ANALYSIS OF RESOURCE CYCLES IN MARINE CONTAINER TERMINALS

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Abstract

The aim of the article is to introduce the reader to the logistic model of the Baltic Container Terminal the possibilities of optimal use of existing resource pool of the terminal as well as analyzing marginal efficiency of available resources. One of the challenging tasks was to arrive at a reasonable level of detail abstraction of the logistic model. The article concentrates on aggregated operation blocks and adjustment of respective parameters to observed terminal productivity data. Simulation analysis yielded a set of optimal solutions. The solutions obtained proved stable with regard to the input data. The methodology discussed shows good potential in application for related diverse terminal processes.

Key words: marine, port, container, terminal, simulation, BCT

1. Project Overview

This work presents the general results obtained within the frames of the *Baltoports-IT IST-2001-33030* project *Simulation and IT Solutions: Applications in the Baltic Port Areas of he Newly Associated States.* The aim of this project was creating a simulation model of the *Baltic Container Terminal* using Rockwell Arena software. The key requirements brought forward by the management of the terminal was separate resource modeling and ability to monitor each single resource unit at any point of time.

2. Introduction

The container terminal logistics chain consists of four types of resources (numbers in parenthesis indicate the respective maximum units of the given resource type employed): quay crane (up to 2) yard crane (up to 2), forklifters (up to 2), and trucks (up to 6). This chain processes four types of inputs: 20ft containers, 40ft containers, vessel hatch covers, and restow containers (containers to be moved aside when accessing cargo on the vessel, irrespective of type). The logic of the model incorporates two logistic chains (both loading and discharging): 1) 40ft container chain and 2) 20ft container chain. Logical structure of each of these logistic chains above as well as the basic process blocks distinguished in the model are presented on FIGURE 1 below (only discharge illustrated in this case).

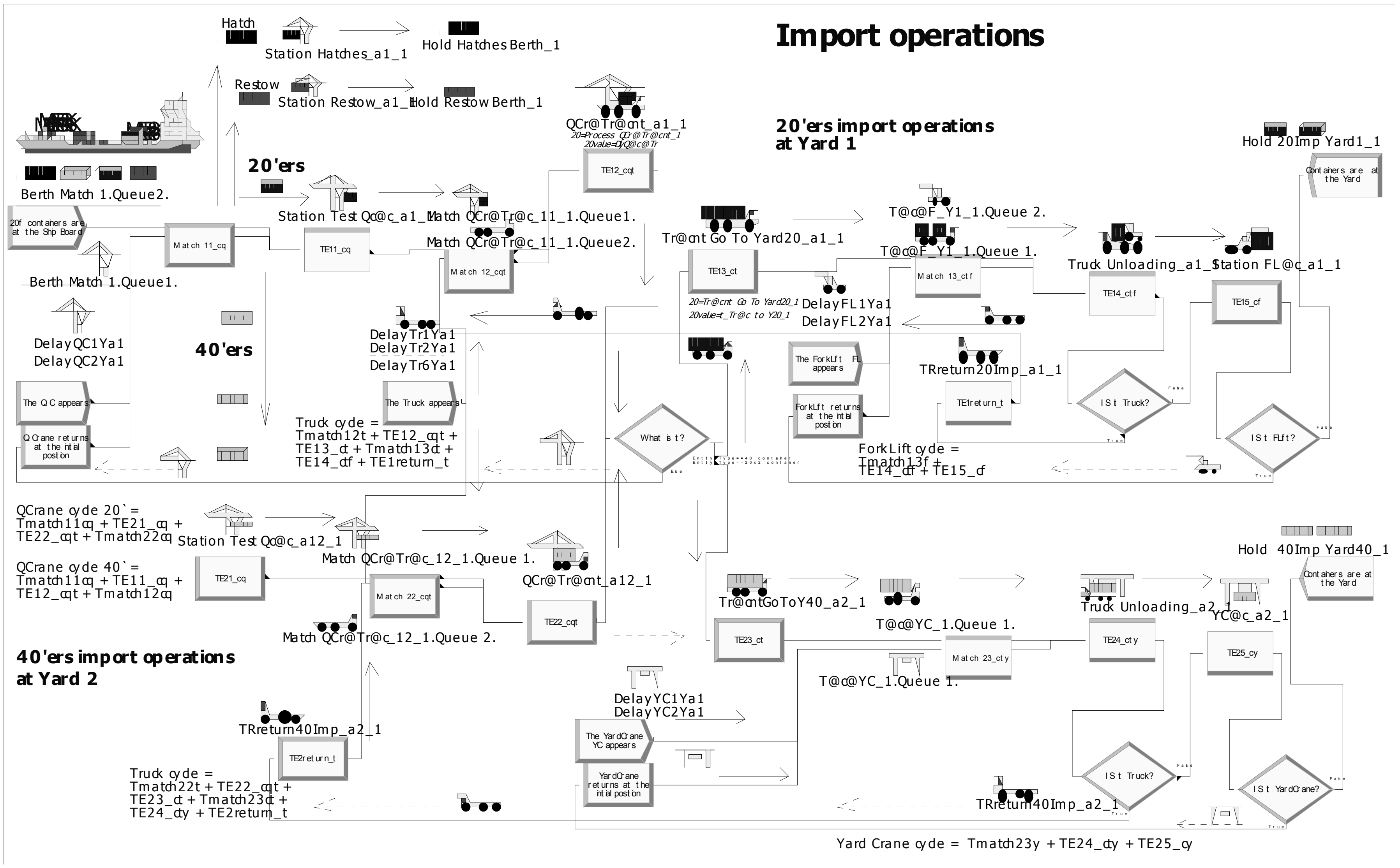


***FIGURE 1**. Model overview: discharge of 20ft and 40ft containers*

Due to the overview nature of the article, the authors delimit themselves to discussion of 40ft container chain solely to illustrate the basic underlying principles of modeling terminal logistics.

3. Resource Cycle Overview

As it follows from FIGURE 1 above, in the simulation among the available resources there can distinguished separate logical resource cycles. Thus, for the modelling purposes there emerged three logical resource cycles: the quay crane cycle, the truck cycle, and the yard crane cycle. Basing on these logical entities the performance of the model vis-a-vis real-life data is tested, as well as these allow easier adjustment of the model (see below for a more detailed discussion).

In order to introduce the outlined cycles, let us consider the terminal processes involved in a discharge of 40ft containers off vessel. Following the logistics chain of the port let us take a look at the first operation cycle, the quay crane.

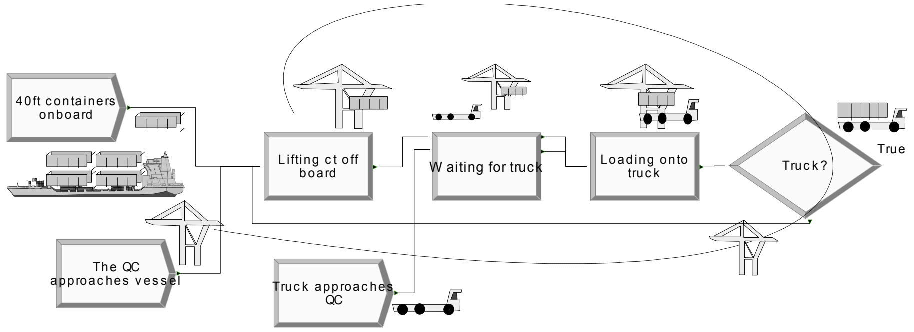


FIGURE 2. *Quay crane cycle*

The quay crane cycle breaks down into the following lower-level operations (see FIGURE 3 below): the crane head moves to container to be taken off the vessel, grabbing the container and moving it to truck position, waiting, positioning, and placing container onto truck, return to initial cycle position.

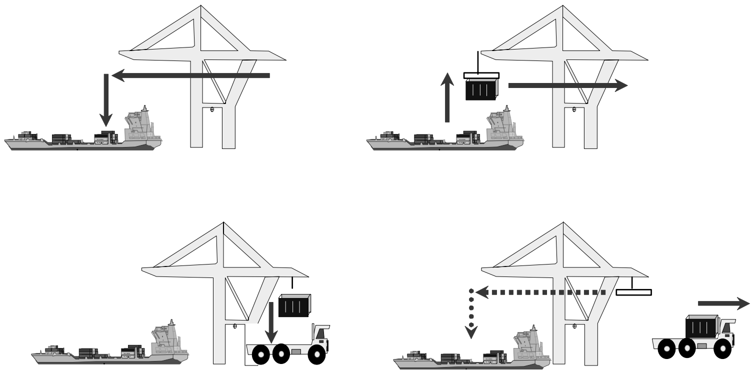


FIGURE 3*. Quay crane cycle*

In a similar manner, the operations as well as cycles for the other two types of resource (yard crane and trucks) are determined. Omitting some minor details, the truck cycle is portrayed on FIGURE 4.

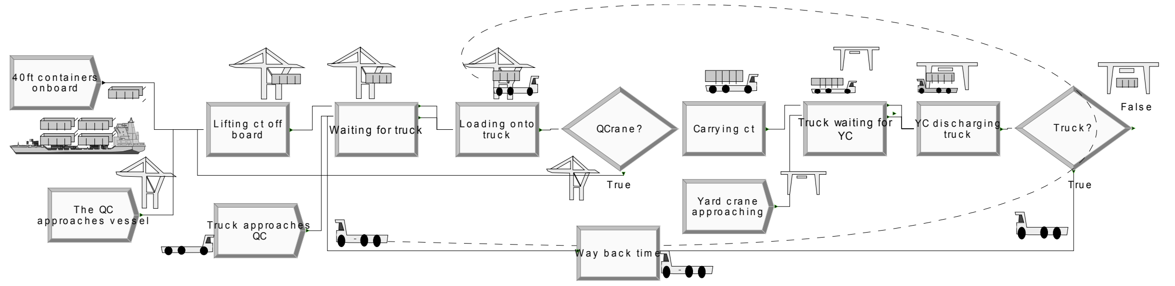


FIGURE 4. *Truck cycle*

Completing the resource cycle overview, the end-point of the 40ft container discharge chain is the yard crane cycle, presented on FIGURE 5 below.

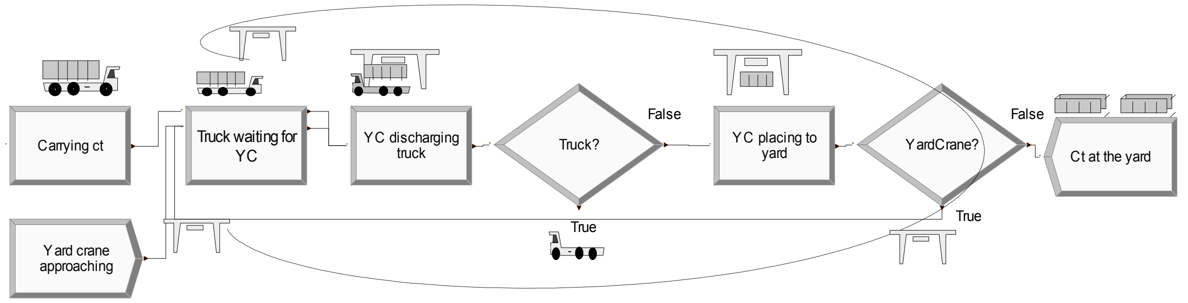


FIGURE 5. *Yard crane cycle*

4. Model Parameters

The model incorporates a two-tier resource parameter structure: 1) parameters of the lower technological level (durations and probability distributions of elementary operations for each type of resource), and 2) parameters of resource cycles outlined above (cycle durations and respective probability distributions). Parameters of the model also include number of simultaneously employed resources of each type, number of containers of different types to be discharged, and hatch covers necessary to be processed on the vessel.

The running parameters of the model are controlled with the help of hierarchically organized monitoring variables of each process modeled, which allows spot measurements. These monitoring variables are recorded in a dynamic database and can be traced for spot analysis of different "*what if…?"* scenarios.

5. Parameter Adjustment

Adjustment of model parameters involved indirect methods, whose attractiveness lies in much lower financial and time costs compared to direct measurements. Moreover, such an approach allows determining combinations of all model parameters, leading to optimal overall productivity and thus identifying existing inefficiencies in the terminal technological chain.

The simulation task formulated was to determine the values of the three resource cycles of the model Tq (quay crane cycle), Tt (truck cycle), and Ty (yard crane cycle) at a given level of terminal performance with different number of trucks available.

The calculations employed observed terminal productivity data NP(n)real. As indicated by the BCT management, the NP(n)real productivity value for the 40ft container load/discharge chain for the set of 3 trucks available constituted 24 +/-1.5 moves/hour. The productivity of bundle of resources with 4 trucks constituted 30 +/-1.5 moves/hour, and respectively 32 +/-1.5 moves/hour with 5 trucks available.

At the first stage the identification of the three cycles Tq(model), Tt(model), Ty(model) there was applied data of real BCT productivity with the given set of resources (1 quay crane, 1 yard crane, with 3, 4, and 5 trucks respectively). Thus, one of the reasonable options of analyzing model adequacy would be minimizing the least squares deviation of the model-yielded from the observed data with different number of trucks available (see FIGURE 6).

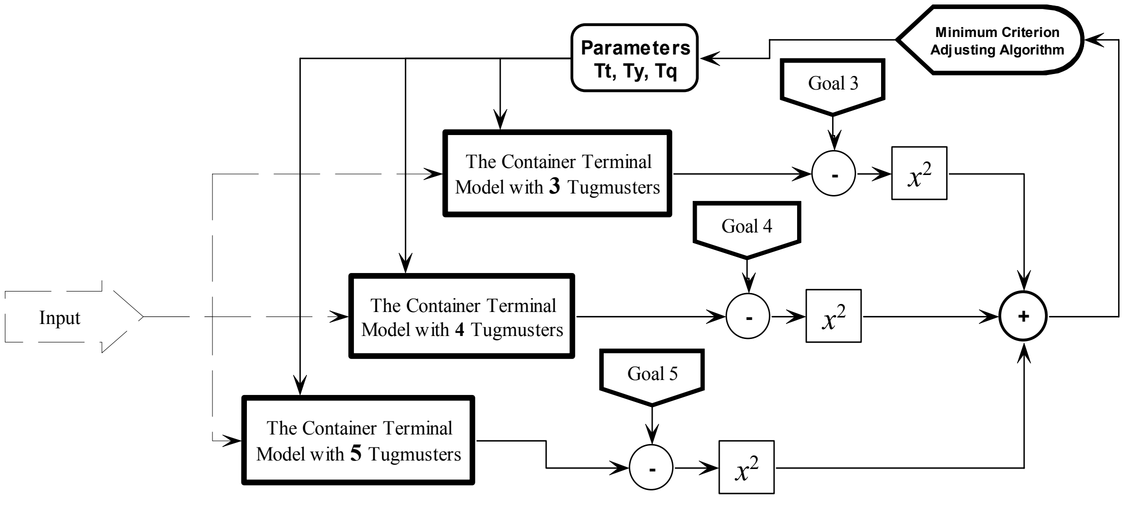


FIGURE 6. *Block-scheme of resource cycle parameter estimation (Tq, Tt, Ty)*

The elapsed truck cycle duration would then equal

Tttot = Tct&q + Tcqt + Tct + Tct&y + Tcty + Treturn

where:

Tct&q	–	truck waiting for the quay crane to pick the container off the truck.
Tcqt	–	container loading time
Tct	–	time necessary for the truck to carry the container to the yard where it is supposed to be stored
Tct&y	–	the waiting time of the yard crane for the truck carrying the container
Tcty	–	discharging container from the truck by the yard crane
Treturn	–	empty truck returning to pick another container

It should be pointed out that the period of the truck waiting for the quay crane to load the container onboard Tct&q as well as the Tct&y, the waiting time of the yard crane for the truck carrying the container, are non-stationary values as they are highly dependent on the number of the trucks. These values are not pre-determined, they are obtained during the modelling process since depend on involved resource co-ordination.

With an acceptable degree of precision it is possible to estimate and introduce the following values into the model: Tcqt, Tcty, Tct, and Treturn.

Whereas, it might be noted that Treturn =Tct *K, where K<1. Average values of Tcqt and Tcty as well as their respective statistical distributions are determined by the technological processes of loading and discharging by the quay crane and the yard crane. Therefore, the actual cycle duration at any point of time cannot be determined precisely, but can be modified manually by adjusting the Tct value.

By analogy to the to the truck cycle above, other resources' cycles are determined in a similar manner. It should be also noted that the resource cycle durations are correlated not only through the tightly distributed load/discharge micro-operations (e.g., Tcqt, Tcty) but are also affected by the highly dispersed time losses in queues. Since in practice the durations of elementary operations are not strictly determined, the time of every independent elementary operation was modeled by an individual uniformly distributed random generator whose boundaries are proposed by the BCT personnel.

Thus, in order to obtain an average productivity value as a model output, e.g. $NP(3)_{model}$, the model takes in the respective number of trucks (in this case: three) and for each set of resource cycle values Tq(model), Tt(model), Ty(model) it simulates discharge of 150 containers at a run (the average number of containers per vessel), basing on which the average productivity value is calculated. In the same manner the average $NP(n)_{model}$ productivity value is calculated for all the other input values. So, over the discrete subset of the values of four arguments **n** trucks, **Tq**(model), **Tt**(model), **Ty**(model) the value of productivity function NP(x, y, z, u) is determined. The task lies in finding the values y, z, u under which the value of the criterion will be minimal

$$\mathrm{Crit}(x, y, z, u) = \mathrm{sqrt}\left[(24 - NP(3, y, z, u))^2 + (30 - NP(4, y, z, u))^2 + (32 - NP(5, y, z, u))^2\right]$$

$$\text{where } y = \mathbf{Tq}(\text{model}),\ z = \mathbf{Tt}(\text{model}),\ u = \mathbf{Ty}(\text{model}).$$

The methodology of the above criterion yielded rather different results, which indicated either existence of local minima or a trough (a continuous set of minima) on the criterion surface, indicating flaws in operation efficiency. Rather detailed analysis of criterion surface is represented on FIGURES 7, 8, and 9.

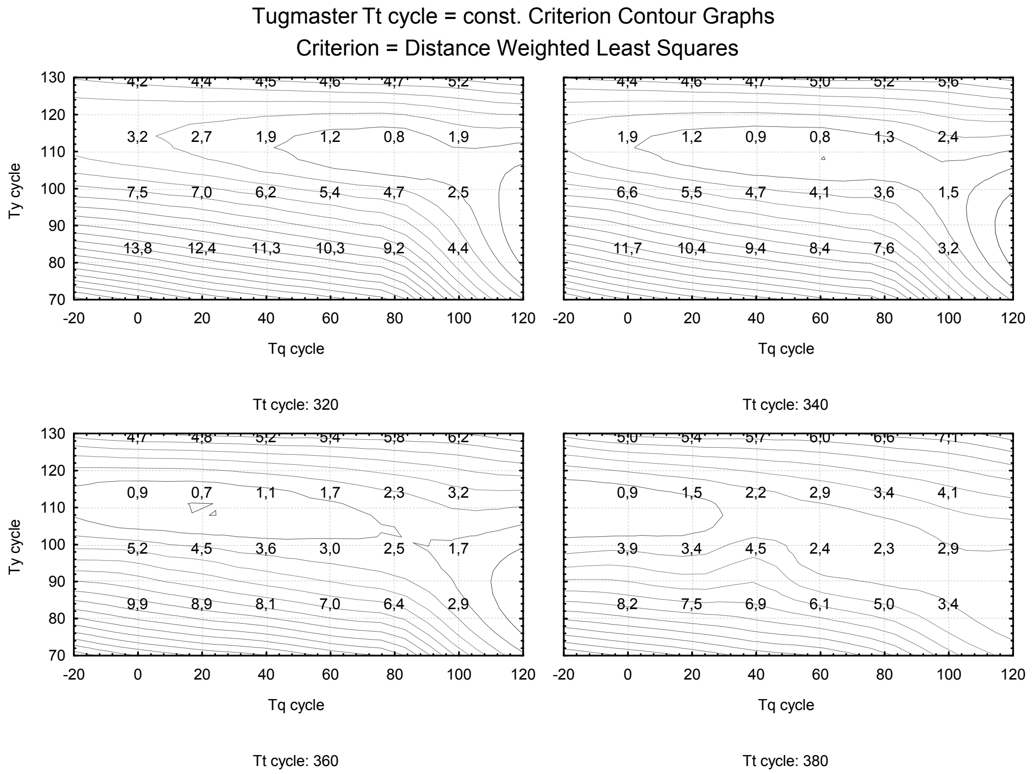


FIGURE 7. *Adequacy criterion contour graph, where Tt(model) truck cycles are equal to 320, 340, 360, and 380 secs. The criterion is represented as a function of two variables, X-scale: Tq(model), Y-scale Ty(model). As Tt(model) increases, the criterion minimum shifts outwards left from Tq(model)=80 to Tq(model)=20, with Ty(model) held constant at the level of 110 seconds*

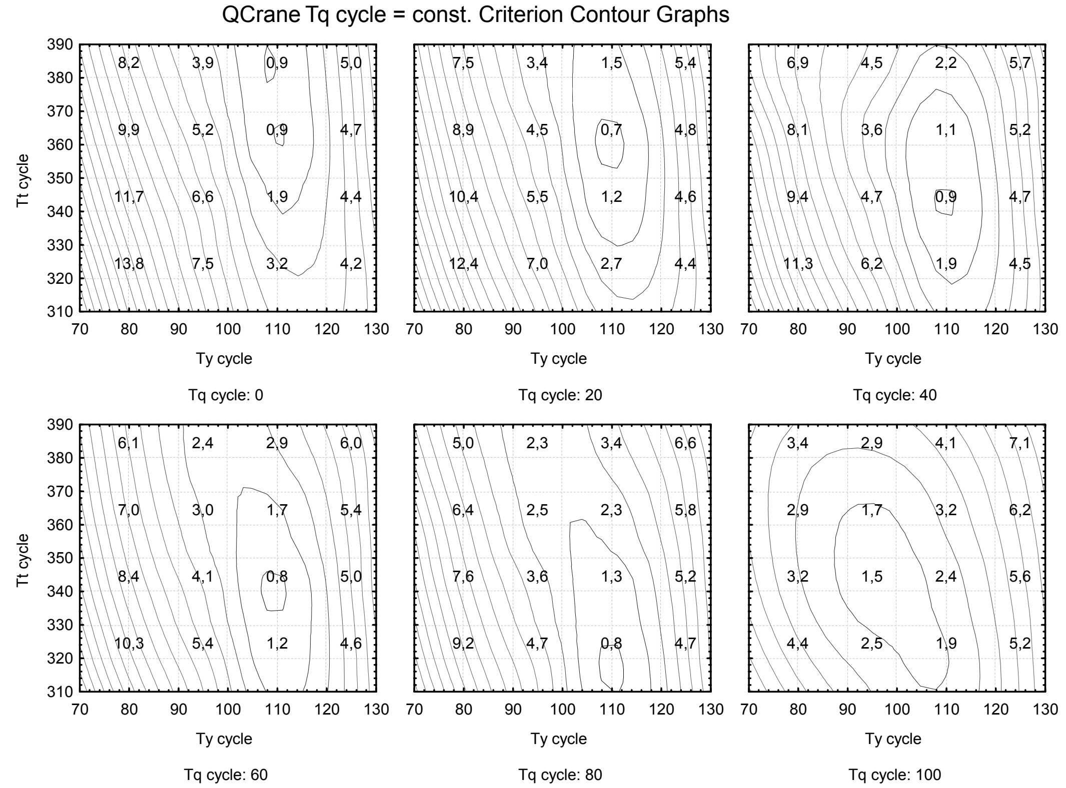


FIGURE 8. *Criterion contour graph, where Tq(model) quay crane's cycles are equal to 0, 20, 40, 60, 80, and 100 seconds. The criterion also represents a function of two variables, Ty(model) plotted on x-scale and Tt(model) on the y-scale. As Tq(model) increases, the criterion minimum shifts downards parralel to y-scale from Tt(model)=380 to Tt(model)=320, with Ty(model) held constant at the level of 110 seconds*

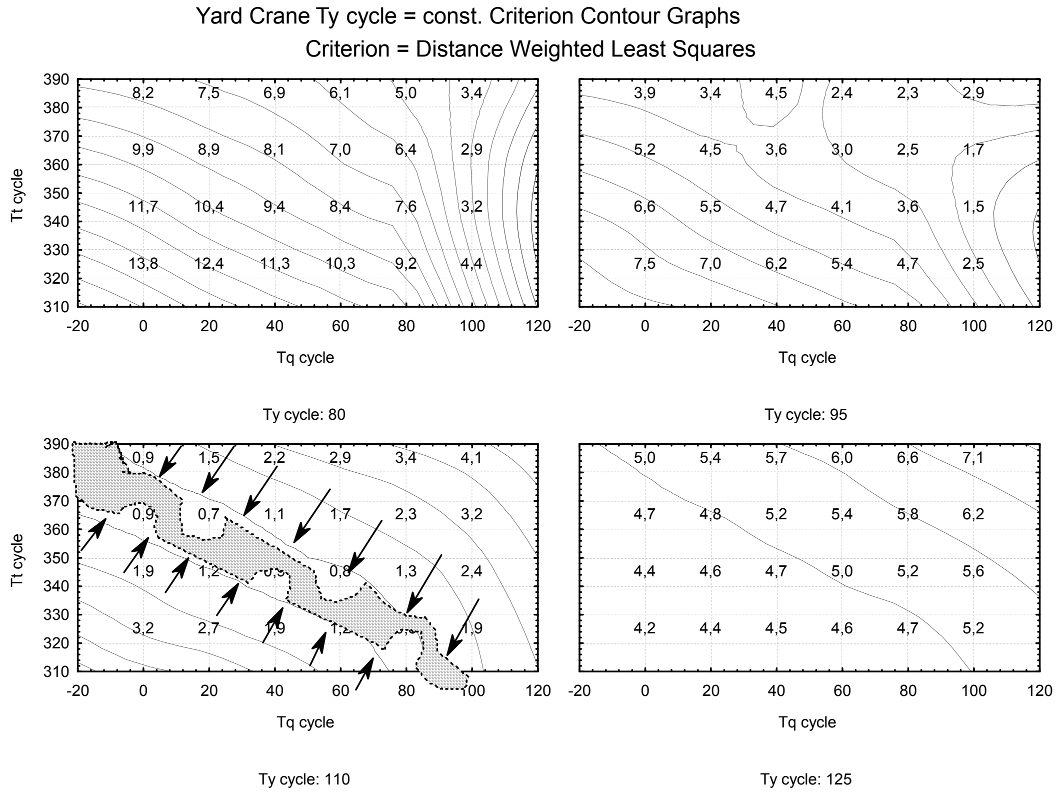


FIGURE 9. *Criterion contour graph, where Ty(model) yard crane cycles are equal to 80, 95, 110, and 125 seconds. Similarly to previous casees, the criterion is represented as a 2D function of two variables: Tq(model) plotted on x-scale and Tt(model) on y-scale. As Ty(model) increases, the criterion minimum appears at Y = Ty(model) = 110 seconds. The criterion is no local minimum but a trough and is approximated by Tt(model) = 380 – ¾ * Tq(model), Ty(model) = 110 seconds*

6. Testing Obtained Parameters for Sensitivity to Variations in Input Data

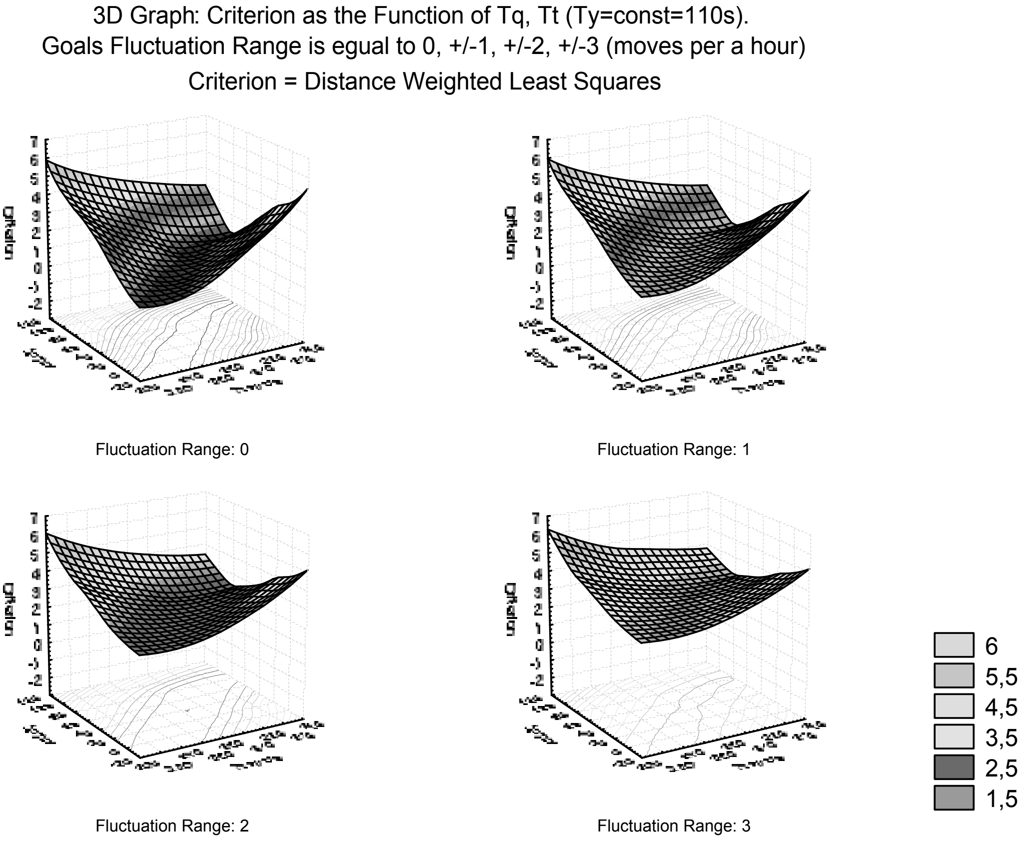
Now our task lies in analyzing the obtained values of y, z, and u bringing the criterion to its minimum and testing its sensitivity for variations in input productivity data

NP(3)real = 24 +/-1.5, NP(4)real = 30 +/-1.5, NP(5)real =32 +/-1.5.

Thus, there should be sought a dependence of the average criterion values on the randomly distributed parameters y, z, u:

AverCrit(x, y, z, u)] = Average{sqrt [(24 + delta(i) – NP(3, y, z, u))^2 + (30 + delta(i) –
– NP(4, y, z, u))^2 + (32 + delta(i) - NP(5, y, z, u))^2]}
where y = **Tq**(model), **z = Tt**(model), **u = Ty**(model),
delta(1) = random value with uniform random distribution [-1, +1]
delta(2) = random value with uniform random distribution [-2, +2]
delta(3) = random value with uniform random distribution [-3, +3]

As follows from FIGURE 10, the graphs indicate that the criterion nature remains unchanged, whereas only the criterion level is being affected. Thus, it might be concluded that the obtained values delivering the criterion minima remain stable to variations in the productivity NP(i)real.



Fluctuation Range: 0

Fluctuation Range: 1

Fluctuation Range: 2

Fluctuation Range: 3

FIGURE 10. *(x-scale: Tt(model), y-scale: Tq(model)) illustrates the criterion surface transformation with different values of* delta *[NP(3)real = 24 +/- 1, +/- 2, +/- 3, NP(4)real = 30 +/- 1, +/- 2, +/- 3, NP(5)real =32 +/- 1, +/- 2, +/- 3] at Ty held constant at 110 seconds*

7. Conclusions

There are several essential conclusions that might be drawn from the project presented.

- The indirect method of parameter estimation of logistical models with load/discharge type of processes with variable number of carriers has been illustrated and proven practical. Moreover, this method proved cost- and time-efficient with a reasonable degree of precision.
- It has been determined that there exists a set of optimal solutions (in terms of adequacy criterion minimization). It was empirically found that all the optimal parameter sets are located along the line Tt(model) = 380 – ¾ * Tq(model), Ty(model) = 110 seconds. It should be noted that direct methods normally yield a single result.
- There has been performed a sensitivity analysis of the solutions obtained which revealed reasonable model stability with regard to variations in productivity values of NP(3)real = 24 +/- 1, +/- 2, +/- 3, NP(4)real = 30 +/- 1, +/- 2, +/- 3, NP(5)real = = 32 +/- 1, +/- 2, +/- 3.
- Due to the formal logical structure of the model, it was revealed that the underlying principles and methodology can easily be transferred to general terminal and warehousing process modeling, which represents practical value for future research in this direction.

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