Proposal of a heuristic model using genetic algorithms to solve and operational port problem

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Abstract

This article is characterized by the presentation of some problems found in ports that emphasize the Berth Allocation Problem, for which a heuristic model has been proposed to resolve this problem. This heuristic proposal is based on Genetic Algorithms and its objective is to allow the learning of this subject, besides urging the reader to implement a computer-based tool that uses these heuristics to solve this problem, practically and efficiently.
Keywords: Genetic algorithm; berth allocation problem; Competitiveness.

Resumo

O presente artigo caracteriza-se pela apresentação de alguns dos problemas portuários, enfatizando o Problema de Alocação de Navios em Berços, para o qual se propõe um modelo heurístico de resolução. A heurística proposta baseia-se nos Algoritmos Genéticos e tem por objetivo tornar possível o aprendizado deste assunto, além de instigar o leitor a implementar uma ferramenta computacional baseada nesta heurística para resolver o problema de maneira prática e eficiente.
Palavras-chave: Algoritmo genético; Problema de alocação de berços; Competitividade.

1 Introduction

The administration of a maritime port complex involves many decision-making problems, which can happen at: strategic, tactical and operational levels. There are many operational problems and methods addressed in technical literature; however, they are aimed at the sizes of the mooring berths, which are compatible with an expected demand of vessels. Other studies seek to simulate operations that consider costs, investments and responsibilities, in other words, directed towards a system of economic operational sizing of container terminals (FERNANDES, 2001).

According to Silva and Coelho (2007), a gap still remains to be explored regarding the research and methods of relevant operational problems that are found in port systems: the berth allocation problem, BAP.

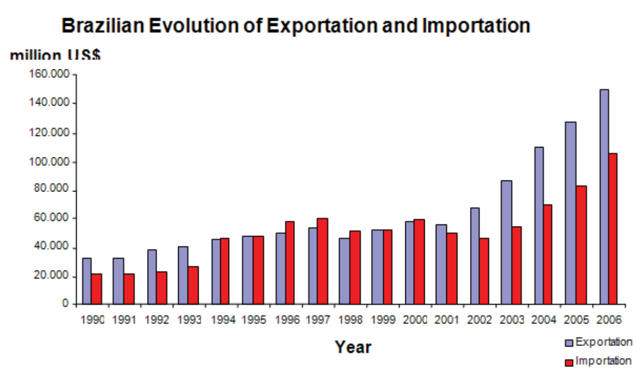
In this case, the article is divided into 4 chapters, including this introduction. In chapter 2, transport will be presented as an economic developer, specifically related to maritime transport and, also, information relating to the port operation, as well as the problem under study in this article. In Chapter 3, a heuristic method is proposed that solves the BAP, for which the main variables involved in problem have been identified. The model that has been developed endeavors to determine the sequence of vessels allocation to mooring berths, therefore minimizing the total time spent servicing the vessels, as well as the operational cost. Finally, in Chapter 4, the final considerations, conclusions and recommendations are shown for future studies

2 Contextualization and Systemic View of the Maritime Transport System

According to Novaes (2004) the distribution of products from factories to wholesale or retail outlets can be done using several transportation methods: highway, rail, waterway transports, by air, pipe work systems for special cases (gas, gasoline, diesel, ethanol). Like this, the investments in transports such as in any project, should be preceded by technical-economical viability studies. For this, it is necessary to carry out a discerning comparative analysis of the costs and benefits of the project (PEIXOTO, 1977).

2.1 The Importance of the Maritime Transport and Costs

Waterway transport includes all types of transport made on water. It includes the fluvial and lake transport (inland waterways) and maritime transport (NOVAES, 2004). According to Peixoto (1977) the technological progress and the increase in the world's population will cause a great increase in the demand for some items and therefore, as can be seen in Graph 1 both the exported and imported volume show a significant growth.



Graph 1 –Brazilian export and import volumes (1990-2006)
Source: Site of the Ministry of the Development, Industry and Overseas Trade

Therefore, to meet the whole demand that may occur, marine transport should concentrate its efforts on the recovering the transportation deficiency that has become worse over recent decades, this may done by the construction of new ports or the refurbishing of existing ones, the construction of shipyards, the upgrading of the merchant fleet, the training of labor or even the search for the optimization of the current control systems for the ports operation, which have been obstacles to the country´s economic expansion.

Adapting old ports to new cargo operational methods, requires large investments, in an attempt to reduce the length of time that the vessel remains in the port, thereby maximizing its performance for the owner and reducing the operational cost with the use of mechanization. Where investments do not occur, the cargo and discharge operations of the vessels are slow, the costs and the losses are high.

2.2 Port Operations

2.2.1 Some Problems Found in Ports

Several problems are encountered in ports, some of them are shown below:

- Problems with the acquisition or rental of equipment;
- Problems with the rental of equipment to be used in port services;
- Problems with the sizes of the berths;
- Problems with the port layout;
- Problem with the allocation of vessels to berths.

According to Nishimura et al. (2001), the majority of berths in large ports are rented, in other words, rented by the ship´s operators for the containers processing to obtain a greater productivity.

In this context, it is interesting to limit the number of effective berths. The allocation of vessels in this system, that is, the attribution of berths to vessels that dock for loading/unloading, the reduction of time required to carry out this task becomes important; because the handling time for a specific vessel will not necessarily be the same for each berth.

2.2.2 Definition of the Allocation Problem

According to Guan et al. (2004), the problem of allocating space in the berths for vessels in port terminals, is considered as being the berth allocation problem. In the definition of Moon (2000) the problem consists of determining the moment of the mooring and the positions for each vessel in the port terminal. A more complete definition is that the problem consists of determining the allocation plan for the vessel that moor in the port in the berths, so that each vessel is allocated a berth for a length of time to do the loading/unloading activities with the intention of reducing operational costs.

Because of berth space being very limited and thousands of containers are handled daily, an effective allocation of berths becomes critical for the efficient administration of the flow of containers. When there is no available space at the berths, the vessel needs to wait before mooring and, this time should be the least possible, because a stopped vessel generates unnecessary arrears in delivery schedules, as well as extra costs (Waterway Survey CNT, 2006).

However, the mooring position is also a very important variable in the decision for the following reasons. The containers that are to be loaded onto the vessels arrive at the port several days before the vessels arrive at the port. Therefore, if a vessel is moored near to the container storage area, of the containers to be loaded on the vessel, the transportation cost of the containers by trucks or other internal transport equipment that is used in the port, can be minimized because the distance traveled will be less than if the storage area of the containers is far from the mooring berth.

2.2.3 BAP Mathematical Formulation

Amongst the formulations found in the bibliographical survey, the work done by Imai et al. (2001) stands out, initially developed for a static model, in other words, when is considered that all vessels arrive in the port, for later allocate each one to an available berths, always respecting the restrictions.

Later the authors solved this problem with the use of a dynamic model, in which the information that is known prior to the arrival of each vessel is taken into consideration and that, vessels don't arrive in the port before the berths which have been attributed to them, become available.

In the dynamic BAP formula the defined binary variables *xijk* specify if vessel *j* should be supported as the k_{th} vessel in the berth *i* as follows:

$$Minimize \sum_{i\in B}\sum_{j\in V}\sum_{k\in O}\left\{(T-k+1).C_{ijk}+S_i-A_j\right\}.x_{ijk} + \sum_{i\in B}\sum_{j\in W_i}\sum_{k\in O}(T-k+1).y_{ijk} \quad (1)$$

Subject to:

$$\sum_{i\in B}\sum_{k\in O} x_{ijk} = 1 \qquad \forall j\in V, \quad (2)$$

$$\sum_{j\in V} x_{ijk} \le 1 \qquad \forall\, i\in B,\ k\in O, \quad (3)$$

$$\sum_{l\in V}\sum_{m\in P_k}\left(C_{il}x_{ilm}+y_{ilm}\right)+y_{ijk}-\left(A_j-S_i\right).x_{ijk}\ge 0 \qquad \forall\, i\in B,\ j\in W_i, k\in O, \quad (4)$$

$$x_{ijk}\in\{0,1\} \qquad \forall\, i\in B,\ j\in V,\ k\in O, \quad (5)$$

$$y_{ijk}\ge 0 \qquad \forall\, i\in B,\ j\in V, k\in O \quad (6)$$

Where:

$i\,(=1,...,I)\in B$	group of berths,
$j\,(=1,...,T)\in V$	group of vessels,
$k\,(=1,...,T)\in O$	group of service orders,
S_i	the moment in which the berth *i* becomes available for the planning of berth allocation,
A_j	the arrival of vessel *j*,
C_{ij}	the handling time of the vessel *j* in berth *i*,
x_{ijk}	1 is the vessel *j* is handled as the k_{th} vessel in the berth *i* 0 if not.
P_k	subgroup of O such as $P_k=\{p/p<k\in O\}$,
W_i	subgroup of vessels as $A_j\ge S_i$,
y_{ijk}	time available in berth *i* between the departure of the k_{th} vessel and the arrival of the k_{th} vessel when the vessel *j* is being served as the k_{th} vessel.

The objective function (1) is to minimize the total waiting and handling time for each vessel. The group of restrictions (2) guarantees that each vessel should be handled in some berth in a service order (the order of being attended to). The group of restrictions (3) guarantees that each berth attends to, at the most, one vessel at a time.

Bearing in mind that the system is static, *Si* ≥ *Aj*, in other words, the vessels will always arrive before the time of the berth becoming available. The restrictions (4) guarantee that the vessels should be handled after arriving.

Later a heuristics solution was proposed for this problem, because this could not be solved in polynomial time, using the method of the optimization of the sub-gradient, based on the Lagrangian relaxation of the original problem - dynamic BAP.

2.2.3.1 Proposed Techniques to Solve the BAP

The majority of the studies related to ports, focus their attention on strategic and tactical problems. Because most berths are operated by private shipping companies, few studies have ever been carried out into the allocation of vessels in berths (Imai et al., 2001). According to Dai et al. (2004) there is a large amount of studies on operational research applications about container operations. In Table 1, the relationship between research that was found in the literature for solving the BAP is shown:

Table 1 – Bibliography found on BAP

Pesquisador	Ano	Trabalho
Brown et. al	1994, 1997	Allocation problem in naval ports
Lim	1998	Bidimensional problem of packing
Moon	2000	Integer linear programming
Imai, Nishimura e Papadimitriou	2001	Lagrangean Relaxation
Nishimura, Imai e Papadimitriou	2001	Genetic algorithms
Park e Kim	2003	Subgradient optimization, dynamic programming
Kim e Moon	2003	Simulated annealing

There is additional research that seeks a solution for the BAP, is available form Park and Kim (2003), Dai et al. (2004), Guan and Cheung (2004) and, Mulato and Oliveira (2006).

3 Proposal to solve the BAP

3.1 General Idea of the Proposed Method

Similar to the series of studies carried out by Imai, Nishimura and Papadimitriou (2001, 2003), the intention of this survey is to propose an alternative tool for solving the BAP, which differs from other studies that were found that deal with the insertion of variables related to operational costs, that are carried out in practice, making the model the closest to the activities carried out in the ports. An example is, the inclusion of the berthage fees for a vessel in the port, which is of great relevance in the decision making process.

In practice, we know that a port receives several sizes of vessels, therefore, they charge different rates for the length of time spent in the port (termed as berthage fees). In a survey held in the port of Itajaí (SC) was obtained the information that the daily berthage rate for a ship in the port is close to US$ 15,000.00. Thus, in his way, probably, it will more viable to service a large vessel first, leaving the smaller vessels for later, in order to avoid high costs for staying in the port.

Therefore, in this survey some parameters are considered as being of great relevance for solving the BAP, proposing a solving methodology that is easily implemented and that can offer good results.

3.2 Parameters for solving the BAP

In order to demonstrate the port operations with respect to its mooring plan it is necessary to determine some parameters that are pertinent to the problem, so that these reflect to the maximum, the real problems found in ports.

3.2.1 Costs (Vessel and Port)

The port system, because of its responsibilities and activities, involves several taxes that are charged for its operations. Firstly, the construction cost of the terminal, then, costs related to the acquisition of trucks and equipment, labor expenses, fuel, amongst others. As the focus of this survey is the berth allocation problem, only the port operational costs are considered.

For the preparation of this article the mooring tariffs and transport of cargo were considered, these were considered to have the greatest impact on making up the operational cost of the port.

The mooring rates are charged per linear meter of the wharf that is occupied by the moored vessel and for a certain period, or fraction, in hours. Some ports adopt the nomenclature 'period' to designate a certain number of elapsed hours from the moment of the vessels mooring in a berth, until its removal from that berth. For instance, the port of Santos (SP) uses a period of six continuous hours. In this way, if a ship is moored in certain berth for seven hours, it will have to pay the mooring rate for two periods, because it went over the limit of six hours in a single period.

The rates charged for cargo handling is charged for the handling that is done with the vessel. This rate may be based on tons moved or number of containers; however, the charging criteria should be defined at the time of the negotiations between the owner and the port authority.

These two charges are considered as being the main tariffs that are charged for using the port infrastructure, there are also charges for the use of the terrestrial infrastructure and general services.

3.2.2 Restrictions

Amongst the several restrictions that influence the mooring decision process of a certain vessel, the following should be highlighted: time, depth, length of equipment and the vessels schedules.

With regard to the time restriction, it is necessary to consider the arrival time of the vessel in the port, as well as the time of the availability of the berth. Berth availability, is understood to be moment when a vessel leaves a berth, thereby freeing it to receive another vessel. In practice, ports consider a time interval between the release time of the berth and a new mooring at that berth. This interval is used to prepare the berth for the next mooring, by removing or the repositioning of equipment, relocation of labor, etc. The Itajaí Port allows two hours for this interval.

The draft restriction is responsible for ensuring that the berth depth is greater than the draft of the vessel so that the vessel can be moved without any problems. Usually the vessels draft represents 70% of the depth of the water at the berth, this for greater security in the mooring operation.

The length restriction should verify that the length of the berth is greater than the length of the vessel so that it can adequately come alongside the berth.

Regarding the equipment, it is necessary to evaluate the probable berths (which already complied with previous restrictions) that will receive a certain vessel, ensure that it has suitable equipment to undertake the loading and unloading operation of the merchandise. Assume that a certain berth complies with the length and depth restrictions, and it is also unoccupied, already taken into account the period of time required between the release of a vessel and the mooring of another; nevertheless, it is necessary to verify that this berth has equipment capable of meeting the needs of the vessel which is a candidate for the mooring, because depending on the type of merchandise, different equipment will be required. For this study, it has been considered that all berths have suitable equipment available for any type of vessel to be handled.

The restriction scheduling to be considered in this study is to ensure that the staging of the vessels occurs in two possible ways: the earliest date of liberation of the vessel or by the least allocation cost. In some cases, and depending on the merchandise type to be handled, it may be better to carry out the load/unloading operation in the shortest period of time; mainly in the case of perishable products, where the time factor plays a fundamental role in the shelf life of the product, even if that allocation has a greater cost.

In other cases, usually for nonperishable products, such as ores, iron, aluminum, it is more convenient to guarantee that the allocation has the smallest possible cost, not to increase the cost of the merchandise. Like this, probably, the ship will wait for a mooring for a longer period, however, with a lower allocation cost if the criterion of the earliest release date was used.

3.2.3 Decision Making Variables (When and How to Allocate Each Vessel)

The port administration, that has a list of vessels to be moored within a certain period of time, a week, a fortnight or a month, should prepare a mooring plan, in other words, create a system of scheduling vessels, to guarantee that all vessels are dealt with in the shortest period of time or at the lowest possible cost. For this, it is necessary to verify if all the restrictions are satisfied for the staging to begin.

The mooring plan should be capable of allocating the vessels to berths in the best possible way, in other words, to determine in 'which' berth should each vessels be moored, as well as 'the time' of the mooring, and analyze if there was any waiting time on the part of each vessel, considering costs that will optimize the ports operating system, at the end of the staging, to determine a group of berths that are handling a group of vessels moored in different periods, with different capacities, tariffs and productivity rates.

Port activities involve the daily arrival and departure of several vessels (the port of Rotterdam, has 60 vessels on average), as well as the use of several berths (Rotterdam has five mooring areas and another two areas for emergency mooring), the scheduling of the vessels can be slow on many occasions, requiring the use of Information Technology (IT).

3.3 Heuristic Allocation Algorithm

In an attempt to offer an easily implementable method that can provide good results for solving the BAP, a heuristic algorithm has been suggested for the allocation of berths for vessels.

Initially a simplified algorithm has been proposed that is capable of analyzing a list of vessels (each one containing information on the time of arrival, draft, load, length and differential tariffs), and a list of berths (with information relating to the release time, the considered interval, depth, length, productivity, tariffs), to verify that the restrictions have been satisfied and, later, allocate each vessel to a berth.

The list of vessels that are to be moored, is not necessarily informed according to the arrival schedule, and therefore the algorithm has the allocation criteria to verify the final time of release of a certain berth, add the interval period to be considered (two hours, in the case of the Itajaí port), then allocate a ship to this berth.

Supposing there is a list with two ships to be moored, according to Table 2:

Ship ID	Length	Depth	Cargo	Arriving time	Cost to be waiting
n1	220	14	150	18/8/2007 17:00	2.000,00
n2	210	14	125	18/8/2007 12:30	1.700,00

Table 2 – Example of a list of vessels to be moored
Source: the author

And a list of two existent berths, according to Table 3:

Berth ID	Length	Depth	Productivity (container/hour)	Release Time	Anchorage tariff	Movement tariff (per container)
b1	260	16	50		2,50	45
b2	250	**13**	45		2,30	45

Table 3 – Example of a list of berths to be occupied
Source: the author

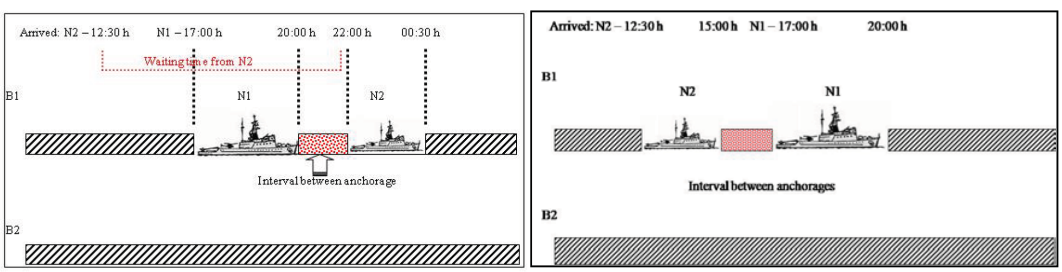
After scheduling the vessels, it is noted that the berth *b2* does not comply with draft restriction, because both vessels need 14 meters for mooring and berth *b2* only has 13 meters of water. This way, both will have to be handled in berth *b1*, which meets the length and depth restrictions.

As the list of vessel starts with vessel *n1* with an arrival time of 17:00 h, this should be the first ship to be allocated. It is worth mentioning that this criteria is used in this survey, and may be altered between authors, in other words, initially the list of vessels may be arranged in accordance with the time of arrival, to later to carry out the staging.

Also considered in this example is the time of liberating both berths as being free to make for staging at any moment, in other words, a vessel can be moored in any one of the berths from when it arrives (if the restrictions are complied with).

We can then go to vessel *n1* that has its arrival time set 17:00 h. As already mentioned, it will be handled by berth *b1*, from the time of its arrival. As this vessel has 150 tons of merchandise to unloaded and berth *b1* has a capacity of 50 tons per hour, this vessel *b1* will take 3 hours to be handled, therefore, terminating its port activities at 20:00 h. From this moment forward, a period of two hours will be added (using this example) so that the berth can undergo the necessary treatment to receive the next vessels at about 22:00 h.

Using this time schedule, vessel *n2* moors into berth *b1*, it has 125 tons of cargo to be handled, and it will finish it handling at 00:30 h, freeing the berth at that time. Like this, it can be concluded that vessel *n1* didn't have any waiting time and vessel *n2* had a waiting time of 9:30 h, according to Figure 1 (a).



(a) (b)

Figure 1 - Servicing vessels varying the sequence
Source: the author

To calculate the total cost of the allocation (CA), consider:

$$MinCA = \sum_{i \in N} \sum_{j \in B} \left\{ \left[\left(E_i + A_{ij} \right).CP_i \right] + \left(C_i.TMov_j \right) + \left[\left(L_i.TAtrac_j \right).P \right] \right\}.x_{ij} \tag{7}$$

Subject to:

$$\sum_{i \in N} \left(L_j - L_i \right).x_{ij} \geq 0 \quad \forall j \in B \tag{8}$$

$$\sum_{i \in N} \left(D_j - D_i \right).x_{ij} \geq 0 \quad \forall j \in B \tag{9}$$

$$Mcheg_i + \sum_{i \in N} A_{ij}.x_{ij} - Mlib_j \geq 0 \tag{10}$$

Where:

CA: is the objective function of the allocation cost;
Ei: waiting time for the vessel *i*;
Aij: time servicing the vessel *i* in the berth *j*;
CPi: Cost of the vessel *i* stopped;
Mchegi : arrival time of the vessel *i*;
Mlibj: time of liberating the berth *j*;
Li: length of vessel *i*;
Lj: length of berth *j*;
Di: draft of vessel *i*;
Dj: depth of berth *j*;
TAtracj: mooring fees charged for the berth *j* of vessel *i*;
Ci: vessels load *i*;
TMovj: movement fees charged for the berth *j* for vessel *i*;
P: number of periods charged for;
xij: binary variable of the type 0-1, where it is assumed that the value 1 if the vessel *i* has been serviced at berth *j* and assume 0 otherwise;
N = {n1, n2, ..., nk}, represents the group of vessels;
B = {b1, b2, ..., bm}, represents the group of berths.

The equation (8) represents the restriction on the length of the berth *j* which should be greater than the length of the vessel *i*; restriction (9) indicates that the draft of the ship *i* should be less than depth at berth *j* and, restriction (10) indicates that the time of mooring and servicing of the vessel *i* should be greater than the time of freeing of berth *j*, in other words, a vessel cannot be moored and serviced by a given berth before being liberated from the handling of the previous vessel.

Therefore, the total cost of this allocation would be $29,500.00 obtained using equation (7). If the service list began with vessel *n2*, which would be handled first, the total allocation cost would be $23,700.00, because the vessels would stay in the port for less time, there would be no waiting time for any vessel, according to Figure 1 (b).

In consequence, this results in a vessel downtime cost less than the first allocation, in other words, in this case, the cost reduction would be approximately 20%.

Because the cost varies a lot from one allocation sequence to another, it becomes necessary to evaluate the several possibilities of sequences that can exist, and for this search not to be exhaustive, a genetic search algorithm has been proposed that analyzes the possible allocation sequences.

3.4 Genetic Search Algorithm

According to Soares (1997), a procedure for the selection of the method is to carry out an exhaustive study on available optimization algorithms, verifying the characteristic of reaching the global solution more frequently for a certain number of executions. That is a factor for measuring the potentiality of the algorithms and, amongst the most effective methods, are the Genetic Algorithms - GA. GA´s are applied as a random search technique that have been used by a great number of followers (DÁVALOS & STANGE, 1994).

In accordance with Tcholakian and Stange (1994), in the GA´s each point of the space solution is considered as a chromosome or an individual. The group of chromosomes is called a population. The individuals in the population grow generation by generation through operations between the chromosomes, such as the selection, crossover and mutation operations.

3.4.1 Characterization of the Chromosome

For Mayerle (1996) it is in the chromosome where the characteristics of the researched solutions are stored. According to Goldbarg and Luna (2000), a chromosome is usually defined as a vector of components.

Like this, for the BAP, a chromosome may be represented by a sequence of vessels, which carry in themselves the values of the variables:

$$\text{Chromosome} = \{N3_1, N2_2, N1_3, ..., Nn_k\}$$

where *Nnk* represents the *kth* vessels in the list, and each vessel occupies a position in this list (for instance: the vessel *n3* occupies position #1 in the list).

3.4.2 Generation of an Initial Population

An initial population is formed, in principal, through some evaluation performance mechanism (GOLDBARG & LUNA, 2000). The individuals are coded in a finite sequence of vessels and in this way, each component of the sequence is called a gene, which is associated to a variable of the problem.

This evaluation performance, better known as fitness, represents the individual's capacity to adapt to the environment. In the case of GA, when applied to the optimization of combinatory problems, its size relates to the value of the objective function, which can be calculated according to the expression shown in (7).

Considering that for a BAP we want to find the minimum value for the objective function, the fitness measure should be considered as; the smaller the value is, the bigger the adaptation capacity will be.

3.4.3 Selection Technique

To arrange the individuals of the population during the search process of the fitness size is (represented by f_n), calculated by (7), as already mentioned. The order is given in the following way: $f_1 \le f_2 \le ... \le f_n$. Moreover, this way, the first individual of the population presents the best performance, while the last individual has the worst performance of all the population. This way the method always chooses individuals with best performances causing them to reproduce.

3.4.5 Crossover

The crossover operator, is considered as the fundamental characteristic of the GA. Pairs of genitors are chosen, randomly, from the population and, based on the aptitude, new individuals are formed from the exchange of genetic material. This way, the descendants will be different from their parents, but with genetic characteristics of both genitors (PACHECO, year unknown).

There are several rules that exist to make up the individuals crossing and like this, for the problem related to this survey, is was opted to innovate and to differentiate the other rules, considering the average of the occupied positions for the individuals in the chromosomes

Considering two chromosomes:

$$C1 - \{N3_1, N2_2, N4_3, N1_4\}$$

$$C2 - \{N2_1, N4_2, N1_3, N3_4\}$$

The averages of the positions are calculated occupied by each individual in the two chromosomes:

N1: occupies positions 4 and 3, therefore the average is 3.5;
N2: occupies positions 2 and 1, therefore the average is 1.5;
N3: occupies positions 1 and 4, therefore the average is 2.5;
N4: occupies positions 3 and 2, therefore the average is 2.5;

Next, list them in ascending order and, when there is parity, randomly select any one of these to occupy the position:

$$1{,}5 \leq 2{,}5 \leq 2{,}5 \leq 3{,}5$$
$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$
$$N2_1 - N3_2 - N4_3 - N1_4$$

As there was parity between the N3 and N4 individual averages, it was decided to insert in the list, in the second position, vessel N3 and, followed by vessel N4.

3.4.6 Mutation Operation

After making the crossover, the mutation takes space. This is a genetic operator which is introducing new characteristics to the individual or even to restore characteristics that were lost in operations, for instance, in the crossover.

In this way, the mutation assures that the probability of arriving at any point in the search space is never zero, as well as solving any problem relating to maximums (or minimums) places, because with this mechanism, the direction of the search may be altered slightly. In the GA system, a mutation is an event that has a probability p_m for each bit of the chain of characters of all the individuals in the population, which could become an expensive operator.

In the BAP, the mutation should be done randomly after the crossover, using a mutation rate, in other words, a probability that this procedure will occur.

The mutation operator has an important role in the growth of the population (introduction and restoration of characteristics), however a secondary genetic operator is considered, which should happen with a low probability, considering the high computing cost.

3.5 Implementation of the Proposed Algorithm

For the implementation of the suggested method, it is suggested that this be based on the Imai et. al (1994, 2001, 2003, 2005) and Nishimura et. al (2001) studies.

In this way, the proposal for solving the BAP is the construction of a program, which can be developed using Delphi®, where the behavior of the proposed variables method should be implemented, tested and analyzed. The suggestion to use Delphi® is because this includes several simulation methods and it allows for the possible representation of dynamic aspects, where some variables can be implemented – such as berth productivity - with the objective of being closest to the reality that is needed.

The suggestion of the heuristic method for solving the BAP is idealized for generic use, so that it can be adapted to any marine port terminal by simply modifying a few parameters.

4 Final Considerations

At the end of this article it is hoped that some implications that are present in a port administration have been conveyed concisely, more specifically the problem relating to the allocation of ships to berths and the respective implications.

It is hoped that something has been learnt about genetic algorithms, an easily understood tool and application, which is proposed for the solving of the BAP.

To take this survey a step further, it is intended to implement a program to use the suggestions in this article, the use of the genetic algorithm and the inclusion of pertinent variables relating to the real problem, allowing for testing of the suggested methodology and the evaluation of the results, validating them with the intention of helping in the administration of the port system.

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References

Anuário Estatístico dos Transportes. Disponível em:

< http://www.geipot.gov.br/anuario2001/complementar/Tabels/722.xls>

BROWN, G. G., LAWPHONGPANICH, S., THURMAN, K. P. (1994): Optimizing ship berthing. Naval Research Logistics, v. 41, 1-15.

BROWN, G. G., CORMICAN, K. J., LAWPHONGPANICH, S., WIDDIS, D. B. (1997). Optimizing submarine berthing with a persistence incentive. Naval Research Logistics, v. 44.

DAI, J., LIN, W., MOORTHY, R., TEO, C.-P. Berth allocation planning optimization in container terminal. Disponível em:

<http://www.bschool.nus.edu.sg/staff/bizteocp/berthplanningjuly2004>

DÁVALOS, R. V., STANGE, P. (1994). Uma comparação entre otimização global via algoritmos genéticos e via Gams. Anais do congresso XXVI Simpósio Brasileiro de Pesquisa Operacional, p. 696-701. Florianópolis.

FERNANDES, M. G. (2001). Modelo econômico-operacional para análise e dimensionamento de terminais de contêineres e veículos. Dissertação de Mestrado. São Paulo: Universidade de São Paulo, Departamento de Engenharia Naval e Oceânica da Escola Politécnica da Universidade de São Paulo.

GOLDBARG, M. C. LUNA, H. P. L. (2000). Otimização combinatório e programação linear: modelos e algoritmos. Rio de Janeiro: Campus.

GUAN, Y.; CHEUNG, R. K. (2004). The berth allocation problem: models and solutions methods. OR Spectrum, v. 26, 75-92.

IMAI, A., NAGAIWA, K., TAT, C. W. (1994). Efficient planning of berth allocation for container terminals in Asia. Journal of Advanced Transportation, v. 31, n. 1, 75-94.

IMAI, A., NISHIMURA, E., PAPADIMITRIOU, S. (2001). The dynamic berth allocation problem for a container port. Transportation Research Part B, v. 37, 401-417.

IMAI, A., NISHIMURA, E., PAPADIMITRIOU, S. (2003). Berth allocation with service priority. Transportation Research Part B, v. 37, 437-457.

IMAI, A., SUN, X., NISHIMURA, E., PAPADIMITRIOU, S. (2005). Berth allocation in a container port: using a continuous location space approach. Transportation Research Part B, v. 39, 199-221.

KIM, K. H., MOON, K. C. (2003). Berth scheduling by simulated annealing. Transportation Research Part B, v. 37, 541-560.

LIM, A. The berth planning problem. (1998). Operations Research Letters. v. 22, 105-110.

MAYERLE, S. F. (1996). Um sistema de apoio à decisão para o planejamento operacional de empresas de transporte rodoviário urbano de passageiros. Tese de Doutorado-UFSC. Florianópolis.

MOON, K. C. (2000) A mathematical model and a heuristic algorithm for berth planning. Brain Korea 21 Logistics Team, July.

MULATO, F. M., OLIVEIRA, M. M. B. de. (2006). O impacto de um sistema de agendamento antecipado de docas para carga e descarga na gestão da cadeia de suprimentos. Revista Produção Online. v. 6, n. 3, p. 96, set./dez.

NISHIMURA, E., IMAI, A., PAPADIMITRIOU, S. (2001). Berth allocation planning in the public berth system by genetic algorithms. European Journal of Operational Research, v. 131, 282-292.

NOVAES, A. G. (2004). Logística e gerenciamento da cadeia de distribuição. 2ª ed. Rio de Janeiro: Campus.

OBITKO, M. Website tutorial. (1998). Genetic algorithms with Java examples.

PACHECO, M. A. C. Algoritmos genéticos: princípios e aplicações. ICA: Laboratório de Inteligência Computacional Aplicada. Departamento de Engenharia Elétrica. Pontifícia Universidade Católica do Rio de Janeiro. Fonte desconhecida.

PARK, K. T., KIM, K. H. (2002). Berth scheduling for container terminals by using a sub-gradient optimization technique. Journal of the Operational Research Society, v. 53, 1054-1062.

PARK, Y.-M., KIM, K. H. (2003). A scheduling method for berth and quay cranes. OR Spectrum, v. 25, 1-23.

PEIXOTO, J. B. (1977). Os transportes no atual desenvolvimento do Brasil. Rio de Janeiro: Biblioteca do Exército.

Pesquisa Aquaviária CNT: Portos Marítimos: Longo curso e cabotagem. Brasília: Confederação Nacional do Transporte: 2006.

SILVA, V. M. D., COELHO, A. S. (2007). Uma visão sobre o problema de alocação de berços. Revista Produção Online, v.7, n. 2. ISSN 1676-1901.

SOARES, G. L. (1997). Algoritmos genéticos: estudo, novas técnicas e aplicações. Dissertação de Mestrado. Belo Horizonte: Escola de Engenharia da Universidade Federal de Minas Gerais.

TCHOLAKIAN, A. B., STANGE, P. (1994). Um algoritmo para a construção de funções de pertinência via algoritmos genéticos. Anais do congresso XXVI Simpósio Brasileiro de Pesquisa Operacional, p. 111-116. Florianópolis.

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