A SIMULATION-BASED APPROACH FOR RESOURCE MANAGEMENT AND CONTROL: A REAL CASE STUDY OF A SPANISH CONTAINER TERMINAL

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ABSTRACT
M&S has proved to be a day-to-day tool highly indispensable for complex systems design, management and training. Therefore, the proposed research study aims at developing a simulation model to recreate the complexity of the Algeciras port, one of the biggest container terminals in Spain. The simulation model is developed by using the discrete event simulation software Arena and is validated considering three validation scenarios. Lastly, based on the simulation outputs, a specific analysis about the port management and control policies has been presented.

Keywords: Container terminal, Simulation, Management, Scheduling.

1. INTRODUCTION

As attested by the International Maritime Organization, Container terminals (CTs) are important nodes in intermodal transport networks: sea-trade is more than 90% of the world trade and 80% of the general cargo is carried in containers. The containers trade growth along with the increased competitive pressure of the global market makes the need for optimized and effective container terminal operations evident (Ambrosino *et al* 2006). However, optimization, management and control of terminal operations are very complex tasks (Polo and Diaz, 2006). This complexity is inherent in the nature of terminal related processes and in the need to ensure high receptivity levels. In such a context, the capability of CTs resources and facilities to support different sizes of ships, the optimal dock design and the ability to improve decision-making are crucial aspects (Notteboom, 2007). Regarding ship size, important advances have been made and the load capacity of ships has increased considerably. In fact, to date, the capacity of the largest containerships in the world is up to 12,000 TEUs with lengths greater than 350 meters and service speed up to 25 knots allowing a travel time of 4 days between China and the U.S. west coast.

Moreover, the small vessels which make short trips cannot be neglected; this type of transportation is well known as Short Sea Shipping (SSS) and is supported by many governments and international institutions owing to the general will to reduce environmental impacts. Several research works dealing with SSS can be found in the literature; i.e. Paixao and Marlow (2002) present the main strengths and weaknesses of SSS whereas Martinez and Olivella, (2005) discuss specific opportunities for SSS. As mentioned above, to ensure high levels of receptivity and manage vessels of variable size optimally, an excellent dock design is required. To this purpose, Imai et al. (2005) define two dock design strategies: one is based on a discrete location with fixed points for berths while the other is based on a continuous location with no fixed points for berths. Since the continuous location strategy ensures higher flexibility and allows different kinds of ships to dock, the authors decided to adopt it in this research work. Therefore, based on this strategy, the dock is divided into segments and each incoming ship may take one or more segments depending on its length.

In addition, the literature review in the field of CTs management allows pointing out that simulation-based approaches have proved to be suitable for dealing with the main issues of CTs management and control: Liu et al (2002), Cortés et al. (2007), Longo (2007, 2010, 2011), Bruzzone (2002, 2004, 2010) and many others. Liu et al (2002) analyse the productivity of automated container terminals. Cotés et al (2007) and Arango et al. (2011) proposed a simulation model for analysing the freight traffic in the Seville inland port. Longo (2007, 2010 and 2011) propose some successful simulation models for container terminals management and analysis; in addition Longo (2010) presents an advanced simulation framework for investigating and analyzing the security problem within container terminals. Noticeably, in these works, simulation is used in combination with advanced methodologies like Design of Experiments or Response Surface Methods. Besides Bruzzone et al. (2010) describe distributed simulation architecture for marine workers training. Proven that Modelling and Simulation (M&S) based approaches are successful and useful tools in CTs decision processes, the purpose of this study is to develop a simulation model able to recreate the main operations (the loading and unloading of containers in the quay zone, the handling operations in the yard zone and the loading-unloading of containers to the land transports) of the Algeciras container terminal, one of the main ports in Spain and Southern Europe. To recreate the port complexity some simulation models have been developed and integrated by using the simulation software Arena. The rationale behind the use of a M&S based approach lies in the need for a real time operating tool which could be able to speed up and improve decision making processes. In addition the authors have a long experience in developing simulation models in Industry and Supply Chain nodes (i.e. Bruzzone et al. 2000; Bruzzone et al., 2007, Longo et al. 2012), with particular attention to mairne ports and container terminals (Bruzzone and Longo, 2012) for both decision making and training.

The work is organized as follows: in section 2 the real port scenario is presented; in section 3 the simulation model is described; in section 4 the main results are discussed; finally, conclusions are drawn.

2. THE REAL PORT SCENARIO

The scenario under study is a real system: the Algeciras container terminal shown in Figure 1.

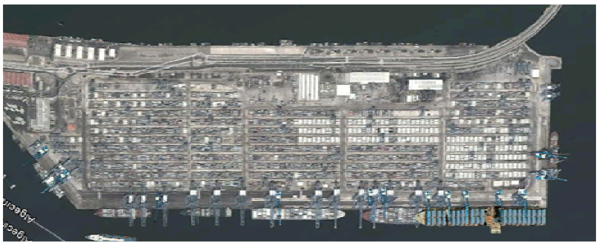

Figure 1 Layout of the Algeciras port

The container terminal is located on Juan Carlos I Quay, covers an area of 686,132 m^2 and has a capacity of 10,476 TEUs (20-foot containers). It has 1,941 m of berth with 14-16 m draughts. This container terminal is one of the APM Terminals and employs 15 portainer cranes (ten of them Post-Panamax, 3 x 70 tm, 3 x 65 tm, 4 x 50 tm, 5 x 40 tm) and 46 transtainers - RTG (19 x 61 tm, 19 x 40 tm, 8 x 32 tm). This information, along with all the data for the simulation model development, (resources, facilities and traffic data like arrival dates, departure dates, unload containers numbers, load containers numbers, etc.) have been taken from the annual report of the port authority of Algeciras 2010. Table 1 shows an abstract on freight traffic (159 ships came to the port in October). The 159 containerships transported 214.065 TEUS (20-foot Equivalent Unit) and 88.7% of this freight traffic was transit traffic toward other ports; therefore the Algeciras terminal container is considered a hub container terminal.

In addition, onsite inspections and interviews of the top management were executed with the aim to gain knowledge about the system under study. As result of these preliminary research activities, a conceptual model of the main container terminal operations was outlined. The conceptual model draws up the main processes, objects, entities and actors that have a crucial influence on the system performances and therefore have to be included within the simulation model. On the other hand all the elements that were considered outside the scope of the study have not been included. Therefore the conceptual model is representation of the system under study and it is based on the following assumptions:

Table 2 Freight traffic

Traffic	Total 2010	October 2010	Represent
Total TEUS	2,810,242	214,065	7.62%
Transit TEUS	2,493,872	195,852	7.85%
Import TEUS	81,323	8,829	10.86%
Export TEUS	86,439	9,384	10.86%
Containerships	2,308	159	6.89%

- The dock is divided into 82 segments of 24 metres each.
- Three types of ships are considered: small vessels, whose length does not exceed 8 segments; medium-size ships with a length between 8 and 14 segments; large ships with a length between 15 and 17 segments.
- As quay cranes move on the same railway, possible interferences between displacements should be considered.
- Only 40 feet standards containers size are considered.
- The maximum number of working sections per ship is three.
- The staking plan is known.
- The minimum distance between two ships involved in loading/unloading operations is one free segment.

Based on this assumption a simulation model has been developed and used to decide which block of the storage area has to be used for containers unloading. The precise containers location (micro-simulation) will not be considered in this work.

3. THE SIMULATION MODEL

The simulation model of the container terminal recreates the main operations of the container terminal: the container pre-marshalling problem, the landside transport, the stowage planning problem, the yard allocation problem, etc. See Steenken et al. (2004), and Stahlbock and Voß (2008) for complete and interesting reviews on the most relevant problems in a container terminal. To this purpose, the simulation model can be profitably used to evaluate the effects of alternative decisions-making policies without affecting the behaviour and the performances of the real system.

The simulation model has been developed by using ARENA, a commercial discrete event simulation software which has been chosen for its recognized capabilities in complex systems modeling and simulation and also because it can be easily integrated with other software/tools for input data and simulation results analysis (moreover, it includes Visual Basic for further applications development). It also supports importing Microsoft Visio flowcharts and reading from or outputting to Excel spreadsheets and Access databases.

The simulation model proposed in this research study can be considered the first step toward the development of a support tool for the Algeciras container terminal management. The above mentioned tool will be based on the combined use of both simulation and optimization approaches: simulation will be used for optimization model testing in different situations (scenarios). However, in this preliminary work the focus is on the simulation model development therefore scheduling and resources assignment decisions are taken by using basics rules (management modules). These rules will be later replaced with an optimization model. The conceptual framework where the simulation model is placed is shown in Figure 2. This figure underlines that the main input to the simulation model are: the real data (starting module) and the rules that are currently followed to implement the CT management processes (Management Module). The Starting, Management and Simulation modules are described below.

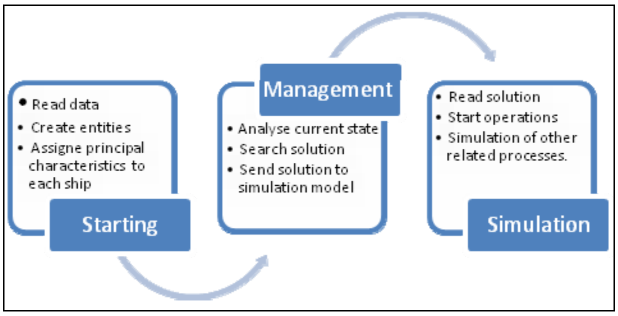

Figure 3: Models interaction

3.1. The Starting Module

Real data (i.e. arrival times, ships names, shipping companies, etc.) are taken from an external file. For testing purposes in the current version of the simulation model, these data have been extracted from the Algeciras port real database and refer to October 2010. These data have been mainly used to schedule ships arrivals; to this end a set of modules for data management and manipulation has been introduced (Figure 3). Among them, the ReadWrite module is the most important: it reads or writes values in an external document type txt, dat, xls, etc. After reading the external file, the entity representing container ship is created. The ship entities are characterized and identified by a set of attributes, including among others: the scheduled arrival times, the ship name, the shipping company, the length of the ship, the number of sections with containers, the number of containers to be loaded and unloaded, the locations of these containers in the storage area, etc.

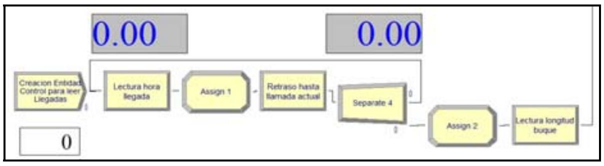

Figure 4 Read data modules

3.2. Management module

When a ship is created (arriving at the CT), it is sent to a scheduling module, where basics rules are applied to solve the quay crane scheduling problem and the berth allocation problem. These modules are shown in figure 4. Currently such rules are implemented based on suggestions/experience of the planners working in the real system.

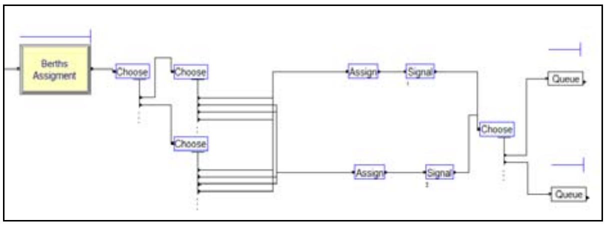

Figure 4: Scheduling modules

3.3. Simulation module: virtual dock and complementary operations

Each ship has an attribute that allows identifying the segments that have been assigned to that particular ship. In the simulation model a virtual dock has been developed, it is used to take and represent the segments that each ship will need. Therefore, the virtual dock moves along the dock line representing the specific group of segments where the operations are being carried out and allows the unloading, loading and transportation processes of all the containers to be simulated. The modules of the virtual dock are shown in figure 5.

Basically, the ship berths in the virtual dock until it has completed the handling operations. After completing the handling operations, the ship is ready to leave the dock and get into the towing process releasing all the resources that had been assigned to (i.e. the dock segments, the quay crane and the virtual dock). Distances between the points of the storage area and each location (segment) of the dock line are stored in a matrix.

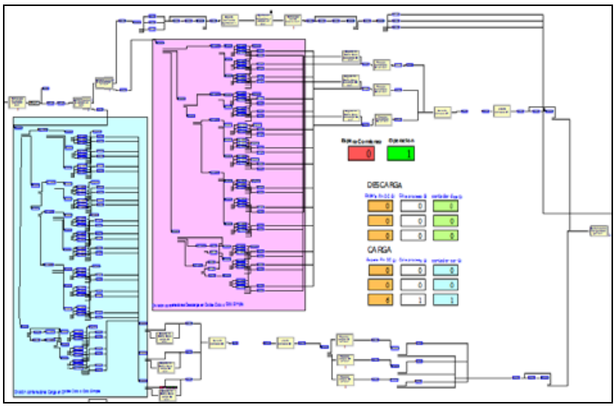

Figure 5 Virtual dock modules

Moreover, the virtual dock simulates resources assignment based on the rules of the management module, i.e. the quay crane scheduling. In fact, according to the assumptions introduced in section 2 , a ship could have from 1 to 3 work sections (with containers), and therefore 1, 2 or 3 quay cranes could be assigned to each ship. Additional examples of ships operations are depicted in Figure 6: the firs ship has 3 working sections and 1 quay cranes assigned, the second ship has 3 working sections and 2 quay cranes assigned and the third ship has 2 working sections and 2 quay cranes assigned.

Figure 6 Ships in operations

Moreover, in order to recreate the CT operating conditions, complementary operations have been included in the simulation model. As a matter of fact, when ship handling operations occur, landside handling operations, which involve shuttle vehicles like forklifts and trucks, have to be performed accordingly. Therefore, on the simulation side specific modules for complementary operations are needed for ensuring a logical flow of containers import and export. Note that the operations time depends on the containers location.
Figure 7 and Figure 8 show the truck modules and the train modules respectively. These modules have been developed as a part of the simulation model to take into account landside operations.

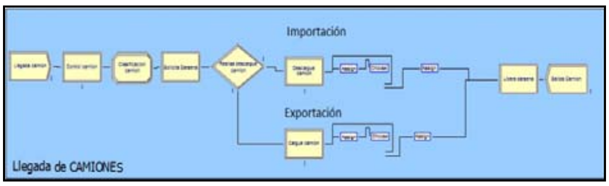

Figure 7: Truck modules

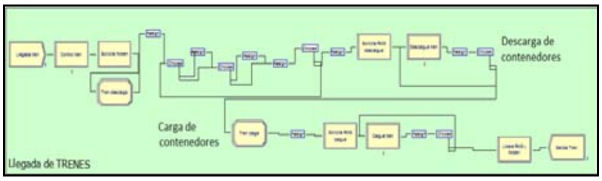

Figure 8: Train modules

Lastly, the animation of the simulation model is shown in Figure 9 where the most important areas are depicted: A identifies the trains area, B identifies the trucks area, C identifies the storage area and D is the ships operation area.

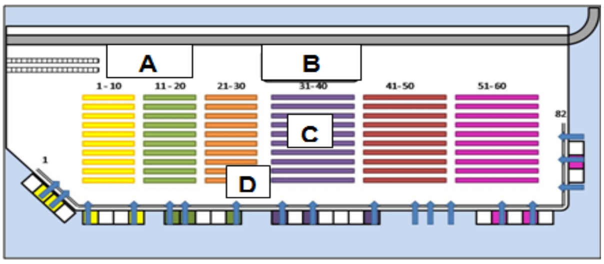

Figure 9: Animation of the simulation model

4. RESULTS AND ANALYSIS

Even if the main goal of the first part of this research work was the definition of the CT conceptual model and the implementation of the simulation model, some preliminary analyses have been carried out to validate the simulation model. Specifically three different scenarios have been considered. The initial scenario is based on the real data taken from the annual report of the Algeciras port authority. These data include arrival times and ships information for 159 containerships. The remaining information such as the number of work sections and containers to load and unload were calculated according to the real freight traffic (107.032 40 feet standard containers). The simulation results for this first scenario show the capability of the simulation model to come up with acceptable results in terms of waiting time, handling time and service time.

Apart from the first scenario, two additional scenarios have been considered in order to check the capabilities of the simulation model to behave correctly in case of increases in containerships traffic and containers traffic. In fact, for the second scenario, the ship arrivals times are the same of the first scenario while the number of containers carried by each ship was increased by 20% (128,438 40 feet standard containers in total). For the third scenario, the number of containers and sections per ship are the same of the second scenario while the number of ship arrivals was increased by 20 units (179 containerships and 128,438 40 feet standard containers in total), it means the 12.5% raise in containership traffic and the 20% raise in containers traffic. In this last case in order to assign correctly the ships arrival times a distribution fitting procedure on the real data has been carried out (see Montgomery and Runger, 2006 for further information about distribution fitting procedures). The vessels arrival times were assigned according to the results of distribution fitting procedure (Poisson process, exponential distribution) and the same approach was adopted for ships length assignment.

For each scenario, ten model replications were executed therefore thirty replications were analysed. Simulation results and analysis are reported in the remaining part of this section.

Table 2 summarises ships operations times expressed in hours; handling operations time, resources waiting time and logistic operations time were considered. The sum of these time values is known as service time and is an important data for evaluating CT performances. Since containers traffic and ships traffic are different for each scenario, the results in terms of service time are also different. However, the minimum handling time has similar values because the probability that a ship with few containers to load/unload will arrive, is the same for all the scenarios. Furthermore, the second scenario has the worst results compared to the other scenarios. This is consistent with expectations because the container traffic was increased. Therefore, from this preliminary analysis, it is possible to ascertain that the simulation model behaves coherently.

		Scenario 1	Scenario 2	Scenario 3
Waiting time	Min	0	0	0
	Max	4.15	7.91	4.05
	Average	0.25	0.31	0.25
handling time	Min	4.96	4.99	4.69
	Max	15.96	19.24	15.8
	Average	6.85	7.65	6.72
Service time	Min	4.96	4.99	4.69
	Max	16.16	20.43	16.33
	Average	7.1	7.98	6.97

Table 2 Ships operations time (h)

Figure 10 shows the ship rate for each interval of the handling operations time (lower than six hours, between six and seven hours, between seven and eight hours, between eight and nine hours, greater than nine hours). Even in this case, since the number of containers for each ship is greater in the second scenario, the first and the third scenario have the best results in terms of handling operation time which is between 6 and 7 hours for almost 80% of the containerships.

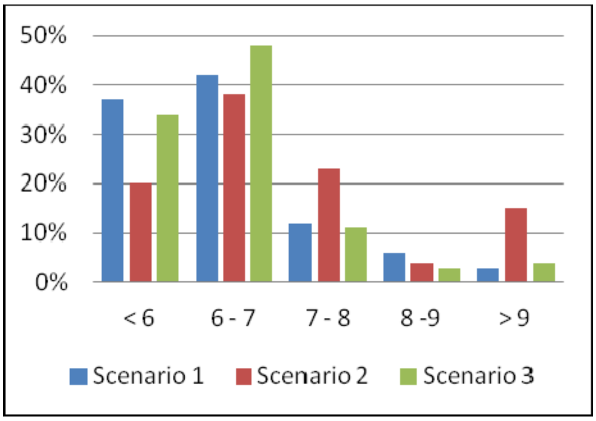

Figure 10: Handling operation time

Analyzing the workload for each segment berth (see Figure 11), it is possible to notice that certain sections have a greater workload than others. It happens because the sections close to the streets and to the dock are preferred to the other sections since they allow minimizing the total handling operation time. Once again the analysis of these preliminary results allows pointing out that the simulation results are coherent with the expected results and with the real system behaviour.

At this stage, the simulation model is used to carry out further analysis on the system behaviour. In detail, simulation runs have been executed in order to identify the criticalities and gain a greater insight into the CT management and control.

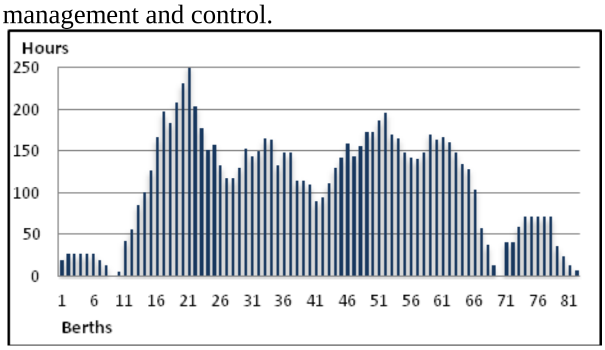

Figure 11: Berth segments workload

To this purpose, the main causes of waiting time were studied. As reported in Figure 12, the main bottleneck in the Algeciras container terminal is the berth and its bottleneck effect increases when the traffic increases. Lastly, the bottleneck called “Others” represents other resources less important for this study such as; Tugboats, Trucks, Forklifts, etc.

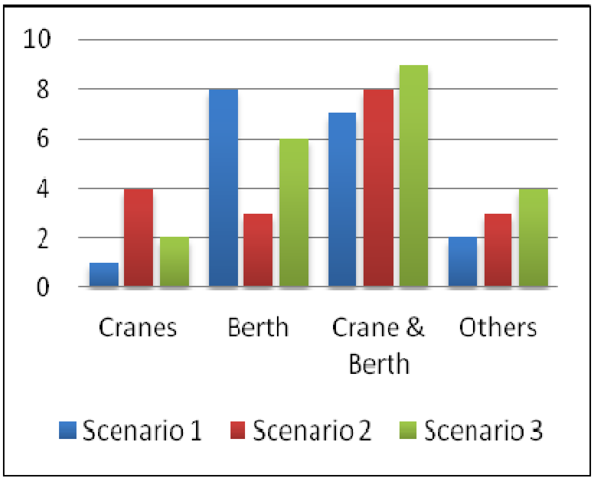

Figure 12: Mains bottlenecks

The Quay cranes workload has been analyzed also, in fact it is very important to schedule this resource properly for maintenance activities. Figure 13 shows the containers handled for each crane and it is possible to notice that cranes number 1 and 2 have the lowest workload owing to their localization in the initial dock line.

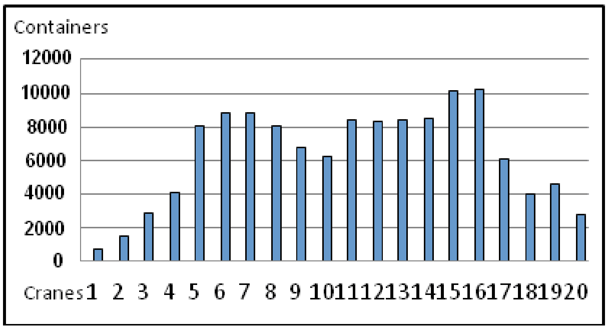

Figure 13: Quay cranes workload

5. CONCLUSIONS

In this paper a well-established hub port has been considered: the Algeciras port. The port operations have been modelled by using the discrete event simulation software Arena and three scenarios were considered for validation purposes. First, the real freight traffic was considered; then the second scenario was developed considering a containers traffic increase; lastly in the third scenario a ship arrivals increase was considered.

The output data analysis allows pointing out that simulation is a valuable tool with great potential for CTs management and control. In addition, the simulation study output suggests that berths resources are the main cause of bottlenecks, therefore to serve the new freight traffic current berths resources have to be improved. As already mentioned, future work will involve the development of an optimization module that will be integrated within the simulation module in order to optimize management policies for the Algeciras port. Furthermore, handling equipment such as forklifts and Reachstackers, will be considered more accurately for minimizing costs, handling operations times, bottlenecks, etc.

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