SIMULATION-BASED RESOURCE POOLING AT THE BALTIC CONTAINER TERMINAL

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KEY WORDS

Simulation, model, marine container terminal, economic efficiency, income, optimization.

ABSTRACT

The aim of the article is finding an optimal set of resources for the BCT container terminal. The pool of available resources consists of three types: quay cranes, trucks (tug-masters), and yard cranes. The article illustrates applicability of BCT logistical model based on Arena simulation package for choosing a resource set with known resource productivity values, initial prices and operational costs that would maximize terminal operating income. Comparison of obtained results with the traditional approach shows 18-20% average improvement in calculation precision.

INTRODUCTION

A set of available resources leads to the problem of an optimal choice of resource units for a given technological chain. Since any resource unit is involved in a logistic chain along with other resources, inevitable delays in technological operations as well as queues between resources units during load and discharge operations bring overall efficiency to a certain level, which sometimes is rather different from the efficiency of each separate resource unit.

Obviously, the upper productivity boundary of the whole logistic chain will not exceed productivity of the slowest resource in the chain. In order to know what the real predicted productivity value would be, we can use an adequate model of the processes to be studied.

The data obtained from the model allow estimating the real-life expected productivity and its statistical distribution for each combination of the resources in focus. Then, as a closer approximation for reality, for economic calculations the modeled productivity rather then nominal input resource productivity characteristics can be employed.

The paper is aimed at demonstrating power of simulation in finding an optimal resource combination in logistics chains. To achieve this aim, resource pooling at the Baltic Container Terminal (BCT) is considered. Namely, we shall discuss exploring both simulation-based and traditional approaches in order to decide on an optimal set of resources to be used for processing 40ft containers (Merkuryev et.al., 2002).

ORIGINAL INPUT DATA

The set of relationships between terminal resources to be considered when addressing the problem studied is illustrated on Figure 1.

The task in focus considers the following pool of resources:

– Three quay cranes, QC1, QC2, and QC3 having different initial cost Pq1, Pq2, and Pq3, and nominal maximal productivity of Nq1, Nq2, and Nq3 (which are the average values of the work cycle Tq1_set, Tq2_set, Tq3_set ) and complete depreciation duration of Lq1, Lq2, Lq3.

– Four sets of identical tug-masters 3Tr, 4Tr, 5Tr, 6Tr in work-teams of 3, 4, 5, and 6 machines per team. The tug-master sets have
the initial cost of Pt1, Pt2, Pt3, Pt4, average full work cycle time Tt1_set = Tt2_set = Tt3_set = Tt4_set = 430 seconds +/- 10% and identical service duration Lt1 = Lt2 = Lt3 = Lt4.

Three types of yard cranes YC1, YC2, and YC3 having different initial cost, Py1, Py2, and Py3, nominal maximal productivity Ny1, Ny2, and Ny3 (average cycle duration Ty1_set, Ty2_set, Ty3_set ) and expected service durations of Ly1, Ly2, Ly3.

Finally, 36 possible combinations of resource allocation are represented in a 3-D graph below, where the X-scale represents the number of trucks in the tug-master workgroup, Y-scale depicts the expected work cycles of the different types of quay cranes, and vertical Z-scale portrays workcycle durations in seconds of different types of yard cranes.

Table 1. Resource utilization costs per unit.

<table>
<thead>
<tr>
<th>NP, moves/hour</th>
<th>Depreciation, EUR/h</th>
<th>Salary, EUR/h</th>
<th>Fuel and electricity, EUR/h</th>
<th>Maintenance, EUR/h</th>
<th>Total costs, EUR/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>3.125</td>
<td>0.9</td>
<td>0.2</td>
<td>23.8</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>3.125</td>
<td>1.8</td>
<td>0.4</td>
<td>24.9</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Thus, the economic model of the task can be defined as below.

**ECONOMIC MODEL**

For every combination of resources considered, the economic efficiency criterion can be represented as a difference between the expected income P(NP) per hour (which grows in direct proportion to the number of containers processed) and the total related costs:

\[
\text{CRITERION } ijk (NP) = P(NP) - S_{\text{SSS}}ijk(NP) - S_{\text{other}} (1)
\]

where
- P(NP) – gross revenue per hour;
- S_{\text{SSS}}ijk(NP) – total costs related to one working hour along every type of resource \(i\) (\(i=1,2,3\)), \(j\) (\(j=1,2,3\)), \(k\) (\(k=1,2,3,4\)); they depend non-linearly on net productivity NP (in moves per hour) of the whole chain;
- S_{other} – other terminal fixed costs related to processing of one container (office costs, rent, fixed salary of personnel, etc.).

Now formally the task lies in searching for such a set of resources under which the efficiency criterion (1) would yield a maximum value, namely

\[
\text{MAXIMUM } [\text{CRITERION } ijk (NP)] = C_{\text{max}} u,v,w (2)
\]

where \(u, v, w\) – specific indices of resources, yielding a maximum value for the criterion.

The task, however, is not merely finding a maximum value, but rather arriving at a set or several sets of parameters leading to a maximum.
The resource dependencies as summarized in Table 1 as well as the behavior of the criterion (1) as NP changes are represented on Figure 3 below.

The graphs above portray cost analysis for each separate resource unit (upper left and right panes) and behavior of revenues and costs SSS122 on productivity NP. Red line indicates operating profit. The maximum value is reached at NP=37 moves per hour.

Depreciation and salary expenses are basically unchanged as transportation speed remains within +/-15% boundaries and are therefore considered as fixed for each resource. Fuel or electricity costs are proportional to the number of moves done. Finally, maintenance expenses were split into two main categories: linear and non-linear cost components. The former depicts the fact that excessive physical speed of operation leads to increased wear and tear of machinery and consequently an increase in maintenance costs (which is depicted as a non-linear growth in costs in the graph above).

**FINDING VALUES OF THE EFFICIENCY CRITERION**

The criterion of economic efficiency of utilizing a certain combination of resources is calculated as a difference between the hourly income at given productivity (net of average fixed costs related to one hour of operation) and operating per-hour costs as in Table 1.

Now in order to obtain numerical results, we have to run the model with every possible set of resources (model run for 154 modeled vessels per each resource set) while monitoring the values of productivity. The number of containers on a certain vessel is modeled by random generators, whose statistical distribution was adjusted in accordance with real-life data.

The next step would be incorporating the newly found productivity Ni values into the economic model of resource utilization. The total costs per given combination of resources are being subtracted from the hourly income of the terminal at the current productivity of operation. The remaining sum is considered to be the criterion of efficiency in focus whose maximal value is to be found.

Thus, we will be able to obtain the variety of values of efficiency criterion and choose an optimal solution from several tens of thousands of the productivity values observed within the studied logistical chains.

Undoubtedly, such a criterion is tightly related to productivity level reached by a certain combination of resources, but how? The answer lies in a...
structure of the data, which are plotted on Figure 4 as a dependence of the efficiency criterion (1) of the modeled productivity NP.

![Figure 4. Dependence of the efficiency criterion (1) on the model-obtained values of productivity NP.](image)

As it follows from the graph, at the same level of productivity, the value of the economic efficiency criterion is higher for a smaller amount of trucks. However, non-linear behavior of the maintenance costs does not allow efficient use of three trucks in a more productive chain; the next most efficient option is using workgroups of four trucks. This rash conclusion, however, still needs a thorough proof, which is yet to be made.

The described obtaining of data through modeling of each resource set’s productivity is illustrated on Figure 5.

![Figure 5. Illustration of methodology for estimating resource distribution efficiency](image)

Inputs for the model are real observed statistical distributions of containers (upper left pane) carried by entering vessels. For each analysis run (single analysis is based on statistics of modeled 154 vessels) the model parameters are certain sets of resources consisting of the quay crane (one of the three available models), truck workgroups (three to six trucks per workgroup), and a yard crane (of three available models).

The output data are observed productivity values on each of 154 vessels per run with the given set of terminal resources. The upper right pane illustrates two histograms: the histogram of real values of productivity based on database of the container terminal and a histogram of modeled performance with the terminal set of resources. The Kolmogorov-Smirnov test confirms the statistical identity, which speaks in favor of reliability of the model.
The performed analysis illustrated that the global optimum was found for the workgroup of three trucks, where the highest average value of the criterion reached EUR 88 per hour for the most productive (and expensive) cranes QC3 and YC3.

Without a corresponding analysis of the histograms and testing them for normality it is impossible to apply standard procedures of statistical analysis for defining uncertainty intervals for obtained values and a consequent choice of the highest value. For example, with four trucks the combinations QC2 + YC1 and QC3 + YC3 result in the same value for the efficiency criterion equal EUR 87, which lies less than one percent below the maximum value of EUR 88.

Thus, at least three combinations of resources tend to compete for the maximum result. In order to make the final choice, a more detailed analysis of the obtained data is necessary.

As it follows from the graph, seven combinations of cranes with average values above EUR 80 still require a more detailed analysis, as confidence intervals to some extent overlap and do not speak clearly in favor of either option.

For such an analysis first resources yielding close to maximum value have to be considered. The figure below contains all possible resource combinations arranged in descending order with respect to value of efficiency.

Let us consider the case of four trucks separately.
The obtained values of the efficiency criterion are depicted as columns on the graph above. As it is seen from the graph, the surface has a concave character with maximum values in two corner points. This corresponds to the following pairs of yard and quay cranes, which are opted for the optimal choice: QC1 and YC1, QC3 and YC3, QC2 and YC1, QC2 and YC2, QC1 and YC2.

Thus, one of the resources has been determined for sure, which is workgroup of four trucks with nominal productivity of NP=33 and initial cost of EUR 166700.

<table>
<thead>
<tr>
<th>Type</th>
<th>YC1 (45)</th>
<th>YC2 (40)</th>
<th>YC3 (37)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QC1 (45)</td>
<td>1000000</td>
<td>21307 (99%), crt=88 EUR</td>
<td>21415 (100%), crt=85 EUR</td>
</tr>
<tr>
<td>QC2 (40)</td>
<td>920000</td>
<td>20632 (96%), crt=87 EUR</td>
<td>20233 (94%), crt=86 EUR</td>
</tr>
<tr>
<td>QC3 (37)</td>
<td>870000</td>
<td>18851 (88%), crt=87 EUR</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Relative costs of resources for statistically similar criterion values.

In order to finalize the choice of the pair of cranes among the remaining options, we could use the table below, whose cells contain initial costs and value of criterion of efficiency. Values in parentheses indicate the percentage of the maximal value, which is 21415 for QC1 +YC2. Leaving other possible reasoning apart, the optimal choice would be equipment at minimal prices. Table 3 represents costs of equipment discussed above.

<table>
<thead>
<tr>
<th>Type</th>
<th>YC1</th>
<th>YC2</th>
<th>YC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>875000</td>
<td>820000</td>
<td>770000</td>
</tr>
<tr>
<td>QC1</td>
<td>1000000</td>
<td>1875000</td>
<td>1820000</td>
</tr>
<tr>
<td>QC2</td>
<td>920000</td>
<td>1795000</td>
<td>1740000</td>
</tr>
<tr>
<td>QC3</td>
<td>870000</td>
<td>1745000</td>
<td>1690000</td>
</tr>
</tbody>
</table>

Table 3. Initial costs of yard and quay cranes.

The choice of cheaper and least productive resources QC3 +YC3 is the optimal choice in the considered task. Thus, the optimal choice of resources consists of quay crane QC3, a workgroup of four trucks and yard crane YC3.

Average values efficiency criterion of such set of resources is summarized in Table 2. It equals EUR 87 with average productivity of N= 27 moves/hour. Nominal performance of QC3 equals 37 moves/hour, whereas that of YC3 lies at 33 moves/hour, thus there still remains at least a 20% slack in crane productivity. The structure of the costs is illustrated in Figure 9. Cost structures portrayed here indicate that these are unevenly distributed for each resource as well as among the members of the logistic chain.
COMPARING RESULTS WITH TRADITIONAL APPROACH

Let us consider the rationale behind the complex modeling of rather simple logistics chains consisting of three basic elements: loading the cargo – transporting the cargo – unloading cargo. Why cannot this task be solved without the modeling? Why is traditional approach not enough?

In order to address these questions, let us try to solve the same task without using the BCT model and compare the results obtained. Within the frames of a formal approach, a logistical chain of elements \( QC_i \) + \( Tr_j \) + \( YC_k \) can reach a maximum speed of operation equal to the speed (\( NP_{QC} \), \( NP_{Tr} \), \( NP_{YC} \)) of the slowest element, that is

\[
NP_{\min (i,j,k)} = \min (NP_{QC}, NP_{Tr}, NP_{YC})
\]

where indices \( i,j,k \) stand for the types of resources used in the given chain.

Now, in order to arrive at a numerical value for the economic efficiency (1), the obtained value of productivity \( NP_{\min (i,j,k)} \) has to be incorporated into the calculation table of expenses and the costs associated with the given productivity level have to be summed as in (1):

\[
\text{CRITERION}_{\min (i,j,k)} = SS_{ijk} (NP_{\min (i,j,k)})
\]

The highest value among the ones calculated will thus correspond to the best choice of resources in the logistics chain.

All this would be true under the assumption that the whole chain would function with the speed of its slowest node. However, it is obvious that an increase in total productivity of the chain would result in increased wear and tear of the equipment, first of all of the slowest one, which might eventually result in breach of the chain functionality.

Thus, the key condition for the approach in focus is the assumption of the speed of the chain, which would equal that of the slowest element. Since productivity of each piece of equipment lies within the +/-10% boundaries of nominal value, let us consider influence of a statistical deviation of each chain member on productivity of the whole logistics chain. For example, let us consider a chain consisting of \( QC2 + Tr5 + YC2 \), where \( NP(QC2) = 40 \), \( NP(Tr5) = 41.9 \), \( NP(YC2) = 40 \). As productivity of the
slowest link in the chain is 40, we use this value as productivity of the whole chain.

Figure 10 considers the influence of 10% statistical deviation of elements of the chain, consisting of QC2, Tr5, and YC2 on the maximum productivity of the whole chain (as per traditional approach). The histograms on the graph correspond to 2000 observations of QC2, Tr5, YC2 productivity distributions and the obtained histogram of the least productive element in the chain. The average value of the productivity equals 39.967 with the standard deviation of 0.0481, which corresponds well with the obtained value of 40.

In order to test the traditional system also under statistical fluctuations let us use once again the model of the terminal.

Figure 10 illustrates productivity histograms for each resource (upper-left and right panes) and a histogram of productivity of the whole chain SSS122. Productivities of the two types of cranes are practically normally distributed (panes on the left) as well as the workgroup of tug-masters. The productivity of the whole logistics chain has a triangular distribution; therefore standard deviation is not quite characteristic measure for this population.

Now let us consider the real-life values of productivities (3) of all the resources considered with the average values obtained through modeling. These results are plotted in the graph above, where the x-scale contains min(NPqci, NPtrj, NPyc), and the y-scale contains average values of productivities of resource combination used in the model. It follows from the graph that the assumption of the speed of operation as being equal to the productivity of the slowest element of the chain does not hold, whereas the error grows in line with the growth in productivity and within the considered boundaries (NP=20 to 40) constitutes 10% to 25%, which cannot be acceptable as the resource productivity itself differs by 15%-25%.

As the economic indicators directly depend on chain productivity, it is obvious that the differences in the values of the criterion (2) and (4) will be significant and thus will bring to questionable results.

**CONCLUSIONS**

The paper illustrates a practical application of the simulation in resource pooling. Namely, it has addressed the following issues:

- **Precision of calculation.** In spite of the simplicity of the traditional approach discussed above, its precision is essentially lower than that of the simulation-based analysis.

- **Range of applicability.** The considered load-discharge model of operations of the BCT can be easily adapted for modeling cargo transfer in terminal systems like air, vehicle, and train transportation.

- **Analysis of probabilities and risk calculation.** Thoroughly created and tested model of certain operations allows not only monitoring basic technological and economic status of the processes, but also estimating the associated risks.

**ACKNOWLEDGEMENTS**

The presented research has been undertaken within the BALTPORTS-IT project “Simulation and IT-Solutions: Applications in the Baltic Port Areas of the Newly Associated States” of the IST Programme of the European Commission.

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**BIOGRAPHIES**

**Yuri Merkuryev** is Habilitated Doctor of Engineering, Professor of the Institute of Information Technology at Riga Technical University, Head of the Department of Modelling and Simulation. His professional interests include a methodology and practical implementation of discrete-event simulation, supply chain modelling and management, as well as education in the areas of modelling, simulation and logistics management. He is Programme Director of the Master-level curriculum “Industrial Logistics Management” at Riga Technical University. Prof Merkuryev has wide experiences in performing research and educational projects in the simulation area, at both national and European levels. He regularly participates in organising international conferences in the simulation area. He is Track Co-Chair for “Simulation in Logistics, Traffic and Transport” at the annual European Simulation Symposium, and General Chair of the 2005 European Simulation Multiconference, to be held in June, 2005 in Riga, Latvia. Prof. Merkuryev authors about 180 scientific publications, including 4 books. He is Board member of the European Council of the Society for Modelling and Simulation International, President of Latvian Simulation Society, and Board member of Latvian Transport Development and Education Association.

**Vladimir Bardatchenko** got his Doctor of Engineering degree in Informatics, from Riga Technical University, and later had been employed as a docent at the same university. For around 10 years has taken position of analyst in several commercial companies as well as in institutions taking part in the PHARE programme. Starting from 2001, is being a leading simulation analyst of the RTU Department of Modelling and Simulation.

**Andrey Solomennikov** is M. Sc. in Economic Logistics and B. Sc. in Economics and Business Administration (from Stockholm School of Economics in Riga). Formerly he was a research analyst at the Institute of Economics of the Latvian Academy of Sciences. Starting from 2001, is being an assistant simulation analyst of the RTU Department of Modelling and Simulation.

**Fred Kamperman** graduated in 1973 from Higher Nautical College (university level) and started career at sea as a deck officer. The period from 1977 until 1990 he spent at different terminals (multipurpose and container terminals) in the Port of Rotterdam in charge of Terminal Management Operations and Engineering. During 1991-1996 was Operations Manager of Freeport Terminal Malta, responsible for daily operations, terminal set up, in respect of training of workforces, implementing procedures extending quay, yard, equipment and increasing productivity levels to recognized high levels. Since 1997 until today is Terminal Manager at Baltic Container Terminal LTD in Riga, responsible for development of terminal in all respects (workforces, engineering, IT). During this period is consequently involved in 2 projects, DAMAC-HP and BALTPORTS-IT, funded by the European Commission, covering simulation and information systems design aspects with applications in Latvian ports. Involved in port and terminal consultancy.