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An Estimation of the Average Waiting Cost of Vessels Calling Container Terminals in Northern Vietnam

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북베트남 컨테이너 터미널에 기항하는 선박의 평균대기비용 추정

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Abstract : *Several studies have been completed on the topic of container terminals in Northern Vietnam. Few of them, however, deal with competition in terms of costs related to vessel waiting time or cargo handling. This paper estimates the average waiting cost per TEU for all the container terminals in Northern Vietnam. After average waiting time was first estimated by applying queuing theory, uncertainty theory was applied to estimated vessel daily cost. A simulation was performed to create a series of data representing waiting cost per TEU in relation to the rate of volume handled/capacity of each terminal. Non-linear regression based on this series was used to present a function for the relationship between the average waiting cost of each terminal and the rate of volume handled /capacity.*

Key Words : *Northern Vietnam, Average waiting cost, Queuing theory, Uncertainty theory, Non-linear regression*

요 약 : 북베트남의 컨테이너 터미널을 주제로 한 연구는 다수 있지만, 선박의 대기시간이나 화물처리에 관련한 비용 측면에서의 경쟁을 다룬 연구는 거의 없다. 이 논문은 북 베트남에 입지한 컨테이너 터미널의 TEU당 평균대기비용을 추산해 본 연구다. 우선 대기행렬이론을 적용하여 평균대기시간을 추산한 뒤, 불확실성 이론을 적용하여 선박의 일당 비용을 추산할 것이다. 그리고 각 터미널의 하역능력 내지 물동량 처리율과 관련하여 TEU당 일련의 대기시간을 산정하기 위해 시뮬레이션을 실시하였다. 추산된 일련의 대기시간을 근거로 하여 각 항만의 평균대기시간과 물동량 처리율/하역률 간의 관계를 제시하기 위한 함수를 추정하기 위해 비선형회귀법을 적용하였다. 연구 결과는 북베트남의 컨테이너 터미널간의 경쟁상황에 관한 후속 연구에서 게임이론을 적용하는 데 이용될 수 있을 것이다.

핵심용어 : 북베트남, 평균대기시간, 대기행렬이론(queuing theory), 불확실성 이론(uncertainty theory), 비선형회귀(non-linear regression)

1. Introduction

Sea-port industry in Northern Vietnam has witnessed an impressive development in recent years. From 2005 to 2016, both the number of berth and total berth length has doubled the figure and area of container yard in the whole region has increased more than three times. After 2018, the competition among the container terminals in the area will be forecasted to be tougher when the Lach Huyen International Container Terminal begins its operation. The list of local container terminals and their throughput are presented in the Table 1.

There were several studies on the topic of container terminals in Northern Vietnam, including Nguyen and Kim (2015), Nguyen et al. (2016a), Nguyen et al. (2016b) and Pham et al. (2016).

Various quantitative methods were applied to analyse the current competition among container terminals in the area; however, none of them deals with the competition in terms of costs related to vessel waiting time or handling cargoes.

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Table 1. Container terminals in Northern Vietnam

No	Terminal	Throughput 2016 (1,000 TEUs)
1	Chua Ve	270
2	Tan Vu	788
3	Dinh Vu	722
4	Nam Hai	255
5	Nam Hai Dinh Vu	464
6	Hai An	293
7	PTSC Dinh Vu	245
8	Doan Xa	240
9	Green Port	280
10	VIP Green Port	350
11	Saigon New Port (SNP)	223
12	Transvina	120
13	Cailan International Container Terminal (CICT)	12
14	Quang Ninh	N/A

Therefore, this paper will plan to estimate the average waiting cost per TEU of all the container terminals in Northern Vietnam. After the average waiting time is firstly estimated by the application of queuing theory, uncertainty theory will be then applied to estimate the vessel daily cost. A simulation is performed to create series of waiting cost per TEU in the relation with the rate of volume handled/ capacity of each terminal. Non-linear regression based on the series is used to present the equation which presents the relationship between the average waiting cost of each terminal and the rate of volume handled/ capacity.

The regression will return such relationship in the following equation:

$$AWCi = f(Xi/CAPi) \tag{1.1}$$

Where:

- AWC is denoted for average waiting cost at terminal i
- Xi is denoted for volume handled by terminal i
- CAPi is denoted for capacity of terminal I which is constant in short period
- (Xi/CAPi) is the rate of volume handled/ capacity which impact the average waiting cost by the equation f(Xi/CAPi) which is the result of regression analysis. When the volume of container handled at terminal increases, Xi/CAPi will increases and average waiting time will likely increase significantly, especially if Xi/CAPi is equal or greater than 0.8.

The result can be used for further researches on the topic of competition among container terminals in Northern Vietnam, especially, studies applying game theoretical approach.

2. Estimation of Vessel Waiting Time

According to Radmilovic and Jovanovic (2006), the average total port time of container vessel can be estimated by:

$$T = T_W + T_b + T_{ber} + T_{unber} \tag{2.1}$$

Where:

- Tw is average waiting time of vessel for free berth
- Tb is average service time per vessel
- Tber is average berthing time (Tber = 1.0 hour per vessel, according to international practice)
- Tunber is average unberthing time (Tunber = 1.0 hour per vessel, according to international practice)

According to Thoresen (2003), the berth occupancy ratio in percents due to working time including peak factor/week can be defined by:

$$B_{\mathrm{or}} = \frac{T_{wtc} \times 100}{B_n \times \dfrac{W_d \times W_h}{S_{cs}}} \tag{2.2}$$

Where:

- Bor is berth occupancy ratio in percentage
- Twtc is total working time per vessel from berthing to unberthing in hours
- Bn is number of berths
- Wd is working days/week
- Wh is working hours/day
- Scs is number of container vessels berthing/ week

According to Radmilovic (1992), the average waiting time/average service time ratio can be defined by:

$$\gamma = f(c,\rho) = \frac{T_w}{T_b} = \frac{L}{c\rho} \tag{2.3}$$

Where:
- Tw is average waiting time
- Tb is average service time
- ρ is berth occupancy
- L is average number of container vessels in ports
- c is number of berth

Queuing theory is the study of waiting lines. There are three parts of a queuing system, including: arrivals to the system, queue line itself and service facilities. Kendall (1953) developed a notation for queuing models under the three characteristics: pattern of arrival, service time distribution and number of channels. The form is:

Arrival distribution/ Service time distribution/ Number of available service channels.

Specific letters are used to present probability distribution: M for Poisson distribution, D for constant rate, G for general distribution with given mean and variance.

Arrival characteristics have three major parts, including:

- Size of the calling population, which can be limited or unlimited
- Pattern of arrivals: this is according to a known pattern or randomly. In the case of random arrivals, the arrivals follow a Poisson distribution. Arrival of calling vessels to container terminals, therefore, follows Poisson distribution. The Poisson distribution is (Haight, 1967):

$$P(X=x) = \frac{e^{-\lambda}\lambda^{x}}{x!} \tag{2.4}$$

Where:
- P(X) is the probability of x arrivals
- x is number of arrivals per unit of time
- λ is the average of arrival per unit of time
- e equals to 2.7183

The M/M/s model is characterized by Poisson arrival distribution/ Exponential service time/ Multi channel. According to this model, the average waiting time of a customer is (Kleinrock, 1975):

$$W_q = \frac{L_q}{\lambda} \tag{2.5}$$

$$L_q = \frac{P_0 \times (\frac{\lambda}{\mu})^{s+1}}{(s-1)!(s-\frac{\lambda}{\mu})^2} \tag{2.6}$$

$$P_0 = ((\sum_{n=0}^{s-1} \frac{(\frac{\lambda}{\mu})^n}{n!} + \frac{(\frac{\lambda}{\mu})^s}{s!}(\frac{s\mu}{s\mu-\lambda}))^{-1} \tag{2.7}$$

Where:
- Wq is the average waiting time
- Lq is the length of the queue
- s is the number of channel
- λ is the average of arrival per unit of time
- μ is average of service rate
- P0 is the probability that there is no customer in the line

There are also some assumptions required in order to validate the models:

- Number of arrival vessels in a period of time is random
- All berths of a terminal have the same service rate
- Arrival vessels are served under the basis of first come, first served

3. Estimation of Vessel Daily Cost

After the estimation of vessels' waiting time, the vessel daily cost is required. In this section, a survey under the uncertainty theory developed by Liu (2015) will be performed to complete the given task.

3.1 Uncertainty theory

In analyzing the random phenomena, probability theory has been widely utilized. The study of it was started by Pascal and Fermat in the 17th century but not until 1933 did Kolmogorov successfully build up such a complete foundation for its application. Probability theory needs a large enough sample size to have an estimated probability distribution that is close enough to the long-run cumulative frequency. However, it is not always the case that samples are available to determine the density function of a random variable. Without enough data, some domain experts should be invited to evaluate the belief degree that an event may occur. Some researchers employ subjective probability to deal with the problem; however, Liu in his work pointed out that probability theory may lead to counterintuitive result. At the same time, the concept of fuzziness which was initiated by Zadeh via membership function in 1965 was also taken into consideration in dealing with undetermined properties. Again, Liu claimed the negative chance of using a fuzzy variable as a suitable tool for modelling uncertain quantities. He stated that: “The world is neither random nor uncertain, but sometimes it can be analyzed by probability theory, and sometimes by uncertainty theory.”

Uncertainty theory was introduced by Liu in 2007 and refined by him in 2010. It takes normality, self-duality, countable sub-additivity and product measure as the fundamental axioms to construct basic theoretical work, including uncertain process, uncertain calculus, uncertain differential equation, uncertain logic, uncertain inference, and uncertain risk analysis. The three essential concepts of uncertainty theory can be categorized as follows: uncertain measure, uncertain variable and uncertainty distribution, with uncertain measure recognized as most important. Uncertain measure is used to indicate the belief degree that an uncertain event may happen. The uncertain variable represents a quantity within uncertainty, which is a measurable function from a space of uncertainty to the set of real number, while uncertain distribution describes uncertain variable in a visible way to easily understand.

The study of uncertain statistics was proposed by Liu in 2010 to obtain the uncertainty distribution of experts’ experimental data which was collected based on a questionnaire. In order to determine the uncertainty distribution of an uncertain variable, empirical uncertainty distribution, which is a type of linear interpolation method, was introduced. If an uncertainty distribution has a known functional form with an unknown parameter, the principle of the least squares method is employed. Meanwhile, a method of moments can be used with a non-negative uncertain variable with unknown parameters. In this paper, uncertainty theory can be applied due to the fail of normal statistics in collecting financial report of shipping lines but experts' experimental data is available.

3.2 Application of uncertain statistics to estimate the vessel daily cost

Liu (2015) proposed a questionnaire survey for collecting expert’s experimental data. The starting point is to invite domain experts to complete a questionnaire about the meaning of an uncertain variable ξ “How much do you think is the daily operating cost of container vessel which is … TEUs in terms of capacity?”

We first ask the domain experts to choose a possible value x that the uncertain variable ξ may take, and then quiz him: “How likely is ξ less than or equal to x?” Denote the expert’s belief degree by α. Note that the expert’s belief degree of ξ greater than x must be $1 - \alpha$ due to the self-duality of uncertain measure. An expert’s experimental data (x, α) is thus acquired from the domain expert. Repeating the above process, the following expert’s experimental data are obtained by the questionnaire:

$$(x1,\alpha 1),(x2,\alpha 2),....(xn,\alpha n) \tag{3.1}$$

Based on those experts’ experimental data, Liu (2015) suggests an empirical uncertainty distribution:

$$\Phi(x)=\begin{cases} 0, & \text{if} x < x_1 \\ \alpha_i+\dfrac{(\alpha_{i+1}-\alpha_i)(x-x_i)}{x_{i+1}-x_i}, & \text{if} x_i \le x \le x_{i+1}, 1 \le i \le n \\ 1 & \text{if} x > x_n \end{cases} \tag{3.2}$$

The empirical uncertainty distribution Φ has an expected value:

$$E[\xi]=\frac{\alpha_1+\alpha_2}{2}x_1+\sum_{i=2}^{n-1}\frac{\alpha_{i+1}-\alpha_{i-1}}{2}x_i+(1-\frac{\alpha_{n-1}+\alpha_n}{2})x_n \tag{3.3}$$

In this study, vessels’ daily costs include all costs that the operators spend to maintain the continuous working of the vessel in port. It may include, but not limited to: fuel cost, labour cost, maintenance cost, depreciation cost, etc… Port cost and cargo handling charge which is charged by port authority and terminal operators are out the vessels’ daily cost. There were various researches on the container vessels’ operating cost such as researches of Cullinane and Khanna (1998) or Australian Bureau of Transport Economics (1982). However, all those researches did not cover a wide range of container vessels, especially, feeder vessels which are common to container terminals in Northern Vietnam. Furthermore, those researches are far out of date and the selected sample does not represent the location of Vietnam. Therefore, in this research, daily cost of vessels calling container terminals in Northern Vietnam will be defined by a survey which deploys experience of experts following the uncertainty theory.

Therefore, the container vessel sizes which will be used for the survey are: 400 TEUs, 600 TEUs, 1,000 TEUs, 1,200 TEUs, 1,600 TEUs and 2,000 TEUs. The survey is sent to experts who have worked at least 10 years in the field related to container vessels’ operation such as shipping companies, ship broking companies which are both Vietnamese and foreigners, and keep manager positions in those entrepreneurs.

Table 2. Summary of Container vessels calling terminals in Northern Vietnam

Vessel size (TEUs)	Routes	Shipping lines
420; 560; 700; 1,000; 1,807	HP- HCM	VOSCO, VSCS, Bien Dong, Hai An, …
600; 1,000	China-VN-Malaysia	Evergreen
629; 764	HP-HK-Xiamen-Shanghai	HASCO/ Shanghai Jinjang Shipping
1,022; 1,600	HP-Singapore-Tanjung Pelepas	Maersk, MSC
1,022	HP-Sekou-Laemchabang-Bangkok	NYK
737	HP-Kaoshung	Gemadept Shipping
2,045	HK-HP-HK-Fuzhou-Shantou	MSC
1,009	Incheon-Busan-Shanghai-HP-Shantou-Fuzhou	KMTC/CK Line
1,613	FAS-HP-UIH-HCM-PKL	CMA-CGM
1,200	HP-DN-HK-Taichung	Yangming
2,200	Intra-Asia	Maersk Line

The opinion of experts are collected and calculated by the equation (9) and the final result is the average of all the experts' results. The survey result is summarized in the Table 3.

Table 3. Results of the survey examining the daily costs of vessels calling terminals in Northern Vietnam

Vessel size (TEUs)	Number of answer	Min (USD/day)	Max (USD/day)	Standard deviation	Mean (USD/day)
400	6	2,150.8	3,350	427.72	2,702.65
600	14	2,750	4,525	481.41	3,426
1,000	21	3,100	4,875	417.43	3,925
1,200	18	3,400	4,675	346.12	4,114
1,600	8	4,100	4,725	103.48	4,400
2,000	5	4,775	5,300	97.9	4,970

4. Relationship between average waiting cost per TEU and annual throughput

The input data of all container terminals in Northern Vietnam is presented in the Table 4. The rate of arrival and number of containers handled per vessel is randomized. When the rate of arrival and number of containers handled per vessel are changed, the average waiting time/average service time ratio will be changed correspondingly by the equation (1.1). Average service time can be calculated simply by dividing the number of containers handled by handling speed. Then, the average waiting time can be estimated, accordingly.

When the rate of arrival and number of containers handled per vessel will be changed, then, the volume of containers handled in a year is also changed accordingly. By repeating the step many times, we will have series of average waiting time for different (Xi/CAPi). The average waiting cost per TEU, then, can be estimated by multiplying the average waiting time by the vessel's running cost per hour which is defined by dividing the vessel daily cost by 24.

Base on those series of (Xi/CAPi), we then, perform a non-linear regression to define the relationships between the rate of terminals' throughput and waiting cost per TEU. Non-linear regression is required in this case because the relationship between average waiting cost and the rate of Xi/CAPi is never linear. From common experiments of ports and terminals over the world, when Xi/CAPi increases, the average waiting cost of calling vessels will increase by power function.

Table 4. Input data for queuing model

Terminals	Number of berth	Handling speed (TEUs/vessel/h)	Capacity (1,000 TEUs)
Chua Ve	5	40	550
Tan Vu	5	60	1,000
Dinh Vu	2	60	500
Nam Hai	1	50	150
Nam Hai Dinh Vu	3	60	500
Hai An	1	40	250
PTSC	1	40	250
Doan Xa	1	40	250
Green Port	2	50	350
VIP Green Port	2	60	550
SNP	1	40	250
Transvina	1	40	250
CICT	3	40	520
Quang Ninh	3	40	500

The non-linear regression can be performed by application of SPSS. The result is concluded as follows:

- Chua Ve Terminal: f(X/CAP) = 16.172(X/CAP)^4
- Tan Vu Terminal: f(X/CAP) = 3.080(X/CAP)^4
- Dinh Vu Terminal: f(X/CAP) = 1.268(X/CAP)^4
- Nam Hai Terminal: f(X/CAP) = 0.492(X/CAP)^4
- Nam Hai Dinh Vu Terminal: f(X/CAP) = 1.446(X/CAP)^4
- Hai An Terminal: f(X/CAP) = 1.697(X/CAP)^4
- PTSC Terminal: f(X/CAP) = 3.48(X/CAP)^4
- Doan Xa terminal: f(X/CAP) = 5.489(X/CAP)^4
- Green Port Terminal: f(X/CAP) = 5.389(X/CAP)4
- VIP Green Port Terminal: f(X/CAP) = 4.215(X/CAP)^4
- SNP Terminal: f(X/CAP) = 15.64(X/CAP)^4
- Transvina Terminal: f(X/CAP) = 16.48(X/CAP)^4
- CICT terminal: f(X/CAP) = 16.776(X/CAP)^4
- Quang Ninh Terminal: f(X/CAP) = 23.738(X/CAP)^4

5. Conclusion

By applying queuing theory and uncertainty theory, the paper presents functions which estimate the average waiting cost per TEU of all container terminals in Northern Vietnam. Those functions imply different increasing rate of average waiting cost in different container terminals when serving increasing volume of containers. The paper results are also useful to estimate the other user costs (OUC) of terminals when applying game theory in competition/cooperation of container terminals in one port. Saeed and Larsen (2010) developed a game model to deal with the handling charges of container terminals of one port. The model is then applied in the research of Kaselimi et al. (2011) and Munim et al. (2017). In all the researches, the other user costs OUC for choosing terminal i have the following form:

$$OUCi = COi+f(Xi/CAPi) \tag{5.1}$$

Where:

- OUCi is other user costs of terminal i
- COi is inland transportation cost of terminal i
- f(Xi/CAPi) is the function of the volume handled by terminal i(Xi) and capacity of terminal I(CAPi).

This function describes that when the volume handled increase, the waiting cost which is paid by shipping lines will increase.

Despite of the fact that terminals have different operational characteristics such as number of berth, number of cranes or handling speed in previous studies, the function f(Xi/CAPi) was set exactly the same for all the terminals. The results of this paper, therefore, can improve the game model and contribute to local container terminals' strategies under non-cooperative or cooperative game.

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