SIMULATION, ANALYSIS AND OPTIMIZATION OF CONTAINER TERMINALS PROCESSES

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ABSTRACT

The freight logistics includes all the processes which are needed to supply industry, retail and wholesale and the end customers with goods. Such processes generate a flow of goods that, in the global supply chain, mainly relies on the activities carried out within worldwide container terminals. In this paper, the authors present a simulation model of a real container terminal. The simulation model is jointly used with optimization techniques (genetic algorithms) to carry out a range allocation optimization on berth assignment to incoming ships and number of tractors for each quay crane with the aim of minimizing the average time spent by each ship in the port area (decreasing, as consequence, costs and increasing service level provided to final customers).

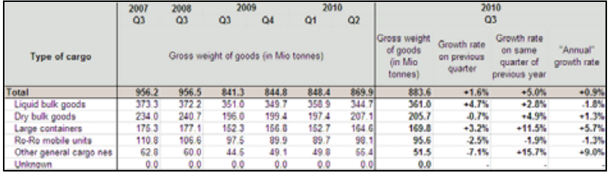
Keywords: container terminals, supply chain node, simulation, optimization, genetic algorithms

1. INTRODUCTION

According to the TRANSvisions report of the EU (TRANSvisions, 2009), the freight transportations in Europe (in terms of tonnes-km) are expected to increase by 1.7% per year (until 2030). Today, it is estimated that 80% of Europe trade is carried by sea, and that short sea shipping accounts for 40% of freight transport. With over 400 million passengers that annually pass through European ports (EU-27 main ports) and more than 169.8 millions of tonnes transported by using containers (see table 1), maritime transport has a direct impact on the EU GDP as well as on the quality of life of many European people.

In addition, during the last years the growth of international goods trades has increased the demand for maritime transportation services; by the end of 2008, however, this sector has begun to suffer the consequences of the financial crisis (see figure 1), even if activities in European ports have continued their gradual recovery from the global economic downturn, with an increase of 1.6% in the 3rd quarter of 2010 compared to the 2nd quarter of 2010 (Maritime transport of goods - quarterly data, 2011). Data in table 1 also shows that the growth rate on the same quarter of 2009 is about 11.5% while the annual growth rate is about 5.7%.

Table 1: Quarterly data for European ports
Source: Maritime transport of goods - quarterly data (2011)



Type of cargo	2007 Q3	2008 Q3	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3 Gross weight of goods (in Mio tonnes)	2010 Q3 Growth rate on previous quarter	2010 Q3 Growth rate on same quarter of previous year	2010 Q3 "Annual" growth rate
	Gross weight of goods (in Mio tonnes)									
Total	**956.2**	**956.5**	**841.3**	**844.8**	**848.4**	**869.9**	**883.6**	**+1.6%**	**+5.0%**	**+0.9%**
Liquid bulk goods	373.3	372.2	351.0	349.7	358.9	344.7	361.0	+4.7%	+2.8%	-1.8%
Dry bulk goods	234.0	240.7	196.0	199.4	197.4	207.1	205.7	-0.7%	+4.9%	+1.3%
Large containers	175.3	177.1	152.3	156.8	152.7	164.6	169.8	+3.2%	+11.5%	+5.7%
Ro-Ro mobile units	110.8	106.6	97.5	89.9	89.7	98.1	95.6	-2.5%	-1.9%	-1.3%
Other general cargo nes	62.8	60.0	44.5	49.1	49.8	56.4	51.5	-7.1%	+15.7%	+9.0%
Unknown	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	-	-

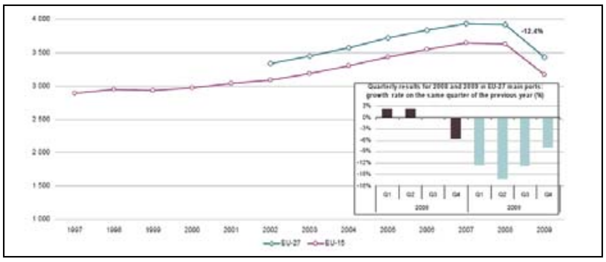


Figure 1: Gross weight of seaborne goods handled in all ports (in million tonnes). *Source: Maritime ports freight and passenger statistics (2010)*

In such a context and with the renovating competitive pressure, both Northern European ports and ports of the Mediterranean area are demonstrating an aggressive behavior in terms of quality and service level provided to the final customers, with the aim of increasing ports receptivity, improving efficiency, reducing times and costs for container handling operations (trying to meet the main requirement dictated by the shipping lines companies: minimization of the time spent by the ships in the port).

Actually, container terminals management is a quite complicated issue in which theories and analytical models, proposed over the years by researchers, very often have not tackled correctly the design and management problems (above all in terms of results applicability). A typical container terminal environment is usually characterized by multiple operations that run concurrently, such as quay cranes loading and unloading operations, containers handling operations between the berth and the yard area, containers handling operations within the yard area (also including trucks loading and unloading operations), rail services management and containers inspections operations. Usually, such complexity requires to use an approach able to recreate the system considered without restrictive or simplifying assumptions. In this context the authors have extensively used Modeling & Simulation (M&S) both as decision support system (i.e. for container terminal resources management), for operators training and for security enhancement and containers inspection procedures analysis (some of the research proposed by authors over the years are presented in the next section).

In this paper, the authors propose a simulation model of a container terminal located in the upper Tyrrhenian sea. The simulation model is jointly used with optimization techniques (genetic algorithms) to carry out a range allocation optimization on berth assignment to incoming ships and number of tractors for each quay crane with the aim of minimizing the average time spent by each ship in the port area (decreasing, as a consequence, costs and increasing service level provided to final customers).

The paper is organized as follows: section 2 briefly surveys related works, section 3 presents the container terminal and the simulation model, section 4 proposes simulation results and analysis and finally conclusions summarizes the main findings and research activities still on going.

2. RELATED WORKS

M&S approach plays an important role as problem solving methodology and enabling technology for investigating the behaviour of supply chain nodes (Longo & Mirabelli, 2008; De Sensi et al., 2008) and it is usually very effective for design and management of container terminal operations. As already mentioned before, M&S has been used in the logistics and maritime area both to support decision – i.e. for container terminal design and resources management as well as for security issues (above all after 9/11) – and as one of the most effective methodology for port personnel training at any level (i.e. quay crane operators, yard equipment operators, drivers, port managers, etc.). Even in Education, M&S has proven its capability to transmit sharp concepts and support the full comprehension of complex systems (such as marine ports, see for instance Bruzzone et al., 2007; Longo, 2007).

The survey of the research works, proposed by other researchers in the last 20 years, shows that, even with a common M&S denominator, there is heterogeneity among the scientific approaches due to the different models, techniques and methods used for facing decision support problems and training in container terminals (as proven by the analysis of the following references).

Simulation model are often used to analyze or predict the performance of existing container terminals as done by Yun and Choi (1999) and Shabayek and Yeung (2002). In this case, aspects such as simulation model Verification, Validation and Accreditation (VV&A, Balci, 1998) become even more critical because they strongly affect the extent to which simulation can predict the performance of the real container terminals.

Simulation is also jointly used with optimization techniques in order to solve multi-objective optimisation problems involving multiple stochastic variables (in this case, the optimization problem involves contrasting and competing objectives and requires the definition of multiple performance measures). Approaches used see the combination of simulation with both advanced statistic methodology (i.e. Analysis of Variance, Response Surface Methodology, etc.) and artificial intelligence techniques. Examples of research works that deal with optimization problems in container terminals can be found in Gambardella et al. (2001), Kia et al. (2002), Moorthy and Teo (2006), Lee et al. (2007), Lau and Zhao (2008). Among others, the following are still the most challenging optimization problems in container terminals: resources allocation and scheduling of loading and unloading operations (both on the berth and in the yard area), containers allocation in the yard area and the berth allocation problem to a set of incoming vessels. In many cases, artificial intelligence techniques used include genetic algorithms and ants theory.

M&S is also used to support container terminal design and for investment decisions (Bielli et al., 2006; Alattar et al., 2006; Ottjes et al., 2006). In this case, the main aim is to increase both the service level provided to the final customer (by reducing the total time spent by each vessel in the port and the queue of the incoming vessels) and the vessels traffic. The design of multi-terminal systems for containers handling that share limited resources is another challenging problem in which simulation has been profitably used.

The authors of this paper have extensively used Modeling & Simulation (M&S) in the past. Longo et al. (2006) develop a container terminal simulation model; the simulation model is equipped with an advanced graphic user interface to generate different conditions (regarding all the port main operations) an output section to monitor multiple performance measures. The simulation model is used to identify the most important parameters that affect the total number of stored containers. In Longo (2007), an integrated model (made up by five different simulation models) is proposed and used to educate student to analyze complex systems such as container terminals. In Bruzzone et al. (2010) an overview of the architecture of the TRAINPORTS simulators (developed by using the High Level Architecture, HLA) is proposed. The TRAINPORTS simulators include multiple federates (i.e. Straddle Carriers, Quay Cranes, Reach stackers, Trucks, etc.) and can be used to support marine workers training providing the sensation to be in a real container terminal environment. In Longo (2010), simulation is jointly used with advanced design of experiments techniques and response surface methodology for the design and integration of the security procedures (specifically, container inspection activities) in the container terminal operations. Effective operational policies and practices to improve the containers flow management toward the inspection area are proposed, as well as the impact of container inspection operations on the container terminal efficiency is investigated. This approach is further extended in Longo (2011) where an advanced 3D simulation framework for investigating and analyzing the security problem within marine ports environment is proposed with the aim of finding out security gaps and redesigning the most critical security procedures and infrastructures.

3. THE CONTAINER TERMINAL SCENARIO AND THE SIMULATION MODEL

The authors consider a real container terminal, located in the upper Tyrrhenian Sea, with a current capacity up to 1.5 million of TEUs per year and trades, to date, amounted to around 1 million of TEUs. The direct access to sea allows easy maneuvering for different types of ships; the 1.500 m of berth and the 15 m deep water allow the simultaneous docking of multiple container and ro-ro ships. The yard area includes more than 12000 ground slots (up to 900.000 squares meters) with a dedicated rail service (multiple tracks, capacity up to 120 trains per week). The container handling equipment includes 10 portainers post-panamax for ships loading and unloading operations (from 40 to 50 tonnages), 50 tractors (for connection between the docking area and the yard area), 23 Rubber Tired Gantry (for container movements in the yard area) and 3 Rail Mounted Gantry (up to 45 tonnages) for trains loading and unloading operations.

3.1. The STEP Simulation Model

The simulation model of the container terminal (called STEP, *Simulation and analysis of container TErminal Processes*) recreates the main operations of the container terminal and it is in four different parts. Each part recreates specific processes and activities of the container terminal.

Figure 2 shows the flow chart recreating ships arrival and departure operations, as well as ships loading and unloading operations. Without enter in the flow chart details, note that, for each berth module, a specific class recreates containers unloading and loading operations; in addition the object positioned just before the six parallel classes implements all the logics for berth assignment to each incoming ship.

Similarly figure 3 shows trains arrival and departure and trains unloading and loading operations (flow chart in the upper part of figure 3). Two specific classes recreate the 8 different rail tracks. The lower part of figure 4 shows the trucks arrival and departure operations and the trucks unloading and loading operations.

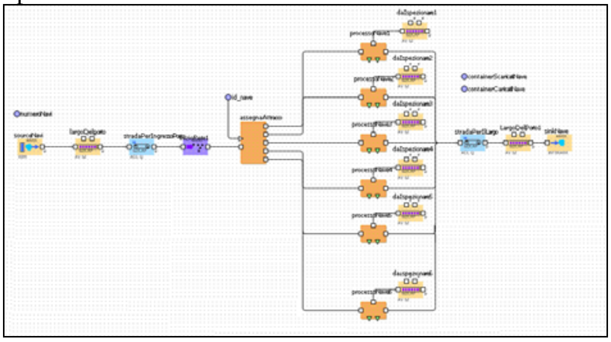


Figure 2: Ships arrival/departure and unloading/loading operations

It should be noted that trucks flow chart has a double "Y" shape. In correspondence of the first "Y", trucks are subdivided in empty and full; in correspondence of the second "Y", unloading/loading options are modelled (i.e. a full truck after the container unloading operation must load another container before leaving or must leave the port empty, etc.).

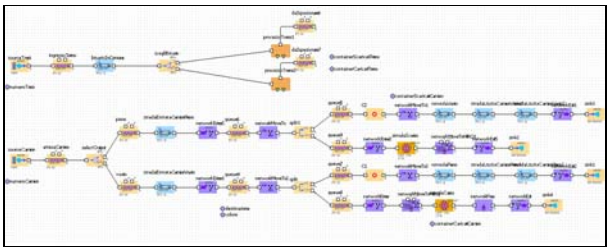


Figure 3: Trains arrival/departure and unloading/loading operations; trucks arrival/departure and unloading/loading operations

Finally, figure 4 shows the containers inspection operations. The containers inspection phase is made up by several and different operations. First of all, by using a scanning equipment a digital image of the container is created (i.e. by using gamma ray). The image analysis aims at discovering container anomalies. In addition to image analysis, physical check, visual check and radiation inspections are usually carried out. In case of anomalies detection, the container is subjected to further and more detailed inspections (Longo 2010).

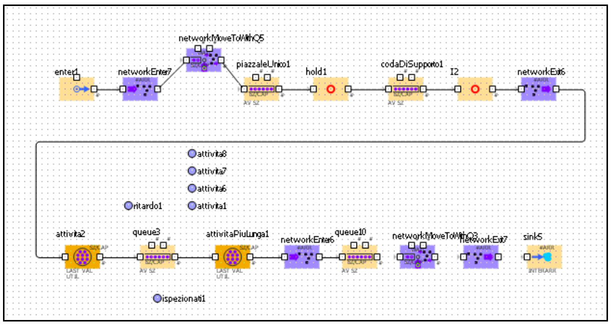


Figure 4: Security procedures and containers inspection operations.

3.2. Simulation Model Animation, Graphic User Interface and Simulation Output Section

The development of the simulation model animation is based on the network concept. A network is made up of departure and arrival points (represented by rectangles) and trajectories that connect departure and arrival points. The simulation model animation includes 4 different networks:

- the ships network that is used by ships for entering and exiting the port;
- the yard network that is used by tractors, rubber tired gantries and trucks (for containers movements in the yard, between the yard and the berth, between the yard and the rail service and between the yard and the area outside the port);
- the trains network (used by trains for entering and exiting the port and by rail mounted gantries);
- the security inspection network that is used for moving containers between the yard area and the security area where inspection procedures are executed.

The animation networks described above are shown in figure 5.

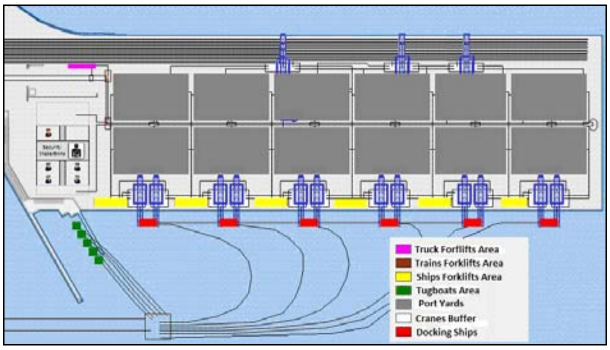


Figure 5: Simulation Model Animation Networks

The simulation model is finally equipped with a graphic user interface and a simulation output section. The following parameters values can be easily changed by using the sliders provided by the graphic user interface:

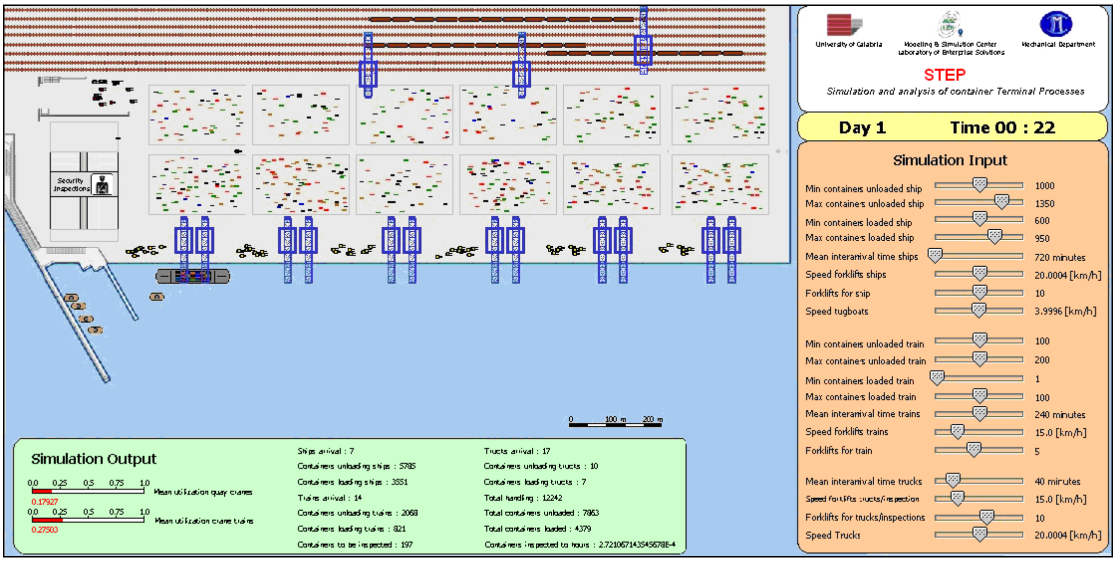
- the minimum and the maximum number of container to be unloaded/loaded from/to a ship
- the inter-arrival time between two consecutive ships (also eventually providing a ships arrival list);
- the speed of the tractors;
- the speed of the tugboats;
- the minimum and the maximum number of container to be unloaded/loaded from/to a train
- the inter-arrival time between two consecutive trains (also eventually providing a trains arrival list);
- the inter-arrival time between two consecutive trucks (also eventually providing a trains arrival list);
- the number of tractors used to serve quay cranes;
- the number of tractors used to serve rail mounted gantries;
- the number of tractors used to serve the inspection area.

The simulation output section shows the main simulation results including mean utilization level of quay cranes and rail mounted gantries, total number of ships, trains and trucks arrived in the terminal, number of containers unloaded/loaded from/to ships, trains and trucks, total number of handled containers and total number of inspected containers. Figure 6 shows the model during a simulation run execution (figure 6 also depicts the input and output sections).

4. ANALYSIS AND RESULTS

The STEP simulation model is used to investigate different operative scenarios in terms of resources allocation. In particular, after some preliminary analysis the authors used the STEP simulator jointly with Genetic Algorithms to carry out a multiple optimization on berth assignment to incoming ships and number of tractors serving each quay crane over a fixed time horizon with the aim of minimizing the average time spent by ships in the port area. Such time depends on multiple factors and the complexity of the overall system requires to use *ad hoc* simulation models and optimization techniques to come up with feasible and optimal solutions. In fact, the total time spent by each ship in the port depends on the storage area chosen for the containers unloaded from the ship as well as from the position of the containers that must be loaded on the ship. Another important factor affecting the total time spent in the port is the number of available resources used to serve the ship (i.e. number of quay cranes simultaneously working on the same ship, number of tractors/trailers to move container from the berth to the yard area and vice-versa). The optimization proposed in this paper considers a 33 days time frame, 30 incoming vessels of different dimensions and different number of containers to unloaded/loaded; the optimization simultaneously takes into account the berth assignment to each incoming ship and the number of tractors for each quay crane.

The objective function (to be minimized) is the average time spent by ships in the port area and Genetic Algorithms (GAs) are used to find out the optimal berth assignment scheduling and the optimal number of tractors/trailers to be assigned to each quay crane. Our experimental analysis considers roughly one month of real data (33 days) that include the information needed to simulate all the terminal container activities (unloading/loading times, containers position in the yard, available cranes/tractors, etc.). A sample of this data is reported in table 2 in terms of ships arrival time,



STEP

Simulation and analysis of container Terminal Processes

Day 1 Time 00 : 22

Simulation Input

Min containers unloaded ship 1000
Max containers unloaded ship 1350
Min containers loaded ship 600
Max containers loaded ship 950
Mean interarrival time ships 720 minutes
Speed forklifts ships 20.0004 [km/h]
Forklifts for ship 10
Speed tugboats 3.9996 [km/h]

Min containers unloaded train 100
Max containers unloaded train 200
Min containers loaded train 1
Max containers loaded train 100
Mean interarrival time trains 240 minutes
Speed forklifts trains 15.0 [km/h]
Forklifts for train 5

Mean interarrival time trucks 40 minutes
Speed forklifts trucks/inspection 15.0 [km/h]
Forklifts for trucks/inspections 10
Speed Trucks 20.0004 [km/h]

Simulation Output

Mean utilization quay cranes 0.17927
Mean utilization crane trains 0.27503

Ships arrival : 7
Containers unloading ships : 5785
Containers loading ships : 3551
Trains arrival : 14
Containers unloading trains : 2068
Containers loading trains : 821
Containers to be inspected : 197

Trucks arrival : 17
Containers unloading trucks : 10
Containers loading trucks : 7
Total handling : 12242
Total containers unloaded : 7863
Total containers loaded : 4379
Containers inspected to hours : 2.721067143545678E-4

Figure 6: the STEP simulation model during an execution of a simulation run

number of containers to be unloaded and number of containers to be loaded. The total workplan consists of 30 vessels and about 173,473 TEU movements.

4.1. Preliminary analysis and simulation model validation

As mentioned above, some preliminary analyses have been carried out to validate the simulation model. According available data, the Container Terminal handles roughly 1 million of TEU per year. In order to validate the simulation model, the following factors have been changed and the behavior of the simulated terminal has been analyzed: (i) ships inter-arrival times; (ii) number of tractors; (iii) quay cranes efficiency (in terms of loading/unloading times). To come up with reliable results, each preliminary scenario has been replicated three times (the length of the simulation run is 1 year) and simulation results have been averaged out as shown figure 7 and figure 8.
Figure 7 shows the behavior of the simulated container terminal (in terms of number of TEU movements over 1 year) when the ships inter-arrival time is changed according to a Poisson process between 4 hours and 18 hours and the number of available tractors (for container movements from the berth to the yard and vice-versa is kept constant, 40 tractors). The upper curve in figure 7 corresponds to the high efficiency case for quay cranes, while the lower curve corresponds to the low efficiency case.
Similarly, the figure 8 shows the behavior of the simulated container terminal when the ships inter-arrival time is changed according to a Poisson process between 4 hours and 18 hours and the number of available tractors is 50. Again, both the quay cranes high efficiency and low efficiency cases are reported.

Note that both the inter-arrival time and the number of available tractors have a remarkable effect on the number of TEU movements over 1 year.

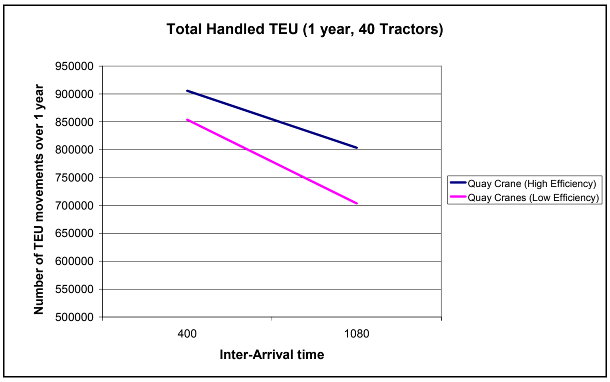


Figure 7: preliminary analysis, TEU movements over 1 year versus inter-arrival times for different level of quay cranes efficiency (45 available tractors)

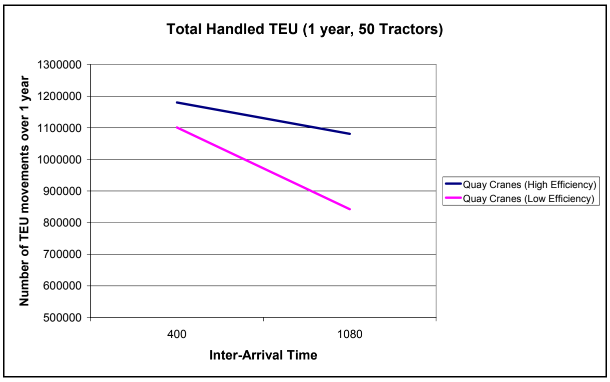


Figure 8: preliminary analysis, TEU movements over 1 year versus inter-arrival times for different level of quay cranes efficiency (50 available tractors)

These preliminary results have been presented and discussed with subject matter experts confirming that the STEP simulation model is able to recreate with satisfactory accuracy the behavior of the real container terminal.

4.2. Berth assignment and number tractors optimization

The optimization of the berth assignment to the incoming ships and number tractors assignment to each quay crane over a time horizon of one month has been performed by using GAs. The fitness function is the average time spent by ships in the port area; the GAs performs a range allocation optimization trying to minimize the average time spent by the ships in the port area.

Table 2: Ships arrival time, number of containers to be unloaded and loaded

Ship ID	Arrival Time	Container To Unload	Container to Load
1	1/5/11 6.00 AM	2441	2035
2	2/5/11 6.00 PM	1446	1890
3	4/5/11 12.00 AM	1608	1780
4	5/5/11 12.00 AM	4406	4236
5	6/5/11 12.00 AM	2371	1963
6	6/5/11 12.00 PM	3710	3697
7	8/5/11 6.00 AM	2729	2200
8	9/5/11 6.00 AM	3250	3359
9	10/5/11 12.00 PM	2921	2891
10	11/5/11 12.00 PM	3516	3500
11	12/5/11 6.00 PM	4385	4250
12	13/5/11 12.00 PM	1681	1790
13	14/5/11 12.00 PM	4177	4088
14	16/5/11 6.00 AM	2340	2169
15	16/5/11 12.00 PM	937	840
16	18/5/11 6.00 AM	4730	4892
17	19/5/11 4.00 PM	2388	2850
18	21/5/11 1.00 AM	2535	2462
19	21/5/11 7.00 PM	3938	3785
20	23/5/11 4.00 AM	4412	4169
21	23/5/11 8.00 PM	1822	1982
22	25/5/11 6.00 AM	4857	4687
23	25/5/11 12.00 PM	2351	2159
24	27/5/11 9.00 AM	3649	3537
25	27/5/11 11.00 PM	2176	2169
26	29/5/11 8.00 AM	1406	1563
27	30/5/11 6.00 AM	3149	3367
28	31/5/11 4.00 PM	1981	1998
29	2/6/11 1.00 AM	2279	2087
30	3/6/11 10.00 AM	3942	3819

It is worth saying that only the total time of those ships that have to unload more than 2300 containers has been considered for the optimization. The main idea is to include in the optimization only bigger ships, which can have an impact on the container terminal business. In addition, the threshold in terms of number of containers (to include or exclude a ship from the optimization process) is one of the parameter of the simulation model; therefore additional scenarios could be investigated considering different threshold values and also eventually including a costs analysis.

The STEP simulation model was used for simulating and evaluating the fitness function for all the solutions proposed by the GAs. In particular, the authors iterated the GAs for 50 generations and the simulation model evaluated the fitness function for each chromosome. Each solution was tested over the pre-defined time horizon (33 days). Table 3 consists of the optimization results in output from the GAs: for each ship, the berth position is reported as well as the number of tractors for each quay crane.

Table 3: GAs optimization results

Ship ID	Berth Position	Tractors for crane 1	Tractors for crane 2
1	2	5	4
2	4	4	5
3	1	4	4
4	5	6	5
5	3	5	4
6	4	4	5
7	2	4	4
8	1	5	6
9	3	5	4
10	5	5	6
11	4	5	6
12	2	4	4
13	1	5	6
14	5	4	5
15	3	4	3
16	2	5	6
17	4	4	4
18	1	5	5
19	5	5	5
20	3	6	5
21	1	4	4
22	4	5	6
23	2	6	5
24	3	5	6
25	5	4	4
26	1	3	4
27	4	5	6
28	2	4	5
29	5	5	4
30	1	6	5

Figure 9 shows the performance graph of the genetic algorithms optimization, in terms of worst, average, and best fitness over 50 generations. Note that based on this optimization procedure it was possible to obtain significant improvements in terms of average time spent by each ship in the port area.

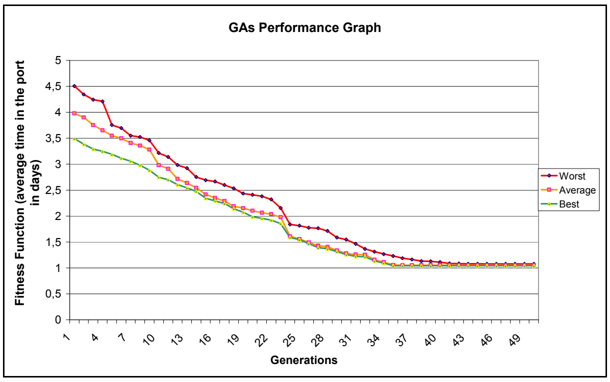


Figure 9: GAs performance graph

The GAs initial population was randomly generated therefore initial solutions provided by GAs are characterized by very high values of the fitness functions. Better initial solutions could be obtained starting from an initial population (berths assignment and tractors assignment) generated according to subject matter experts estimations.

Furthermore, the main aim of the optimization was the correct berth assignment in order to have feedback to improve the allocation of containers in the yard (yard optimization). This in turn leads to a better service level (in terms of reduced times) provided to final customers.

5. CONCLUSIONS

The paper deals with process analysis and optimization in a real container terminal. A simulation model of a container terminal has been developed; the implementation of the simulation model (called STEP) is presented as well as some preliminary analysis devoted to validate the simulation model.

The STEP simulation model has been used jointly with genetic algorithms to carry out a range allocation optimization on berth assignment to each incoming ship and number of tractors to be assigned to each quay crane. The fitness function is the average time spent by ships (only certain ship, those ships that may affect the container terminal business) in the port area; the minimization of this fitness function is pursued as opportunity to provide the final customers with higher service levels.

Further research activities are still on going using the same simulation model to carry out additional optimizations that include also the scheduling of containers unloading/loading operations, number of quay cranes to assign to each incoming ship, allocation of yard cranes and allocation of containers in the yard as well.

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