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A SIMULATION-BASED OPTIMIZATION APPROACH FOR INTEGRATED PORT RESOURCE ALLOCATION PROBLEM

ABSTRACT

In the last few years, the remarkable increase of containerized trade and the resulting increase in congestion and operating costs of container terminals have indicated the importance of integrated management of port resources. This research investigates an integrated decision problem that deals with the simultaneous optimization of berth allocation, tugboat and quay crane assignment. The main contributions of the work are the integrated simulation modelling of port resource allocation problem and proposing an effective evolutionary path re-linking algorithm to find a globally good solution for the problem. The effectiveness of the proposed evolutionary algorithm is tested on RAJAEE Port as a real case. The result demonstrates the effectiveness of the proposed simulation-based optimization approach to find the near optimal solution within a reasonable time. The simulation experiment shows that the objective function value is affected significantly by the arrival disruptions and it is not sensitive to the variations of berth operation time.

KEYWORDS

container terminal; evolutionary path re-linking; berth allocation; simulation-based optimization

1. INTRODUCTION AND MOTIVATION

Today container terminals play an important role in the global trade, and better efficiency through organizational and operational efforts is being required. With the continuous increase in volume of marine cargo, efficient transporting and handling of vessels and containers has become a critical issue. The allocation of berth locations to ships arriving at container terminals is a critical part of the port operation management. Tugboat allocation is also an important task of the port operation system. Efficient tugboat allocation has direct and significant impact on which vessels wait in the port. The process of decision-making in ports is too complex to use mathematical programming and exact approaches. Hence, the applications of meta-heuristic approaches with the combination of simulation are more flexible and powerful solutions. A study by [1] proposed simulation-based optimization approach for the quay crane scheduling problem. In [2] a simulation optimization method through genetic algorithm for scheduling loading operations in container terminals has been developed. In [3] the combination of simulation and optimization methods with the aim of increasing the productivity of the terminal has been proposed.

This paper addresses the port operation planning including berth allocation, quay crane and tug assignment problems using simulation and optimization. The most important research objective is the integration of the crucial problems of berth allocation, tug allocation and quay crane assignment for better coordination of port operations. A solution approach for this problem is an effective tool for a port planner to generate an integrated resource allocation plan. The main constraints in the proposed simulation model include the tugboat availability and dynamic variation of tides.

The remainder of the paper is organized as follows. The following section presents a summary of literature review on port operation research models and algorithms. The problem statement is presented in Section 3. Section 4 explains the simulation model that has been developed. In Section 5, the proposed evolutionary optimization algorithm is described in details. Computational results of optimization method are presented in Section 6, and the conclusion and suggestions for further research are summarized in Section 7.

2. LITERATURE REVIEW

Because of the complexity, dynamic nature and importance of container transport, there have been a growing number of studies that deal with operation research models related to a container terminal. In the following sections a comprehensive review of related studies is presented.

2.1 Berth Allocation and Crane Assignment Problems

The Berth Allocation Problem (BAP) refers to efficient allocation of ships to appropriate berths. The main objective is to minimize the total service time for all ships. Discrete and continuous schemes are two primary approaches that can be used to model BAP. In this paper, a discrete berth allocation model is proposed that considers fixed length and dynamic available draft for every berth. Both discrete and dynamic versions of BAP are NP-hard problems [4]. In literature, a growing amount of attention is devoted to study the effect of unpredictable events and disruptions on the BAP. In [5] the disruption management problem of berth allocation to deal with the unexpected disruptions in container terminals is studied. The problem of recovering a baseline berth allocation plan in a dynamic situation as disruptions occur for bulk ports is also studied [6]. There are also some papers in literature that investigate the port planning problems with tidal variation constraints. In [7] the BAP is modelled in discrete form as a transportation problem wherein *N* ships are considered as suppliers and *M* tidal time windows are considered as consumers. In [8, 9] the ship scheduling algorithms considering environmentally-dependent time-varying draft and tug availability constraints is developed. In [10] an exact algorithm and a GA-based heuristic for the discrete and dynamic berth scheduling problem are developed.

The quay crane assignment problem (QCAP) refers to allocation of quay cranes to multiple vessels for container loading and unloading operations. QCAP is an important decision problem in a port container terminal. An intelligent allocation of cranes to the incoming vessels will decrease service time and increase terminal productivity, leading to higher revenues. A primary objective is to minimize the vessel's overall completion time. Another related problem is the quay crane scheduling problem (QCSP) which consists of scheduling loading and unloading operations on cranes that are assigned to a vessel for its service [11]. The QCSP is one of the operational planning problems found at container terminals and this problem is not addressed in this paper.

2.2 Tugboat Assignment Problem (TAP)

The economic benefits of a port are directly influenced by the berth allocation, quay crane assignment and allocation of the tugboats. A tugboat deficiency can result in an increase in the vessel waiting time at anchorage and berth. In contrast, low tugboat utilization imposes direct and indirect economic costs upon the port system [12]. To the best of our knowledge, limited studies are available on the tugboat allocation problem or the tugboat scheduling problem (TSP). In most research literature, the combination of the tugboat assignment problem with other port decision problems is not directly addressed. In [13] the assignment problem of load barges for pusher tugs for the scheduled period of one day is studied. In [14] a discrete event simulation model to analyze the port tugboat operations is developed. A study by [15] proposed a hybrid evolutionary strategy optimization for port tugboat allocation and operation scheduling. The situation in which more than one tugboat may simultaneously serve one vessel at the same moment of time is investigated, and a kind of general set multiprocessor task scheduling is presented. A study by [16] developed a heuristic simulation and optimization method for the allocation of tugboats in a port. In [12] a hybrid evolutionary strategy with the particle swarm optimization algorithm for solving a tugboat scheduling model is proposed. A study by [17] developed a mixed-integer programming model combined with a scheduling rule for the TAP. A study by [18] formulated the tugboat scheduling problem on a multi-anchorage basis as a multiprocessor task scheduling problem to minimize the total operation times for all tugboats in a port. It should be noted that the reviewed papers addressed the static version of the tug assignment problem while in this paper, a dynamic version is studied and analyzed.

2.3 Integrated models

Recent extensions of the BAP are integrated planning of berth allocation and quay cranes [19-21]. For a container terminal, effective berth and quay crane schedules have a great influence on the improvement of both operations. Some of the most important integrated port optimization models are summarized in *Table 1*. Due to complexity of the integrated port optimization problems, most of the proposed solution ap-

Table 1- Integrated port optimization models

Paper	Problem	Model	Solution approach
[22]	BAP+QCAP	Resource constrained project scheduling problem (RCPSP)	Heuristic
[20]	BAP+QCAP	MIP model	Genetic algorithm
[23]	BAP+QCAP	MIP models	Heuristic
[26]	QCAP+QCSP	MIP model	Simulation-optimization approach
[24]	BAP+QCAP	Multi-objective resource allocation theory	Heuristic
[27]	BAP+ QCAP	Mathematical model	Multi-objective hybrid genetic algorithm
[5]	BAP+QCSP	Simulation optimization approach	Local rescheduling and taboo search
[28]	BAP+QCSP	MIP models	Evolutionary algorithm
[29]	BAP+QCAP+QCSP	MIP models	Heuristic
Current paper	BAP+TAP+QCAP	Simulation based optimization	Evolutionary path re-linking

proaches are heuristic, meta-heuristic and simulation-based optimization.

In [20] a mix integer programming model has been developed for simultaneous berth and quay crane allocation problem and a genetic algorithm is proposed to find the solution. Heuristic approach for simultaneous optimization of berth and quay crane assignment has been addressed by [22], [23] and [24]. A study by [25] proposed a simulation-based Genetic Algorithm (GA) search procedure for the simultaneous berth and quay crane scheduling problem with uncertainties of vessel arrival time and container handling time. They study the discrete berth allocation problem for vessels arriving dynamically with different service priorities.

To the best of our knowledge, most proposed approaches are based on decomposing the whole problem and applying heuristic or meta-heuristic algorithms. We integrate the berth allocation problem with the quay crane operations and vessel carrying plan considering a limited number of tugboats (*Figure 1*). In the first stage, the berthing plan should be generated which represents allocating of vessels to berths in a feasible way. In the second stage, the generation of tugboat assignment plan for the arriving vessels will be made. Tugboats should be assigned to both incoming and outgoing vessels. The quay crane assignment problem is the next stage to complete the berthing operation of vessels.

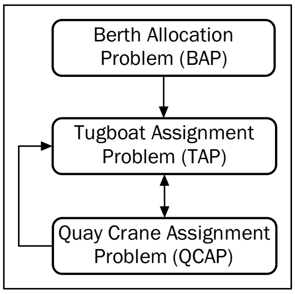

Figure 1 - The port operation models integrated in this research

3. PROBLEM STATEMENT

In this section, the problem will be described in detail and in the following sub-sections the specifications and constraints will be discussed. Various important considerations in decision-making for the berthing of a vessel are berth availability according to the tide level, draft constraint and length limit. As a new constraint, a time-varying draft condition into a berth allocation problem is introduced. The objective is to minimize the overall completion time of vessels. We aim to develop an integrated port planning model and solve it by simulation optimization. The proposed methods are tested on a real case: the RAJAEE Port. This Port is considered the most active container terminal in Iran. The RAJAEE Port plays a vital role in trading between Iran and other countries and has a substantial effect on the economy of the country. The case used to evaluate the proposed simulation-based optimization approach is a large-scale one in terms of the number of vessels and the number of berths. Therefore, it is a suitable case for testing the proposed solution method. The information given about this case is provided in the following sections. The simulation model and platform are discussed briefly in the next section.

3.1 Simulation platform

In this research, a discrete approach to berth modelling is utilized. The simulation model of a container terminal has been developed in Enterprise Dynamics discrete-event simulation software. Enterprise Dynamics from INCONTROL Simulation Software B.V., Utrecht and the Netherlands is chosen as a simulation platform because of its capability for developing the required objects and the ability to implement customized optimization algorithms. Enterprise Dynamics has designed various types of objects (atoms) to model real world processes. Atoms or simulation blocks are used for establishing the logic and store data. ED also has a built-in programming language called 4DScript. ED is used in different areas such as port simulation [30], railway planning [31, 32] and manufacturing [33, 34].

3.2 Berth Allocation Model

In this paper, two major types of operating vessels in the port are assumed in the berth allocation problem. First, liner vessel that works on regulated paths with specified schedules and second, tramp or feeder vessels that get hired for doing jobs in transportation systems and are planned and scheduled for that job exclusively. The problem is the allocation of berths to arriving vessels and assigning a number of cranes to each vessel. The berth allocation procedure is difficult as a result of variation in ship arrival times, arriving ships of various sizes, drafts and TEUs, different lengths and dynamic draft of berths, entrance channel constraints and limited tugboats. In this research, we also deal with uncertainty and stochastic disturbances in vessel arrival times. The arrived vessels should wait until all the necessary conditions are met. These various conditions are availability of berths and tugboats, berth length and draft level of the available berths. We also consider two safety issues for the entrance channel accessibility. First, the variations in entrance channel draft should be considered continuously, and the simulation model can use it to check whether a departure or leaving is allowed or not. The allowable draft for each vessel at each point in time is a restrictive factor for movements and berthing. Second, the entrance channel is designed in a manner that allows only ships with the same direction to pass it at the same time that means that crossing and conflicting of two opposite vessels is not allowed.

3.3 Quay Crane Assignment

After a ship reaches a berth, the quay crane operations start using available resources. A maximum number of quay cranes (QCN) can simultaneously load and unload cargo from a container ship. QCN is an attribute of each arriving vessel that depends on the characteristics of the vessel. The number of cranes that are already assigned to a vessel can increase. In the middle of loading and unloading operations, some new adjacent cranes may be released, and they can be assigned to the crane operations of the ships. Therefore, QCs are allowed to move to other berths before finishing processing for currently assigned vessels. This type of operation adds more flexibility to the terminal system. In this situation, the remaining loading and unloading time may decrease. After every re-allocation of cranes to vessels, the remaining completion time for crane operations should be estimated by creating an event in the event-handler. The flowchart of a conceptual model for quay crane assignment is illustrated in *Figure 2*. The flowchart is translated to 4Dscript language and used in the developed simulation model in ED. The terms and symbols used in quay crane assignment model are summarized in *Table 1*.

Table 2 - Terms used in modelling quay crane operations

Symbol	Description
QC_N	The maximum potential number of *QCs* that can be assigned to a vessel
$QC_S(t)$	The number of *QCs* already assigned to the vessel at time *t*
AQC	The number of new *QCs* allocated to the vessel
$QC_A(t)$	Number of idle available *QCs* in berth at time t
$RC(t)$	The number of containers remaining on vessel at time *t*
AR	The average speed of a normal QC per hour

Quay crane capacity and the assignment plan to vessels and also tonnage of carriers determine the service time for vessels in berths. The number of QCs which have already been assigned to the vessel at time *t* which is denoted by $QC_S(t)$, may increase after Δt due to the available QCs in the neighbouring berths. This new assigned cranes result in decreasing of vessels operation time. The availability of idle cranes will be checked periodically after Δt. After the berth operations have been accomplished, the ship will be prepared to depart from the berth.

3.4 Tugboat Assignment Model

The tug assignment plan is undertaken because in this way, the port schedules are more realistic since the availability of tugboats is considered. In the container port, the tugboats provide services for the vessels, including docking, berthing, shifting berth and departing from the berth or un-berthing. Tugs are needed to bring vessels into or out of a port. After carrying the vessels to berths, tugs return to the tug station or wait to transfer other vessels. Tugging vessels from one berth to another berth is called shifting berthing [18]. This work considers only berthing and un-berthing operations as tugboat services. The moment a vessel arrives at a container terminal, the vessel will request tugboats for docking at a berth. If there is an available berth, the container terminal will allocate the appropriate number of tugboats to the vessel for towing to the reserved berth. In this research, the vessels are ordered by the actual arrival time to anchorage, and the tugboat allocation is based on the First-Come-First-Served (FCFS) principle. The service time of tugs depends on the current location of the tugboat and the origin and destination of the vessel.

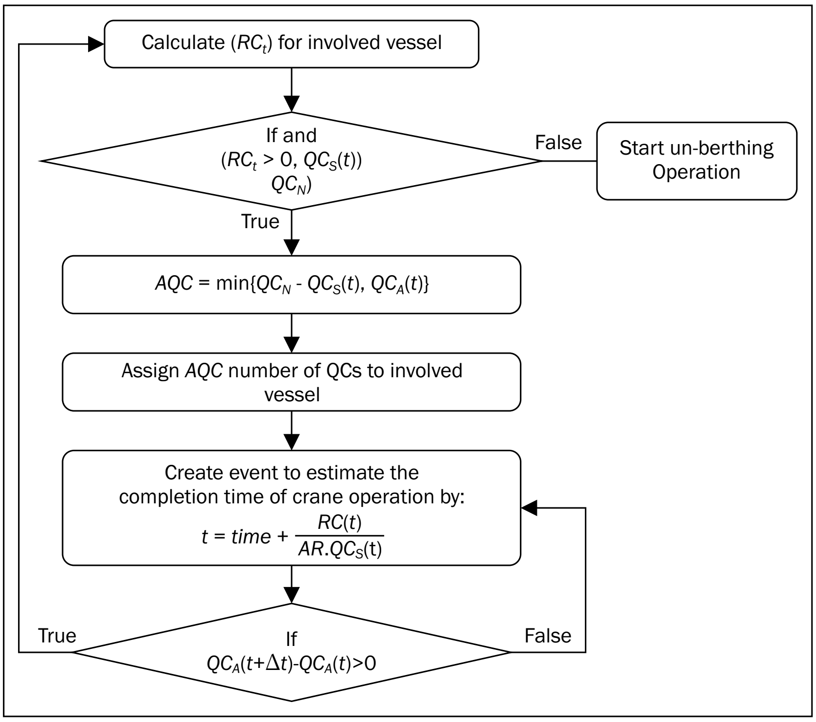

Figure 2 - A conceptual model of quay crane assignment

The assumptions about port topology are that the port contains a single entrance channel where vessels cannot pass each other and that the distances between berths are small compared to the distance from the berths to anchorage.

4. SIMULATION MODEL FOR INTEGRATED BAP, QCAP AND TAP

In this section, the proposed discrete-event simulation model will be described. A computer simulation model has been developed for integrated planning of dynamic and discrete berth allocation, quay crane assignment and tug allocation problems. Such a model can be created by designing customized objects and writing code in a 4DScript programming language. Simulation models can be used to determine the required resources to complete the port operations, subject to a set of constraints [35]. The use of simulation in connection with optimization may also assist port managers to develop effective and robust berth allocation strategies. The model is composed of objects that can be classified into resources, servers and queues. Resources are tugs to transport vessels. Servers represent the main process such as berthing, un-berthing and crane operations. It should be stated that for validation purpose, the simulation model is driven by detailed historical input data from the port terminal. In the following sections, we discussed the analysis of input data. These input data include the generation of vessel arrivals, assigning characteristics of vessels and tide distribution. The generated arrival distribution is validated and verified statistically against historical data obtained from a real container terminal.

4.1 Data input modelling

Comprehensive historical data about the ship arrivals and operations are available. The collected data are investigated to fit appropriate probability distributions, find averages and evaluate other input parameters that in later stages are used to generate the input for the simulation model. The arrival pattern of ships at the anchorage of RAJAEE port follows a negative exponential distribution as expected. The simulation model therefore assumes that the ship arrival at the anchorage follows a negative exponential distribution function. This arrival distribution is fitted for historical data of RAJAEE port during 2005 to 2011 using autofit tool in ED.

4.2 Modelling tidal effects in the simulation model

Most ports have safety restrictions on the draft of ships that are allowed to enter or leave the port to prevent groundings of deep-draft ships. These draft restrictions usually depend on the tide and therefore vary cyclically with time. When there is no available water depth for ships that are loaded fully at the quay, they must wait until the sea level becomes higher than the required draft. Generally, tides are the periodic increase and decrease of sea levels affected by

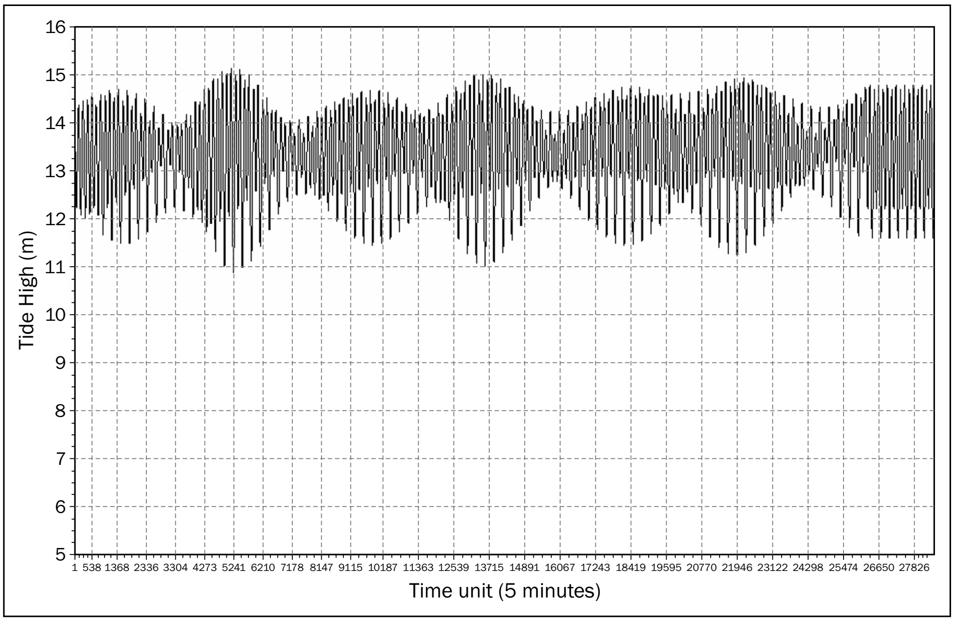

Figure 3 - Long-term tidal variations at RAJAEE port, Iran, during a 90-day period

the gravitational forces. In the case of tidal variations, draft status depends on high tide levels and subsequently available depth at the low tide condition is not adequate for the movement of vessels. A historical data graph on tide level at RAJAEE Port is shown in *Figure 3*. Tidal data for the study period must be available in the simulation model. A complete tidal cycle is approximately 13.8 days with mean sea level of 2.345 m. The highest water level is nearly 4.131 m.

4.3 Estimations in berth planning

Port operational management uses estimation indexes to plan berth allocation. These indexes are Expected Time of Arrival (ETA), Expected Time of Berthing (ETB), Expected Time of Completion (ETC) and Expected Time of Sailing (ETS). Among these estimations, ETA is known, but the other parameters depend strongly on berth availability, operational constraints, tidal variations, vessel handling time and the priority of the vessels. In reality, the actual arrival time of vessels to anchorage may deviate from the baseline plan because of bad weather condition and unexpected failures during the sea journey, which can disturb the base berth allocation schedule and probably make the whole solution infeasible. Both positive and negative deviations may disrupt the berth allocation plan and cause additional waiting time in anchorage. Deviation between the ETA and ATA through the historical data from 2005 to 2012 in RAJAEE Port is shown in *Figure 4*. It shows that the deviation variance increases across time.

The mean and standard deviation of this distribution are calculated and summarized in *Table 3*. The distribution of deviation is assumed to be normal with 0.737 hours of mean and 11.9 hours as standard deviation. This distribution is used to evaluate the robustness of the berth allocation plan.

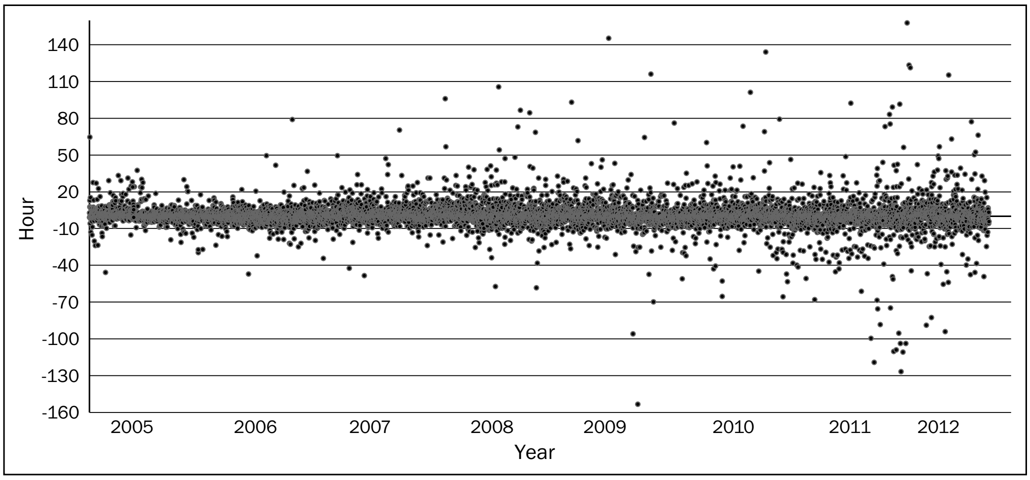

Figure 4 - Deviation between Expected Time of Arrival and Actual Time of Arrival in RAJAEE Port

Table 3 - Fitting test for deviation in ETA data

Distribution Summary		Chi Square Test	
Distribution:	Normal	Number of intervals	= 10
Expression:	NORM(0.737, 11.9)	Degrees of freedom	= 7
Square Error:	0.110380	Test Statistic	= 4.48e+003
		Corresponding p-value	< 0.005
Data Summary		**Kolmogorov-Smirnov Test**	
Number of Data Points	= 7,807	Test Statistic	= 0.171
Min Data Value	= -154	Corresponding p-value	< 0.01
Max Data Value	= 158		
Sample Mean	= 0.737		
Sample Std Dev	= 11.9		

5. SIMULATION-BASED OPTIMIZATION

In this paper, the proposed simulation-based optimization method for berth, tug and quay crane assignment problems consists of optimization and simulation as major modules (*Figure 5*).

The combination of the simulation and optimization approaches can handle the stochastic and dynamic nature of this real world problem. Simulation model is used as solution evaluation tool and the solution population evolves and will be refined according to the resulting performance of the solutions. The evolutionary path re-linking (EvoPR) algorithm is a population-based meta-heuristic algorithm that can be integrated with different meta-heuristics. Evolutionary optimization approaches such as the Genetic Algorithms and Scatter Search explore the solution space by generating and then evolving a population of solutions. The evolution is done by methods that generate new solutions by means of combination of two or more individuals that are in the current pool of solutions. With the same idea, the EvoPR algorithm searches the path between two elite solutions selected from an elite set to find new high-quality solutions and to improve the quality and diversity of the elite set population. Different successful applications of path re-linking are reported in literature. For example, [36] used evolutionary path re-linking as an intensification step. In EvoPR, the solutions in the pool are evolved as a series of populations P_1, P_2 ... of equal size. The initial population (P_0) is the pool of randomly generated solutions. In iteration k of EvoPR, path re-linking is applied between a set of pairs of solutions in population P_k and, with the same rules used to test for membership in the pool of elite solutions, each resulting solution is tested for membership in population P_{k+1}. This evolutionary

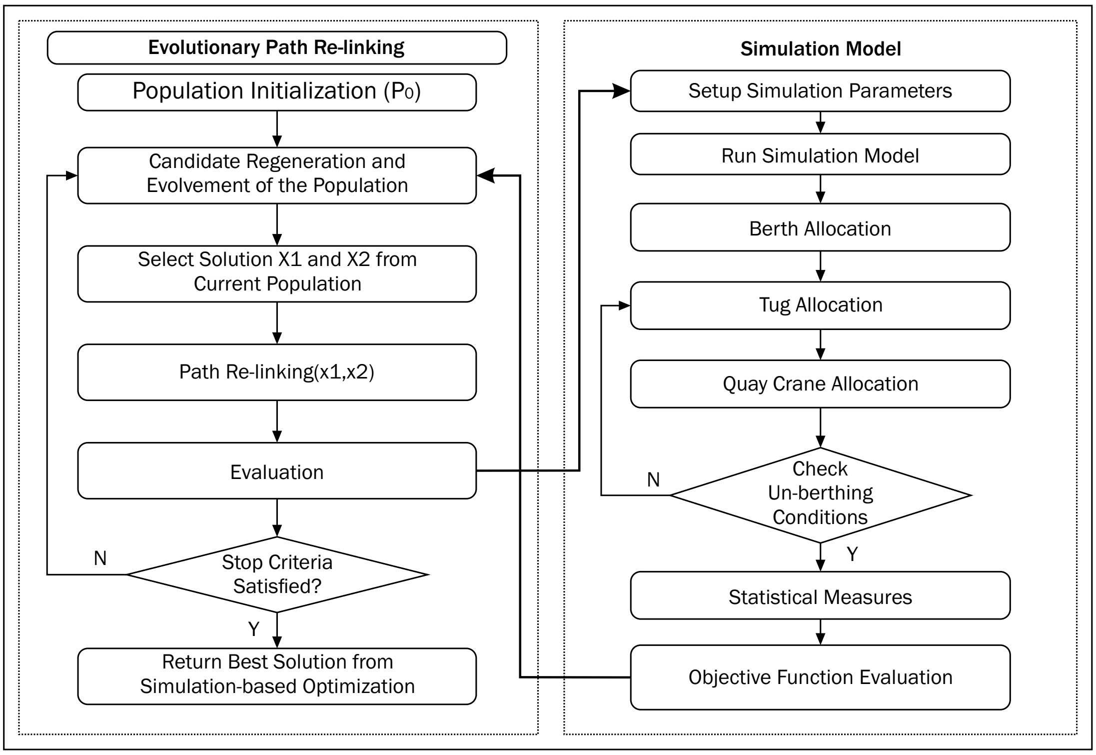

Figure 5 - The proposed simulation-based optimization framework

process is repeated until no improvement is seen from one population to the next.

In this paper, an integer matrix form is proposed to encode a solution. Every vessel experiences berth operation, tugboat allocation, quay crane operation and another tugboat allocation to leave port. Parameters used in solution representation with their ranges are summarized in *Table 4*.

Table 4 - Parameters used in encoding the scheme of solution representation

Solution encoding parameters	Range
Total number of incoming vessels to port (n)	[1,n]
ID number of terminal	[1,2]
ID of the assigned berth	[1,7]
Type of allocated tugboat	[1,4]

The solution can be represented in an integer n*k matrix (*Table 5*). In the investigated problem, k is equal to 4. For example, if we assume that there are 10 ships that should to be served, then the coding expression of the solution should be a 10×4 matrix.

6. EXPERIMENT ANALYSIS

The proposed simulation-based optimization framework will be applied to a real case study referred to as the RAJAEE terminal container port located in the south of Iran. First, the collected data from RAJAEE Port will be summarized and discussed in the next section. Next, the computational result will be discussed in optimization result section.

6.1 RAJAEE Port

The RAJAEE Port is located at a distance of 1,500 kilometres from Tehran, the capital city of Iran, and there is a 23-kilometre distance between this port and the Persian Gulf. This port connects to more than 80 ports worldwide, and the highest rate of cargo transit through the country and towards Central Asia passes through this port. The information for RAJAEE Port is summarized in *Table 6*. Terminal number 1 of RAJAEE Port consists of 850 meters of berths with a depth of 17 metres and 70 hectares of yard, and this terminal can accept even 7^{th} generation of container ships. The current capacity of the port for transportation is approximately 2 million TEU per day. This capacity cannot meet all the incoming demands considering the remarkable growth of container operations, and consequently, the containers have a long stopping time there, which is the underlying problem for the port performance. To tackle this problem, a new terminal will be constructed, including 2,050 metres of berths with a depth of 16 metres and 140 hectares of yard.

All types of Liners and Feeder Ships are provided with services in the container terminal of RAJAEE Port, and 21 shipping channels of Liners are active there. The statistics related to container loading and unloading indicate that the RAJAEE Port is the only port in Iran connected to the container transport information net-

Table 5 - An example of the solution representation scheme used in optimization algorithm

Vessel #	Assigned terminal #	Assigned berth #	Tugboat# allocated (docking)	Tugboat# allocated (Un-berthing or leaving)
1	1	4	2	3
2	1	2	4	4
3	2	3	1	1
4	1	1	2	1
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
n	2	2	1	1

Table 6 - Summarized information for RAJAEE Port

Terminal No.	Berth No.	Berth length (m)	Water depth of berth (m)	The number of available quay cranes
1	4	340	12	10
	5	300	12.5	
	6	270	12.4	
	7	250	11.7	
2	25	365	15.8	8
	26	370	16	
	27	375	16.2	

Table 7 - Categorizing entering vessels and probability distribution of their length and required depth

Vessel type(%)	Vessel type (%)		Average Length(m)	Average Draft	QC norm	Percentage (%)	Total Operation (Boxes)
Liner 65.80%	type 1	35.26%	173	8.6	1.95	38.27,35.15, 19.89, 6.69	288, 736, 1218, 1867
	type 2	38.28%	222	12.8	2.51	12.31,30.84,29.09,27.76	351, 756, 1221, 2229
	type 3	21.37%	279	14.5	3.15	1.75,11.12,26.01,61.12	380, 854, 1247, 2727
	type 4	5.09%	316	14.5	3.57	8.88, 13.9, 77.22	797, 1229, 3164
Feeder 34.20%	type 1	13.42%	77	5.1	0.88	38.27, 35.15	137, 539
	type 2	37.34%	136	6.7	1.53	19.89, 6.69, 12.31	314, 729, 1084
	type 3	33.60%	165	8.2	1.87	30.84,29.09,27.76, 1.75	284, 745, 1169, 1640
	type 4	15.65%	216	12.5	2.44	11.12,26.01,61.12, 8.88	338, 728, 1245, 2079

Table 8 - Types and quantity of tugboats

Tugboat type by horse-power	1,100ps	2,400ps	3,000ps	4,400ps
Quantity of tugs	1	1	2	5
Length of carrying vessels (L)	Small vessels	m	M	m

work, and by considering the importance of container transportation in international transit, the crucial role of this port in the north-south corridor becomes clearer. The information for incoming vessels according to historical data is summarized in *Table 7*.

There are 9 tugboats working in RAJAEE Port. Different types of tugboats are used at port according to the horsepower unit, such as 1100PS, 2400PS, 3000PS, and 4400PS. The allocation rules for tug assignment are summarized in *Table 8*.

6.2 Optimization results

The proposed optimization algorithm has been examined on real large-scale test problems. Test problems are extracted and prepared from real data for the arrival of the vessel to port during 2005 to 2012. The problem size for *i*th test problem (n_i) which represent the number of vessels are n_1=412, n_2=968, n_3=950, n_4=1,164, n_5=1,274 and n_6=2,737. The initial population (P0) is also set to 100 for all test problems. The average total waiting time of vessels at both anchorage and berth is selected as an objective function. The best solution found by an optimization algorithm in different test problems is shown in *Figure 6* and *Figure 7*. The test problems are completely independent form each other and they are extracted from a real data set. The vessel's arrival pattern for all these six test problems are negative exponential but with different averages. The average inter-arrival time between two consecutive vessels for test problems are 10.06, 9.04, 9.21, 7.53, 6.87, and 6.54 hours.

The result in these figures also shows the convergence rate of the evolutionary optimization algorithm to an optimal solution, but there is no guarantee that the best solution found will be the optimal solution.

The results indicate that the proposed meta-heuristic is fast and effective for large-scale berth allocation problems. Based on results from the simulation experiments, the effect of unpredictable tidal levels was considered significant, affecting the performance of the port. These uncertainties about weather condi-

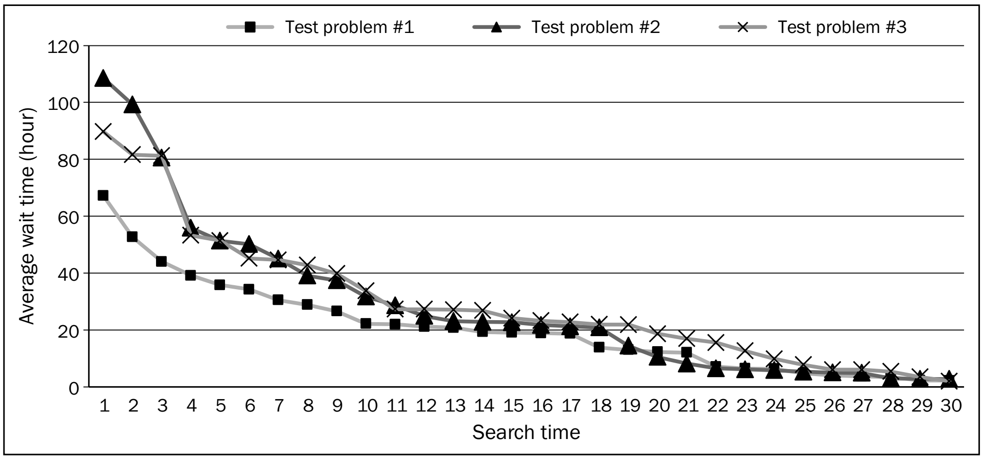

Figure 6 - Objective function value of the best solution found during the search (Test problems #1, 2, 3)

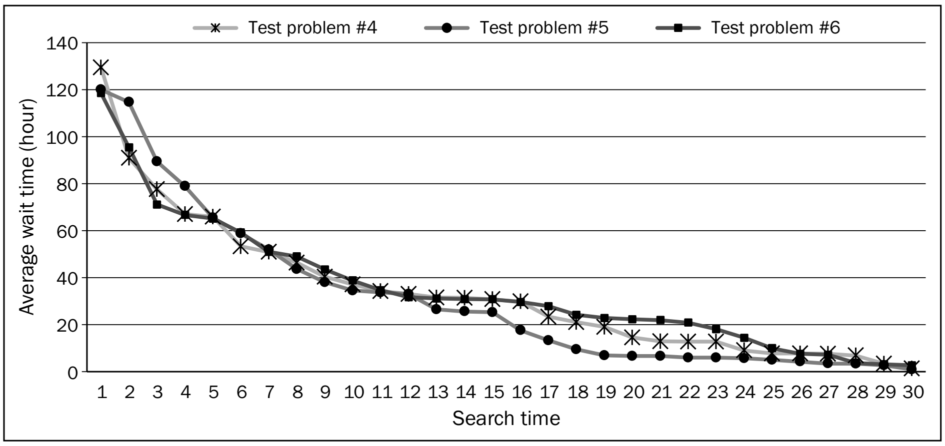

Figure 7 - Objective function value of the best solution found during the search (Test problems #4, 5, 6)

Table 9 - Result of simulation model for the average of all test problems

Criteria	Average	Standard Deviation	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Berth Utilization in Terminal#1	23.66%	1.5	21.81	25.52	22.39%	26.01%
Berth Utilization in Terminal#2	22.54%	2.61	19.29	25.79	20.70%	27.01%
Operation time (min)	3010.74	786.66	2033.78	3987.71	2054.58	3955.27
Handling time (min)	3755.72	932.99	2597.03	4914.42	2639.22	4886.53

tions that have an effect on wait times can be evaluated suitably by simulation experiments.

It is also interesting to analyze other performance measures by simulation model. To do this, using best solutions found in the test problems, a simulation experiment is conducted to calculate the average berth utilization and estimate vessels operation and handling times by 95% of confidence level (*Table 9*).

6.3 Robustness measurement

In this section, the robustness of the final best solutions found in the test problem is evaluated. We take the best solution found during the search time as the final solution. The deviation distribution of ETA is used as a disruption factor to disturb the best solution. The result of robustness measurement for test problems 1, 2 and 3 shows that the disrupted solutions are sensitive to the variation of ETA (*Figure 8*). By the simulation experiments, we can see that the objective is most sensitive to the arrival disruptions and not sensitive to the variations in berth operation time.

Table 10 shows the results of the simulation model and summarized statistic measures on the test instances 20 iterations. In general it can be seen that the solution quality is not stable by the stochastic disruptions.

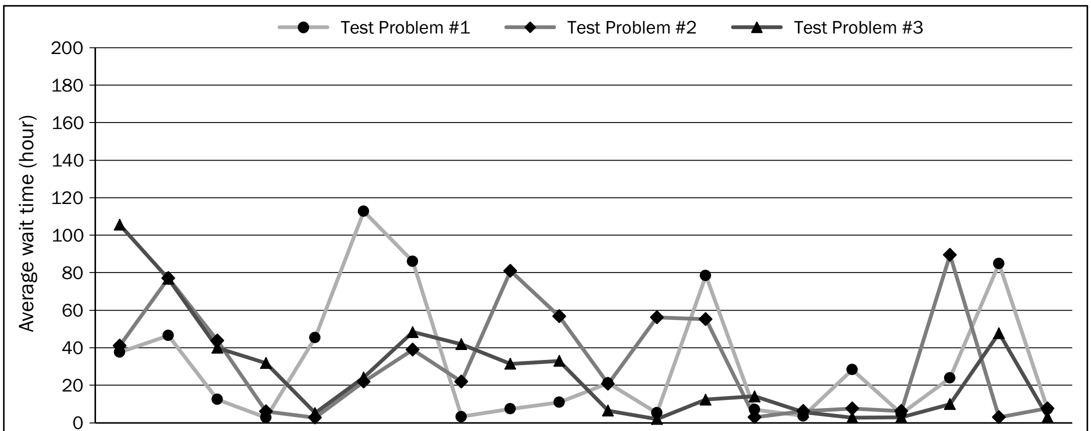

Figure 8 - Variation in objective function value of best solution for test problem#1 to #3

Table 10 - Summary of statistic measures for test problems #1 to #3 in 20 iterations

Average wait time (hour)	Test problem#1	Test problem#2	Test problem#3
Average	31.466	32.323	27.234
Standard Deviation	33.718	28.845	27.516
Minimum	2.796	2.731	1.961
Maximum	112.728	89.518	105.481

7. CONCLUSION

In this research, a dynamic berth allocation problem was studied. It takes into account the vessel type, tidal effect, allocation of tugboats to transfer vessels, and quay crane assignment planning. A simulation-based optimization is proposed to deal with stochastic processes and dynamic tides. The inclusion of tide variations is probably a realistic variable that affects the performance of berth allocation solution. The berth allocation problem was treated in a discrete framework, and the aim was to minimize total wait time for ships using an evolutionary path re-linking optimization algorithm. The main contributions of the work were the integrated modelling of port operation problem, considering the dynamic tugboat assignment problem and proposing an effective and fast evolutionary optimization algorithm to find a globally good solution for the problem. Among the benefits of the proposed simulation model is a novel integrated view of port resources in container terminals, which are formulated as a unified resource allocation model.

The effectiveness of the optimization algorithm was verified by the numerical experiments. The proposed evolutionary algorithm shows its flexibility and fast rate of convergence for the large scale port optimization problem. The simulation model has been applied to container terminals in IRAN, and it was found to be effective in optimizing integrated port operations as well as in evaluating the solution robustness. The robustness of the best solutions subject to disruptions on vessels' arrival times was also analyzed. According to the simulation result, it can be concluded that the objective function value is affected significantly by the arrival disruptions. Therefore we need to design flexible and robust resource allocation plan to handle disruptions. Further research is identified as the berth allocation problem for the development of methods to improve important performance measures such as timeliness and robustness. Port disruption management is also a critical new topic of further research.

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چکیده

ارائه رویکرد بهینه سازی مبتنی بر شبیه سازی برای مسئله یکپارچه تخصیص منابع در بندر

عبدالرضا شیخ السلامی[1]، غلامرضا ایلاتی[2]، عرفان حسن نایبی[3]

در سال های اخیر، افزایش قابل ملاحظه ای که در حجم مبادلات کانتینری رخ داده و منجر به افزایش تراکم تردد کشتی ها و هزینه‌های عملیاتی در بنادر کانتینری شده است، اهمیت مدیریت یکپارچه منابع بندر را روشن نموده است. در این تحقیق، مسئله تصمیم گیری و بهینه سازی یکپارچه تخصیص پهلوگاه ها، تخصیص یدک کش ها و جرثقیل های اسکله ای مورد بررسی قرار گرفته است. نوآوری های اصلی تحقیق در ارائه مدل شبیه سازی ترکیبی تخصیص منابع و ارائه الگوریتم بهینه سازی تکاملی اتصال مسیر در راستای یافتن جواب های بهینه سراسری برای مسئله تحقیق است. الگوریتم بهینه سازی تکاملی پیشنهادی در بندر شهیدرجایی پیاده سازی گردیده و کارائی این الگوریتم مورد ارزیابی قرار گرفته است. نتایج بر این مورد تاکید دارد که رویکرد بهینه سازی مبتنی بر شبیه سازی از کارائی لازم برای یافتن جواب های نزدیک به بهینه در زمان معقول برخوردار می باشد. نتایج شبیه سازی نشان می‌دهد که حساسیت مقدار تابع هدف نسبت به اختلالات در زمان ورود کشتی ها بیشتر از تغییرات زمان عملیات کشتی ها است.

واژه های کلیدی

بندر کانتینری، اتصال مسیر تکاملی، تخصیص پهلوگاه، بهینه سازی مبتنی بر شبیه سازی

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