CONTAINER TERMINAL SIMULATION. A CASE STUDY: PORT OF VALENCIA.

López-Ansorena Iñigo\textsuperscript{1}, Camarero-Orive Alberto\textsuperscript{2}, González-Cancelas Nicoleta\textsuperscript{3}, Camarero-Orive Alfonso\textsuperscript{4}

\textsuperscript{1} Department of Civil Engineering: Transportation, Polytechnic University, Madrid, Spain. E-mail: ilopezans@gmail.com

\textsuperscript{2} Department of Civil Engineering: Transportation, Polytechnic University, Madrid, Spain. E-mail: alberto.camarero@upm.es

\textsuperscript{3} Department of Civil Engineering: Transportation, Polytechnic University, Madrid, Spain. E-mail: nicoleta.gcelsius@upm.es

\textsuperscript{4} Department of Civil Engineering: Transportation, Polytechnic University, Madrid, Spain. E-mail: alfonso.camarero@upm.es

ABSTRACT

This paper is concerned with the study of non-Markovian queuing systems in container terminals. The methodology presented has been applied to analyze the ship traffic in the port of Valencia located in the Western Mediterranean. Two container terminals have been studied: the public container terminal of NOATUM and the dedicated container terminal of MSC. This paper contains the results of a simulation model based on queuing theory. The methodology presented is found to be effective in replicating realistic ship traffic operations in port as well as in conducting capacity evaluations. Thus the methodology can be used for capacity planning (long term), tactical planning (medium term) and even for the container terminal design (port enlargement purposes).

KEY WORDS: simulation, modelling, berths, container terminals
INTRODUCTION

The importance of the container traffic is a key factor in making the Port of Valencia one of the first logistics platform in Southern Europe. The port of Valencia has a mixed hub management model (import, export and transhipment), as the strategy which best ensures connectivity with the world's markets and emphasises the crucial service that the port provides. The strategy of the port is focused on building customer loyalty among the major shipping companies by increasing their international container transhipments, coupled with continuous efforts to grow productivity and with it, efficiency and service quality.

Optimization of the facilities is an extremely important goal in the container terminal planning process, in which analytical method and simulation are two primary methods used in the majority of literature. This paper presents a ship-berth link modelling methodology based on statistical analysis of container ship traffic data obtained from Container Terminals located in the port of Valencia. The efficiency of operations and processes on the ship-berth link has been analyzed through the basic operating parameters such as berth utilization, average number of ships in port, average service time, average total time that ship spend in port, etc. The Port of Valencia aerial view is shown in Figure 1.

Figure 1.- Port of Valencia aerial view

Source: Google earth
The two container terminals studied have been the public container terminal of NOATUM and the dedicated container terminal of MSC. The public container terminal has two quays: Principe Felipe and East, with 1,500 and 330 metres long respectively, the available storage area is 914,613 m² on the Principe Felipe Quay. The dedicated MSC Container Terminal has one quay: Transversal de Costa Quay, with a length of 686 metres and an available storage area of 332,077 m². Both container terminals have a 16 metre-deep berthing face. The Traffic evolution is shown in Table 1.

### Table 1: Traffic evolution

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEUS / vessel NOATUM CT</td>
<td>1,189</td>
<td>1,320</td>
<td>1,335</td>
<td>1,262</td>
<td>1,207</td>
</tr>
<tr>
<td>TEUS NOATUM CT</td>
<td>1,743,885</td>
<td>1,903,720</td>
<td>1,934,699</td>
<td>2,109,663</td>
<td>2,320,629</td>
</tr>
<tr>
<td>Ship calls NOATUM CT</td>
<td>1,467</td>
<td>1,442</td>
<td>1,449</td>
<td>1,671</td>
<td>1,921</td>
</tr>
<tr>
<td>TEUS / vessel MSC CT</td>
<td>1,304</td>
<td>1,323</td>
<td>1,314</td>
<td>1,369</td>
<td>1,505</td>
</tr>
<tr>
<td>TEUS MSC CT</td>
<td>629,854</td>
<td>910,000</td>
<td>1,152,000</td>
<td>1,410,138</td>
<td>1,520,000</td>
</tr>
<tr>
<td>Ship calls MSC CT</td>
<td>483</td>
<td>688</td>
<td>877</td>
<td>1,030</td>
<td>1,010</td>
</tr>
</tbody>
</table>

Source: Own elaboration

### RELATED LITERATURE

According to the literature review, queuing models are widely used for container terminal modelling and planning. The models provide the possibility to assume and solve realistic problems incorporating real data from ports. These models, in most cases, are used for strategic or tactical decisions using the common nomenclature of queuing theory A/B/C\(^5\) (Kendall’s notation). The determination of optimum number and capacity of berths at the terminal has been treated by many studies with both theoretical and practical sides. Some of the studies are:

---

\(^5\) “A” symbolizes the ship inter-arrival distribution, “B” symbolizes the service time distribution, and “C” the number of berths.
Kozan E. (1997) analyzed port operation by means of queuing theory, and compared the results of queuing theory with simulation. Huang W. C. et al. (2007) proposed a methodology to determine the optimum number of berths and facilities for a container terminal. The author referred to the suggestions of Noritake M. (1978) and Noritake M. and Kimura S. (1983) and adopted the M/Ek/N queuing model, with k =3.

Shabayek A. A. and Yeung W. W. (2000) incorporated the Witness simulation software to develop a simulation model for the Kwai Chung container terminals in Hong Kong. Kuo T. C. et al. (2006) studied the evolution of the ship arrival and service time distribution in public and dedicated container berths in the port of Kaohsiung (Taiwan) by comparing the variance in the patterns of 1,400 ships in the container terminal and 7,700 ships in the entire port.

Huang W. C. and Wu S.C. (2005) estimated the initial number of berths in relation between “traffic density” and “the parameter of the initial facilities”. Dragović B. et al. (2005) and Dragović B. et al. (2006) developed and described simulation and analytical methodology to study the performance evaluation of ship-berth link at container terminals using queuing models to formulate average container ship cost function, computational experiments are reported to evaluate the efficiency of Pusan East Container Terminal (PECT) in Korea.

Recently in Novaes et al. (2010) a short survey on mathematical approach of queuing models applied to container terminals planning has been presented. In addition, they described some approximate methods for more complex queuing models based on approximate formulas to estimate mean waiting times. Finally Dragović B. et al. (2011) has compared new and old queuing theory results for container terminal performance evaluation.

**METHODOLOGY**

Container Terminal developments clearly show that the integration of shipping and transhipment operations are providing efficiency benefits that can only be obtained with more interaction between shipping lines and terminal operators than just information exchange. Examples are adjustment of arrival times, sailing scheme based service levels rather than fixed service levels, and flexibility with regard to the load plan.
The arrival time of vessels and the service time in port are difficult to control due to disturbing circumstances, such as weather conditions, delays at port, administrative procedures, etc. Thus, actual arrival and departure times may deviate from scheduled times. Furthermore, usually they are also difficult to change because they affect global sailing schemes.

As the success of Valencia container terminals is significant, in this paper, an application of a simulation model (using MATLAB® software) to simulate Valencia container terminals is developed and described. The objective was to investigate to what extent a simulation model could predict the actual container terminal operations in NOATUM container terminal and MSC container terminal with a high order of accuracy. Port congestion can be precisely assessed by using the simulation model taking into account each significant step of the process. The stages of the research process are shown on Figure 2.

**Figure 2.-** Stages of the research process

1.- Data collection and statistical study

2.- Modelling and Simulation

3.- Results and analysis

CONCLUSIONS

Source: Own elaboration

1.- Data collection and statistical study

In container ports, expressions of port performance are based on data recorded by port authorities, which traditionally tend to focus on traffic recordings and parameters used in tariffing of port services. Most available and reliable data are related to the maritime interface where information is more easily collected than on the land interface. Port
Authorities usually monitor berth occupancy and dwelling time of ships, characteristics of calls, and availability and performance of ship-to-shore cargo handling.

Most of the time, developing a relevant set of indicators would require more information; a survey is the only way to identify whether existing data are reliable, the cause and extent of existing problems and the way they could be monitored.

The ship arrival distribution test and the ship service time distribution test are vital pieces of basic research for port planning, and also a basis for theoretical queuing models in port capacity analysis. The test result of the ship arrival distribution and service time distribution will influence the choice of the queuing model, which subsequently influences relevant variables measured from such model.

Arrival patterns and service time patterns are basic input parameters that have to be assumed or inferred from observed data collected in the data base of the port. Both patterns are approximated by a statistical law (Erlang distribution), ranging from the random distribution (Erlang 1) for inter-arrival time of arrivals to increasingly regular ones (Erlang 2, 3...) for the service-time pattern. Due to the difficulties of measure the real service time (period of time spend in ship to shore handling), a simplification has been done considering service time as time in port. Statistical data show that during our study period (2007 – 2010), there were altogether 10,000 ship calls at NOATUM and MSC container terminals. Two examples of arrival and service time patterns are shown in Figure 3.

**Figure 3.-** NOATUM Container Terminal performance. Year 2008

Source: Own elaboration
2.- Modelling and simulation

The choice of queuing model is based on the characteristics of the arriving ship, the container terminal ship service, and the container terminal characteristics (number of berths available, draught, number of quay cranes, etc.).

In the previous section the required parameters for each element in the simulation model have all been calculated on the basis of their own distributions. Then the simulations were carried out using a MATLAB® queuing program. For 10,000 incoming and outgoing container ships simulation testing, the model gives a simulated system time and shows the determining variables like berth utilization, efficiency, average number of ships, waiting time, etc. with the usual symbols of stochastic queuing systems nomenclature. The simulation model has the following three categories of input factors:

- Inter-arrival ship arrival distribution and \( \lambda \) (mean arrival rate of ships).
- Service time distribution and \( \mu \) (mean service time rate of berths).
- Number of berths \( n \), (a set of identical berths where an homogenous fleet of ships call on a “first come first serve” basis).

The output of the simulation model includes:

- \( L \) is the average number of ships in container terminal, or in other words, the expected number of ships in the container terminal queuing system within the period \( T \).
- \( L_q \) is the average number of ships in queue, or in other words, the expected number of ships that are waiting for service in the container terminal system.
- \( W \) is the average waiting time in the container terminal system (includes service time).
- \( W_q \) is the average waiting time a ship is waiting for an available berth, or in other words, the mean time a ship spends in line waiting for service.
- \( W_s \) (Service Time) The vessel service time is the total time the vessel stayed at the quay, also called the berth time. The service time includes the working and non working periods. The time-in-port is especially
important for deep-sea vessels, because the excess of an agreed time window may result in a disturbance in the sailing scheme. This indicator is a measure for the speed with which a vessel is handled.

- $\rho$ Utilization factor of the facility (or berth occupancy) is the actual berth utilization time to the gross berth time available. The longer the quay, the higher the berth occupancy can be, without increasing the vessel service time due to a full quay.

\[
Efficiency\ ratio = \frac{W}{W - W_q} = \frac{W}{W_s}
\]

- $P_n$ = Prob. of exactly n vessels are in queuing system.

All these indicators may be used to forecast port productivity and assess future capacity. The following section presents and analyzes the results of the simulations.

3.- Results and analysis

The simulation refers to the establishment of a model similar to the actual system, for running various scenarios (which represent 2007-2010 period) and understand the system behaviours in order to evaluate the berth activity in each container terminal. The results obtained help in visualising the deployment of quays.

The first parameter to be considered is the number of berths available, which depend mainly on:

- The available space and other constraints as number and location of bollards, depth constraints etc.

- The annual cargo throughput of the terminal.

- The predetermined level of vessel servicing to be offered by the terminal (which depends on the corresponding waiting periods discussed previously).

For example, a 1,000 metre quay can theoretically receive three POST-PANAMAX type ships at the same time. Only simulation systems could take these details into account. Analytical approaches require that a number of berths be specified in advance. It must be done by considering the length of ships commonly operated. Thus, if a terminal
actually accommodates ships with various sizes and berthing space can be optimized, its real capacity may be slightly underestimated.

The most important issue in port operations is the availability of adequate berth capacity. A quay too small with few berths will give rise to queues for ships and delays in cargo delivery. Berths that are too small, limit the maximum vessel size, which in turn limits the throughput capacity. Sufficient quay length needs to be provided to enable the anticipated number of vessels to berth with an acceptable level of vessel queuing and berth occupancy. The average number of vessels with a fixed length that are served daily is shown in Figure 4.

**Figure 4.-** Average number of vessels with a fixed length that are served daily

![Average number of vessels with a fixed length that are served daily](image)

Source: Own elaboration

An optimal use of space and resources will have a significant impact on operational cost and level of service. The occupancy rate of a group of berths expresses the percentage of time that berth positions are occupied by ships being serviced. The effect of berth occupancy on waiting time depends on the probability distributions of arrivals and of servicing times as well as on the number of berths available at the terminal that is being examined. Taking a closer look at the results concerning the total berth occupancy, it is quite obvious that the number of quay cranes has a great impact on the duration of the servicing process. The average occupancy factor for each container terminal is shown in Figure 5.
Figure 5.- Average occupancy factor

![Average occupancy factor graph](image)

Source: Own elaboration

The simulated scenarios of each container terminal represent an important management tool for tracking progress against strategic goals, helping the management teams to know whether they are succeeding in their mission. These simulation results could help the terminal operators to maximize the number of ships serviced with a satisfactory service level. The number of container vessels per day in NOATUM and MSC container terminals are shown in figures 6 and figure 7 respectively.

Figure 6.- Number of container vessels per day. NOATUM Container Terminal

![Number of container vessels per day. NOATUM CT graph](image)

Source: Own elaboration
**Figure 7.**- Number of container vessels per day. MSC Container Terminal

![Number of container vessels per day. MSC CT](image)

Source: Own elaboration

Each terminal must examine the various arrival times at port and the allocation of the respective service time in accordance with the number of berths offered, before making the most appropriate strategy.

To optimize the number of ships/day in NOATUM and MSC container terminals, the only feasible alternative is to increase the average number of vessels with a fixed length that are served daily, the quay length and/or increase the waterside handling capacity, (which is mainly determined by the number of quay cranes, in combination with their gross productivity). Other alternatives are either to alter the contractual service time or the call pattern of the vessels.

**CONCLUSIONS**

The most important factor in providing a high quality berth service in container terminals is to ensure on-time services for customer liners by minimizing vessel delay and increasing gross berth productivity. Queuing theory has been very useful for understanding (modelling) and analyzing operations in order to improve the performance of container terminal berth system. Based on the scenarios proposed, the main terminal parameters have been studied and determined, by means of simulation.

This article shows the results of a proposed simulation model of NOATUM container terminal and MSC container terminal, enabling
container terminal operators to find optimization possibilities. The following applications on the usage of the present model are proposed:

1st) The model can be used in long term planning for the need of additional berths or reducing workforce that may be necessarily, through the use of forecasted average inter-arrival time of container vessels. Obviously, high average waiting times (or exceedingly high degree of utilization of container terminals) would signal the need for additional berths.

2nd) The model can be used for cost analysis, as the simulation provides two important parameters, i.e. the average system ratios and the degree of utilization of container terminals, which are essential to establish cost-effective system. The optimum berth use depends on the cost ratio between berths and vessels.

REFERENCES


