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Genetic Algorithm to Solve Container Storage in Aden Container Terminal

Aseel Abdan Abdan MOHAMMED

Information Technology Department - Faculty of Engineering / University Aden, Aden – Republic of Yemen

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ABSTRACT

In this paper, the container storage problems were considered under uncertainty where the storage area is organized in fixed stacks with a limited height. Such problems appear in several practical applications, e.g., when loading container terminals, container ships or warehouses. Commonly in container terminals, the containers are stored in yards on top of each other using yard cranes and incoming items arriving at a party filled storage area have to be assigned to stack under the restriction that not every item may be stacked on top of every other item and considering that some items with uncertain data will arrive later. For this reason, a number of studies have proposed the use of Genetic Algorithm (GA) as the means to obtain the solution in reasonable time. This study extends the research in this area by utilizing the GA that is available in Global Optimization Toolbox in Matlab 2021b to facilitate development.

INTRODUCTION

Container terminals are an absolutely critical asset to a nation's economy, infrastructure and quality of life. As the world trade market resolves more barriers every day, containers become more important to transport goods from countries and continents to anywhere in the world.

Nowadays the maritime transport has a key role in the international trade, and a growing number of industries require an effective and efficient service in order to meet the 5 R's of lean logistics: The Right product in the Right quantity and Right conditions, at Right place in the Right time, pursing a low-cost strategy focused on the minimization of the "Total Cost" due to all logistics activities. In this context, the container terminals and its facilities play a fundamental role in the global supply chain.

The temporary storage of the inbound and outbound containers is one of the most important services at the container terminal that is known as the Storage Space Allocation Problem (SSAP). The storage area in the terminal is divided into the several blocks of containers. Each block consists of a number of containers stacks that are of4-5 tiers of containers.

The fast storage and retravel of containers at the blocks are essential for the economic performance of container terminals and also shipping companies. These issues affect directly on the traffic of handling equipment and consequently on the dwell and turn-around time of vessels. The processes of the storing (or retrieving) of a container includes the time for adjusting RTGCs, picking up container, moving toward the allocation place and downloading container. Since a container must be allocated to (or picked up from) a certain place at the block, it may be necessary to relocate one or more other containers for accessing to that container. This means a higher operating time and cost for RTGCs. Thus, it can be stated that balancing workload between blocks is critical element of the efficiency of the container terminal and it is important in reducing transportation costs and keeping shipping schedules.

MOTIVATION

As many researchers focus on the berth allocation problem and quay crane scheduling, in this research the problem of containers stowage is addressed and better solved using the Genetic

Algorithm; as the long turnaround time is mainly caused due to yard storage and container stowage problems.

In addition, continuing our focus in research and studying the Yemen ports, as what was done in [1] by solving the berth allocation problem of Ma'alla Port, here we study Aden Container Terminal.

Container terminals are important connection between different transportation modes, nowadays most of the transportation customers use the containers for their trading. Both, customers and port managers and also shipping lines concern about productivity, because productivity has effect on port efficiency more than other factors; on the other hand, long turn around time has a huge impact on ships and port customers which cause more waiting and process time.

With less waiting time customers can do their job faster and don't waste extra time because the time that vessels stay in the port area, they should pay charges for that. For this reason, customers and vessels prefer to leave berthing area as soon as it possible, here comes the importance and the need for an approach to queue problem and guarantee the service quality at berth area.

In a nutshell, developing and solving the yard storage space allocation problem will significantly result in a speed up and more efficiency in quay crane scheduling and minimize berth time of vessels. In addition, and this is a very important point to notice that by this research we will improve the performance within the current existing equipment without the need for new more upgraded ones.

LITERATURE REVIEW

A number of researchers studied the yard stowage, scheduling of yard cranes in a container terminal; problems associated with allocating and scheduling the resources such as berth, storage space and handling equipment in a container terminal have been extensively studied in the past few years.

Traditionally, in scientific literature many studies appeared on both the planning and management of container terminals, with the aim of jointly increasing efficiency and reducing operational costs. In the past, planning and management of operations in container terminals have been studied separately and independently for the seaside (berth and quay) [2], the landside (yard and gates), and the transport area (between quay and yard) of terminals.

In this part, will present different reviews of literature treating yard storage problem:

In the seaside research field, three main problems have been investigated: the Berth Layout Problem (BLP), the Berth Assignment Problem (BAP), the Quay Crane Assignment Problem (QCAP) and the Quay Crane Scheduling Problem (QCSP).

In my previous research [1], the Berth Allocation Problem (BAP) of Ma'alla Port was estimated the optimum number of berths and cranes required in order to minimize vessels queuing time. The optimization strategies are based on the hypothesis that the increment number of berths and cranes can reduce the average waiting time at port. The Queuing theory has been made as a main reference to determine the best selection of parameters in the mathematical model. The use of mathematical model is the best fundamental for simulation analysis. The best selection of variables in the mathematical model will improve waiting time. The developed mathematical model can be used for existing and new port, for through simulation.

Also, a review of studies on seaside operations appeared in scientific literature in the period 2004-2015 is in [3,4]. In both papers, authors classify studies by means of the assumptions and performance measurements adopted.

As far as concern the transport area, the main problems investigated in scientific literature deal with the selection of the MHE (Material Handling Equipment) to be adopted and the number of vehicles to be adopted as well as their routing and dispatching. In this research area also collision and deadlock problems are investigated, since in many terminals automated vehicles (Automated Guided Vehicles AGVs or Automated Lifting Vehicles- ALVs) are often adopted. A review of scientific contributions on this topic is in [5,6].

With reference to the landside area, storage yard layout, yard MHE selection and scheduling, storage allocation problem, container re-shuffling and truck arrivals management are the main problems investigated in scientific literature.

Reviews of scientific contributions on these topics are in [7,8]. More recent contributions can be found in [9] (on integrated schedules of MHEs), in [10] (integrated schedules of QCs, Yard Trucks YT and Yard Cranes YCs) in [11] (YCs scheduling minimizing the energy consumption), in [12] (vehicles scheduling, yard crane scheduling and container storage location).

Hamdi *et al* [13], studied a combination between two known problems, the first was the storage location assignment problem, and the second is the straddle carrier scheduling problem. In fact, they studied the multi-objective integrated problem of location assignment and straddle carrier scheduling (IPLASS) in maritime container terminals at import. They proved that the problem is NP-complete.

In [14], Mei *et al*, they process a novel integer programming model to solve optional problem of yard crane scheduling with minimal energy consumption at container terminals from low carbon perspective.

The berth allocation and quay crane assignment using genetic algorithm was studied in [15] by Maria *et al*, they consider the problems as a representative example of scheduling problems where a typical objective is to minimize the service time.

Luiz de Araujo and Placido P. [16] approached the container problem with maximization of the weight distribution. They applied a genetic algorithm to found solution in maximize its weight distribution.

Seyecl Homayouni *et al* in [17] formulated the integrated scheduling of quay cranes, automated guided vehicles and handling platforms in SP-AS/RS and were solved using the simulated annealing with genetic algorithms.

Aden Container Terminal

Aden Container Terminal was officially opened in 1999 and various international container terminal operators have operated it. It is currently managed by Aden Ports Development Company, since 20 September 2012.

The ACT is located on the north shore of Aden inner harbour and handles import, export and transshipment containers. The total length of the quay is 710m and depth alongside is 16.0m at chart datum (zero tide). It can accommodate container ships of up to 350m LOA. The berths are equipped with seven ship to shore gantry cranes. Two were installed in 2012, each having a 60 metres outreach from the front of the fenders (22 rows) and 65 MT lifting capacity under the spreader. The other four are Reggiane super post-Panamax Ship to Shore (STS) gantry cranes (4 installed in 1999 of which 1 was demolished in Jan 2020, and 1 installed in 2002), each having a 52m outreach from the front of the fenders (18 rows) and a lifting capacity of 40 MT under the spreader.

The container yard covers a total area of 45 hectares. The yard provides 6,635 x 20 foot ground slots for standard containers in 31 yard blocks, most of which are 46 slots long. Storage capacity is 19,477 TEUs when stacked three high and four high stacking can be used.

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A total of 16 Rubber-Tyred Gantry cranes (RTGs) are available in the container yard. Around 29 tractor units and 65 trailers move containers between the quay and the yard, supported by reach stackers for handling empty containers and other work and (9) forklifts.

Figure 1 Aden Container Terminal. Photo: Earth Google

The yard has 269 reefer container power points in a dedicated bay. A 97m x 48m CFS and multi-country consolidation shed, with office space, is located to the rear of the container yard, together with terminal offices.

Power is provided to ACT by an independent power station (14.7 MW). It also has a desalination plant, workshops, waste treatment plant and reefer container repair, maintenance and cleaning facilities. ACT operates a fleet of service, maintenance and emergency vehicles and is in the process of modernizing its infrastructure, equipment and operations to provide additional handling capacity.

Table 1 Equipment & Machinery of ACT

Equipment & Machinery	**No.**	**Operating Capacity**
Gantry Cranes	6	4 of them have a lifting capacity of 40 tons and two of which have a lifting capacity of 65 tons
RTGS	16	All of them have a lifting capacity of 40 tons, 12 of which are GPC type and 4 type Fantuzzi
Forklifts	9	5 of them have a capacity of 3 tons, 3 with 5 tons capacity and one of 15 tons capacity
Tractors	29	12 of them are Kalmar type, 10 are Mafi type, and 7 are Magnum
Trailers	65	57 trailers of 40 feet loading capacity, 5 of 40 feet loading capacity for unloading and loading in warehouses, 3 of 20 feet loading capacity
Reefer Points	269	420 /220 V
Storage Capacity	6636	19.477
Total area	45	Hectares

Problem Description

The unloading task consists of a set of operations performed by (quay and yard) cranes and vehicles to unload a container from the vessel and discharge it into a slot of a bay in the container yard. The yard comprises several blocks, each one having several bays; each bay contains a set of rows, and each row consists of a set of tiers, usually 4 or 5 (Figure 1). The quay crane moves from its dwell point to the vessel, lifts a container and transfers it ashore to be loaded on a vehicle (train or truck). The loaded vehicle goes to the load/unload station of the appropriate block and shifts the container to the yard crane. The yard crane moves the container to a predetermined row of a bay in a particular block and places the container in the slot.

The loading operation is also carefully planned in a container terminal. In order to have an efficient stowage plan, the outgoing containers should be put into storage in a good configuration, i.e. if need be, an outgoing container should be picked up immediately, instead of having several containers being stacked on top of it and needing to be moved elsewhere. Although the order in which containers will be picked up is usually not known in advance, a rough estimate of residence time can usually be made which could be used to identify which containers should (not) be put on top of each other.

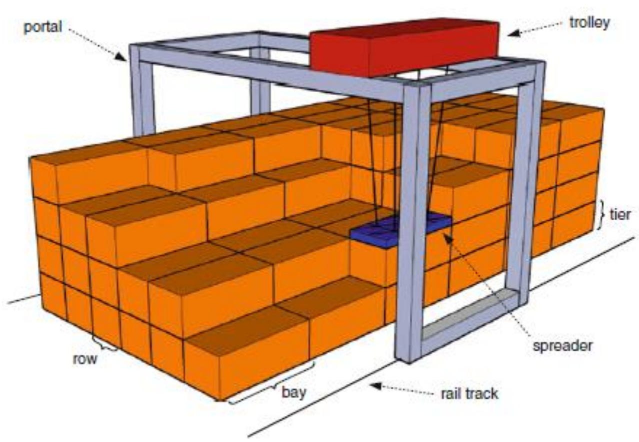

Figure 2 Schematic RMGC yard block

In this paper we consider the case when the containers unloaded from vessels (incoming containers) are given ranks according to their priorities which depend on their time of departure: the lower the rank number, the higher the priority associated, i.e. the sooner the container will be scheduled for departure. In order to facilitate the work of the yard crane and improve the containers handling time when they have to be picked up from the block and loaded on vessels, the containers should be stacked above each other with higher priority (lower rank number) containers located at the top of the row. This type of layout ensures easy access to outgoing containers at the expected time of transfer without further reshuffles.

Our approach is focused on the operational decisions that have to be made by terminal operators and attempts to optimize the container stacking in the block as well as the incoming vessel berthing time by minimizing the handling time of the yard crane while placing the containers in the slots of the stacking area in the right priority order, i.e. no higher priority container is placed beneath a lower priority container.

The Genetic Algorithm

Optimization of the integrated scheduling of container handling and storage equipment is so important to the port authorities to ensure that they use the whole capacity of the equipment. However, the integrated scheduling is an NP-hard problem [18,19], i.e., no systematic method exists to find the optimal solution of this problem, especially for relatively large instances. The mathematical methods are not able to find optimum solutions for large-scale cases of integrated scheduling problem in a reasonable computation time. Therefore, meta-heuristic algorithm (i.e., the genetic algorithm) are proposed to find near optimal solutions for this problem.

1.1 Principles of the GA

The genetic algorithm is a well-known heuristic algorithm, following the natural evolution process. Haupt and Haupt [20] stated that like any other meta-heuristic algorithm, GA do not guarantee to find the optimal solution.

The GA commence by defining optimization variables, objective functions and control parameters [21]. Usually, GA receive works on an initial population involving the individual solutions represented by “Chromosomes”, which are strings include all genes (i.e., variable) involved in a possible solution. The chromosomes are evaluated based on the “objective function” which is the desired objective of the problem.

In any iteration of the GA, some of the current individuals are replaced with new generated offspring. “Crossover rate” is defined as ratio of the number of offspring produced in any iteration to the population size. A pair of individuals from the current population is selected as the parents of a pair of offspring. Highly fitted individuals, relative to the whole population, have higher chance to be selected as parents in next generation, while less fitted individuals have a corresponding low probability of being selected [22].

One of the most widely used selection schemes is called the "biased roulette wheel scheme" in which each current string in the population has a roulette wheels slot sized in proportion to its fitness. The roulette wheel scheme can be described as follow [20,22]:

- Sum of the fitness of all the population members; the result is called total fitness.
- Generate a random number, θ, between zero and total fitness.
- Return the first population member whose cumulative fitness is greater than, or equal to θ.

The aforementioned procedure is repeated to select as many parents as required for the crossover operator. Another popular selection scheme is the "tournament" procedure, in which, two sets of the individuals with *n* members are selected randomly. The best individual of each set is selected as a parent. This procedure is repeated for any number of parents required for the crossover operation [21].

Mutation is another operator is implemented to ensure that every subspace of the problem solution space is subjected for selection [22]. The "mutation rate" is defined as the percentage of the total number of genes (parents and offspring together with) in the population. In GA, mutation operator has a vital role, firstly, to replace the gene lost from the population during the selection process; and secondly, to provide the genes that were not present in the initial population. Frequently, a swap mutation operator has been used for the GA application in scheduling literature [19]. However, problems arising are fixed by using a repair operator. "Crossover" and "Mutation" operators are implemented widely to reproduce new offspring, which are in charge of exploration and exploitation of the feasible solution space, respectively. It is stated that exploration and exploitation abilities of GA are the most essential tools to find better solutions for the NP-hard problems [21].

1.2 Encoding and Initialisation

A GA starts by chromosome encoding and initialisation. A chromosome is composed of genes whose values can be either bit-strings, real numbers, symbols or characters, the interpretation of these strings being entirely problem dependent.

We considered genes to be composed of two cells (Figure 5(a)), the row (left cell) and the priority rank (right cell) that is valid for that row (according to the right priority order).

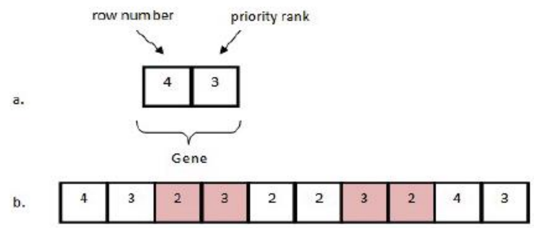

Figure 3 Chromosome representation

A chromosome is a set of genes randomly selected from the list *P*. The chromosome length is fixed and is equal to the number of incoming containers, *N*. In order to establish the slot (row/tier) where each of the containers will be placed, the chromosome will be decoded from left to right. For each placement, the row rr is given by the left cell of a gene *g*, and the tier *k* is obtained by considering the number of occurrences of gene *g* in chromosome from left to right and the number of slots for row rr (e.g. for chromosome in Figure 2: $r = 4$, $k = 3$ for the first gene, $r = 2$, $k= 3$ for the second gene, $r = 2$, $k = 2$ for the third gene, etc.).

In order to generate feasible chromosomes, the constraints *(C1)*, *(C2)* and *(C3)* must be applied for each chromosome (Figure 3).

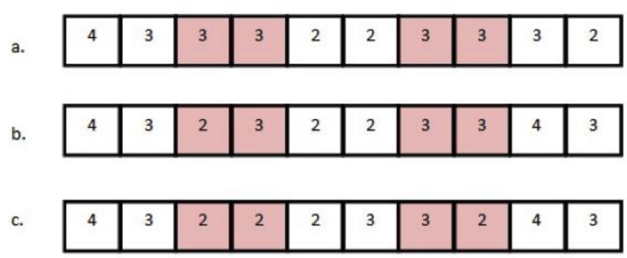

Figure 4 a. According to *C1*, this chromosome is not feasible as it proposes to place three containers on the third row, whilst this row has only two slots; b. According to *C2*, this chromosome is not feasible as it locates four containers of priority rank equal to three, whilst only three containers of that priority rank are to be unloaded; c. According to *C3*, this chromosome is not feasible as it places on the second row a container with a priority rank equal to two beneath a container with a priority rank equal to three.

After encoding the chromosomes, we set the algorithm parameters (population size, maximum number of generations, crossover and mutation probabilities) and generate the initial population.

1.3 Evaluation

The fitness function is problem specific and measures the quality of the solutions. In our model, the fitness function is the one described by [4] and is determined by decoding the chromosomes from left to right, a gene being ci, $i \in \{1,2,\ldots,NN\}$. Since one of the objectives of this problem is to minimize the handling time of the yard crane, the smaller the value of fitness obtained, the better the solution (chromosome).

1.4 Selection, crossover and mutation operators

Genetic operators used in GAs maintain genetic diversity and are analogous to those which occur in the natural world: selection (or reproduction), crossover (or recombination) and mutation. These operators are implemented to produce new offspring, which are in charge of exploration and exploitation of the feasible solution space.

According to the crossover probability, some of the least fitted individuals will be replaced by a new set of offspring. The parents were selected by the tournament selection method, which works by running several tournaments, i.e. selecting a number of individuals from the population at random and then selecting only the best of those individuals (with the best fitness).

Next, we used a version of the three parents crossover, dependent of the nature of our problem and designed by taking into consideration the constraints (*C1*) and (*C2*). The crossover operator randomly selects three parents and breeds three children setting in the offspring gene a value taken from one of the three parents from the matching position (see Table 1). The offspring created replaces the parents.

Table 2 Pseudo-code of crossover operator

% s: population size

% n: chromosome length

```
% pc: crossover probability
for i = 1:s do
Choose a random integer between 0 and 1 (we call it cLimit)
if cLimit < pc then
select chromosome i as parent
end
for k = 1:numberOfParents-2
P1 = parents(k);
P2 = parents(k+1);
P3 = parents(k+2);
for i = 1:n do
% creating Child1
if P1(i) = P2(i) AND P1(i) follows C1 and C2 then
offspring1(i) = P1(i)
else
if P2(i) follows C1 and C2 then
offspring1(i)= P2(i)
else
if P1(i) follows C1 and C2 then
off spring1(i) = P1(i)
```

else

if P3(i) follows C1 and C2 then

offspring1(i) = P3(i)

else

for j = 1:n do

if P3(j) follows C1 and C2

offspring1(i) = P3(j)

end

% create Child2 in an analogous manner: combine P2 with P3 and if one of the genes does not follow constraints C1 and C2, get a gene from P1.

% create Child3 in an analogous manner: combine P3 with P1 and if one of the genes does not follow constraints C1 and C2, get a gene from P2.

end

In next step of the GA, we used the swap mutation operator to enhance the chromosomes by changing their sequence of genes. This operator works by generating two different random numbers within the length of the chromosome that will specify the places of the genes that will be swapped.

Owing to the random nature of the GA, violations of constraint (*C3*) may occur in any chromosome during crossover or mutation. Hence, a repair subroutine is applied to impose the right priority order and make the chromosome a feasible one.

The algorithm was implemented in Matlab R2021a and the terminating condition was to either a predefined number of generations reached or 97% of the population had same fitness value. After several generations, the best individual (solution) is obtained, i.e. the one with the smallest numerical value of the fitness function.

Figure 4 illustrates a possible solution found by the proposed GA, which may be interpreted as the plan of container stacking. The order of execution of tasks by the yard crane is arbitrary, and, given the way the objective function is defined, does not affect the solution of the problem.

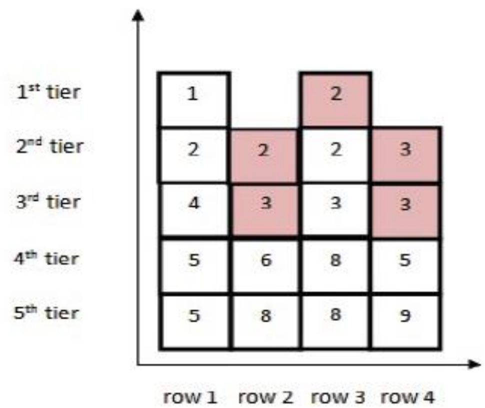

Figure 5 Best solution of the proposed GA (an example)

1.5 RESULTS

Table 2 shows the characteristics of the problem tested in this paper. The basic configuration of the stacking area (see Figure 5) is the same with the one from the earlier work of the same authors. Likewise, we used the same data as in [12] for the operational time for the yard crane. We used minutes as the base time unit; hence, if a yard crane movement takes 14 seconds in real life, it takes 0.23 time units in the problem.

In a real-world situation, it is uncommon for a terminal operator to know exactly when a container will arrive or depart. However, at any time, a container has a residence time left in the block. In order to implement our residence time stacking strategy, we used a residence time divided into 5 classes.

Table 3 Characteristics of the selected problem

Number of rows (R)	12
Maximum number of tiers (K)	5
Number of slots	25
Number of incoming containers (N)	19
Number of priority ranks (PR)	5

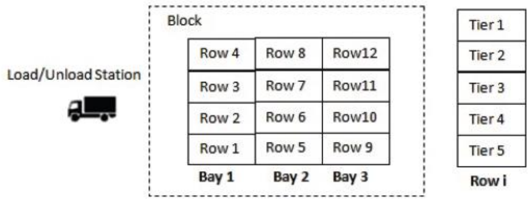

Figure 6 the proposed layout of a block

We evaluated the performance of the proposed GA through several test cases on the control parameters of the GA: the crossover/mutation probabilities. Currently, there are no well-established optimum values for these parameters and they are problem specific [7]. In order to get statistically robust results, each of the test cases was solved using the proposed GA for 10 runs (see Table 3). All the cases have the same population size (50) and the same maximum number of generations (100).

Table 4 GA parameters

Case number	Crossover probability	Mutation probability
1	0.90	0.01 : 0.1, step 0.01
2	0.75	
3	0.60	
4	0.45	
5	0.30	
6	0.15	

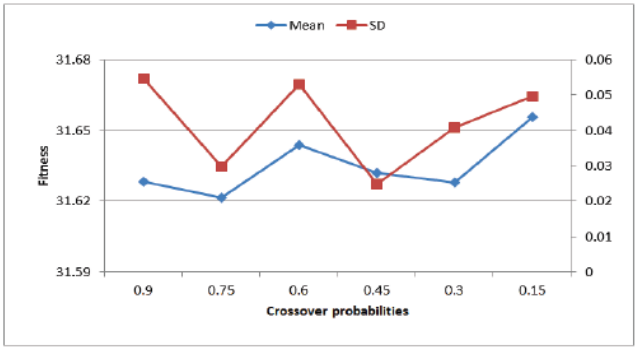

Figure 7 Average fitness using different crossover probabilities

The results of the test cases are presented, in terms of the mean of the fitness values and the standard deviation (SD), in Figures 6-9. The standard deviation values are less than 10% of the mean values for these test cases, which means that the GA can find solutions close to each other in its various runs. Based on the minimum fitness value, the best combination of crossover and mutation probabilities is a crossover value of 0.9 and a mutation value of 0.01.

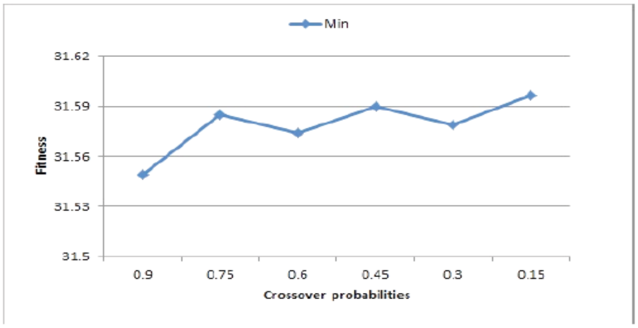

Figure 8 Minimum fitness using different crossover probabilities

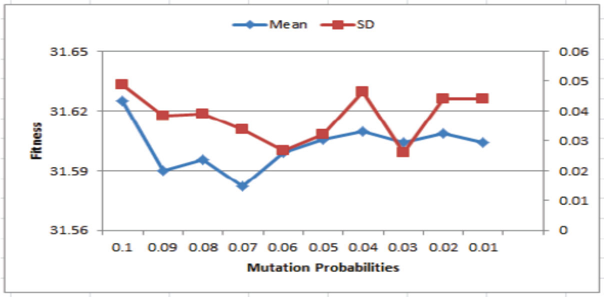

Figure 9 Average fitness using different mutation probabilities

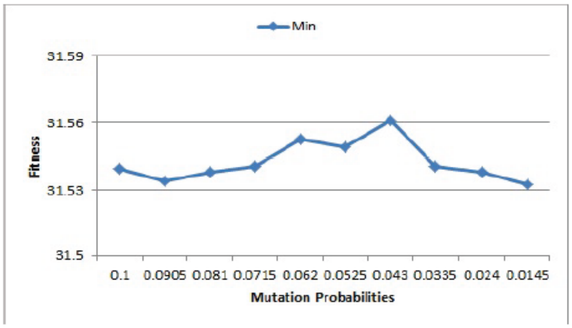

Figure 10 Minimum fitness using different mutation probabilities

For further evaluation of the performance of the proposed GA, as well as of the RTS strategy, we used the GA described in [12], which implements a random stacking (RS) strategy. Using a RS strategy, a container is placed at a randomly chosen allowed location, with every possible location having an equal probability of being chosen.

The RS strategy is the most basic stacking strategy and is often used as a benchmark algorithm. The results of the comparison can be found in Figure 10.

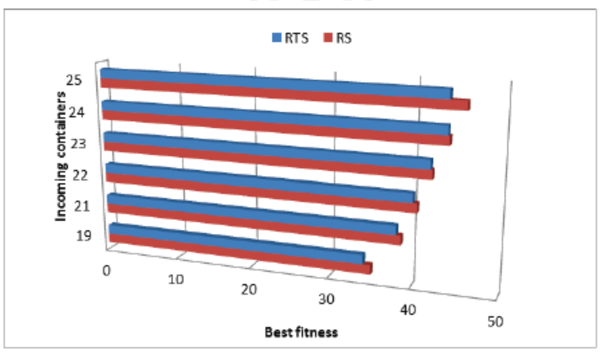

Figure 11 RTS and RS strategy results

Having the same configuration of the stacking area (Table 4), the RTS algorithm performs better, in terms of handling time, than the RS algorithm, confirming the results from [1] and [2]. Therefore, we can conclude that the random strategy is good when there is no additional information regarding the incoming containers, but getting a good estimate for the residence time of containers may lead to better results in a real life scenario in terms of berthing time, as well as to a stacking plan that will minimize further reshuffles.

Table 5 RTS and RS strategy results

Strategy		RTS	RS
GA parameters	Crossover probability	0.75	0.9
	Mutation probability	0.06	0.1
Problem characteristics	Rows	12	12
	Tiers	5	5
	Slots	25	25
	Priority ranks	5	-

CONCLUSION

The container storage problem was addressed in this paper, which involves making efficient decisions fast in order to meet the requirements of the terminal operators as well as those of the ship owners, solve it by means of residence time stacking strategy. A genetic algorithm was proposed to optimize the process of stacking the containers in the right priority order, i.e., no lower priority container is placed upon a higher priority container.

The type of layout given by the solution of the proposed method minimizes the reshuffles and reduces the time spent by a ship in the port quays, by allowing it to be loaded within a short time.

Likewise, the berthing time of the incoming vessel is also reduced by minimizing the handling time of the yard crane while stacking the incoming containers.

Future Work

As future work, we intend to refine the problem characteristics based on observations from real case situations and introduce more parameters related to the stacking options, such as the container weight (lighter containers are stored on top of heavier ones) or nature (regular, tank, empty or refrigerated).

Furthermore, the length and width of blocks are important variables in the designing the layout of yard and they also influence the container handling process.

In a real-world situation, a terminal operator rarely knows exactly when a container is going t arrive or depart; however, at any time, a container has a residence time left in the block.

Hence, based on the residence time stacking strategy adopted, this optimization method may lead to reasonable solution in real life settings.

In a real-world situation, a terminal operator rarely knows exactly when a container is going to arrive or depart; however, at any time, a container has a residence time left in the block.

Hence, based on the residence time stacking strategy adopted, this optimization method may lead to reasonable solution in real life settings.

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