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Facility Sharing in Business-to-business Model: A Real Case Study for Container Terminal Operators in Hong Kong Port

Abstract In maritime shipping, sharing economy could prove to be a valuable approach. Nowadays. because of the prevalence of transhipment, and alliance of ship liners, a port with multiple terminal operators needs to manage a large amount of inter-terminal transfer (ITT) of containers. ITT increases operating cost for both carriers and terminal operators. For Hong Kong Port (HKP), a port with five operators, ITT becomes a major problem and burden. One can reduce ITT by assigning vessels to nearby berths. However, such nearby berths may belong to other terminal operators. Indeed, terminal operators can benefit from each other if facilities can be shared. This paper proposes a novel approach to study how the sharing of facility between terminal operators in HKP – who compete for market share – can benefit each other. Here, we propose two resource-sharing strategies. We have conducted numerical experiments based on real data collected from HKP. We examine the performance of the two strategies with respect to costs, service level, and operations efficiency. We found that the sharing economy concept works well in this business-to-business model. It successfully reduces operating cost, while improving the service quality without sacrificing benefits of individual operators. Lastly, recommendations along with insights are provided.

Keywords: Facility sharing; sharing strategies; container terminal, inter-terminal transfer; business-to-business sharing model.

1. Introduction

Sharing economy is prevalent nowadays. The idea of sharing economy refers to the creation of additional benefits, such as economic benefits, environmental benefits by sharing the available resources with others (Acquier et al. 2017). This idea has attracted increasing attention from practitioners in different industries. Its concept may prove to be beneficial to the maritime shipping.

Container terminal operators are under pressure to optimise efficiency, especially at hub ports where a large amount of transshipment are handled in a short period of time (Fan et al. 2012, Paul and Maloni 2013, Jin et al. 2015). To stay competitive, terminal operators have been looking for effective approaches to maintain high operational efficiency (Vis and Koster 2003). Comprehensive reviews on container terminal operations studies are provided in Steenken et al. (2004), Stahlbock and Voss (2008), and Bierwirth and Meisel (2010).

In the past, adjacent ports ran independently, competing for shipping lines' business. Horizontal collaboration or "co-opetition" relationships did not exist until the late 1990s, port co-opetition can result in stronger bargaining power against government policies, investment barriers, mega-carriers and shipping alliances. To attain benefits, adjacent port operators should establish partnerships at various levels, including commercial branding and marketing, coordinating rates, operations, value sharing, and joint governance. Nowadays, many companies collaborate to stay competitive (Chung et al. 2011).

With intense competition faced by the global maritime industry, there have been many collaborations and alliances in the last two decades worldwide. In Asia, one example is the state-directed merger, bringing together the operations of five ports – forming the current Ningbo-Zhoushan port. In North America, inter-governmental agreements have been made between the Port of Portland and the Port of Vancouver to align operations since 1990s. In 2014, the Seattle and Tacoma port commissions unified their terminal management under a single Seaport Alliance. Here, the two port commissions manage cargo terminal investments and operations together, while retaining their respective governance structures (Portoftacoma, 2014). Moreover, Port of Rotterdam collaborated with the Port of Amsterdam by merging independent port data systems for better services. Hamburg port also collaborates with nearby ports, as well as with two Baltic Sea ports, and market themselves as a Northern European metropolitan area (Mclaughlin & Fearon, 2013).

Although collaboration may increase competitiveness (Chung et al. 2011), it could be very time consuming and difficult to negotiate the long-term collaboration terms, as well as getting the approval from all regulatory bodies before the alliance can be established. Also once entering the alliance agreement, the flexibility of individual port is limited.

This paper addresses sharing economy as it is applied to the Hong Kong Port (HKP), a container port with multiple terminal operators. Our contributions are summarized as follows: First, after reviewing the literature of sharing economy and the current practices of container terminal operations, we propose a facility sharing strategy based on the idea of sharing economy to container terminals. Second, we conduct numerical experiments to illustrate the proposed strategy based on real data collected from operators in HKP. Third, we demonstrate sharing economy could be a pragmatic approach to share facility among the operators in HKP. Our work shows that the operating cost of the operators worked independently in the same port is much higher than they worked collaboratively. We also find that full collaboration is less achievable in a competitive environment as some operators may have to sacrifice its own benefit in some situations for the benefits of the port. The sharing economy can indeed create benefits for the operators (e.g. reducing cost, improving service quality, as well as the social welfare) without scarifying their own benefits, which supports the adoption of sharing economy in HKP. Last, we provide detail managerial insights to managing port operations within the context of sharing economy. In short, we believe that the value of rental cost between operators could be an important issue to be addressed in the proposed strategy. Moreover, the sharing economy can enable the operators' flexibility in handling capacity and service mix. Nowadays, there are a number of container ports that utilizes multiple operators, such as Port of Singapore and Port of Seattle. For such terminals, our work would be a good reference if they are to consider sharing economy in their future.

We believe that this study of sharing facilities in container terminals is the first work to examine the sharing economy concept in container port operations management and is a first effort to examine the concept of sharing economy with competitor-to-competitor model.

The rest of the paper is organized as follows: Section 2 reviews the existing literature, Section 3 presents the background of the real case study of the HKP, and the two proposed facility sharing strategies, Section 4 analyses and discusses the performance of the sharing strategies, Section 5 provides managerial implications and conclusions.

2. Literature Review

We review the most related papers in two areas: i) sharing economy, and ii) container terminal operations.

2.1 Sharing Economy

Since the First International Workshop on Sharing Economy held in the Netherlands in 2015, there is an increasing body of literature on the concept of sharing economy and its applications. Resources such as accommodation, car, bike, and clothing have been shared in many ways via e-platforms, such as Airbnb, Uber, Peerby, and Bycykel respectively. Sharing economy emphasizes on non-ownership and temporary access of resources (Kathan et al.

2016). It heavily relies on information and communication technologies, such as Internet and social technologies (Mohlmann 2015). More companies and consumers have found that sharing is a way of sustainable and profitable alternative (Lamberton and Rose 2012, He et al. 2017, Jiang and Tian 2018). However, may sharing economy be also beneficial to container port industries, this remains unexplored. Although operations management studies in the field of container port are numerous, none of them has applied the concept of sharing economy (Chung and Chan 2013, Wang et al. 2014, Ma et al. 2014, Kaveshgar and Huynh 2015, Maknoon et al. 2015, Ma et al. 2017).

Traditionally, sharing economy is mainly focusing on peer-to-peer (P2P) or customer-to-customer (C2C) based economic activities. Some of the most remarkably successful examples are well-known as the Airbnb and Uber (Cannon and Summers 2014, Zerva et al. 2017). In P2P sharing model, peer customers will pay certain amount of money to acquire resources shared by other peers through an e-platform (Tussyadiah 2016). A review of sharing economy can be found in Cheng (2016). Other than the sharing of accommodations, cars, etc., there are many others such as the sharing of knowledge (Chen et al. 2015), energy sharing (Li et al. 2017), used good (Xue et al. 2018). There are also business-to-consumer (B2C) sharing model, in which a company offers the shared resources to consumers through an online platform (e.g. sharing of hotel prices information such as Booking.com (Ert et al. 2016), or sharing of bike (Retamal 2017)). Some researchers are working on business-to-business (B2B) sharing applications, such as sharing information between suppliers and retailers (Choi 2013), sharing information for inventory management (Choi 2011), and sharing information across the supply chain (Choi et al. 2016). However, there is a lack of literature on studying B2B sharing model, in which companies involved are competitors.

Other than new startups, who operates on many different P2P and B2C sharing models (Martin et al. 2017), in recent years, the concept of sharing economy has attracted many traditional companies to change their business models or practices. For example, to vehicle manufacturers, Bellos et al. (2017) studied a business model of an original equipment manufacturer (OEM) of vehicle. In the study, they found that such OEMs nowadays have to consider consumer’s concern on car sharing in their product designs. In this area, Kung and Zhong (2017) conducted an analytical study on the optimal pricing strategy for delivering groceries from retailers to consumers. Sharing economy also lead to the concept of sharing cities. Cohen and Muñoz (2016) studied the idea of integrated sharing economy activities to form a more sustainable consumption and production (SCP) in both private and public sectors. They concluded 5 groups of 18 sharing activities to create a sharing cities-SCP Typology.

Sharing economy has shown its power and new business opportunities brought to different industries in reality. In literature, its significances and benefits have also been proved by many operations management studies. Recently, Choi et al. (2019) studied on food leftover problems. They proved that by providing a food leftover sharing platform under the sharing economy concept. It does benefit to the retailers, the supplier, the consumer, and the environment. More importantly, they identified the logistics cost is a key factor in affecting the successfulness of the system. Roma et al. (2019) studied on incumbent's prices in hotel industries. They found that the effect of incumbent prices is in fact depending on the type of incumbents and accommodation period. Xue et al. (2018) studied the impact of selling secondhand product on company's profitability and environment, such as through a company-enabled P2P platform. They studied a two-period model and interestingly demonstrated that secondhand sales can in fact lead to a win-win outcome to both company's profit and environmental impact. Feng et al., (2019) have also studied on the impact of secondary market platform on companies.

2.2 Container Terminal Operations

A typical container terminal consists of two main parts: i) quay side, and ii) yard side (Ma et al. 2017). In quay side, the most classical problems involved are berth allocation problem (Ursavas 2015), quay crane assignment problem (Guan et al. 2013, Ma et al. 2014), and quay crane scheduling problem (Chung and Chan 2013). In yard side, yard storage allocation problem is the most significant (Petering 2009). Connecting the quay side and the yard side is mainly done by internal vehicles, known as the internal yard truck scheduling problem (Wang et al. 2014, Kaveshgar and Huynh 2015).

The premise of port complementarity and competition was investigated by Lam and Yap (2011). They argued that the decision by liner services to call at a particular port at Pearl River Delta (PRD) could be influenced by the joint competitive offering of a group of ports in the area. Wang et al. (2012) further proposed a game theory model for the regional port cluster concept with a division of responsibilities for cargo flows between Hong Kong and other PRD ports.

Nowadays, in most of the busiest container terminals, transshipment is one of the most active activities (Cordeau et al. 2015, Maknoon et al. 2016). Transshipment refers to transferring an unloaded container from one vessel to another vessel for uploading (Zhen et al. 2016). Lee et al. (2012) proposed a multi-terminal system and pointed out the complexity of handling the resources and operations. They also explained the uniqueness and differences between traditional single terminal and multi-terminals in transshipment management. The most important operational issue was ITT as it induces a large operational cost. They developed a two-level heuristic algorithm to minimise the total inter-terminal and intra-terminal handling charges induced by transshipment flows. Later, Jin et al. (2015) proposed a column generation-based approach to solve the problem. They extended the problem scope and simultaneously dealt with three inter-related decisions, including: i) assigning preferred berthing positions, ii) determining service time for cyclically visiting vessels, and iii) allocating storage yard space to transshipment flow. They aimed to minimise the total container movement distance. Zhen et al. (2016) focused on transshipment hub operations, and specifically, on the concept of the berth and yard templates in determining container flow in transshipment hubs. Recently, Ma et al. (2017) further considering practical constraints, which were the discontinuity issues in berth layout. They pointed out that disregarding this issue may lead to seriously low berth space utilisation. To model the discontinuities, they developed a mixed 0-1 LP with a Guided Neighbourhood Search heuristics.

Our paper contributes to the development of sharing economy and its literature. It shows that sharing economy could create benefits for ports with multiple operators. This is the first study to examine the sharing economy concept in container port operations management and is a first effort to examine the concept of sharing economy with competitor-to-competitor model.

3. Background of the Real Case Study – HKP

There are ports with multiple operators. For examples, in Asia, HKP has five operators (Hong Kong International Terminals: HIT, Modern Terminal Limited: MTL, COSCO-HIT, DP World: DPW, and Asia Container Terminals: ATC) as shown in Figure 1, while the Port of Singapore has three operators (Port of Singapore Authority: PSA, Cosco-PSA, and Jurong Town Corporation: JTC). In USA, the Port of Seattle also has two operators (SSA Marine, and Total Terminals International).

Here, we took HKP as a case study. In 2017, HKP was ranked the world's fifth busiest port, handling over 20 million Twenty-Foot Equivalent Units (TEUs) annually. Today, HKP is an international transshipment hub, with international transshipment accounting for 71.2% of the total throughput in 2017, up from 41.6% in the early 2000s. According to the study on the Strategic Development Plan for Hong Kong Port 2030 (BMT Asia Pacific, 2014), the upward trend is expected to continue; transshipment is expected to reach 24 million TEUs (i.e. 75% of total throughput) by 2030.

In the past few years, carriers have struggled with the slower than expected global growth in the international shipping, overcapacity, and low freight rates (UNCTAD 2017). To counter huge financial losses, carriers have turned to larger alliances to help their bottom lines. In 2017, three new major shipping alliances were formed: **2M Alliance:** Maersk, MSC, HMM; **THE Alliance:** Yang Ming, Hapag-Lloyd (with UASC), and ONE (a new joint venture between NYK, MOL and K Line in April 2018); and **Ocean Alliance**: CMA CGM, Evergreen, OOCL, COSCO Shipping. The three alliances represent 77.2% of global container capacity and 96% of all East-West trade.

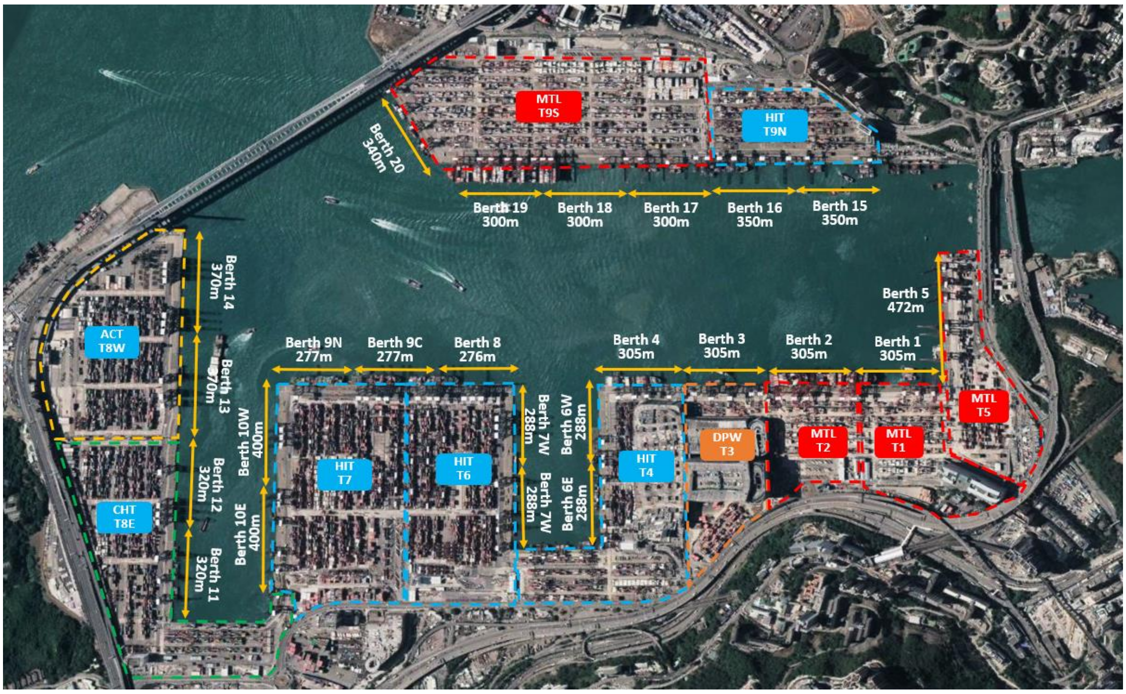

Figure 1. Layout of HKP with the five major terminal operators.

The alliance reshuffle has had an impact on ports. Multiple carriers combining their cargo loads on respective single vessels means that ports have to deal with more frequent of container movements among these vessels. When ocean carriers are consolidating into larger alliances, more transshipment services are needed at each hub port. To fully utilise the vessel, alliances prefer to consolidate shipments with similar destinations in one single vessel.

The average container dwell time at HKP ranges from three to five days. However, the shortest transshipment time (discharging from origin vessel to loading onto destination vessel) can be as short as only a few hours. The increase in transshipment at HKP have therefore put further pressure on the terminals' limited yard and berth capacity, aggravating port congestion. The utilisation rate of HKP rose from 75.5% in 2005 to 89.2% in 2014 (THB, 2015). On the other hand, the short service time requirement for transshipment has imposed pressure on the terminal operators. The process is even more complicated when a container is required to be transferred to other terminals.

At HKP, there are an increasing number of mega vessels carrying containers from multiple liners. Each vessel has its contract with a specific terminal operator. Due to the reformation of carrier alliances, there has been an increase in the number of inter-terminal trucking during operations. For example, if a container is discharged at Terminal 4 (T4) as shown in Figure 1, and later loaded onto another vessel also at T4, the operation and planning is controlled within the same zone and is relatively simple. However, if a container is discharged at T4 and later loaded onto another vessel berthing at Terminal 1 (T1), which is operated by another terminal operator, extra operations and charges are required (Figure 2).

Terminal operators charge liners an ITT handling fee. At HKP, 15% of 17 million annual throughput requires ITT. There is also an increasing trend for ITT due to changes in carriers' alliances. ITT creates under-utilisation and extra operations. When several mega vessels arrive during the same period, the ITT situation becomes even more acute resulting in longer vessel waiting time and turnaround time. This affects HKP's efficiency, including berth-on-arrival rate, vessel waiting time and yard productivity. In addition, high ITT means a lot of drayage at the yard, with many movements of containers between operators.

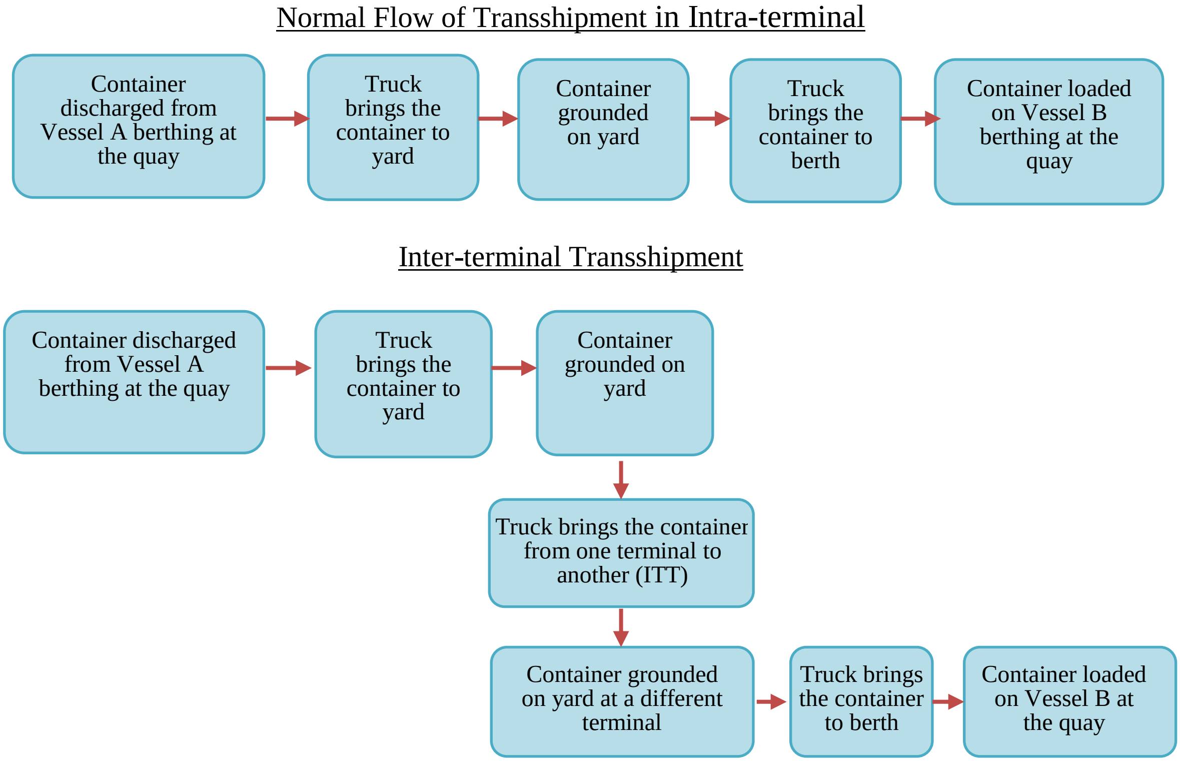

Figure 2. Intra-terminal and Inter-terminal Transshipment Process Flow.

4. Facility Sharing Strategies

According to the real industrial configuration, we formulate a container port operated by a set of individual operators K (indexed by k), where K' is the total number of operators in the port. Each operator k owns a sub-set of berth sections B_k, where B is the total set of berths with $B = B_1 \cup B_2 \cup B_3 \ldots \cup B_{K'}$. Each berth section b has its starting point

(SL_b), ending point (EL_b), and available start time (o_b). Each operator k has its own set of incoming vessels V_k, where V is the total set of incoming vessels for all the operators with $V = V_1 \cup V_2 \cup V_3 \ldots \cup V_K$. Let the planning horizon be L.

Vessel Information.

Each vessel (indexed by *i*) has the following information:

μ_i	length of vessel $i \in V$.
ω_i	handling volume of vessel $i \in V$.
h_i	handling time of vessel $i \in V$, assume to be pre-determined by its handling volume and the number of quay cranes assigned.
θ_i^s,θ_i^e	earliest berthing time and latest completion time of vessel $i \in V$
$\lambda_{i,j}^t$	transshipment volume (TEUs) moving from vessels *i* to $j \in V, i \neq j$.

Cost Coefficients.

$C_{i,b}^O$	general operation cost for assigning vessel $i \in V$ to berth section $b \in B$.
$C_{b,r}^T$	cost for moving one container (in terms of TEU) from berth sections *b* to *r*, where *b*, *r* $\in$ *B*. This is known as *ITT cost*.
C_i^D	cost penalty for delay berthing of vessel *i* $\in$ V_k at a time unit.

Variables.

$\delta_{i,j}^T$	= 1 if completion time of vessel *i* is earlier than berthing time of vessel *j*, and 0 otherwise, where $i \neq j \in V$.
$\delta_{i,j}^B$	= 1 if vessel *i* is berthed right after vessel *j* in the berth axis, otherwise 0, where $i \neq j \in V$.
$\varphi_{i,b,j,r}$	= 1 if vessel *i* moors at berth section *b* and vessel *j* moors at berth section *r*, otherwise 0, where $i \neq j \in V$, and *b*, *r* $\in$ *B*
σ_i	completion time of vessel $i \in V$.
β_i	assigned berthing position of vessel $i \in V_k$ according to its middle point.
$x_{i,b}$	= 1 if vessel $i \in V_k$ is assigned to berth section $b \in B$, otherwise 0.
ε_i	berthing time of vessel $i \in V$.

4.1 Full Sharing Strategy (FSS)

We first formulate the concept of FSS. This represents the situation where all operators work together to maximize the total benefit of the port. In FSS, all facilities in the port are shared and operators are allowed to use any berth and quay cranes. In this model, we assume that the amount of containers to be unloaded is fixed and have fixed prices, and can be handled by existing capacity. In essence, the revenue component would remain unchanged and the objective can be minimization of total cost. The berth assignment specifies the berthing position (β_i) and time (ε_i) for vessel $i \in V$. The objective function (1), specifically, is to minimize the sum cost of: (i) operation cost, (ii) delay penalty cost, and (iii) ITT cost induced by transshipment of containers.

4.1.1. FSS-Model

The FSS model can be expressed as a mixed 0-1 linear program as follows:

$$\boldsymbol{Min\ Z} = \sum_{i\in \mathrm{V}}\sum_{b\in B} C^{O}_{i,b}(x_{i,b}) + \sum_{i\in \mathrm{V}} C^{D}_{i}\,\omega_i(\varepsilon_i - \theta^{s}_{i}) + \sum_{i\in \mathrm{V}}\sum_{j\in \mathrm{V}}\sum_{b\in B}\sum_{r\in B} C^{T}_{b,r}\lambda^{t}_{i,j}(\varphi_{i,b,j,r}) \tag{1}$$

subject to:

Constraints (2) ensure each vessel *i* is assigned to only one berth section.

$$\sum_{b\in B} x_{i,b} \;=\; 1, \qquad \forall i \in \mathrm{V} \tag{2}$$

Constraints group (3-5) is the berthing position constraints. The quay is divided into a set of berth sections B, and the length of the berth section b is calculated by $(\mathrm{EL_b} - \mathrm{SL_b})$. Constraints (3) ensure that no vessels will be assigned to the same berth at the same time. Constraints (4) ensure that two adjacent vessels will not overlap during the berthing. Constraints (5) ensure in all dimensions, no vessel will be overlapped.

$$\varepsilon_i + h_i \le \varepsilon_j + \left(1 - \delta^{T}_{i,j}\right)\cdot M, \qquad \forall i,j \in \mathrm{V}, i \ne j \tag{3}$$

$$\beta_i + (\mu_i + \mu_j)/2 \le \beta_j + (1 - \delta^{B}_{i,j})\cdot M, \qquad \forall i,j \in \mathrm{V}, i \ne j \tag{4}$$

$$\delta^{T}_{i,j} + \delta^{T}_{j,i} + \delta^{B}_{i,j} + \delta^{B}_{j,i} \ge 1, \qquad \forall i,j \in \mathrm{V}, i \ne j \tag{5}$$

Constraints (6) are used to ensure the feasibility of berthing position β_i for vessel $i \in V_k$ in each berth section $b \in B$, where M is a large number.

$$SL_b + \mu_i/2 - \left(1 - x_{i,b}\right)M \le \beta_i \le EL_b + \left(1 - x_{i,b}\right)M - \mu_i/2, \ \forall i \in \mathrm{V}, \forall b \in B \tag{6}$$

Constraints (7) calculate the completion time of each vessel.

$$\varepsilon_i + h_i = \sigma_i, \qquad \forall i \in V \tag{7}$$

Constraints group (8-10) guarantees the vessel berths after the berth available start time and within its feasible turnaround time interval.

$$\varepsilon_i \ge \theta^{s}_{i}, \qquad \forall i \in \mathrm{V} \tag{8}$$

$$\varepsilon_i \ge x_{i,b}o_b, \qquad \forall i \in \mathrm{V} \tag{9}$$

$$\sigma_i \le \theta^{e}_{i}, \qquad \forall i \in \mathrm{V} \tag{10}$$

Constraints (11) are the constraints for connecting $x_{i,b}$, and $\varphi_{i,b,j,r}$, and Constraints (12) are for non-negativity.

$$\varphi_{i,b,j,r} \geq x_{i,b} + x_{j,r} - 1, \qquad \forall i,j \in V, i \neq j, \forall b,r \in B \tag{11}$$

$$\varepsilon_i,\ \sigma_i, hi,\ \beta_i \geq 0 \tag{12}$$

4.2 Sharing Economy Strategy (SES)

The preceding FSS model assumes that all operators perform to minimize the overall cost of the port. In practice, it is more realistic that the individual operator would minimize its own cost but could adopt resource sharing (similar to FSS). However, when operators optimize their individual plan to satisfy their own set of incoming vessels V_K with consideration of resource sharing, the resulting sets of respective optimal solutions might not be feasible. It might be caused by unavailability of some resources from other operators. Hence, we describe the schematic model of SES and propose an algorithm for a port with multiple operators to optimize their individual plans while ensuring the feasibility of SES.

4.2.1. Schematic Model of SES

SES is expressed by a two-connected model as shown in Figure 3: the first model, **SES-M**, is for a master problem to optimize the overall cost of the port, while the second model, **SES-S**, is for a sub-problem to optimize the cost of an individual operator.

To consider the realistic practice that operator may concern more on its own benefits than that of the port. The **SES-S** is solved by every individual operator first. The goal of the sub-problem is to determine the berth assignment plan for the incoming vessels with minimum cost. With resources sharing, the model considers all berths in the port (similar to FSS), which means the vessels can be assigned to other operators' berths. Here, we introduce a rental cost parameter $\left(C_{i,b}^{r}\right)$ in the objective function. When a vessel b is berth at other's berth $b,$ a rental cost is imposed on the renter. The model makes a trade off between the costs induced by delay serving and berth renting. Moreover, to determine the ITT cost, constraints (14) are introduced to assume all the vessels from other operators are berth at their own terminals. However, this model also assumes all others' berths are always available. In fact, it is subjected to others' berth assignment plans.

To ensure the feasibility of the berth assignment, the solution (berth assignment plan) obtained by each operator will be added into the master problem to re-determine a feasible berth assignment for the vessels assigned to others' berths in **SES-S**. All the vessels waiting for re-assignment are in set V_w. The goal of the master problem is to minimize the overall cost. In **SES-M**, we assume that the operators share all idle resources (berths) with others. To avoid the reassignment of the used resources, we introduced constraints (16-19) to fix the berthing section (b_i), the berthing position (p_i), the berthing time (s_i), and the completion time (c_i) of the vessel i which berths at its operator's berth. Then, the unoccupied resources can be allocated to the vessels in V_w.

Since the proposed model involves two stages, an SES algorithm is developed to solve the problem.

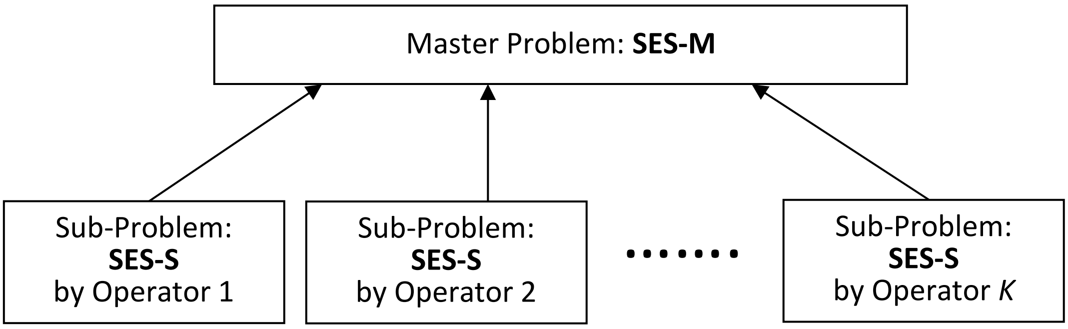

Figure 3. Schematic model of SES

SES-S:

$$\text{Max } Z_2 = \sum_{i\in V_k}\sum_{b\in B_k} C^O_{i,b}\, x_{i,b} + \sum_{i\in V_k} C^D_i\, \omega_i(\varepsilon_i - \theta^s_i) + \sum_{i\in V_k}\sum_{j\in V}\sum_{b\in B}\sum_{r\in B} C^T_{b,r}\lambda^t_{i,j}\,(\varphi_{i,b,j,r}) + \sum_{i\in V_k}\sum_{b\in B\setminus B_k} C^r_{i,b} x_{i,b} \tag{13}$$

subject to:

Equations (2) – (11), where the set V in the Eq. (2) – (10) are changed to the set V_k. (14)

$\sum_{b\in B} x_{i,b}\cdot b = b_i, \forall i \in V\setminus V_k$

SES-M:

$$\text{Max } Z_3 = \sum_{i\in V}\sum_{b\in B} C^O_{i,b} x_{i,b} + \sum_{i\in V} C^D_i\, \omega_i(\varepsilon_i - \theta^s_i) + \sum_{i\in V}\sum_{j\in V}\sum_{b\in B}\sum_{r\in B} C^T_{b,r}\lambda^t_{i,j}\,(\varphi_{i,b,j,r}) + \sum_{i\in V}\sum_{b\in B} C^r_{i,b}\, x_{i,b} \tag{15}$$

subject to:

Equations. (2) – (11), where the set V in the Eq. (2), (6) – (10) are changed to the set V_w.

$$\sum_{b\in B} x_{i,b}\cdot b = b_i, \qquad \forall i \in V\setminus V_w \tag{16}$$

$$\beta_i = p_i, \qquad \forall i \in V\setminus V_w \tag{17}$$

$$\varepsilon_i = s_i, \qquad \forall i \in V\setminus V_w \tag{18}$$

$$\sigma_i = c_i, \qquad \forall i \in V\setminus V_w \tag{19}$$

4.2.2. SES Algorithm

The SES algorithm consists of three steps:

Step 1. Each individual operator k optimizes according to its own set of incoming vessels V_k and berths B_k, and the associated quay cranes by solving **SES-S**.

Step 2. The berth assignment of vessels V_k in berth $b \in B_k$ of each operator k from *Step 1* is fixed to determine the list of idle berths for sharing. If a vessel is better to be assigned to other berths, the vessel is set aside in the set V_w for further assignment (the list of berths seeking).

Step 3. Run the **SES-M** based on the two lists released by the operators and see if the solutions can further generate revenue by minimizing the overall costs of each individual operator.

The pseudo code of the SES algorithm is presented as follows:

```
Step 1:   For $k$ = 1 to $K'$
              Input: vessel $i \in V_k$ and berth $b \in B$
              Solve SES-S;
                  Output 1.1: A berth plan for vessels $i \in V_k$ assigned to berth $b \in B_k$.
                  Output 1.2: A berth plan for vessel $i \in V_k$ assigned to other berths $b \in B \backslash B_k$.
          End for

Step 2:   For $k$ = 1 to $K'$
              Input: (1.1) and (1.2) from Step 1.
              Output 2.1: From (1.1), determine the variable {$b_i$, $p_i$, $s_i$, and $c_i$} of vessel $i \in V_k$ assigned to berth $b \in B_k$ and release all unused berths for sharing (list of idle berths for sharing).
              Output 2.2: From (1.2), add vessel $i \in V_k$ assigned to berth $b \in B \backslash B_k$ to the waiting list ($V_w$) for further assignment (list of berths seeking).
          End for

Step 3:   Input: (2.1) all vessel $i \in V_w$ from Step 2.
          Input: (2.2) all shared berths by fixing the variable {$b_i$, $p_i$, $s_i$, and $c_i$} from Step 2.
          Solve SES-M;
          Output 3.1: A refined berth plan for all vessel $i \in V_w$
```

5. Numerical Experiments and Result Analysis

This section analyses the performance of the proposed strategy - SES with respect to cost, service quality, and operations efficiency among the operators. Another two strategies, FSS, and IS are employed for benchmarking. The FSS simulates terminal operators working together for the overall benefits of HKP, while the operators employing the IS focus only on their own objectives. Numerical analyses are conducted based on data collected from HKP. All the computational experiments are coded in Java and IBM ILOG CPLEX12.5 on a PC with 16GB RAM.

5.1 Details of the Test Instances and Parameter Settings

HKP consists of nine container terminals operated by five individual terminal operators as shown in Figure 1, and in which the quay is divided into 13 continuous berth sections with the berth section length ranged from 305m to 900m. One-month historical data in 2017 was collected. To have a more comprehensive analysis, the data is divided into six sets with 5-day as a planning horizon according to the number of incoming vessels and the number of containers to be handled. The number of incoming vessels and the transshipment volume in each period varies from 105 to 159, and from 5219 to 7631 TEUs respectively. We consider the cost parameters as follows:

Operation Cost. In general, when a vessel berths, an operating cost will be generated onto the terminal operator who provides the service of loading the container from the vessel onto the ground and vice versa. In this analysis, the operation cost is estimated as HKD$1000 per TEU, based on the terminal handling charges reported by the Research Office of Hong Kong Legislative Council Secretariat in 2017. Regarding the current practice, it can be a small variation among different operators. An example of operation cost variation is shown in Table 1:

Table 1 – An example of operation cost of different operators

	Operation Cost (HKD) per TEU
Operator 1 (OP1)	1000
Operator 2 (OP2)	1100
Operator 3 (OP3)	950
Operator 4 (OP4)	950
Operator 5 (OP5)	950

ITT Cost. Since ITT is clearly an extra burden to transshipment hubs, in this study, it is considered as an extra operation cost incurred by moving a container between different terminals operated by different operators. Based on the data collected from HKP, The average cost of one ITT is about HK $300 per TEU.

Delay Penalty Cost. Delayed berthing of a vessel is always avoided by container terminal operators as it is an important measure for evaluating their customer service level. However, it is difficult to justify a value for this cost penalty. It could be subjected to the view of the operator. In this study, an approximate unit cost of penalty is about 0% to 10% of the operation cost.

Rental Cost. The rental cost refers to an additional cost charged by the owner of the resources for renting the resources. It is a critical cost element in this model. Here, as suggested by the industrialist, it is assumed to be 10% of operational cost. In a later section, a sensitivity analysis on the impact of rental cost in sharing economy will be performed.

5.2 Numerical Analysis

There is a total of 6 different scenarios: i) Sets 1 – 3 represent the low, medium, and high number of containers to be handled, and Sets 4 – 6 represent the low, medium, and high number of incoming vessels. In each scenario, three strategies: i) FSS, ii) SES, and iii) IS representing different degrees of resources sharing and with variable range of cost parameters have been analyzed. From the following experimental results, we would be able to see how much benefit of the concept of sharing economy applied to HKP will be obtained.

5.2.1 Analysis on cost aspect

First, we compare the cost performance of the three strategies. The optimization results are plotted as in Figure 4. We use the FSS as the benchmarking strategy for upper bound because it represents the ideal situation that all operators work together to minimize the overall cost of the port instead of their own cost. We also use the IS as the benchmarking strategy for lower bound, mimicking the current practice without resource sharing. Figure 4 show the percentage of cost deviated from the two benchmarking strategies. One can see that the total cost of all operators in the practice of SES is much lower than that of IS. The improvement ranged from the lowest of 23% in Set 3 to the highest of 91% in Set 6. Surprisingly, the cost performance of the proposed SES is very close to the ideal situation as by the FSS. The worst case is only deviated from the ideal situation by 4%. The results demonstrate that the SES outperforms the current practice. It could be a remarkable approach for the terminal operators in HKP to adopt the SES.

We further analyze the impacts of the SES on the cost performance of each individual operator. The total cost of each individual operator by the SES is compared to the total cost by the FSS and the IS, and the results are converted into percentage and summarized in Tables 2 and 3. A positive percentage represents cost reduction by the SES and a negative percentage represents cost increment.

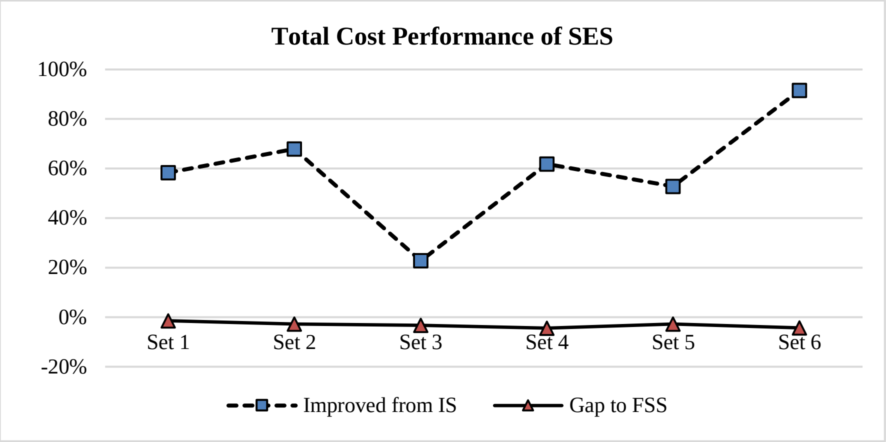

Figure 4. Comparison of total cost of the three strategies.

In Table 2, one can see that in most cases, the total cost of each individual operator is reduced. The reduction is up to 98%. This is mainly because of the reduction from the delay cost and the ITT cost. It is also observed that in some cases, the individual cost of the operator is higher than the IS by about 11%. In the SES, we assumed that operators will seek for shared resources from others and release the idle resources for sharing at the same time. Once the resources are shared to other operators, the operator cannot reschedule the already fixed schedule and the shared resources even though they cannot find other shared resources as they want. Therefore, it may cause the poorer individual cost performance than the IS. In fact, if an individual operator cannot find the resources from others as they want, they have the rights to reschedule their own resource. Here, we want to simulate the worst situation that may happen by using the SES for a fair theoretical comparison.

Table 2 – Cost improvement percentages of individual operators by the SES comparing with the IS.

to IS	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**
Operator 1	0%	15%	37%	0%	4%	-11%
Operator 2	0%	97%	33%	97%	0%	-9%
Operator 3	1%	0%	-2%	0%	-2%	7%
Operator 4	94%	95%	30%	98%	94%	0%
Operator 5	0%	0%	39%	0%	78%	0%

In Table 3, it is interesting to see that in some cases, the total cost of each individual operator by the SES is lower than that by the FSS. This is because in the FSS, the objective is to maximize the overall benefit of the port rather than an individual operator. As a result, some operators may have to sacrifice. As mentioned previously, it does not make sense that operators sacrifice themselves for the goodness of the port. We believed that the SES is much more realistic and practical for implementation.

Table 3 – Cost improvement percentages of individual operators by the SES comparing with the FSS.

to FSS	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Operator 1	-4%	-7%	-7%	-5%	-6%	-5%
Operator 2	0%	-23%	-24%	-23%	-20%	-27%
Operator 3	0%	1%	-1%	0%	-3%	1%
Operator 4	-5%	-4%	3%	-12%	-7%	2%
Operator 5	0%	-1%	-1%	0%	-5%	3%

The behavior of the proposed sharing strategy is analyzed to examine the sensitivity to the range of rental costs. As shown in Figure 5, as the rental cost becomes larger, the number of vessels berth at others' berths reduces. We can clearly see that the number of vessels served by others drop significantly when the rental cost is imposed from 0% to 10% of operation cost. Also, we can see that the reduction of penalty cost without causing a significant change in this case.

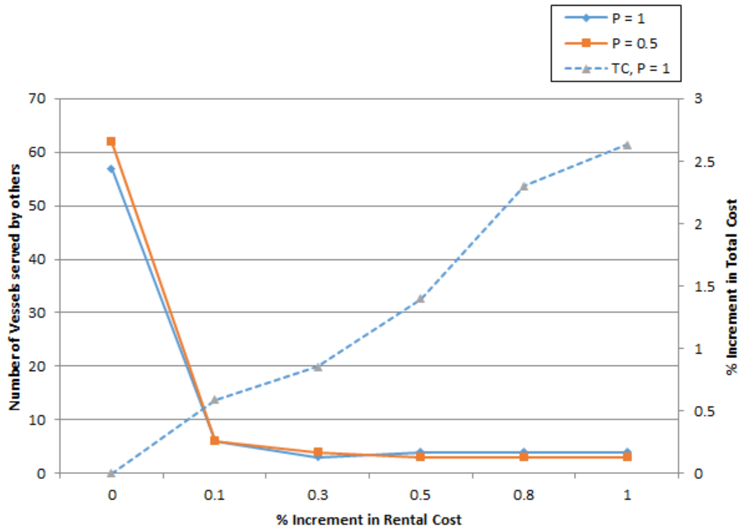

Figure 5. Sensitivity analysis on the impact of rental cost

5.2.2 Analysis on service quality aspect

The results are summarized as in Table 4. One can see that most of the delays happen in the IS, while there is no delay in the FSS. This is because operator can only rely on its own resources in the IS. In the opposite, all the resources are shared to avoid delay in the FSS. To take the balance between the IS and the FSS, the proposed SES can minimize delay in majority of the cases. From most of the delay cases, we can observed that seeking for shared resources from other operators can successfully help to avoid or reduce the delay, e.g. in Set 1, Operator 4, and in Set 2, Operator 1, etc. Interestingly, in Set 6 for Operator 3, there is a delay of 8 minutes in the IS. However, in the SES, the delay increases to 71 minutes. This seems to be unsatisfactory. However, referring to the individual total cost in Table 2, the total cost is reduced by 7%. This demonstrates the proposed SES can provide higher flexibility to every operator in the system.

Table 4 – Comparison of delay performance for the three strategies.

	Set 1			**Set 2**			**Set 3**			**Set 4**			**Set 5**			**Set 6**		
	IS	**SES**	**FSS**	**IS**	**SES**	**FSS**	**IS**	**SES**	**FSS**	**IS**	**SES**	**FSS**	**IS**	**SES**	**FSS**	**IS**	**SES**	**FSS**
Operator 1	0	0	0	67	0	0	211	0	0	0	0	0	38	0	0	15	0	0
Operator 2	0	0	0	727	0	0	24	0	0	2064	0	0	0	0	0	2567	0	0
Operator 3	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	8	71	0
Operator 4	930	0	0	1606	0	0	161	0	0	8368	58	0	1956	0	0	0	0	0
Operator 5	0	0	0	0	0	0	76	0	0	0	0	0	160	0	0	0	0	0

5.2.3 Analysis on ITT aspect

Lastly, we analyze the performance of the ITT activities by using the three strategies. The results in Figure 6 indicate that ITT cannot be avoided unless the terminals can be operated by using the FSS, in another word under full collaboration, or by a single operator. However, if the different operators can work on the SES, ITT can still be improved in most of the cases. But when the number of incoming vessels is high as shown in Set 6, ITT cannot be improved because the availability of shared berth becomes less.

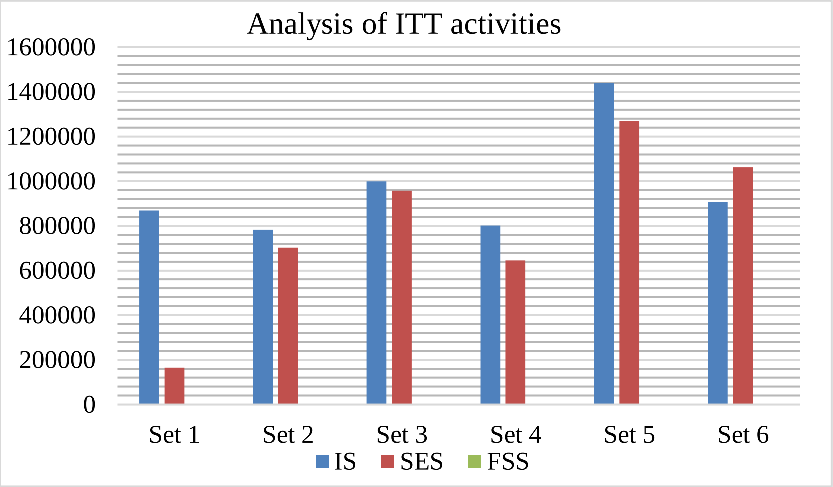

Figure 6. Comparison of ITT activities by using the three strategies

6. Managerial Implications and Conclusion

The concept of sharing economy facilitates resources sharing in container port industries. It has demonstrated its promises in many businesses and in many different business models, including P2P (or C2C) and B2C. However, to the best of our knowledge, its application has not been applied in container port industry. This work is the first attempt to study whether the concept of sharing economy (B2B sharing model) can benefit the terminal operators in a container port through the real case study of the HKP. We collected one-month historical data from the HKP and analyzed the cost performance, service quality and ITT performance of the terminal operators under three strategies: i) FSS, ii) SES, and iii) IS.

By analyzing the three strategies on the 6 different scenarios as in Sets 1 – 6, we found that the performance of the SES is as close as the performance of the FSS in terms of the total cost. It remarkably outperforms the IS by a huge percentage of cost reduction. The results demonstrate that the concept of sharing economy can be applied in a container port with multiple operators who are competitors in nature. Moreover, the findings from our numerical experiments clearly show that if operators in the same port worked independently, their operating cost is higher than working collaboratively. Therefore, we suggest that operators should work together and collaborate as one single port. However, the results also find that in some situations of full collaboration, the operator may have to sacrifice its own benefit for the benefits of the port. This may discourage and induce difficulties to achieve full collaboration unless other strategy is uncovered.

Instead of full collaboration, the concept of sharing economy seems a better and reasonable option. The findings demonstrate that none of the operator sacrifice itself for the others in the study, and the operators have improved their overall cost performance as well as their service quality by resources sharing. Moreover, when more resources are shared, it will be easier for other operators to find an optimal berth which can reduce ITT. In HKP, such high number of ITTs has induced a lot extra use of resources (such as trucks, gantry cranes, etc.), and caused high amount of carbon emissions. The reduction of ITT not only helps to reduce their operating cost and improve operations efficiency but also benefits the environment. More importantly, the saving on the ITT can avoid the extra charge to their customers (liners). Consequently, it increases their price competitiveness, and the saving of the customers can reduce the shipping cost charging the shippers. In other words, the social welfare can also be benefited. This provides a solid support for the operators to apply the concept of sharing economy and demonstrates that B2B sharing model is beneficial. In particular, the rental cost in sharing economy is a unique and crucial factor in determining its success. We can also see that the lower the rental cost, the higher the sharing activities occurred among operators. Therefore, another important issue to address is the value of rental cost between operators. Indeed, this cost can be a decision variable, to be negotiated between operators, and a rational approach to its determination its highly recommended. This would be an interesting piece of future research.

Furthermore, the sharing strategy enables the operators' flexibility in both capacity and service mix. Comparing to the case without resources sharing, operators with resources sharing may be able to increase their handling capacity. In this connection, the operators may handle more vessels than they originally can. This flexibility may also well suit the current environment where the demand is more fluctuated. Moreover, various terminal operations and services can be supported via resource sharing. For example, the terminals with small berth space, now they would be able to rent a larger berth from others in order to handle a larger vessel, etc.

In this paper, we explored the adoption of sharing economy in container port industries. This paper has not considered storage operations and traffic conditions – we assumed unlimited yard storage space and traffic free condition. Interested readers may explore such aspect in future research.

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