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Quay Cranes and Yard Trucks Scheduling Problem at Container Terminals

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ABSTRACT

A bi-objective mathematical model is developed to simultaneously consider the quay crane and yard truck scheduling problems at container terminals. Main real-world assumptions, such as quay cranes with non-crossing constraints, quay cranes' safety margins and precedence constraints are considered in this model. This integrated approach leads to better efficiency and productivity at container terminals. Based on numerical experiments, the proposed mathematical model is effective for solving small-sized instances. Two versions of the simulated annealing algorithm are developed to heuristically solve the large-sized instances. Considering the allocation of trucks as a grouping problem, a grouping version of the simulated annealing algorithm is proposed. Effectiveness of the presented algorithms is compared to the optimal results of the mathematical model on small-sized problems. Moreover, the performances of the proposed algorithms on large-sized instances are compared with each other and the numerical results revealed that the grouping version of simulated annealing algorithm outperformed simulated annealing algorithm. Based on numerical investigations, there is a trade-off between the tasks' completion time and the cost of utilizing more trucks. Moreover increasing the number of YTs leads to better outcomes than increasing the number of QCs. Besides two-cycle strategy and using dynamic assignment of yard truck to quay cranes leads to faster loading and unloading procedure.

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1. INTRODUCTION

Particularly over the past decades, container terminals have been playing a significant role in the global transportation system [1]. According to a review by the Maritime Transport [2], the global container port throughput has grown to 752 million 20-foot equivalent units (TEUs) in 2017. This reflects the addition of 42.3 million TEUs in that year. The report estimates 5% growth in total TEU capacity by January 2019 [2]. Given the progressive growth rate of the transported containers volume in the last decade, the operational efficiency of container terminals must be optimized .

In this study, the assignment of containers to the quay cranes and trucks as well as the sequence of tasks performed by each quay crane and each truck are determined. The objective function of the presented model is a linear combination of the makespan of the vessel and the sum of the quay cranes' completion times. The management of these complicated operations is an attractive issue for researchers, especially in the past years. In 1989, Daganzo [3] for the first time presented a mathematical model for the quay crane scheduling problem assuming a certain number of vessels and QCs in the berth. Kim and Park [4] proposed a mixed integer programming (MIP) model considering several constraints regarding the quay crane scheduling problem. The model was later modified by Moccia et al. [5]. There are a plethora of other hypothesis on the real-world instances in works of researchers including assumptions such as a safety distance between cranes (e.g. Nguyen et al., [6]; Kaveshgar et al., [7]), cranes non-crossing (e.g. Tavakkoli-Moghaddam et al. [8]; Emde, [9]), precedence relationship between containers (e.g. Kim and Park, [4] ; Sammarra et al., [10]) and unidirectional schedules for quay cranes (e.g. Legato et al., [11]; Chen and Bierlaire, [12]). A comprehensive categorization and review of various articles in this field was carried out by Bierwirth and Meisel [13, 14].

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Beside works studying the independent scheduling problems of quay cranes (QCs) and yard trucks (YTs); there are several studies carried out in the recent years approaching both problems in integration. Chen et al. [15] considered and formulated the integrated operational management problem of QCs, YTs and YCs as a hybrid flowshop scheduling problem. Furthermore, considering precedence and blocking constraints, they developed a Tabu search algorithm with an objective function to minimize the makespan [15]. A mathematical model to solve the joint quay crane and truck scheduling problem was proposed by Tang et al. [16]. Considering both inbound and outbound containers, besides developing several valid inequalities, they proposed two lower bounds for their presented model. Kaveshgar and Huynh [17] studied the joint scheduling problem of QCs and YTs. Also they developed a mixed integer programming (MIP) model as well as a genetic algorithm for solving the presented problem. Based on the solution for several numerical problems, the proposed algorithm showed suitable results [17]. In 2019, to solve the problem of simultaneous allocation of vessels to the berths, QCs to vessels and YTs to QCs, Vahdani et al. [18] proposed an integer programming model plus two metaheuristic approaches based on genetic algorithm and particle swarm optimization (PSO) algorithm. The results showed that the simultaneous solving of such problems could lead to an improvement in the efficiency of these resources and reduce the completion time [18]. Fazli et al. [19] addresed quay crane assignment and scheduling problem and proposed a mathematical model and Red Deer Algorithm (RDA) for solving this problem. At the same time, assuming the cranes do not cross each other, Behjat and Nahavandi [20] investigated the simultaneous and integrated scheduling and allocation of QCs and YTs. For solving this problem, they developed an integer programming model and a metaheuristic solving method regarding to the imperialist competitive algorithm [20].

The assumption that quay cranes do not cross each other is a practical constraint in the management of container port operations. In the current study it is assumed that prior to solve the scheduling problem there were no assumptions about how QCs would be assigned to vessels or containers. This assumption could improve the efficiency in the allocation of the valuable resources at container terminals and increase their productivity by decreasing the constraints on the assignment of QCs. Moreover, along with other real-world assumptions, such as assuming precedence relationships or safety margin which are considered in this study, such an assumption leads to an increase in the complexity of problem-solving. Taking the safety margin between QCs into consideration is a real-world assumption which was neglected in Behjat and Nahavandi's study [20]. In this paper, considering the main real-world assumptions, a novel integrated bi-objective mathematical model based on the flexible jobshop problem concept is developed. To the best of our knowledge, there is no published work in the related literature that have modelled this problem considering the below mentioned assumptions the way presented in this study. Moreover, a solving method based on simulated annealing algorithm and the grouping concept is developed for solving the proposed problem, especially for large-sized problems.

2. PROBLEM STATEMENT

It is expected that the integrated management of QCs and YTs help improve the efficiency of container management operations. Furthermore, with the dynamic assignment of yard trucks to containers (rather than vessels or QCs), an improvements in the utilization of YTs is expected. In this study, the assignment of containers to the quay cranes and trucks as well as the sequence of tasks performed by each quay crane and each truck are determined. The objective function of the presented model is a linear combination of the makespan of the vessel and the sum of the quay cranes' completion times. Utilizing a weighted linearization method to convert a multi-objective problem to a single objective one is a typical method for solving such problems.

The vessel's completion time is reduced to the lowest value by minimization of the makespan. Additionally, the minimization of the sum of the QCs completion times leads to the better utilization of quay cranes. In addition to the faster completion of tasks, this objective function will reduce the idle time of quay cranes. Among different schedules with equal makespan values, the schedule with the minimum sum of completion time for quay cranes is commonly considered as the most desirable solution. Nevertheless, the minimization of makespan enjoys greater significance. Accordingly, the makespan minimization weight in the objective function is more important than the reduction in the completion time of quay cranes.

In this study, it is assumed that at the same time, each crane or truck can only serve one container. Due to the linear placement of QCs on the rail, it is impossible for them to cross one another. In the literature, this practical assumption is known as the non-crossing assumption. There are no preset restrictions on the assignment of QCs to vessels or bays. Depending on the location of the containers at the vessel based on the stowage plan, there is a precedence relationship between containers that should be considered while loading and unloading. The cranes working on adjacent bays should have a certain distance as safety margin from one another. The purpose is to find a sequence of processing containers on QCs and YTs which minimizes the makespan of the vessel and the sum of the completion times of the containers on the QCs.

As previously mentioned, in order to increase the efficiency and utilization of YTs, each truck can serve several QCs. Basically, there are two types of operations for yard trucks. One is the one-cycle strategy in which each truck is assigned to and merely serves one crane. The other operation is called the two-cycle strategy where the trucks work with different cranes leading to a better utilization for them.

3. MATHEMATICAL MODEL

The presented model in this study is developed based on the model proposed by Behjat and Nahavandi [20] and is inspired from the concept of flexible jobshop problem for the modelling of integrated assignment and scheduling problem of QCs and YTs. The problem under study here is to consider quay cranes and yard trucks as machines, and containers are tasks that need to be processed on these machines. As both inbound and outbound containers are investigated, the issue can be considered as a special case of a flexible jobshop scheduling problem. The existence of real-world assumptions, such as the non-crossing cranes and the presence of a safety margin between them, make this problem more complex than a flexible jobshop problem.

There are two operations on QCs and YTs required for the completion of every container's task. To show these operations, notation O_hj is used where h stands for the number of operations and j shows the number of containers. For each inbound container, Operation 1 is performed by quay cranes and Operation 2 is proceeded by yard trucks. For the outbound containers, this operation count will be reversed. For instance, in the case of outbound containers, O_2j is the operation which is done by QCs on containers. In the proposed model, a dummy container is considered as the first container to be processed on each QC or YT. The parameters, decision variables, and the model are as follows:

Parameters:

m	Number of machines (sum of the number of QCs and YTs)
n	Number of jobs (containers)
Q	Number of quay cranes
i, j	Jobs index
l, h, l'	Operations index
k	Machines index
q_j	Location of job j (bay number)
Ω	Set of precedence constrained containers
J_1	Set of inbound containers
J_2	Set of outbound containers
Φ	Set of operations which should be processed on QCs
δ	Safety margin among quay cranes based on the number of bays
f_{hjk}	1, if machine k is capable to process the O_{hj} 0, o.w.
M	A large number
$\propto_1$	The weight of the makespan component of the objective function
$\propto_2$	The weight of the sum of the quay cranes completion times in the objective function
p_{hjlik}	The processing time of O_{hj} on machine k if it is processed immediately after O_{li} on machine k

Variables:

X_{hjlik}	1, if operation O_{hj} is processed immediately after the operation O_{li} on machine k 0, o.w.	$h, l = 1,2$ $i, j = 1, \dots, n$ $k = 1, \dots, m$
s_{hj}	The start time of operation O_{hj}	$h = 1,2$ $j = 1, \dots, n$
c_{hj}	Completion time of operation O_{hj}	$h = 1,2$ $j = 1, \dots, n$
C_k	Completion time of the last job on quay crane k	
Y_{hjk}	1, if operation O_{hj} is processed on machine k 0, o.w.	$h = 1,2$ $j = 1, \dots, n$ $k = 1, \dots, m$
Y'_{hjli}	1, if operation O_{hj} is processed after operation O_{li} (not immediately) 0, o.w.	$h, l = 1,2$ $i, j = 1, \dots, n$

The model:

$$Min \propto_1 C_{max} + \propto_2 \sum_{k=1}^{Q} C_k$$

$$\sum_l \sum_{i=0} \sum_k X_{hjlik} = 1 \quad \forall h = 1,2 \quad \forall j = 1, \dots, n \tag{1}$$

$$\sum_h \sum_j \sum_k X_{hjlik} \leq 1 \quad \forall l = 1,2 \quad \forall i = 1, \dots, n \tag{2}$$

$$\sum_l \sum_i X_{hjlik} \leq f_{hjk} \quad \forall h = 1,2 \quad \forall j = 1, \dots, n \quad \forall k = 1, \dots, m \tag{3}$$

$$\sum_h \sum_j X_{hj10k} \leq 1 \quad \forall k = 1, \dots, m \tag{4}$$

$$\sum_h \sum_j X_{hjlik} \leq \sum_{l'} \sum_{i'} X_{lil'i'k} \quad \forall k = 1, \dots, m \tag{5}$$

$$c_{hj} \geq c_{(h-1)j} + \sum_l \sum_i \sum_k X_{hjlik} \cdot p_{hjlik} \quad \forall h = 1,2 \quad \forall j = 1,\dots,n \quad (6)$$

$$c_{hj} \geq c_{li} + \sum_k X_{hjlik} \cdot p_{hjlik} - M(1 - \sum_k X_{hjlik}) \quad \forall h,l = 1,2 \quad \forall i,j = 1,\dots,n \quad (7)$$

$$s_{hj} \geq c_{li} \quad \forall (i,j) \in \Omega \quad \forall h,l = 1,2 \quad (8)$$

$$\sum_l \sum_i X_{hjlik} = Y_{hjk} \quad h = 1,2 \quad j = 1,\dots,n \quad k = 1,\dots,m \quad (9)$$

$$M(Y'_{hjli} + Y'_{lihj}) \geq \sum_k k \times Y_{hjk} - \sum_{k'} k' \times Y_{lik'} + 1 \quad h,l = 1,2 \quad j,i = 1,\dots,n \quad \forall q_j < q_i \quad O_{hj}, O_{li} \in \Phi \quad (10)$$

$$M(Y'_{hjli} + Y'_{lihj}) \geq \delta \times (\sum_k k \times Y_{hjk} - \sum_{k'} k' \times Y_{lik'}) + q_j - q_i \quad h,l = 1,2 \quad j,i = 1,\dots,n \quad \forall q_j < q_i \quad O_{hj}, O_{li} \in \Phi \quad (11)$$

$$s_{hj} + \sum_l \sum_i \sum_k X_{hjlik} \times p_{hjlik} = c_{hj} \quad h = 1,2 \quad j = 1,\dots,n \quad (12)$$

$$c_{li} - s_{hj} + M \times Y'_{hjli} \geq 0 \quad \forall h,l = 1,2 \quad \forall i,j = 1,\dots,n \quad (13)$$

$$c_{li} - s_{hj} - M \times (1 - Y'_{hjli}) \leq 0 \quad \forall h,l = 1,2 \quad \forall i,j = 1,\dots,n \quad (14)$$

$$C_k \geq c_{hj} - M \times (1 - Y_{hjk}) \quad \forall j = 1,\dots,n \quad h = 1,2 \quad \forall k = 1,\dots,Q \quad (15)$$

$$s_{hj}, c_{hj}, C_k \geq 0 \quad \forall h = 1,2, \quad \forall j = 1,\dots,n, \quad k = 1,\dots,Q \quad (16)$$

As mentioned earlier, the objective function is the minimization of a weighted sum of the vessel makespan and the sum of completion times of the quay cranes. Reducing a multi-objective optimization model to a single objective problem through a linear combination of the objective functions is a common approach in similar problems. In cases with the same makespan, solutions that also minimize quay cranes' idle times are preferred in order to enhance the utilization of cranes. Since minimizing the makespan is more important than the utilization of QCs, it is assumed that $\propto_1 = 0.99$ *and* $\propto_2 = 0.01$.

The constraint set (1) ensures that the operation O_{hj} is processed after exactly one operation. The constraint set (2) guarantees that at most one operation can be processed after the previously completed operation. The constraint set (3) ensures that the operation O_{hj} is processed on the machine that is capable to process the operation. For example, the first operation of outbound containers ($O_{1j}, j \in J2$) cannot be processed on a quay crane. Based on the constraint set (4), following the dummy jobs, only one job can be processed. The constraint set (5) ensured that if the operation O_{li} is not processed on machine k, any other operation cannot be processed after this operation on the mentioned machine. Constraint set (6) is incorporated into the model to calculate the completion time of the operation O_{hj}. The constraint set (7) ensures that each machine processes no more than one operation at the same time. The precedence relationship between containers is considered in the constraint set (8). The constraint set (9) is incorporated into the model to determine which operation is processed on which machine. The constraint set (10) constitutes the quay crane's non-crossing limitation. For two containers, if $Y'_{hjli} + Y'_{lihj} = 0$ (*i.e.* O_{li} and O_{hj} are processed simultaneously), if the position of container *j* is on the left side of the container *i* then the QC that processes operation O_{hj} is on the left side of the QC processing O_{li}. The constraint set (11) is incorporated in the model to ensure the safety margin among quay cranes. Assume that there should be a two-bay margin among adjacent quay cranes, and cranes 3 and 5 are processing containers simultaneously, there should be at least a 4 ((5-3) ×2=4) bay-margin between the cranes. The constraint set (12) computes the start time of operations. The constraint sets (13) and (14) are incorporated into the model to compute the Y'_{hjli} variable, showing the simultaneous processing of two operations. Lastly, the completion time of the last job on the quay crane k is calculated based on the constraint set (15).

Applying some simplification and assuming only inbound containers and the assumption that there is only one vessel at the terminal, the problem proposed in this research can be transformed into the jobshop scheduling problem with the makespan minimization objective function. Thus, the new simplified problem is of an NP-hard one as mentioned in the literature [21]. Therefore, it could be concluded that the former intricate problem is also an NP-hard problem. Hence, there is no possible way to precisely solve large-scale instances, and search-based metaheuristic methods are required to be developed to solve the problems.

4. SIMULATED ALGORITHM

The simulated annealing (SA), first proposed by Kirkpatrick et al. [22] in 1983, is a metaheuristic optimization algorithm which is effective in solving combinational optimization problems. This algorithm was inspired by an annealing treatment in metallurgy. The algorithm works by starting from an initial answer and moves to the next one based on the neighborhood search structure at each step of the algorithm. The condition for accepting a new neighborhood solution and moving on to that answer is that the new answer must be better than the current one. If not, it will be accepted with a defined probability. This probability is calculated based on the number of iterations performed and the objective function difference between the new and the current answers. The algorithm accepts the new solution with a probability of $e^{-E/T}$ if the problem has a minimization objective (or $e^{E/T}$ if the problem has a maximization objective), where E is the difference of objective function values between the current and the new solutions, and T is the current temperature [23].

4. 1. Solution Representation In this study, the initial solution is randomly generated. The proposed algorithm's solution representation has two main parts; the first one is the containers' processing sequence on the quay cranes and the allocation of the cranes to the containers, and the second part is the processing sequence of containers on the yard trucks and their assignment to each truck.

4. 2. Neighborhood Search Structure Two different operators are defined for generating a neighbor solution. Based on Operator 1, one point is randomly chosen along the array, thereafter, the position of tasks is replaced with each other with respect to the point (Figure 1).

Based on the second operation, the positions related to two elements along the array are swapped with each other. These movements are repeated for a random number of times (Figure 2).

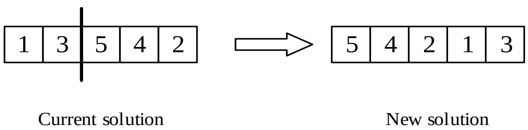

Figure 1. How Operator 1 works

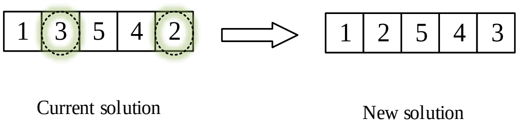

Figure 2. How Operator 2 works

4. 3. Grouping Simulated Annealing The grouping problems are somehow categorized as optimization problems in which the members of an arbitrary set of G are divided into several subgroups with the intersection of null and a sum equal to the set G. The key assumption in such problems is that the order of groups is of no importance. Some problems in optimization, including graph coloring, bin packing, batch-machine scheduling, and packing/partitioning problems, could be considered as the grouping problems. The allocation of QCs and YTs to containers are two assignment problems being discussed in this study. Since the arrangement of the quay cranes is important in their assignment (due to assumptions such as the safety distance or lack of crossing movements of the cranes), this problem cannot be considered as a grouping problem. Nevertheless, the problem of allocating yard trucks to containers is assumed to be a grouping problem because these trucks are similar and there is no specific spatial constraint on their allocation [24].

In the grouping version of the algorithm (G-SA), to update the allocation and sequence of containers on QCs in each iteration, Operators 1 and 2 are used according to Figures 1 and 2. The container group's allocation and sequence on the YTs, though, will be updated according to Figure 3.

4. 4. Stopping Criteria If the temperature reaches its minimum, the proposed SA will stop. This algorithm also stops when after a predetermined number of iterations, no improvement has been occurred in the current best solution.

5. NUMERICAL RESULTS

54 random sample instances are solved to evaluate the performance of the proposed mathematical model and the solution quality of the presented metaheuristic algorithms. To generate such random problems, the ranges proposed by Behjat and Nahavandi were used [20].

The design parameter values of the proposed SA (T_0, T_{final}, α) affect the performance and results of the algorithm. T_0 and T_{final} respectively represent the initial and final temperatures, and α is used as the cooling rate in each iteration (temperature in iteration n is equal to $\alpha \times$ temperature in iteration n-1). The parameters of the proposed SA are tuned by setting a trade-off between time and quality of the solutions. In order to find appropriate values for the parameters of algorithm, different combinations of parameters were tested on a large number of test instances, and 100, 0.01 and 0.96 values selected as the best values for T_0, T_{final} and α, respectively.

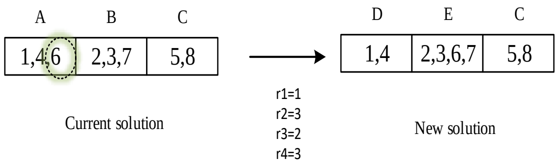

Figure 3. How G-SA crossover works

Problems in smaller dimensions can be precisely solved using CPLEX software which in addition to validating the presented model, create a situation to evaluate the performance of the developed algorithms. The proposed SA was able to obtain one optimal results from 6 proposed examples. For the rest of the examples, the difference between the answer obtained from the SA and the optimal mathematical model is between 1.67 and 3.43. This is while the G-SA was able to obtain an optimal solution of 3 examples out of 6. The mean difference between the optimal solutions obtained from the mathematical model and the near-optimal solutions of the SA and G-SA algorithms are 1.89 and 0.71, respectively, indicating the superiority of G-SA performance.

In Table 1 the relative percentage deviations (RPDs) values are presented for larger instances with three and four QCs in order to evaluate the performance of the developed algorithms. RPD as a performance measure is calculated based on the following equation:

$$RPD = (\sum_i \frac{OFV_i - OFV_i^{min}}{OFV_i^{min}})/n \times 100 \quad (17)$$

where n is the total number of solved instances, OFV_i stands for the objective function value for the given algorithm after solving the i^{th} instance and OFV_i^{min} is the best objective function value resulted from the given algorithm for the i^{th} instance.

For further evaluation of the proposed metaheuristics, the impact of the number of YTs on the makespan was also investigated. In Figure 4 the impact of the using a greater number of yard trucks and quay cranes on the objective function value is demonstrated. For this, an instance with 15 containers was solved for 2 to 4 QCs and 2 to 10 YTs. The results showed that there is a significant inverse correlation between the objective function value and the number of YTs.

The efficiency of two-cycling strategy versus one-cycling strategy for assignment of containers to the YTs has been studied by solving 9 random instances with two QCs and variable number of YTs. In the one-cycling scenario specific number of YTs are assigned to a quay crane at the beginning. However in two-cycling scenario, it is allowed to assign YTs in a dynamic manner during the time span of processing the containers. The results of solving these instances are shown in Figure 5.

TABLE 1. The RPD values for the proposed algorithms

No. of QCs	No. of YTs	No. of instances	Algorithms RPD (%)	
			SA	G-SA
	6	8	11.90	0
Three-QC	8	8	4.81	1.95
	10	8	8.34	2.02
	Total	24	8.35	1.32
	6	8	7.81	2.50
Four-QC	8	8	6.83	0.38
	10	8	6.95	0.29
	Total	24	7.19	1.05

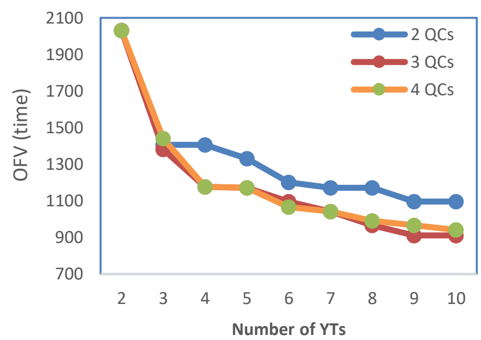

Figure 4. Effect of increasing the number of resources (YTs and QCs) on the objective function

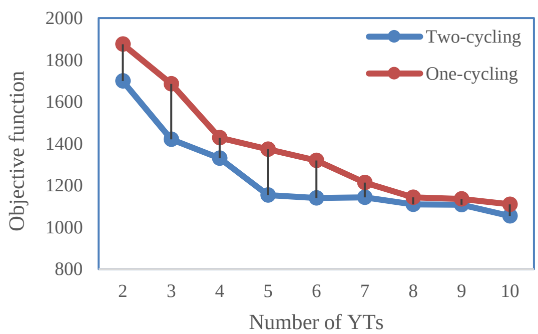

Figure 5. Comparison of the YT assignment strategies (two-cycling vs. one cycling)

6. CONCLUSION AND FUTURE STUDIES

An integrated scheduling and allocation problem of quay cranes and yard trucks at container ports is presented in this study. A mathematical model of bi-objective integer programming was developed taking into account real-world constraints, such as no quay cranes passing through each other, precedence relationships and safety distance between cranes. Since the presented problem falls into the category of NP-hard problems, two different versions of SA are presented for solving the problem. Based on the several numerical experiments, these algorithms can obtain optimal or near-optimal solutions, especially for small-scale problems. Moreover, given the concept of grouping in hybrid optimization problems, G-SA is proposed considering the allocation of yard trucks as a grouping problem. This algorithm produces better solutions than SA.

There are some limitations in the presented research which need to be considered in the future studies. There are a few sources of uncertainty in the real world that affects the scheduling of quay cranes and yard truck. Deviation of loading and unloading operation times of vessels from the estimated time, equipment failures, and other unforeseen events may cause disorders in the deterministic schedule. This leads to significant increasing of handling costs and dissatisfaction of the customers. So considering these uncertainties and dynamics of the real world is important and could be focused in the future researches.

Moreover there are vessel stability constraints which refer to appropriate distribution of containers weight on the vessel. That affects the sequence of loading or unloading containers on the vessel. This is a critical factor that should be considered during loading and unloading containers. Otherwise it may cause sagging, twisting or even overturning of the vessel.

In this research it is simplified by considering a pre-defined stowage plan. But some modifications of containers processing sequence may be needed during the loading/unloading process of the vessel. In other words, dynamic and real time rescheduling of containers may be required in the real world problems. This is another future research direction that could be followed by researchers.

Considering uncertainties in assumptions such as container processing time, proposing real time approaches based on the vessel stability constraints and offering a method to find a lower bound for evaluation of the metaheuristic algorithm are among what may be of interest to other researchers as a future research direction.

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Persian Abstract

چکیده

زمان‌بندی و تخصیص جرثقیل‌های اسکله‌ای در بنادر کانتینری از مسائل مهم و کاربردی در بهبود بهره‌وری این ترمینال ها به شمار می‌رود. در این تحقیق یک مدل ریاضی با هدف مدیریت یکپارچه جرثقیل‌های اسکله‌ای و کامیون‌های محوطه ارائه شده است. در این مدل فرضیات کلیدی دنیای واقعی از جمله فرض عدم عبور جرثقیل‌ها از روی یکدیگر و نیز فاصله ایمنی بین جرثقیل‌های در حال کار در نظر گرفته شده اند. نتایج عددی نشان می‌دهد که مدل عدد صحیح پیشنهادی، می‌تواند در حل مسائل با ابعاد کوچک به تصمیم گیران کمک کند. با این وجود به دلیل NP-hard بودن مساله پیشنهادی، الگوریتم های فراابتکاری به منظور حل مساله در ابعاد بزرگ تر پیشنهاد شده‌اند. همچنین با توجه به اینکه کامیون‌های محوطه به عنوان یکی از منابع اصلی مساله، تفاوت خاصی با هم ندارند، می‌توان از رویکرد گروه‌بندی در حل مساله استفاده نمود. از این رو الگوریتم شبیه سازی تبرید با رویکرد گروه‌بندی توسعه داده شده است که براساس آزمایش‌های صورت گرفته عملکرد بهتری نسبت به الگوریتم شبیه سازی تبرید عادی دارد.