A genetic algorithm for solving the quay crane scheduling and allocation problem

S Olteanu, D Costescu, A Ruscă and C Oprea

University Politehnica of Bucharest, Department of Transport, Traffic and Logistics, Spl. Independentei no. 313, district 6, 060042, Bucharest, ROMANIA

E-mail: ltn_sergiu@yahoo.com

Abstract. International sea-freight container transportation has grown dramatically over the last years and container terminals represent nowadays a key actor in the global shipping network. The management of a container terminal is a complex process that involves many decisions. Among the problems to be solved, there are the spatial allocation of containers on the terminal yard, allocation of ships to berths and cranes, scheduling priorities and operations in order to minimize ship's turnaround time, one of the main indicators of the terminal performance for the shipping companies. An efficient use of quay cranes is crucial, since quay cranes are highly expensive and represent one of the most scarce resources in the terminal. The quay crane allocation problem aims to efficiently assign quay cranes to vessels that must be operated over a given time horizon. The allocated cranes must be sufficient to complete the workload within the given time window, although many configurations are possible. In this paper, we will mainly focus on the quay crane scheduling problem, considering other logistic activities as given. This problem can be split into two sub-problems. First, specific quay cranes must be assigned to specific tasks. Second, a detailed schedule of the loading and unloading moves for each quay crane should be constructed. In this case, the number of quay cranes assigned to the vessel is assumed to be known in advance. The paper presents a solution for solving the quay crane scheduling and allocation problem that is based on working with modern optimization techniques such as genetic algorithms. The genetic algorithms are soft computing techniques that are used for optimization and search. Thus, the solution is obtained through a C++ built on simulation model that, over the analytical modelling of container`s terminals activity, has the main advantage of providing a greater level of detail and avoids too many simplifications. Also, three different scenarios that describe operational situations have been taken into account.

1. Introduction

Docked vessels for loading/unloading operations can be operated by multiple quay cranes at the same time, with a direct influence between the total operating time and the number of cranes. However, the number of quay cranes assigned to a ship for operation shouldn`t be very high due to the existence of multiple spatial restrictions.

An efficient use of quay cranes is crucial since quay cranes are highly expensive equipment and represent a limited resource of terminal. The issue of allocating the quay cranes suppose an efficient cranes assignation so that unloading/loading process to be performed within a predetermined time.

The quay crane program development represent an operational problem that on behalf of terminal decision makers implies the assignation of the quay cranes with certain technical and operating characteristics for handling in order to be   makers to assign quay cranes with certain technical and operating characteristics so as to be able to handle specific loads (containers). Starting from this assignment, a detailed motion program is developed for each crane. Problems arising from interference between cranes, service priorities and other operational restrictions must be taken into account [1].

Figure 1 represents a schematic representation of a quay crane assignment and scheduling plan. For every time step, a certain number of cranes is allocated to vessels; the number of cranes may vary (as for vessels 2 and 3) or remain constant (as for vessels 1, 4 and 5) during vessel's stay-at-the-port. Furthermore, not only the amount but specific cranes (identified by an index) are assigned to vessels; finally, the assignment must not exceed the total quay crane capacity, which is of 4 quay cranes in the example.
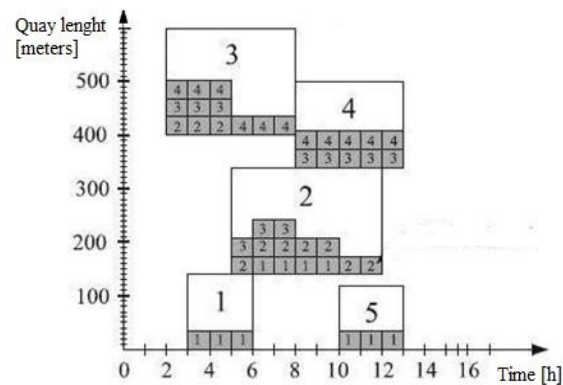
Figure 1. Example of quay crane assignation program [1].

The paper presents a solution for quay crane scheduling and allocation problem that is based on working with genetic algorithms. Genetic algorithms are adaptive heuristic search techniques based on the principles of genetics and natural selection which Darwin stated (survives who is better suited). The mechanism is similar to the biological process of evolution. The main feature of this process is that only the species that are better adapted to the environment are able to survive and evolve over generations, while those less adapted fail to survive and in time disappear, as a result of natural selection. The surviving and evolving probability over generations of the species becomes greater as the adaptation degree increases and this, in optimization terms, means that the solution approaches to the optimal one. The power of genetic algorithms comes from their simplicity and from the fact that even if they do not give the optimal solution, certainly the proposed solution is always close to the best results.

2. Literature review
The transports and logistics field is a major source of optimization problems with a high degree of complexity. Lately, maritime transport and logistics platforms are operationally the main beneficiaries of research results in the field, driven by the intense increase in freight transport, especially in containerized cargo.

The quay crane allocation problem has been first formulated by Daganzo (1989) as an integer programming model, being solved by Peterkofsky and Daganzo (1990) through a branch and bound algorithm. The Branch and Bound method can be applied to problems that can be represented on a tree graph [2,3].

Kim and Park (2004) have developed a quay crane programming model in which they have prioritized tasks and have taken into account restrictions imposed by crane interferences. Models developed to solve the problem of quay crane programming offer solutions based on branch and cut algorithms (Moccia et al, 2006), various optimization algorithms for combinatorial problems (Sammarra et al, 2007) and genetic algorithms [4,5,6,7].

Bierwirth and Meisel (2009) developed a model simplifying some restrictive hypotheses of previous models [9]. The problem enunciated by them is solved by a branch and bound algorithm. Finally, the effects of dual cycle crane operations on loading / unloading operations were investigated by Goodchild and Daganzo [3].

Cordeau et al (2005) studied the problem of chew crane programming as a problem for optimizing vessel processing time and crane timing. To solve this problem, they proposed a branch and cut algorithm. Lee et al (2008) studied the problem of quay crane programming considering the

restrictions imposed by crane interference on the same quay. The solution proposed by them is based on genetic algorithms [10,11].

Currently, genetic algorithms are heavily used in developing optimization models because they are easy to be implemented, with applicability to specific issues in almost all technical areas. By using these models, the authors have provided efficient operational and energy solutions to optimize transport between different origins and destinations. Jung and Kim (2006) proposed a genetic algorithm to solve the problem and simulated the scheduling of loading / unloading operations under multiple crane operation on the same quay [12]. The charging operations programming methods developed by them take into account the interference between adjacent quay cranes.

3. Modelling framework
As it has been already briefly presented in the introduction, the paper describes an innovative solution for the operational issues that managers from maritime container terminals have to deal with. In order to solve the quay crane scheduling and allocation problem, the authors have designed their own IT tool which encompasses computerized simulation technics along with genetic algorithms working principles and randomly generated variables. The simulation model has been developed using C++ programming language and the physical model taken into consideration for the solution development has a structure similar to the one presented in the figure 2.
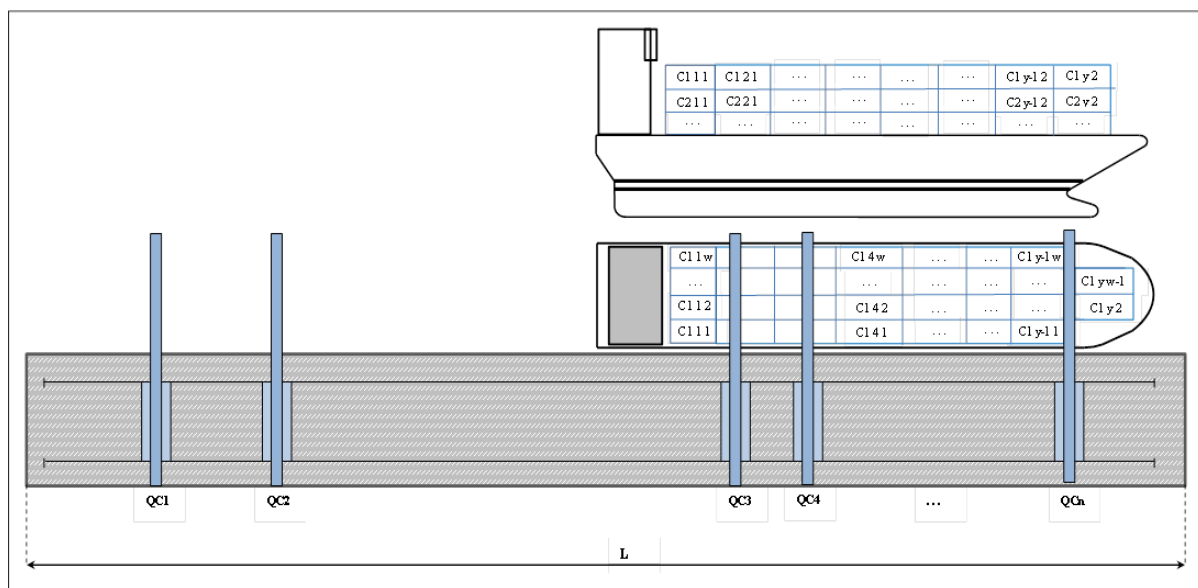
Figure 2. Quay cranes physical model.

For the system formalization, the quay length (L) and the number of the assigned cranes (QC) are given. Also, the payload of each arrival ship is encoded as a 3D matrix and the position and the destination of each container is well defined. For performing the loading/unloading process, the cranes are moving along the quay and their trips lengths are measured in units of 20 feet. For example, considering the quay cranes positions presented in figure 2, if the C 1 1 2 container have to be unloaded, the quay crane number 3 will have to change its current position to the left with 1 unit of 20 feet. Unloading the containers whose positions are not accessible will require extra unloading/loading and rearranging movements of the containers located on the superior layers.

From the functional point of view, the ships for which the unloading/loading process has been already initialized, have absolute priority and the incoming ships will be served whether their length doesn`t exceed the available quay length, otherwise the incoming ship will have to wait till the unloading/loading process of the previous ship is achieved.

The mechanism of improving the quay cranes allocation and scheduling problem can be reduced to the following mathematical formulation, equation (1):

$$\min\left(\sum_{i=1}^{N} \left(T_{pi} + T_{di}\right) \times c_{SN} + \sum_{j=1}^{k} t_{pij} \times c_{mp} \right) \qquad (1)$$

where: -   N is the number of incoming ships within H time interval;
      -   T_{pi} is the total processing time for ship i;
      -   T_{di} is the delay time of ship i, when the ship i lenght exceeds the available quay lenght;
      -   c_{SN} is the average ship stationing cost;
      -   t_{pij} is the total processing time of the ship i with the crane j;
      -   c_{mp} is the crane average using cost.

Before describing the functional framework of the simulation model, the following assumptions have to be made:

* The handling time for a single container is a normal randomly generated variable.
* The ships arrival moments are exponential randomly generated variables.
* The handling time for a single container is a normal randomly generated variable.
* The ship type and the transported payload is a normal randomly generated variable.
* The quay cranes have all the same productivity.

The functional framework is described in the following steps:

Step 1: The entry data is initialized (quay length, number of quay cranes etc.).

Step 2: The ship type and their associated payload is randomly generated. For modelling the system, 3 types of ships have been considered, depending on their size (length expressed in feet and loading capacity expressed in TEU).

Step 3: Ships arrival times are randomly generated.

Step 4: The availability of enough quay length is tested. Whether there is enough quay length, the first unloading/loading process solution is randomly generated. Each generated solution is encoded as a 2D matrix, each row of the matrix containing the visiting order location for each quay crane. An example of a 2D matrix solution is presented in the figure 3. The row containing only 0 values signifies that for obtaining the minimum cost of use, the quay crane number 4 should not be assigned to any location. The matrices solutions represent the chromosomes from which new solutions will be generated.

QC1	C 1 1 2	C 1 3 1	C 2 2 3	C 1 1 4	C 2 2 1
QC2	C 3 3 1	C 3 1 5	C 4 3 2	C 3 1 1	C 5 5 1
QC3	C 3 9 4	C 4 4 6	C 6 6 1	C 4 4 2	C 5 5 6
QC4	0	0	0	0	0

Figure 3. Example of a matrix solution of a system with 4 quay cranes.

Whether there is not enough quay length, the ship unloading/loading process is delayed till the unloading/loading process of the previous ship is finished.

Step 5: The previous generated solution is tested and if the fitness function value is not the desired one, starting from the previous solution/chromosome, through permutation mutations as it is shown in figure 4, new solutions are generated [13].

QC1	C 1 1 2	C 2 2 3	C 1 3 1	C 1 1 4	C 2 2 1
QC2	C 5 5 1	C 3 1 5	C 4 3 2	C 3 1 1	C 3 3 1

Figure 4. New solution obtained through randomly generation and mutation.

Step 6: Step 5 is performed till fitness function values tend to be constant.

Step 7: The entire mechanism is stopped when the ship arrival time exceeds the predetermined H time interval.

Also, the functional framework of the simulation model can be briefly described by the following logical scheme (figure 5):
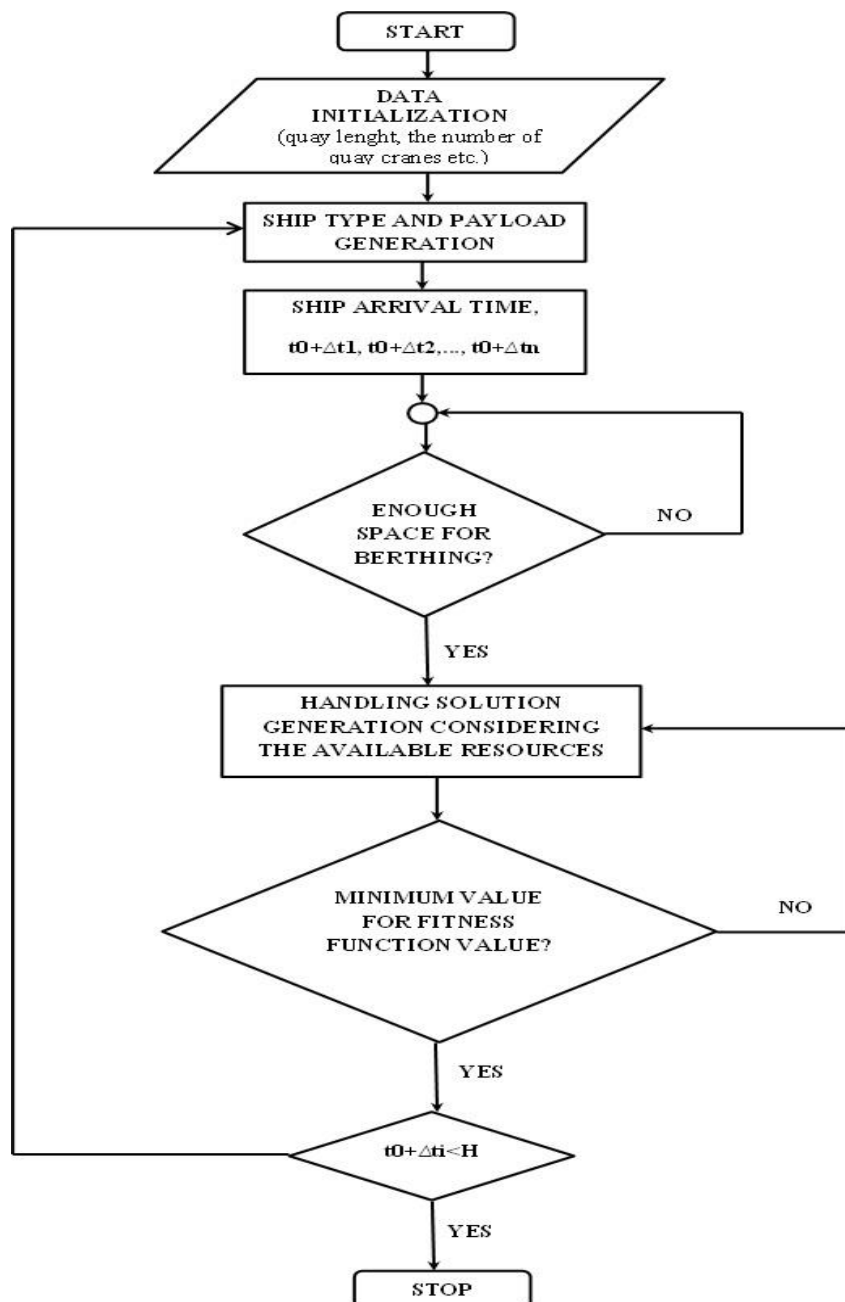
Figure 5. Logical scheme of the model.

4. Results

For testing the simulation model the following constants have been considered:
- quay length, L=1100 meters;
- the average berthing delay cost is 5 monetary units, the average handling operations time cost is 7 monetary units ($c_{SN} = 7 + 5 = 12 m.u.$), the average crane using cost is $c_{mp} = 8 m.u.$;
- the quay is equipped with 7 cranes;
- the considered ship types are: Type 1(Panamax, 3000 TEU loading capacity), Type 2 (Feeder, 1500 TEU loading capacity) and Type 3(Small feeder, 500 loading capacity).

The following results have been obtained (table 1):

Table 1. The simulation model results.

Ship type	Payload [containers]	Ship`s costs [m.u.]	Minimum fitness function	Total costs [m.u.]

		Unloaded	Loaded	Unloaded / loaded	Berthing delay cost	Handling operations time cost	value for quay cranes operations [m.u.]	
Ship arrival time 1	2	88	42	21	0	281	182	463
Ship arrival time 2	1	56	24	11	98	174	114	288
Ship arrival time 3	2	12	35	10	0	247	98	345
Ship arrival time 4	3	17	5	3	0	79	56	135
Ship arrival time 5	3	31	17	10	0	114	91	215
Ship arrival time 6	1	75	34	20	129	254	212	595
Ship arrival time 7	2	65	23	6	118	158	122	399
Total		**344**	**180**	**81**	**345**	**1307**	**875**	**2440**

The fitness function variation values for each ship are presented in table 2.

Table 2. The fitness function variation variables.

Generation \ Ship	Fitness function values for quay cranes operations [m.u.]									
	10th	20th	30th	40th	50th	60th	70th	80th	90th	100th
Ship I	315	309	289	256	232	217	204	188	184	182
Ship II	326	288	243	224	205	147	121	117	116	114
Ship III	267	234	221	198	178	168	145	114	102	98
Ship IV	175	168	145	134	112	94	88	65	58	56
Ship V	202	189	167	148	145	128	117	102	94	91
Ship VI	372	338	312	293	287	256	248	228	218	212
Ship VII	238	223	216	197	184	175	157	139	128	122

Comparing to the average value of the fitness function, for each ship, the following economies have been obtained (figure 6):
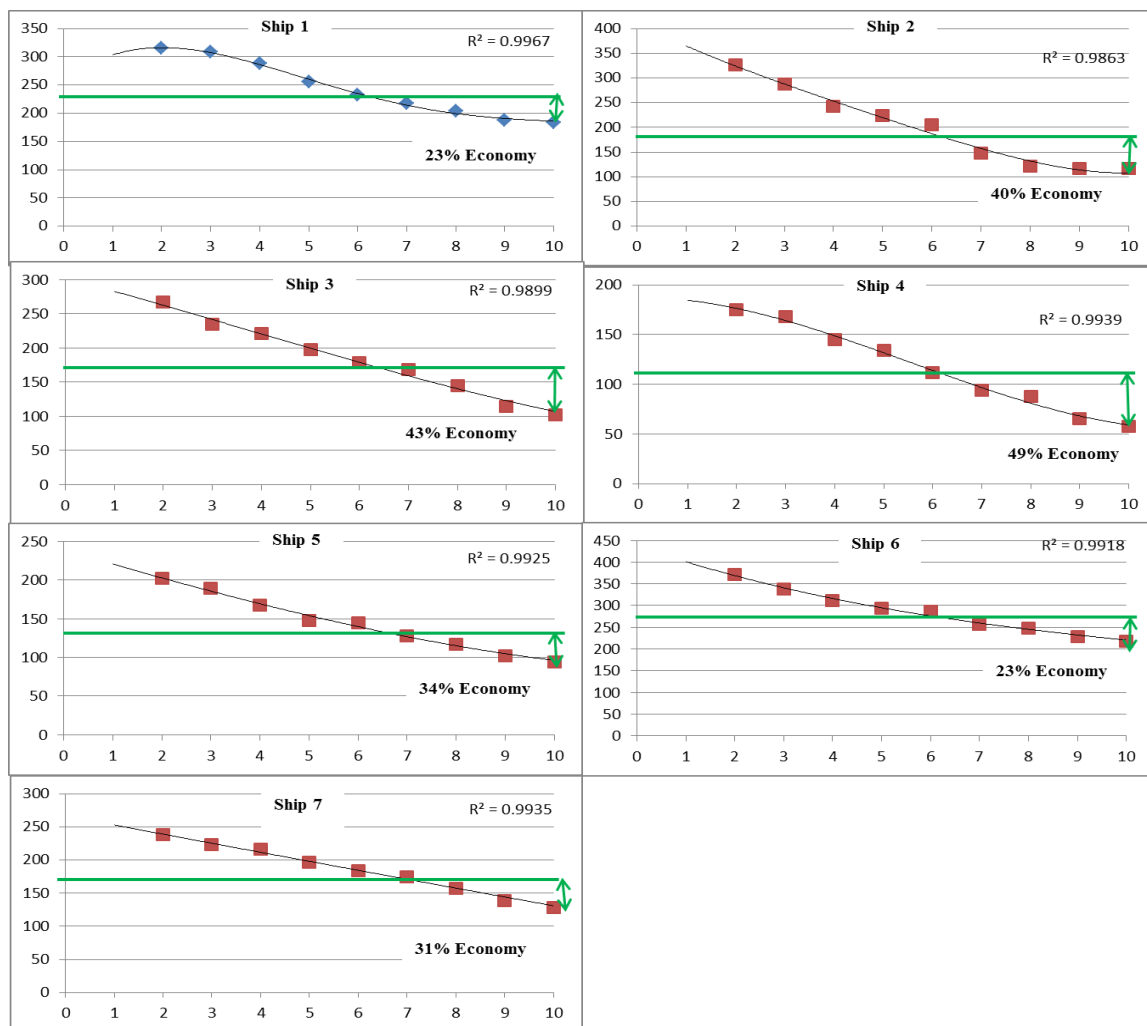
Figure 6. Fitness function values for each ship.

5. Conclusions

Till recently, studies and researches in the field of intermodal freight transport have been devoted almost exclusively to terminal location issues, which is justified by their strategic nature in the development of multimodal transport networks. The literature of operations optimization within the intermodal terminals is quite recent and does not benefit from many research projects. Moreover, the works in the field have not benefited from an integrated, multidisciplinary approach, having authors from IT and mathematical field or from the transport field. For this reason, it is appropriate to continue the research by developing studies and optimization models that take into account both the latest trends in computerized simulation and the valuable expertise and knowledge of transport researchers. Thus, the current requirements of any technical field, which imply the development of optimization models with applicability in multiple domains, but which can be easily adapted to solve problems with high degree of specificity in various fields, could be met.

6. Acknowledgement

7. References

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