GENETIC ALGORITHM FOR INTEGRATED MODEL OF BERTH ALLOCATION PROBLEM AND QUAY CRANE SCHEDULING WITH NON-CROSSING SAFETY AND DISTANCE CONSTRAINT

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DEDICATION

This thesis is dedicated to my beloved family for their never-ending support and care.

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ABSTRACT

Berth Allocation and Quay Crane Scheduling are the most important part of container terminal operations since berth and quay cranes are an interface of ocean-side and landside in any port container terminal operation. Their operations significantly influence the efficiency of port container terminals and need to be solved simultaneously. Based on the situation, this study focuses on an integrated model of Continuous Berth Allocation Problem and Quay Crane Scheduling Problem. A comprehensive analysis of safety distance for vessel and non-crossing constraint for quay crane is provided. There are two integrated model involved. For the first integrated model, non-crossing constraints are added wherein quay cranes cannot cross over each other since they are on the same track. The second integrated model is focused on the safety distance between vessels while berthing at the terminal and at the same time, quay crane remains not to cross each other. These two constraints were selected to ensure a realistic model based on the real situation at the port. The objective of this model is to minimise the processing time of vessels. A vessel's processing time is measured between arrival and departure including the waiting time to be berthed and servicing time. A new algorithm is developed to obtain the good solution. Genetic Algorithm is chosen as a method based on flexibility and can apply to any problems. There are three layers of algorithm that provide a wider search to the solution space for vessel list, berth list, and hold list developed in this study. The new Genetic Algorithm produced a better solution than the previous research, where the objective function decreases 5 to 12 percent. Numerical experiments were conducted and the results show that both integrated models are able to minimize the processing time of vessels and can solve problem quickly even involving a large number of vessels. Studies have found that the safety distance set as 5 percent of vessel length gives the best solution. By adding safety distance to the integrated model with non-crossing constraint, the result indicates no improvement in the model objective function due to increasing distance between vessels. The objective function increases in the range of 0.4 to 8.6 percent. However, the safety distance constraint is important for safety and realistic model based on the port’s real situation.

ABSTRAK

Peruntukan pelabuhan dan penjadualan kren pangkalan adalah bahagian terpenting dalam operasi di terminal kontena kerana pelabuhan dan kren pangkalan adalah antara muka bagi lautan dan daratan dalam mana-mana pelabuhan kontena. Secara signifikannya ia mempengaruhi kecekapan operasi terminal pelabuhan kontena dan perlu diselesaikan serentak. Berdasarkan situasi tersebut, kajian ini memfokuskan pada model bersepadu yang menggabungkan masalah peruntukan susunan kapal berlabuh yang berterusan dan penjadualan kren pangkalan. Analisis yang komprehensif terhadap jarak keselamatan kapal dan kekangan penyeberangan untuk kren pangkalan telah disediakan. Terdapat dua jenis model bersepadu yang terlibat. Bagi model pertama, kekangan penyeberangan ditambahkan di mana kren pangkalan tidak boleh menyeberangi antara satu sama lain kerana mereka berada pada landasan yang sama. Model bersepadu yang kedua berfokuskan kepada jarak selamat antara kapal semasa berlabuh di terminal dan pada masa yang sama memperuntukan kren pangkalan tidak boleh menyeberang antara satu sama lain. Kedua-dua kekangan ini dipilih untuk memastikan model berbentuk realistik berdasarkan keadaan sebenar di pelabuhan. Objektif kajian ini adalah untuk meminimumkan masa operasi kapal. Masa pemprosesan kapal diukur antara ketibaan dan masa berlepas termasuk masa menunggu untuk berlabuh dan masa servis. Algoritma baharu dibangunkan bagi mendapatkan penyelesaian yang terbaik. Algoritma Genetik dipilih sebagai kaedah berdasarkan fleksibiliti dan sesuai digunakan dalam sebarang masalah. Tiga lapisan algoritma yang menyediakan carian yang lebih luas bagi penyelesaian senarai susunan kapal, senarai pelabuhan, dan senarai menunggu dibangunkan dalam kajian ini. Algoritma Genetik baharu ini menghasilkan keputusan yang lebih baik berbanding dengan kajian yang lepas di mana fungsi objektif telah menurun sebanyak 5 hingga 12 peratus. Kajian berangka juga telah dijalankan dan hasil menunjukkan kedua-dua model bersepadu ini dapat meminimumkan masa pemprosesan kapal dan dapat menyelesaikan masalah dengan cepat walaupun melibatkan jumlah kapal yang besar. Kajian mendapati jarak keselamatan ditetapkan sebagai 5 peratus daripada ukuran panjang kapal memberikan penyelesaian yang baik. Dengan menambahkan jarak keselamatan kepada model bersepadu dengan kekangan penyeberangan, hasilnya menunjukkan tidak terdapat peningkatan dalam fungsi objektif model yang harus dicapai dalam meningkatkan jarak antara kapal. Fungsi objektif model meningkat dalam julat 0.4 to 8.6 peratus. Walau bagaimanapun, kekangan jarak keselamatan adalah penting untuk model keselamatan dan realistik berdasarkan keadaan sebenar di pelabuhan.

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LIST OF ABBREVIATIONS

ACO	-	Ant Colony Optimization
BAP	-	Berth Allocation Problem
BAPC		Continuous Berth Allocation Problem
B&B	-	Branch-and-Bound Method
BLP	-	Bi-Level Programming
CT	-	Container Terminal
DBAP	-	Dynamic berth allocation problem
DDBSP	-	Discrete Space And Dynamic Vessel
FCFS	-	First Come First Serve Rule
GA		Genetic Algorithm
GRAPS		Greedy Randomized Adaptive Search Procedure
IBAPCQCSP	-	Integrated Continuous Berth Allocation Problem and Quay Crane Scheduling
NSGA II	-	Non- Dominated Sorting Genetic Algorithm II
moGA	-	Multi-Objective Genetic Algorithm
MINLP	-	Mixed-integer nonlinear model
MOMCAA	-	Multi-Objective Multi-Colony Ant Algorithm
LOA	-	Length overall
LVF	-	Large Vessel First
PAF	-	Position Assignment Formulation
QC	-	Quay Cranes
QCSP	-	Quay Crane Scheduling Problem
QCSNC	-	Quay Crane Scheduling With Non-Crossing Constraints
RBAP	-	Robust Schedule For Berth Allocation
RHH		Rolling Horizon Heuristic
RPF	-	Relative Position Formulation
SWO	-	Squeaky Wheel Optimization
SA	-	Simulated Annealing
VND	-	Variable Neighbourhood Descent

LIST OF SYMBOLS

a_k	-	arrival time of vessel k
b_k	-	berthing position of vessel k,
B	-	set of berths equal size sections
B_0	-	Initial solution of berth that vessel depart
c_k	-	the earliest time that vessel k can depart
h_k	-	number of holds of vessel k
H_k	-	length of vessel k, including horizontal safety distance
L_0	-	Initial solution of vessel's berthing list
L_i^t	-	location of crane i at time period t
M	-	a large positive scalar
p_k^i		processing time of hold i of vessel k
p_k^{max}	-	maximum hold processing time for vessel k (p_k^{max}: $\max_i \{p_k^i\}$)
S_k	-	the total length of berths
Q	-	a set of identical quay cranes operating on a single set of rails.
t_k	-	berthing time of vessel k,
T	-	time period of vessels
V	-	a set of vessels with a known arrival time
x_{ikj}	-	1, if vessel k is proceeded at berth, as the l th vessel
z_i	-	the beginning berthing location of a vessel

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The market environment in which container terminals operate is changing rapidly due to the globalization and adoption of containerization since the late 1960s. Container shipping plays a noteworthy and significant job in the world transportation framework and the worldwide inventory network. A container terminal (CT), as a focal point in the transportation arrange, goes about as an exchange of the various modes engaged with the general transportation process. Proficiency and profitability upgrades in terminal activities are significant in decreasing the general trip duration and costs which have accordingly been receiving more consideration recently. Despite profoundly used terminals, vessel's quick administration is important to fulfil clients' needs and to give adequate adaptability to the terminal administration.

Berth allocation and quay crane scheduling fundamentally impact port activities' effectiveness of port activities since berth and quay cranes are an interface among ocean-side and landside in any port container terminal. Practically speaking, berth scheduling and quay crane scheduling issues are drawn closer successively by terminal administrators. A berth schedule utilizes evaluations of total berth time for every vessel and attempts to split cranes among the vessels to dock simultaneously. Terminal administrators can build up a superior operational arrangement if actual crane prerequisites are considered while deciding berth schedules [1].

In container terminals, including a long quay, productive berth designation is an indispensable factor for fruitful terminal operations. Since the mid-1990s, container terminals have been seriously considered. The extent of freight shipped by containers has consistently expanded because of container transport benefits, for example, less product packaging, less harming, higher efficiency, and simpler transhipment between various modes [2]. In any case, the challenge between port container terminals has impressively expanded, brought about by enormous development rates on major maritime container routes. To prevail in the savage challenge, a critical benefit is the high proficiency of activities in port container terminals [3].

Berths and quay cranes are the two most significant assets utilized in CTs during loading and discharging. The turnaround time of vessels is influenced straightforwardly by the berthing time and the quantity of quay cranes allotted. Along these lines, their productive portion is urgent to ensure the smooth activity of container terminals. The general problem may be stated as follows:

The berth allocation problem consists of assigning incoming ships to berthing positions. For vessels arriving over time, the terminal administrator assigns them to berths to be served (loading and unloading containers) as quickly as time permits. Various variables influence the berth and time assignment of every vessel. Quay cranes (QCs) are used at the coastline of a terminal for releasing and stacking containers from and onto vessels. The proficient usage of this specialized equipment considers short vessel handling times and early take offs. Subsequently, well-arranged crane activities are significant for quick terminal tasks and contrasted with expensive investments into new equipment. They give a cheap opportunity to accomplishing an attractive competitive advantage.

The berth allocation issue can be separated into two classifications: discrete and continuous, as indicated by various indexing techniques to determine the berthed vessels [5]. In the past studies of discrete berth allocation issue, the whole terminal space is apportioned into a few berths and the distribution is arranged dependent on the partitioned berth space. This circumstance may lead to some unused berthing space. Under the nonstop location approach, vessels are permitted to be served at any place the empty spaces are accessible to physically oblige the ships through a continuous location system. This kind of issue looks pretty much like the cutting-stock issue where a set of commodities are proficiently pressed into some crates. A rectangle shape can represent a vessel in pause and service at a berth in a time-space notion or Gantt chart.

Consequently, effective berth usage is a kind of sorting "vessel rectangles" into berth-time accessibility as a box with some constrained packing scheme to such an extent that no pivot of ship rectangles is permitted. When considering the vessels' arrival time, the static arrival and dynamic arrival are distinguished [6], where all the vessels are already at the port. If they berth right away, then they are considered as the static case. Otherwise, in the dynamic case, vessels are allowed to arrive during container operations at the port.

One of the basic issues in a container port activity is the scheduling of QC to serve the berthed container vessels. QCs are industry-standard apparatus for loading and discharging containers to and from vessels. Among the most significant Quay Crane Scheduling (QCSP) is non-crossing. To abstain cranes' intersection, the QCSP requires a spatial limitation, which isn't associated with a machine scheduling issue. For the most part, quay crane scheduling manages the issue of deciding a handling sequence of vessel bays for quay cranes appointed to a vessel. The turnaround time of a vessel in a terminal is straightforwardly reliant on the of quay cranes allotted. The more essential number of quay cranes assigned to a given vessel, the snappier the turnaround time will be for that vessel. At the same time, the port management should consider the vessel's safety distance to ensure the operation is under control.

Many researchers study them separately in the early works on Berth Allocation Problem (BAP) and QCSP. However, berth allocation and quay crane scheduling significantly influence port operations since they are the most important resources in container terminals at seaports. Thus, these two resources should be simultaneously considered while making operational plans because of the physical limitation of berth space and capacity limitation of quay crane handling. Well-organized berth allocation and QC scheduling plans greatly affect the terminal's container turnover increase, improving terminal and vessels' operational cost reduction and improving customer satisfaction. As the service interface between the terminal and vessels, the high performance of quayside operation also directly or indirectly impacts the efficiency of other operational sections such as yard, yard cranes, and transhipment trucks [5].

1.2 Motivation

One of the issues in seaside operations planning is the quay crane scheduling and service time to vessels that have to be unloaded and loaded at a terminal. Well-planned berth and crane operations are important for fast terminal operations compared with costly investments into new equipment. Based on operations at the port, many researchers have produced various models to solve the problems. More attention has been gaining lately on the effectiveness and productivity improvements in terminal operations since it is crucial in reducing the overall period of trip duration and costs. To overcome the problems, vessels' fast service is essential to achieve customer satisfaction and provide sufficient flexibility for the terminal management.

In order to become a fast service container terminal, the resource’s presence at the seaport container terminal must be well known. Berths and quay cranes are the two most important resources used in container terminals during loading and discharging. According to Ak [1], terminal operators can develop a better operational plan if actual crane requirements are considered while determining berth schedules. Berth allocation and quay crane scheduling significantly contribute to port operations' efficiency since berth and quay cranes are the interface between seaside and landside in any port container terminal. Practically, berth allocation and quay crane scheduling problems are approached sequentially by terminal operators.

A berth schedule is determined by estimating the total berth time for each vessel, and then try to split cranes among the vessels planned to dock simultaneously. For container terminals with a long quay, efficient berth allocation is a vital for successful terminal operations. In ensuring more efficient operation at the port, safety factors also need to be emphasized, namely the safe distance between vessels while anchoring at the port. When vessels approach each other, there are recommendations on the minimum distance to keep. The geometrical shape that this distance forms around the vessel defined as the ship domain, which was studied since the early 1970s.

1.3 Problem Background

To succeed in the competition between port container terminals, high efficiency of port operation is required. Many researchers studied BAP and QCSP separately, but several studies have focused on the integrated models. However, several research studies on the integrated model have recently embarked, not focusing on non-crossing and safety distance deeply. In space-related problems, a model with a discrete berth has been employed widely by viewing the berthing area as a finite set of berths, where every berth can accommodate only one vessel at a time. Wang [3] integrated discrete berth allocation and quay crane scheduling problems with non-crossing, suggesting studying BAPC to enhance the efficiency. A discrete model may bring about in possessing some unutilized berthing space. Yet, in continuous space, vessels are permitted to be served any place the vacant spaces are accessible to physically suit the vessels using a continuous location system.

Besides BAP, Quay Crane Scheduling also essentially impacts the activity's effectiveness since berth and quay crane are the interface between the ocean side and land side in any port container terminal. Practically, QCs along a similar berth are mounted on similar tracks, which denies them from intersecting each other at any moment. To obtain QC scheduling arrangement precisely and effectively will give prompt advantage and contribution to consequent port activities. Nonetheless, numerous works did not consider the non-crossing constraints between quay cranes, implying that the quay cranes may ridiculously traverse one another. The handling time of a container ship at a berth is identified with its quay crane schedule. By coordinating BAPC and QCSP, container terminal activity proficiency will improve and become increasingly pragmatic.

QCs are industry-standard apparatus for loading and discharging containers from and into vessels. Among the most important QCSP is non-crossing. The QCSP acquires a spatial constraint that is not affected by a machine scheduling problem to avoid cranes' crossing. However, researchers assumed non-crossing in their QC operations without looking into the detail whether these conditions are sufficient to guarantee a realistic solution.

Few researches have been directed towards improving the productivity of QC scheduling with the thought of non-crossing limitations. In any case, Lee and Chen [4] noticed that the past models of QC scheduling with non-crossing constraints (QCSNC) might lead to ridiculous model solutions. The paper inspected the basic inadequacies in modelling QCSNC and suggested additional requirements to fix the issue, becoming increasingly practicable. However, the authors only concentrated on the QC and not integrated with BAPC. According to Lee and Chen [4], many researchers assume QCs should not be across each other, and each vessel bay is only handled exactly by one QC during the planning horizon.

In the integrated model of BAPC and QCSP, the safety distance between vessels is important in safety management of the port. Safety distance between a vessel is a distance to ensure the vessel will not cause danger or damage to the thing or other vessels regarding to all relevant safety factors. There are a few studies on the safety distance of the vessel, including while overtaking process. For example, Nie et al. [5] examined a one-way channel for one-way traffic flow. The authors said that interval distance between two vessels arrives at the minimum-security distance at a specific time when the front vessel leaves the channel, where the vessel impedance will arrive at the maximum. However, there are only a few studies in depth on the safety distance while berthing as is in the study of Rodriguez et al.[6] and Rodriguez et al. [7].

In the selection of research methods, various methods have been used to solve BAP and QCSP such as Tabu search, Genetic Algorithm, and adaptive large neighbourhood-based heuristic framework. A few researchers likewise concentrated around the metaheuristic of hybrid GAs consolidating exact resolution algorithms (for example branch and bound), local search (for example Memetic Algorithms) or different metaheuristics (for example Tabu Search) to ensure at least the local optimality of the solutions (single or Pareto set) or in improving the convergence patterns. However, GA has been shown to be very efficient and effective in scheduling problems at the container's terminal seaside operations. [8].

GA has the advantage of flexibility over other more traditional search techniques. They impose no requirement for a problem to be formulated in a particular way. Moreover, there is no need for the objective function to be differentiable, continuous, linear, separable, or any particular data-type. They can be applied to any problem, for example, single or multi-objective, single or multi-level, linear or non-linear, etc) for which there is a way to encode and compute the quality of a solution to the problem [8].

Several studies presented GA for the seaside operations in the simultaneous berth and quay crane scheduling problem by applying GA to generate vessels' berth allocation. Then, it proposed a heuristic to schedule crane transferring such as [8] for BAPC and QCSP, the GAs presented to date lack in the design of sophisticated reproduction techniques, as they rely on existing methodologies (e.g., simple swap and insert techniques). Two main weak spots of GAs based heuristics are the lack of optimality criteria of the final solution and the relatively poor exploitation of the physical problem's special characteristics and how to construct improved approximations of the feasible search space [8].

1.4 Problem Statement

A container terminal's baseline schedule originates from the integration model of BAP and QCSP that considers related constraints. Integration of these problems is important because studying BAPC and QCSP separately cannot show the overall system performance. This study aims to investigate the integration of BAPC and QCSP since both problems fundamentally impacting port operation effectiveness by focusing on non-crossing for quay crane and then safety distance constraints between vessels. BAPC allows the vessel to be berthed anywhere along the berth. Compared to the model with discrete berths, this modeling perspective typically provides more freedom for port operators to assign berthing positions.

QCs along a similar berth are mounted on similar tracks, which precludes them from intersecting each other at any moment. The QCSP acquires a spatial constraint that is not affected by a machine scheduling problem to avoid the crossing of cranes. Non-crossing QCs are an important part of QCSP for a realistic situation. However, many researchers not consider non-crossing constraint in their study or assumed non-crossing in their QC operations without looking into the detail whether these conditions are sufficient to guarantee a realistic solution. To overcome the issue, non-crossing constraint with consideration realistic solution is considered in this study.

For port safety management, safety distance between vessels also important to be considered due to vessel's blind spot. Safety distance between a vessel is a distance that will ensure the vessel will not cause danger or damage to the thing or other vessels regarding to all relevant safety factors and calculated based on the length of the vessel. Just a few studies look in depth on the safety distance while berthing. Most researchers only consider safety distance in the model without making a detailed study in calculating safe distance between vessels. Since safety distance is calculated based on the length of the vessel, this study examines to find the most appropriate safety distance of the vessel and also considers it one of the main focuses on examining whether this constraint give impacts to the model.

This study develops solution methods utilizing the Integrated Continuous Berth Allocation Problem and Quay Crane Scheduling (IBAPCQCSP). The metaheuristics method that will be used to solve this problem is Genetic Algorithm(GA) since GA has the advantage of flexibility over other more traditional search techniquesHowever, Boile et al.[8] stated that for BAPC and QCSP, the GAs presented to date lack in the design of sophisticated reproduction techniques, as they rely on existing methodologies (e.g., simple swap and insert techniques). Therefore, new algorithm of GA is developed to overcome the limitation stated earlier to improve approximations of the feasible search space. The new Algorithm GA which consist of A three-layer algorithm of GA explores L^p, B, L_h more thoroughly in respective layer and produces the L^p_{best}, B_{best} and $L_{h,best}$.

1.5 Research Questions

The problem statement raises several research challenges. These challenges will be addressed by providing answers to the following questions:

i) How to integrate Continuous Berth Allocation Problem and Quay Crane Scheduling Problem with non-crossing constraint?
   a) What are the parameters and variables involved?
   b) How to translate the non-crossing constraint into a mathematical form using the parameters and variables?

ii) How to incorporate vessel's safety distance into the integrated model of BAPC and QCSP with non-crossing constraints?
   c) What are the parameters and variables involved?
   d) How to translate the safety distance constraint for BAPC into the mathematical form using the parameters and variables?

iii) How to solve the resulting model?

   a) What method to be used?
   b) What modification could be made to the procedure?
   c) What parameter should be considered in evaluating the performance of the proposed method?

iv) How to validate the finding of method?
   i) What parameters are changed?
   ii) What is the effect on the mathematical results when the parameter is changed?

1.6 Research Objectives

The objectives of the study are as follows:

i) To construct a mathematical model of the integrated BAPC and QCSP with non-crossing constraints.
ii) To incorporate the safety distance constraint of the vessel to the integrated BAPC and QCSP with non-crossing constraint.
iii) To construct new algorithm based on Genetic Algorithm for solving BAPCQCSP.
iv) To validate the finding of the method.

1.7 Scope of the study

This research focuses on integrating the Continuous Berth Allocation Problem (BAPC) and Quay Crane Scheduling Problem (QCSP). Since the BAPC and QCSP are important in port operation, this model aims to minimize the vessel's processing time while berthing at port. Continuous berth allocation will allow the vessel to be berthed anywhere along the berth and provides more freedom for port operators to assign berthing positions.

The first approach for this integrated model is to construct a mathematical model with a non-crossing constraint for QCSP to make sure QC not cross each other as real situation in container terminal. However, this problem does not consider the processing time of QCs in the objective function. Then, the safety distance constraint of the vessel incorporates to the model. Safety distance is important to consider due to safety port management. Data of vessels from one of the ports in Johore and previous research papers are used to generate the objective function.

A new algorithm of GA is developed to improve approximations of the feasible search space. An initial solution is generated based on the First Come First Serve Rule (FCFS). Uniform crossover and uniform mutation operators are applied in this paper. A new algorithm is developed to obtain a good solution consisting of three layers algorithm, which provides a wider search to the solution space. The analysis of objective function is based on the vessel's processing time to measure efficiency of port operation.

1.8 Significance of Research

This research is expected to contribute greatly to the field of mathematics, transportation, and operations management. Mathematics is not restricted only to the classroom and academic use but has extended to management studies. The efficient operation of BAP plays an important role in terminal industries. Along with the recent increase in demand for an efficient management system for BAP and QCSP and the advancement in computer and technology, the importance of effectively using the huge amount of information has become important for a wide-range application. This research produces an avenue for solving the continuous berth allocation problem and quay crane allocation problem, focusing on non-crossing for QCSP and safety distance constraint for BAPC since it based on realistic problem. From the viewpoint of algorithm development, the new algorithms are developed and implemented to solve IBAPCQCSP. The new algorithm is divided into three layers to improve approximations of the feasible search space to get the L_{list}, B_{list}. and L_h which provides a wider search to the solution space. It gave better results as it explores L^p, B, L_h more thoroughly in respective layers and produces the L^p_{best}, B_{best} and $L_{h,best}$.

1.9 Organization of the Thesis

This thesis contains six chapters. The first chapter discusses the introduction to the background of the problem, the problem statement, research question, research objective, scope of the study, the study's significance, and theoretical framework.

On the other hand, Chapter two consists of a literature review on the operation of Seaport Container Terminal, Berth Allocation Problem, Quay Crane Scheduling with non-crossing constraint, Integrated Model of BAPC and QCSP, BAPC with safety distance constraint and Genetic Algorithm as solution methods, which can be applied for solving IBAPCQSP.

Apart from that, Chapter three presents the Research Methodology. It gives the study's guidance and a review of the Genetic Algorithm, which contains a new algorithm for the integrated model. The development of the new algorithm of GA is explained. It was designed for obtaining optimal solutions.

Moreover, Chapter four presents the discussion on the integrated model of IBAPCQSP with non-crossing constraints. Numerical analysis is discussed with various instances. The development and solution of Integrated Continuous Berth Allocation Problem and Quay Crane Scheduling is explained. The new constraint of non-crossing QCs was developed and added to the integrated model. The non-crossing constraint for QCSP is considered a realistic situation based on the real situation in a terminal container. Sensitivity analysis also conducted to examine the stability of the model and provided the other data from previous research for validation.

Furthermore, Chapter five presents the discussion on the integrated model of IBAPCQSP (presented in chapter four) by adding safety distance between vessels. Numerical analysis is discussed with the various instances, and comparisons between two integrated models are made. This chapter provide analyzation of the effect by of adding safety distance constraints to the integrated model. The analysis of the appropriate distance between vessels is discussed to determine the percentage of safety distance depending on the length of the vessel.

Finally, Chapter six presents the present work conclusion, while the recommendations for future research are also presented.

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