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MODELS AND METHODS FOR OPERATIONS IN PORT CONTAINER TERMINALS

ABSTRACT

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 maximize performances based on some economic indicators. Since the container port facilities are very expensive, it is desirable to optimize their performance, making better management decisions. This paper wants to present the contribution of the simulation and optimization techniques with the aim of improving the cooperation between different types of equipments, increasing the productivity of the terminal and helping in minimizing costs. In particular, the Petri net is used to present berth operations, and the genetic algorithm is used for scheduling container loading/unloading operations by cranes in order to minimize the maximum time it takes to serve a given set of vessels.

KEYWORDS

transportation, berth management, scheduling, simulation, optimization

1. INTRODUCTION

In the last 30 years the revolutionary development of container handling has increased the efficiency of worldwide trade (by about 9.5% per year) and will continue to do so at an 8% growth rate in the coming years [1]. So the increasing demand for container transportation results in various issues, including risk of terminal congestion, delivery delay, and economic loss. The main role of a container terminal is the transfer and storage of containers. *Figure 1* shows a typical container terminal layout composed of “Quayside area” and “Storage yard”.

In a container terminal, it is important to guarantee fast operations to reduce delays in delivering goods to ships, trains and trucks, and consequently, to reduce sea, road or rail transport time. Therefore, container terminals have a fundamental role in the interchange between roads, railway and sea networks, and therefore they are usually equipped with modern equipment, advanced transport systems and up-to-date information and communication technologies. In this context, the efficiency of a given terminal depends on its internal organization according to its planning and control strategies.

Many optimization problems associated with a container terminal have been extensively studied in the past few years. Vis and De Koster (2003)[1] gave a comprehensive review of literature. Kim and Park (2002)[1] treated quay cranes scheduling as an m-parallel machine scheduling problem. Meersmans [2] provided models and algorithms for scheduling container handling equipment in an integrated way in an automated container terminal but considered only loading operations.

This paper considers the Container Terminal of the Port of Koper as case-study. With Slovenia’s accession to EU on 1 May 2005, there was an increase in operations (*Table 1, Figure 2*) on the Port of Koper container terminal. The Port Master’s office therefore adopted a strategic decision on the expansion of the terminal (e.g. quay and yard extensions, new equipment, increased TEU capacity, infrastructure developments) in order to meet the demands of the European markets. As the system is gaining in complexity and with the requirements for lower costs and efficiency

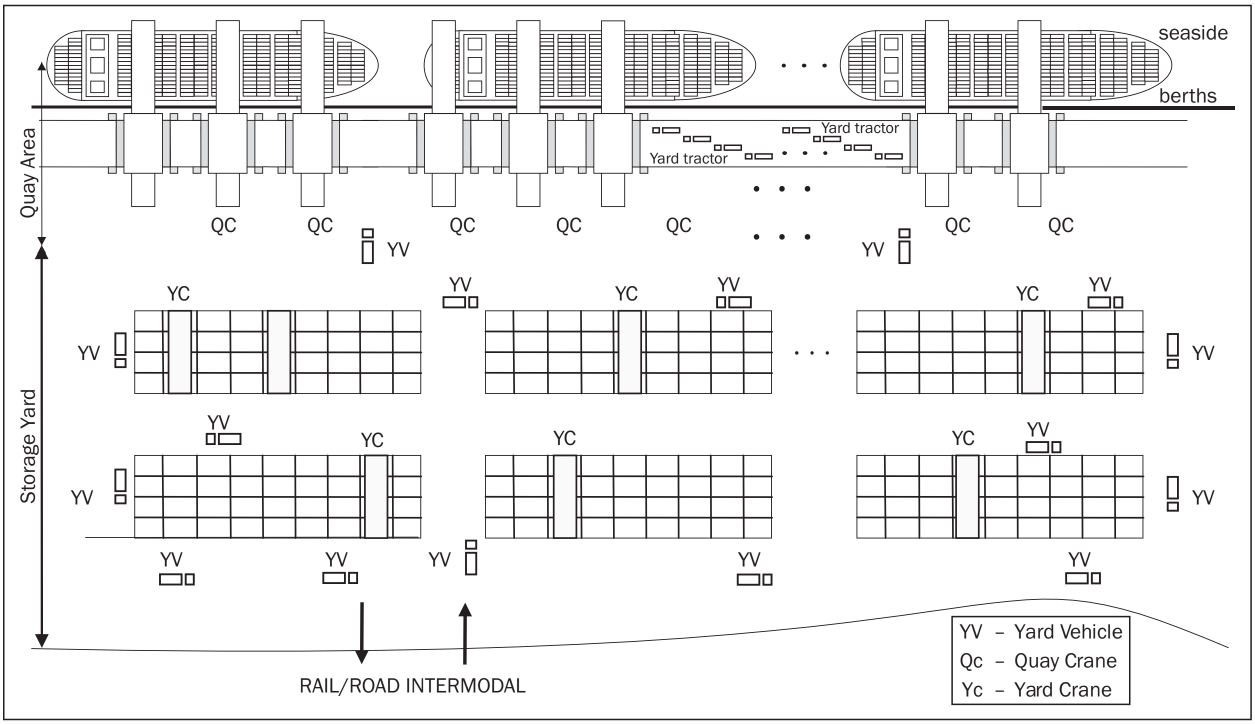


Figure 1 - Typical layout of a maritime container terminal

Table 1 - Container transhipment and container terminal capacity from 2006 to 2015

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Capacity (1000 TEU)	300	350	400	600	600	600	800	800	800	1000
Traffic-10% growth	218.97	305.65	385.12	423.63	465.99	512.59	563.58	620.24	682.26	750.49

Source: U. Horvat, E. Twrdy: "The impact of introducing sea motorways on increase of container transhipment in the Port of Koper", 11th International Conference on Traffic Science, Portorož, Slovenia, 2008

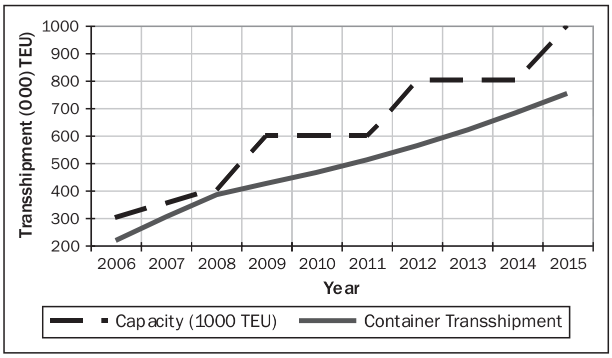


Figure 2 - Changes in container transhipment regarding container terminal capacity from 2006 to 2015

being competitive, the terminals are becoming more and more important. It is considered that research can help in the study of advanced models in representing, simulating, and in on-line control of the terminal activities to achieve better productivity of the terminal and to make better strategic decisions.

2. SYSTEM DESCRIPTION

Container terminals (CT) provide many services, e.g. container loading/unloading to/from vessel and feeder ships for import or export purposes, internal container movement from ships to stacking areas and vice versa, stacking containers in dedicated areas distributed in the terminal area, container inspection for customs requirements, reefer handling and storage, stuffing, etc. All the above processes need several shared and reusable resources and equipment, to fulfil the tasks involved in handling and transporting containers: quay cranes (QC) or yard cranes (YC), transport vehicles, e.g. multitrailers or automatically guided vehicles, straddle carriers, yard stacking deposits, automatic stacking cranes or automatic storage/retrieval systems, railway tracks, human operators. All processes and operations are usually planned, scheduled, monitored, and controlled by a central supervisor and make use of information technologies, to allow fast ship operations, optimization of the usage of facilities, and to reduce lag times.

Currently, the Port of Koper is among the ports being used for container transport for Central and Eastern Europe. In comparison to northern European ports, the sea route from Koper to the Mediterranean countries and countries beyond the Suez is shorter by over 2000 nautical miles. At the moment, this is the biggest advantage of the Slovenian port. The Port of

Koper is a multipurpose port, equipped and trained as transhipment and storage for any kind of goods. They achieved 15.4 million of ton of transhipment in 2007 and exceeded the amount of transhipment in 2006 by 10% [2]. Container transhipment amounted to a record of 305,648 TEU. The containers are transported between the terminal and hinterland by road or rail. Both container flows, inbound and outbound, are handled simultaneously. Thus, effective port operation determines the terminal efficiency to a great extent.

The Port of Koper has ten terminals: Container and Ro-Ro Terminal (with 500m of operative coastline), Car Terminal (with 500m of operative coastline and four Ro-Ro wharfs for car acceptance), Fruit Terminal (with 427m of operative coastline), General Cargo Terminal (with 833m of operative coastline), Timber Terminal (with 250m of operative coastline), Livestock Terminal (with 86m of operative coastline), Alumina Terminal (with 200m of operative coastline), Terminal for Minerals (with 500m of operative coastline), Terminal for Cereals and Fodder (with 200m of operative coastline) and Liquid Cargoes Terminal (with 200m of operative coastline). In the late 2005, the CT extended over 160,000m^2 of storage area, its annual capacity was limited to 182,250 TEU (Twenty-foot equivalent units), one-time storage was limited to 11,500 TEU, and three moorings for container ships with sea depth of 9 to 12m, and 3 railway lines lead to the terminals. The Port of Koper was equipped with 4 shore-side gantry cranes, 4 transtainer cranes at the warehouse and 1 transtainer crane for loading and unloading wagons. It was also equipped with 4 manipulators and 3 forklift trucks for empty containers and tugs, 40 yard trucks and 30 trailers. Last but not least, skilled workforce and information and communication technologies are used for terminal management and real-time container tracking.

Figure 3 - Container terminal of the Port of Koper

Source: Internal material of the Port of Koper

2.1 General overview of operations in a container terminal

The main operations of a typical container port may be classified in one of the seven basic types [4]. These are:

- Manoeuvring of ships between anchorage areas and berths;
- Berthing and deberthing of ships;
- Positioning of cranes alongside ships;
- Loading and unloading of containers;
- Moving containers between the berth and the yard;
- Configuring and operating the yard;
- Moving containers between the yard and the gate.

Business-technical systems of CT are characterized by complicated, highly sophisticated logistic transport activities, which integrate physical freight flows, financial flows and information flows (*Figure 4*).

The upper part of the circle shows the transport activities, while the lower part shows the subjects. Both, activities and subjects are directed to the two basic phases of cargo flow:

a) from freight receiving in the port to freight loading onto the ship,
b) from freight unloading from the ship to its delivery by truck or train.

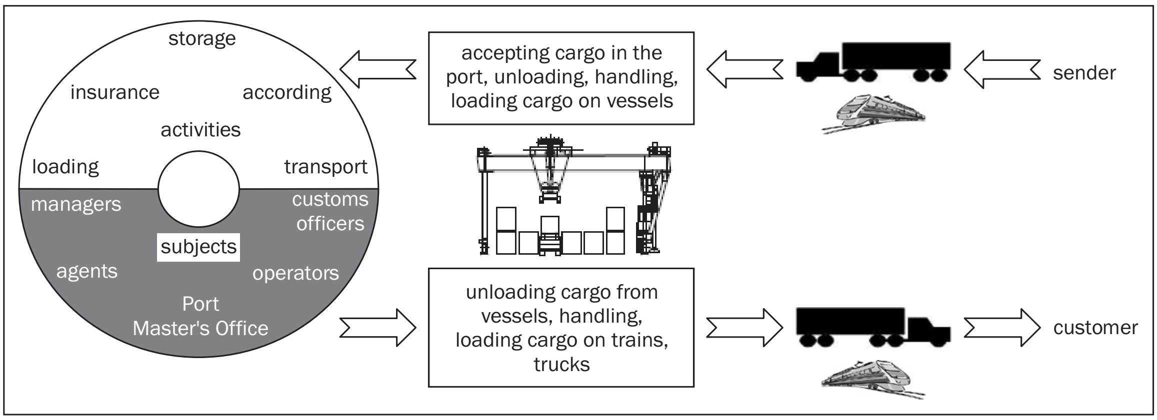


Figure 4 - Actions and subjects of the Port of Koper

The complexity of the terminal processes arises from several interactions between the operations and from the variety of stochastic processes [4] (e.g., ship arrival rates, times required for each step of container's movement, equipment failure times, equipment repair times, number of containers loaded and unloaded). With simulation models it is possible to fully describe the system and they are long-lasting. On the other hand, analytical modelling of container terminal consists of setting up mathematical models and equations which describe certain stages in the functioning of the system. The main problem of container terminal analytical models relates to the fact that they lose in detail and flexibility, so they simplify the real situation. Therefore, simulation modelling is better than analytical one in representing the random and complex environment of a container terminal. Analytical or simulation models can also be used for workload balancing, for defining work rules and work crew schedules wsithin short and long periods.

3. TRENDS IN OPTIMIZATION AND SIMULATION IN CONTAINER TERMINALS

The crucial terminal management problem is optimizing the balance between the ship-owners who request quick service of their ships and economical use of allocated resources. Since both container ships and container port facilities are very expensive, it is desirable to utilize them as intensively as possible.

The manager can trust the computer-generated solutions only by validating them by means of a simulation model of the complex environment of container terminal. Thus, the simulation tool also becomes a means to introduce new approaches into traditional settings. A simulation model of a container terminal is basically a computer program written in a general purpose language (C/C++) or in a special simulation-oriented language – simulator (MODSIM, MES CTMS, Arena, Petri Nets).

The simulation models are used to analyze bottleneck and deadlock problems, conflicts, container handling techniques, vehicle and vessel scheduling (departure and arrival rates), equipment utilization and operational efficiency (yard, gate and berth). So, a simulation implements the most important aspects of the processes at the container terminal. The advantage of simulation modelling over analytical modelling of container terminals is that it allows for a greater level of detail and avoids too many simplifications. Universities and research institutes tend to demonstrate innovative optimization algorithms and apply them to the real world case-studies.

4. SOLUTION METHODOLOGY

The review of the literature has shown that various modelling paradigms are proposed to describe the operations carried out in a terminal. Discrete-event systems are well suited to representing various activities performed in container terminals[3]. For this reason, some flexible models have been proposed, that can depict discrete events in solving the ship berthing problem in a container terminal. Petri nets (PN) seem to be a complete modelling tool for CT.

To increase the productivity of CT, the problem is how to realize all the processes within an optimal time, at a minimal cost. The objective of the scheduling system is to organize in time the realisation of interdependent tasks considering the constraints regarding time, cost and resources. Several scheduling methods have been developed, but the decision was made to apply a genetic algorithm for the given example of berthing problem in CT.

4.1 Petri nets

Discrete-event simulation is a significant analysis tool for designing complex terminal systems. Typically, discrete-event simulation models the entities' movement through the system and the changes caused in the state of the system. It is a very general modelling framework; the entities can represent the necessary operations, the shared resources, the synchronized and parallel operations. The CT can be seen as a discrete event system. For example, the container events include the following:

- Transport. The containers are transported by feeder services between container depots, customers, and ports. A transport event may schedule a subsequent load or unload event if the container is transported to a consignor or a consignee.
- Load. The container is loaded with cargo. A load event schedules a subsequent transport event to the first port on the chosen path for the shipment.
- Unload. The cargo on the container is unloaded. If the container belongs to the carrier, an unload event schedules a subsequent transport event to a chosen container depot. If the container belongs to the customer, the simulation stops keeping track of the container when the unload event takes place.

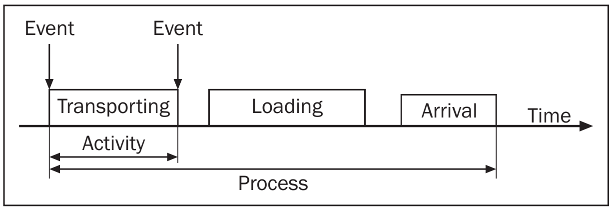


Figure 5 - Model of container transhipment logic

– Arrival. The container arrives at a port or at a container depot.

Other events include booking requests for container movement, and the movement of surplus empty containers between container depots.

Figure 5 shows the "Loading" process. Events are normally paired instances, i.e. start of transporting and end of transporting. An activity is described by the duration between the pair subsequent events, e.g. "Transporting". The process combines the collection of events or activities and mimics the lifecycle of the entity; in this case "Loading".

In particular, Petri nets are very powerful tools which give graphical representation of the discrete event systems model (for more details about Petri nets see Murata, 1989[3]). Their basic capability is in the graphical representation and formal analysis of all the processes in a discrete event system. PN are suitable to describe and simulate the dynamic behaviour of complex systems characterized by precedence relations, concurrency, synchronization conflicts and mutual elimination of events.

When compared with other existing formalisms, PN show the possibility of allowing the identification of critical system conditions (blocking, deadlock, congestion). This can help the system designer in preventing these states, which can critically reduce the terminal performance.

An ordinary PN is a bipartite graph formalized by a four-tuple N = (P, T, A, MO), in which places in set P and transitions in set T are linked by arcs in set A to represent how the system state changes. The places may contain tokens, which represent certain objects, while the number of tokens may change during the execution of the net. A transition is enabled if each of its input places contains enough tokens and it can fire by consuming tokens from the input places and producing tokens for the output places. The places are depicted by a circle, transitions by bar and model events changing the state, directed arcs by → and tokens by ● in the schematic representation, as tokens, representing resource-units (cranes, vehicles, etc.) or entities (i.e. containers) in the process, flow through the net.

4.2 Genetic Algorithms

The Genetic Algorithm (GA), proposed initially by John Holland (1975), is part of a bigger set called Evolutionary Algorithms. GA is a heuristic optimization method and it is inspired by the mechanism of natural selection, a biological process in which the rule is "the fittest will survive". It weeds out the bad and tends to produce more of the good individuals.

The main idea behind the GA is smart exploration of a response surface, where simultaneous searches are performed through specific points from this surface. GA presumes a potential solution as an individual, which can be represented by a chromosome. A chromosome must be represented by a codification and must comprise information which characterizes the individual. For the chosen type of solution representation it is necessary to define the genetic operators as well. It is important for the operators not to produce new individuals which represent impossible solutions because this reduces the efficiency of the algorithm. This idea is familiar to biological applications. Throughout the genetic evolution, starting from a population of chromosomes, GA tends to yield good quality offspring, and this means better solutions to the problem. The number of genes of this chromosome equals the number of variables of the proposed problem (for more details about GA see Gudelj[3]).

5. SHIP BERTHING PROBLEM FOR PORT OF KOPER

The problem here is to assign berths to arriving vessels and determine the number of cranes allocated to each vessel[4]. The port turnaround time of the departing vessel and the allocation of the same berth and cargo handling resources to the next ship may serve as examples. The aim of this plan is to minimize the total stay or delay times of vessels at a port and increase capacity at the container terminal. To accommodate process-orientation, the "if-else" statement is extensively used together with a combination of calculations related to port operations.

The berth allocation task is complex due to different ship arrival times, different number and size of arriving ships, multiple quays, different lengths of berths, different number and capabilities of cranes, navigation constraints and so on [5,6].

Upon arrival, a ship needs to be assigned a berth along the quay. If there is no ship in the queue, the available berths are allocated to each arriving ship. The first-come-first-served principle is employed for the ships without priority and ships from the same class with priority. In other cases ships are put in queue. Usually berth occupancy is based on the length of the container ship and the time it spends at the berth. After berthing, the ship is assigned the requested number of QCs. Cranes must be assigned to vessels over time and the availability of cranes has 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 case all QCs are busy, the ship is put in queue for the QCs. Finally, after completion of the loading process, the ship leaves the port. All operations have certain

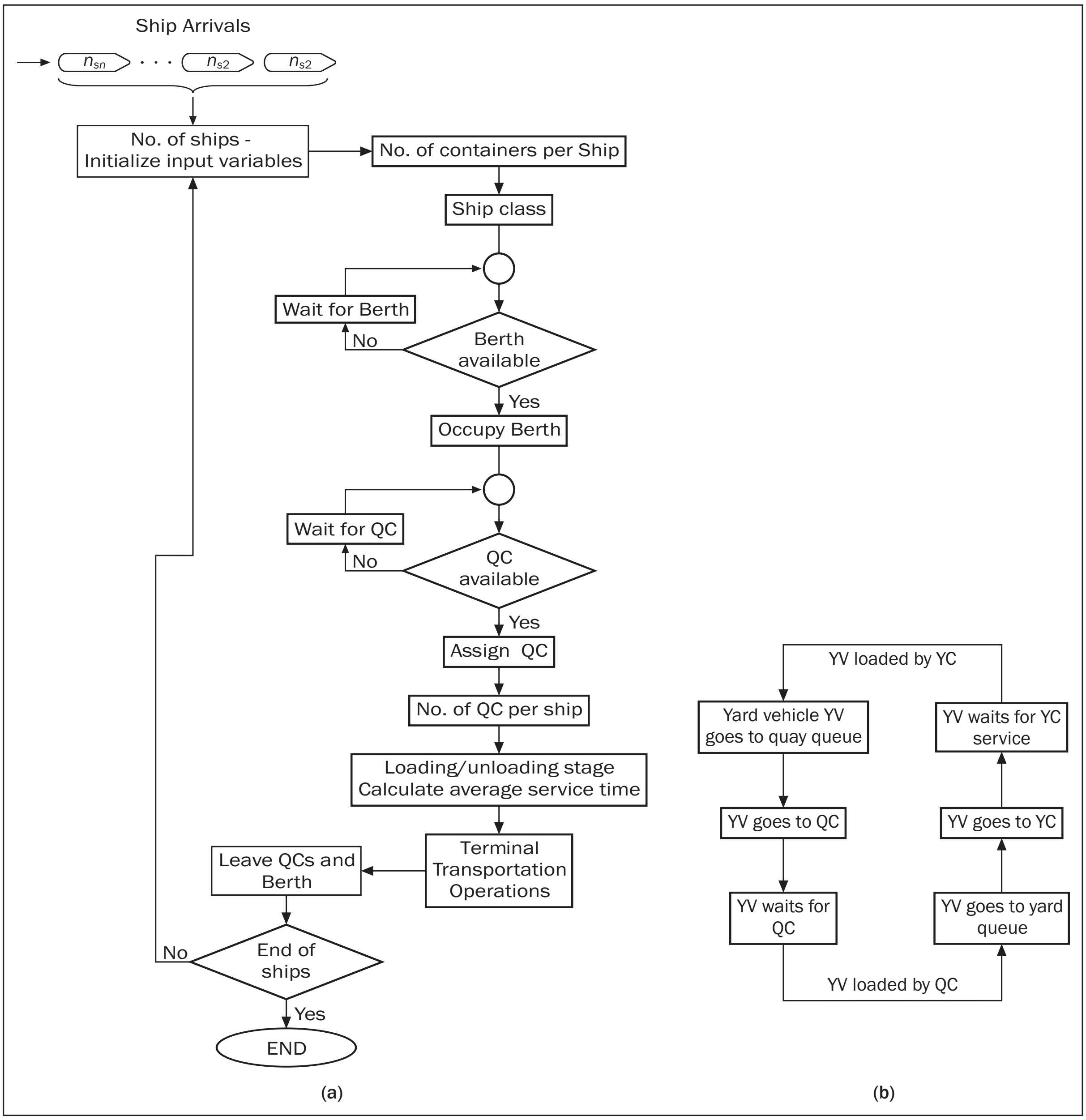


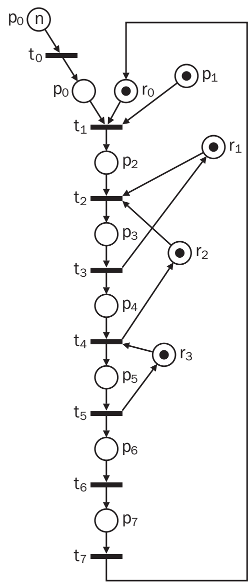
Figure 6 - (a) Model of berthing process logic; (b) Terminal transportation process

duration. This procedure is presented in the flow diagram shown in *Figure 6*.

The process combines the collection of events or activities and mimics the lifecycle of the entity; in this case "Berthing". This approach of process orientation applied in the PN is shown in *Figure 7*. The presence of a mark (black dot) in a given place means that the corresponding condition is available. PN represents the initial state after ship arrivals in the port: the mark (n) in place p0 represents the number of ships in arrival queue and place p1 denotes the number of containers available for unloading by the considered QC.

If there are marks in places r_1, r_2 and r_3, this will mean the number of available resources: QC, a trailer and YC (for adopted unloading plan obtained by optimization algorithms). The dot in place p_2 means that the nautical conditions allow their processing.

The choice of berth position and the crane assignment problem for the Port of Koper is solved by the same genetic algorithm which was used in [7]. This research is based on the date recorded for each arriving ship over a two year period at the container terminal of the Port of Koper[2] [8]. Using data, the number of containers exported with each ship averaged 450, which we used in our analysis. Also, it is estimated that an average berthing time per ship is 21.90 hours. Then, the priority of the ship is assigned depending on its size. The ship size is important for making the ship service priority strategies.



Meaning of places	
p_0	Ship arrivals
p_1	Containers per ship
p_2	Navigation conditions
p_3	Awaiting berthing
p_4	Container picked up from the ship and loaded on a trailer by QC
p_5	A trailer with container on the stocking area
P_6	Container picked up from a trailer
p_7	Container stacked
p_8	Ship available for leaving the berth
r_0	Berth availability
r_1	QC availability
r_2	Trailer availability
r_3	YC availability
Meaning of transactions	
t_0	Waiting for the berth
t_1	Processing of the ship berthing
t_2	Picking container from ship and loading on a trailer
t_3	Transport from quay to the stocking area by a trailer
t_4	Pick-up from a trailer
t_5	YC positioning container on the stocking area
t_6	Awaiting / delay
t_7	Leaving the berth

Figure 7 - PN model of berthing process

Source: This model was developed by using Visual Object Net ++ - Petri-Net CAD/CAE Tool

Chromosome representation

The chromosomal structure needs to code the key features of the problem. In Holland's work, chromosomes are usually represented in binary strings. However, when problems are related to a real environment, binary encoding is not appropriate. Permutation representation and random keys representation are two of the most widely used methods to represent chromosome syntax for scheduling types of problems. The population initialization technique used in this GA algorithm is a random real-number initialization (Figure 8). Before encoding individuals, calling vessels are ordered by their arrival time and berths should be identified by 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, symbol "4" in the 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 8 - Encoding assignment problem of berth

Fitness Measure

In this approach, *berthing_Time* is a multiobjective cost function that depends on the distance from the berthing location of a vessel to the location in the marshalling yard where 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:

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

where

$z+ = \max\{0, z\}$

a_i = expected arrival time of i-th vessel in the port;

y_i = real arrival time of i-th vessel in the port;

x_i = assigned berthing position of i-th vessel;

b_i = the best berthing location of i-th vessel;

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

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

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

Evaluation

All experiments were run on a PC with Pentium 4-M 2.20Mhz under Windows. The designed scheduling procedure with Genetic Algorithm software has been developed in the Matlab software package. A tournament selection of parent solutions for mating, crossover rate ranging of 20% and mutation rate of 20% are used in simulation optimization. It has been estimated that the objective value of container ship cost has been reduced by about 18.69% (about 17.80 hours). Also, it was found that the two–point crossover took longer CPU time per simulation (about 50%) than single-point crossover, but the difference in solutions is not significant.

6. CONCLUSION

The main role of container terminal is the transfer and storage of containers. The performance of CT is of crucial importance for ship and cargo owners who request quick service. It is mandatory to ensure a sufficiently short lay time for container vessels in the port and to achieve further reduction of the terminal operating costs. For this reason, the management of CT must develop mechanisms to increase productivity when necessary.

This paper presented the use optimization and simulation techniques as decision support tools in the management of CT for the Port of Koper. It proposed the Petri net model and the genetic algorithm for solving the problem of berth and crane assignments. The advantage of PN over many other graphical modelling tools is that it has a mathematical formalism that makes the dynamic behaviour of the underlying system well-defined. PN has shown to be an important tool for easy-to-read modelling of information flows and different interactions in CT. The main contribution of this paper is the development of a rule-based method for the berth dispatching problem and the use the multiobjective fitness function in GA to improve the CT production. Preliminary results seem to be promising.

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SAŽETAK

MODELI I METODE ZA OPERACIJE NA KONTEJNERSKIM TERMINALIMA

Upravljanje kontejnerskim terminalom je veoma složen proces koji uključuje donošenje brojnih odluka. Među problemima koji se trebaju riješiti valja istaknuti prostorno raspoređivanje kontejnera u stovarištu, dodjeljivanje vezova i dizalica brodovima, određivanje i dodjeljivanje prioriteta veza, određivanje rasporeda operacija kako bi se povećala učinkovitost vrednovana nekim ekonomskim pokazateljima. Kako je oprema u kontejnerskim lukama veoma skupa, poželjno je optimizirati njihove značajke kako bi Uprava bila u mogućnosti donijeti što bolje odluke. U radu su korišteni model Petrijevih mreža kojim se prikazuju operacije vezivanja plovila, a genetski algoritam se koristi za određivanje rasporeda operacija ukrcaj/iskrcaj kontejnera pomoću dizalica u cilju minimiziranja ukupnog vremena koje je potrebno za posluživanje zadanog broja plovila.

KLJUČNE RIJEČI

prijevoz, upravljanje vezovima, raspored, simulacija, optimalizacija

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