Genetic Algorithm for Solving Berth and Quay Cranes Assignment problems

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Abstract

The management of a container terminal is a complex process that involves a vast number of decisions. The berth is the most important resource that affects the capacity of the terminal.

The problem is here to allocate berths to arriving vessels and to determine which cranes in the berths process the docked vessels. For creating the berth schedule, the calling schedule of vessels, favourable berthing location (near primary storage, for example) and the number of available cranes can be considered simultaneously.

This paper discusses an optimization technique for scheduling Berth and Quay cranes using genetic algorithm (GA). Genetic Algorithms are useful for finding near-optimal solutions. GA requires non-trivial time, but hopefully will search a wider part of the solution space.

The objective is to reduce the total stay or delay times of vessels at a port i.e. the waiting, loading and discharging of containers should be done as quickly as possible, in order to save on terminal costs.

1 Introduction

The main function of a container port terminal is to provide transfer facilities for containers between sea vessels and land transportation modes, trucks and rail in particular. It is a highly complex system that involves numerous pieces of equipment, operations, and container handling steps [9]. The assignment of resources to tasks and the scheduling of these tasks are thus among the major container port terminal planning issues. Three main areas make up a container terminal. The sea-side area encompasses the quays where ships berth and the quay-cranes that provide the loading and unloading of containers into and from ships. The land-side area provides the interface with the land transportation system (the so-called hinterland of the port) and encompasses the truck and train receiving gates, the areas where rail cars are loaded and unloaded, and the associated equipment. Trucks are generally loaded and unloaded directly in the yard area. This third area is dedicated for the most part to stacking loaded and empty containers for import and export (in some terminals, facilities are also provided for the loading and unloading containers). Various types of yard cranes are associated with this area. So-called transporters, primarily yard trucks or automated vehicles, move containers between the three areas. **Error! Reference source not found.** illustrates part of a container port terminal. One ship and two quay cranes are displayed in the sea-side area, while only trucking is shown in the land-side area. Four container stacks are displayed in the yard area, as well as one type of yard crane used to transfer containers between yard transporters and outside trucks and stacks, as well as to change the position of containers in the yard as required.

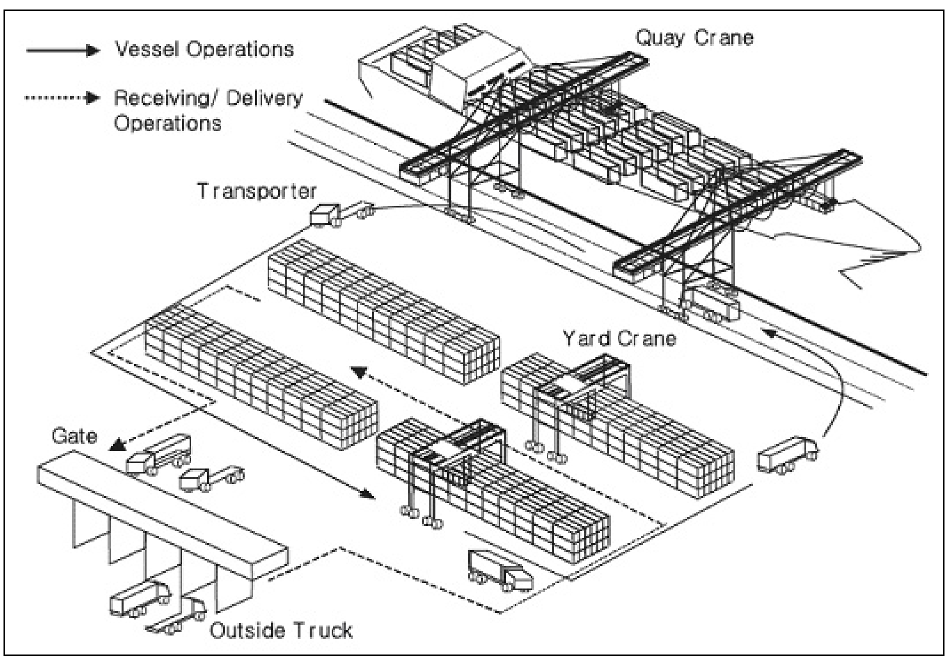

Figure 1. Example of a Container Terminal (Park 2003.)

When a ship arrives at the container port terminal, it is assigned a berth and a number of quay cranes. The berth is the most critical resource for determining the capacity of container terminals because berth construction costs are the highest compared to the investment costs for the other facilities in the terminal. One direction for improving the overall productivity of the berth is to utilize the berth efficiently. Planners in container terminals usually construct a berth schedule, which determines the berthing time and position of a container ship at a given quay. During the unloading operation, a quay crane transfers a container from a ship to a transporter. Then, the transporter delivers the import (unloading) container to a yard crane that picks it up and stacks it into a given position in the yard.

The berth scheduling and the quay-crane allocation problems are related because the number of quay cranes assigned to a vessel impacts the berthing duration of the ship. Most studies treat the two issues separately to avoid the complexity of the integrated problem. The study by Park and Kim [9] is an exception.

Before arrival of a ship, a berth has to be allocated to the ship. The schedules of large oversea vessels are known about one year in advance. Berth scheduling involves determining the time and position at which each arriving vessel will berth. Quay-crane allocation is the process of determining the vessel that each quay crane will serve and the time during which the quay crane will serve the assigned vessel.

Besides technical data of ships and quay cranes (not all quay cranes can be operated at all ships) other criteria like the ship's length have to be considered. All ships to be moored during the respective time period have to be reflected in berth allocation systems. Several objectives of optimized berth allocation exist. From a practical point of view the total sum of shore to yard distances for all containers to be loaded and unloaded should be minimized. This corresponds to maximum productivity of ship operation. Automatic and optimized berth allocation is especially important in case of ship delays because then a new berthing place has to be allocated to the ship whereas containers are already stacked in the yard.

This article presents a solution method for determining the berthing time and position of each vessel and the number of cranes to be allocated to the vessel using a meta-heuristic optimization method, namely a Genetic Algorithm (GA). GA is an evolutionary optimization technique, formulated on the basis of the mechanics of natural selection and evolution. It offers great flexibility in solving such optimization problems as it does not require any information on the gradient of the objective function and has the ability to move out of local optima.

2 Literature Review

There is by now a huge literature on the applications of operations research in container operations [9]. Berth planning problems may be formulated as different combinatorial optimization problems depending on the specific objectives and restrictions that have to be observed. Lai and Shih [7] studied the problem of assigning one of the discrete segments of a berth to vessels and suggested several simple rules for the assignment.

Li et al. [8] discuss the more general problem of 'scheduling with multiple job-on-one-processor pattern' with the goal of minimizing the makespan of the schedule. This is known as the multiprocessor task scheduling problem. Vessels can represent jobs and a processor can be interpreted as a berth. Computational experiments show the effectiveness of a heuristic method with near optimal results.

Imai et al. [3] study berth allocation and optimization of berth utilization using a heuristic procedure. The same authors develop a GA-based heuristic procedure for solving the nonlinear problem of berth allocation for vessels with different service priorities [5].

Kim and Kim [6] present a routing algorithm for a single gantry crane loading export containers out of the stack onto waiting vehicles. The objective is to minimize the crane's total transfer time including set-up and travel times. Daganzo [1] was the first who discussed that the limitation in the length of a berth must be considered simultaneously during the crane scheduling. However, more emphasis was placed on schedules of quay cranes than that of the berth which is the main issue of this study. Regarding the crane-scheduling problem, Daganzo [2] suggested an algorithm for determining the number of cranes to assign to ship bays of multiple vessels. Park and Kim [9] combine a berth assignment approach with consideration of quay crane capacities.

3 Problem description

The critical terminal management problem is optimizing the balance between the ship owners who request quick service of their ships and economical use of allocated resources. For the customers of a container terminals (owners of the ships and the shippers), it is paramount to minimize turnaround time, i.e. the waiting, loading and discharging of containers should be done as quickly as possible, in order to save on terminal costs. Thus, an effective way to increase the capacity of a terminal is to improve the efficiency of its berth.

The problem is here to assign berths to arriving vessels and determine the number of cranes allocated to each vessel. The aim of this plan is to minimize the total stay or delay times of vessels at a port. The objective is to increase capacity at the container terminal by reducing the turn-around time.

In the berth allocation task, each container ship that arrives at a terminal is assigned a berth and a location where it can dock in the terminal usually by a 'port captain'. The major factors influencing both berth occupancy rates and turn-around time are: the number and size of arriving container ships; configurations of containers in the ship's bays; number of cranes; length of the berth and navigation constraints. Usually berth occupancy is based on the length of a container ship and the time it spends at the berth. The charge and discharge operations at the container vessel are performed by quay cranes. Cranes must be assigned to vessels over time. The availability of cranes has a direct bearing on the port stay time or delay times. The operational crane assignment problem involves assigning a given set of cranes to serve all scheduled container vessels at minimum cost. If a crane is not available, it must be brought from adjacent berth.

In this paper, we try to integrate the berth allocation and determination the crane numbers assigned to the docked vessels using a two-phase genetic algorithm. In the first phase, we address multi-objective berth assignment for arrived vessels with the objective of minimizing the penalty cost resulting from delayed departures of vessels and the additional handling cost resulting from deviation of the berthing position from the best location on the berth. The berthing times and the positions of vessels are determined. We use a genetic algorithm to find a set of non-dominant berth assignment solutions. Another genetic algorithm has been used to determine the number of cranes to be allocated to the vessel to minimize the penalty corresponding to the departure delays of the vessels leaving after the requested departure time.

The following assumptions simplify the complexity of problem modelling on one hand and keep the essential features of real-life practices on the other hand. Most of the assumptions are assumed by relevant studies in literature [7], [9].

A1. Each vessel has a maximum and a minimum number of quay cranes (QCs) to be assigned. QCs are identical, both in terms of productivity in loading/discharging containers and in terms of moving speed from bay to bay.

A2. The duration of berthing of a vessel is inversely proportional to the number of cranes assigned to the vessel.

A3. The safety distance between adjacent QCs is also in number of bays. This safety distance is nonzero and hence only one QC can work on a bay at a time.

A4. Once a QC starts processing a bay, it leaves only when it has finished the workload of this bay.

A5. For each vessel, a penalty cost is incurred by berthing earlier or later than the previously committed time. A departure of a vessel later than the previously committed departure time also incurs a penalty cost.

A6. Every vessel has a most favourable location of berthing. The most favourable location is the location nearest to the marshalling yard where most containers are to be loaded or discharged to.

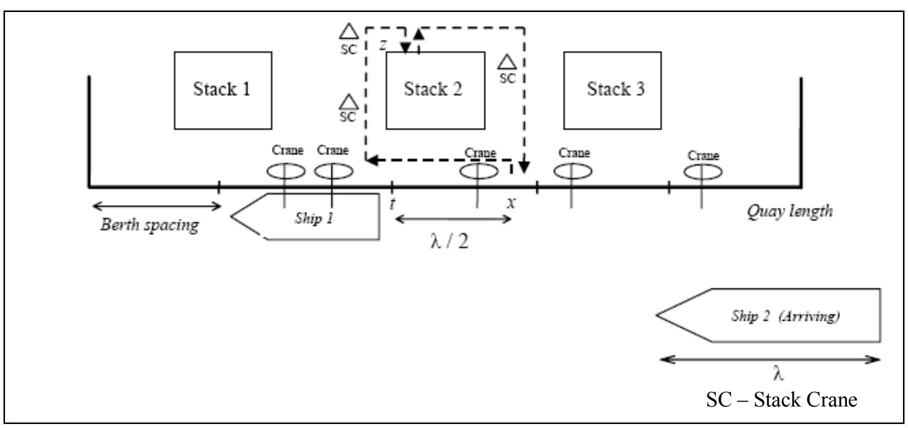

Figure 2. The entities and distances involved in the assignment of a berth position

Figure 2 illustrates an interesting case. The arriving ship's ideal berth position *t* is occupied by another ship. The arriving ship either will have to wait until the other ship leaves the berth, or an alternative berth position is determined, for instance the one that minimize the distance travelled by the vehicles. The choice of berth position presents many possible options in limiting distances travelled and/or minimizing the turn-around time.

The model for the berth planning can be expressed as a time-space diagram (**Error! Reference source not found.**) where two different vessels (*i*-th and *j*-th) are presented in ascending order of arrival times in a given planning horizon. The *x*-axis indicates berth position while the *y*-axis indicates time. Each rectangle in the figure is associated with a vessel that occupies a section of the berth for a specified time period. For example, from time a_i to d_i, the berth section from position p_i is occupied by vessel *i*-th. Here, a_i and d_i are the planned processing start time and completion time, respectively, and $b_i = d_i - a_i$ includes the preparation time for docking and departing.

4 Solution methodology and implementation

Genetic algorithm is inspired by the theory of evolution and it is well suited for multi-objective optimization problems. The main issues in developing a genetic algorithm are chromosome representation, initialization of the population, evaluation measure, crossover, and mutation and selection strategy. GA evaluates each chromosome against an objective (fitness) function and, through a probabilistic selection process, selects some chromosomes to form what is known as an *intermediate population*. Mimicking the evolutionary strife for survival, the fitter chromosomes have higher probabilities of selection. Chromosomes from the intermediate population are then randomly paired to exchange genetic materials, and produce offspring in the crossover process. Lastly, in the mutation process, genes, on some probabilistically selected chromosomes, are made to mutate and form the next population. The process of going from one population to the next represents one generation in the execution of the GA. This evolutionary process goes on improving the fitness of the solutions through subsequent generations.

Also, genetic parameters such as population size, probability of crossover and probability of mutation, are to be determined before execution of the genetic algorithm. In the following sections, these issues and the overall procedure are introduced. For more details see [3].

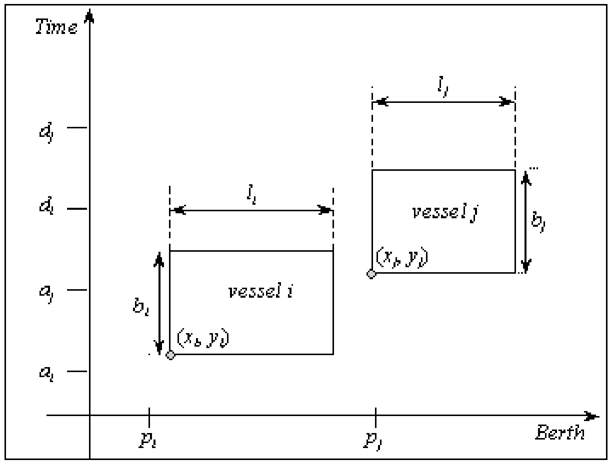

Figure 3. The space-time diagram of a berth assignment problem

Chromosome representation

The chromosomal structure needs to code the key features of the problem. We use the chromosome representation shown in **Error! Reference source not found.**. Before encoding individuals, calling vessels are ordered by their arrival time and berths should be identified with their number *No*. To encode the solution of berth assignment problem, the length of the chromosome is set to the number of vessels to be docked at the yard area. Each integer in the chromosome represents a unique identification of berth *No*, and the position of each gene represents the vessel number to which the berth is assigned.

The example has 10 calling vessels to be handled by a quay crane and six berths. Chromosome consisting of 10 integers, which represents the handling sequence of the yard crane for the 10 jobs. The symbols in the string are the identifications of berth No. Under ship 1, the symbol "4" in string shows that berth 4 serves vessel s1. Under vessel 8, "4" in the string says that ship 5 is also served at berth 4 and so on.

Vessels	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10
String	4	3	6	3	2	3	5	4	3	1

Figure 4. Encoding assignment problem of berth

Hence, for such a chromosome representation does not capture the crane numbers allocated to vessel *i*-th arising from berth assignment in phase I, we developed the procedure in genetic algorithm to determine crane numbers which are available for vessel *i*-th for all time segments.
Table 1 shows part of the random key representation of the crane numbers.

Initialization of the population

Due to the large search space, population is initialized by randomly selecting berths available with uniform distribution.

Table 1. Random key representation of the crane numbers

	Time segments													
	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{10}	t_{11}	t_{12}	t_{13}	t_{14} …
berth1	0	0	0	0	0	1	1	2	1	1	3	1	2	1
berth2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
berth3	1	2	1	1	1	1	1	1	1	1	2	1	1	1
berth4	2	2	2	1	1	1	1	1	1	1	1	1	2	1
berth5	1	1	2	1	3	1	1	2	1	1	1	1	3	3
berth6	1	4	3	1	2	1	1	0	0	0	0	0	0	0

Chromosome feasibility

Each chromosome in the population is checked for feasibility. Considering assumptions (A5) and (A6), in phase I, some constraints must be added in order to guarantee that the position of the rightmost end of vessel *i* will be restricted by the length of the berth (1) and to ensure that two adjacent vessels will never be in conflict with each other with respect to the berthing time (2) and the berthing position (3). In these last constraints M is a big (i.e. 100000) value that void the relationship when the respective z_{ij} is different from 1. Constraint (4) excludes the case in which case the rectangles representing schedules for vessel i and j overlap with each other. Constraint (5) implies that a vessel cannot berth before she arrives.

$$x_i + l_i \le L \quad \text{for} \quad i = 1 \dots N \tag{1}$$

$$y_i + b_i = y_i + M\,(1 - z^{y}_{ij}) \quad \text{for} \quad i, j = 1 \dots N,\ i \neq j \tag{2}$$

$$x_i + l_i = x_i + M\,(1 - z^{x}_{ij}) \quad \text{for} \quad i, j = 1 \dots N,\ i \neq j \tag{3}$$

$$\sum_{i=1}^{m} z^{x}_{i,j} = 1 \quad \text{for} \quad j = 1 \dots N \tag{4}$$

$$y_i \ge a_i \quad \text{for} \quad i = 1 \dots N \tag{5}$$

where:

N = The total number of vessels

m = The total number of different berthing positions

L = The length of the berth

x_i = The berthing position of vessel *i*-th (a decision variable)

y_i = The berthing time of vessel *i*-th (a decision variable)

a_i = The estimated arrival time of vessel *i*-th

b_i = The requested time for the ship operation for vessel *i*-th.

This value includes the requested allowance between departure of a vessel and berthing of another vessel.

l_i = The length of vessel *i*-th. This value includes the requested gap between adjacent vessels.

$$z^x_{ij} = \begin{cases} 1 \text{ if vessel } i \text{ is located in the left-hand side of vessel j} \\ 0 \text{ otherwise} \end{cases}$$

$$z^y_{ij} = \begin{cases} 1 \text{ if vessel } i \text{ is located lower side of vessel j} \\ 0 \text{ otherwise} \end{cases} .$$

Evaluation

A chromosome is evaluated against its fitness value associated with the objective and constraints.

In the berth planning, we try to minimize the penalty cost resulting from delayed departures of vessels and the additional handling cost resulting from deviation of the berthing position from the best location on the berth. However, in this example the fitness value is composed of the berthing time which is the time taken to berth vessel and the time taken for the vessel to set sail once all its containers have been exchanged.

The first function, *berthing_Time* is the cost function that depends on the distance from the berthing location of a vessel to the location in the marshaling yard where outbound containers for the corresponding vessel are stacked, the penalty cost incurred by berthing earlier or later than the expected time of arrival, and the penalty cost incurred by the delay of the departure beyond the promised due time. It is represented as follows:

$$Berthing\_Time = \sum_{i=1}^{N} \left\{ c_{1i} \left| x_i - s_i \right| + c_{2i} \left(a_i - y_i \right)^+ + c_{3i} \left(y_i - a_i \right)^+ \right\} \quad (6)$$

where $x+ = \max\{0, x\}$.

s_i = The best berthing location of vessel *i*-th

c_{1i} =The additional travel cost per unit distance for delivering containers of vessel *i*-th resulting from deviation of berthing location from the best position

c_{2i} = The penalty cost of vessel *i*-th per unit time of arrival before a_i

c_{3i} = The penalty cost of vessel *i*-th per unit time of arrival after a_i

The other *Crane_Operation_Time* function is the handling cost function of containers which computes the penalty corresponding to the departure delays of the vessels leaving after the requested departure time.

$$Crane\_Operation\_Time = \sum_{i=1}^{N} c_{4i}\left(C_i - d_i\right)^{+} \tag{7}$$

where

d_i = The requested departure time of vessel i-th
c_{4i} = The penalty cost of vessel i-th per unit time of delay beyond the due time d_i
l_i = The minimum number of cranes that can be assigned to vessel i-th
u_i = The maximum number of cranes that can be assigned to vessel i-th
c = The total number of available cranes ($c > u_i$)
Y_{ki} = The number of cranes allocated to vessel i-th at time segment k, $k = 1 \ldots T$

$l_i \le Y_{ki} \le u_i$, if $Tk \le j < Ck$; 0, otherwise.

C_i : The completion time of container handling for vessel i-th (decision variable)

$$C_i = \sum_{k=1}^{T}\left(\frac{t_v * n_{ki}}{Y_{ki}}\right) \tag{8}$$

T = The total number of time segments
t_v = The average variable service time of single shore crane per container. It is calculated as 1.7 minutes/container with variation 0.18 min/container [9].
n_i = The number of containers for vessel i-th at time segment k

The objective function of the berth-planning problem can be written as

$$Min \sum_{i=1}^{N}\sum_{j=1}^{m}\sum_{k=1}^{T}\left\{Berthing\_time + Crane\_Opertation\_Time\right\}. \tag{9}$$

Selection for reproduction

Each offspring's fitness value is used as a criterion to perform the potential new parents' selection. A roulette wheel selection procedure [3] is used to select N_{pop} chromosomes and place it in the intermediate population for reproduction, where N_{pop} is the population size. According to this method, the probability of selection is calculated using the formula (10), where f_i is the fitness value (9) of chromosome i in the current generation.

$$P_{select_i} = \frac{f_i}{\sum_{i=1}^{N_{pop}} f_i} \tag{10}$$

Crossover and mutation

The chromosomes in the intermediate population are subject to crossover and mutation operation to create offspring. Authors propose a modified operator based on partially match crossover, which allows the crossover between parallel sections in two parents. We carry out the mutation operation by randomly selecting a gene in the chromosome and altering its value by ± 20%.

Termination

The GA will terminate in two situations, when it has produced and assessed the *m*-th generation, or when the lower bound is hit.

5 Numerical Example

The experiments were carried out on PC with Pentium 4-M 2.20 MHz under Windows. The designed scheduling procedure with genetic algorithm is developed in the Matlab software package by authors.

In the data set, five problems with 10 through 40 vessels were generated. The arrival times of vessels, the handling times of of vessels, the lengths of vessels, and the preference positions for vessels are constructed by forming their expected value from an uniform distribution of U(1, 170), U(5, 44), U(15, 35), and U(1, 6)[1], respectively. The cost coefficient of c_{1k}, c_{2k}, c_{3k}, and c_{4k} was assumed to be \$1000, \$1000, \$1000, and \$2000, respectively.

For each problem, the total number of available cranes is 9, the maximum number of cranes that can be assigned to each vessel is u_i =7 and the minimum number of cranes that can be assigned to vessel l_i =2. The assignment of QCs per ship was assumed an uniform distribution of U(2,7).

By experiments, it is found that population size 100 and generation number 2500 make a relatively stabilized objective value. The objective value is low for the same iteration when pc=0.8 and pm=0.2 (crossover probability and mutation one). So they are adopted in the experiments.

Table 2 reflects the input data of 10 vessels. **Error! Reference source not found.** shows the optimal schedules for our first berth assignment problem.

Vessels	s1	s2	s3	s4	s5	s6	s7	s8	s9	s10
String	3	5	6	4	2	3	4	4	4	2

Figure 5. The solution of berth assignment problem

[1] U(*a*,*b*) represents the uniform distribution which has a constant probability density function between its two parameters *a* (the minimum) and *b* (the maximum).

Table 2. Input data - Vessel characteristics

No Vessel	1	2	3	4	5	6	7	8	9	10
L	122	70	140	90	90	140	193	223	149	96
nc	237	298	246	287	215	244	292	298	246	234
A	1	2	3	4	5	6	7	18	18	20
B	1	2	3	4	5	6	7	38	24	23
D	0	0	0	0	0	0	0	20	6	3

A-Time of arrival; B-berth_time; D–delays; L–Ship length; nc–Number of container per ship

The objective value of container ship cost has been reduced from 3.598e+006$ to 2,878e+006$.

6 Conclusions

Container terminal operation management has become crucial to meet the demand of container traffic effectively and efficiently. This paper proposes a two-phase approach for integrate berth assignment and crane allocation problems. We have developed a multi-objective genetic algorithm for assigning berths to vessels and for determination the optimal cranes number for each vessel. First computational tests came along with good results encouraging further research in the field improvement model and algorithm which follow that model.

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Genetski algoritam za rješavanje problema rasporeda sidrišta i kontejnerskih dizalica

Sažetak

Upravljanje kontejnerskim terminalima je složen proces koji uključuje veliki broj odluka. Sidrište plovila u luci je najvažniji resurs koji utječe na kapacitet terminala.

Problem je odrediti najprikladnije mjesto sidrenja plovila koji dolaze u luku obzirom na raspored dizalica. Da bi se ovaj problem riješio, mora se istovremeno voditi računa i o udaljenosti sidrišta i o broju dostupnih dizalica.

U radu se analizira optimalizacijska metoda – genetski algoritam (GA) za određivanje najboljeg rasporeda te sidrišta plovila koji dolaze u luku i dizalica. GA je koristan za nalaženje rješenja bliskih optimalnom, jer je prostor rješenja problema najčešće prevelik da bi računalo moglo pretražiti sva rješenja u nekom razumnom vremenu. GA zahtjeva značajno vrijeme izvođenja, ali sigurnost dobivenih rezultata se povećava postupkom ponavljanja procesa rješavanja.

Svrha optimiranja je da se skrati vrijeme čekanja plovila u lukama, vrijeme koje je potrebno za ukrcaj/iskrcaj tereta na/u plovila, kako bi se upravljanje kontejnerskim terminalima bilo jeftinije.