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The Determination of Times of Transhipment Processes at Maritime Container Terminals

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ABSTRACT: Nowadays managers and decision-makers around the world seek every opportunity to lower costs of the ship's mooring time at seaports. In this article, main operations taking place at maritime container terminals are first disaggregated in several elementary activities. Then the vessel cycle time is analysed while separately investigating the STS (Ship to Shore) crane cycle time, the RTG (Rubber-Tyred Gantry) crane work cycle time and the IMV (Internal Movement Vehicle) transfer time. A triangular distribution describes times of each of the container handling stages while the PERT (Program Evaluation and Review Technique) method is used to estimate the total time for all reloading activities. The paper demonstrates the proposed method effectiveness with data of Baltic Container Terminal (BCT) Gdynia. The use of formulas developed for the calculation of times of individual operations that affect the reloading of a container at maritime container terminals enables an in-depth assessment of the effectiveness of the reloading processes. Thus, the proposed tool gives terminal managers opportunity to track which stage of the container reloading consumes most time and generates biggest costs.

1 INTRODUCTION

Maritime container terminals are key elements of the global transport network. Due to the necessity to shorten the ship's mooring time in the port and to minimise transport and handling costs, port terminals are becoming more efficient while transhipment operations must be carried out quickly. For each ship that comes to the port for service, the terminal earns money. As one of the most important performance measures is the turnaround time of ships in the port, it is necessary to keep this time to a minimum [11].

Unlike other research that propose an optimisation methodology for solving container handling problems using different algorithms [5, 10, 13], this article develops new formulas enabling the calculation of times of individual operations that affect the reloading of a container. Although some authors use the network planning to investigate chosen aspects of everyday port operations [4, 6], there are several contributions of this paper. First, for the better understanding of the processes taking place at maritime container terminals, main reloading operations are disaggregated in several elementary activities. The vessel cycle time is analysed while separately investigating the STS (Ship to Shore) crane cycle time, the RTG (Rubber-Tyred gantry) cycle time, as well as the IMV (Internal Movement Vehicle) transfer time. Then, we propose mathematical formulas for times of each operation influencing both the unloading and then the loading of a container at the maritime container terminal. Thus, it is possible to analyse in detail individual reloading operations and indicate those that can be further improved. Finally, this work assumes that the elements of the PERT

(Program Evaluation and Review Technique) method can be used to estimate the total time for all reloading activities. Therefore, a triangular distribution with parameters (t_o, t_d, t_p) is used when each of the considered stages would most likely take td seconds, but not more than t_p, nor less than t_p seconds. The method we propose is relatively simple, but it gives satisfactory results that can successfully support decision-making. It is also universal. Without significant modifications, it can be used to optimise the operation of different container terminals, with a different layout of quays, storage yard, etc. Moreover, in future research, it can be extended with PERT-LESS cost-time model, thus allowing the determination of the possibilities of potential time reduction for each stage.

2 RESEARCH DESCRIPTION

2.1 *Assumptions*

Table 1 presents basic technical data of reloading devices operating at the BCT Gdynia which were later used to calculate the duration of reloading operations.

Table 1. Technical data of the equipment operating at the maritime container terminal (Authors).

Equipment	Parameters	Technical data
STS	Winch trolley travel length	100 m
	Lifting height from the wharf to the bottom of the winch spreader	~ 35 m
	Crane span	30 m
IMV	Length	18.5 m
	Width	3.0 m
	Height	1.5 m
	Maximum capacity	60 t
	Maximum speed	7 m/s
RTG	Crane travel length	135 m
	Lifting height from the ground to the bottom of the spreader	15 m
	Crane span	20 m

We also assumed that containers were reloaded at the BCT Gdynia at 32 sectors where RTGs were placing 20-ft containers parallel to the quay in 7x22x/1–5/ (width x length x height) blocks. We than assumed that at the described terminal, 2,402 40-ft containers were reloaded, arranged on the ship as follows: 24 containers along, 17 containers across and up to 6 containers above. Four gangs were assigned for the task, consisting of one STS crane, three RTGs, five IMVs and employees necessary for the implementation of operations at the quay and in the storage yard.

2.2 *Notations and parameters*

The following notations and parameters are used throughout the paper to model the container reloading at the maritime terminal.

2.2.1 *Times*

t_{H}^{L} *or* t_{h}^{l} adopted time needed for the load hooking (3 s).
t_{Li}^{L} *or* t_{li}^{l} time needed for the load lifting.
t_{Lo}^{T} time needed for the winch trolley driving and the load lowering
t_{Lo}^{L} time needed for the load lowering.
t_{U}^{L} adopted time needed for the load unhooking (10 s).

t_{Li}^{T} time needed for the spreader lifting and the winch trolley driving.
t_{d}^{c} time needed for the crane bridge driving.
t_{d}^{T} or t_{d}^{t} time needed for the winch trolley driving.
t_{u}^{l} time needed for the load lowering and unhooking.
t_{lo}^{l} time needed for the load lowering.
t_{Li}^{S} or t_{li}^{s} time needed for the spreader lifting.
t_{d}^{ct} time needed for the crane bridge and the winch trolley driving.
t_{Lo}^{S} or t_{lo}^{s} time needed for the spreader lowering.

2.2.2 *Heights*

H_{Li} container lifting height to the bottom of the STS crane traverse.
H_{s} known height of the ship above the waterline (12.5 m).
h_{c} known container height (2.393 m).
h_{sf} adopted safety margin for manoeuvring over the last layer of containers (3 m).
h_{Li}^{L} or h_{li}^{l} height of the load lifting.
h_{IMV} known height of the IMV's trailer (1.5 m).
h_{Lo}^{L} or h_{lo}^{l} height of the load lowering.
h_{lo}^{s} height of the spreader lowering.

2.2.3 *Distances*

s_{d}^{T} or s_{d}^{t} travel distance of the loaded winch trolley.
s_{d}^{c} travel distance of the crane bridge.

2.2.4 *Phases*

f_1 accelerated motion.
f_2 constant speed.
f_3 reduced speed.

2.2.5 *Accelerations*

a_{Li}^{L} or a_{li}^{l} known acceleration for the loaded winch (0.75 m/s^2 or 0.15 m/s^2).
a_{d}^{c} known acceleration for the crane bridge (0.2 m/s^2).
a_{Lo}^{L} or a_{lo}^{l} known acceleration for the load lowering (0.75 m/s^2 or 0.15 m/s^2).
a_{d}^{T} or a_{d}^{t} known acceleration for the winch trolley (1 m/s^2 or 0.4 m/s^2).
a_{Li}^{S} or a_{Lo}^{S} or a_{li}^{s} or a_{lo}^{s} known acceleration for the unloaded winch (0.75 m/s^2 or 0.15 m/s^2).

2.2.6 *Speeds*

v_{LiL} or v_{lil} known accelerated speed of the load lifting (1 m/s or 0.47 m/s).
v_{LoL} or v_{lol} known constant speed of the load lowering (1 m/s or 0.47 m/s).
v_{HLoL} or v_{Hlol} adopted reduced speed of the load lowering (0.25 m/s or 0.08 m/s).
v_{dc} known accelerated speed of the crane bridge (2.17 m/s).
v_{Hdc} adopted reduced travel speed of the crane bridge (1.08 m/s).

v_{dT} or v_{dt} known accelerated travel speed of the winch trolley (3.5 m/s or 1.17 m/s).
v_{Hdt} known reduced speed of the winch trolley (0.58 m/s).
v_{pLi} or v_{lis} known accelerated speed of the empty spreader lifting (2.5 m/s or 0.93 m/s).
v_{los} known speed of the empty spreader lowering (0.93 m/s).
v_{HLoS} or v_{Hlos} adopted reduced speed of the empty spreader lowering (0.25 m/s or 0.17 m/s).

2.2.7 *Other*

b_c known container width (2.352 m).
l_c known container length (5.898 m or 12.032 m).
k number of containers in layers/rows on the ship/yard.
L adopted distance to the first container in the row (15 m).
k_{Sn} number of yard sectors passed along the quay.
l_S adopted length of the yard sector (150 m).
s_n adopted straight-line distance from the quay to the yard (20 m).
k_{Rp} number of rows passed in the storage yard.
b_R adopted width of the yard row (18 m).
k_{Sp} number of sectors passed in the storage yard.

2.3 *Calculations*

The following paragraphs contain formulas used to calculate times of the container unloading from the ship on the IMV (1, 3–22), of transporting it from the quay to the storage yard (34–35) and of unloading it from the IMV by the RTG (2, 23–33). The formulas were written out in detail for the first stages of the STS work cycle only. All calculations are based on own knowledge and observations made during study visits to the BCT Gdynia as well as the literature of the subject [3, 7–9, 12].

The specificity of the work of the STS winch trolley [2] allows us to assume that the times of the container unloading (T1) and loading (T6) at the quay can be calculated in a similar way, as the sum of the following components (1):

$$T_1 = T_6 = t_H^L + t_{Li}^L + t_{Lo}^T + t_U^L + t_{Li}^T + t_{Lo}^S \tag{1}$$

The total times of the container unloading (T3) and loading (T4) in the yard may be determined similarly (2):

$$T_3 = T_4 = t_h^l + t_{li}^l + t_d^c + t_d^t + t_u^l + t_{li}^s + t_d^{ct} + t_{lo}^s \tag{2}$$

2.3.1 *STS crane work cycle*

As shown in paragraph 3.2, times needed for the load hooking (process A in Table 2) and unhooking (process D) were adopted. The latter one is longer and lasts 10 seconds because we also considered the time needed for the container to be put on the terminal vehicle waiting at the quay.

As regards other times of the STS crane work cycle, first we must consider container lifting height to the bottom of the STS crane traverse. It can be calculated as the sum of known height of the ship above the waterline, the height of the containers' layers on the deck, as well as adopted 3 metres safety margin for manoeuvring over the last layer of containers:

$$H_{Li} = H_s + k \cdot h_c + h_{sf} \tag{3}$$

We assume that all containers are un/loaded from/to the ship's deck, so the container is always lifted, and the empty spreader is always lowered at 3 metres. Then, we may determine the time of the load lifting (process B):

$$t_{Li}^L = t\left(f1\right)_{Li}^L + t\left(f2\right)_{Li}^L \tag{4}$$

In the first phase (f_1) the container is lifted to the height $h\left(f_1\right)_{Li}^L$, and in the second phase (f_2) – to the height $h\left(f_2\right)_{Li}^L$. The sum of these two heights must equal the adopted safety margin for manoeuvring over the last layer of containers:

$$h_{Li}^L = h_{sf} = h\left(f_1\right)_{Li}^L + h\left(f_2\right)_{Li}^L \tag{5}$$

The height of the load lifting in the accelerated motion may be determined if we know the acceleration for the loaded winch, or the winch maximum speed for the load lifting:

$$h\left(f_1\right)_{Li}^L = \frac{a_{Li}^L \cdot t\left(f_1\right)_{Li}^{L\,2}}{2} \tag{6}$$

$$a_{Li}^L = \frac{v_{LiL}}{t\left(f_1\right)_{Li}^L} \tag{7}$$

Then, we may calculate the height of the load lifting at constant speed, and later also the time needed for the load lifting in the second phase:

$$h\left(f_2\right)_{Li}^L = h_{Li}^L - h\left(f_1\right)_{Li}^L \tag{8}$$

$$t\left(f_2\right)_{Li}^L = \frac{h\left(f_2\right)_{Li}^L}{v_{LiL}} \tag{9}$$

Total time needed for the winch trolley travel and the load lowering (process C), in turn, consists of two partial times: the winch trolley travel time (t_d^T) and the time needed for the load lowering (without the winch trolley driving) (t_{Lo}^L). Therefore, we have performed our calculations in two steps. First, we calculated the winch trolley travel time:

$$t_d^T = t\left(f_1\right)_d^T + t\left(f_2\right)_d^T + t\left(f_3\right)_d^T \tag{10}$$

In the first phase (f_1), the winch trolley travels the distance $s\left(f_1\right)_d^T$, in the second phase (f_2) – the distance $s\left(f_2\right)_d^T$, and in the third phase (f_3) the same distance as in the first phase $s\left(f_3\right)_d^T = s\left(f_1\right)_d^T$. Once again, in our calculations we may use the known acceleration for the winch trolley and the known maximum travel speed of the winch trolley:

$$s\left(f_1\right)_d^T = \frac{a_d^T \cdot t\left(f_1\right)_d^{T2}}{2} \quad (11)$$

$$t\left(f_1\right)_d^T = t\left(f_3\right)_d^T = \frac{v_{dT}}{a_d^T} \quad (12)$$

Then, we may calculate the distance the winch trolley has to travel at a constant speed:

$$s\left(f_2\right)_d^T = s_d^T - s\left(f_1\right)_d^T - s\left(f_3\right)_d^T \quad (13)$$

In the above formula, we assumed that total travel distance of the loaded winch trolley may be determined as the sum of the adopted 15 metres distance to the first container in the row and the overall width of the containers' layer:

$$s_d^T = L + k \cdot b_c \quad (14)$$

Considering all the above, the time needed for the winch trolley to travel at a constant speed may be calculated as follows:

$$t\left(f_2\right)_d^T = \frac{s\left(f_2\right)_d^T}{v_{dT}} \quad (15)$$

The load lowering begins after the winch trolley has finished traveling. Total time needed for the load lowering consists of three partial times. We must remember that in the below formula times of the load lowering in phases 1 and 3 are equal ($t\left(f_1\right)_{Lo}^L = t\left(f_3\right)_{Li}^L$):

$$t_{Lo}^L = t\left(f_1\right)_{Lo}^L + t\left(f_2\right)_{Lo}^L + t\left(f_3\right)_{Lo}^L \quad (16)$$

The load is being lowered until it is placed on the IMV waiting at the quay. The crane spreader height from the ground may be calculated as the sum of known heights of both the IMV's trailer and the container:

$$h_g^L = h_{IMV} + h_c \quad (17)$$

The adopted height of the load lowering is the difference between the container lifting height to the bottom of the STS crane traverse and of the IMV's trailer ($h_{Lo}^L = H_{Li} - h_{IMV}$), but at the same time we may determine it as below:

$$h_{Lo}^L = h\left(f_1\right)_{Lo}^L + h\left(f_2\right)_{Lo}^L + h\left(f_3\right)_{Lo}^L \quad (18)$$

We assumed that $h\left(f_3\right)_{Lo}^L = 3\,m$, and in next steps we used formula 6 to calculate $h\left(f_1\right)_{Lo}^L$ and formula 9 to calculate $t\left(f_2\right)_{Lo}^L$, as well as $t\left(f_3\right)_{Lo}^L$. Then, we may use the below formula to calculate the height of the load lowering at a constant speed:

$$h\left(f_2\right)_{Lo}^L = H_{Li} - h_{IMV} - h\left(f_1\right)_{Lo}^L - h\left(f_3\right)_{Lo}^L \quad (19)$$

When determining the time needed for the spreader lifting and the winch trolley driving (process E) we first determined the time needed for the spreader lifting (t_{Li}^S), and then – for the winch trolley travel time (t_{dLi}^T). The time needed for the empty spreader lifting was calculated based on the following formula:

$$t_{Li}^S = t\left(f_1\right)_{Li}^S + t\left(f_2\right)_{Li}^S \quad (20)$$

In the first phase (f_1), the empty spreader is lifted to the height $h\left(f_1\right)_{Li}^S$, and in the second phase (f_2) – to the height $h\left(f_2\right)_{Li}^S$. Once again formulas 6 and 12 may be used in subsequent calculations together with the below formula:

$$h\left(f_2\right)_{Li}^S = H_{Li} - h_{IMV} - h\left(f_1\right)_{Li}^S \quad (21)$$

The travel time of the winch trolley with an empty spreader (t_{dS}^T), in turn, may be calculated similarly to the travel time of the loaded winch trolley (10–15). Yet, in this case the winch trolley should take the container from the next row or tier on the ship.

Finally, the STS work cycle ends with the lowering of the empty spreader from the adopted 3 metres safety height on the container (process F). This again takes place in two phases, in accelerated motion $t\left(f_1\right)_{Lo}^S$ and at a reduced speed $t\left(f_2\right)_{Lo}^S$. Both times may be determined according to the formulas 6, 9, 12, and the formula presented below:

$$h\left(f_2\right)_{Lo}^S = h_{sf} - h\left(f_1\right)_{Lo}^S \quad (22)$$

2.3.2 *RTG work cycle*

We determined reloading times in the storage yard in a similar way as at the quay. The adopted time needed for the load hooking (process A in Table 2) in this case equals 3 seconds, while the time needed for the load lifting (process B) is the sum of two components:

$$t_{li}^l = t\left(f1\right)_{li}^l + t\left(f2\right)_{li}^l \quad (23)$$

In the first phase, the container is lifted to the height $h\left(f1\right)_{li}^l$, and in the second phase – to the height $h\left(f2\right)_{li}^l$, while the spreader is always lifted to the total height of 15 metres. In this case we used formulas 5–9, as well as the formula considering the height of the IMV' trailer and of the container:

$$h\left(f2\right)_{li}^l = h_{li}^l - h_{IMV} - h_c - h\left(f1\right)_{li}^l \quad (24)$$

Total travel time of the crane bridge (process C), in turn, consists of three partial times:

$$t_d^c = t\left(f1\right)_d^c + t\left(f2\right)_d^c + t\left(f3\right)_d^c \quad (25)$$

During this time, RTG travels total distance which depends on the place where the container is to be put on the storage yard:

$$s_d^c = k \cdot l_c \tag{26}$$

This distance consists of three distances which can be determined based on the formulas 11, 13 and 15 and the assumption that $s(f3)_d^c = 2\,m$:

$$s_d^c = s(f1)_d^c + s(f2)_d^c + s(f3)_d^c \tag{27}$$

Total travel time of the winch trolley (process D) is also the sum of three components:

$$t_d^t = t(f1)_d^t + t(f2)_d^t + t(f3)_d^t \tag{28}$$

In the first phase, the winch trolley travels the distance $s(f1)_d^t$, in the second phase – the distance $s(f2)_d^t$, and in the third phase – the adopted 1 metre distance $s(f3)_d^t$. Once again, to determine total travel distance of the loaded winch trolley we used the formulas 11, 13 and 15 together with the below assumption:

$$s_d^t = k \cdot b_c \tag{29}$$

The time needed for the load lowering and unhooking (process E) consists of the time needed for the load lowering (t_{lo}^l) and the time needed for the load unhooking (t_u^{l}). We assumed that the latter one lasts 5 seconds. The lowering of the load begins when the winch trolley travel ends. Thus, total time of the load lowering consists of the following times:

$$t_{lo}^l = t(f1)_{lo}^l + t(f2)_{lo}^l + t(f3)_{lo}^l \tag{30}$$

In this case, the height of the load lowering is the difference between the height of load lifting and the product of the container height and the number of containers plus one in layers/rows in the yard ($h_{lo}^l = h_{li}^l - (k+1) \cdot h_c$). Yet, this height may be also calculated with the use of formulas 6, 9, 12, as well as the below formula which assumes that $h(f3)_{lo}^l = 1\,m$:

$$h_{lo}^l = h(f1)_{lo}^l + h(f2)_{lo}^l + h(f3)_{lo}^l \tag{31}$$

The time needed for the empty spreader lifting (process F) at the height equal to the height of the load lowering may be calculated as below:

$$t_{li}^s = t(f1)_{li}^s + t(f2)_{li}^s \tag{32}$$

In turn, to determine the travel time of the crane bridge and the winch trolley (process G), we assumed that except for the case when the crane bridge does not move, the travel time of the crane bridge is longer than the travel time of the winch trolley. Thus, total operation time is influenced by total travel time of the crane bridge. When the crane bridge does not move (the travel time of the crane bridge equals zero), only the travel time of the winch trolley affects total operation time. As the travel speed of the crane bridge and the winch trolley is independent of the load, at this stage the formulas used previously to determine the travel time of the crane bridge (25) and the travel time of the winch trolley with the load (28) may be also used.

The RTG crane work cycle ends with lowering the empty spreader from the adopted height of 15 metres onto the container. It takes place in three phases, in accelerated motion $t(f1)_{lo}^s$, at a constant speed $t(f2)_{lo}^s$, and at a reduced speed $t(f3)_{lo}^s$. To determine these times, we may use formulas presented in this paragraph, as well as the below formula which assumes that $h(f3)_{lo}^s = 1\,m$:

$$h(f2)_{lo}^s = h_{li}^l - h_c - h_{IMV} - h(f1)_{lo}^s - h(f3)_{lo}^s \tag{33}$$

2.3.3 *IMV driving time*

Finally, taking into account the way the terminal vehicles travel along the storage yard and the quay, adopted after Bartosiewicz [1], we calculated the driving time of the IMV. We assumed that this time is a product of the distance travelled by the IMV and known speed of the IMV ($v_{dIMV} = 7\,m/s$):

$$t_{dIMV} = s_{dIMV} \cdot v_{dIMV} \tag{34}$$

We assumed that the distance travelled by the terminal vehicle is a sum of such components as number of yard sectors passed along the quay multiplied by adopted 150 metres length of the yard sector, adopted 20 metres long straight-line distance from the quay to the storage yard, number of rows passed in the storage yard multiplied by adopted 18 metres width of the yard row, as well as number of sectors passed in the storage yard multiplied by adopted length of the yard sector:

$$s_{dIMV} = k_{Sn} \cdot l_S + s_n + k_{Rp} \cdot b_R + k_{Sp} \cdot l_S \tag{35}$$

2.4 *Results*

The paper demonstrates the proposed method effectiveness with data of BCT Gdynia container terminal. Based on our previous assumptions, the formulas presented earlier and the information in Table 1, in the next step we determined times for individual operations, including unloading and then loading of one container at the terminal in question. In this case, we used a triangular distribution with parameters (t_o, t_d, t_p).

Table 2. The shortest (t_o), the most probable (t_d) and the longest (t_p) times (in seconds) for each operation comprising the unloading and loading of one container at the terminal (Authors).

Equipment	Operation	t_o	t_d	t_p
Unloading				
STS	A. Load hooking	3	3	3
	B. Load lifting[a]	4	4	4
	C. Winch trolley driving and load lowering	34	48	60
	D. Load unhooking	10	10	10
	E. Spreader lifting and winch trolley driving	16	25	33
	F. Spreader lowering[a]	12	12	12
IMV	Transfer to the storage yard	37	74	131
RTG	A. Load hooking	3	3	3
	B. Load lifting[b]	26	26	26
	C. Crane bridge driving	0	36	66
	D. Winch trolley driving	5	14	20
	E. Load lowering and unhooking	28	38	49
	F. Spreader lifting	7	12	17
	G. Crane bridge and winch trolley driving	5	36	66
	H. Spreader lowering[b]	20	20	20
Loading				
STS	A. Load hooking	3	3	3
	B. Load lifting[a]	17	25	32
	C. Winch trolley driving and load lowering	15	20	25
	D. Load unhooking	5	5	5
	E. Spreader lifting and winch trolley driving	12	18	23
	F. Spreader lowering[a]	12	15	18
IMV	Transfer to the storage yard	37	74	131
RTG	A. Load hooking	3	3	3
	B. Load lifting[b]	8	19	29
	C. Crane bridge driving	0	36	66
	D. Winch trolley driving	5	14	20
	E. Load lowering and unhooking	46	46	46
	F. Spreader lifting	15	15	15
	G. Crane bridge and winch trolley Driving	5	36	66
	H. Spreader lowering[b]	12	17	22

a - all containers are unloaded from the ship's deck, so the container is always lifted, and the empty spreader is always lowered at 3 m; b - the RTG lifts each container at 15 m, the empty spreader is lowered from this height.

Then, using the PERT method, we estimated the duration of individual reloading activities at the described terminal (Table 3).

Table 3. Times (in seconds) of individual reloading operations for one container handled at the analysed terminal (Authors).

Equipment	Operation	Unloading	Loading
STS	Reloading a container from the ship to the IMV and vice versa	101.5±5.18	85.7±3.66
IMV	Transfer to and from the storage yard	77.3±12.60	77.3±12.60
RTG	Reloading a container from the IMV to the storage yard and vice versa	183.5±15.67	184.2±15.67

The average working time of the STS unloading a container from a ship is approx. 102 seconds, and of the STS loading a container, approx. 86 seconds. The transport of a container by the IMV through the terminal to or from the storage yard takes less than 78 seconds, while the transfer of a container by the RTG takes an average of 184 seconds. Finally, to check for the robustness of our results, we used the cumulative distribution function of the standard Normal distribution and performed the sensitivity analysis. First, we indicated the directive term with 30 and 60 percent probability (Table 4). Then, we depicted distributions for four described stages where the dashed lines correspond to the deadlines for completion in the schedules of both 30 percent and 60 percent probability scenarios (Figure 1).

Table 4. Times (in seconds) of individual reloading operations for one container handled at the analysed terminal (Authors).

Stage	Schedule	
	30 percent probability	60 percent probability
STS unloading	98.78	102.81
RTG unloading	175.28	187.47
STS loading	84.1	86.48
RTG loading	175.98	188.17

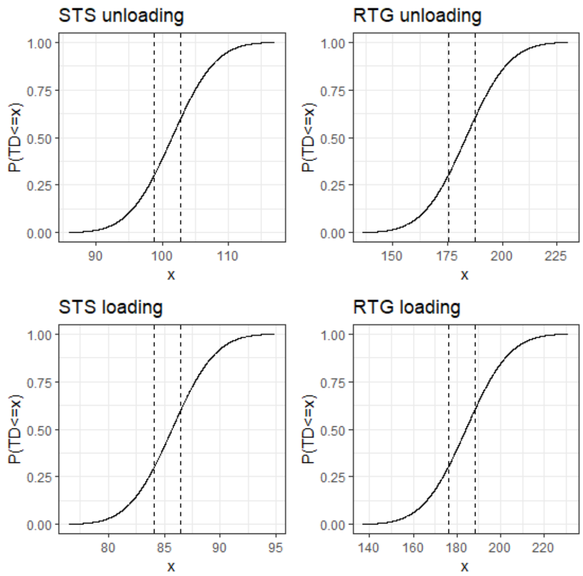

Figure 1. Cumulative standard Normal distribution for each of the PERT models (Authors).

For the STS unloading, the directive term of the container unloading may vary from 98.78 to 102.81 seconds. Shortening this time below the left end of the range carries too high a risk of failure. On the other hand, extending the time limit above the right limit would unnecessarily extend this stage and inevitably increase costs related to, inter alia, a longer stay of the ship at the quay.

The expected values of directive terms are given on the horizontal axis, and the cumulative probabilities are on the vertical axis. In this way, we may determine the chance of the implementation of a given process for various scenarios, from those with almost zero to those with almost 100 percent probability.

3 CONCLUSIONS

In this article we propose formulas to analyse in detail individual reloading operations and indicate those that can be further improved. In particular, the proposed approach allows to determine in which cycle (STS crane work cycle, RTG work cycle, IMV transfer cycle) there are the most delays, the elimination of which may lead to a reduction in the transhipment time, and thus the ship's berthing time in the port. This is particularly useful for decision-makers and terminal operators who are interested, inter alia, in identification of bottlenecks during the container handling, as well as in optimisation of processes taking place in seaports.

Our results show that most time-consuming activities during the unloading include transfer to and from the storage yard (IMV transfer time), driving the trolley and lowering the load (STS cycle), or driving the gantry and the winch trolley (RTG cycle). It also appears that during the loading of one container at the terminal, managers should pay special attention to such aspects as the IMV transfer time, or the time that the STS and the RTG need to lift, lower, and unhook the load. At the same time, the sensitivity analysis we performed proves the accuracy of estimations of the duration of activities that constitute each of the stages.

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