A COMPARISON OF ANALYTICAL METHODS AND SIMULATION FOR CONTAINER TERMINAL PLANNING

Wen-Chih Huang  
Department of Harbor and River Engineering, National Taiwan Ocean University

Tu-Cheng Kuo  
Department of Aviation and Maritime Management, Chang Jung University

Sheng-Chieh Wu*  
Department of Business Administration, Meiho Institute of Technology

No.23, Pingguang Rd., Neipu Shiang, Pingtung County 912, Taiwan, R.O.C

ABSTRACT

Queuing models and simulation are two primary methods applied to container terminal planning. Queuing models tend to result in underestimated outcomes due to ships and berths not being classified by size and length. This paper classified both ships and berths using actual data and then compared the resultant differences of the scenarios with and without classification with the simulation. The comparison shows that the outcomes with and without the classification of ships and berths are located opposite to the outcomes obtained from the simulation, which was deliberately constructed and rendered sufficiently accurate results. The optimal scale of facilities of a container terminal is located between the outcomes of the two proposed scenarios. There is no longer a need to establish a complex and tedious simulation model. The method proposed in this paper provides a convenient way to determine the optimum number of berths and facilities for a container terminal.

Keywords: queuing models, simulation, container terminal, comparison

1. INTRODUCTION

Optimization of the facilities is an extremely important goal in the container terminal planning process in which analytical method and simulation are two primary methods used in the majority of literature. Both of these methods have advantages and drawbacks. Although the result of the analytical method is not as accurate as that of the simulation, it is simple and convenient. However, no relevant studies have yet established a solid conclusion regarding the cost factor and the queuing models, which therefore requires further clarification.

Queuing models are popular methods applied to the previous related studies on container terminal planning among analytical methods. Related studies using queuing models are described as follows: Edmond and Maggs [3] believe that when ships are berthing for operation, the number of cranes used should change with time, in accordance with the number of cranes allocated, the allocation of port laborers, whether or not cargoes continue to arrive, etc. Wanhill [19] pointed out that when weighing the cost factor of the optimum container terminal facility system separately from the unoccupied berth cost and the ship waiting cost, it should include the service cost for the time that the ships are berthed at the container terminal. Noritake [13] and Noritake and Kimura [14] were of the opinion that the decision for the number of public terminal berth facilities must be able to rapidly reflect the changes of the container demands and must consider the costs of both berths and ships. Therefore the number of public terminal berth facilities can be estimated by using the cost ratio between the available number of berths and ships and the average berthing ships in the port. Huang [4] developed an evaluation index, which considers several kinds of cost functions (including ships’ cost, the interest of the cargo as well as its equipment, construction and maintenance, management costs of the port facilities, the cost of installing and removing the cranes and the cost of their operators, the cost of the cargo storing facility, and so on). Based on these indexes, we can analyze the characteristics of the systems of the container terminal in the same harbor at different periods in time and in various container terminals. Kozan [8] analyzed port operation by means of queuing theory, and compared the results of queuing theory with simulation.

In the earlier research, container terminal op-
The ARENA simulation package was used to analyze the operating systems, which were mostly explored by means of queuing models. Since the marine carriage and the container operation techniques on terminals have been drastically changed, some researchers consider queuing theories to be unsuitable for container terminal planning. Therefore, many of these studies used simulation models in container terminal planning. The most popular container terminal simulation models are the UNCTAD port model, PORTSIM, and the MIT port simulator. The UNCTAD port simulation model, developed in 1969, was used to analyze port operations dealing with conventional loose cargo. PORTSIM, developed by the World Bank in the 1970’s, was intended as a project appraisal tool and became useful for evaluating the costs and benefits of changing a port configuration. Developed in the early 1980’s, the MIT port simulator is a refinement of the earlier models, as it permits the analysis of a multipurpose port entailing break-bulk cargo, refrigerated cargo, and containers. Some of these studies relevant to this paper include the following: Hwang [6] established a commonly used simulation program including all the substantial factors that exist in a container port and the operating characteristics thereof. This model was put to the test at Norfolk International Terminal and proved workable. This study discovered that only when the cargo tonnage capacity exceeds the optimum capacity can the effect of lowering cost by increasing the number of berths and machines be shown to be noticeable. Kuo [10] used FORTRAN language to develop a container simulation model and applied to analyze facilities planning for terminal 18, port of Seattle. Kozan [9] proposed a simulation model using the SIMAN simulation program language. The model can handle conditions that are considerably complex and it was used to analyze a cargo handling company at a container terminal in the port of Brisbane, Australia. Razman and Khalid [17] used the ARENA simulation package to analyze the Ke-lang Container Terminal system and discuss crane allocation, resource allocation and the scheduling of the different operations, which were modeled to maximize the performance of the port. Kia [7] proposed a simulation model using SIMPLE++ Object-Oriented Programming software to carry out the analysis of a container terminal system. This study analyzed a simplified version of an actual container terminal system in the port of Pusan, South Korea, and made a comparison with the existing operating system. Pasquale and Rina [15] used graphical objects of the Visual SLAM language to simulate a container terminal. Nam [11] used the AweSim language to simulate the size of the Gamman Container Terminal in Pusan, Korea, in terms of berths and quay cranes. The results reveal that sharing quay cranes with adjacent berths can increase productivity, and that the more berths per operator, the higher the productivity achieved. Cheng and Yang [1] discussed the development of a simulation model that incorporates reverse logistics. Application and testing of the model was facilitated using the case of transportation containers.

We know from past studies that the factors that are taken into account by the simulation methods are comparatively more complete than those of the analytical methods, whereas the analytical method still has the following drawbacks:

1. The average waiting time is often overestimated or underestimated.
2. The reason for underestimating the number of terminals is due to the types of terminals and lengths of the ships not being classified.
3. As to the cost factors, only the costs of the ships and terminal are considered, without the density factor.
4. The service rate is defined by a constant, and so only the numbers of berths are calculated. Since the effect of the number of cranes in operation is not taken into account, it becomes impossible to calculate the optimum layout for the number of berths and the number of operating cranes, which becomes the main source of the problem.
5. The results of the analytical model are not as accurate as those of the simulation: it is therefore an unsuitable method to solve problems in which a high degree of accuracy is required.

In order to avoid the deficiency created by the unreasonable assumptions of the analytical method regarding the terminals and the berthing of the ships, this paper made some modifications regarding the above-mentioned problems and carried out additional analysis and a review using container terminal planning as a case study. This paper compares the differences among the traditional analytical (without-classification; AM1) method, the modified analytical (with-classification; AM2) method, and the simulation method (SM) for container terminal facilities allocation under identical conditions, in order to clarify the characteristics of container port terminal facilities planning using each method. The procedure adopted for this paper is shown in Fig. 1. First, the waiting time ($W_q$) for the analytical methods (without-classification and with-classification) and the simulation are computed separately. Second, using $W_q$, the systematic evaluation index (IND) was calculated. Finally, a comparison was made of the numbers of berths and cranes determined by the analytical method and the simulation.

![Figure 1. The comparison procedure](image-url)
2. THE EVALUATION INDEXES OF THE CONTAINER TERMINAL

Using the aforesaid paper’s evaluation indexes to measure efficiency of container terminal systems, this study will divide the evaluation indexes, in terms of their nature, into two types, that is, the features of the queuing models and the cost function. The definitions of the indexes are stated below:

2.1 The evaluation indexes related to the queuing system

(1) Utilization (ρ)
ρ is the ratio of actual berth utilization time to the gross berth time available. We have used the Nicolau’s formula [12], defined as:
\[ ρ = \left( 1 - \sum_{n=0}^{N+1} P_N(j) \right) \]  
(1)

where \( N \) is the number of berths, and \( P_N(j) \) is the probability of \( j \) ships in the container terminal within the period \( T \).

(2) Degree of congestion (DC)
DC is the probability of having to wait for berths when ships arrive at the container terminal.
\[ DC = \sum_{j=N+1}^{\infty} P_N(j) \]  
(2)

(3) Average number of ships in container terminal (L)
L is the expected number of ships in the container terminal within the period \( T \).
\[ L = \sum_{j=0}^{\infty} j P_N(j) \]  
(3)

(4) Average number of ships in queue (Lq)
Lq is the expected number of ships that are waiting for service in the container terminal system.
\[ L_q = \sum_{j=N+1}^{\infty} (j-N) P_N(j) \]  
(4)

(5) Average waiting time (W) in the container terminal system.
\[ W = \frac{\lambda}{\mu} \]  
(5)

where \( \lambda \) is the mean arrival rate of ships.

(6) Average waiting time (\( W_q; AWT \))
\( W_q \) is the mean time a ship spends in line waiting for service.
\[ W_q = \frac{L_q}{\mu} \]  
(6)

(7) Waiting time factor (\( W_q; AWT/AST \))
\( W_q; AWT \) is the ratio of the average waiting time (\( AWT; W_q \)) to average service time (\( AST; 1/\mu \)).
\[ W_q = \frac{W_q}{AST} \]  
(7)

Using Taha’s [18] definitions of the evaluation indexes of the queuing system, we can calculate, in the steady state, the system’s state probability, and the various features of M/M/N queuing systems can be expressed as
\[ P_N(j) = \left\{ \begin{array}{ll} \frac{(\frac{\lambda}{\mu})^j}{j!} & (0 \leq j < N) \\ \frac{(\frac{\lambda}{\mu})^N}{N!(1-\rho)} & (j \geq N) \end{array} \right. \]  
(8)

where,
\[ P_N(0) = \sum_{j=0}^{\infty} \frac{(\frac{\lambda}{\mu})^j}{j!} \]  
(9)

Using (8) into (1)–(7), we show as follows
\[ ρ = 1 - \sum_{j=0}^{N-1} \frac{P_N(j)(\frac{\lambda}{\mu})^j}{j!} \]  
(10)

\[ DC = 1 - \sum_{j=0}^{N-1} \frac{P_N(0)(\frac{\lambda}{\mu})^j}{j!} \]  
(11)

\[ L = \frac{P_N(0)(\frac{\lambda}{\mu})^j \cdot \rho}{j!(1-\rho)^2} \]  
(12)

\[ W_q = \frac{P_N(0)(\frac{\lambda}{\mu})^j \cdot \rho}{j!(1-\rho)^2 \cdot \lambda} \]  
(13)

\[ W_q \cdot \mu = \frac{P_N(0)(\frac{\lambda}{\mu})^j \cdot \rho}{j!(1-\rho)^2 \cdot N} \]  
(14)

2.2 The evaluation indexes related to cost function

The decision of the cost function in port planning is the key point of optimizing facilities. Accordingly, in the light of the types and definitions of the cost function, this section will explain these in the order of their evolution. Tracing the years since 1960, the cost functions of the port systems presented in the past papers can be categorized into three major types. Plumlee [16] employed the minimization of ships’ waiting cost and berths’ idle cost to present the first type of cost function TC1.
\[ TC_1 = U_s \cdot \lambda \cdot W_q + U_b \cdot N \cdot (1-\rho) \]  
(15)

where \( U_s \) is the cost of ship in unit time, \( U_b \) is the cost of berth in unit time.
Nicolau [12] concerning the ships’ cost, only takes into consideration the cost of waiting berths. In addition, on the part of berths, berths’ idle cost and operation cost are considered, and thus forming TC2, defined as follows:

\[ TC_2 = U_{b} \cdot \lambda \cdot W_q + U_{b} \cdot N \]  

(16)

Where \( U_{b} \cdot N \) are the cost of berths (including berths’ idle cost and operation cost).

Noritake and Kimura [14] and Wanhill [19] added the cost of the service time of ships staying in ports to TC2, thus forming the widely used cost function, of which the definition is TC3,

\[ TC_3 = U_{s} \cdot \lambda \cdot (W_q + 1/\mu) + U_{s} \cdot N \]  

(17)

Accordingly, it is noted that most papers combine the indexes of the queuing system and the total cost function of the cost function to create the major indexes to measure port systems, and thus create the standard to measure the optimal port system. Furthermore, the definitions of cost indexes stated in these papers, in a way, vary. Nicolau [12] defines the cost function as: ships’ waiting cost divided by (berths’ idle cost plus ships’ waiting cost) \((C_{s}/(C_{b}+C_{s}))\): this ratio can be used as the index to judge the optimal ports’ cost, the degree of congestion, and berth utility. Noritake and Kimura [14] used the ratio between berths’ cost and ships’ cost \((\gamma_{bs}=C_{b}/C_{s})\) as the basis for deciding the optimum number of berths in public wharfs. Huang [4] and Huang, et al. [5] stated that the total costs of ships in port can be classified as the costs of ship and cargo \((C_{s})\) and the service cost of the terminal \((C_{t})\). \(C_{s}\) and \(C_{t}\) can be defined as

\[ C_{s} = U_{s} \cdot (\lambda/\mu + L_{q}), \quad C_{t} = U_{s} \cdot X \cdot (\lambda/\mu + L_{q}) \]  

(18)

where \( C_{s} \) is the ship cost including construction, maintenance and operation expenditures of ship, and \( C_{t} \) is the cargo loaded aboard and the interest cost of its related equipment. \( X \) is the average payload of goods (TEU).

\[ C_{t} = C_{p} + C_{p} + C_{h} + C_{m} + C_{co} + C_{yd} \]  

(19)

where \( C_{p}, C_{p} \): the port facilities’ construction and operation costs.

\( C_{h}, C_{m} \): construction costs of the berth and its operation costs.

\( C_{co}, C_{yd} \): cost of handling cranes and maintenance costs; \( AC \) is the average number of cranes in a berth.

\( AC, C_{co}, C_{yd} \): working costs of operators using cranes; \( T \) is the average operating time per ship.

\( C_{yd} \): costs of the storage yard; \( V \) is the average cargo volume of a ship at port, and \( H \) is the average relay time of each cargo.

The total cost can then be obtained as follows:

\[ TC=C_{s}+C_{t}, \quad (S/hr) \]

\[ = (U_{s}+U_{s} \cdot X \cdot (\lambda/\mu + L_{q})) + (U_{s}+U_{s} \cdot X \cdot (\lambda/\mu + L_{q}) \cdot N + U_{m} \cdot N \cdot AC+U_{co} \cdot AT \cdot \lambda+U_{yd} \cdot V \cdot H \cdot \lambda) \]  

(20)

Huang [4] and Huang, et al. [5] used the index IND to estimate the optimal number of berths in a port system, where IND is defined as:

\[ IND=TC/(\lambda \cdot U_{s} \cdot V) \]

\[ = ((1+R_{cg})(1+\mu_{w})+(R_{rg}+R_{cg}+R_{cs}+R_{co} \cdot N/\lambda) \]

\[ + R_{cm} \cdot N \cdot AC \cdot \lambda+R_{cg} \cdot AT \cdot R_{yd} \cdot V \cdot H)/V \]  

(21)

where \( R_{cg}, R_{ps}, R_{cs}, R_{cm}, R_{co}, \) and \( R_{yd} \) are the cost ratios of \( U_{s}\cdot X, U_{s}, U_{s}, U_{s}, U_{m} \cdot U_{co}, U_{cm}, U_{yd} \) divided by \( U_{s} \) respectively.

3. CONTAINER TERMINAL PLANNING USING THE ANALYTICAL METHOD

3.1 Classification of Berths and Ships

In the past, the analytical method frequently made the assumption that the berths allowed the berthing of all ships, but in reality, berths were unable to provide berthing for all the ships due to the differences in their lengths, water depths, and the allocation of the cranes. Often the factors behind the analytical model generated by the application of the queuing models were oversimplified, and did not coincide with the actual conditions. Therefore, this paper applies the queuing models to develop a method with classification to solve the problem of underestimating the number of terminals due to the types of terminals and lengths of the ships not being classified.

In order to include the actual berthing conditions of the ships, this paper classifies the container ships into six categories as A1, A2, B1, B2, C1, and C2 in accordance with cargo tonnage capacity and length of the ship. The berths are classified into three categories AA, BB, CC, as illustrated in Table 1. According to the above classifications of ship types and berths, this paper matches the ship types and berths with the actual conditions. For instance, the A1 and A2 types of ships will occupy an AA type berth, and so on. With this method of classification, specific ships can only be berthed at a designated berth classification which matches with the actual conditions.
Table 1. Classification of the arriving ships and their berths at the container terminal

<table>
<thead>
<tr>
<th>Type</th>
<th>SL(M)</th>
<th>WT(M)</th>
<th>DI(M)</th>
<th>Berths</th>
<th>Ability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.10~0.15</td>
<td>0.15~0.20</td>
<td>0.16~0.20</td>
<td>0.17</td>
<td>2.00</td>
</tr>
<tr>
<td>A2</td>
<td>0.15~0.20</td>
<td>0.20~0.30</td>
<td>0.21~0.30</td>
<td>0.22</td>
<td>2.50</td>
</tr>
<tr>
<td>B1</td>
<td>0.20~0.25</td>
<td>0.25~0.50</td>
<td>0.26~0.50</td>
<td>0.27</td>
<td>3.00</td>
</tr>
<tr>
<td>B2</td>
<td>0.25~0.50</td>
<td>0.50~1.50</td>
<td>0.51~1.50</td>
<td>0.52</td>
<td>3.50</td>
</tr>
<tr>
<td>C1</td>
<td>0.50~0.60</td>
<td>0.60~1.00</td>
<td>0.61~1.00</td>
<td>0.62</td>
<td>4.00</td>
</tr>
<tr>
<td>C2</td>
<td>0.60~1.00</td>
<td>1.00~1.50</td>
<td>1.01~1.50</td>
<td>1.02</td>
<td>4.50</td>
</tr>
</tbody>
</table>

Note: SL: ship length, DL: the design length of the berth

3.2 Queuing Models for the Container Terminal

The choice of queuing model should be based on the nature of the cargo, the characteristics of the arriving ship (whether or not it is a regular ship, tonnage, container handling capacity, course, etc.), and the container terminal characteristics (closing time, cargo handling time). Each terminal must examine the various arrival times at port and the allocation of the respective service time in accordance with the factors described previously, before making the most appropriate choice. This paper refers to the suggestions of Noritake [13] and Noritake and Kimura [14] and adopts the M/Ek/N queuing model, with k = 3.

Because the $W_q$ values cannot be directly obtained mathematically, we used Cosmetatos’ approximation formula [2], which is defined as:

$$W_q = \frac{P_0}{\lambda} \left[ \frac{1 + k}{2k} \left( 1 - \frac{1}{k} \right) - \frac{1}{N} \left( \frac{N-1}{2kN} - \frac{1}{32N^2} \right) \right]$$

(22)

3.3 Results Analysis

Based on the queuing model in the previous section, the parameters and basic data in the model are as per the results of Huang [4]. This paper calculated the results for both methods, without and with classification, as shown in Table 2.

1. The optimum number of cranes and berths under the methods without and with classification were 19/11 and 21/12 respectively, which shows that the optimum number of berths and cranes obtained by without classification are comparatively higher than with classification. As a result, a higher container terminal investment cost ($R_{in} + R_{nc}C^*$) is required.

2. The optimum berth lengths are 2750m and 2950m respectively without and with classification, with the optimum length for a berth being longer with classification.

3. In the method with classification, the values in the IND index are higher than in without classification.

Table 2. A comparison of the results of the analytical method in a year

<table>
<thead>
<tr>
<th>Type</th>
<th>AM-I (Non-classified)</th>
<th>AM-II (Classified)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AA</td>
<td>BB</td>
</tr>
<tr>
<td>TEU</td>
<td>1665622</td>
<td>473093</td>
</tr>
<tr>
<td>VSH</td>
<td>3550493</td>
<td>2990617</td>
</tr>
<tr>
<td>C/N</td>
<td>19/11</td>
<td>6/4</td>
</tr>
<tr>
<td>L</td>
<td>2750M</td>
<td>800M</td>
</tr>
<tr>
<td>$R_{in} + R_{nc}C^*$</td>
<td>4.9</td>
<td>1.6</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.138</td>
<td>0.124</td>
</tr>
<tr>
<td>$DC^*$</td>
<td>0.77</td>
<td>0.697</td>
</tr>
<tr>
<td>$W_c$</td>
<td>1.42</td>
<td>3.58</td>
</tr>
<tr>
<td>$W_c + \rho$</td>
<td>0.09</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Note: $C^*$: The optimum number of cranes
$N^*$: The optimum number of berths
$L^*$: The optimum length of a berth
$\rho^*$: The optimum value of container terminal investment cost; ($I^*=R_{in} + R_{nc}C^*$)
IND*: The optimum value of IND index

The above results can be summed up as follows:

1. Without classification and with classification are two extreme hypothetical conditions.
2. The significance of the method without classification is that all ships, regardless of their size, can occupy any type of berth. Such hypothetical conditions are far looser than in reality. Hence, the results tend to be underestimated.
3. The significance of the method with classification is that all ships berth at their corresponding types of berth in accordance with their ship types. Even when there are vacancies in the larger types of berths, the smaller ships are not permitted to berth at these spaces. Such hypothetical conditions are in fact stricter than in reality, and consequently the calculation results tend to be overestimated.

From these results, this paper proposes the concept of a midpoint between the two (the results of the methods without and with classification) as the “Approach Optimization Determination”. In Fig. 2, the point “AM1” shows the result without classification, which is smaller than the optimum solution. The point “AM2” shows the result with classification, which is larger than the optimum solution. AM1 and AM2 form the range of the results of the analytical method. The result of the simulation...
is closer to the optimum solution than is that of the analytical method; therefore, the range of the results will be smaller than that given by the analytical method. By using this concept, this paper can determine the results accurately and simply.

Fig. 2. The concept of Approach Optimization Determination (A.O.D.)

4. CONTAINER TERMINAL PLANNING USING SIMULATION

Simulation refers to the establishment of a model similar to the actual system for running various experiments and understanding the system behaviors in order to evaluate the gains and losses of various types of system programs based on this method. Due to the complexity of the container terminal operating system, the operating system of the berths in the port cannot easily be fully described in one single mathematical model, and it would be impossible to adopt an on-the-spot proofing method. Therefore, when it comes to container terminal planning, most people use the computer simulation method. The characteristics of the simulation method used by this paper are described below.

4.1 The Design of the Simulation Model

The berth operation system of a container terminal generally has three kinds of events taking place: 1. outgoing ships, 2. incoming ships, 3. ships entering. During simulation, the simulation time is updated based on the most recent occurrence of the three events described above. If more than two events take place concurrently, then the order of processes handled by the program would make the outgoing ships the priority, then the incoming ships, and finally the ships entering.

Many simulation studies carried out their investigation under the assumption of the system running continuously and under steady conditions. However, a simulation model cannot function in such a way because all system simulations require a manual selection of start and finish time, and the time chosen will definitely cause a deviation in conditions that have just started or are close to finishing. This influence caused by a man-made decision regarding the start or finish is referred to as an unstable condition. In reality, the way it is handled is to let the model run for a period of time (the so-called stabilization period) before collecting and calculating the statistics.

The logic of the simulation model in this study is based on the actual condition of the container terminal and is written in FORTRAN language. In order to save computer execution time, the events scanning method is adopted. However, the input data used by this simulation does not entirely coincide with the theoretical layout. Therefore, in order to ensure that it corresponds to the actual conditions, the cumulative probability of the existing data is used for allocation input. However, the service time is determined based on the characteristics and quantity of the cranes generated by the cumulative probabilities. The model ran the simulation 30 times to obtain an average value from the average of ten executions for each time it ran, and used the operation period of 350 ships as the stabilization period.

4.2 The Process of the Simulation Model

As the concept of the model design in the previous section, the framework of the model is shown in Fig. 3. and can be explained as follows:

1. Setting an initial state
   - Starting the program, first read from the basic data the lengths of the simulation terminals, water depths, number of cranes, and whether the collinear is equal to the set value of the terminals. At the same time, set the time for this simulation model.

2. Generation of Ship Arrival
   - According to the analysis of data of various schedule line, this paper produced the parameters of the arrival of ships, such as arrival time of ship, length of the ship, draft, cargo handling capacity, number of cranes, cargo handling rate of the pre-assigned cranes, etc.

3. Assign Berth
   - Use the events scanning method to activate the operation for the simulation model from the time the ship arrives and start directing the ship to enter the port.

4. Ship Berths
   - After the ship enters the port, start assigning the arriving ship to the berth that corresponds to the conditions of the operating regulations. For instance: Is the berth busy or not? Are the depth of water and the length of berth enough for ship berthing? Are the numbers of cranes enough for cargo handling operation? If there is no berth available for the arriving ship, then the ship is to
wait for the earliest available berth that matches its conditions for berthing until the operating ship has finished.

(5) Determine the service time

After the earliest available corresponding berth is found, appoint the ship to enter the port for berthing and compute its required cargo handling hours as well as its departure time, and set the status of this ship as in operation.

(6) Identify whether the system setting time has been reached

Identify whether the program has reached the set simulation time. If not, then repeat step one to continue the simulation. If reached, then stop the simulation process to prepare for the process of related numerical statistics and analysis.

(7) Output the statistical data and the simulation results

Calculate the simulation values generated from the simulation and collect the related parameter values.

Figure 3. The framework of the container terminal simulation model

4.3 Input and Output of the Simulation

The simulation model in this paper is based on incoming and outgoing container ships with the following three categories of input factors:

(1) Berth factors:

Input the actual length and water depth of each berth. A safety factor must be added on both ends for the length of the berthing ship. When there are a series of berths linked in one linear line, then they are treated as one single berth for each related berth location and the number of their assigned overhead cranes.

(2) Ship factors:

a. This paper classifies the ships into six categories in accordance with their cargo tonnage capacities. Enter the percentage of each type of ship, priority percentage of each type of ship, the cumulative probability density of container capacity and the cargo tonnage capacity of each type of ship.

b. The length of a container ship is the main basis for arranging the berthing, as the length of a container ship determines its tonnage capacity.

b. The length of a container ship is the main basis for arranging the berthing, as the length of a container ship determines its tonnage capacity.

(2) Time factors:

a. Inter-arrival time of a container ship: The arrival time of a container ship at port is checked to determine whether it is close to the index allocation, but it is not suitable for the index allocation: it must be allocated with the experiences of the cumulative probability density curves.

b. Import control hours: This simulation hypothesizes the port control hours as 00:00–04:00 hours.

c. Navigation and inspection hours: Container ships generally adopt the port’s method of inspection as they are berthing, which is approximately 0.5 hour from entering port, inspection, to berthing; approximately 2 hours from cargo handling inspection, cable release, to port departure.

d. Cargo handling hours: Such hours are correlated with the number of containers handled and the overhead crane handling efficiency. When there are two or three machines operating concurrently, then there is input data applied to the idle time cumulative probability density, and for the single overhead crane handling efficiency of one, two, or three machine occurrences.

The output of the simulation model includes:

(1) Average ship waiting time for a berth ($W_q$)
(2) Average service time ($1/\mu$)
(3) Utilization ($\rho$)
(4) Evaluation index (IND)

4.4 Model Validation

Validation is concerned with determining how closely the simulation model represents the actual system. The results of the validation are shown in Table 3. For validation purposes, average ship waiting time, average service time and average utilization of berths were obtained through many independent replications, namely 30. A number of average simulation responses were compared against real measures by applying the classical $t$-test (two-sided). Under a probability of rejecting a valid model fixed to the level $\alpha=0.25$, a sample size fixed to $m=30$, and $r=5$ responses, the resulting critical value of the test is $t_{29,0.025}=2.045$. Table 3 shows that model outputs compare acceptably with real measures, as the corresponding $t_{29}$ values are all below the critical values of the test.
**4.5 Simulation Result Analysis**

Based on the actual conditions of container terminal A and the results of the analytical model, we designed several cases as alternative scenarios for the simulation. In those scenarios, the arrangement of the berths is from 9-13 units and the arrangement of the cranes is from 19-26 units. After the results of model calculations with IND as the decision index, scenario 7 results in the better choice, followed by scenario 6. The arrangement of the number of berths and cranes for scenario 7 are 11 units and 20 units respectively, which is 1 berth less and 2 cranes more than the existing condition. The decrease in service hours and the increase in utilization rate indicate that the increase in the number of cranes results in a noticeable enhancement of the service efficiency and the facilities’ utilization rate.

**5. COMPARISONS**

This section organizes the results obtained from the analytical methods and the simulation to find the better container terminal layout condition by comparing the different methods. From Table 5, it is evident that these better arrangements under the methods without and with classification are 11 berths and 19 cranes, and 12 berths and 21 cranes respectively. The better arrangement obtained from the simulation is 11 berths and 20 cranes, which coincides with the above-described results in terms of port investment. Based on the results described above, the data can be organized and generated into a diagram, as shown in Fig. 4. From this diagram, it is evident that the scope of the method with classification covers both the simulation and method without classification, in which the results of the simulation method coincidentally falls in between the methods without and with classification.

---

**Table 3. Validation Comparison of the Simulation Results**

<table>
<thead>
<tr>
<th>Model output</th>
<th>Avg. $t_q$</th>
<th>$t_s$</th>
<th>Avg. $I$</th>
<th>Avg. $t_p$</th>
<th>Real measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheds waiting time ($W_q$)</td>
<td>7.46</td>
<td>1.21</td>
<td>16.33</td>
<td>1.53</td>
<td>55.8</td>
</tr>
<tr>
<td>Service time ($1/t_s$)</td>
<td>Avg. 16.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilization ($I$)</td>
<td>Avg. 55.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4. Simulation Results derived from various scenarios of berths and cranes**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>C</td>
<td>26</td>
<td>24</td>
<td>24</td>
<td>23</td>
<td>22</td>
<td>21</td>
<td>20</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>$L$</td>
<td>296</td>
<td>272</td>
<td>270</td>
<td>269</td>
<td>269</td>
<td>269</td>
<td>268</td>
<td>268</td>
<td>267</td>
</tr>
<tr>
<td>$t_q$</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>18</td>
<td>17</td>
<td>16</td>
<td>15</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>IND</td>
<td>0.17704</td>
<td>0.16925</td>
<td>0.16765</td>
<td>0.16361</td>
<td>0.16037</td>
<td>0.14914</td>
<td>0.14772</td>
<td>0.15621</td>
<td>0.20518</td>
</tr>
</tbody>
</table>

**Table 5. The comparison between the analytical methods and simulation**

<table>
<thead>
<tr>
<th>Analytical Model 1 (Without-Classification)</th>
<th>Simulation Model</th>
<th>Analytical Model 2 (With-Classification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>$L$</td>
<td>16.3</td>
<td>15.2</td>
</tr>
<tr>
<td>$t_q$</td>
<td>15.2</td>
<td>20.6</td>
</tr>
<tr>
<td>IND</td>
<td>0.14772</td>
<td>0.1828</td>
</tr>
</tbody>
</table>

**Figure 4. The comparison of analytical models and simulation**

**6. CONCLUSIONS**

This paper explored facilities allocation planning (number of berths and cranes) from a systematic perspective. Through the comparison of the similarities and dissimilarities of the analytical methods and the simulation, conclusions were obtained as follows:

1. The queuing models tend to produce underestimated results if the ships and berths are not classified into segments by size and length. However, if the ships and berths are classified by size and length, the queuing models will likely provide overestimated results. These hypotheses were two extreme states, not general situations. The optimum solution in general is located between these two hypotheses; it is proved through real data investigation in this paper.

2. This paper made use of the actual data of a certain container terminal to compare the results of two scenarios; with classification and without classification of ship size and berth length. The results indicated that the optimum number of berths and cranes differed between the two scenarios by 1 and 2, respectively.

3. After exhaustively detailed and deliberate modeling, as well as by using real data as inputs, the results of the simulation show that the number of facilities indeed falls somewhere in between the outcomes of the methods with and without classification of ship size and berth length. These findings provide container terminal planners with a convenient and reliable method of determining the optimum number of berths and cranes for a container terminal.
ACKNOWLEDGEMENTS

The authors would like to thank the National Science Council of the Republic of China for its support of the research NSC 89-2213-E-019-022. Some results of this paper are parts of those studies.

REFERENCES


ABOUT THE AUTHOR

Wen-Chih Huang is a professor in the Department of Harbor and River Engineering, National Taiwan Ocean University, Taiwan. His research interests include port planning and management, global logistics management, urban planning and system analysis.

Tu-Cheng Kuo is an associate professor in the Department of Aviation and Maritime Management, Chang Jung University, Taiwan. His research interests include port planning and management, simulation and maritime management.

Sheng-Chieh Wu is an assistant professor in the Department of Business Administration, Meiho Institute of Technology, Taiwan. His research interests include port planning, global logistics management and electronic commerce.

(Received August 2005; revised November 2005; accepted May 2006)
港埠設施規劃解析法與系統模擬之比較

黃文吉
國立台灣海洋大學河海工程學系
郭塗域
長榮大學航運管理學系
吳勝傑*
美和技術學院企業管理系
912 屏東縣內埔鄉美和村屏光路 23 號

摘要

等候理論與模擬為貨櫃碼頭規劃主要的兩種方法，早期以等候理論為主的傳統理論解析，由於船舶與船員沒有分類，與事實有所出入，所以，計算結果偏小。本文提出將船舶及船員分類的方法並以實際數據代入求解，比較不分類法、分類法與模擬等不同方法之計算結果。由結果發現不分類法與分類法兩種計算實為港埠設施配置計畫的兩種極端狀況。因此，本文提出兩者之中間點為近似最適配置之概念。經由詳細的模擬顯示其結果確實落在不分類法與分類法之區間內。除證明本文之推論外，應用本研究的概念將不需要複雜的模擬模式即可求得最精確的結果，提供規劃者一個計算最適解的簡便方式。

關鍵詞：等候模式、模擬、貨櫃終站、比較
(聯絡人：wjiye@seed.net.tw)