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Branislav Dragović, Nenad Dj. Zrnić, Elen Twrdy, Dong-Keun Rooy

# Ship Traffic Modeling and Performance Evaluation in Container Port

*This paper gives ship traffic modeling and performance evaluation in container port. The basic approach used analytical and simulation models. These models are developed for impact analysis of the ship traffic and patterns of arrival ships at terminal performance. Results from both models are compared with each other. Both the simulation and analytical models were applied to evaluate the efficiency of PECT.*

***Keywords***: *ship traffic modeling, analytical and simulation models*

## 1. Introduction

As a anchorage-ship-berth-yard link (ASBYL) at a container terminal is the large and complex system, a performance model has to be developed. In this paper, we propose two models based on simulation and queuing theory, respectively, in order to determine the performance evaluation of ASBYL in port. This paper gives a ASBYL modeling methodology based on statistical analysis of container ship traffic data obtained from the PECT (Pusan East Container Terminal). Implementation of the presented procedure leads to the creation of a simulation algorithm and analytical model that captures ASBYL performance well.

Most papers focus their attention on a container port simulation models which have been used extensively in the planning and analysis of the terminal operating scenario. The investigation and determination of container terminal performance has been treated by many different analytical and simulation models. Numerous studies have been conducted regarding the improvement of the efficiency of ship traffic and operations or berth and quay crane scheduling and planning problem in container port ([1] – [7] and [9]).

This paper is organized as follows. In sections 2 and 3 present a brief description of ASBYL modeling procedure. Also, these sections are concerned with the evaluation of functional estimation models in container port. Section 4 gives model validation and simulation and analytical results for PECT. Finally, we conclude by summarizing the results and contributions of this paper.

## 2. Analytical model

The analytical modeling of ASBYL consists of setting up mathematical models and equations which describe certain stages in the functioning of the system. Queuing theory models for analyzing traffic of ships in port is proposed and shown with different parameters, which indicates that each symbol has the following meaning: $\lambda$ – average ship arrival rate in ships/hour; $\mu$ – average ship service rate in ships/hour; $n_b$ – number of berths per terminal; $n_c$ – number of quay cranes (QCs) per berths; $n_s$ – number of ships present in port; $t_w$ – average waiting time in hours/ship; $t_s$ – average service time in hours/ship; $t_{ws}$ – average time that ships spend in port in hours/ship; $t_{du}$ – berthing/unberthing time in hours; $n_{con}$ – number of containers loading/unloading per ship; $r_{con}$ – QC move time in hours/container; $t_c$ – ships' loading/unloading time in hours/ship; $k_c$ – QC interference exponent and $\theta$ – ship traffic intensity.

The average service time, $t_s$, $t_s = 1/\mu$, where $\mu = (t_c + t_{du})^{-1}$, includes ships loading/unloading time $t_c$, in hours per container ship, expressed as

$$t_c = (n_{con} \cdot r_{con}) / (n_c)^{k_c} \quad (1)$$

where

$$k_c = (\ln(n_{con} r_{con}) - \ln(t_c)) / \ln(n_c) \quad (2)$$

It follows that

$$n_c = \left( \frac{\lambda n_{con} r_{con}}{\theta - \lambda t_{du}} \right)^{1/k_c} \quad (3)$$

Further, it can be shown that

$$t_{ws} = t_w + t_s \quad (4)$$

where

$$t_w(\theta) = \frac{\theta^{n_b}}{(n_b - 1)!\,\mu (n_b - \theta)^2 \left( \sum_{n_s=0}^{n_b-1} (\theta^{n_s} / n_s!) \right) + \theta^{n_b} (n_b - \theta) \mu} \quad (5)$$

for the ($M/M/n_b$) model. Accordingly, this parameter with the notation $\theta$, is equal $\theta = \lambda \cdot t_s = \lambda / \mu$.

In this study, formulae due to Lee and Longton and Cosmetatos have been adapted concerning the average port waiting time of ships ([2] – [6] and [9]). Accordingly with it, when the ships service time has an Erlang distribution with $k$ phases, the following equations are obtained

$$t_{ws} = t_w V_c + t_s \quad (6)$$

for the ($M/E_k/n_b$) model, where $V_c = \frac{1}{2}\left(\frac{1}{k} + 1\right)$ - the coefficient of variation of $t_s$ distribution and $k$ is the number of phases of an Erlang distribution;

$$t_{ws} = t_w \cdot \left[ \frac{1}{2}\left(\frac{1}{k}+1\right) + \left(1-\frac{1}{k}\right)\left(1-\frac{\theta}{n_b}\right)(n_b-1)\frac{(4+5n_b)^{\frac{1}{2}}-2}{32\theta} \right] + \frac{1}{\mu} \tag{7}$$

for the ($M/E_k/n_b$) model.

**Ship traffic**

We use the following symbols: $N_{con}$ - total number of container loaded onto and discharged from ships in port during the period $T$ (in containers); $r_c$ - daily rate (in containers/day); $T$ - time of port operation considered (in days). Then $\lambda = ((N_{con}/T)/n_{con})$, where $N_{con}/T$ is the average number of containers handled in port per day. Similarly, it is seen that $\mu = r_c / n_{con}$. Hence, $\lambda/\mu = N_{con}/r_c T$.

The traffic intensity as the product of the average arrival rate of ships and average service time play a significant role in the queuing models. Accordingly, this parameter with the notation $\theta$, is called the ship traffic intensity and it is equal $\theta = \lambda \cdot t_s = \lambda/\mu$. Further, $\theta$ as a port operation parameter, i.e. berth occupancy index, $n_b\alpha_{n_b}$, can be defined in the following manner ([4] – [6]).

$$\theta = n_b\alpha_{n_b} = n_b - \sum_{n_s=0}^{n_b-1}(n_b-n_s)P(n_s), \tag{8}$$

where $\alpha_{n_b}$ - degree of occupancy of port with $n_b$ berths.

Furthermore, there holds

$$N_{con} = r_c T\theta = r_c T n_b \alpha_{n_b}. \tag{9}$$

Then the average number of ships present in port with $n_b$ berths in the period $T$ is expressed as

$$\overline{n}_s = \sum_{n_{s=0}}^{n_b} P(n_s) + n_b \sum_{n_s=n_b+1}^{\infty} P(n_s) = n_b\alpha_{n_b}. \tag{10}$$

Also, the average number of ships waiting for berths with $n_b$ berths in the period $T$ is obtained as

$$\overline{n}_{s_w} = \sum_{n_s=n_b+1}^{\infty}(n_s-n_b)P(n_s). \tag{11}$$

It follows from (10) and (11) that the average number of ships served at $n_b$ berths in the period $T$ can be written in the form

$$\overline{n}_{s_b} = \overline{n}_s - \overline{n}_{s_w} = \sum_{n_1=1}^{n_b} n_s P(n_s) + n_b \sum_{n_s=n_b+1}^{\infty} P(n_s). \tag{12}$$

In view of that $\sum_{n_s=0}^{\infty} P(n_s) = 1$, the Eq. (12) becomes

$$\overline{n}_{s_b} = n_b - \sum_{n_s=0}^{n_b-1}(n_b-n_s)P(n_s). \tag{13}$$

From Eqs. (8), (9) and (13) we have

$$\theta = \overline{n}_{s_b} = N_{con}/(r_c T) = \lambda/\mu. \tag{14}$$

**Modeling of ship operations**

Model elements of the container terminal can be separated into following group: berth cost in \$ per hour, $c_1 = n_b c_{n_b}$; QCs cost in \$ per hour, $c_2 = n_b n_c c_{n_c}$; storage yards cost in \$ per hour, $c_3 = \theta\mu n_{con} t_{t_{con}} a_{con_{cy}} c_{cy}$; transportation cost by yard transport equipment between quayside and storage yard (container yard – CY) in \$ per hour, $c_4 = \theta\mu n_c t_c n_{cyc} c_t$; labor cost for QC gangs in \$ per hour, $c_5 = \theta\mu n_c t_l c_l$; ships cost in port in \$ per hour, $c_6 = \theta\mu t_{ws} c_s$; and containers cost and its contents in \$ per hour, $c_7 = \theta\mu t_{ws} n_{r_{con}} c_w$. The total cost function, would be concerned with the combined terminals and containerships cost as $TC = \sum_{i=1}^{7} c_i$.

It is necessary to know that only the total port cost function computes the number of berths/terminal and QCs/berth that would satisfy the basic premise that the service port cost plus the cost of ships in port should be at a minimum. This function was introduced by [7]. We point out that their solutions may not be as good as ours because we have simulation approach to determine key parameters $t_w$, $t_s$, $\lambda$, $\mu$, $\theta$ and especially $k_c$. Therefore, to find the optimal solution, their function can be obtained in the following form

$$TC = f(\theta) = n_b\left(c_{n_b} + n_c c_{n_c}\right) + \\ + \theta\mu\left(n_{con} t_{t_{con}} a_{con_{cy}} c_{cy} + n_c t_l\left(c_l + n_{cyc} c_t\right) + t_{ws}(\theta)\left(c_s + n_{r_{con}} c_w\right)\right) \tag{15}$$

where $TC$ - total port system costs in \$/hour; $c_{n_b}$ - hourly berth cost in \$, ($c_{n_{b1}}$ - the initial berth cost, $i$ - interest rate, $n_y$ - economic lifetime in years, $c_{n_{bm}}$ - annual maintenance cost per berth), $c_{n_b} = \left(c_{n_{b1}}\left(i(1+i)^{n_y}/(1+i)^{n_y} - 1\right) + c_{n_{bm}}\right)/(365 \cdot 24)$; $c_{n_c}$ - QC in \$/QC hour; $t_{t_{con}}$ - average yard container dwell time, in hours; $a_{con_{cy}}$ - number of $m^2$ of storage yard per container; $c_{cy}$ - storage yard cost in \$/$m^2$ hour; $n_{cyc}$ - hourly average number of cycle by yard transport equipment between quay side and CY; $c_t$ - transportation cost between quay side and CY per cycle in \$; $t_l$ - paid labor time in hour per gang per ship, $t_l = \max\{t_c\}$; $c_l$ - labor cost in \$/gang hour; $c_s$ - ship cost in port in \$/ship hour; $n_{r_{con}}$ - average payload in containers/ship; $c_w$ - average waiting cost of a container and its contents in \$/container hour.

By substituting Eq. (3) into Eq. (15) we obtain ([4] – [6])

$$TC = f(\theta) = n_b c_{n_b} + \lambda n_{con} t_{t_{con}} a_{con_{cy}} c_{cy} + \left(\frac{\lambda n_{con} r_{con}}{\theta - \lambda t_{du}}\right)^{1/k_c} \times \\ \left(n_b c_{n_c} + \lambda t_l\left(c_l + n_{cyc} c_t\right)\right) + \lambda t_{ws}(\theta)\left(c_s + n_{r_{con}} c_w\right) \tag{16}$$

where $t_{ws}(\theta)$ is defined by the Eq. (6) or Eq. (7) or by a result of simulation modeling.

From the total port cost function per average arrival rate, we can obtain

$$AC = \frac{f(\theta)}{\lambda} = \frac{f(\theta)}{\theta\mu} \tag{17}$$

Eq. (17) shows the average container ship cost in \$/ship, *AC*.

### 3. Simulation model

Most container terminal systems are sufficiently complex to warrant simulation analysis to determine systems performance. The GPSS/H simulation language, specifically designed for the simulation of manufacturing and queuing systems, has been used in this paper [8].

In order to present the ASBCY link processes as accurate as possible the following phases need to be included into simulation model ([1] – [6]):

- **Model structure:** ASBCY link is complex due to different interarrival times of ships, different dimensions of ships, multiple quays and berths, different capabilities of QCs and so on. The modeling of these systems must be divided into several segments, each of which has its own specific input parameters.
- **Data collection:** All input values of parameters within each segment are based on data collected in the context of this research. The main input data consists of ship interarrival times, lifts per ship, number of allocated QCs per ship call, and QC productivity. Existing input data are subsequently aggregated and analyzed so that an accurate simulation algorithm is created in order to evaluate ASBYL.
- **Inter-arrival times of ships:** The inter-arrival time distribution is a basic input parameter that has to be assumed or inferred from observed data. The most commonly assumed distributions in literature are the exponential distribution; the negative exponential distribution or the Weibull distribution ([2] – [6]).
- **Loading and unloading stage:** Accurate representation of number of lifts per ship call is one of the basic tasks of ASBYL modeling procedure. It means that, in accordance with the division of ships in different classes, the distribution corresponding to those classes has to be determined.
- **Number of QCs per ship:** The data available on the use of QCs in ASBYL operations have to be considered too, as this is another significant issue in the service of ships. This is especially important as total $t_{ws}$ depends not only on the number of lifts but also on the number of QCs allocated per ship. Different rules and relationships can be used in order to determinate adequate number of QCs per ship.
- **Flowchart:** After the input parameter is read, simulation starts by generating ship arrivals according to the stipulated distribution. Next, the ship size is determined from an empirical distribution. Then, the priority of the ship is assigned depending on its size. The ship size is important for making the ship service priority strategies. For the assumed number of lifts per ship to be processed, the

number of QCs to be requested is chosen from empirical distribution.  If there is no ship in the queue, the available berths are allocated to each arriving ship. In other cases ships are put in queue. The first come first served principle is employed for the ships without priority and ships from the same class with priority. After berthing, a ship is assigned the requested number of QCs. In case all QCs are busy, the ship is put in queue for QCs. Finally, after completion of the loading and unloading process, the ship leaves the port. This procedure is presented in the algorithms shown in Figure 1.

In order to calculate the ASBYL performance, it is essential to have a through understanding of the most important elements in a port system including ship berthing/unberthing, QCs/ship, yard tractor allocation to a container and crane allocation in stacking area. As described in Figure 2 - process flow diagram of the terminal transport operations, the scope of simulation, strategy and initial value and performance measure will have to be defined. To move containers from apron to stacking area, four tractors are provided for each container crane.

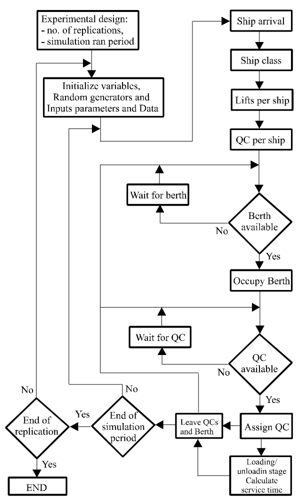



**Figure 1.** Flowchart for a ship arrival/departure

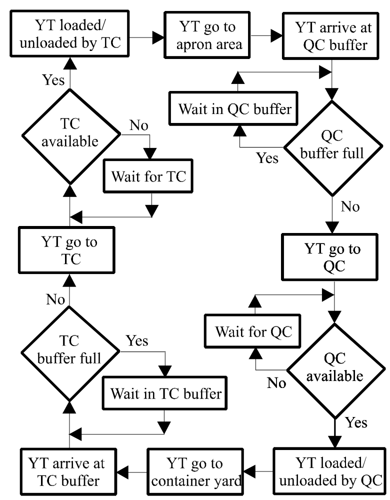



**Figure 2.** Flowchart of the terminal transport operations

### 4. Computational results

This section gives a ASBYL modeling methodology based on statistical analysis of container ship traffic data obtained from the PECT. PECT is big container terminals with a capacity of 2,075,895 twenty foot equivalent units (TEU) in 2006. There are five berths with total quay length of 1,500 m and draft around 14-15 m, Figure 3 ([4] – [6]). Ships of each class can be serviced at each berth.

**Parameters Involved**

An important part of the model implementation is the correct choice of the values of the simulation parameters. The input data for the both simulation and analytical models are based on the actual ship arrivals at the PECT for the ten months period from January 1, 2005 to October 31, 2005 (Figure 3, left) and January 1, 2006 to October 31, 2006 (Figure 3, right), respectively ([4] – [6]). This involved approximately 1,225 ship calls in 2005 and 1,285 in 2006. The ship arrival rate was 0.168 ships/hour in 2005 and 0.176 in 2006. Total throughput during the considering period was 1,704,173 TEU in 2005 and 1,703,662 TEU in 2006. Also, the berthing/unberthing time of ships was assumed to be 1 hour. The ships were categorized into the following three classes according to the number of lifts: under 500 lifts; 501 – 1,000 lifts; and over 1,000 lifts per ship. Ship arrival probabilities were as follows: 23.8% for first class, 40.8% for second and 35.4% for third class of ships in 2005 and 29.9% for first class, 37.7% for second and 32.4% for third class of ships in 2006.

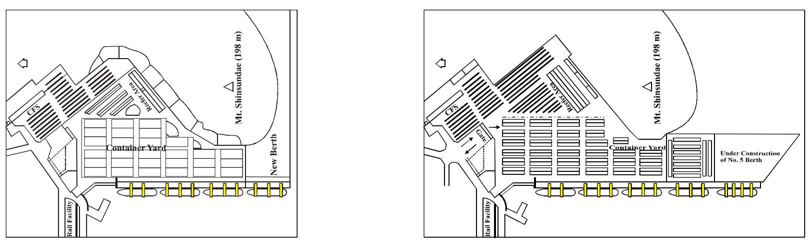
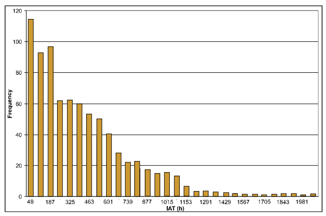



**Figure 3.** PECT layout, 2005 (left) and 2006 (right)

The interarrival time distribution (IATD) is plotted in the Figure 4. Interestingly, even though ship arrivals of the ships are scheduled and not random, the distribution of interarrival times fitted very well the exponential distribution. Service times were calculated by using the Erlang distribution with different phases. To obtain accurate data, we have first fitted the empirical distribution of service times of ships to the appropriate theoretical distribution. Service time distributions are given in 2005: Service distribution (SD) of first class of ships, the 4-phase Erlang distribution, ($E_4$); SD of second class of ships, ($E_4$); SD of third class of ships, ($E_5$) and SD of all classes of ships, ($E_3$). It is observed that for 2006, service time of the first ship class follows the 5-phase Erlang distribution, while the 6-phase Erlang distribution fits very well the service time of the second ship class, than 2-phase Erlang distribution fits very well the service time of the third ship class and all classes of ships follows 4-phase Erlang distribution. Goodness-of-fit was evaluated, for all tested data, by both chi-square and Kolmogorov-Smirnov tests at a 5 % significance level ([5] and [6]).

We have carried out extensive numerical work for high/low values of the PECT model characteristics. Our numerical experiments are based on different parameters of various PECT characteristics presented in Table 1 ([4] – [6]). The described and tested numerical experiments contain four segments in relation to the input variables.



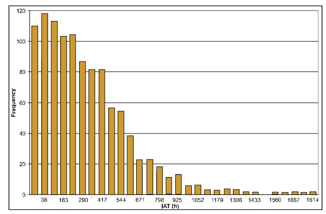




**Figure 4.** IATD of ships at PECT in 2005 (left) and in 2006 (right)

**Table 1.** Input data – Terminal characteristics ([4] – [6])

| Class of ships | Input data | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $n_{con}$ (no. of con.) | | $r_{con}$ (hrs per con.) | | $t_l$ (hrs/gang/ship) | | $c_s$ ($/ship hrs) | | $n_c^*$ | | $k_c$ | |
| | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| First | 313 | 305 | 0.05 | 0.05 | 8.80 | 7.1 | 745 | 739 | 1.7 | 1.9 | 0.80 | 0.90 |
| Second | 782 | 741 | 0.05 | 0.05 | 13.9 | 12.7 | 1098 | 1081 | 2.5 | 2.6 | 0.93 | 0.925 |
| Third | 1444 | 1413 | 0.03 | 0.03 | 20.2 | 17.8 | 1354 | 1365 | 3.1 | 3.3 | 0.97 | 0.965 |
| All classes | 862 | 829 | 0.04 | 0.04 | 14.3 | 12.9 | 1164 | 1155 | 2.5 | 2.6 | 0.91 | 0.911 |

$n_c^*$ - average number of QCs assigned per ship (Real data and Simulation results); $c_{n_{b1}}$ = 62 million $; $i$ = .0663; $n_y$ - 40, $c_{n_{bm}}$ = 6.2 million $; $c_{n_b}$ = 1215 $; $c_{n_c}$ = 38.8 $/QC hour; $t_{t_{con}}$ = 188 hours; $a_{con_{cy}}$ = 63.9 m$^2$/container; $c_{cy}$ = 0.000292 $/m$^2$ hour; $n_{cyc}$ = 9; $c_t$ = 5 $/cycle; $c_l$ = 357 $/gang hour; $n_{r_{con}}$ (601 for I class, 1085 for II class, 1312 for III class, 999 for all classes in 2005; and 642 for I class, 1114 for II class, 1371 for III class, 1042 for all classes in 2006; $c_w$ =1.4 $/container hour. To move containers from apron to container yard (CY), four tractors are provided for each QC. It takes average 10 minutes from apron to CY including unloading/loading time by transfer crane. The average distance between apron and CY is assumed to be 850 meters.

### Model Validation

The simulation model was run for 44 statistically independent replications. After analysis of the port data, it was determined that traffic intensity is about 2.55 in 2005 and 2.25 in 2006, while the simulation output shows the value of 2.61 in 2005 and 2.28 in 2006, respectively.

Average service time shows very little difference between the simulation results and actual data, that is, 14.07 h and 14.35 h in 2005 and 12.60 h and 12.88 in 2006, respectively. The simulation results of the number of serviced ships completely correspond with the real data (i.e. the simulation result of the total number of ships are 1224.1 in 2005 and 1285.88 in 2006, and the real data are 1225 and 1285; the first class of ships: 291.11 in 2005 and 383.3 in 2006, and 291 and 384; the second class: 502.16 in 2005 and 486,01 in 2006, and 501 and 485; and third class: 434,17 in 2005 and 415.02 in 2006, and 433 and 416). In accordance with it, the correspondence between simulation and analytical results gives, in full, the validity to the applied analytical model to be used for the optimization of servicing ships processes at PECT, see Tables 2 and 3.

**Table 2.** Average service time of ships

| Results | Average service time of ships in hours | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (All classes) | | (I class) | | (II class) | | (III class) | |
| | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| Real data | 14.07 | 12.60 | 8.71 | 7.85 | 13.47 | 12.52 | 20.05 | 17.48 |
| Simulation resluts | 14.35 | 12.88 | 8.87 | 8.15 | 13.91 | 12.71 | 20.29 | 17.80 |
| Analytical results | 14.51 | 12.95 | 9.06 | 8.17 | 13.67 | 12.91 | 20.78 | 17.75 |

**Table 3.** Average waiting time of ships

| **Results** | Average waiting time of ships in hours | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (All classes) | | (I class) | | (II class) | | (III class) | |
| | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 | 2005 | 2006 |
| Simulation resluts | 2.42 | 1.15 | 2.45 | 1.29 | 2.43 | 1.15 | 2.39 | 1.01 |
| Analytical results, AM I | 3.19 | 1.85 | 3.25 | 1.21 | 3.24 | 2.14 | 3.07 | 2.21 |
| Analytical results, AM II | 2.63 | 1.29 | 3.15 | 1.41 | 2.71 | 1.32 | 2.04 | 1.15 |

**Simulation and analytical results**

The impact of the different models is determined by comparing the key performance measures of simulation and analytical approaches to those of the real data of PECT. According to this, judging from the computational results for some numerical examples of the ($M/E_k/n_b$) – using average waiting time, $t_w$ from Eq. (6) (for brevity analytical model I (AM I)) and ($M/E_k/n_b$) – using average waiting time, $t_w$ from Eq. (7) (for brevity analytical model II (AM II)) models, it can be confirmed that Eq. (6) is inclined to estimate the values of $t_{ws}$.

The average time that ships spend in port for simulation model (SM) is 15.036 h for all classes of ships in 2006. This is about 15% shorter than that of SM, 17.799 hours in 2005 and about 1.5% shorter than that of AM II, 15.245 hours in 2006. For first class of ships, the average time that ships spend in port is 10.380 hours for AM II in 2006, about 0.6% shorter than SM, 10.441. This time is 15.232 hours for second class of ships (AM II) in 2006, about 12% shorter than AM II in 2005. Finally, the average time that ships spend in port for third class of ships is 19.818 hours (SM) in 2006, about 16% shorter than SM in 2005 or 2% shorter than AM II, 20.270 h in 2006.

The results presented here support the argument that average cost per ship or container served, can be easily obtained by the use of the average cost curves in function of traffic intensity and QCs/berth. All numerical results presented in Figure 5 are obtained by using the input data from Table 1. Simulation testing (Simulation model (SM)) was than carried out by using the GPSS/H. The solution procedure for AM I and AM II models was programmed using the MATLAB program.

Figure 5 compares the average ship costs of different ship classes taken by SM, AM I and AM II models at a PECT in 2005 and 2006. They graphically show the sensitivity of the average ship costs to the various values of $\theta$. In curve SM for all classes of ships in 2006, the minimum cost per ship served decreases by about 3.3% in 2006 with respect to 2005. However, the average costs per first class of ships served decrease in 2006 by about 7% than the minimum cost in 2005, see curve AM II. This decrease for second class of ships is about 2% in 2006 with respect to the minimum cost in 2005 for curve AM II. Finally, in curve SM for third class of ships, the minimum cost per ship served decreases by about 2.6% ($138,019) than the minimum cost in 2005 ($141,697).

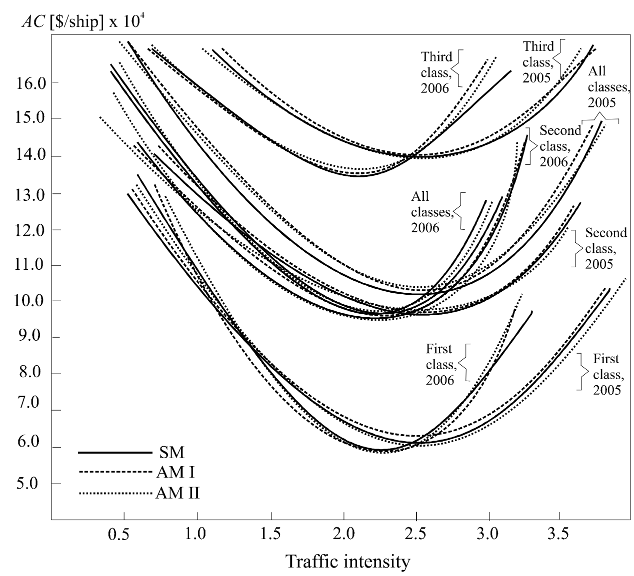



**Figure 5.** Average container ship costs for various $\theta$ ($\theta$ = 0.5–3.5) – (1) Minimum *AC* in 2005 are: $101,094 (SM) for all classes of ships; $62,955 (AM II) for first class of ships; $98,632 (SM) for second class of ships and $141,697 (AM II) for third class of ships; (2) Minimum AC in 2006 are: 97,749 (SM) for all classes of ships; $58,507 (AM II) for first class of ships; $96,721 (AM II) for second class of ships and $138,019 (SM) for third class of ships

Accordingly, it will be useful to graphically show the range of container capacity which can be optimally handled with the specific number of berths, i.e. optimal range of traffic intensity. For the reason already stated in the numerical experiments, the average ship cost in $/ship, *AC*, has been adopted as a measure to determine the average traffic intensity and the optimal number of QCs/berth $n_c$ ($n_c$ =1 - 7) for the constant number of berths/terminal in this study.

## 5. Conclusions

A simulation model employing the GPSS/H has been developed to ASBYL performance evaluation of PECT. It is shown to provide good results in predicting the actual ASBYL operations system of the PECT. The attained agreement of the results obtained by using simulation model with real parameters has been also used for validation and verification of applied analytical model. In accordance with that, the correspondence between simulation and analytical results gives, in full, the validity to the applied analytical model to be used for optimization of processes of servicing ships at PECT. Finally, these models also address the issues such as the performance criteria and the model parameters to propose an operational method that reduces average cost per ship served and increases the terminal efficiency.

We develop analytical and simulation models, which provide solutions to large-sized problems usually encountered in practice in reasonable computational times, and analyze its effectiveness. These models can be used to obtain a good solution to the real problem.

However, presented simulation and analytical methodology and results are convenient for different analyses, planning and development of port system, for example, increasing the number of berths or traffic intensity depending on the optimum berth capacity and average ship cost. The optimum number of berths, optimum traffic intensity, optimum berth capacity and associated average terminal and ship costs could be extensively used in different analyses of port system in real world.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## References


[1] Dragović B., Park N. K., Radmilović Z. and Maraš V., *Simulation modeling of ship-berth link with priority service*, Maritime Economics & Logistics, 2005, 7(4), 316-335.

[2] Dragović B., Park N. K., Radmilović Z., *Modeling of ship-berth-yard link*

*performance and throughput optimization*, Proceeding of Annual Conference – The IAME 2006, Melbourne, Australia, 2006, 1-21.
[3] Dragović B., Park N. K., Radmilović Z., *Ship-berth link performance evaluation – simulation and analytical approaches* –, Maritime Policy & Management, 2006, 33(3), 281-299.
[4] Dragović B., Zrnić N.Dj., Radmilović Z., *Ports & container terminals modeling*, Research monograph, Faculty of Transport and Traffic Engineering, University of Belgrade, 2006.
[5] Dragović B., Park N. K., Radmilović Z., *Anchorage-ship-berth-yard link modeling in container port*, *Proceedings of the* 11th WCTR 2007, Berkeley, CA, USA, 2007, 1-21.
[6] Dragović B., Park N. K., Ryoo D-K., Meštrović R., *Ship traffic in container port: Modeling methodology and performance evaluation*, First International Forum of Shipping, Port and Airport, China, Conference Proceedings of IFSPA 2008, Hong Kong, 2008, 1-15.
[7] Schonfeld P., Sharafeldien O., Optimal berth and crane combinations in containerports, Journal of Waterway, Port, Coastal, and Ocean Engineering, 1985, 111(6), 1060-1072.
[8] Schriber T. J., An introduction to simulation using GPSS/H, New York, Wiley, 1991.
[9] Zrnić N.Dj., Dragović, B., *Containerports efficiency in function of traffic intensity*, *Proceedings of* the MARIND 2001, Volume I, Varna, Bulgaria, 2001, 109-115.

*Addresses:*

- Prof. Dr. Branislav Dragović, University of Montenegro, Maritime Faculty, Dobrota 36, 85330, Kotor, Montenegro, branod@ac.me
- Prof. Dr. Nenad Dj. Zrnić, University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35, Serbia, nzrnic@mas.bg.ac.rs
- Prof. Dr. Elen Twrdy, Faculty of Maritime Studies and Transport, University of Ljubljana, Portorož, Slovenija, Elen.Twrdy@fpp.uni.lj-si
- Prof. Dr. Dong-Keun Rooy, Korea Maritime University, College of International Studies, Division of Shipping Management, 1 Dongsam-dong, Youngdo-gu, Busan, Korea, dkryoo@hhu.ac.kr