World Academy of Science, Engineering and Technology
International Journal of Industrial and Systems Engineering
Vol:12, No:3, 2018

Pre- and Post-Analyses of Disruptive Quay Crane Scheduling Problem

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Abstract**—**In the past, the quay crane operations have been well studied. There were a certain number of scheduling algorithms for quay crane operations, but without considering some nuisance factors that might disrupt the quay crane operations. For example, bad grapples make a crane unable to load or unload containers or a sudden strong breeze stops operations temporarily. Although these disruptive conditions randomly occur, they influence the efficiency of quay crane operations. The disruption is not considered in the operational procedures nor is evaluated in advance for its impacts. This study applies simulation and optimization approaches to develop structures of pre-analysis and post-analysis for the Quay Crane Scheduling Problem to deal with disruptive scenarios for quay crane operation. Numerical experiments are used for demonstrations for the validity of the developed approaches.

Keywords**—**Disruptive Quay Crane Scheduling, pre-analysis, post-analysis, disruption.

I. INTRODUCTION

OCEAN cargo transportation has two categories, container transportation and bulk transportation. According to statistics of the International Association of Ports and Harbors, container transportation is increasing dramatically as indicated in Fig. 1 [1]. From 2010, the growth rate of contender transportation is faster than bulk transportation. Taking the base of 2009, the transported volumes of global containers within five years were growing 189% in average.

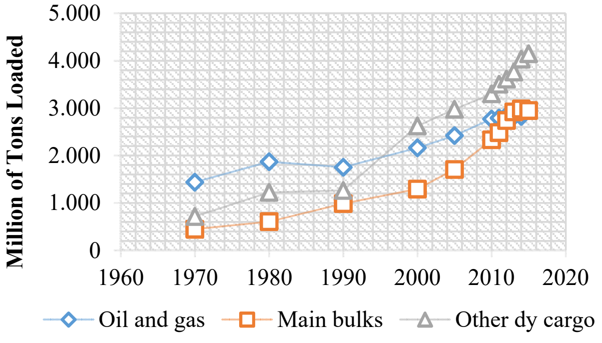

Fig. 1 Growing rates of ocean Transportation Goods from 1970 to 2015 [1]

Some statistics in Taiwan also show the same tendency. From the year 2011 to 2017, one of the major container terminal port, i.e. Kaohsiung harbor, the throughput containers were from 9636288.5 TEUs in 2011 to 10271018 TEUs in 2017. The growth rate around 6% [2]. No matter from data of the total container growth of world or the statistical data of Kaohsiung harbor, container transportation is critical to every country from economics perspectives. Besides, container terminal operations are the main income sources of sea harbors. Consequently, the operational efficiency of the container terminal is one of the essential issues for a harbor. In a container terminal, there are four primary operations, including berth allocation, quay crane operations, storage operations, and security inspections, in which the quay crane operation takes around 70% operational time, that is, quay crane operations determine operation efficiency in a container terminal [3].

The research of quay crane operations started from [4]. In the research, the researcher established a mathematical model to discuss crane operations under deterministic and stochastic time setting scenarios. However, there were no systematical approaches to solve the problem. The researchers did not consider some physical limitations in the mathematical model, such as, two neighboring cranes might collide with each other. Although there was a drawback in the study, quay crane scheduling problem (QCSP) got attentions buy more and more researchers since then. Reference [5] followed the research of [4], applied branch and bound (B&B) method to solve the problem. Reference [6] applied B&B to solve QCSP, and proved that QCSP is a NP-hard problem. That is, solving the problem is less efficient by theoretical approaches, such as B&B, Branch and Cut [7], or Relaxation methods [8]. In order to conquer the difficulties of theoretical approaches, heuristics, dynamic programming, and meta heuristics are considerably proposed by researchers to solve the QCSP [6], [9], [10]. Those approaches can be applied to acquire feasible solutions or near-optimal solutions; however, solution quality cannot be guaranteed. The above research did not consider disruptive conditions. In the real world, crane disruptions often occur. From disruption records in Keelung and Taipei harbors, sometimes grapples of the crane are out of order so that the crane cannot load or unload containers. Sometimes a strong breeze making dangerous operational conditions stops operations temporarily, or scheduled trucks cannot meet their assignments. All of these disruptive conditions will seriously inference efficiency of crane operations. In the academic field, QCSP with disruptive scenarios just started, only small amount of researches can be found [11], [12]. Consequently, this study solves QCSP with considering uncertain factors in the solution approach to simulate disruptive scenarios. Pre- and post-analyses of QCSP are performed to examine when uncertain factors are included in the algorithm.

The structure of this study is as follows: Section I describes

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the research background, motivation, and literatures related to this study, and explain why uncertain factors should be taken into the solution approaches. Section II introduces the solution framework of the pre- and post- analyses of QCSP. Section III demonstrates computational experiments of pre- and post-analyses of QCSP to exam the impacts of uncertain factors. Section IV concludes this study.

II. SOLUTION FRAMEWORK

This study applies simulation optimization structure to combine simulation software AweSim and mata heuristic, i.e. Particle Swarm Optimization (PSO) to analyze disruptive quay crane scheduling problem (DQCSP). An AweSim model example is shown in Fig. 2. In the simulation model, the developed algorithm can be embedded through Event Node. Once the entity goes through the Event Node, simulation clock is temporally suspended, at the time moment, all computations are finished to determine the attributes of entity. According to the attributes of entities, QCSP algorithm can define the instant values of decision variables and objective value. After simulation time reaches, final decisions can be made, and objective value can be defined.

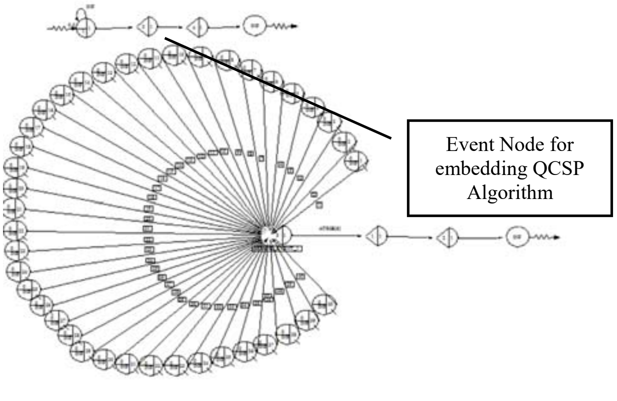

Fig. 2 An example of AweSim simulation diagram

PSO is a matured algorithm structure, which can be defined by:

$$v_{jh}(t) = v_{jh}(t-1) + c_1\varphi_1(x^*_{jh} - x_{jh}(t-1)) + c_2\varphi_2(x^\#_h - x_{jh}(t-1)) \quad (1)$$

$$x_{jh}(t) = x_{jh}(t-1) + v_{jh}(t) \quad (2)$$

in which, $v_j(t)$ is the velocity of j^{th} particle at time t and $x_j(t)$ is location of j^{th} particle at time t. x^*_j(pbest) is the best of current location of j^{th} particle at time $t-1$. $x^\#$(gbest) is the best location of all particles at time $t-1$. φ_1 and φ_2 are rand numbers. c_1 is individuality coefficient, and c_2 is sociality coefficient. When PSO is applied, decision variables can be translated by $x_j(t)$ so that the solutions of the problem can be updated by iterative processes of $x_j(t)$ using (1) and (2).

For the pre-analysis, there are two steps which is shown in the following steps. The flow chart is shown in Fig. 3.

Pre-Analysis

Step 1. Generate stochastic time settings, including uncertain load/unload container processing time, disruptive probabilities of quay crane operations.

Step 2. Initialize the generated time settings and initial solutions. Convert initial solution to the initial velocity and location of particles, put them into the PSO algorithm.

Step 3. Start PSO algorithm until reaching stop criteria.

Step 4. Output the decision variables

Step 5. Verify the output results through AweSim simulation model to exam the solution quality of pre-analysis.

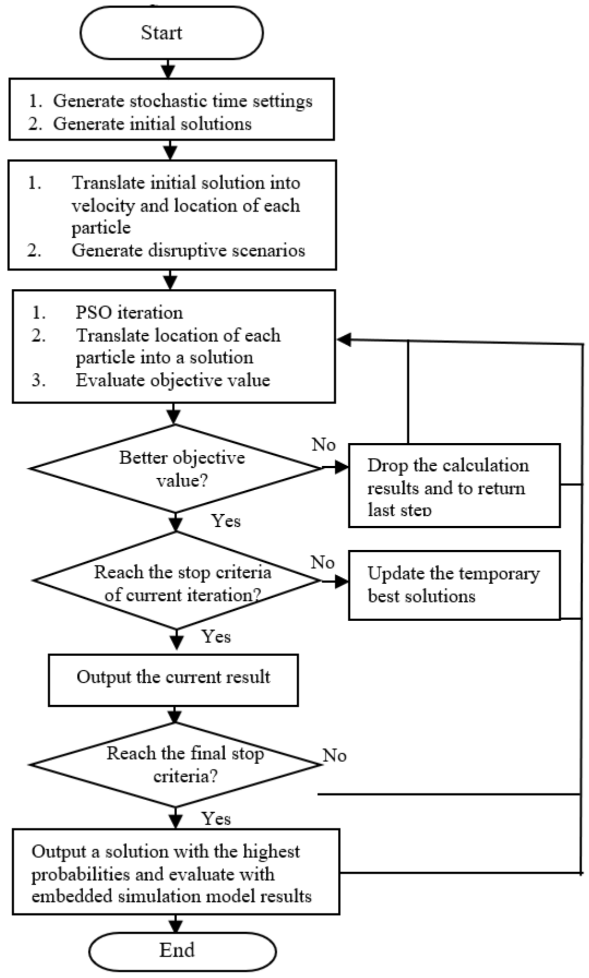

Fig. 3 Flowchart Pre-analysis of DQCSP

Post-analysis is different pre-analysis. The main difference between these two approaches is the post analysis using deterministic time settings to acquire initial solutions by the embedded model to evaluate disruptive risks. The flowchart of the post analysis is shown in Fig. 4.

Example of Translating a Location of a Particle into a Solution

1. Letting locations of a group of particles is shown in Table I.

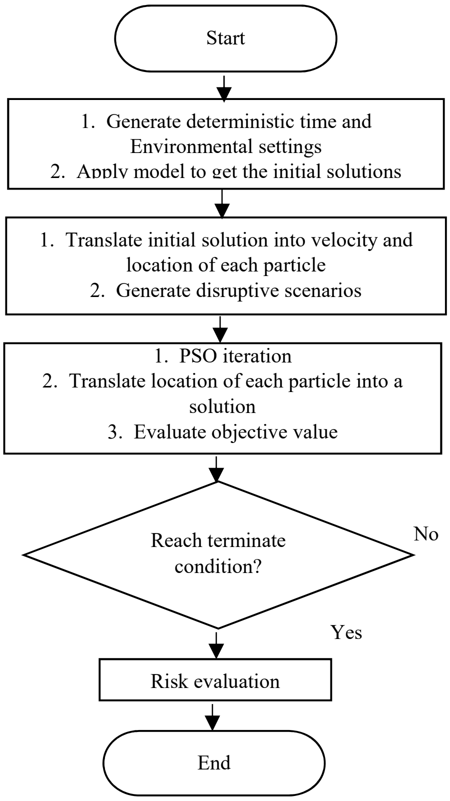

Fig. 4 Pareto Frontier of the test case

TABLE I
LOCATIONS OF A GROUP OF PARTICLES

-3.7	4.1	2.4	3.9	-2.3	-1.1	0.96	0.99	-3.3

2. According to the number, rank the location from the smallest number to the largest number, which is shown in Table II.

TABLE II
RANK ORDER OF A GROUP OF PARTICLES

1	9	7	8	3	4	5	6	2

3. Crane assignment by [3] can be used for lord/unload jobs to different cranes ways minor modification. There is a deficiency of crane assignment rule of [3] that two cranes might collide with each other.

Local Search Algorithm

Besides, in order to further improve solution quality of PSO, a local search algorithm is purposed as follows.

Step 1. $i = 1$, N is a number of crane, M is the maximal iteration number.

Step 2. Assigned to last job of crane i, to crane i+1, if objective value become better, continue Step 2 until no improving of objective value or $i > M$, go to Step 3.

Step 3. If $i > M$, go to Step 6, otherwise $i = i + 1$

Step 4. Continue Steps 2 and 3 until $i = \mathrm{N} - 1$, go to Step 5

Step 5. Add 1 to iteration number, repeat Step 2-4 until iteration number is greater than M . go to Step 6

Step 6. Output the results

III. COMPUTATION RESULTS

In general, a container vessel is assigned two to four cranes; therefore, the test case in this study will be a three-crane-15-holds case. The disruptive scenarios have two conditions with risks 5% and 10%. Parameter settings are listed in Table III.

TABLE III
PARAMETER SETTINGS FOR COMPUTATIONAL EXPERIMENTS

scenario	number of crane	Holds in a vessel	average of containers in a hold	standard deviation of containers a hold	number of runs	Disruptive risks
1	3	15	30	5	100	5%
2	3	15	30	5	100	10%

The computer machine for computational experiments is laptop with INTEL CORE-i7-6500U@2.5GHz CPU, 8GB memory, and operating system Windows 64bits. Computational results of pre-analysis are shown in Tables IV-VI.

TABLE IV
PRE-ANALYSIS COMPUTATIONAL RESULTS DUE TO LOCAL SEARCH IN NON-DISRUPTIVE SCENARIOS

	PSO			PSO+Local		
	Start hold	End hold	Ave. Makepan	Start hold	End hold	Ave. Makespan
1	1	5	302	1	4	258
2	6	10	255	5	9	280
3	11	15	330	10	15	258
M		330			280	

TABLE V
PRE-ANALYSIS COMPUTATIONAL RESULTS DUE TO DISRUPTIVE RISKS WITHOUT LOCAL SEARCH

	PSO+5%			PSO+10%		
	Start hold	End hold	Ave. Makepan	Start hold	End hold	Ave. Makespan
1	1	5	403	1	5	432
2	6	10	369	6	10	385
3	11	15	338	11	15	348
M		403			432	

TABLE VI
PRE-ANALYSIS COMPUTATIONAL RESULTS DUE TO DISRUPTIVE RISKS WITH LOCAL SEARCH

	PSO+Local+5%			PSO+Local+10%		
	Start hold	End hold	Ave. Makespan	Start hold	End hold	Ave. Makespan
1	1	4	318	1	5	432
2	5	10	405	6	10	400
3	11	15	328	11	15	361
M		405			432	

Table IV shows pre-analysis computational results in non-destructive scenarios. In the case, results show that PSO + Local is better than only PSO. From computational results, three cranes have different assigned jobs, which indicate the Local Search enhances solution quality effectively. The relative difference between these two methodologies is approximately 15.2% ((330-280)/330 *100%), which shows that Local Search improves solution quality of the original computational results from PSO greatly. Table V shows us the analysis of risk effects. More disruption occurrence brings longer makespan. In the test numerical case, 5% extra disruption makes approximately 6.7% additional operation time ((432-403)/432 *100%, Table V). If Local Search is included in the PSO, 5% extra disruption makes approximately 6.3% additional operation time ((432-405)/432 *100%, Table VI).

Post-analysis uses the same experiment cases in the pre-analysis. The computational results are shown in Tables VII-IX. The computational results of post-analysis have the same tendency as those of pre-analysis, but with great difference in disruptive scenarios. Tables VIII and IX show that for the same risk settings, 5% and 10%, extra disruptions cause 17.7%(611-503)/611*100%) and 15.0% (532-452)/532*100%) respectively (Tables VIII and IX). From the comparisons of computational of pre-analysis and post-analysis, it could conclude that when stochastic time settings are applied, it is better using pre-analysis approach rather than post-analysis approach. Also, this study suggests that QCSP had better be analyzed in disruptive scenarios than in deterministic scenarios.

TABLE VII
POST-ANALYSIS COMPUTATIONAL RESULTS DUE TO LOCAL SEARCH IN NON-DISRUPTIVE SCENARIOS

	PSO			PSO+Local		
	Start hold	End hold	Ave. Makepan	Start hold	End hold	Ave. Makespan
1	1	5	302	1	4	258
2	6	10	255	5	9	280
3	11	15	330	10	15	258
M		330			280	

TABLE VIII
POST-ANALYSIS COMPUTATIONAL RESULTS DUE TO DISRUPTIVE RISKS WITHOUT LOCAL SEARCH

	PSO+5%			PSO+10%		
	Start hold	End hold	Ave. Makepan	Start hold	End hold	Ave. Makespan
1	1	5	393	1	5	354
2	6	10	503	6	10	611
3	11	15	346	11	15	426
M		503			611	

TABLE IX
POST-ANALYSIS COMPUTATIONAL RESULTS DUE TO DISRUPTIVE RISKS WITH LOCAL SEARCH

	PSO+Local+5%			PSO+Local+10%		
	Start hold	End hold	Ave. Makepan	Start hold	End hold	Ave. Makespan
1	1	4	258	1	4	301
2	5	9	452	5	9	532
3	10	15	414	10	15	475
M		452			532	

IV. CONCLUSIONS

This study applies an embedded simulation and PSO to develop pre-analysis and post-analysis of destructive QCSP, which is different from deterministic analysis of QCSP. In order to enhance the solution quality, the solution approach is combined with Local Search algorithm. The computational results indicate that pre-analysis algorithm has batter crane assignments than post-analysis algorithm. Also, deterministic time setting scenarios are not enough for solving the real world problems, which indicates that destructive QCSP should be seriously studied in the future.

ACKNOWLEDGMENT

The author would like to thank the research project funding support from Ministry of Science and Technology, R.O.C. The project number is MOST 106-2221-E-033-047.

REFERENCES

[1] International Association of Ports and Harbors, https://www.iaphworldports.org/statistics.

[2] Taiwan International Ports Corporation, https://kl.twport.com.tw/chinese/.

[3] K. H. Yang, “The Influence of the Quay Crane Traveling Time for the Quay Crane Scheduling Problem”, *Proceeding of the International MultiConference of Engineers and Computer Scientists*, vol. 2, 1298-1301, 2012

[4] C. F. Daganzo, “The crane scheduling problem,” *Transportation research Part B*, vol. 23, no. 3, 1989, pp.159-175.

[5] R. I. Peterkofsky and C. F. Daganzo (1990). "A branch and bound solution method for the crane scheduling problem," *Transportation Research Part B*, vol. 20, no. 3 1990, pp. 159-172.

[6] D. H. Lee, H. Q. Wang and L. Miao, "Quay crane scheduling with non-interference constraints in port container terminals," *Transportation Research Part E* vol. 44 no. 1 2008, pp. 124–135.

[7] Moccia, L., et al. (2006). "A branch-and-cut algorithm for the quay crane scheduling problem in a container terminal." Naval Research Logistics 53: 45-59.

[8] Y. Guan, K. Yang, and Z. Zhou (2013). "The crane scheduling problem: models and solution approaches," *Annals of Operation Research*, vol. 203, no.1, 2013, pp. 119-139.

[9] A. Lim, B. Rodrigues, F. Xiao and Y. Zhu, “Crane scheduling using Tabu search,” *14th IEEE International Conference on Tools with Artificial Intelligence*, 2002.

[10] Y. Zhu and A. Lim, "Crane scheduling with non-crossing constraint," *Journal of the Operational Research Society*, vol. 57, 2006, pp.1464-1471.

[11] N. Al-Dhaheri, A. Jebali, A. Diabat "A simulation-based Genetic Algorithm approach for the quay crane scheduling under uncertainty," *Simulation Modelling Practice and Theory* vol. 66: 2016, pp. 122-138

[12] C. Liu, L. Zheng, and C. Zhang, "Behavior perception-based disruption models for berth allocation and quay crane assignment problems," *Computers & Industrial Engineering*, vol. 97, 2016, pp. 258-275.

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