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Original article

Application of Game Theory and Uncertainty Theory in Port Competition between Hong Kong Port and Shenzhen Port

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Abstract

This paper unveils the strong competition in container cargo between Hong Kong Port which has been emerging as an international maritime center since the 1970s and Shenzhen Port which has recently gained remarkable achievements in the Pearl River Delta region. Among various competing strategies, the study focuses on the long-term one in which two ports will decide to compete by investing in capacity. The purpose of this research is to examine their decision making process and to suggest future strategic actions in the current situation. Within its scope, only economic profit brought back from the investment is considered. For this reason, an uncertain payoff two-person game model is developed where an uncertain factor of demand is involved. In applying Uncertainty theory (Liu, 2013), the two methods to solve the game are introduced, including uncertain statistics and the expected Nash Equilibrium strategy. The results obtained from this research generate meaningful suggestions for future competition plan for the two selected ports, which conclude that Shenzhen is the dominant port in this long-term strategy. Compared to existing works on the same topic, the paper shows its distinctiveness by studying the latest competitive situation with regard to the uncertain demand in the game model.

Keywords: Hong Kong Port, Shenzhen Port, Container Cargo, Competition, Game Model, Uncertain Payoff

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I. Introduction

After more than half a century since its introduction, the container continues to have an important role in enhancing the global transportation system. Especially in recent decades when containerization and the increasing bargaining power of shippers have brought freedom to shipping lines in making port choices. As a result, port competition has dramatically increased among major seaports and the competition among ports in the Pearl River Delta (PRD) is a clear example. The increase of port competition such as from Shenzhen Port (SZP) and Guangzhou port has led to a considerable decline in Hong Kong Port (HKP) industry which used to be the busiest port in the world. It has witnessed the port pie has been re-divided during the sixteen-year period because of the increasingly fierce competition among the three ports as illustrated in Figure 1. Among the ports of concern, the most visible rivalry is directly between HKP and SZP. HKP with good geographical location, transparent custom clearance and high service level, as an international maritime center, has played a dominant role in handling cargoes and containers in its linked-in regions. On the other hand, since reforming and opening, SZP experienced a notably fast developing rate as the so-called "Shenzhen speed" which has also played a decisive role in the economic development of Shenzhen (Wei, 2013). Hong Kong competes with Shenzhen in the same cargo hinterland as the PRD. In 2013, the container throughput of SZP reached 23.3 million TEU, while that of HKP is only 22.3 million TEUs (See Figure 2). Shenzhen, thus, has surpassed Hong Kong to become the world's third busiest container port for the first time, which re-segmented the port market to be half-half for these two ports.

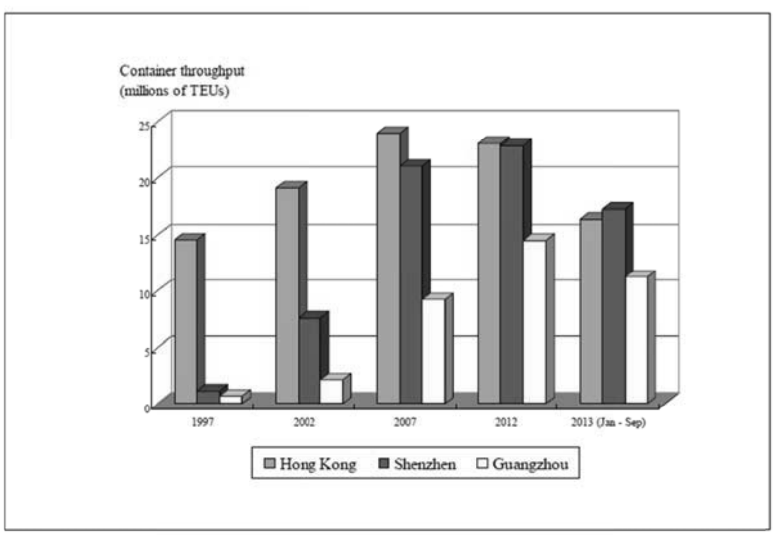

Figure 1: Comparison of container throughput in Hong Kong, Shenzhen and Guangzhou

Source: Legislative Council of Hong Kong (2013), p.3

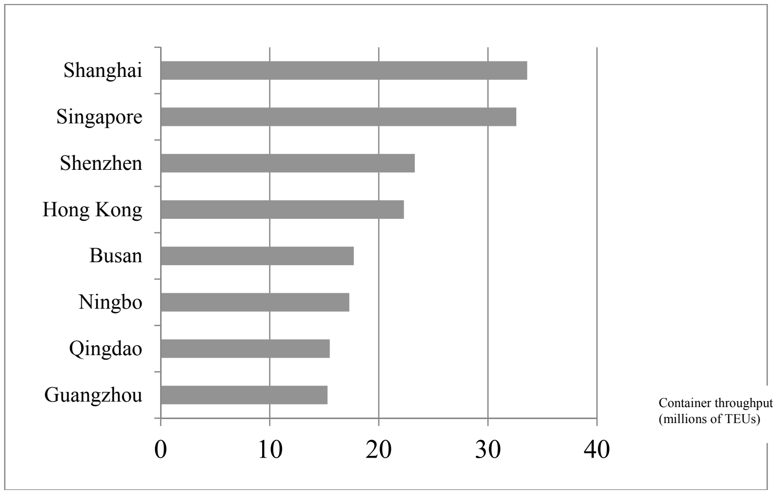

Figure 2: The largest container ports worldwide in 2013

Source: Statista (2014)

In dealing with this rising competition, the two ports must come up with strategic actions in both short-term and long-term plans. This research digs into the long-term competing strategy of capacity expansion investment. The nature of this strategy can be clearly seen from the following point of views. Firstly, capacity of HKP and SZP are, in fact, smaller than the actual throughputs that the two ports are supposed to deal with, which are about 22 million TEUs in 2013. When ports are dealing with excessive throughput over its real capacity, congestion cost incurs. This immediately reduces the attractiveness of the port itself comparing with other rivals. Hence, in the rising transport market, capacity expansion not only helps to create a larger playground for shippers but also solve the issues of market demand, prospectively reduce vessel's turnaround time and increase port attractiveness. Secondly, the expansion allows ports to enjoy a cost advantage from economies of scales, especially HKP with its considerably high cost structure. Thirdly, when ports compete in quantity, an increase in capacity will increase own port's output and reduce the competing port's output. Owing to capacity expansion, the market can be fully served without the need of other entrants. Therefore, in the context of recent port development in the PRD region, port expansion dissuades new entrants from the port market. It was pointed out by Zhang (2008) that calls for more capacity in the port or its hinterland to reduce congestions are stronger in a competitive setting than in the absence of rivalry, such as a single port case. All things considered, capacity expansion is indeed a long-term strategy worthy of consideration.

Following this approach, the paper aims to investigate the two selected ports' decision making process regarding the mentioned long-term plan by applying game theory and uncertainty theory. In particular, a two-person game is built, in which the study of how one port decides to invest given the result from the other port's choice is presented. In considering the real-world factors in this game, it is recognized that uncertain demand which constitutes ports' payoff should be included. Demand factor is indeed a fluctuating variable in the future. Different values of demand can be acquired with a certain percent of chance under different circumstances. Because the future is unidentified, circumstances are also not surely known. This fact was also admitted by Wang, that the characteristics of a regional port system made it truly difficult to forecast future port throughput accurately (2006, p.437). In addition, previous future port forecasts did not really show its perfection; for example, it was predicted that the future port traffic scenarios for HKP in 2010 increased to at least 26.14 million TEU while the real throughput in 2013 was actually only about 22 million TEU (GHP Hong Kong Ltd, 2004). Furthermore, experiences in port expansion seems not to be sufficient and sufficiently reliable since there existed ideas about the appearance of Container Terminal 9 of Hong Kong which was "too much, too late" (Bloomberg, 2004). All these stated reasons raise up the idea of applying Uncertainty theory (Liu, 2013) in forecasting uncertain demand.

II. Literature Review

Several research literatures have also studied capacity expansion as well as have used game theory to investigate general competition and port competition issues in both short-term and long-term plans.

As to the general competition, Tabuchi (1994) constructed a two-stage game in which firms first select the location and then observe the chosen locations and compete in price. The result suggested that two firms maximized their distance in one dimension, but minimized their distance in the other dimension; the firms were better off if they are located sequentially rather than simultaneously; and the welfare loss in equilibrium was 1.6 to 4 times as large as that in optimum. Besides, Gilbert (1984) developed a theory of competition in markets with indivisible and irreversible investments. The research showed that if firms acted as Nash competitors with binding contracts, revenues would exceed costs for any number of firms and otherwise identical firms would earn different profits.

In considering short-term port competition strategy or price competition, Park (2012) used the Hotelling's game to solve the problem of equilibrium price which concluded that a port with better service, lower port charge and shipping cost could monopolize all transhipment containers in a specific route while the other one must increase service level or give up the market.

With respect to capacity expansion using game theory, Park (2006) developed a game theoretic model for an oligopoly trans-shipment container market. This analysis proved that it would be costly and unprofitable to pursue defence of all trans-shipment cargoes that was lost to the low-cost terminal. Development efforts should focus on those markets that yielded greater differences in value between the two hub ports and less vulnerable to capture by a lower cost port operation. Luo (2009) also investigated the long-term strategy of two ports that proved both ports could expand only when the market demand was sufficiently high.

This study does add to the body of literature which considers port competitiveness, but with a more practical approach. In details, it concerns uncertainty in the investment decision that distinguishes this research from the previous ones. As a matter of fact, any long-term decision involves investment risks due to future unknown factors. Since future variables are mysterious to players and each player's payoff is also unidentified to the other, a proper method to evaluate them should be reached. Liu (2013) stated that real decisions are usually made in the state of indeterminacy. In order to model indeterminacy, there exist two mathematical systems, namely probability and uncertainty theory. However, as mentioned above, experiences from port expansion are not sufficient and reliable to construct a large-enough sample size so uncertainty theory is the only solution to the problem.

III. Theoretical basis

3.1. Game model

It is assumed that the capacity expansion project is managed by a separate operator so profit from the project is evaluated as that of an independent property, rather than one accumulated from ports' profit in its existing capacity. Another assumption is that the decision of investment is only based on the forecasted financial performance or profit brought back from the project, excluding consideration of other factors.

The game is designed for two players, namely HKP and SZP in which the pure strategy set of each player includes two strategies of Not Invest and Invest. Besides, the payoff of one player depends on that player's own decision given the other's action. Nash Equilibrium (NE) is the optimal choice of both players. The payoff profiles of two ports are presented below:

Table 1: Payoff profiles of Hong Kong Port and Shenzhen Port

HKP/SZP	Not Invest	Invest
Not Invest	0 ; 0	0 ; $\pi_S(C_H^0, C_S^I) - I_S$
Invest	$\pi_H(C_H^I, C_S^0) - I_H$; 0	$\pi_H(C_H^I, C_S^I) - I_H$; $\pi_S(C_H^I, C_S^I) - I_S$

(Note: π is profit, $C^I$is capacity after expansion; C^0 is capacity without expansion; I is investment cost)

Given the payoffs above, two ports come up with the following strategic decisions:

- $(\pi - I)_{H,S} > 0$: Both choose to Invest. NE is (Invest, Invest)

- $(\pi - I)_{H,S} \leq 0$: Both choose Not Invest. NE is (Not invest, Not invest)
- $(\pi - I)_H \leq 0$ and $(\pi - I)_S > 0$: HKP chooses Not Invest and SZP chooses Invest. NE is (Not invest, Invest)
- $(\pi - I)_S \leq 0$ and $(\pi - I)_H > 0$: SZP chooses Not Invest and HKP chooses Invest. NE is (Invest, Not invest)

3.2. Payoff determination

3.2.1. Function

Payoff function of the two ports is determined as the difference between port revenue and operating expenses and investment cost, which is presented as below:

Revenue function: $\mathrm{R} = \mathrm{P} \times \mathrm{D}$

Operational Cost function: $E = x \times D \times \text{Cost factor}$

Cost factor $= \frac{D}{C}$ (This factor denotes the property of port's operating cost which is proportional with demand and decreases owing to capacity)

Payoff function:

$$\pi = \mathrm{P} \times \mathrm{D} - x \times \mathrm{D} \times \frac{D}{C} - I \quad (1)$$

(Note: R is revenue, P is price, D is demand, x is unit cost)

3.2.2. Uncertain Payoff

3.2.2.1. Preliminary of Uncertainty Theory

At first, some following basic concepts and properties of uncertainty theory will be used throughout this paper.

Definition 1 (Liu, 2013) An uncertain variable is a measurable function ξ from an uncertainty space $(\Gamma, \mathcal{L}, \mathcal{M})$ to the set of real numbers, such that $\{\xi \in \mathrm{B}\}$ is an event for any Borel set B.

Definition 2 (Liu, 2013) The uncertainty distribution of an uncertain variable ξ is defined by $\Phi(x) = \mathcal{M}\{\xi \leq x\}$ for any real number x. For example, the linear uncertain variable has an uncertainty distribution

$$\Phi(x) = \begin{cases} 0, & if x < a \\ (x-a)/(b-a), & if a \leq x < b \\ 1, & if x \geq b \end{cases} \quad (2)$$

denoted by $\mathcal{L}(a, b)$where a and b are real numbers with $(a < b)$.

Definition 3 (Liu, 2013) Let ξ be an uncertain variable. Then the expected value of ξ is defined by

$$\mathrm{E}[\xi] = \int_0^{+\infty} \mathrm{M}\{\xi \geq x\}\, dr - \int_{-\infty}^{0} \mathrm{M}\{\xi \leq x\}\, dr \quad (3)$$

provided that at least one of the two integrals is finite.

3.2.2.2. Methods to decide payoff value

There are two methods in deciding the payoff value. Firstly, if Demand is considered as an uncertain variable (ξ), it can be estimated using Uncertain Statistics. After that, the payoff of each player in each situation is calculated using expected value of Demand - $\mathrm{E}(\xi)$. Given the expert's experimental data, Liu (2013, p.127) suggested a type of linear interpolation method to obtain its empirical uncertainty distribution of ξ, that is:

$$\Phi(x) = \begin{cases} 0, \ if \ x < x_1 \\ \alpha_i + \frac{(\alpha_{i+1} - \alpha_i)(x - x_i)}{x_{i+1} - x_i}, \ if \ \mathrm{x_i} \leq x \leq x_{\mathrm{i+1}}, 1 \leq \mathrm{i} < n \\ 1, \ if \ x > x_{\mathrm{n}} \end{cases} \tag{4}$$

According to the empirical uncertain distribution, the following expected value of ξ is found to be:

$$\mathrm{E}[\xi] = \frac{\alpha_1 + \alpha_2}{2} x_1 + \sum_{i=2}^{n-1} \frac{\alpha_{i+1} - \alpha_{i-1}}{2} x_1 + (1 - \frac{\alpha_{n-1} + \alpha_n}{2}) x_n \tag{5}$$

Secondly, if Payoff is considered as an uncertain variable (ξ), the game can be solved by using the Expected NE strategy for uncertain variables as below.

Any two-person game can be presented as $\Gamma = \langle \{\mathrm{I}, \mathrm{J}\}, \mathrm{U \ x \ V}, \mathrm{A}, \mathrm{B} \rangle$ where $\mathrm{U} = \{1,2, \ldots, \mathrm{m}\}$ be the pure strategy set of player I, and $\mathrm{V} = \{1,2, \ldots, \mathrm{n}\}$ be the pure strategy set of player J; A and B comprise $\mathrm{m} \times \mathrm{n}$ matrices with ξ_{ij} and η_{ij} symbolizing the payoffs of the player I and J associated with the strategy profile (i, j), respectively. Accordingly, the mixed strategy game is illustrated as $\Gamma' = \langle \{\mathrm{I}, \mathrm{J}\}, \mathrm{S_I \ x \ S_J}, \mathrm{A}, \mathrm{B} \rangle$ where the sets of all mixed strategies available for two players are $S_I = \{(x_1, x_2, \ldots, x_m)^T \in \mathcal{R}_+^m | \sum_{i=1}^m x_i = 1\}$ and $S_J = \{(y_1, y_2, \ldots, y_n)^T \in \mathcal{R}_+^n | \sum_{j=1}^n y_j = 1\}$.

When the strategies are randomized, a mixed strategy profile $(x, y)$from each player's own set is chosen which generates the outcome of the game to be $(x^T A y, x^T B y)$, where $x^T A y$ and $x^T B y$ are the expected payoffs of player I and J respectively. Since the players' goals are to maximize the expected value of their uncertain payoffs, the best responses of player I to a strategy $y^* \in S_J$ are the optimal solutions of the uncertain expected value model is $\max_{x \in \mathrm{S_I}} \mathrm{E}[x^\Gamma \widetilde{\mathrm{A}} y^*]$and the best responses of player J to a strategy $x^* \in S_I$ are the optimal solutions of the uncertain expected value model is $\max_{y \in \mathrm{S_J}} \mathrm{E}[x^{*\Gamma} \widetilde{\mathrm{B}} y]$.

Then based on the rational reactions of the player, Gao (2011) presented a new NE strategy as follows:

$$\mathrm{u}^* = \mathrm{E}\left[x^{*\Gamma} \widetilde{\mathrm{A}} y^*\right] \geq \mathrm{E}\left[x^\Gamma \widetilde{\mathrm{A}} y^*\right] \quad \forall x \in S_I \tag{6}$$

$$\mathrm{v}^* = \mathrm{E}\left[x^{*\Gamma} \widetilde{\mathrm{B}} y^*\right] \geq \mathrm{E}\left[x^{*\Gamma} \widetilde{\mathrm{B}} y\right] \quad \forall y \in \mathrm{S}_J \tag{7}$$

The pair (u^*, v^*) is called the expected value of the game. Let $(x^*, y^*) \in S_I \times S_J$ be an Expected NE Strategy (ENES) then the expected value of the game is $\left(x^{*\Gamma}\Delta y^*, x^{*\Gamma}\nabla y^*\right)$ where

$$\Delta = \begin{bmatrix} E[\xi_{11}] & E[\xi_{12}] & \dots & E[\xi_{1n}] \\ E[\xi_{21}] & E[\xi_{22}] & \dots & E[\xi_{2n}] \\ & \dots & & \\ E[\xi_{m1}] & E[\xi_{m2}] & \dots & E[\xi_{mn}] \end{bmatrix} \quad (8)$$

$$\nabla = \begin{bmatrix} E[\eta_{11}] & E[\eta_{12}] & \dots & E[\eta_{1n}] \\ E[\eta_{21}] & E[\eta_{22}] & \dots & E[\eta_{2n}] \\ & \dots & & \\ E[\eta_{m1}] & E[\eta_{m2}] & \dots & E[\eta_{mn}] \end{bmatrix} \quad (9)$$

Let all entries ξ_{ij} and η_{ij} be independent uncertain variables, then a strategy $(x^*, y^*) \in S_I \times S_J$ is an ENES in Γ if and only if the point $\left(x^*, y^*, x^{*\Gamma}\Delta y^*, x^{*\Gamma}\nabla y^*\right)$ is an optimal solution to the following quadratic programming problem:

$$\begin{cases} max(x,y,u,v) \quad x^T(\Delta_H + \nabla_S)y - u - v \\ \quad subject\ to: \ \Delta y \le (u,u,\dots,u)^T \\ \qquad \nabla^T x \le (v,v,\dots,v)^T \\ \qquad \forall x \in S_I;\ y \in S_J;\ u,v \in \mathcal{R} \end{cases} \quad (10)$$

IV. Case study

4.1. Scenario

HKP is supposed to consider the expansion of Container Terminal 10 (CT10) with a capacity of 2.6 mil TEUs (Legislative Council of Hong Kong, 2001) and an investment cost of $HK 10 billion (San, 1998) (equivalent to $1.3 billion). While SZP is assumed to plan the Yantian terminal expansion project with a capacity of 3.7 million TEUs and an investment cost of RMB 11 billion (Zi, 2005) (equivalent to $1.8 billion). The plan for CT10 and Yantian terminal were floated years ago; however, were postponed due to weak shipping demand. Thus, figures of CT9 and previous Yantian terminal expansion related numbers are used in our study. If the Yantian project is normalized as the same size with CT10 of 2.6 million TEUs, the corresponding investment cost will be driven down to $1.2 billion. If the cost is amortized over 20 years, the yearly allocated cost will be $65 million and $60 million for HKP and SZP respectively.

According to the Study on HKP Cargo Forecasts (GHP Hong Kong Ltd, 2008), future port traffic scenarios are divided into five cases in which the total future volumes of HKP are projected to be 24.9, 25.4, 26.3, 27.2 and 33.8 million TEUs. However, the fifth case is very hard to implement since there is yet no solution to the cost disadvantage of HKP. Therefore, we omitted the fifth scenario in our study. With projected TEUs profile, the growth in volume of TEUs can be calculated relatively as 2.9, 3.4, 4.3 and 5.2 million TEUs.

Since exact port charges are difficult to determine due to the different pricing structure of port operation and confidentiality, port prices are assumed to be terminal handling charges (THC) which are in turn approximately $250 and $150 for HKP and SZP (Legislative Council of Hong Kong, 2013). Besides, based on the analysis of Wang, HKP implements especially high land transportation costs and port operation costs which are about two to three times more than that of SZP (2000, p.10), the operating cost of HKP and SZP are assumed to be $200 and $80 respectively. Furthermore, the market share of the two ports in the container port market is 50% - 50%, which is based on the most recent statistics of port throughputs in 2012 and 2013 (See Figure 1, 2).

4.2. Case 1 – Consider Demand as an uncertain variable

Let us assume an expert in port management is employed to give out an evaluation of future cargo demand, the following data is then collected from the questionnaire. The content of it is about "How likely is demand less than or equal to each forecasted demand level?"

Following pairs of estimation data are supposed to be given:

(x_1, α_1) = (2.9, 0)
(x_2, α_2) = (3.4, 0.5)
(x_3, α_3) = (4.3, 0.8)
(x_4, α_4) = (5.2, 1)

According to empirical uncertainty distribution, Expected value of Demand is calculated as:

$$E[\xi] = \frac{0+0.5}{2}2.9 + \frac{0.8-0}{2}3.4 + \frac{1-0.5}{2}4.3 + \left(1 - \frac{0.8+1}{2}\right)5.2 = 3.68 \text{ (million TEUs)}$$

Applying this expected value of demand to equation (1), we come up with the following results:

- If HKP invests, SZP does not invest: π_H = \$-186.72 million
- If HKP invests, SZP does not invest: π_S = \$75.31 million
- If 2 ports invest: π_H = \$134.57 million, π_S = \$111.83 million

Therefore, regardless of whether HKP invests or not, SZP has a dominant strategy of Invest with positive gain in all cases and HKP should follow the same strategy. NE is (Invest, Invest, 134.57, 111.83)

4.3. Case 2 – Consider Payoff as an uncertain variable

Following the future port traffic forecast mentioned above, all calculated values of the two ports' payoffs in all cases are considered as independent uncertain variables. The uncertain payoffs ξ_H and η_S of two ports can be computed as below:

$\xi_{H11}(0,0,0,0)$; $\xi_{H12}(0,0,0,0)$;
$\xi_{H21}(13.08,(104.23),(412.31),(845))$; $\xi_{H22}(135.77,137.69,116.92,65)$
$\eta_{S11}(0,0,0,0)$; $\eta_{S12}(116.23,94.31,16.08,(112))$;
$\eta_{S21}(0,0,0,0)$; $\eta_{S22}(92.81,106.08,120.27,122)$

Two ports adopt the expected value criterion so we have:

$$\Delta_H = \begin{bmatrix} 0 & 0 \\ (337.12) & 113.85 \end{bmatrix} \quad \text{and} \quad \nabla_S = \begin{bmatrix} 0 & 28.65 \\ 0 & 110.29 \end{bmatrix}$$

To simplify the problem, only pure strategies are assumed to be adopted, so it is easy to see that the following optimal solution satisfies the relative quadratic program: (Invest, Invest, 113.85, 110.29). The result confirms its consistency with the first method which gives SZP a better prospect of further development.

V. Conclusion

The result yielded from the two methods come to the same conclusion that SZP is dominant in capacity investment while HKP can only gain profit from investing when SZP also does. This conclusion reflects the fact that SZP, with strong growth rate in containerized cargo throughput for a number of years despite some general declines across Asia during the global financial crisis, can continue to develop and prospectively surpass HKP in the near future. HKP with high cost structure and without solutions to the problem finds no other way to deal with increasing market demand but to wait for the expansion of the other port. Besides, both ports incur losses when demand far exceeds available capacity, especially HKP. It experiences a loss in profit when demand is just 0.8 million TEUs more than its capacity, because of the extra cost to deal with excess demand. This study; thus, raises up an issue of congestion costs when ports have to deal with extra throughput due to demand growth. However, it opens up opportunities for a bright future when ports can both gain profit as they commit to the investment strategy to adapt to market demand; but again, HKP is the one that needs more consideration as well as a better future forecast in order not to incur losses in operation.

In general, it can be said that a port with a more competitive service price, lower operating costs and investment costs are more likely to expand capacity to adapt to the increase in market demand, while a more expensive port with its high costs profile may be more reluctant to engage in long-term investment. This paper demonstrates with thorough investigation of the latest situation between two selected ports and is unique in taking account of a real-world factor of uncertain demand to its analysis. However, as the uncertainty theory relies entirely on experts' knowledge to determine its set of data, this study can only be applied practically when sufficient professional and qualified experts are there to provide reliable ideas on the issue of interest.

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