



SIMULATION OF STEVEDORING WORK IN THE KLAIPEDA OIL TERMINAL

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Abstract. The paper presents the approach of developing simulation models of stevedoring work in oil terminal using aggregate approach and simulation system ARENA. Aggregate approach permits to develop formal specification of simulated systems. Aggregate specification of the system is presented as a set of interacting piece-linear aggregates. Controlling sequences are used for formal description of each piece-linear aggregate. Transformation of aggregate formal specification to ARENA system operators permits to develop a simulation model. The developed model permits to evaluate characteristics of the Klaipeda oil terminal which are used both in queuing theory and analysing timing properties of real-time systems.

Keywords: oil terminal, piece-linear aggregates formalism, simulation system ARENA.

1. Introduction

The Klaipeda harbour is one of the biggest harbours in the Baltic States (Estonia, Latvia and Lithuania). Reconstruction of the harbour requires a lot of investments and it is important that it would be efficiently used. This problem can be solved applying corresponding models [1, 2, 3]. Models permitting to evaluate metal and container transportation through the Klaipeda harbour are presented in [4]. Presented in this paper created models permit to evaluate the interaction of various kinds of transport means (sea, railway, motor transport) during the transportation of loads; occupation of harbour embankments, loading/unloading mechanisms, van loading/unloading grounds.

This paper presents a simulation model of the Klaipeda harbour oil terminal. The model permits to evaluate two groups of characteristics. The first group of characteristics is used in queuing theory. Examples of such characteristics are occupation coefficients of embankments, platforms and reservoirs etc. The other group of characteristics is used analysing real-time systems [5]:

- Probabilities that arrived ship finds the needed volume of oil;
- Probability of ship staying time in a harbour is less than some their values, etc.

Creating the Klaipeda harbour oil terminal an aggregate approach [6] was used for the formalisation of terminal operation. The software implementation of a simulation model was done using ARENA simulation system.

The paper is structured as follows: the section *Aggregate model of the Klaipeda oil terminal* contains ag-

gregate specification characteristics of an aggregate model; model formal specification is presented in the second section and the investigation results are given too.

2. Aggregate Model of the Klaipeda Oil Terminal

Aggregate approach is widely used for formal description, simulation and validation of complex systems [7]. The general idea of the method is a system decomposed to separate piece-linear aggregates (PLA) and each PLA of the system is described using the method of controlling sequences. The advantage of this approach is its ability to describe the analysed system mathematically strictly.

2.1. Conceptual Model of Terminal

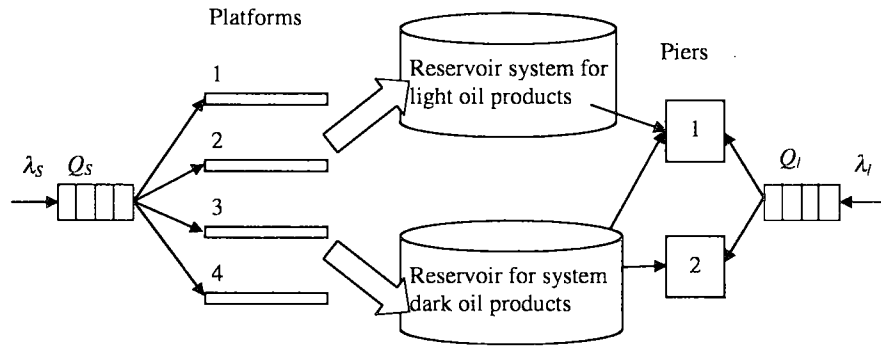
The structural scheme of the Klaipeda oil terminal is presented in Fig 1.

The created model represents the transportation of oil products through the Klaipeda harbour in the following ways:

- Oil products are divided into two groups: light and dark, without subsequent details;
- Total amount of reservoir capacities at the Klaipeda oil terminal for dark products is 250,000 m³, and for light products it is 100,000 m³;
- There are four pouring platforms at the terminal: two of them are assigned for dark products, one for light products and one for both light and dark products;
- Maximum 32 tank cars in each platform can be served at the same time;
- There are two embankments at the oil terminal. In the first embankment both kinds of oil products can be

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Use of platforms: 1, 2 – light oil products; 3, 4 – dark oil products

Fig 1. Structural scheme of queuing system which represents transportation of oil products through the Klaipeda harbour

poured and in the second only dark oil products can be poured;

- Trains arriving at the Klaipeda terminal are turned to two queues, one for dark oil products and one for light oil products;

Parameters of the model and simulated characteristics:

- Intensity of orders flow for dark and light oil transportation is λ_D and λ_L respectively (number of orders per 24 hours);
- Capacity of one train is v_s (tonne);
- Light oil products make p -th part of total flow of trains ($p = 0.3$);
- Train of 32 tank cars with oil is served for: a) dark oil products poured out from the train in 8 hours; b) light oil products poured out from the train in 4 hours;
- Equipment pumps 1 kilotons of oil products to a ship in an hour.

Intensities of trains and tankers arriving to oil terminal, depending on volume of exported oil, are presented in Table.

The following characteristics can be simulated:

- average level of oil in reservoirs,
- occupation coefficients of each platform,
- average length of queues with light and dark oil products (amount of tank cars),

Intensities of trains and tankers arriving to oil terminal depending on volume of exported oil.

Amount of transported oil (Megatons)	λ_D	λ_L
3.5	4.09	3.82
4.0	3.58	3.34
5.0	2.86	2.67
6.0	2.38	2.23
7.0	2.04	1.91
8.0	1.79	1.67

- average time of storing of oil products at terminal (days),
- annual amount of transported tons.

2.2. Aggregate Specification of the Klaipeda Oil Terminal

Aggregate scheme of specification is presented in Fig 2. Specifications of aggregate trains flow, tankers flow and embankments are presented below.

Aggregate Trains flow

1. Set of input signals. $X = \{x_1\}$, where $x_1 = (O_N, O_S)$, x_1 – the order for oil transportation; O_N – the number of order, O_S – the amount of ordered oil.
2. Set of output signals. $Y = \{y_1\}$, where $y_1 = (O_N, O_S, N_T)$, y_1 – the train has arrived to terminal, N_T – number of tank-wagon in a train.
3. Set of external events $E' = \{e'_1\}$, where $e'_1 - 1$. the start of order process.
4. Set of internal events. $E'' = \{e''_1, e''_2, e''_3 \dots\}$, where e''_i – the arrival of i -th train to terminal.
5. Controlling sequences. $e''_i \mapsto \tau_i \in [a, b]$, where τ_i – is uniformly distributed value in interval $[a, b]$. Its semantics is the time interval during which trains for i -th order will arrive.
6. Discrete part of state. $v(t) = (n(t), O_1(t), O_2(t) \dots)$, where $O_i(t) = (O_N(t), O_S(t), N_T(t))$, where $n(t)$ – the number of trains with oil has departed.
7. Continuous part of state. $z_v(t) = (w(e''_1, t), w(e''_2, t) \dots)$.
8. Initial state. $w(e''_i, t_0) = \infty$, $n(t_0) = 0$. 1. Time of trains arrival to the terminal is unknown and there are no trains going to the terminal.
9. Transition and output operators. $H(e'_1)$:

$$n(t_m) = n(t_{m-1}) + O_S / V_T$$
,
 where V_T – the capacity of tank-wagon;

$$O_i(t_m) = (O_N, O_S, C_T)$$
;

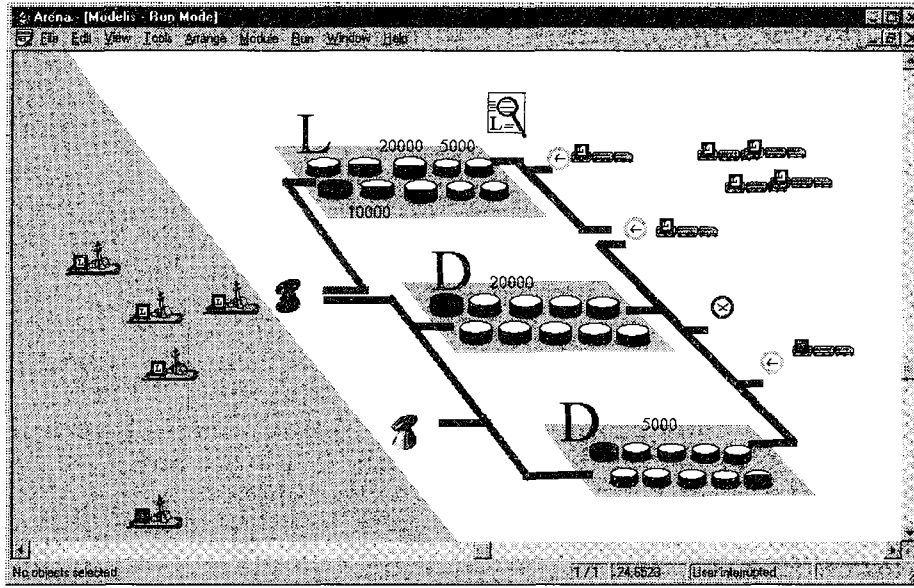


Fig 3. Graphical representation of the model

and $\chi_1(t_{m-1})=0$ then $w(e_1^*, t_m) = t_m + O_s / P_E$,
 where P_E – pouring rate;

$$\chi_1(t_m) = 1;$$

$$O_1(t_m) = x_1.$$

if $x_1 \in S_D(t_{m-1})$ and $\chi_1(t_{m-1}) \neq 0$ and

$$\chi_2(t_{m-1}) = 0$$
 then

$$w(e_2^*, t_m) = t_m + O_s / P_E;$$

$$\chi_2(t_m) = 1;$$

$$O_2(t_m) = x_1.$$

if $x_1 \notin S_D(t_{m-1})$ then

$$A_D(t_m) = A_D(t_{m-1}) \cup \{x_1\}.$$

$G(e_1')$:

if $\chi_1(t_m) \neq \chi_1(t_{m-1})$ or $\chi_2(t_m) \neq \chi_2(t_{m-1})$ then

$$Y = \{y_1\}, y_1 = x_1.$$

$H(e_3')$:

$$A_D(t_m) = A_D(t_{m-1}) \setminus \{x_3\}.$$

if $x_3 \in A_D(t_{m-1})$ and $\chi_1(t_{m-1})\chi_2(t_{m-1}) \neq 0$ then

$$Q_D(t_m) = \text{enq}(Q_D(t_{m-1}), x_3).$$

if $x_3 \in A_D(t_{m-1})$ and $\chi_1(t_{m-1}) = 0$ then

$$w(e_1^*, t_m) = t_m + O_s / P_E;$$

$$\chi_1(t_m) = 1;$$

$$O_1(t_m) = x_3.$$

if $x_3 \in A_D(t_{m-1})$ and $\chi_1(t_{m-1}) \neq 0$ and

$$\chi_2(t_{m-1}) = 0$$
 then

$$w(e_2^*, t_m) = t_m + O_s / P_E;$$

$$\chi_2(t_m) = 1;$$

$$O_2(t_m) = x_3.$$

if $x_1 \notin A_D(t_{m-1})$ then

$$S_D(t_m) = S_D(t_{m-1}) \cup \{x_3\}.$$

$G(e_3')$:

if $\chi_1(t_m) \neq \chi_1(t_{m-1})$ or $\chi_2(t_m) \neq \chi_2(t_{m-1})$ then

$$Y = \{y_1\}; y_1 = x_3.$$

$H(e_1')$:

if $\#Q_D(t_{m-1}) = 0$ then

$$\chi_1(t_m) = 0.$$

if $\#Q_D(t_{m-1}) > 0$ then

$$Q_D(t_m) = \text{deq}(Q_D(t_{m-1}));$$

where deq – is operator who removes the first element from the queue;

$$O_1(t_m) = (O_1^N, O_1^S) = \text{First}(Q_D(t_{m-1}));$$

where First – is the operator who returns the value of the first element of the queue;

$$w(e_1^*, t_m) = t_m + O_1^S / P_E.$$

$G(e_1')$:

if $\#Q_D(t_{m-1}) > 0$ then $Y = \{y_1\}, y_1 = O_1(t_m).$

3. Simulation Results

Formal specification of terminal was used developing a model with ARENA. New ARENA elements were created for each aggregate of specification. Template of new elements has been created using ARENA. Each element of the template represents aggregate from aggregate specification. The graphical representation of the model is presented in Fig 3.

Simulation results are got using the following parameters of the model:

1. Parameters of terminal input streams:

a) Annual amount of transported oil.

Parameter	Experiment number					
	1	2	3	4	5	6
1.a (kilotons)	3500	4000	5000	6000	7000	8000
Simulation time (days)	3650	3650	3650	3650	3650	3650

- b) Part of total amount of transported oil for each kind of oil.
- c) Size of ordered oil.
- d) Time interval during which oil products have to be delivered by trains.
- e) Time interval after the start of service after which the tanker has to arrive.
- f) Number of wagons in a train.
- g) Capacity of a wagon.

Parameter	Kind of oil product	
	Light	Dark
1.b	40%	60%
1.c (kilotons)	[10,12]	[25,30]
1.d (days)	[1,3]	[1,3]
1.e (days)	5	5
1.f (tonne)	50	50
1.g (tonne)	50	50

2. Parameters characterizing the structure of terminal:
- a) Number of reservoirs and their capacities which are used for each kind of oil.
 - b) Number of platforms.
 - c) Subsets of platforms used to serve different kinds of oil.
 - d) Number of wagons in each platform which can be served at the same time.

Parameter	Kind of oil product	
	Light	Dark
2.a (tonne)	20	10
Tanks capacities:		
Tank_1 - 2	20000	20000
Tank_3 - 6	20000	10000
Tank_7 - 10	20000	5000
Tank_11 - 20	5000	
2.b,2c	4	
Platforms system:		
Platform_1 - 2	–	Yes
Platform_3	Yes	Yes
Platform_4	Yes	–
2.e	2	
Embankment system:		
Embankment_1	–	Yes
Embankment_2	Yes	Yes

e) Subsets of embankments used to serve different kinds of oil.

3. Technological parameters of the terminal:
- a) Time during which oil products are poured from wagons to reservoirs for each kind of oil
 - b) Rate of pouring oil from reservoirs to a tanker
4. Parameters characterizing the control of terminal:
- a) Order of performance decision-making algorithm, which evaluates the number of wagons, which are in railway station.
 - b) Order of performance decision-making algorithm, which does not evaluate the number of wagons, which are at railway station.
 - c) Algorithm carrying orders of tankers and evaluating only needed amount of empty reservoir for the realization of order.
 - d) Algorithm carrying orders of tankers and evaluating needed amount of empty reservoir for the realization of order and number of wagons at the railway station.

Parameter	Kind of oil product	
	Light	Dark
3.a (hours)	4	8
3.b (kilotons/day)	25	25
4.a	–	–
4.b	–	–
4.c	–	–
4.d	Yes	Yes

Fig 4 depicts dependencies of platforms occupation with respect to the transported amount of oil. Fig 5 depicts similar dependencies of embankments.

Simulation results show that up to 8 megatons per year of oil products can be transported through the Klaipeda oil terminal.

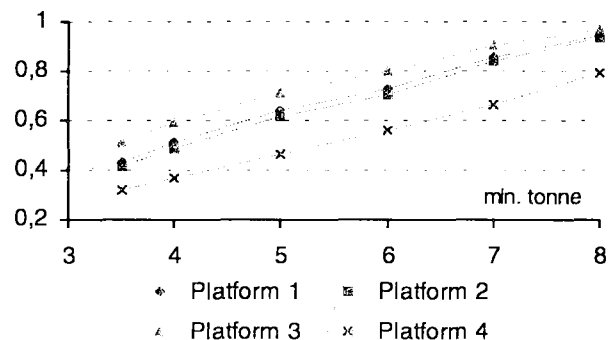


Fig 4. Dependencies of platform occupation with respect to the transported amount of oil

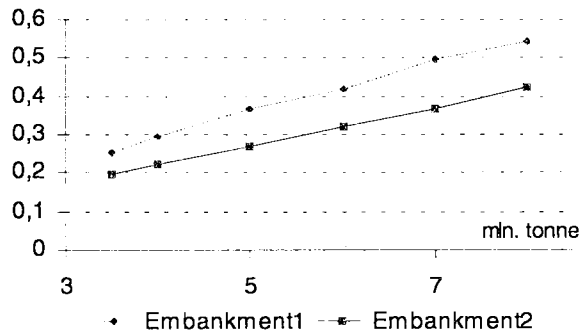


Fig 5. Dependencies of embankments occupation with respect to the transported amount of oil

Figs 6–8 depict distribution functions service time for order (t_O), tank-wagon (t_W) and tanker (t_T). Each dependency has been evaluated at the different amounts of oil transported through terminal per year.

Fig 9 depicts dependences of mean volume in reservoirs for dark and light oil with respect to transportation amount of oil.

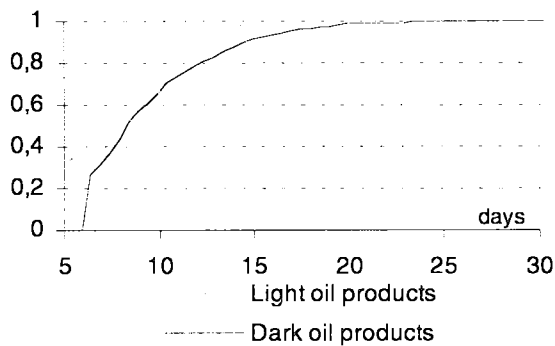


Fig 6. Distribution function service time for order for different kinds of oil product. (transportation amount is 6 megatons)

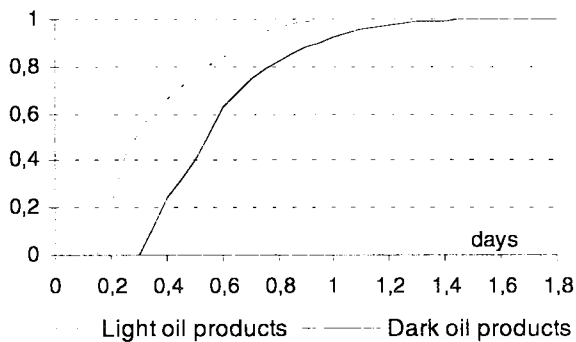


Fig 7. Distribution function service time for tank-wagon for different kinds of oil products (transportation amount is 6 megatons)

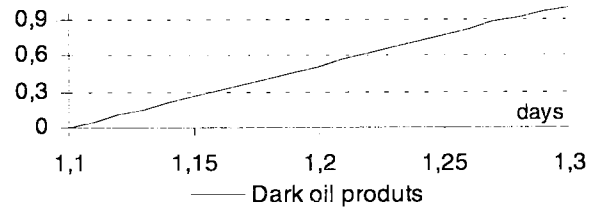
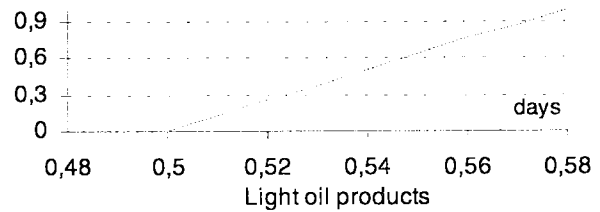


Fig 8. Distribution function service time for tanker for different kinds of oil products. (transportation amount is 6 megatons)

4. Conclusion

The presented simulation approach permits to combine advantages of formal methods and simulation system ARENA developing simulation models for the analysis of stevedoring work in oil terminal. Formal specification permits to describe the simulated system mathematically strictly. ARENA system permits to realize software implementation and animation of the developed model.

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