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# Measuring port performance of Shanghai Yangshan Deep-water Port by using DEA model with AHP restrain cone

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# World Maritime University

Shanghai, China

ITL - 2010

# Measuring port performance of shanghai yangshan deep-water port by using DEA model with AHP restrain cone

By

**ZHAO WenJie**

China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirement for the award of the degree of

**MASTER OF SCIENCE**

**In**

**INTERNATIONAL TRANSPORT AND LOGISTICS**

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# DECLARATION

**I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.**

**The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.**

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# ABSTRACT

Title of Dissertation: **Measuring port performance of shanghai yangshan deep-water port by using DEA model with AHP restrain cone**

Degree: **Master of Science in International Transport and Logistics**

**Abstract:** This thesis is focused on the measurement of port efficiency in yangshan deep-water port by means of data envelopment analysis (DEA) model together with analytic hierarchy process (AHP) restraint cone. Although there are abundant of article to discuss about measuring port performance by DEA or AHP, little has done contribution to combination of DEA and AHP. The author of this thesis provides a radically different solution to the methodology of evaluation with the integration of both DEA and AHP.

**Key words: yangshan deep-water port, DEA, AHP, port performance**

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AHP Analytic Hierarchy Process

DEA Data evaluate analysis

# Chapter 1 Introduction

## 1.1 Background and research aim

Background

The Yangshan deep-water port is a new port in Hangzhou Bay south of Shanghai. Built to circumvent growth limitations for the Port of Shanghai as a result of shallow waters, it allows berths with depths of up to 15 metres to be built, and is capable of handling the largest container ships today. (wikipedia)The port achieves this by building on the offshore islands of Greater and Lesser Yangshan (part of the Zhoushan archipelago), which have been amalgamated by land reclamation and connected to the mainland via the Donghai Bridge, the latter of which was opened on 1 December 2005 as the third-longest bridge in the world at 32.5 km in length. Since the implementation of international shipping center in shanghai, shanghai port, especially yangshan deep-water port arouse more and more attention among the shipping industries.

In order to support trade oriented economic development, port authorities have increasingly been under pressure to improve port efficiency by ensuring that port service are provided at a high level. Port form a vital link in the overall trading chain and, port efficiency is an important contributor to a nation's international competitiveness(Tongon, 2001).

Port performance evaluation is vital to the related authority. Not only for the reason that port authority is really concerned about how well the port functioned, but also

Research aim

Port consists of lots of activities that is hard to evaluate its efficiency. What's more, the port efficiency appraisal research will affect the planning and strategy of port itself and its hinterland. Since the launch of shanghai international shipping center by the Chinese government, the role of shanghai yangshan deep-water port has been more and more important. Therefore, one effective and logical methodology for measuring port efficiency is urgently needed. However, available studies have not provided a satisfactory answer to the problem of making segment-comparisons of port efficiency. In other words, ports have traditionally made use of quantitative measures to assess their performance, such as total throughput, the size and equipment of the port, ect. While from the quality of the services being offered, little information can be found. The author of the thesis finds the existing problems, and makes some improvement of the measurement for port performance.

## 1.2 Literature review

Mentzer and Konrad (Mentzer, 1991)define performance as an investigation of effectiveness and efficiency in the accomplishment of a given activity and where the assessment is carried out in relation to how well the objectives have been met. Usually, we define it as an accomplishment, and such words as "good", "great", "acceptable" are often used in modifying performance. However, it is too ridiculous to simply use those terms for port performance measurement. The reason is that the port activities combine great amounts of elements, which are hard to measure in the daily life. Moreover, as UNCTAD ([UNCTAD], 1987) mentions that the port itself is a very complex entity that provides different kinds of services such as cargo handling, vessels loading discharge operation and consolidation of inland transportation, things becomes even more complicated with the interrelationship of the above mentioned factors. Therefore, many people have done research work on this subject.

According to Cullinane(Cullinane, 2002), productivity and efficiency are the two most important concepts in this regard and are frequently utilized to measure performance. But which kind of element exactly affects productivity and efficiency turn to be the focal point of others' attention.

Marlow and Paix~ao (Marlow, 2001) points out that ocean freight rates are closely related to port efficiency and productivity. Unproductive seaport performance will increase the price that shippers should pay for inventory charges which will lead to less profit for the port. Nevertheless, the Drewry studies(Drewry, 2002) examined container port performance in an effort to provide guidance to terminal operators. This indicates that there exists a shortcut to measure port performance, which equals to terminal operation measurement. Later on, World Bank officer, Xiamena Clark (Clark, Dollar, & Micco, 2004) suggests that some legal restrictions can negatively affect port performance. For instance, in many countries, workers are required to have special license to be able to provide stevedoring services, artificially increasing seaport costs. Finally, Song(Song & Panayides, 2008) conceptualizes the measurement for port/terminal integration in the supply chain.

Generally speaking, port performance can be divided into two categories: macro and micro performance([UNCTAD], 1999). Macro performance indicates quantifying aggregate port impacts on economic activity while Micro performance is more focusing on quantitative dealing with the inputs and outputs of the activities. Accordingly, the measurement can also be divided into the macro and micro method.

The former is more focused on economic impacts while the latter combines many categories and is discussed by most people.

**Macro performance measurement**

Macro performance measures upon the economic aspect. In a unique application in ports, Dio and Itoh(Dio, 2001) use a **computable general equilibrium(CGE)model** to analyze the impacts of port efficiency improvements on the Japanese economy. The objective is to analyse the relationship between given size ‘shock’ to productivity growth on the GDP of a region, country or group of countries (Cooperation(APEC), 1999). As far as I am concerned, CGE models have gained more popularity in the last decade. It also applies across different sectors including for quantifying the benefits of improved port efficiency on trade facilitation.

**Micro performance measurement**

Micro performance evaluation covers a wide range of sphere listed as follows: Physical Productivity Measurement, Frontier approach which can be specified into two, which are parametric approach and non-parametric approach.

When we mention **Physical Productivity Measurement**, many performance metrics used in the literature only provide ‘snapshot’ measurements, such as for a single port operation (loading, discharging, storage, distribution, etc.) and/or facility (crane, berth, warehouse, etc.) (Bichou, 2006). Similarly, according to Khalid Bichou (Bichou & Gray, 2004) Physical indicators generally refer to time measures and are mainly concerned with the ship (e.g. ship turnaround time, ship waiting time, berth occupancy rate, working time at berth).Sometimes, co-ordination with land modes of transport is measured, such as cargo dwell time or the time elapsed between cargo being unloaded from a ship until it leaves the port.

Chinonye Ugbma(Ugboma, Ogwude, Ugboma, & Nnadi, 2007) identifies and assesses the key determinants of port service quality and determines the quality of service offered by two ports in Nigeria using **SERVQUAL model** and **a Customer Satisfaction Index** to measure port users' level of satisfaction at these ports. It is a **parametric approach**. By making use of the regression model, the author gets customers' satisfaction:

$S_{I\,v} = I_X = \alpha_0 + \beta_1 CORE + \beta_2 RELATION + \beta_3 TANGIBLE + \beta_4 YEARS + \varepsilon$ (CORE= Core dimension of service quality, RELATION= Relational dimension of service quality, TANGIBLE= Tangible dimension of service quality, YEARS=Number of years respondents have been using the port, ε=Error term)

This approach is an innovative method to measure the port performance in respect of service quality in ports. Due to the essence of its 5 dimensions, the variables will affect the performance functionally. SERVQUAL model serves as an early warning system for port managers by diagnosing service deficiencies in the service quality.

**Data Envelopment Analysis (DEA)** is another tool to measure performance which is the representation of **non-parametric approach.** DEA has been proven effective in performance evaluation when multiple performance measures are emerging. Roll and Hayuth(Roll, 1993) first introduced the term DEA in container port performance research. He used single time hypothesized cross-section data to evaluate performance in port. After that, Tongzon(Tongzon, 2001) used DEA to provide an successfully measurement of four Australian ports and twelve other international ports for the year 1996. Nevertheless, Martinez-Budria (Martinez-Budria, 1999) attempted to estimate the efficiency of 26 Spanish ports from 1993 to 1997 by means of DEA. There is no doubt that many studies have been done to adopt the DEA method to measure port performance.

However, they all have some shortcomings in the research. Firstly, the ports they selected were almost in developed countries, which the results can not be used in the developing countries. Secondly, they just unitarily rely on DEA method, not combine it with other tools to make error analysis so as to obtain the optimal outcomes. Later on, Hung (Hung, Lu, & Wang, 2010) tries to explore the operating efficiency, the scale efficiency targets, and the variability of DEA efficiency estimates of Asian container ports. He is the one that put emphasis on the Asian container ports. By means of both DEA and bootstrap method, Hung investigates the geographical factors that influence the port performance and finds out the resource reallocation could prove the port performance.

On the other hand, **measuring liner port performance**(Marlow A, 2003) is another non-parametric approach by Marlow. He argues that the new port measurement indicators will also focus on qualitative issues as they bring increasing visibility within the port environment and along the transport chain, enhancing a better integration of all supply chain logistics elements.

The analytic hierarchy process **(AHP)** method (Satty, 1990) is particularly suitable for modeling qualitative criteria and has found extensive applications in a wide variety of areas such as selection, evaluation, planning and development, decision-making, forecasting, and so on(Vaidya, 2006). However, due to the fact that AHP is more focus on the decision maker's favor, the result will be largely affected by the experience of them, AHP will end by its own limitation.

## Conclusion

After gathering and analyzing the literature review of the port performance measurement, we may gain the thoughts that the evaluation can be achieved under macro and micro ways. Not only the economic impact but also the productivity and frontier approach can do contribution to the port efficiency measuring. Similarly, there are two way to approach the measurement, which is DEA and AHP method. However, they all has its shortcomings. In order to avoid the error of estimation, not 100% rely on either the historical statics or the experience or favor from the decision maker, a new integration of DEA and AHP model has been discussed in the thesis.

### 1.3 Research Methodology and framework

This thesis is focused on the measurement of port efficiency in yangshan deep-water port by means of data envelopment analysis (DEA) model together with analytic hierarchy process (AHP) restraint cone. The author of this thesis provides a radically different solution to the methodology of evaluation with the integration of both DEA and AHP.

Here are the following steps. Firstly, choose the sample, which is all the statistics of yangshan port from 2000 to 2009. Secondly, set up the influential factor of port performance. Thirdly, get the subjective result of key factor from questionnaire survey. Fourthly, calculate the weight by AHP model from the survey. Fifthly, use the input and output value to seek the port efficiency by DEA-AHP model.

The author divides the thesis into four parts, which are “problem definition”, “methodology definition”, “data collection” and “performance evaluation”, particularly. The framework has been illustrated in figure 1 as follows.

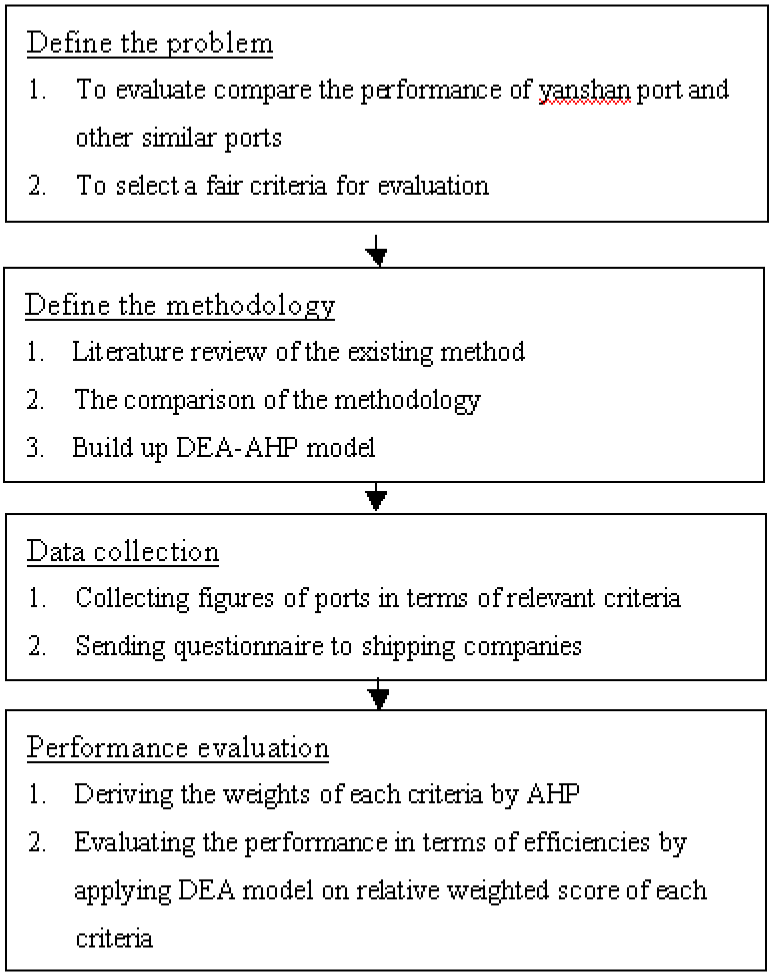


Figure 1- Framework of the thesis

# Chapter 2 Overview of methodology

In this chapter, the author of the essay will introduce two mean methodologies, DEA and AHP model, respectively. After the explanation of the conceptual exposition and steps of the two methods, the author integrates them into the DEA-AHP model and gives the detailed differentiation about them. The main structure of this chapter will be illustrated in the figure 2.

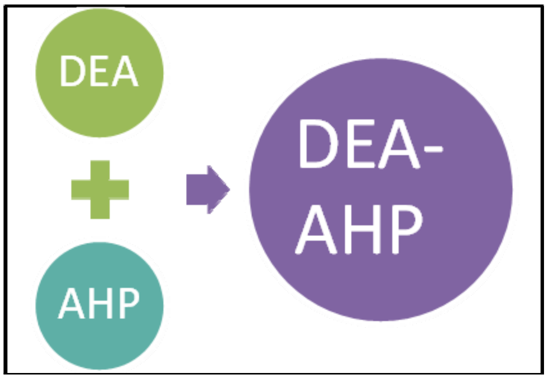


Figure 2- Structure of research methodology

## 2.1 DEA model

### 2.2.1 Conceptual Exposition

Efficiency is a fundamental concept in the field of economics and has been variously defined in different textbooks. By far, many existing article use DEA as a method to measure efficiency. DEA is a methodology based on a linear programming (LP) model for evaluating relative efficiencies of decision making units (DMUs) with common inputs and outputs. It is used for ranking and analysis of DMUs such as industries, universities, hospitals, cities, facilities layouts, etc.(Azadeh, Ghaderi, & Izadbakhsh, 2008)

This DEA model is a production function describes the relationship between inputs and outputs in a production process. (Dinc, Haynes, & Tarimcilar, 2003) We may make some research on the efficiency, so that efficiency can be increased by the following steps. Firstly, we can minimize inputs while holding output constant. Secondly, we can maximize output while remaining inputs. Last but not least, a combination of both can successfully raise up the performance.

### 2.1.2 DEA-CCR model

DEA was first proposed by Charnes et al. (1978)and introduced CCR (Charnes-Cooper-Rhodes) model, to produce the efficiency frontier based on the concept of Pareto optimum.DEA is a powerful tool to evaluate the performance of the organizations in terms of their relative efficiencies.DEA is a non-parametric method of efficiency analysis. The production units are often referred as decision-making units (DMUs).DMUs are directly compared against a peer or combination of peers.DEA is particularly effective in handling complex processes, where these DMUs use multiple inputs to produce multiple outputs.(Jyoti, Banwet, & Deshmukh, 2008)

Suppose there are $N$ DMUs, with m input factors and n output factors, let $k\ (1 \leq k \leq N)$ denote one of the N DMUs. The efficiency $E_k$ of the *k*th DMU, with outputs $Y_{rk}\ (\text{with } r = 1, \dots, n)$ and inputs $X_{ik}\ (\text{with } i = 1, \dots, m)$ is calculated by the following CCR model:

$$Maximize, E_k = \frac{\sum_{r=1}^{n} U_r Y_{rk}}{\sum_{i=1}^{m} V_i X_{ik}} \qquad (1)$$

$$\text{Subject to } \frac{\sum_{r=1}^{n} U_r Y_{rj}}{\sum_{i=1}^{m} V_i X_{ij}} \leq 1, j = 1, \dots, N \qquad (2)$$

Where:

$E_k$: the relative efficiency of a DMU "k".

$U_r$: the weight given to output r.

$V_i$: the weight given to input i.

$Y_{rk}$: the amount of output r (r = 1, ..., s) from DMU "k".

$X_{ik}$: the amount of input i (i = 1, ..., m) from DMU "k".

$Y_{rj}$: the amount of output r (r = 1, ..., s) from DMU "j".

$X_{ij}$: the amount of input i (i = 1, ..., m) from DMU "j".

N: the number of DMU.

s: the number of outputs.

m: the number of inputs.

From the above formulation, the kth DMU is efficient when $E_k$ equal 1 and inefficient if $E_k$ less than 1.The variables $U_r$(r=1,...,n) and $V_i$(I=1,...,m) are the weights to be derived for the corresponding output and input factors while maximizing the efficiency of the kth DMU.

2.2 AHP model

AHP was firstly introduced by Saaty(1980) to support multi-criteria decision making. Thomas Saaty's Analytic Hierarchy Process(AHP) provides a powerful tool that can be used to make decisions in situations where multiple objects are present.

Generally speaking, there are three steps in all to get the final results. The following part will introduce them specificly.

Step 1: build up AHP model

As shown in the figure 3 below, AHP model is built up.

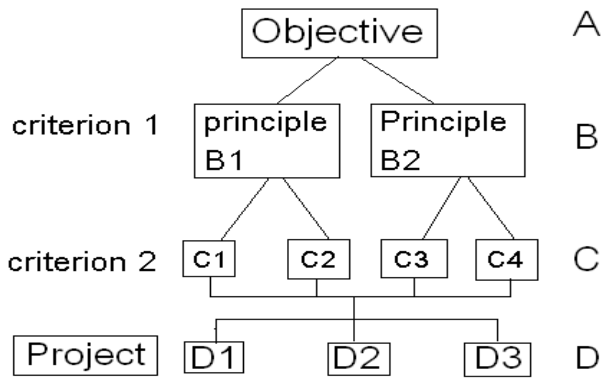


Figure 3- AHP model

Step 2: determine each criterion's weight

There are three sub-steps in all.

Firstly we need to build pairwise comparison matrices. To obtain the weights, we begin by forming a matrix A, known as the pairwise comparison matrix. The entry in row i and column j of A, labeled $a_{ij}$, indicates how much more (or less) important objective i is than objective j.

"Importance" is measured on an integer-value 1-9 scale with each number having the interpretation shown in table 1:

Table 1- interpretation of the value aij

| Value of $a_{ij}$ | Interpretation |
|---|---|
| 1 | Objective i and j are equally important |
| 3 | Objective I is slightly more important than j |

| | |
|---|---|
| 5 | Objective I is strongly more important than j |
| 7 | Objective I is very strongly more important than j |
| 9 | Objective I is absolutely more important than j |

For example:

If $a_{13}$=3, then objective 1 is slightly more important than objective 3; if $a_{13}$ =4, value not in the table, then objective 1 is somewhere between slightly and strongly more important than objective 3. if $a_{13}$ =1/3, then objective 1 is slightly less important than objective 3.

We can create a metrics A, which is $A = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix}$. The rules have to be followed, which are listed below.

1. all $a_{ii}$=1, $(i = 1,2,\cdots,n)$
2. $a_{ji}=1/a_{ij}$ , $(i, j = 1,2,\cdots,n)$
3. $a_{ij}>0$, $(i, j = 1,2,\cdots,n)$

Secondly, we need to normalize pairwise comparison matrices A to get A*. For each of the columns of A, divide each entry in the column by the sum of the entries in the column. This yields a new matrix in which the sum of the entries in each column is 1. Here is the formula: $a_{ij}* = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$. $(i, j = 1,2,\cdots,n)$

Thirdly, we need to estimate the weight $W_i$ for criterion i, finally we get the weight for each criterion. Here is the formula: $W_i = \frac{\sum_{j=1}^{n} a_{ij} *}{n} \; (i, j = 1,2,\cdots,n)$

Step 3: Checking for consistency

Any pairwise comparison matrix can suffer from inconsistencies. We now describe a procedure to check for inconsistencies.

1) Compute AW

$$AW = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix} \bullet \begin{pmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{pmatrix}$$

2) Calculate $\lambda_{\max}$

Find the ratio of each element of AW to the corresponding weight in W and average these ratios.

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}$$

3) Compute the constancy index CI

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

4) Compute the constancy ratio CR

$$CR = \frac{CI}{RI}$$

We can check the random index RI in table 2, and expert suggests that if CR=CI/RI<0.10, then the degree of consistency is satisfactory.

Table 2- Average random index value

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.52 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 | 1.45 | 1.49 | 1.52 | 1.54 |

## 2.3 An integrated AHP and DEA model

### 2.3.1 Analysis of shortcoming for AHP and DEA model

Although AHP and DEA are very popular in measuring efficiency or performance among every aspects of business, these two models, sometimes, cannot satisfy the decision makers. The reasons can be told by their character tics.

On the one hand, in AHP, the weight of each criterion is largely depended on the taste of individual. It is hardly for people to avoid the error when determining the weight, because different people will judge the case on different point of view and the "importance" will be fluctuated by individuals, as well. As for the port performance evaluation, there are several factors to affect the outcome. For example, 3 inputs (number of berth, water depth and number of machinery) and 1 output (annual throughput) are 4 criterions in AHP. Expert A will consider that when measuring the port performance, the most important factor is number of berth, so he define that to be the priority. Similarly, expert B will think annual throughput to be the top rank. The result will, of course, differentiate from each other. Thus, the score of AHP is more or less restricted to the subjective factors and cannot take on the whole picture of the issue.

On the other hand, in DEA, the result is purely calculated by the statistics from the database, which will lead to another extreme. As long as people have picked up the input example, efficiency can be measured by computer software at once.

However, under DEA model, the efficiency lacks in the experienced weight. In other words, it is not possible for DEA methodology to reflect the relationship between one criterion and another. Again, we can take the previous example. We use 3 inputs and 1 output to measure port performance. The accurate figures are accessible from the port statistics and we may easily obtain the efficiency by computer. DEA model helps decision maker to measure performance in terms of the same weight between each factor. However, we can hardly guarantee those criterions to be equally important. Therefore, the efficiency calculated by computer from input data will result in error, as well.

### 2.3.2 Main features of AHP-DEA model

The AHP-DEA model can be summarized as follows.

$$
\begin{aligned}
&\max \mu^T \cdot y_0 = V_P \\
&s.t.\begin{cases} \omega^T \cdot X - \mu^T \cdot Y \geq 0 \\ \omega^T \cdot x_0 = 1 \\ \omega \in V, \mu \in U \end{cases} \\
&V = \{\omega \mid A \cdot \varpi \geq 0, \omega \geq 0\} \\
&U = \{\mu \mid B \cdot \mu \geq 0, \mu \geq 0\}
\end{aligned}
$$

In AHP model, V is the input scale, and U is the output scale. A is the input "importance matrix", B is the output "importance matrix". $\varpi$ is the input criterion weight, $\mu$ is the output criterion weight. In DEA model, X is the DMU for input, and Y is the DMU for output. For the consideration of subjective and objective factors, the author integrates AHP with DEA model.

The author of the essay has summarized the main feature of the new integrated AHP-DEA methodology, which has the following advantages over other two methods of absolute priorities:

1) Less pairwise comparisons: the new integrated AHP-DEA methodology only requires the DMU to provide a pairwise comparison matrix on decision criteria, but requires no experts to make any pairwise comparisons on alternatives or linguistic grades.

2) Less computation: the new integrated AHP-DEA methodology has no synthesis of pairwise comparison matrices and requires no heavy calculation.

3) No limitation to the number of linguistic assessment grades.

The new integrated AHP-DEA methodology groups alternatives into different categories for each criterion, which are characterized by linguistic assessment grades. This turns out to be much easier and more practical than ranking ordering decision alternatives in the voting AHP when the number of decision alternatives is very large.(Ying-Ming Wang, 2008)

# Chapter 3 Overview of Shanghai yangshan deep-water port

## 3.1 Environmental analysis of yangshan deep-water port

The Yangshan deepwater port is located close to a chain of islands between the Hangzhou Bay and the mouth of the Yangtze River. The location of Yangshan is very ideal for large container ships. Yangshan, as a natural and superb deepwater port, is just 45 nautical miles from international waters and about 27 kilometers away from the Luchao Port in Nanhui District. The Donghai Bridge links the port with Shanghai's network of communication lines and gives it good connections with the economic hinterland of the Yangtze River Delta.

As illustrated in the picture, Yangshan deepwater port is in the frontier of shanghai, and making up for the natural shortcoming of shanghai port. It takes less than an hour by bus to go from Pudong to the port. The 32.5-km-long Donghai Bridge, linking the yangshan Island with Pudong, is one of the focal points during the first stage construction of the port. A standard two-way, six-lane expressway with emergency parking areas is 31.5 meters wide and designed for vehicles to travel at up to 80 km per hour. The tonnage of the vessel that is allowed to go through the bridge is limited to 5000. The main hole of the bridge is 45m in height.


Tips:

Figure "A" stands for yangshan deepwater port.

Figure 4- Overlook of Yanshan port and shanghai

Source: google map from www.google.com

Besides, there is another creative design for transportation system, called Luchao harbor railway terminal. It is the a intermodal rail yard that closely connect with the Donghai Bridge. Shown in figure 5, driving directions from luchao harbor to Yangshan port is **44.6** km. It allows the intermodal activities operating smoothly in the Yangshan deep-water port.

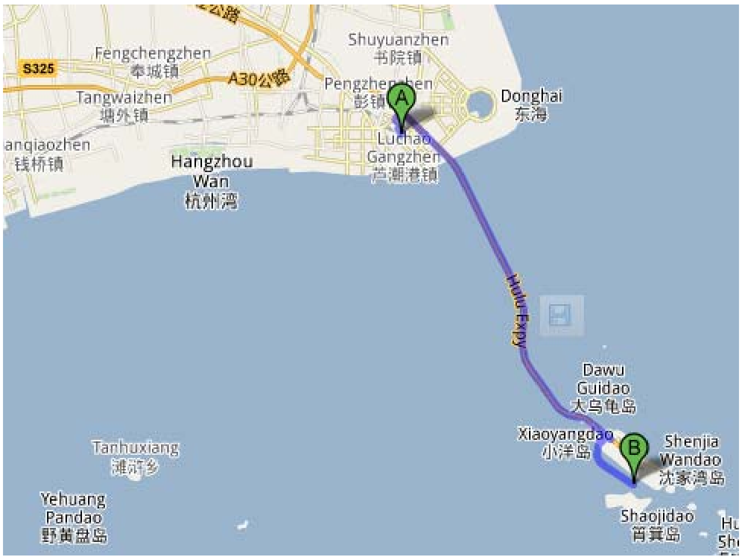


Figure 5- Distance between Yanshan port and Luchao Harbor railway terminal
Source: google map from www.google.com

Then turn to the terminal aspect, figure 6 illustrates the general picture of railway terminal in Luchao harbor. There are four lines, one container yard for putting import and export container boxes. By means of the robber-tired gantry crane and chassis, the container on the chassis can be loaded directly to the rail. It saves the repackaging time and cost just because the cargo will stay in the container box during the process of transportation.

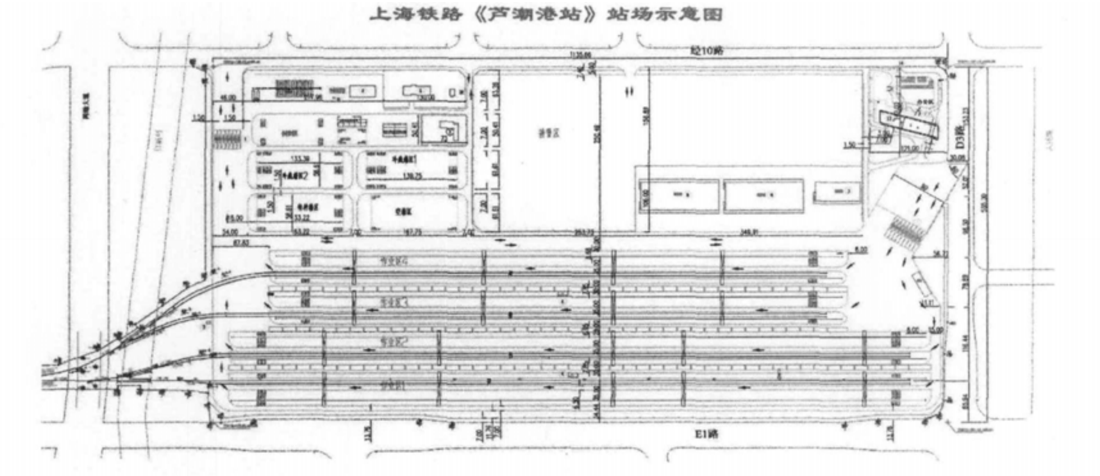


Figure 6- Shanghai Luchao Harbor railway terminal area
Source: The system analysis of Railway-Sea Container Transport of Yangshan port, (may 2007)

As summarized, yangshan port has successfully become the door of shanghai to welcome the increasing volume of containers. The first two phases of the US$14.5 billion Yangshan deep-sea port are now open, with a 2020 target year for achieving the full capacity of the port (33 to 50 deep-sea berths) at 25 million TEUs per year.

### 3.2 Influential factor of port performance

From the existing thesis, the influential factors chosen by different authors are differentiated from each other, when determining the measurement of port performance. Most of the authors pick the criterion of infrastructure to be the input, and throughput to be the output. Chart shows the summary of evaluating indexes.

Table 3- Summary of Evaluating Indexes

| author | Input data | Output data |
|---|---|---|
| Tongzon<br>(Tongzon, 2001) | Number of quay cranes<br>Berth number<br>Yard area<br>Labor | Throughput<br>Loading and discharging efficiency |

| | | |
|---|---|---|
| Valentine and Gray<br>(valentine, 2001) | Container berth length<br>Total berth length | Container throughput<br>Total volume of cargo |
| Wang, song, and Cullinane<br>(Wang, 2003) | Yard length<br>Yard area<br>Number of Quay Crane<br>Number of straddle carriers | Container throughput |
| Ping Ji, Teng-fei Wang, Kevin Cullinane<br>(P. J. Kevin Culliance, Teng-fei Wang, 2005) | Terminal length<br>Terminal area<br>Number of Quayside gantry<br>Number of Yard gantry<br>Number of Straddle carrier | Container throughput |
| Kevin Cullinane, Teng-Fei Wang, Dong-Wook Song, Ping Jin<br>(Culliane, 2006; T.-f. W. Kevin Culliance, 2006) | Yard Length<br>Yard Area<br>Number of Quay Crane<br>Number of rubber tired crane | Container throughput |

Source: *Attached literature review*

As illustrated in table 3, many authors are willing to choose berth length, number of loading and discharging facilities and yard area to be the input data when measuring port performance efficiency.

Generally speaking, when shipping companies decide to choose a port, they consider many factors as the key decision unit. Somehow, the port authority is also desperately anxious about these factors, and wants to attract more shipping corporations to his port by optimizing these relevant variables. The author of the paper has summarized the key factors listed as follows.

First of all, it's the berth length. The berth length is quite vital to port daily operation due to the fact that it will affect the average waiting time for ship to call the port. Second one is berth number. It is no exaggeration saying that port capability is largely constituted by total number berth. The third one is the berth-depth. Under the trend of macro-scale of ship size, some port is worried about the limited berth-depth that cannot serve the giant container vessels. The shortage of berth-depth will prevent one port from growing into modernization. The forth factor is stacking capacity. The size of stacking area makes great impact on terminal operation efficiency. In other words, the bigger yard area to be, the less chance is for stevedore to repacking the container boxes. Large size of stacking area allows full utilization of the facilities such as quay gantries, tractors and container cranes, which will largely decrease the lead time for each ship when loading and discharging boxes. Then we turn to the loading and discharging facilities efficiency, especially the quay crane efficiency, we consider that the total number of loading and discharging equipment will be another important factor for port. This index is also very important, because it will affect the waiting time for ships on berth.

The above factors are the input data, as for the output data, we may say that the first criterion is annual throughput. It reflects the operational capacity of port, and is closely related to the service level and operational efficiency. The annual throughput becomes the basic index when the port authority evaluates port performance. And this index is very sensitive, if one port operates badly, throughput will drop accordingly. But if one port operates very great in aspect of its sufficient operation, appreciated service level and qualified punctuality, more and more shipping companies are willing to select this port to be their mother port. The annual throughput will rocket accordingly. The second criterion, which is vessel berthing time, reflects the service level. All the shipping companies want the port works faster and faster, because all the ships have their own time-schedule, like a shuttle bus, need to call different ports one after another. And less vessel berthing time will provide the ship-owner more room to arrange the voyage. No shipping companies are happy to see the vessel berthing time occupy the large part of total voyage time, thus this index needs to be counted. However, not like annual throughput, berthing time is a negative figure, should be controlled within a certain sphere.

After considering the accessibility of the data and above analysis of the influential factors, the author of the paper chooses 7 factors listed in table 4..

Table 4- Container port performance influential factors

<table>
<tr><td rowspan="7">Container port performance influential factors</td><td rowspan="5">Input data</td><td>A. Container berth length(m)</td></tr>
<tr><td>B. Berth number</td></tr>
<tr><td>C. Loading and discharging equipment<br>(Container quay cranes, Rubber tire gantry cranes and Tractors)</td></tr>
<tr><td>D. Stacking capacity(TEU)</td></tr>
<tr><td>E. Berth depth(m)</td></tr>
<tr><td rowspan="2">Output data</td><td>F. Annual throughput(TEU)</td></tr>
<tr><td>G. Vessel berthing time(hrs)</td></tr>
</table>

### 3.3 Data collection

In principle, Yangshan port has three-stage of construction. Stage 1 and 2 firstly put into operation in 2003, later on, in 2009, Stage 3 has put into operation. From the yangshan port website, we can get the statistics of three stages about the main facility and main equipment, shown in figure 7, figure 8 and table 5 below.

**1 Main Facilities**

| | |
|---|---|
| **Quay length:** | Quay length 1600 meters,Designing annual throughput capacity 4.3 million TEUs |
| **Container stacking yard:** | Land area 2.4 million $m^2$ including stacking yard area 1.39 million $m^2$ ,Total slots of 150,000 TEUs including reefer container slots of 2556 TEUs and dangerous cargo container slots of 1000 TEUs |
| **Gates:** | All intelligent gates, with 20 lane-in and 13 lane-out |

**2 Main Equipment**

| | | |
|---|---|---|
| **Quay crane:** | QC with single spreader | **21** |
| | QC with twin spreaders | **13** |
| | RTG | **108** |
| **Container Tractor:** | 220 | |

Figure 7- Facility and equipment of yangshan port(stage 1 and 2)

Source: Yangshan port website from http://www.shsict.com/eng/shebei.html

| 机械名称 Type of Equipment | 台数 Unit | 起重吨位(吨) Lifting Capacity (ton) | 外伸距(米) /堆高 Outreach (m) / Height |
|---|---|---|---|
| 桥吊 Quay Crane (QC) | 13 | 61 | 63米 / 63m |
| | 1 | 80 | |
| | 2 | 40 | 35米 / 35m |
| 轮胎吊 Rubber-tyred Gantry Crane (RTGC) | 2 | 60 | 堆四过五 / 1 over 4 |
| | 46 | 40 | |
| 集装箱堆高机 Heavy Duty Forklift | 8 | 8 | 堆高7层 / Stacking 7 |
| 集装箱正面吊 Reach Stacker | 2 | 45/42 | 堆高4/5层 / Stacking 4/5 |
| 铲车 Forklift | 10 | 3 | |
| | 4 | 5 | |
| | 1 | 25 | |

Figure 8- Equipment of yangshan port (stage 3)

Source: Yangshan port website from http://www.sgict.com.cn/gdweb/

Table 5- Facility of yangshan port (stage 3)

| | First phrase | Second phrase | Total |
|---|---|---|---|
| Quay length (m) | 1350 | 1250 | 2600 |

Source: shanghai port data from http://www.simic.net.cn/news/detail.jsp?id=18340

From the previous data and statistics from yangshan port authority, the author of the paper makes a summary about the 7 variables in terms of current figure from year 2005 to 2008 and forcast figure in year 2020, shown in table 6 below.

Table 6-Summarized data of yangshan port

| | | current data | | | | forecast data |
|---|---|---|---|---|---|---|
| | Year / Item | 2005 | 2006 | 2007 | 2008 | 2020 |
| input | Berth length (1,000m) | 1.4 | 3 | 4 | 6 | 10 |
| | Berth number | 5 | 9 | 12 | 16 | 30 |
| | Equipment (set) | 374 | 390 | 450 | 524 | 650 |
| | Stacking capacity (10,000m$^2$) | 220.185 | 240.000 | 260.580 | 299.285 | 450 |
| | Berth depth(m) | 15.5 | 16 | 17.5 | 20 | 25 |
| output | Throughput (10,000TEU) | 300 | 322 | 610.8 | 822.8 | 17,994 (Estimated) |
| | Berthing time(hr) | 13.89 | 12.45 | 11.20 | 10.00 | 10 (expert's estimation) |

Source:

Current data is from Ministry of Communications, Transport StatisticsYearbook, year 2005,2006,2007 and 2008

Forcast data is from website of http://www.jy56.gov.cn/new.asp?id=6722

As shown in table 6, the output of throughput and berthing time in 2020 has to be estimated. The author of the paper achieves final estimation through two steps. First step, we pick up the statistics of shanghai port throughput as the sample and make the forecast. Second step, we get the forecasted throughput of yangshan port based on the proportion of throughput between yangshan and shanghai port.

- First step

As table 7 shows, the throughput of Shanghai port from 1978 to 2009 has been categorized to cargo throughput and container throughput. Firstly, under multi-regression by excel, we assume period to be X, and cargo throughput per year to be Y, (see figure 9) then we can get the formula to be $\mathbf{Y = 5.5045x^3 - 184.94x^2 + 2206.7x +}$

**3594.4**, and correlationship $\mathbf{R^2=0.9709}$, which is close to 1. In 2020, the period is 43, put this figure into the formula. After that, we get the estimated volume of cargo throughput in 2020 to be **1,941,747,215** tons. Secondly, we compare the cargo throughput and container throughput together, and find their similarity by means of the regression in excel. As shown in figure 10, by assuming X to be cargo throughput, Y to be container throughput, we can get the formula to be $\mathbf{Y = 3E\text{-}07x^2 + 0.0366x - 423.95}$ **and** $\mathbf{R^2 = 0.9827}$. At last, we get the container throughput forecast in 2020, to be **179,939,915** TEU.

Table 7- Shanghai port throughput

| Period | year | Cargo throughput (10,000 tons) | Container throughput （10,000 TEU） |
|---|---|---|---|
| 1 | 1978 | 7955 | 0.8 |
| 2 | 1979 | 8350 | 1.3 |
| 3 | 1980 | 8483 | 3.1 |
| 4 | 1981 | 8335 | 4.9 |
| 5 | 1982 | 8796 | 6.6 |
| 6 | 1983 | 9191 | 8 |
| 7 | 1984 | 10066 | 11.5 |
| 8 | 1985 | 11291 | 20.2 |
| 9 | 1986 | 12604 | 20.4 |
| 10 | 1987 | 12833 | 22.4 |
| 11 | 1988 | 13320 | 31.3 |
| 12 | 1989 | 14604 | 35.4 |
| 13 | 1990 | 13959 | 45.6 |
| 14 | 1991 | 14679 | 57.7 |
| 15 | 1992 | 16297 | 73.1 |
| 16 | 1993 | 17596 | 93.5 |
| 17 | 1994 | 16581 | 120 |
| 18 | 1995 | 16567 | 152.7 |
| 19 | 1996 | 16402 | 197.1 |
| 20 | 1997 | 16397 | 252.7 |
| 21 | 1998 | 16388 | 306.6 |
| 22 | 1999 | 18641 | 421.6 |
| 23 | 2000 | 20440 | 561.2 |
| 24 | 2001 | 22099 | 634.1 |
| 25 | 2002 | 26384 | 861.4 |
| 26 | 2003 | 31621 | 1128 |
| 27 | 2004 | 37896 | 1455 |
| 28 | 2005 | 44317 | 1808 |
| 29 | 2006 | 53740 | 2171 |
| 30 | 2007 | 56000 | 2615 |

| | | | |
|---|---|---|---|
| 31 | 2008 | 58200 | 2800.6 |
| 32 | 2009 | 59000 | 2500 |

Source: Collected by Shanghai port authority

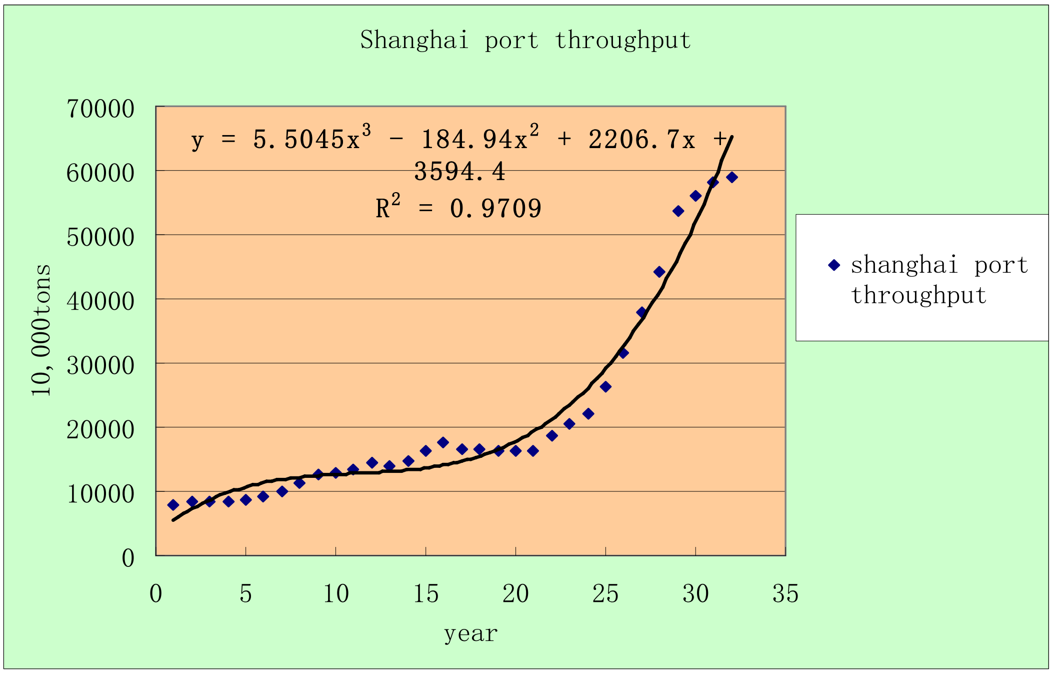


Figure 9- outcome of the simulation on throughput estimate by excel

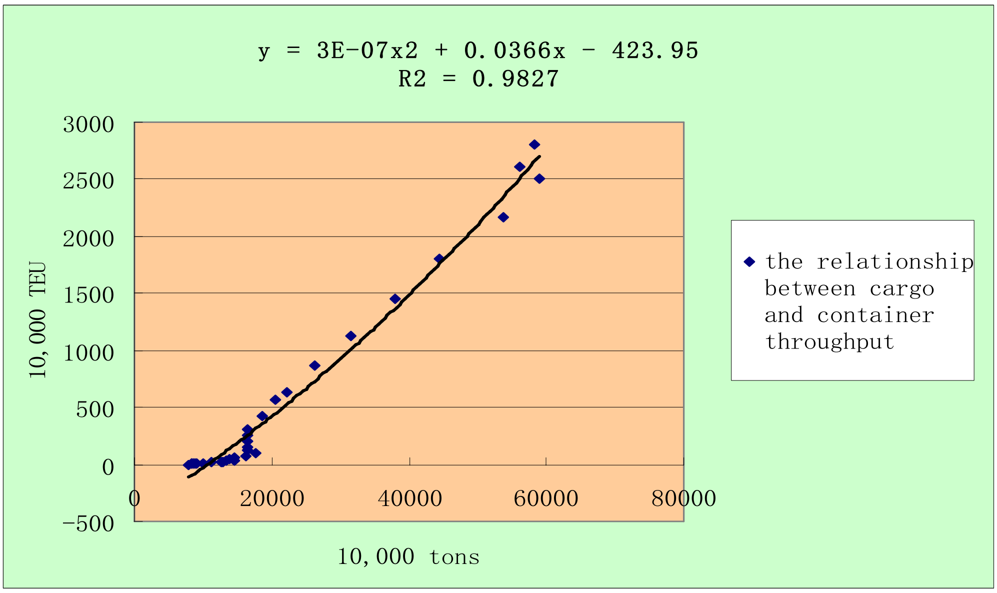


Figure 10- outcome of multinomial series between cargo and container throughput

- Second step

Seen in table 8, we can firstly get the average throughput of yangshan port and shanghai port from 2005 to 2008. Then we calculate the weight of yangshan port to be 21.88%. In 2020, the estimated throughput of shanghai port is **179,939,915** TEU, so the estimated throughput of yangshan port is **179,939,915*21.88%= 39,370,854** TEU

Table 8-Comparison between yangshan port and shanghai port

| year | Yangshan port throughput (10,000TEU) | shanghai port throughput （10,000 TEU） |
|---|---|---|
| 2005 | 300 | 1808 |
| 2006 | 322 | 2171 |
| 2007 | 610.8 | 2615 |
| 2008 | 822.8 | 2800.6 |
| average | 513.9 | 2348.65 |
| proportion | 21.88% | |

Indicated by figure 11, we get the simulation formula to be $\mathbf{Y= 0.06X^2-1.592X+15.415, R^2=0.9999}$. Then we get the estimated berthing time of 2020 to be **5.035**. However, the outcome of this figure is out of reality, which expert thinks the minimum of berthing time can only round **10** hours. Thus, the author of the paper uses **10** to be the estimated berthing time of 2020.

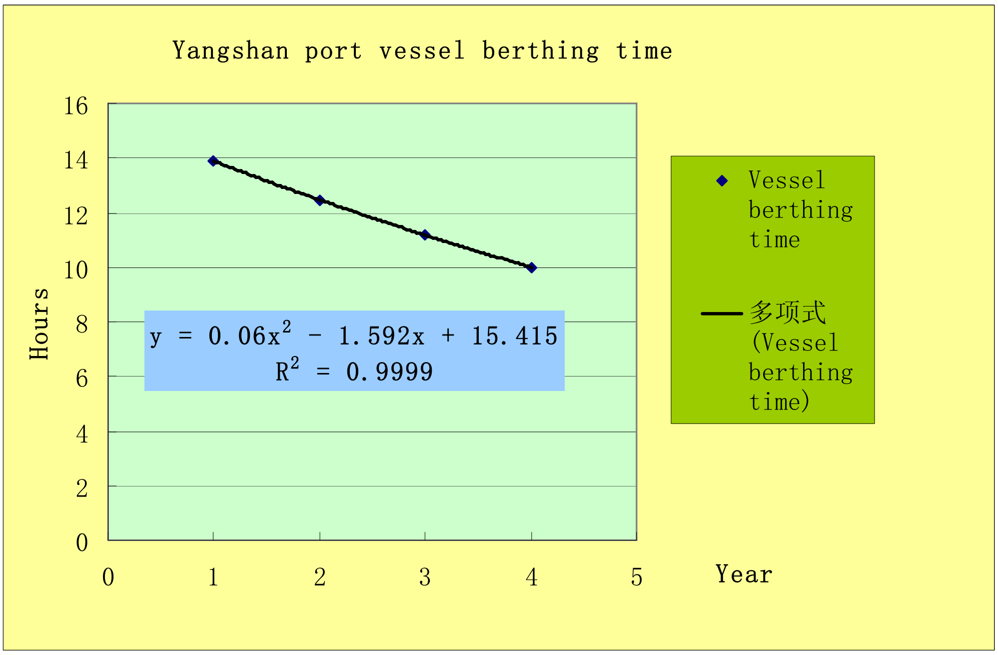


Figure 11- outcome of the simulation on yangshan port vessel berthing time

# Chapter 4 The Analysis of port evaluation

## 4.1 Questionnaire survey of the factor

The purpose of survey is mainly due to data collection on 8 influential factors. After the questionnaire survey, the author of the paper can make use of the collected data to get weights of each factor by means of AHP.

The sampling range is mainly from the experts of port analysis such as the professors of maritime university, the professional port stuffs, government officials and people from container shipping companies such as COSCO, CMA-CGM, MAERSK, K-LINE, ect.

This survey is in the form of questionnaire, which is attached at the end of the paper (Appendix A). By sending e-mail to all relevant people, the author of the paper gets the results.

There are totally 50 sets to be sent, and successfully get 40 sets back. Among the collected 40 samples, 5 are from exporters like university professors, the rest samples are from governmental officials, port stuff and people from the shipping companies.

The questionnaire is divided into two parts, which are input and output. Table 9 illustrates the summary of sampling frame. The meaning for figure 1-9 and character A-F refers to appendix A.

Table 9- summary of sampling frame

| FORM 1 | | | | |
|---|---|---|---|---|
| question | | Maximum score | Minimum score | Mean |
| 1 | B is … to A | 7 | 3 | 5 |
| 2 | C is … to A | 9 | 5 | 7 |
| 3 | C is … to B | 5 | 1 | 3 |
| 4 | D is … to A | 5 | 1 | 3 |
| 5 | D is … to B | 7 | 3 | 5 |
| 6 | D is … to C | 5 | 1 | 3 |
| 7 | E is … to A | 1 | 1 | 1 |
| 8 | E is … to B | 1 | 1/7 | 1/3 |
| 9 | E is … to C | 1 | 1/5 | 1/3 |
| 10 | E is … to D | 3 | 1/9 | 1/3 |

| FORM 2 | | | | |
|---|---|---|---|---|
| Question | | Maximum score | Minimum score | Mean |
| 1 | F is … to G | 9 | 3 | 5 |

From the summary of questionnaire results, the author of the paper builds up the pairwise comparison matrix of input and output data, shown as the table 10 and 11.

Table 10- pairwise comparison matrix of input data

| | A | B | C | D | E |
|---|---|---|---|---|---|
| A | 1 | 1/5 | 1/7 | 1/3 | 1/3 |
| B | 5 | 1 | 1/5 | 1/3 | 1 |
| C | 7 | 5 | 1 | 3 | 3 |
| D | 3 | 3 | 1/3 | 1 | 3 |
| E | 3 | 1 | 1/3 | 1/3 | 1 |

Table 11- pairwise comparison matrix of output data

| | F | G |
|---|---|---|
| F | 1 | 5 |
| G | 1/5 | 1 |

### 4.2 Determination of the weight

Hereby there are two kinds weight in the calculation. One is the input weight, the other is the output weight. By AHP model, we can calculate both weight, respectively. The following parts are the calculation.

1) Forming a matrix $A_{input}$ and $A_{output}$

$$Ainput = \begin{pmatrix} 1 & 1/5 & 1/7 & 1/3 & 1/3 \\ 5 & 1 & 1/5 & 1/3 & 1 \\ 7 & 5 & 1 & 3 & 3 \\ 3 & 3 & 1/3 & 1 & 3 \\ 3 & 1 & 1/3 & 1/3 & 1 \end{pmatrix}$$

$$Aoutput = \begin{pmatrix} 1 & 5 \\ 1/5 & 1 \end{pmatrix}$$

2) Normalized matrix $A_{input}$ to get A*inputBy the formula of $a_{ij}* = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$

$$a_{12}* = \frac{1}{1+5+7+3+3} = 0.0526$$

$$a_{21}* = \frac{1/5}{1/5+1+5+3+1} = 0.0196$$

$$a_{31}* = \frac{1/7}{1/7+1/5+1+1/3+1/3} = 0.0711$$

The others are the same process like it, then we get the $A_{input}$*.

$$Ainput^* = \begin{pmatrix} 0.0526 & 0.0196 & 0.0711 & 0.0667 & 0.0400 \\ 0.2632 & 0.0980 & 0.0995 & 0.0667 & 0.1200 \\ 0.3684 & 0.4902 & 0.4976 & 0.6000 & 0.3600 \\ 0.1579 & 0.2941 & 0.1659 & 0.2000 & 0.3600 \\ 0.1579 & 0.0980 & 0.1659 & 0.0667 & 0.1200 \end{pmatrix}$$

Also normalized matrix $A_{output}$ to get A*oupt

$$a_{11}^* = \frac{1}{1+1/5} = 0.8333$$
$$a_{12}^* = \frac{1/5}{1+1/5} = 0.1667$$
$$a_{21}^* = \frac{5}{5+1} = 0.8333$$
$$a_{22}^* = \frac{1}{5+1} = 0.1667$$

$$A^*output = \begin{pmatrix} 0.8333 & 0.8333 \\ 0.1667 & 0.1667 \end{pmatrix}$$

3) Estimate the weight for criterion i.

By the formula of $W_i = \frac{\sum_{j=1}^{n} a_{ij}^*}{n}$

The input weight $W_A$ to $W_E$ is calculated as follows.

$$W_A = \frac{0.526 + 0.0196 + 0.0771 + 0.0667 + 0.0400}{5} = 0.0500$$
$$W_B = \frac{0.2632 + 0.0980 + 0.0995 + 0.0667 + 0.1200}{5} = 0.1295$$
$$W_C = \frac{0.3684 + 0.4902 + 0.4976 + 0.6000 + 0.3600}{5} = 0.4632$$
$$W_D = \frac{0.1579 + 0.2941 + 0.1659 + 0.2000 + 0.3600}{5} = 0.2356$$
$$W_E = \frac{0.1579 + 0.0980 + 0.1659 + 0.0667 + 0.1200}{5} = 0.1217$$

The output weight $W_F$ and $W_G$ is:

$$W_F = \frac{0.8333 + 0.8333}{2} = 0.8333$$

$$W_G = \frac{0.1667 + 0.1667}{2} = 0.1667$$

4) Checking for consistency

a. Input weight consistency checking

$$AW = \begin{pmatrix} 1 & 1/5 & 1/7 & 1/3 & 1/3 \\ 5 & 1 & 1/5 & 1/3 & 1 \\ 7 & 5 & 1 & 3 & 3 \\ 3 & 3 & 1/3 & 1 & 3 \\ 3 & 1 & 1 & 1/3 & 1 \end{pmatrix} \bullet \begin{pmatrix} 0.0500 \\ 0.1295 \\ 0.4632 \\ 0.2356 \\ 0.1217 \end{pmatrix}$$

$$= \begin{pmatrix} 1\times 0.0526 + 1/5\times 0.0196 + 1/7\times 0.0711 + 1/3\times 0.0667 + 1/3\times 0.0400 \\ 5\times 0.2632 + 1\times 0.0980 + 1/5\times 0.0995 + 1/5\times 0.0667 + 1\times 0.1200 \\ 7\times 0.3684 + 5\times 0.4902 + 1\times 0.4976 + 3\times 0.6000 + 3\times 0.3600 \\ 3\times 0.1579 + 3\times 0.2941 + 1/3\times 0.1659 + 1\times 0.2000 + 3\times 0.3600 \\ 3\times 0.1579 + 1\times 0.0980 + 1/3\times 0.1659 + 1/3\times 0.0667 + 1\times 0.1200 \end{pmatrix}$$

$$= \begin{pmatrix} 0.2612 \\ 0.6723 \\ 2.5325 \\ 1.2935 \\ 0.6341 \end{pmatrix}$$

1) Calculate $\lambda_{\max}$

Find the ratio of each element of AW to the corresponding weight in W and average these ratios.

$$\lambda_{\max} = \sum_{i=1}^{n} \frac{(AW)_i}{nW_i}$$

$$AW = \begin{pmatrix} 0.2612 \\ 0.6723 \\ 2.5325 \\ 1.2935 \\ 0.6341 \end{pmatrix} \qquad W_i = \begin{pmatrix} 0.0500 \\ 0.1295 \\ 0.4632 \\ 0.2356 \\ 0.1217 \end{pmatrix}$$

$$\lambda \max = \frac{0.2612}{5 \times 0.0500} + \frac{0.6723}{5 \times 0.1295} + \frac{2.5325}{5 \times 0.4632} + \frac{1.2935}{5 \times 0.2356} + \frac{0.5341}{5 \times 0.1217} = 5.3169$$

2) Compute the constancy index CI

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{5.3169 - 5}{5-1} = 0.0792$$

3) Compute the constancy ratio CR

Since n=5, then check table 2 in chapter 2, we can get RI=1.12.

$$CR = \frac{CI}{RI} = \frac{0.792}{1.12} = 0.0707 < 0.10$$

The degree of consistency is satisfactory.

b. Output weight consistency checking

The process is the same like input weight consistency checking. The degree of output weight consistency is also satisfactory.

Table 12- Input and output weight

| | Input index | | | | | Output index | |
|---|---|---|---|---|---|---|---|
| | berth length (m) | Berth (number) | Equipment (number) | Stacking capacity (TEU) | Berth depth (m) | Annual throughput (TEU) | Berthing time (hr) |
| weight | 0.0500 | 0.1295 | 0.4632 | 0.2356 | 0.1217 | 0.8333 | 0.1667 |

Table 12 shows the final weight for input and output index, which will be used into AHP-DEA model for further calculation.

### 4.3 Application of AHP-DEA model

The author of the paper utilizes software DEAP2.1 to calculate the efficiency combined with AHP model. From table 13, we see the raw data of software deap2.1, the first two column are output criterion, the rest are input criterions.

Table 13- Raw data of software deap2.1

| year | output1 | output2 | input1 | input2 | input3 | input4 | input5 |
|---|---|---|---|---|---|---|---|
| 2005 | 249.990 | 2.315 | 0.070 | 0.648 | 173.237 | 51.876 | 1.886 |
| 2006 | 268.323 | 2.075 | 0.150 | 1.166 | 180.648 | 56.544 | 1.947 |
| 2007 | 508.980 | 1.867 | 0.200 | 1.554 | 208.440 | 61.393 | 2.130 |
| 2008 | 685.639 | 1.667 | 0.300 | 2.072 | 242.717 | 70.512 | 2.434 |
| 2020 | 14994.400 | 1.667 | 0.500 | 3.885 | 301.080 | 106.020 | 3.043 |

Save the those raw data as the txt file of "port.txt", then fulfill the instruction file named "Eg1-ins.txt", illustrated in figure 12, in which the data file name is "port.txt", number of firm is "5", number of outputs is "2" and number of inputs is "5". After that, run the function program by typing in the name of instruction file "Eg1-ins.txt", shown in figure 13. Finally we get the results, indicated in figure 14.

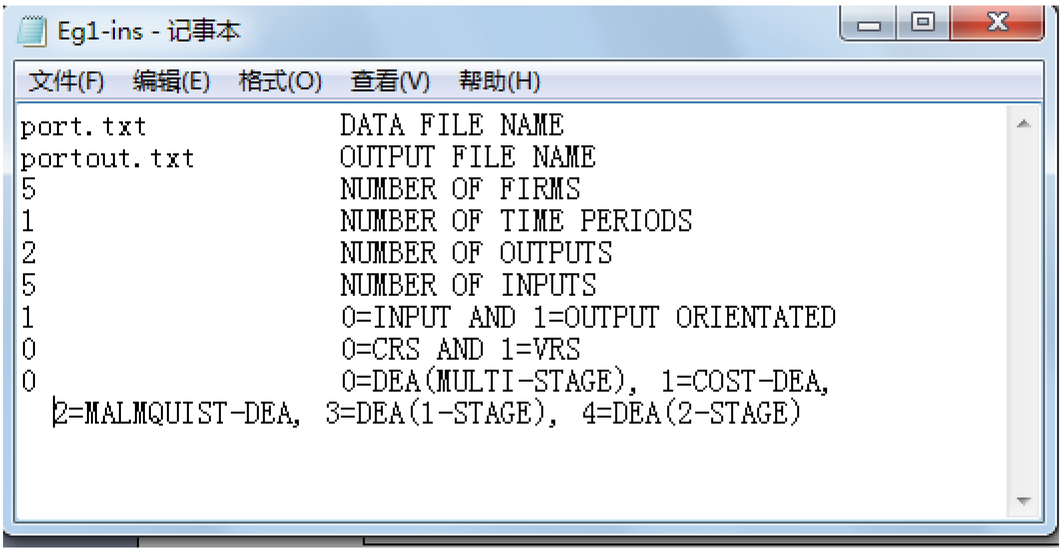


Figure 12- instruction file of DEAP2.1

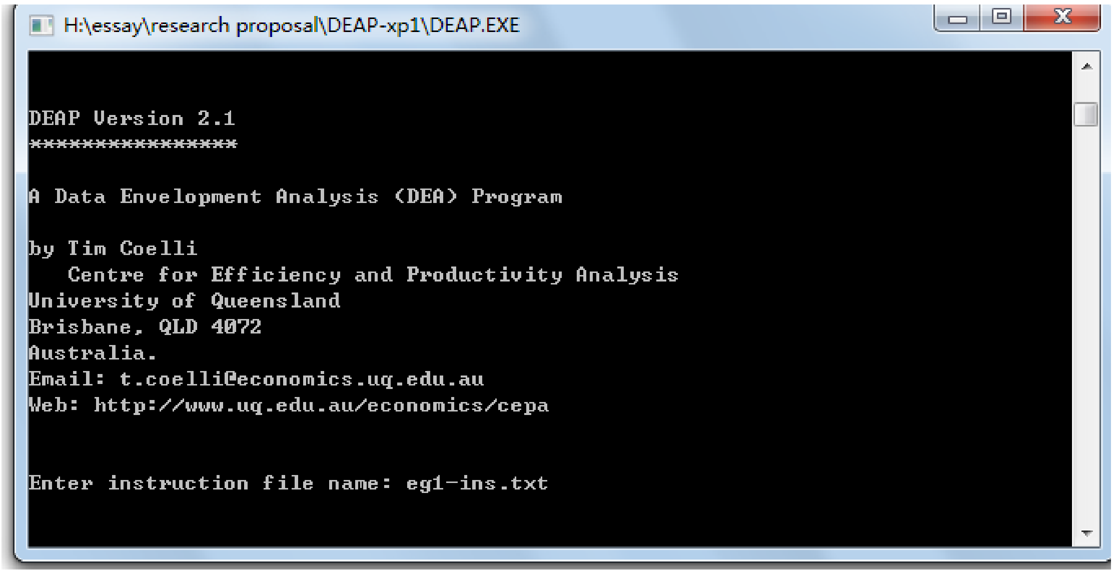


Figure 13- function program

```
 Results from DEAP Version 2.1

Instruction file = eg1-ins.txt
Data file        = PORT.txt

 Output orientated DEA

 Scale assumption: CRS

 Slacks calculated using multi-stage method


 EFFICIENCY SUMMARY:

  firm    te
    1   1.000
    2   0.871
    3   0.731
    4   0.582
    5   1.000
```

```
Results for firm:     1
Technical efficiency = 1.000
 PROJECTION SUMMARY:
  variable            original        radial        slack      projected
                         value      movement     movement          value
 output     1          249.990         0.000        0.000        249.990
 output     2            2.315         0.000        0.000          2.315
 input      1            0.070         0.000        0.000          0.070
 input      2            0.648         0.000        0.000          0.648
 input      3          173.237         0.000        0.000        173.237
 input      4           51.876         0.000        0.000         51.876
 input      5            1.886         0.000        0.000          1.886
 LISTING OF PEERS:
  peer   lambda weight
    1      1.000


Results for firm:     2
Technical efficiency = 0.871
 PROJECTION SUMMARY:
  variable            original        radial        slack      projected
                         value      movement     movement          value
 output     1          268.323        39.800        0.000        308.123
 output     2            2.075         0.308        0.000          2.383
 input      1            0.150         0.000       -0.076          0.074
 input      2            1.166         0.000       -0.487          0.679
 input      3          180.648         0.000       -1.734        178.914
 input      4           56.544         0.000       -2.914         53.630
 input      5            1.947         0.000        0.000          1.947
 LISTING OF PEERS:
  peer   lambda weight
    1      1.027
    5      0.003
```

```
Results for firm:     3
Technical efficiency = 0.731
 PROJECTION SUMMARY:
  variable           original        radial         slack     projected
                        value      movement      movement         value
 output     1         508.980       187.769         0.000       696.749
 output     2           1.867         0.689         0.000         2.556
 input      1           0.200         0.000        -0.110         0.090
 input      2           1.554         0.000        -0.742         0.812
 input      3         208.440         0.000       -12.178       196.262
 input      4          61.393         0.000        -2.172        59.221
 input      5           2.130         0.000         0.000         2.130
 LISTING OF PEERS:
  peer   lambda weight
    5      0.028
    1      1.084


Results for firm:     4
Technical efficiency = 0.582
 PROJECTION SUMMARY:
  variable           original        radial         slack     projected
                        value      movement      movement         value
 output     1         685.639       493.265         0.000      1178.904
 output     2           1.667         1.199         0.000         2.866
 input      1           0.300         0.000        -0.187         0.113
 input      2           2.072         0.000        -1.069         1.003
 input      3         242.717         0.000       -17.878       224.839
 input      4          70.512         0.000        -2.253        68.259
 input      5           2.434         0.000         0.000         2.434
 LISTING OF PEERS:
  peer   lambda weight
    5      0.059
    1      1.196


Results for firm:     5
Technical efficiency = 1.000
 PROJECTION SUMMARY:
  variable           original        radial         slack     projected
                        value      movement      movement         value
 output     1       14994.400         0.000         0.000     14994.400
 output     2           1.667         0.000         0.000         1.667
 input      1           0.500         0.000         0.000         0.500
 input      2           3.885         0.000         0.000         3.885
 input      3         301.080         0.000         0.000       301.080
 input      4         106.020         0.000         0.000       106.020
 input      5           3.043         0.000         0.000         3.043
 LISTING OF PEERS:
  peer   lambda weight
    5      1.000
```

Figure 14- Output of DEA analysis

The efficiency of yangshan port from 2005 to 2008 is 1.000, 0.871, 0.731 and 0.582, respectively. The great performance was in year 2005, after that, since more traffic attracted, the total throughput was getting bigger and bigger. Even many equipment has been put into operation, the operational efficiency can not satisfy most customers. However, in year 2020, with the prediction of the cargo volume and berthing time, together with the construction planning of yangshan port authority, the author of the paper made another performance evaluation. Shown in figure 14, the efficiency is up to 1, which means, if yangshan port can establish its development on facilities and total yard area, it will achieve a good performance.

# Chapter 5 Conclusion

The paper is mainly focus on the study of port efficiency. After reviewing of similar studies, the author of the paper find the truth that many scholar use traditional DEA model to evaluate port efficiency. Although this model has been implemented into this field with its own advantage, DEA cannot overcome the shortcomings of objective judgment. Because this kind of model does not reflect weight of each input data and output data, somehow, another model AHP can provide the weight analysis.

The paper of the author integrate DEA with AHP model to make evaluation of port performance, this attempt has successfully avoid shortages of single application of DEA and AHP model. By the utilization of DEA-AHP model, we may find the results more reasonable, both considering the objective and subjective factors.

Another innovation is the data selection. The author of the paper forecast yangshan port's operational data in 2020, in order to make comparison to current performance.

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Appendix A

## Questionnaire on the weight of influential index

Thanks for answering the following questions.

I. Vocation of form filler (   )

A. Professors of maritime university

B. Port stuff

C. Government officials

D. People from shipping company

II. Explanation

In the questionnaire, the character A to H stands for different meanings listed as follows.

| | |
|---|---|
| A | Container berth length(m) |
| B | Berth number |
| C | Loading and discharging equipment<br>(Container quay cranes, Rubber tire gantry cranes and Tractors) |
| D | Stacking capacity(TEU) |
| E | Berth depth (m) |
| F | Annual throughput(TEU) |
| G | Vessel berthing time(hrs) |

And figure 1 to 9 stands for the different interpretation listed as follows.

| Value of $a_{ij}$ | Interpretation |
|---|---|
| 1 | Objective i and j are equally important |
| 3 | Objective I is slightly more important than j |
| 5 | Objective I is strongly more important than j |
| 7 | Objective I is very strongly more important than j |
| 9 | Objective I is absolutely more important than j |

III. According to your experience, please answer the following questions. The chart has already listed 15 questions, each question can only choose one option. Please tick in the form 1 and 2.

| FORM 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| question | | 1 | 3 | 5 | 7 | 1/3 | 1/5 | 1/7 |
| 1 | B is … to A | | | | | | | |
| 2 | C is … to A | | | | | | | |
| 3 | C is … to B | | | | | | | |
| 4 | D is … to A | | | | | | | |
| 5 | D is … to B | | | | | | | |
| 6 | D is … to C | | | | | | | |
| 7 | E is … to A | | | | | | | |
| 8 | E is … to B | | | | | | | |
| 9 | E is … to C | | | | | | | |
| 10 | E is … to D | | | | | | | |

| FORM 2 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Question | | 1 | 3 | 5 | 7 | 1/3 | 1/5 | 1/7 |
| 1 | F is … to G | | | | | | | |