ATOM-N 2022 "Advanced Topics in Optoelectronics, Microelectronics and Nanotechnologies", 25-28 august 2022, Constanta

The dynamics of a maritime container terminal complex system: optimization process design

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1. INTRODUCTION

The global flow of goods and materials is a decisive component in port operations and in container terminals, a fact that can critically frame the operational efficiency in such fields. The advantage and operational efficiency of these logistics components depends on the fast and efficient movement of goods in the terminal. To increase operating efficiency, it is recommended to use software as suitable operating solutions [1], [2], [3]] . The simulations obtained with the help of specialized software offer a series of features and capabilities, such as : building an efficient operational flow in ports and cargo terminals, easy to monitor; optimizing operating times in a terminal with the help of models that provide strict information to facilitate the operations of loading/unloading goods, operating equipment, failure times; evaluations of loading and unloading methods; identifying the occurrence of blockages on the operational flow; concrete requirements related to the technical details of the operating equipment in the terminal, as well as the storage characteristics of the goods.

2. METHODOLOGY

2.1.Defined methodology

Simulation-based optimization defined as the method "for evaluating system performance for a given configuration, while the optimization algorithm explores alternative configurations as a function of space and identifies the optimal setting" [7]. Simulation-based optimization is applied in practice as a screening procedure [8], [9], [10], [11], [12], 13]. These solutions target parameter configurations. To evaluate the configuration of a specific parameter, one must enter a system that imitates in real time the constituent elements of the container terminal. This is done through a simulation software [14], [15], [16] .

This study is based on real data from Constanta Container Terminal, and it is studied the statistical relevance between operational indicators and applied inverse statistics as a pertinent tool for waiting time expectancy. It is proposed a simulation based-optimization process viewing the dynamics of the Container Terminal as a complex system, because during operation, many sources of disturbance and uncertainty exists.

The research starts by looking at the statistical relevance of the different operational indicators, out of which it choses berth arrival time, first lift time, quay length occupied by the ship, total crane moves (containers, hatch lids, etc.), crane hours (the sum of the hours worked by multiple cranes), berth hours (actual) and work hours (actual), determining the descriptive statistics and the correlations between operational indicators.

Through inverse statistics (exit time statistics), it reverses the roles of the variables, the fluctuant variable becomes fixed, and the fixed one, variable.

The real data obtained from the Container Terminal are analyzed and processed in JASP (JASP, 2022)[21] and Mathematica (Mathematica, 2012)[22], both the graphs and the tables below are generated with these programs.

3. DATA AND RESULTS

3.1. Statistical interpretation of real data in a container ship terminal

In the following the real data obtained from the Container Terminal for one month (actually 35 days), 42 feeder type ships (between 135m and 240m in length), going through 24 500 containers movements is investigated. Out of the different operational indicators, it was chosen berth arrival time, first lift time (when quay cranes started operating), quay length occupied by the ship, total crane moves (containers, hatch lids, etc.), crane hours (the sum of the hours worked by multiple cranes), berth hours (actual) and work hours (actual) (Table 1)[21].

The correlation plot for the main indicators Berth Length, Total Moves, Crane Hours, Berth Hours and Work Hours shown in Figure 4, depicts the good correlation between the indicators, with the exception of the length occupied by the ship alongside quay (normal occurrence, normally not affecting directly operational aspects of the terminal, but port taxes). In Figure 5 a, b, c, d, e using scatter plots, there are compared operational indicators, with good correlations (see Figure 4), the Berth Length, Total Moves, Crane Hours, Berth Hours and Work Hours against each other, observing the density of the indicator above and to the right, in blue the regression line, and in gray the 95% confidence interval.

The results obtained above using the Pearson's Correlation method :in Table.2, the Total Moves, Crane Hours, Berth Hours and Work Hours indicators showing really strong positive correlations (Pearson's r >0.9 and p-values < .001) are checked. The results depicted in Table 2 can be also clearly evaluated in Figure 6, the correlation scatter plots, the dotted lines showing the 95% prediction intervals for each plot (Figure 6. Correlation scatter plots of the operational indicators (JASP, 2022, adapted).

3.2 Inverse statistics

In the following, in order to employ the inverse statistics (exit time statistics), it will be introduced the ships Berthed timeline and the First Lift timeline (as seen in Table 3), and will be used the mean interval between the consecutive ship arrivals (approximatively 20 hours).

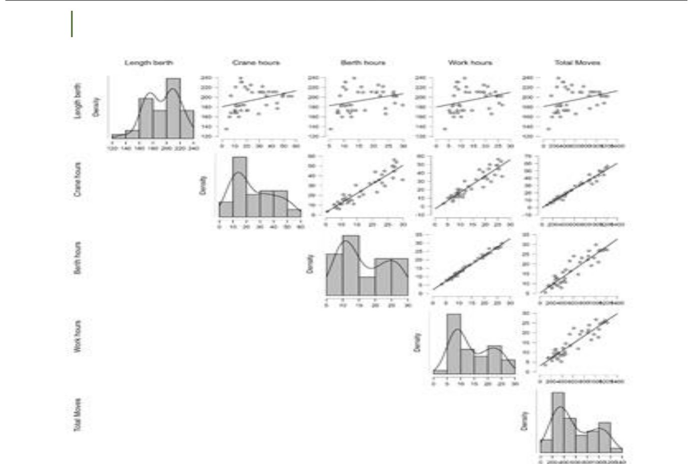
The waiting iteration (or the first passage iteration) associated to the threshold value , for the Total Moves, Crane Hours operational indicators, can be defined by analogy with the time series case [14]:

The analysis was performed for several values of the threshold parameter , in the case of Total Moves indicator, are chosen +200, +300 and +500 necessary moves, respectively for Crane Hours indicator +10, + $n_w(\delta) = \inf\{k > 0; OpInd_{n+k} - OpInd_n \geq \delta\}\ if\ \delta > 0$ eded hours. In order to be able to compare the different results is defined the distribution of probability.

Figure 7. The probability (%) distribution of waiting iterations for a ship arrival which needs +200-500 crane moves more than the last arrived (Mathematica, 2012). Figure 8. The probab $p_\delta = \frac{n_w(\delta)}{N_\delta}$ %) distribution of waiting iterations for a ship arrival which needs +10-25 crane operation hours more than the last arrived (Mathematica, 2012).

Table 1. Descriptive statistics for operational indicators [21].

	Length berth	Total Moves	Crane hours	Berth hours	Work hours
Valid	42	42	42	42	42
Missing	0	0	0	0	0
Mean	194.204	583.500	25.045	16.669	14.258
Standard Deviation	23.596	341.587	15.092	7.259	7.102
Minimum	135.000	96.000	3.500	5.500	3.500
Maximum	239.000	1214.000	56.350	29.830	26.750



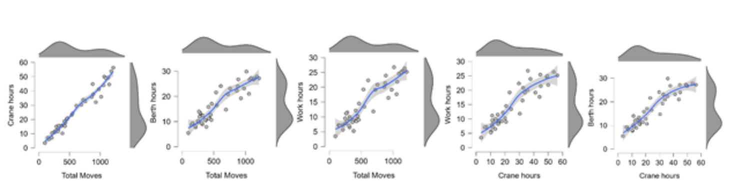


Figure 5. Scatter plots of chosen operational indicators[21].

Table 2. Pearson's correlation of operational indicators [21].

Variable		Length berth	Total Moves	Crane hours	Berth hours	Work hours
1. Length berth	Pearson's r	—				
	p-value	—				
2. Total Moves	Pearson's r	0.332	—			
	p-value	0.032	—			
3. Crane hours	Pearson's r	0.344	0.982	—		
	p-value	0.026	< .001	—		
4. Berth hours	Pearson's r	0.304	0.925	0.928	—	
	p-value	0.050	< .001	< .001	—	
5. Work hours	Pearson's r	0.300	0.917	0.922	0.995	—
	p-value	0.053	< .001	< .001	< .001	—

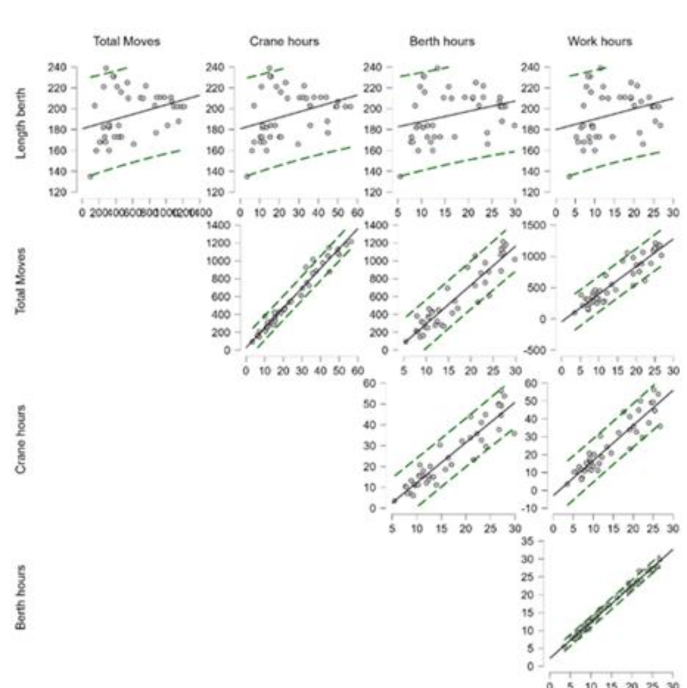
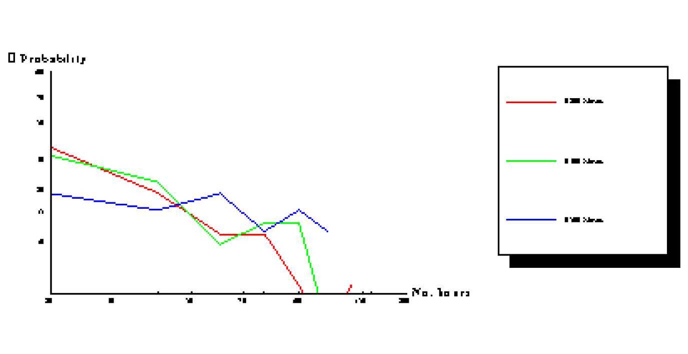
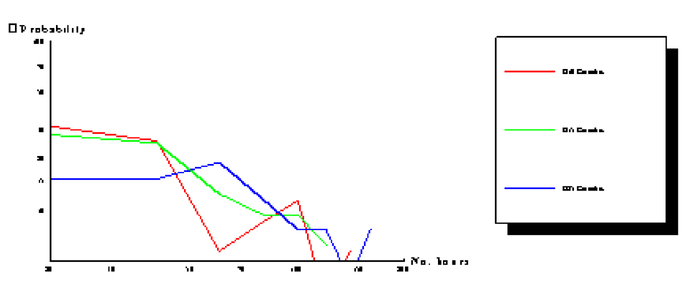


Table 3. Time line and average differences [21].

Descriptive Statistics	Berthed Hours	First lift Hours
Mean	416.978	418.532
Standard Deviation	250.048	250.008
Minimum	0.000	3.167
Maximum	851.833	853.250

Descriptive Statistics	Berthed Hours	First lift Hours
Mean	20.282	20.240
Standard Deviation	15.510	15.664
Minimum	0.000	0.000
Maximum	67.833	69.333





5. CONCLUSIONS. The goal of the study is to determine the statistical relevance of the chosen operational indicators of a real data sample from Constanta Container Terminal and to put the bases of a future study on a larger data timeline (with better integration methods), forming the tools for optimal design of the container terminal seen as a complex system, and as a decision support functionality on the sequence of container handling operations.

6. ACKNOWLEDGEMENT: All acknowledgments for technical and financial support for Constanta Maritime University.

7. REFERENCES

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