Anticipation of Performance Parameters Evolution in a Container Terminal

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Abstract
Performance of container terminals are influenced by different functional parameters. The paper presents a case study of performance anticipatory analysis, in the context of various functional parameter changes, for the container terminal in Constantza. The results offer valuable information to the management team of the container terminal, in the decision-making process aiming to maximize the terminal efficiency and to offer attractive conditions to their actual or potential clients.
The analysis process was conducted using a GPSS simulation model. Anticipated effects of individual and combined functional parameter changes yield by the simulation experiments are extensively discussed.
Keywords: container terminal, performance, anticipation, modeling, simulation.

1 Introduction

Anticipation of container terminals operating performances is very important for both maritime transport lines and terminals management. In order to make the best decisions for an efficient management of a container terminal it is crucial to anticipate the effect of both external parameters, such as those related to ship arrivals and operating requirements, and internal parameters, such as servicing policies, operating equipment performance etc. The performance parameters thus determined allow comparing the efficiency of equivalent terminals in the aim of selecting the necessary steps for activity improvement.

The complexity of the simulation model used for performance analysis is determined by the complexity of the container terminal under study and the container traffic through it. It ranges from sophisticated simulation models (Bluemel, 2000) to simpler models, but sufficient for terminals serving a reduced container traffic, as the terminal in Constantza, considered in this paper.

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2 Container Terminal Operating Performances

The main operating parameters, considered by both maritime transport lines and terminals management, are those related to the ship turn-round time in port. These parameters result from the service diagram, also named ship in port "standard station" (de Monie, 1987), presented in figure 1, where:

1 - Ship arrival at roadstead time.

2 - The moment of ship departure from roadstead to the allocated berth. The *waiting in roadstead* time, while the ship waits for berth allocation, if there is no vacant berth of the required type is $t_{WR} = t_2 - t_1 \geq 0$.

3 - The moment of ship arrival at the allocated berth. The *shifting* time, $t_d = t_3 - t_2$, represents the time the ship needs to move along the access channel and to the berth, to take the pilot on board and to be undertaken by 1...4 tug boats (depending on the ship size and the hydro-meteorological conditions).

4 - Ship berthing time; the time interval $t_{m1} = t_4 - t_3$ is spent for ship landing and fastening drills to quay.

5 - The moment when ship arrival control (sanitary, customs) is completed.

6 - Ship operation starting time; the interval $t_{wo} = t_6 - t_5 \geq 0$ is called *pre-operating* waiting.

7 - The moment of ship operation completion. The ship *operation* time, $t_o = t_7 - t_6$, is a succession of periods in which one works, alternating with periods of interruptions, caused by lack of wares, equipment failing, absence of port facility (dockers teams, cranes, bad weather etc).

8 - The moment when ship departure control is completed. The time needed for this control is $t_c = t_8 - t_7$.

9 - The moment the ship leaves the berth, after departure manoeuvres; $t_{m2} = t_9 - t_8$; $\overline{t_{m1}} \approx \overline{t_{m2}} = \overline{t_m}$;

10 – Ship arrival at roadstead time; $t_d = t_{10} - t_9$ is called ship *shifting* time.

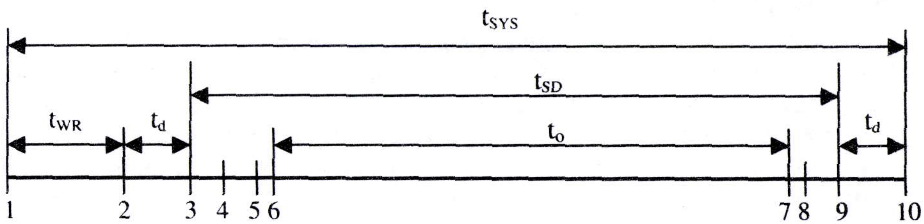

Figure 1: Standard station of ship in port

So, the main performance parameters of ship station in port are:

1) $\overline{t_{SYS}}$ - The average time of ship station in port (system) or the time for turnaround of ship in port, expressed in hours. It represents the period of time between ship arrival at roadstead, aiming to enter an operative berth with certain characteristics, and ship

return to roadstead, ready to leave. This is the most important performance parameter as it is a synthetic parameter which evaluates the entire port activity.

$$\overline{t_{SYS}} \cong t_{WR} + t_{SD} \quad (1)$$

2) $\overline{t_{WR}}$ - average waiting in roadstead time, in hours;

3) $\overline{t_{SD}}$ - average time needed for serving a port-container ship at berth, in hours, time interval while the berth is not available for another ship;

4) $\overline{t_O}$ - average time for operating a port-container ship, in hours; it depends on the following factors:

n_c - the average number of containers manipulated at a ship, in physical containers/ship or TEU/ship;

r_c – handling rate, in hours/physical container;

n_m – the number of cranes serving the ship.

If the cranes work un-interferingly at a ship (they do not interfere each other), and the work is equally distributed on the n_m cranes, the operating time of port-container ship can be determined by eq.2:

$$t_o = \frac{n_c \cdot r_c}{n_m} \quad [hours / ship] \quad (2)$$

If there is interference (mainly because of means of transport activity under the cranes) and the number of cranes is unvaryingly distributed at ships, then the operating time is determined with eq.3:

$$t_o = \frac{n_c \cdot r_c}{(n_m)^f} = \frac{n_c}{P_{em} \cdot (n_m)^f} \quad [hours / ship] \quad (3)$$

where the exponent $f < 1$ represents the interference coefficient, with its typical value $f = 0.85$.

3 Functional Model of a Container Terminal

The model presented in figure 2 was developed for the container terminal in Constantza. This terminal has two identical berths, at each berth operating a quay crane of the same productivity.

Data concerning the container terminal functional parameters have been collected during a one-year period, the mathematical-statistic analysis of the data registered in the real system leading to the following results:

- This queuing system is of the type ***M/E$_2$ /2: (∞;FIFO)***, where, according to Kendall's notation:

  M – represents the ships enter flow of Poisson type;

  E$_2$ – the distribution of operating times is Erlang of order k=2;

  2 – the number of serving stations;

  ∞ - the requests are not rejected from the system and once the waiting line entered, they cannot leave it;

  FIFO – the requests are processed in First-In-First-Out order.

- ➢ The external parameter represented by the ship interarrival time has an Exponential distribution, with a mean of ≅ 33.8.
- ➢ The system has two parameters represented by random variables, the pre-operation waiting time t_{wo} and the ship operation time t_o , with distributions:
  - o Exponential with a mean of 2.75 for t_{wo}
  - o Erlang with a mean of 17.57 for t_o

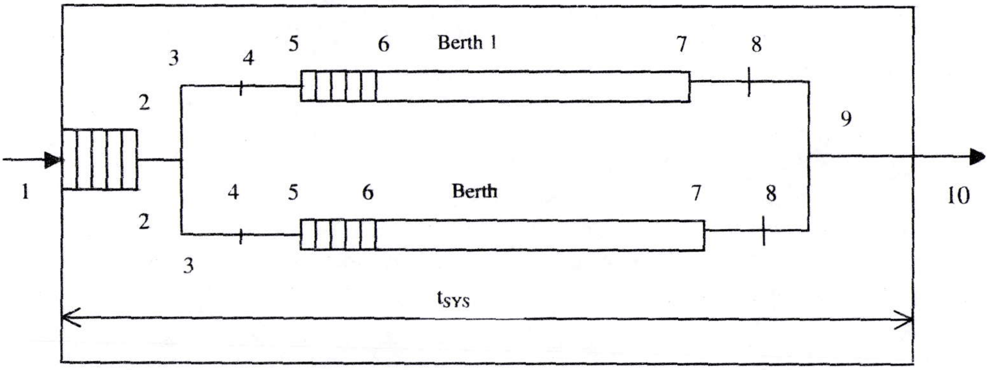

Figure 2: The conceptual model of ship activity in Constantza container terminal

4 Anticipation of Parameter Changes Effects

There are both external and internal parameters of the considered container terminal that could be subject to change in the future, affecting more or less the terminal performance parameters:

- Increasing traffic in the container terminal will lead to changes of the time interval between ships arrival, affecting its mean or even its type and, consequently, other functional parameters, such as the waiting in roadstead time and the station in port time.
- Management decisions taken in order to ensure a more efficient use of existing facilities or even for new investments will improve the performance parameters.
- In case of increased average capacity of serviced ships, the (pre)operation time will be longer if the operating facilities remain unchanged, but it is difficult to intuitively evaluate its evolution if the servicing parameters are improved.

It is obvious that the qualitative effects of such parameter changes can be anticipated intuitively in most cases, but in the management decision-taking process more precise, quantitative information should be available. Such information can be provided as a result of simulation experiments. The GPSS/H (Banks, et al, 1991) model developed for the container terminal considered (Kalisz, Popescu, 2001) allowed an extensive study of the effect of different parameter changes, as well as of the effect of different servicing strategies. (Popescu, Kalisz, 2004).

5 Simulation Results

The basic GPSS/H model of the considered container terminal was first validated with the specific data. In subsequent simulation experiments the effects of various parameter changes on the main performance parameters - $\overline{t_{SYS}}$ and $\overline{t_{WR}}$ - were analyzed, thus obtaining valuable quantitative anticipation of these changes consequences.

Several of these changes were analyzed in case of different types of ship interarrival time distributions:

- Exponential
- Erlang with k = 2, 4, 6
- Normal.

5.1 The Influence of Mean Interarrival Time

The results of the simulation experiments (Raicu, Popescu, 2000) carried out for different ship interarrival distributions, summarized in figure 3, reflect the influence of the mean interarrival time (I) on the waiting in roadstead time.

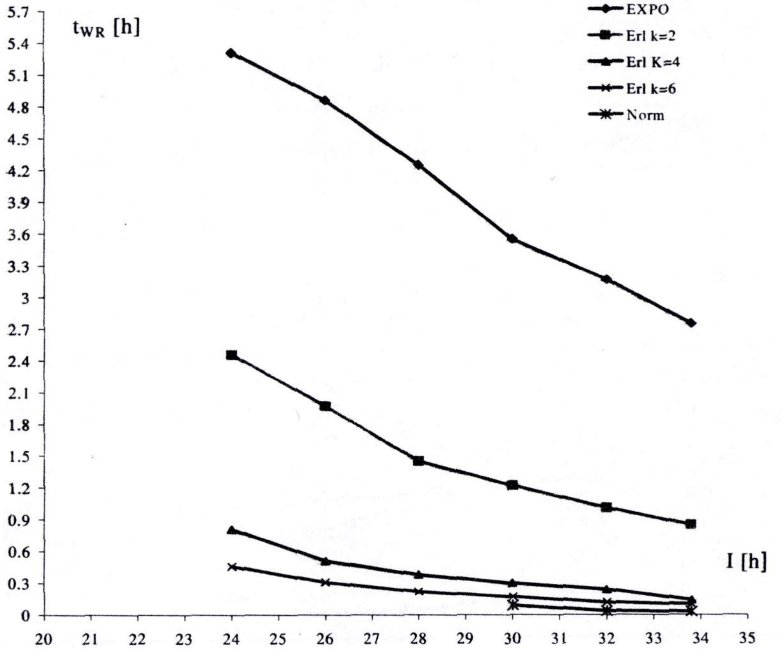

Figure 3: The influence of I on t_{WR}

The diagrams in figure 3 show that:

- the exponential distribution leads to the highest values of waiting in roadstead time ($\overline{t_{WR}}$ of 2.75...5.31 hours)
- in case of distributions Erlang k=6 and k=4 this waiting time is less than 1 hour
- $\overline{t_{WR}}$ is almost null in case of Normal distribution.

Similar conclusions are drawn in case of the average time of ship station in port (system), presented in figure 4 as a function of ship interarrival time attributes.

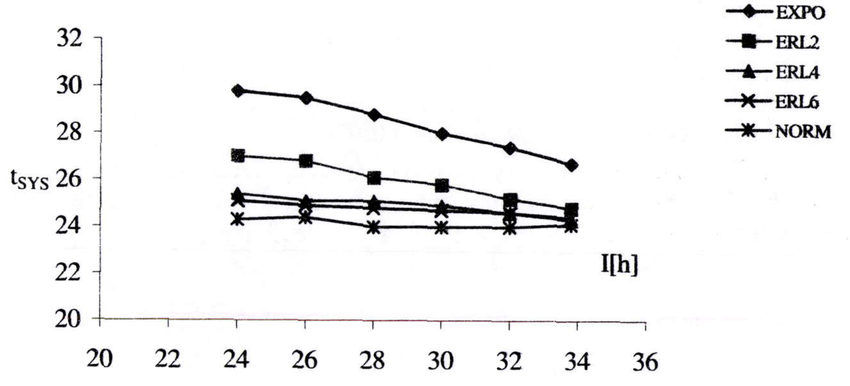

Figure 4. The influence of interarrivals on t_{SYS}

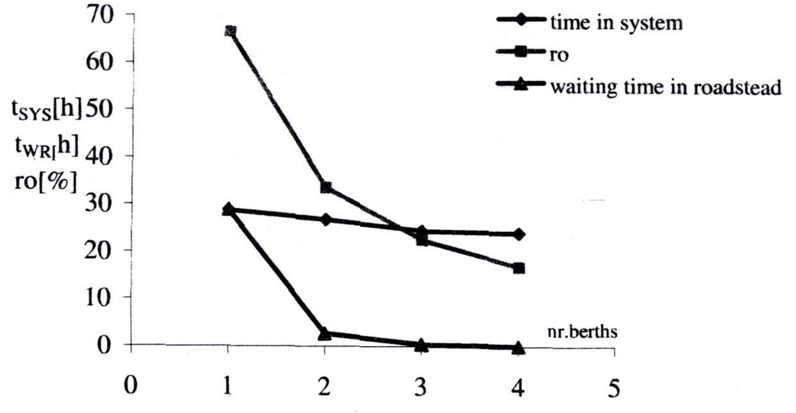

Figure 5: The influence of berths number for t_{SYS}, t_{WR}, ro

5.2 The Influence of Berths Number

In a container terminal the berth number can be either diminished, if serious technical problems appear in one berth, or increased, due to an important development investment. The effects of such changes were analyzed by performing simulation experiments on variants of the basic model, with 1,2,3,4 berths. Figure 5 presents the results anticipated for t_{SYS}, t_{WR} and *ro* – the berth utilization ratio.

The intuitive anticipation, that berths number influences essentially both $\overline{t_{SYS}}$ and the berth utilization ratio is confirmed. The values of the simulation results show that when introducing a third berth in the considered terminal the berth utilization ratio decreases too much (under 25%) and thus such a decision is not recommended.

5.3 The Influence of Pre-operating Time

There are different causes that force the ship to wait in berth, before operation starts. In the case of the considered container terminal this pre-operation time is a random variable with an exponential distribution and mean of 1.5 hours.

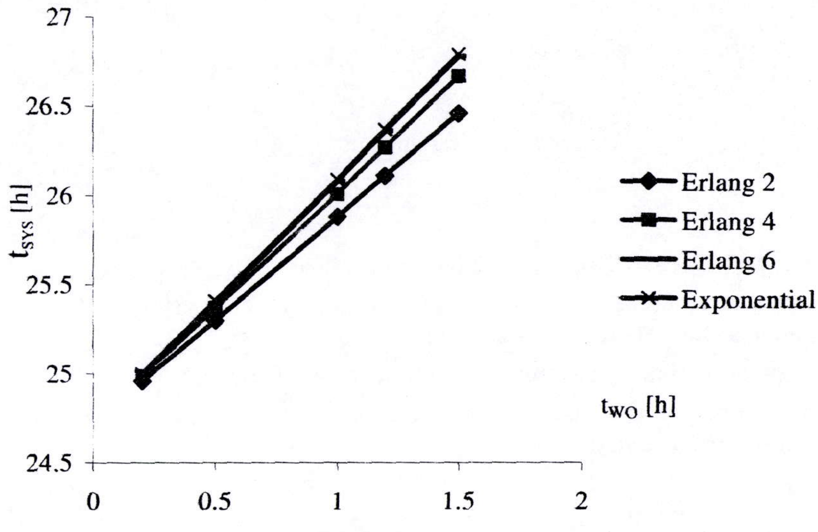

Figure 6: The influence of t_{WO} over t_{SYS}

Figure 6 reflects the influence of $\overline{t_{WO}}$ over $\overline{t_{SYS}}$, when different distributions and several mean values were considered.

5.4 The Influence of Ship Operating Time

The ship operation performance can be altered by various causes such as crane breakdowns, bad weather, lack of electricity, inefficient containers transfer between ship and container yard (when the productivity of this operation is inferior to that of the quay crane) etc. In the analysed case the ship operating time t_O is a random variable, with Erlang distribution k=3. Figure 7 presents the influence of operating time t_O on $\overline{t_{SYS}}$ for several others values of k.

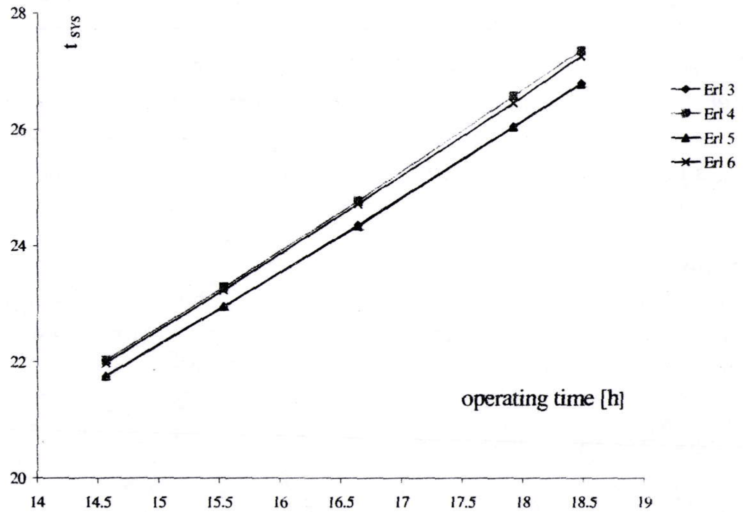

Figure 7: The variation of t_{SYS} with t_o

5.5 The Influence of Quay Crane Number

Figures 8 and 9 present results of simulation experiments performed for 1 to 4 cranes operating on a ship. These results confirm

- the operating time t_o and ship station time in system $\overline{t_{SYS}}$ are shortened;
- the ship operating productivity is increased;
- the crane productivity.

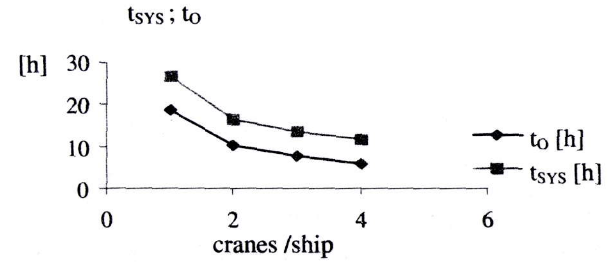

Figure 8: The variation of t_{SYS} and t_O with the number of cranes allocated to a ship

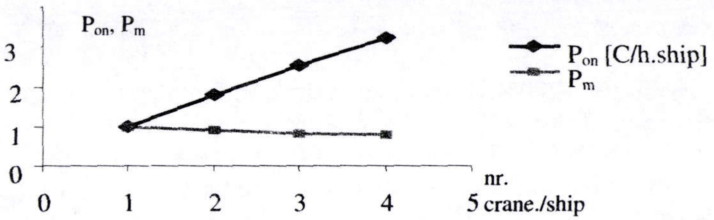

Figure 9: The effect of increasing the crane number allocated at a ship on operating productivity at ship and productivity of a crane

6 Conclusion

The paper presented how computer simulation can be used in order to anticipate the effect of different changes in the parameters of a container terminal, thus avoiding risks implied by some strategic, tactical and operational decisions.

The simulation experiments were performed on the GPSS/H simulation model of the container terminal in Constantza. These experiments provided quantitative anticipatory information on the effects of functional parameters changes, that lead to the following conclusions:

- the anticipation of berth utilization ratio evolution shows that the existent number of berths is justified;
- the distribution of ship interarrival time plays a very important role in reducing waiting in roadstead time and, consequently, increasing the terminal efficiency. It follows that the port operator has to find stimulating methods for ships planned arrival, in order to ensure instant receiving and operating, with benefic effects for both ship station in port and terminal productivity.

Any other parameters change hypothesis can be easily analyzed by performing the appropriate simulation experiments that will anticipate the effect of such changes on performance parameters of the container terminal.

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