist port operators with the development of a fully-specified berth schedule, for container ships as well as for other general cargo or passengers ships, to ensure that the ships will be moored and departed in a timely manner.

Keywords: Internet of Ships; Smart Ports; Intelligent Maritime Transportation; Berth

Allocation Problem; Seaside Operational Problems;