Works Rescheduling in Container Terminals

Manuscript received September 19, 2024; revised March 08, 2025

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***Abstract*— Container transportation plays a vital role in freight movement, with container yards serving as critical hubs for operations. This paper focuses on the rescheduling of handling equipment in response to unexpected crane failures, which disrupt planned tasks. To address this challenge, a heuristic algorithm is proposed, incorporating the Longest Processing Time and List Scheduling procedures. Two rescheduling strategies are evaluated through numerical experiments. The results indicate that the second strategy outperforms the first in most cases by improving efficiency, albeit with more changes to the initial schedule. The numerical examples demonstrate the effectiveness of the algorithm, achieving feasible rescheduling solutions within less than one second for all tested cases. These findings highlight the algorithm's efficiency and practicality in real-world container yard operations.**

Keywords*— *Containers, Heuristic, Makespan, Rescheduling, Scheduling, Yard Cranes

I. Introduction

Seaports and river ports play a crucial role in freight movement. These ports are divided into various zones, including docks, cargo warehouses, and gates for transportation companies. Each zone presents unique operational challenges. This paper delves into addressing the operational issues specifically within the storage yard, a hub of bustling activity. Enhancing the operational efficiency of this area will have a direct and indirect impact on the port's overall performance, leading to increased revenue, reduced costs, and improved customer service. The primary operations at the storage yard involve loading and unloading containers using various handling equipment, including gantry cranes, reach stackers, forklifts, and straddle carriers. These devices receive dispatch instructions from the port's coordination center to execute containers handling tasks within the yard. This kind of equipment could be broken suddenly. In case of broken equipment, the jobs schedule should be rescheduled. Hence, this research deals with the problems of job rescheduling in uncertainty situations.

There are many researchers considering the scheduling problems of yard cranes in container terminals. In study [1], the authors investigate the optimization of yard crane operations where tasks have varying ready times. This scheduling problem is equivalent to a dynamic problem, which the authors prove to be NP-complete. To address this computationally intractable problem, a heuristic algorithm is proposed and evaluated through numerical experiments on real-world sized instances. Study [2] also contributes to the field of yard crane scheduling. Focusing on container port environments, the authors address the dynamic scheduling problem with the goal of minimizing overall workload. To handle real-world scale instances, a heuristic algorithm is developed and evaluated empirically. The results demonstrate the algorithm's ability to produce near-optimal solutions efficiently. In this study, the focus is on rubber-tired gantry cranes, and the flexibility of crane movement between container blocks is considered. In recent research [3], the authors investigate the yard crane scheduling problem within the context of automated container terminals. Despite automation, these terminals retain the fundamental components of traditional container terminals.

Unfortunately, there are a few articles studying rescheduling of yard cranes, in recent years. [4] This research investigated rescheduling problems for multiple identical yard cranes in the event of equipment failure [5] The authors studied both the berth allocation and quay crane assignment simultaneously based on the uncertainty of vessels' arrival. They built a mathematical model that can be solved effectively. While [6], they considered the rescheduling of quay cranes and AGV (Automation Guided Vehicles) in an automatic container terminal. The study was based on the simulation tool to verify the effectiveness of the operations. Another research considering the rescheduling problem is article [7]. The study solved the problem of rescheduling for straddle carrier (SC) in an automatic container terminal. The authors provided two solution methods, a branch and bound algorithm for small size problems and a heuristic for normal size ones. Furthermore, research [8] tackled the flexible job-shop scheduling problem using a hybrid approach that combines multi-agent systems (MAS) and ant colony optimization (ACO). The proposed algorithm demonstrated its efficacy in handling both partial and total rescheduling scenarios. This research will investigate the rescheduling of heterogeneous yard cranes, departing from previous studies that assumed homogeneous crane fleets.

In the rest of this article, the next section is the problem description. Section three is the solution method. After that, the numerical examples are used to verify the solution approach. And the last section is the conclusion of this study.

II. Problem Description

In many small and medium container ports, the yard cranes are not investigated simultaneously. Hence, many kinds of cranes work together. Eventually, reach stackers and forklifts also work together. Previous research has often assumed that all cranes are the same. They are difficult to apply to these ports. In this article, the rescheduling problem of yard crane in container yard is considered. As mentioned above, this study applies to container yards which have many kinds of cranes or equipment. Any jobs in a yard have their operations time based on their location and which equipment is used to handle the jobs. If equipment cannot handle the job, the operation time is infinite.

This research paper investigates the rescheduling of yard cranes in container terminals. The problem involves numerous

 EISSN: 2961-872X ● PISSN: 2961-8924 ● DOI:10.56741/IISTR.esl.00725

container handling tasks in the yard, which are to be performed by multiple cranes. In real-world operations, crane breakdowns can occur, leading to incomplete tasks. This paper proposes two strategies for transferring tasks from the broken-down crane to other operational cranes. To evaluate the efficiency of the loading and unloading process, the makespan, or the completion time of the last task, is used as the objective of the problem

Objective function

$$\text{Min} \quad Max(C_k), \quad k = 1, 2, ..., m$$

Where:

C_k is the completion time of crane k where $k = 1, 2, \ldots, m$,

m is the number of cranes or equipment.

The problems are solved by following assumptions:

- Once a job is started, it must be completed by only one crane (non-preemptable).
- All jobs must be available before the scheduling starts.
- When a crane breaks down, it must stop working from the time of breakdown until the end of the shift (no recovery during the shift).

Table 1 provides an example of the tasks performed by yard cranes and other equipment in a container yard. In this example, 10 tasks, which are the loading/unloading job of cranes in container yards, are generated. The table values represent the handling time for tasks by each equipment. This time can be estimated based on the container locations within the yard, equipment velocity, and the equipment's loading and unloading capacity. Fig. 1 depicts the job sequencing of all equipment in Table 1.

Table 1. An example of tasks in yard containers

	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5
Task 1	208	154	143	41	298
Task 2	73	39	103	135	26
Task 3	269	150	127	88	133
Task 4	39	59	40	217	10
Task 5	175	288	25	86	34
Task 6	138	91	258	154	193
Task 7	102	191	223	258	49
Task 8	100	102	260	285	129
Task 9	265	290	278	288	195
Task 10	291	104	167	267	10

In case of shutdown of equipment, the jobs scheduling of equipment must be rescheduled. In this study, once the equipment is broken, it cannot be repaired in the working horizon. Next section will explain the heuristic rules to renew the jobs schedule. There are two strategies applied. In the first strategy, the set of rescheduling jobs is determined by the broken equipment in step 1 of this algorithm. In contrast, the second strategy determines the set of rescheduling jobs based on all equipment at the time of a breakdown.

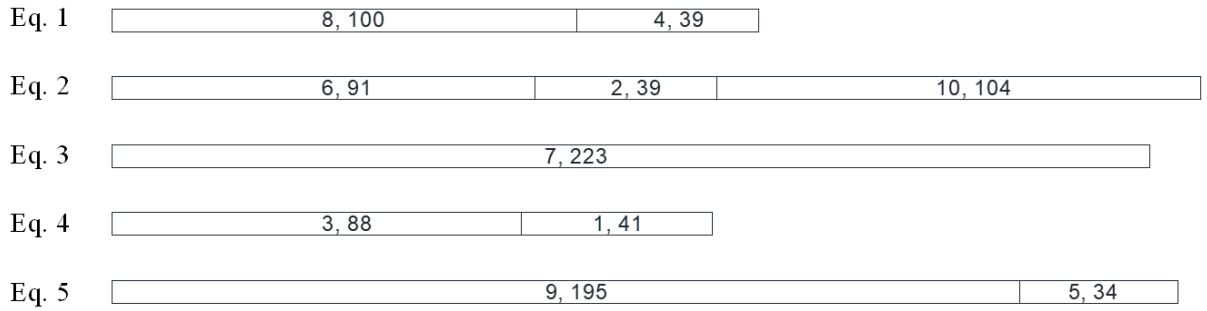

Fig. 1. The Gantt chart of jobs sequencing

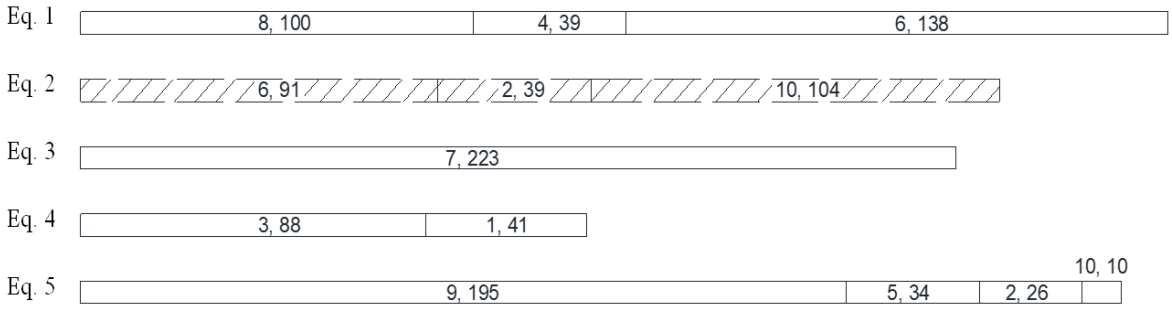

Fig. 2. The new schedule for all equipment

III. HEURISTIC ALGORITHM

To solve the rescheduling problem, a scheduling algorithm is used to create a work schedule for the cranes when a failure occurs that causes a crane to stop operating.

The objective is to minimize the overall completion time. However, the multi-crane scheduling problem with crane-dependent processing times is NP-hard, making it computationally intractable to find an exact optimal solution.

To solve the problem of rescheduling work in the container yard, this study proposes a heuristic algorithm. The process of this algorithm is as follows:

- Step 1: all tasks that have not been completed at the time equipment broken are stored in a list.
- Step 2: Sort the list in order descent of the minimum of task operation times.
- Step 3: Assign the job at the top of the list to the equipment so that the task completion time is minimized.
- Step 4: Delete the first task.
- Step 5: If there has remained task in the list, return step 2, otherwise stop the algorithm and return results.

As an example, assume that the equipment number 2 in table 2 shuts down at time 50 minutes from beginning. In that case, tasks 6, 2 and 10 need to be assigned to other equipment. Applying the algorithm, the new jobs sequencing is presented in Fig. 2.

The heuristic algorithm is a hybrid of the Longest Processing Time (LPT) rule and nearest list scheduling. To address potential crane failures, two rescheduling strategies are proposed:

- Strategy 1: Upon a crane breakdown, all unfinished tasks of the failed crane are reinserted into the scheduling algorithm to be reassigned to other operational cranes.
- Strategy 2: A global rescheduling is triggered whenever a failure occurs, where all tasks are re-optimized for the remaining active cranes.

IV. NUMERICAL EXAMPLES

To verify the algorithm, 36 problems are generated. This study uses the uniforms distribution between 3 and 100 minutes to generate the operation time of tasks. The reason for 3-minute operations is that it is the minimum time a yard crane can handle a container beneath it. And the 100-minute operation involves a crane that is far from the target container. Table 2 shows the makespan of all cranes in the container yard. The column original schedule represents the base schedule of all cranes. The next two columns show the rescheduling results for two different strategies. The first strategy, in table 2, is rescheduling tasks that come from the shutdown crane. The second strategy, in table 3, is to reschedule tasks that originate from all cranes at the time of a yard crane failure. The "task reschedule" columns reflect the quantity of tasks necessitating rescheduling. In strategy one, only the remaining tasks of the broken crane are taken into account; therefore, the number of tasks requiring rescheduling is relatively small. In contrast, in strategy two, all remaining tasks are rescheduled; therefore, the number of rescheduled tasks is greater than that in strategy one. Moreover, the computation time of these heuristics is less than one second. Hence, the algorithms can handle the real size of an NP-hard problem without being time-consuming.

Table 2. The makespans of original scheduling

No.	**Tasks**	**Cranes**	**Original Schedule**	**Strategy 1**	
			Makespan	Tasks reschedule	Makespan
1	50	7	66	9	102
2				7	86
3				4	81
4		8	58	8	81
5				6	73
6				4	72
7		9	52	7	77
8				6	74
9				4	68
10		10	52	7	74
11				6	67
12				4	65
13	60	7	82	9	110
14				8	109
15				5	105
16		8	69	9	98
17				6	87
18				4	82
19		9	61	9	83
20				7	83
21				5	74
22		10	57	8	80
23				6	80
24				4	71
25	70	7	98	9	133
26				7	125
27				6	128
28		8	83	8	108
29				6	107
30				5	101
31		9	71	9	100
32				8	99
33				5	84
34		10	71	7	102
35				5	87
36				4	87

Table 3. The makespans of rescheduling

No.	Tasks	Cranes	Original Schedule	Strategy 2	
			Makespan	Tasks reschedule	Makespan
1	50	7	66	38	99
2				26	93
3				13	82
4		8	58	36	81
5				25	73
6				10	70
7		9	52	34	67
8				25	75
9				9	68
10		10	52	33	63
11				22	70
12				7	65
13	60	7	82	47	125
14				33	114
15				18	99
16		8	69	46	98
17				29	83
18				15	82
19		9	61	43	89
20				30	80
21				12	74
22		10	57	43	83
23				32	83
24				13	73
25	70	7	98	54	146
26				39	124

 EISSN: 2961-872X ● PISSN: 2961-8924 ● DOI:10.56741/IISTR.esl.00725

No.	Tasks	Cranes	Original Schedule	Strategy 2	
			Makespan	Tasks reschedule	Makespan
27				20	123
28		8	83	55	108
29				36	111
30				16	104
31		9	71	53	102
32				37	97
33				18	86
34		10	71	51	94
35				34	97
36				18	86

V. CONCLUSIONS

The paper has studied the rescheduling problem of handling equipment in container yards. The cranes can have different capacities. A heuristic algorithm based on two procedures Longest processing time and list scheduling is applied to solve the problems. Two strategies are applied to the problems. The second strategy outperforms the first one in most cases. Nevertheless, the second strategy makes more changes than the other. The numerical examples are used to show the effectiveness of the algorithm. For all cases of the problems in the numerical examples, the algorithm can finish the calculation in less than one second.

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