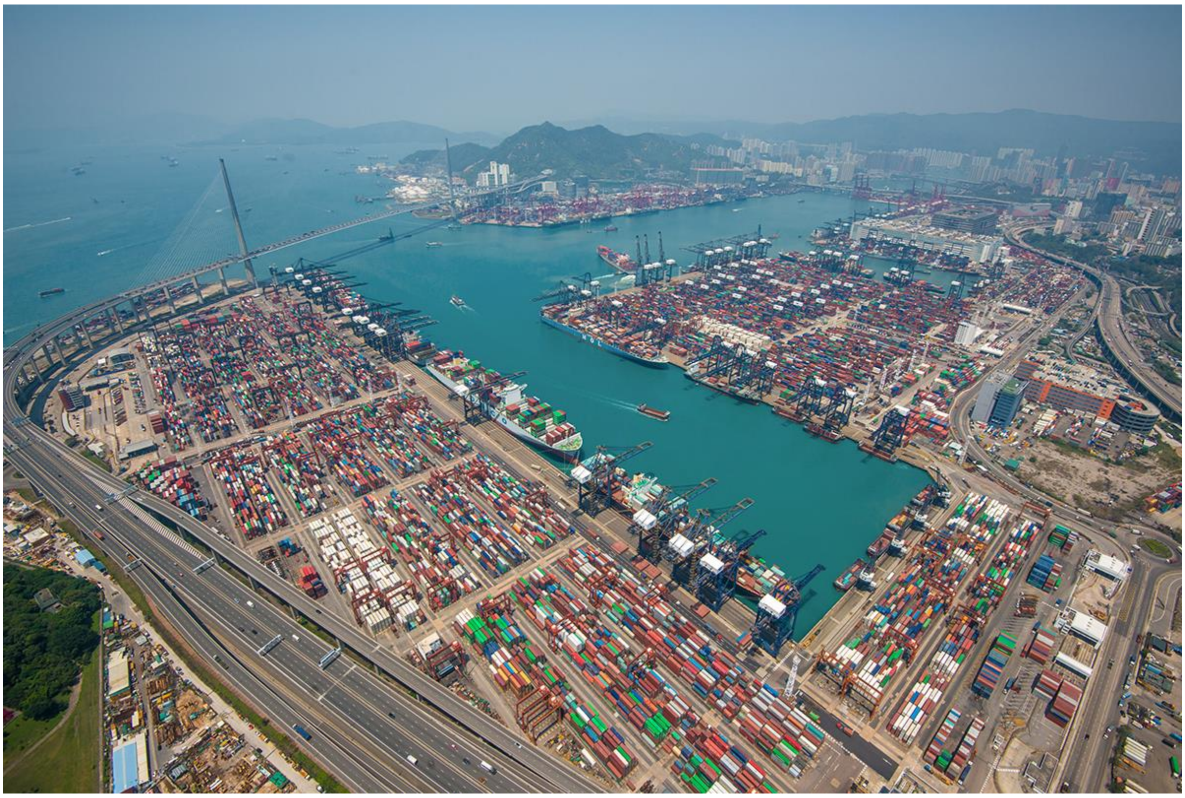
Collaboration at the Hong Kong Port –

Benefits from Facility Sharing



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Abstract

The Hong Kong maritime industry is facing severe competition from ports in the Pearl River Delta (PRD) and throughout Asia. In recent years, its throughput has declined steadily. The maritime industry, a significant contributor to the Hong Kong economy, must find ways to remain sustainable in a changing environment. The industry has evolved, with mega vessels, more cargo alliances, and a surge in transshipment containers. All of this has resulted in a complex operating environment for the Hong Kong Port (HKP), which consists of five different terminal operators. The new business environment, coupled with different and independent operators, has led to a critical increase in the number of Inter-Terminal Transfers (ITT), the movement of a container between two independent terminals. More ITT means extra handling time, increased burden on roads and resources, as well as significant charges to shipping lines, which in turn directly jeopardises the competitiveness of HKP.

In this paper, we propose a collaboration model to address these challenges. The optimisation-simulation model assumes that terminal operators can collaborate and share their facilities. Using a month of real-time data from the Kwai Tsing Container Terminals (KTCTs), we examine the impact of facility sharing on operational efficiency when terminals deal with transshipment operations. The results show that the proposed collaboration is promising: (1) ITT was reduced by 49%, (2) better customer service could be provided through reduced waiting times and costs, (3) potential port charges could be reduced, and (4) the negative impact on the environment near HKP could be reduced. We conclude by providing recommendations for the successful implementation of terminal collaboration.

1. Introduction

With intense competition faced by the global maritime industry, we have witnessed many collaborations and alliances in the last two decades – to survive and to compete. In Asia, one example is the state-directed merger between Ningbo Port and Zhoushan Port to improve overall value, which was completed in September 2015. The operations of Ningbo, Zhoushan, Jiaxing, Taizhou and Wenzhou came under a common platform to bring synergies to the ports in Zhejiang. The Port of Ningbo-Zhoushan is now the fourth busiest port in the world. Four international ports in Japan (Kobe, Osaka, Amagasaki-Nishinomiya-Ashiya combined and Sakai-Semboku in Osaka Bay) declared themselves 'Hanshin Port' in 2007. Later, three other major Japanese ports – Tokyo, Yokohama and Kawasaki – entered into a Basic Agreement of Collaboration (Hoshino, 2010).

There have also been several collaborations in North America. Since the late 1990s, a series of inter-governmental agreements were made between the Port of Portland (in Oregon) and the Port of Vancouver (in Washington) to align operations. Similarly, the Seattle and Tacoma port commissions unified the management of their marine cargo terminals and related functions under a single Seaport Alliance in 2014. As an alliance, the two port commissions manage marine cargo terminal investments and operations, and do planning and marketing together, while individually, they retain their existing governance structures and ownership of assets (Portoftacoma, 2014). In December 2016, Miami's South Florida Container Terminal and Port of Miami Terminal Operating Company formed an alliance to jointly negotiate, set, and approve terminal rates, charges, rules, and regulations, as well as the rates of return between the terminals (Hutchins, 2016). In 2015, the two busiest and largest ports in the US, the Port of Los Angeles and Long Beach, began collaboration talks. This collaboration was approved by the Federal Maritime Commission to prevent congestion and cargo delays (Gcaptain.com, 2015).

Similarly, Europe's largest port of Rotterdam collaborated with the Port of Amsterdam by merging independent port data systems in order to offer customers a broader range of services. They formed one single port community information system serving both operational and administrative purposes (CNA Staff, 2008). Hamburg port also collaborates closely with ports including Cuxhaven, Brunsbüttel, Glückstadt, as well as with the Baltic Sea ports of Lübeck and Kiel. These ports act together and market themselves as a Northern European metropolitan area (Mclaughlin & Fearon, 2013).

1.1 Benefits of Collaboration

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, when such a co-operative concept was proposed (UNCTAD, 1996; Juhel (2000). Ports were expected to adapt themselves to a flexible traffic distribution pattern through several port outlets. Strategic alliances between adjacent container ports acted as a counter-strategic option against their counterparts in shipping lines, in order to survive the increasingly competitive business environment (Avery, 2000). Port co-opetition can result in stronger bargaining power against government policies, investment barriers, mega-carriers and shipping alliances (Song, 2010). Co-opetition was proposed by Noorda (1993) – meaning a mixture of competition and co-operation – who argued that those engaged in the same or similar markets should consider a win-win strategy, rather than a win-lose one. Song (2003) further expanded the concept by identifying five motivations (strategic, financial, economic, operational and marketing) for such a strategy. 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. They should make decisions by consensus. According to Song (2003) and Hoshino (2010), port collaborations have resulted in significant benefits to the port operators, such as:

1. Formation of a large-scale port with expanded capability to capture more business. This is welcomed by alliances with many mega vessels. For example, about a year after integration, Ningbo-Zhoushan port's container transportation in tonnage increased by more than 30% and attracted eight new routes to Southeast Asia (People's Daily Online, 2016).
2. Reduce cost and increase efficiency at the collaborated port. Shippers and shipping companies compare the cost and efficiency of operation between two neighbour ports and select a port of call. Collaboration reduces the chance of a damaging rate-cutting war among terminal operators to attract business from the powerful carrier alliances.
3. Improve the ability to deploy efficient and critical infrastructure. This is important to attract large-scale containerships.
4. Share port facilities to increase flexibility and utilisation. They also jointly develop and deploy container handling equipment and technologies.

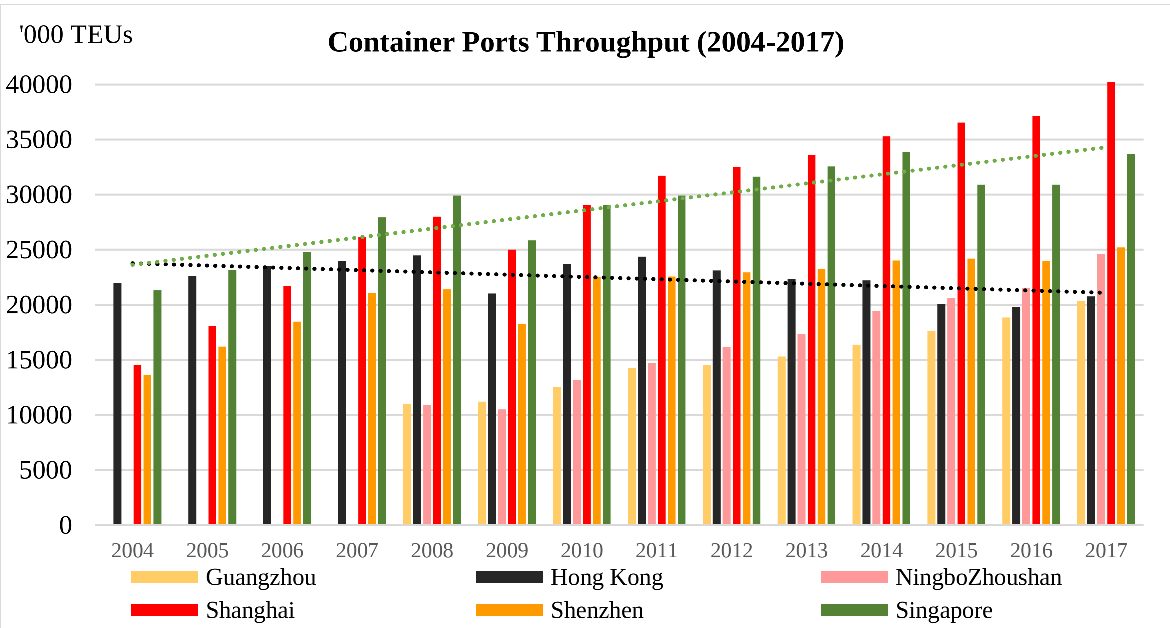
5. Invest at a regional level to better meet customer needs and demands. This enhances customer service.
6. Revise the work process to eliminate non-value-added activities, thereby reducing port and harbour costs.
7. Reduce port and harbour charges and provide better customer service to attract carriers. They share information with customers through a single portal site, and open a single window to deal with documentation.
8. Market as one port, administered by a marketing committee.
9. Unify and simplify procedures necessary for the use of any port in the alliance.
10. Consolidate and increase the bargaining power of different ports through the creation of large, single entities, expand business scope globally and improve government rules and regulations to facilitate sustainable business development.

The PRD in South China, which comprises the three major ports of Guangzhou, Hong Kong and Shenzhen, was suggested for co-opetition by Song (2003). The premise of port complementarity and competition was investigated by Lam & Yap (2011). They argued that the decision by liner services to call at particular ports could be influenced by the joint competitive offering of a group of ports in the PRD, instead of one individual entity. 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. In short, port authorities, port operators and other stakeholders should explore opportunities that could be capitalised via complementary relationships between ports.

However, none of these studies calculated the actual benefits in a concrete way. In fact, these benefits can be measured in terms of cost, efficiency, utilisation, flexibility, process flow etc. To increase port operators' confidence in collaboration, benefits must be calculated explicitly. In this report, we propose a facility sharing system, which comprises an optimisation model and a simulation mode to measure the benefits of port facility sharing. We conduct explicit experiments, based on real-life data to conduct scenario analysis. In this study, we model the integration of terminals at Kwai Chung and Tsing Yi, which is currently operated by five different operators. In the future, such a model could be extended to model the integration of adjacent ports in the region. In the next section, an overview of HKP is presented. The major challenges are discussed in Section 3. It is followed by the design of the facility sharing system, as well as the simulation results. Finally, managerial insights are identified, and a conclusion is presented.

2. Overview of HKP

Hong Kong has a long maritime history, with the advantages of a natural harbour, a free economy and a strategic location. These strengths have contributed to Hong Kong becoming one of the major shipping hubs and a thriving container port in the Asia Pacific region. In the 1990s, ports in mainland China began to take off. Ports in the PRD have rapidly developed over the past decade, posing significant challenges to HKP. The throughput growth of nearby ports demonstrates rapid development which has outstripped that of Hong Kong. Once the world's busiest port, Hong Kong lost its top position in 2005 to Singapore. It has subsequently slipped further behind the fast-growing ports of Shanghai and Shenzhen over the past decade. In 2017, Hong Kong was ranked the world’s fifth busiest port (Figure 1), with Guangzhou close behind. Hong Kong was, on the one hand, up against rivals from the PRD as they all shared a similar cargo hinterland, and on the other, competing with Singapore for transshipment cargo. Although the Hong Kong and Singapore ports are both located in a multi-port region with well-developed economies, and that they processed similar throughput volumes in the 2000s, the respective growth of these ports have taken different directions.



Source: Marine Department of the HKSAR, ports are listed alphabetically

Figure 1. Container Ports Throughput (2004-2017).

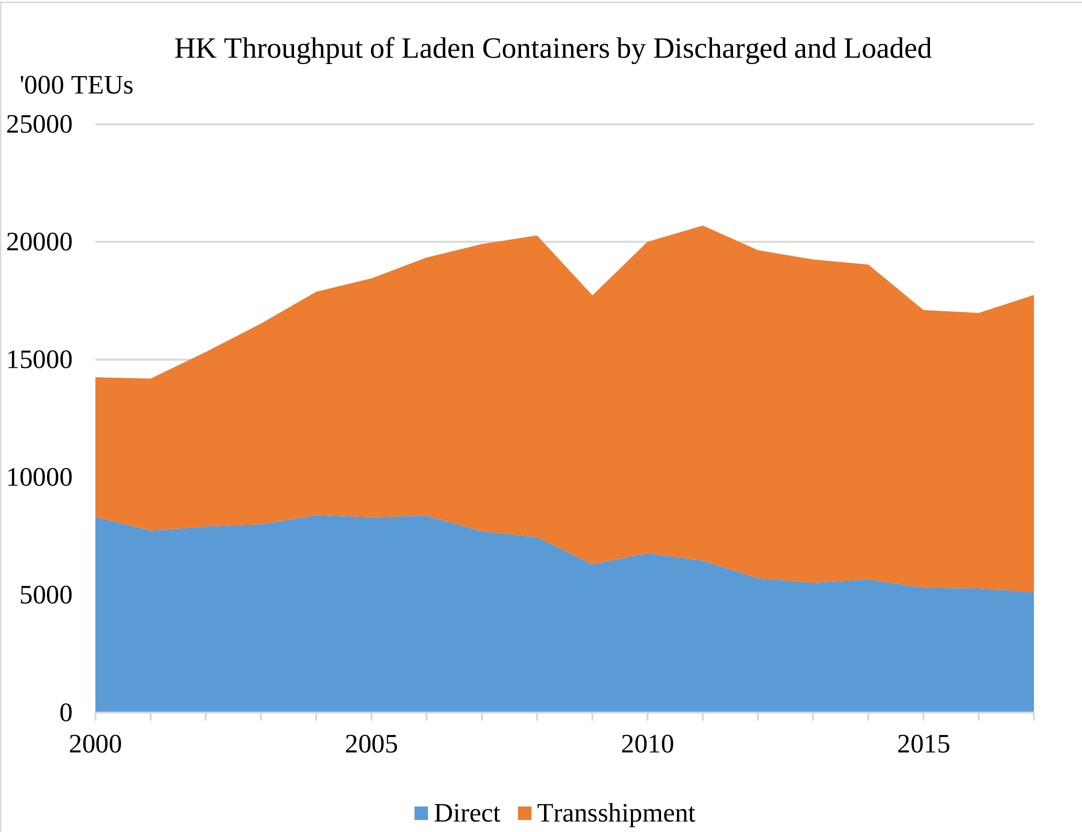
Recently, there have been suggestions that Hong Kong should close the maritime port, give up the maritime industry and focus on developing other fast-growing industries. These views underestimate the economic contribution by the maritime industry. In 2015, the maritime and port industry contributed 1.3% (HK$29 billion) of Hong Kong's Gross Domestic Product (GDP) and directly employed 88,000 employees (2.3% of total employment) (Transport and Housing Bureau, 2017). In comparison, the maritime industry in Singapore employed more than 170,000 people and contributed 7% of the country's GDP (Woo, 2018). The actual economic impact contributed by the maritime industry should go beyond these figures, as economic value should also include indirect and induced employments. Indirect employment includes ship repairs, insurance, and shipping-related financial and legal services. Induced impact refers to the employment and income generated by the spending of income by the direct and indirect employees on local goods and services. Although there are no concrete figures from the Hong Kong Government, we can reference studies by the Hong Kong International Airport and the European Union (EU). According to the Hong Kong International Airport Master Plan 2030 (2011), each direct job at the airport generated around 2 indirect and induced jobs in 2008. Within the EU, every direct job from the shipping industry created 2.8 jobs in indirect and induced sectors. In terms of GDP, every €1 million of GDP from the shipping industry created another €1.6 million of indirect and induced GDP to the economy (Goodwin, 2016). Using this estimate, the total economic impact for the maritime and port industry in Hong Kong can be as large as 300,000 employees (with 1 direct jobs creating 2.4 indirect jobs), and HK$75 billion, which is equal to 7.8 % of the city's employment and 3.4% of its GDP. These values have not yet taken into account upstream and downstream parties involved in the sea freight logistics, such as cross border trucking, warehousing, and trading etc. The trading and logistics industry ranks first among the four key economic pillars of Hong Kong, which accounted for 20% of Hong Kong's GDP and 20.4% of its total employment in 2015. In short, closing down the maritime port will affect the income of over 300,000 families, and Hong Kong's GDP may drop significantly in the first few years after the port's closure. Is Hong Kong prepared for such a major transformation?

In view of the importance of Hong Kong's maritime industry in the years to come, it is clear that the HKP must stay competitive. In the following pages we identify the recent challenges faced by the industry.

3. Recent Challenges faced by HKP

3.1 Transshipment is the dominating business

Today, HKP is an international transshipment hub, with international transshipment accounting for 71.2% of total throughput in 2017, up from 41.6% in the early 2000s (Figure 2). 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. However, Hong Kong faces challenges in terms of hardware and software facilities as transshipment requires container terminals to handle a large number of ocean-going vessel calls while efficiently transferring containers between terminals. Yet, the port and terminals at HKP were built in the 1970s to mainly handle direct shipments.



Source: Marine Department of the HKSAR

Figure 2. HK Throughput of Laden Containers by Discharged and Loaded (2000-2017).

3.2 Challenges from Carrier Alliances

In the past few years, carriers have struggled with the slower than expected global growth in 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, namely by working together, sharing ships, maximising efficiency, and minimising costs. With effect from April 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 a surprising 96% of all East-West trade. The alliance reshuffle has had an impact on ports. The alliances have reduced operating costs, resulting in fewer but larger vessels, and the vessel calls are occurring at fewer terminals. The Port of Singapore is set to benefit the most, while Hong Kong will suffer the most (iContainers.com, 2017). Of the 29 Asia-Europe services provided by the three groupings, the Port of Singapore will attract seven more weekly calls, to 34 weekly calls. In contrast, Hong Kong will lose five calls, with only seven weekly calls of northern European loops and three weekly calls of Mediterranean loops, down from ten and five calls previously (Baker, 2017).

Carrier alliances have put extra strain on ports. Multiple carriers combining their cargo loads on single ships means that ports have to deal with much higher quantities of shipping containers at once. While ocean carriers are consolidating into larger alliances, it also means the overall customer volumes are getting larger with more sophisticated operational requirements. This also means more transshipment services are needed at each hub terminal. To fully utilise the vessel, alliances prefer to consolidate shipments with similar destinations in one single vessel. This has created congestion at the ports (Vineyard, 2016).

Moreover, container vessels have grown considerably in size over the past two decades. In 1995, the largest container ship had a capacity of about 5,000 TEUs. Today, many have grown to 18,000 TEUs, and vessels with a capacity of more than 20,000 TEUs came into operation in 2017 (Alphaliner, 2017). The deployment of mega vessels, however, presents physical and operational challenges for ports. A vessel has to be fully loaded to gain the maximum benefits of economies of scale and thus, whichever port it uses, it would expect speedy container handling. For example, port draught, berthing on arrival, sufficient berthing space, outreach of quay cranes, as well as yard productivity and efficiency to support the loading and unloading of containers, are important factors for an alliance when choosing a port.

The average container dwell time at HKP ranges from 3 to 5 days. However, the shortest transshipment service time (discharging from origin vessel to loading onto destination vessel) can be up to 12 hours. The increase in transshipment cargo and concentration of vessels 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 across different terminals.

3.3 Intensified Competition among Ports in Asia

a. Terminal Handling Charge

Price is a differentiating factor for carriers when choosing a port for transshipment. When a carrier berths at Hong Kong, a charge known as the Container Handling Charge (CHC) will be levied by the terminals onto the carrier for the service of loading the container from the ship onto the ground and vice versa. Although CHC will be passed from carriers onto shippers as part of a lump sum of handling fees called Terminal Handling Charges (THC), CHC rates remain competitive as there are multiple terminal operators at the HKP.

Naturally, carriers and shippers prefer lower charges. However, Hong Kong's THC, currently at the rate of HK$2,140, is up to 50% more than its nearby major competitors (i.e. Shenzhen and Singapore), according to the study by the Research Office of the Legislative Council Secretariat in 2017.

Operations at HKP incurred additional ITT charges as containers need to be moved between different terminals operated by various terminal operators. The increase of ITT is also a result of collaboration between carrier alliances. The impacts of this on HKP's competitiveness will be detailed in section 3.4.

b. Port Service Calls

Another key factor that defines a maritime hub is connectivity. HKP serves 330 weekly carriers to some 470 destinations worldwide. However, such figures have decreased by 30% compared to the year 2000. Singapore, on the other hand, has about 200 service sailings with links to more than 600 ports. Shenzhen had only 35 weekly liner services back in 2000 but today provides 226 weekly services to major ports worldwide. Similarly, the Port of Guangzhou has attracted 74 new services over 3 years and by the end of 2017, had 197 liner services as well as over 160 domestic barge services. These figures show that while demand for Asian port services has been on the rise, the same cannot be said for HKP services.

c. Capacity Constraints

To facilitate transshipment, container terminals need sufficient berth and yard areas to quickly discharge and load containers, as well as temporary storage spaces to avoid extensive drayage. However, Hong Kong's KTCTs have smaller areas dedicated for such use compared with what is available at other South Asian terminals.

In total, KTCTs have 24 berths and a total yard area of 279 ha. Shenzhen has 41 berths and a total of 792 ha which spans over 5 areas. Guangzhou has 16 berths and 643 ha. HKP's major transshipment competitor, the Port of Singapore, has 67 berths and over 700 ha yard area which spans over four areas. Singapore is planning to consolidate all the ports to Tuas Megaport by 2040, aiming to handle up to 65 million TEU every year.

Insufficient yard areas affect the productivity and efficiency of terminal operations. The land shortage in Hong Kong has resulted in congestion of the yard stacking areas even when only 60% of the quay is occupied, and the issue often hits critical levels during peak periods when 85% of the quay is occupied (HKCTOA, 2014). This limitation also severely impacts KTCTs' ability to maintain acceptable vessel, barge and truck turnaround times during peak periods. The impact of limited space on productivity is evident when the throughput of HKP is compared to that of the Port of Singapore (Figure 3).

HKP Throughput vs Port of Singapore Throughput (2012-2017)

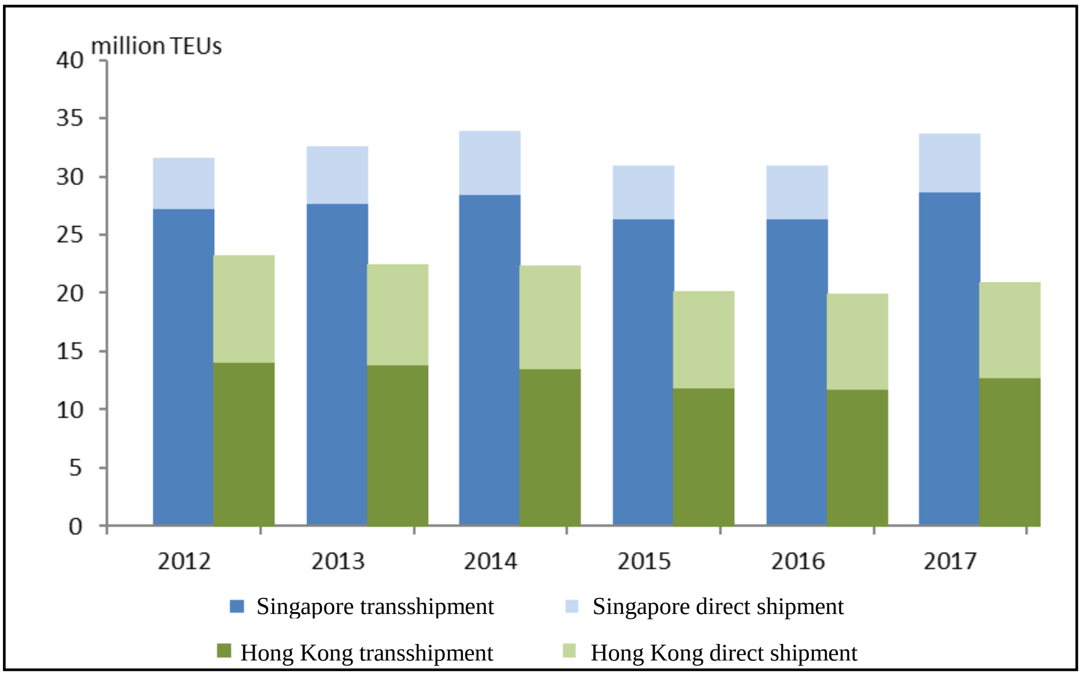


Figure 3. Singapore and Hong Kong Container Throughput (2012-2017).

3.4 Current Procedures in Handling Inter-Terminal Transshipment

In Hong Kong, there are an increasing number of mega vessels carrying containers from multiple liners, each with separate contracts with different terminal operators. KTCTs are operated by five different terminal operators: ACT, CHT, DPW, HIT & MTL (Figure 4). As the HKP is operated by multiple terminal operators, there has been an increase in the number of inter-terminal trucking during operations at the HKP. For example, if a container is discharged at Terminal 4 (T4), and later loaded onto another vessel also at T4, the operation and planning will be controlled within the same zone and it 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 will be required, with charges incurred for the carriers (Figure 5).

Figure 4. KTCTs Terminal Operators.

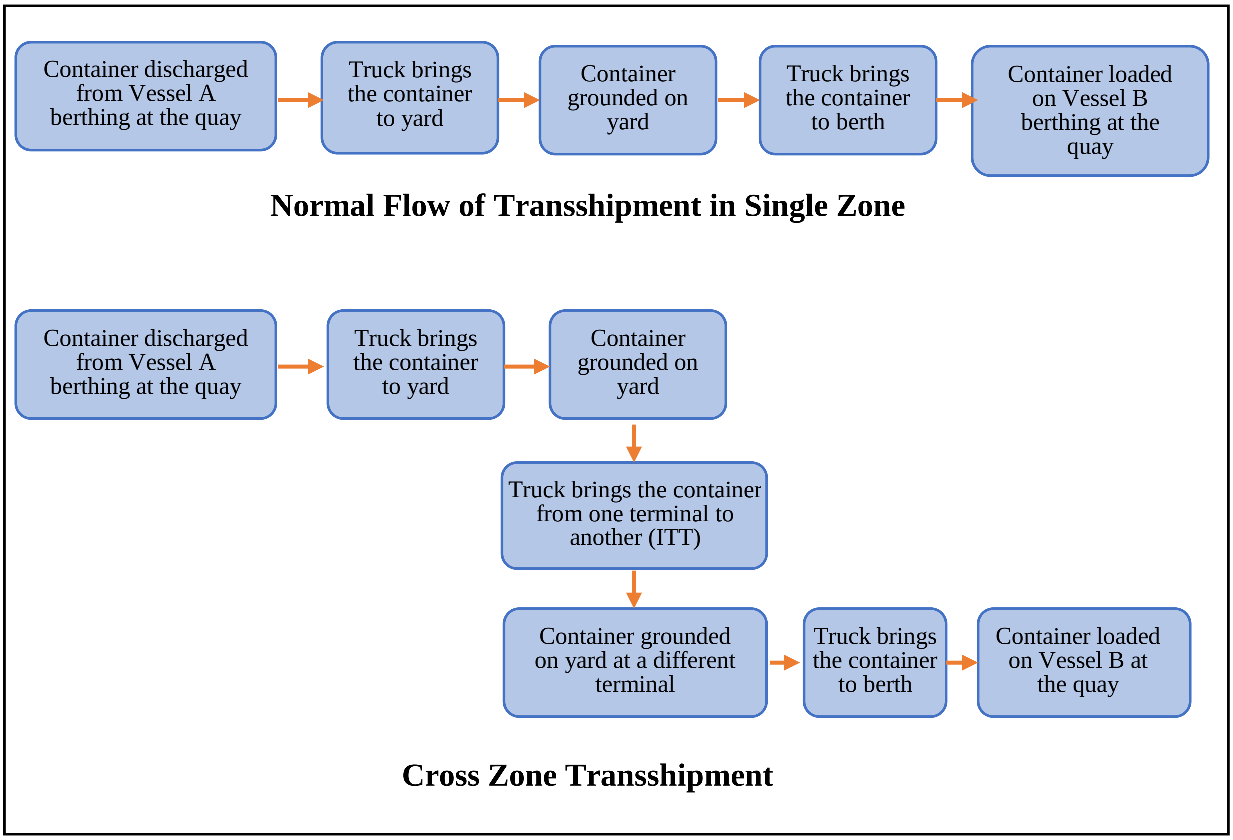


Figure 5. Within Zone and Cross Zone Transshipment Process Flow.

Terminal operators will charge liners an ITT handling fee. HKP is the only port in Asia that levies such a charge on shipping lines. All other major ports in Asia, such as Singapore, Shenzhen and Shanghai, are operated by one operator and so such charges are not applicable. In recent years, among 17 million annual TEUs, which equals about 15% of containers, required ITT. There is also an increasing trend for ITT due to changes in carriers' alliances.

ITT charges are an extra burden for carriers opting for HKP as a transshipment hub. This further reduces the competitiveness of HKP as the carrier alliances perform many transshipment operations. Besides, ITT creates a lot of under-utilisation and extra operations in the already congested terminals. Due to the independent planning and operation of different terminal operators, they face uneven usage of facilities and land. When several mega vessels arrive during the same period, the vessel waiting and turnaround time must be extended. 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 trips required to move containers between terminals. Many trucks are required to conduct external marshalling, which worsens the highly congested Kwai Chung and Tsing Yi road network, not to mention carbon and pollutants emitted during these trips. According to the data we collected from operators, on average, there are 2,150 ITT trips on the road network every day. Can ITT be avoided or reduced? The answer is yes, provided that the operators at the HKP can collaborate, plan and share the berth and yard together.

4. The Proposed Collaboration Model

4.1 Literature Review

Container terminals are under pressure to optimise efficiency, especially at hubs where large transshipment orders need to be handled in a short period of time (Jin et al. 2015; Fan et al. 2012; Paul and Maloni 2013). To stay competitive, terminal operators have been looking for decades for effective approaches to maintain high operational efficiency (Vis and Koster 2003). Comprehensive reviews on relevant studies can be referred to Steenken et al. (2004), Stahlbock and Voss (2008), and Bierwirth and Meisel (2010).

In this study, the focus lies on transshipment hub operations, and specifically, on the concept of the berth and yard templates in determining container flow in transshipment hubs, which was introduced by Moorthy and Teo (2006). They designed a sequence pair approach to pack the vessels in berths with a fixed handling time and proposed an annealing heuristic to minimise the total expected delays and connectivity cost between the berthing positions. 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 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. Other relevant work was done by Zhen et al. (2011). They undertook a comprehensive study, which covered both the berth and yard template to decide where and when the vessel should be moored, how many quay cranes and which sub-blocks should be assigned to each vessel at a tactical level. To solve this highly related and complicated berth and yard integrated template planning, they formulated a Mixed Integer Linear Programming (MILP) for Berth Assignment Problem (BAP) and Quay Crane Assignment (QCA), and another model for the Yard Storage Assignment (YSA). 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 the transshipment flow. They aimed to minimise the total container movement distance.

Recently, Ma et al. (2017) extended the works of Zhen et al. (2011) by further considering practical constraints, which were the discontinuity issues in berth layout. They successfully pointed out that disregarding this issue may lead to seriously low berth space utilisation. In order to model the discontinuities and solve the problem, they developed a MILP with a Guided Neighbourhood Search heuristics.

By combining the contributions of the previously mentioned prominent researchers in the field, we propose a two-stage methodology comprising optimisation and simulation to implement a facility sharing system. Such methodology has been successfully applied in various operation planning situations, such as service network design (Cheung, Leung & Wong, 2001; Cheung, Leung & Tam 2005), airfreight planning (Wan et. al., 2010; Leung et al., 2013; Leung et al., 2017).

4.2 Problem Description

Currently, KTCTs consists of nine container terminals with five major individual terminal operators named, ACT, CHT, DPW, HIT and MTL as shown in Figure 4. Every operator operates individually with limited collaboration except for a co-management between ACT, CHT and HIT has been implemented since 2017. Usually, customers (i.e. incoming vessels) are served at their 'home berth' regardless of transshipment arrangements. The home berth idea is when vessels are assigned a berth located at its contracted terminal, and will be serviced by the same terminal's facilities and resources such as berths, cranes, yards, etc. Such practice creates many ITTs. We aim to improve the efficiency of KTCTs during transshipment by reducing the burden induced by the existing home berth concept.

4.3 Problem Modelling

To optimise efficiencies, terminals should collaborate on infrastructures and computer systems to achieve direct operations (without ITT procedures) for transshipments. We propose a Collaboration Model, which consists of two parts as illustrated in Figure 6. The first part consists of the alliance berth zone allocation, and the second part consists of the berth allocation.

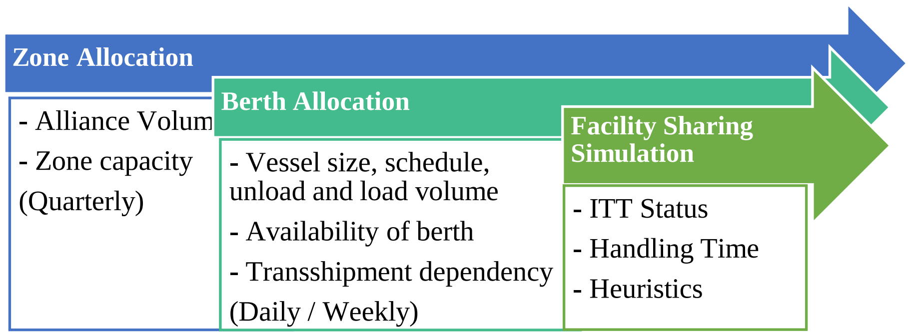


Figure 6. Outline of the Problem.

For the berth allocation, we divide the terminal into a set of alliance berth zones, and each alliance berth zone consists of a number of berth sections. A berth section belongs to which alliance berth zone is denoted by binary input variables. Every section can berth more than one vessel depending on its length, denoting the starting point and ending point of the berth section. Given a set of vessels in the total planning horizon, each vessel is defined by a given turnaround time interval, and a given vessel length. Moreover, a number of effective quay cranes (QC) will be pre-assigned to each vessel.

The objective of the model is to determine the allocation of vessels to berths so that the total operating cost can be minimised. The total cost consists of the total berthing cost, and the total ITT cost. The problem is subjected to the following constraints and considerations:

1. For the vessel assignment, each vessel will be assigned to a berth section once.
2. For berthing conditions, berth length is a critical factor. When a vessel is assigned to a berth, there must be sufficient space for berthing. That is, each vessel can berth at any feasible arbitrary point of its assigned berth section with sufficient length.
3. The handling time required by each vessel is determined by the number of effective QCs being assigned. The vessel handling time can be calculated by dividing its total number of containers by the number of effective QCs pre-assigned multiplied by the QC productivity.
4. The completion time of each vessel equals the sum of its berthing time and handling time.
5. The berthing and completion time of each vessel must be within its feasible turnaround time interval to ensure service quality.
6. Each vessel must not wait more than the maximum waiting time limit.
7. No vessels will be assigned to the same berthing position in the same time period.

4.4 Methodology

Our proposed model consists of two stages: Stage 1 deals with the allocation of alliances to zones, while Stage 2 deals with the berth allocation problems (Figure 7).

Stage 1 – Alliance Berth Zone Allocation

To determine how to allocate different alliances to different zones, the model needs to minimise the total cost penalties of the overflowing containers and customers in berth zones. First, the model makes sure that each alliance will be assigned to a zone once. Second, it ensures that the maximum handling capacity of each berth will not be violated. As the number of combinations was very small for this case, a total of nine combinations, we applied try-and-error to test different combinations.

Stage 2 – Berth Allocation

Based on the solution obtained in Stage 1, we applied heuristic rules to deal with the berth allocation problems. Under the collaboration approach, the vessel arriving will be mainly assigned to the desired alliance berth zone found in Stage 1. Given a set of vessels in sequence, a berth is allocated to the vessel by the following two heuristic rules:

H1: Transshipment volume. For vessels with transshipment volume over a predefined threshold, they will be assigned to the largest transshipment zone instead of their desired alliance berth zone.

H2: Waiting time. To avoid vessels waiting over a certain period to maintain service quality.

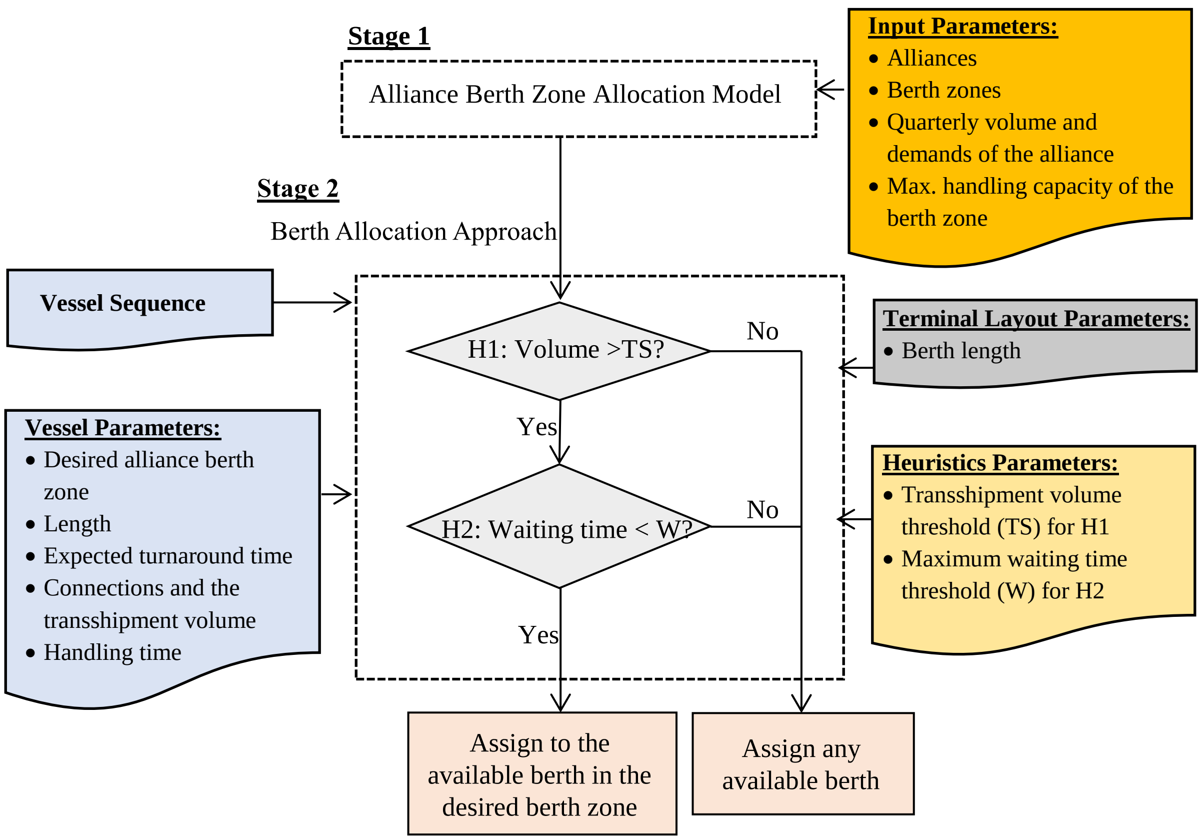


Figure 7. Outline of the Proposed Two-Stage Methodology

5. Simulation and Results

In this section, we test and demonstrate the significance and benefits of the collaboration concept to the Hong Kong container terminal industry. A number of simulation experiments were conducted, with the proposed terminal zone layout Figure 8, in which the capacity of Zone 1, Zone 2, and Zone 3 are 6 berths (1,940m), 14 berths (4,467m), and four berths (1,387m) respectively. The majority of the data used in the experiments was real historical data collected from major terminal operators, whilst the rest were estimations.

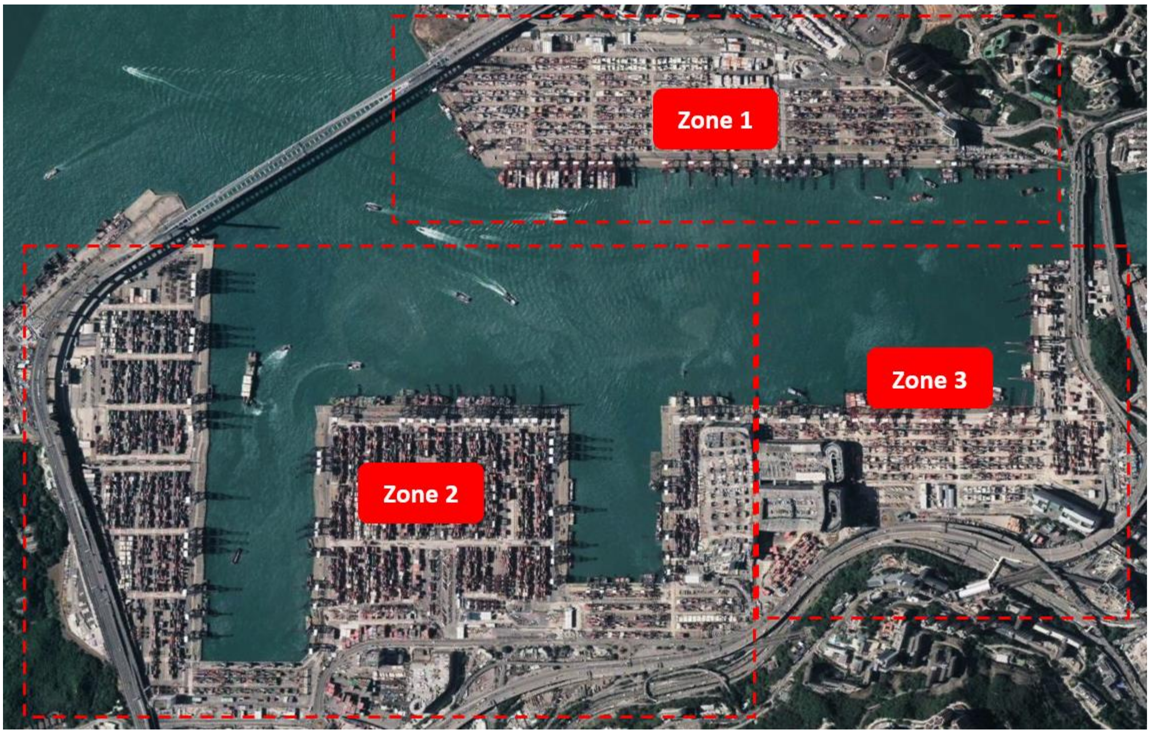


Figure 8. Outline of the Studied Container Terminal Layout

5.1 Simulation Setup

The experiment consists of nine container terminals. Altogether there are 24 berths with length ranging from 277m to 472m. We conducted the experiments by using one-month of historical data in 2017. We divided the data into a warm-up period and a testing period. Data in the first week was used for the warm-up period. For the testing data, the nine container terminals had a total of 609 arriving vessels covered 114,681 transshipment moves. To conduct a comprehensive analysis, we created six scenarios (**S1** – **S6**) representing different vessel demands as follows:

S1: <u>*Average scenario*</u> simulated the real existing environment. The vessel arrivals and transshipments were based on the existing historical data.

S2: <u>*High container volume scenario*</u> simulated the peak situation, which was expected to be busier than S1 by 25%. The number of containers carried by each vessel was projected up by 25% of the actual data.

S3: <u>*Low container volume scenario*</u> simulated the low season. We reduced the number of containers on each vessel by 25% of the actual data.

S4: <u>*Extremely high container volume scenario*</u> simulated an extremely high-volume situation. We increased the number of containers on each vessel by 50%.

S5: <u>*Extremely low container volume scenario*</u> simulated an extremely severe situation, such as economic crises. We reduced the number of containers on each vessel by 50%.

S6: <u>*High vessel number scenario*</u> simulated a peak situation when HKP attracts a lot of vessel callings. The number of vessel arrivals was increased by 50% based on the existing data.

To compare and demonstrate the significances and benefits of the collaboration concept, we designed two operations approaches (**A1 and A2**) for comparison:

A1: A1: Existing approach ("without collaboration") simulates the existing practice, in which ACT, CHT and HIT are under co-management strategy. Therefore ITT between T4, T6, T7, T8W and T8E are eliminated, while the rest terminals adopt the current Home Berth concept which requires ITT.

A2: "With Collaboration" approach simulates the goal of the proposed collaboration concept. Yet, due to geographical restriction, we assumed that ITT can only be fully replaced by direct operations in these four groups:

- Group 1: T4, T6, T7, T8W and T8E
- Group 2: T1, T2, T3 and T5
- Group 3: T3, T4, T6 and T7
- Group 4: T9S and T9N

In addition, we assume that only 50% of ITTs can be replaced by direct operations between Group 5: T4, T6, T7, and Group 6: T1, T2, T5.

We set the thresholds of transshipment volume (*TS*) to be 100 moves and waiting time (*W)* to be four hours. Regarding the setting of the alliance zones, we put *Alliance A* into Zone 1, *Alliance B* into Zone 2, and *Alliance C* into Zone 3 according to the container volume distribution (Figure 9).

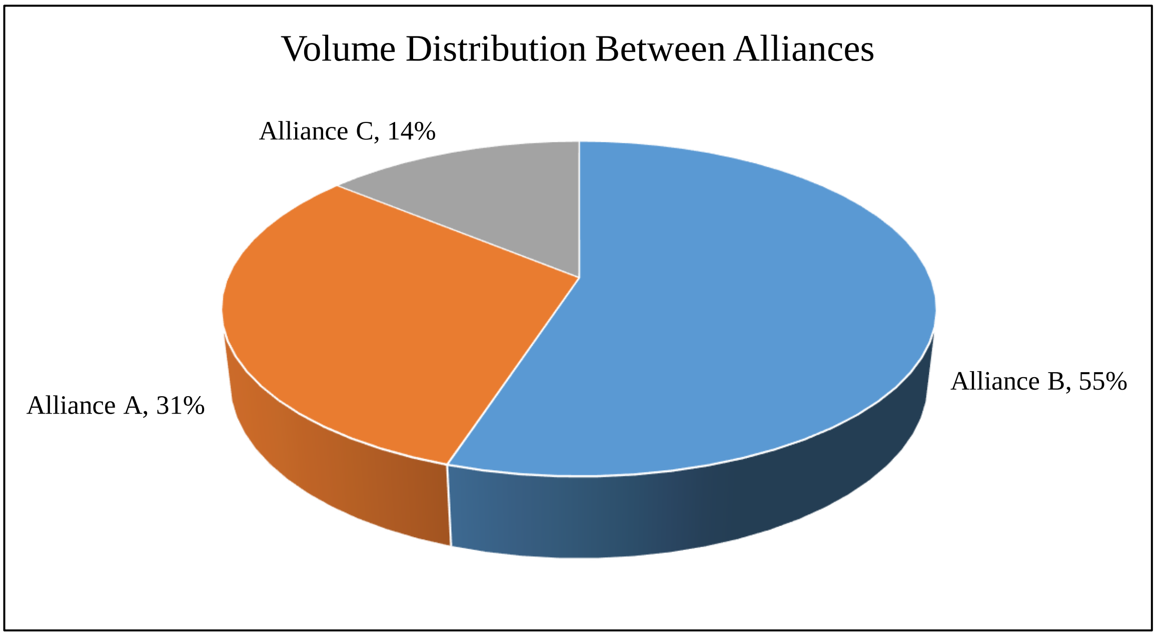


Figure 9. Volume Distribution of Containers Between Alliances.

5.2 Experiment - Studies of Collaboration Concept

We conducted simulations by comparing the two approaches (A1 and A2) in the six scenarios (S1 – S6). As a result, there were a total of 12 instances. The simulation results are summarised in Table 1. In general, the total number of ITT induced, the cost required, as well as the total amount of carbon emissions in A2 were significantly lower than those in A1. This proves that the concept of collaboration can significantly reduce the total number of ITT.

Table 1 – Performance Metrics Summary

		A1 - Without Collaboration		**A2 - With Collaboration**		**Improvement With Collaboration**	
		3-week simulation period	1-year estimation	3-week simulation period	1-year estimation	Improvement at 1-year stimulation (in absolute figures)	Improvement at 1-year stimulation (%)
ITT (number of moves)	**S1**	33,894	589,110	17,149	298,066	-291,044	-49%
	S2	39,288	682,863	21,601	375,446	-307,417	-45%
	S3	23,274	404,524	11,412	198,351	-206,173	-51%
	S4	48,130	836,545	28,726	499,285	-337,260	-40%
	S5	15,815	274,880	7,489	130,166	-144,714	-53%
	S6	32,293	561,283	20,820	361,871	-199,412	-36%
Charges (HK$ 000,000)	**S1**	10.2	177	5.1	89	-88	-49%
	S2	11.8	205	6.5	113	-92	-45%
	S3	7	121	3.4	60	-61	-51%
	S4	14.4	251	8.6	150	-101	-40%
	S5	4.7	82	2.2	39	-43	-53%
	S6	9.7	168	6.2	109	-59	-36%
Environ-ment CO_2 emissions '000 (KG)	**S1**	667	11,595	399	6,940	-4,655	-40%
	S2	719	12,500	514	8,934	-3,566	-29%
	S3	446	7,757	261	4,538	-3,219	-41%
	S4	928	16,134	692	12,020	-4,114	-25%
	S5	304	5,289	170	2,957	-2,332	-44%
	S6	622	10,816	496	8,629	-2,187	-20%

Analysis of ITT Performance

Figure 10(a) and 10(b) shows that the improvement in ITT reduction by using A2 is very stable across different scenarios. This demonstrates that the high total number of ITTs induced in A1 along S1 to S6 was not induced by the quantity of the vessels. Rather, it is affected by the existing home berth practice.

High ITT does not only affect individual terminal operations efficiency, but also the competitiveness of the Hong Kong container terminal industry. The average operation time spent on one ITT is more than half an hour, which involves the extra movements of a container from the yard side to the exit of the terminal, then from the exit to the entrance of the transferred terminal, and lastly from the entrance of the transferred terminal to its yard side (Figure 5). Comparing A2 and A1 in S1, there were 16,745 instances (33,894 moves – 17,149 moves) of unnecessary ITT movements in the current business volume. The annual estimates of the unnecessary ITT round-trip movements are 291,044. If the business volume increases in the future, i.e. in S2, and S4, the number of unnecessary ITT movements will surge up to 17,687 instances (39,288 moves – 21,601 moves), and 19,404 instances (48,130 moves – 28,726 moves) respectively. One can easily conclude that a lot of valuable resources and manpower is wasted on these unnecessary movements. Simplifying the current practice to shorten the transshipment time can definitely increase efficiency, release more resources for other uses, and consequently increase the competitiveness of the whole industry.

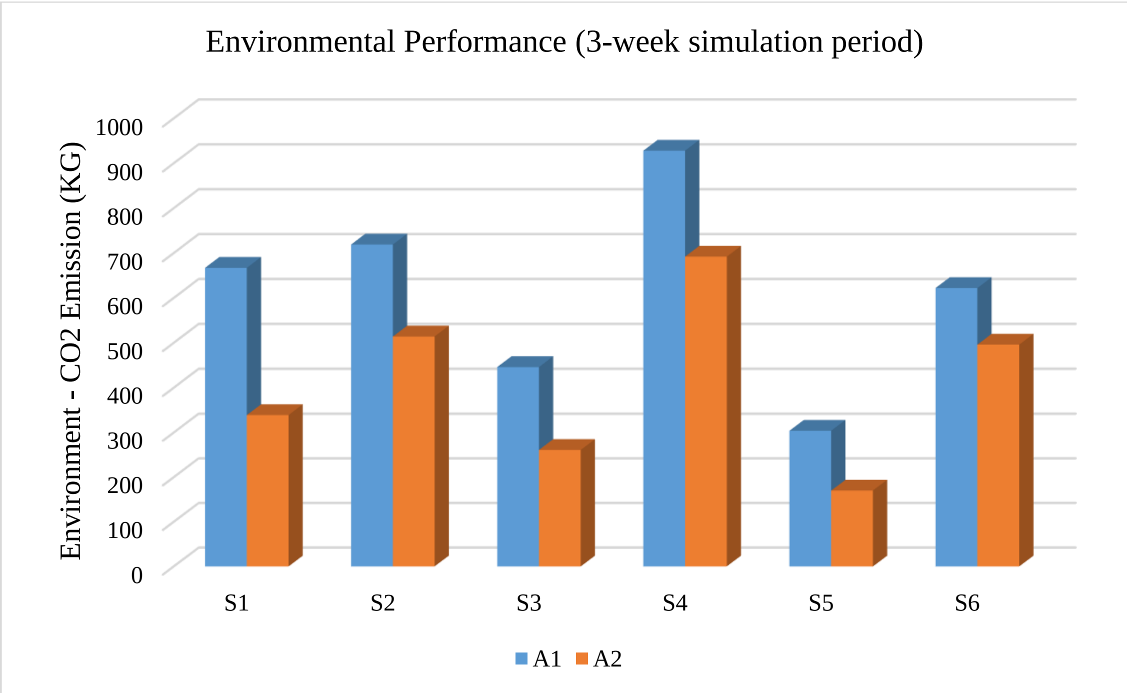


Figure 10(a). ITT Performance (3-week simulation period).

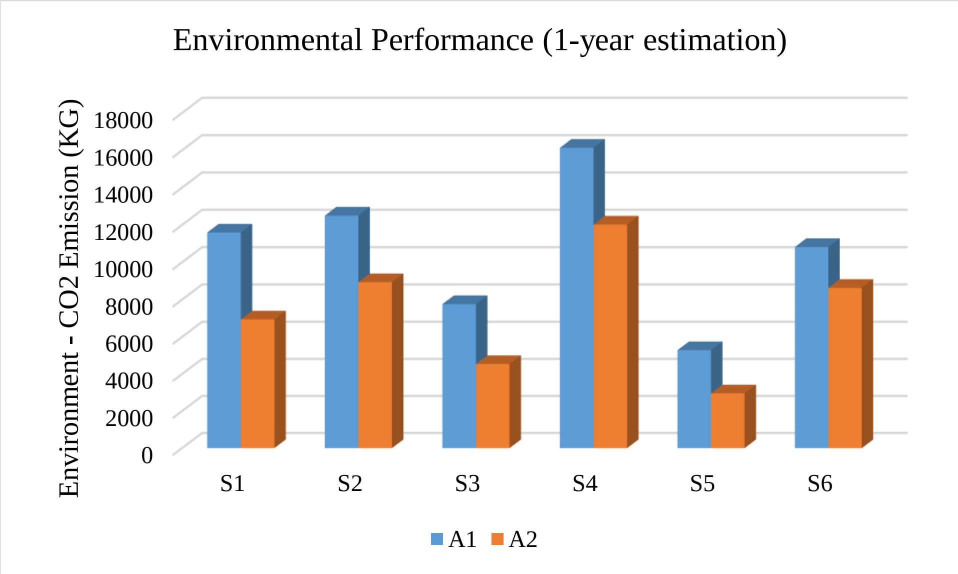


Figure 10 (b). ITT Performance (1-year estimation).

Analysis of Cost Performance

As mentioned above, the total number of ITT can be reduced significantly by the proposed collaboration concept. Such a reduction also implies a great amount of cost saving. Under current practice, the charges incurred by ITT is transferred to the liners directly. This definitely negatively affects the competitiveness of the KCTCs. The average charge of one container ITT is about HK $300. In the existing approach, i.e. A1, it involves a total of 33,894 ITT moves in S1. This translates to a total of HK$ 10.2M induced on unnecessary movements in three weeks, which is equivalent to about HK$ 177M annually. Under the collaboration approach, the total number of ITT moves was only 17,149 times, which was 49% lower than the ‘without collaboration’ approach. If the number of containers to be handled is high, such as in S4, it costs a substantial sum of money, HK$ 14.4M in three weeks. In contrast, for the collaboration approach, the total number of ITT moves was only 28,726 times, which was 40% lower than the ‘without collaboration’ approach. This helps the shippers save about HK$ 5.8M ($14.4M – $8.6M) in three weeks, and about HK$ 101M ($251M – $150M) in a year. Even in the economic downturn scenario (S5), the savings can still be about HK$ 4.3M annually.

Analysis of Environmental Performance

The collaboration approach can help the environment by reducing the amount of carbon emissions from unnecessary ITT moves. It is known that for each litre of diesel burnt, there will be 2.68 kg of carbon emissions. Currently, diesel consumption for each kilometre is about 0.94L/km. Accordingly, we can calculate the total amount of carbon emissions in each scenario above based on the distance between every terminal. From Figures 11(a) and 11(b), we can see that the total amount of carbon emissions is reduced in every scenario. The greatest improvement was obtained in S5 with a 44% reduction. When the total number of containers handled is reduced by 50%, more vessels can be berthed at their target berth, which means ITT can be minimised. Even when some cannot be berthed at their target berth, the proposed A2 approach directs them to berth within the alliance zone, which would minimise the travelling distance when ITT is involved. This demonstrates the significance of the collaboration concept to environmental protection in Hong Kong, which aligns with the Hong Kong Government's initiative on reducing carbon emissions.

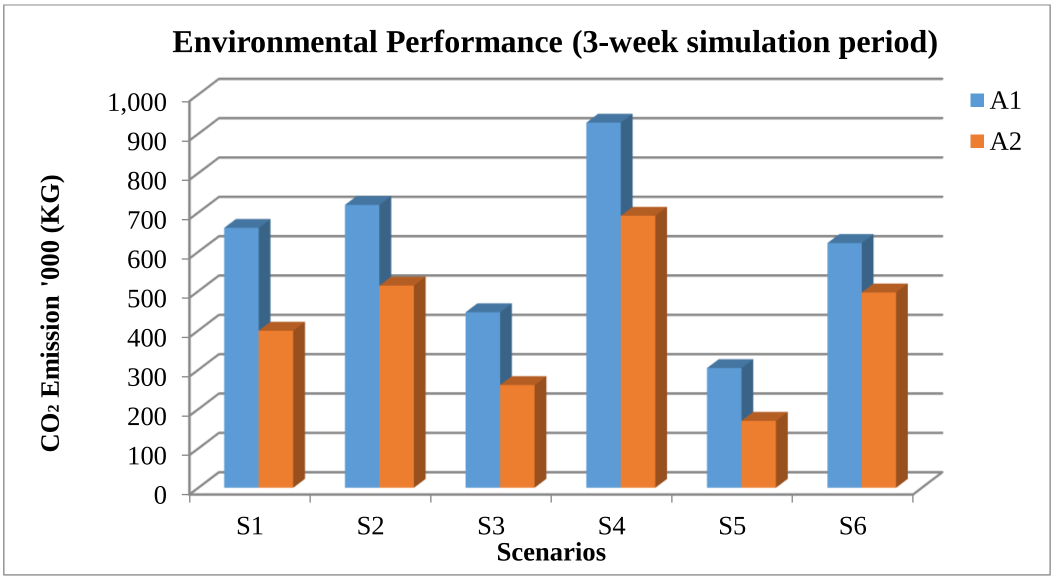


Figure 11(a). Environmental Performance (3-week simulation period).

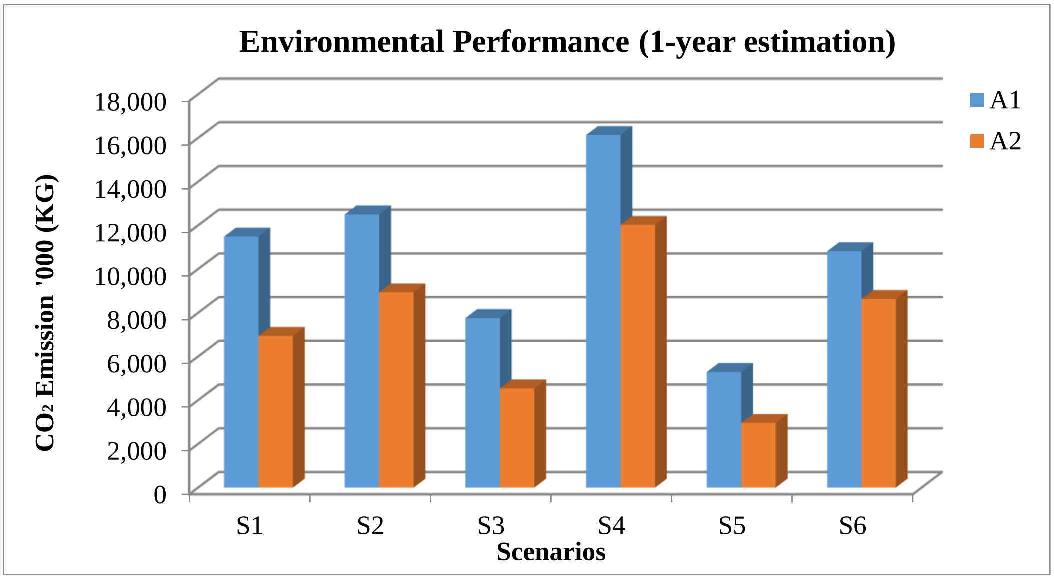


Figure 11(b). Environmental Performance (1-year estimation).

Analysis of Traffic Congestion

As shown in Figure 5, ITT involves extra operations, including moving the container from the arrival berth to its yard by an internal truck, then moving from the yard to the departure terminal's yard by an external truck, and lastly, moving from that yard to the quay by yet another internal truck. ITT involves much more travelling which may induce traffic congestion inside and outside the terminals. One can see in Table 1, according to the existing situation as in S1, there were 16,745 unnecessary ITT moves. It was estimated that the total number of the unnecessary round-trip ITT movements were about 291,044 in a year. As a result, there will be 1,595 trips per day. Cutting the number of trips would reduce the number of trucks required, and relieve road usage.

Analysis of Berth Utilisation Performance

We looked at whether the proposed collaboration concept would affect overall berth utilisation. We analysed the peak scenario S6, with various berth utilisation results shown in Figure 12. If we take a closer look at A1, in Area 3, berth utilisation was relatively lower than the other areas. This implies a low utilisation and ineffective distribution of vessels. For A2, the utilisation for Area 3 improved, and became similar to other areas. Thus, the collaboration concept helps to balance berth utilisation among different terminals.

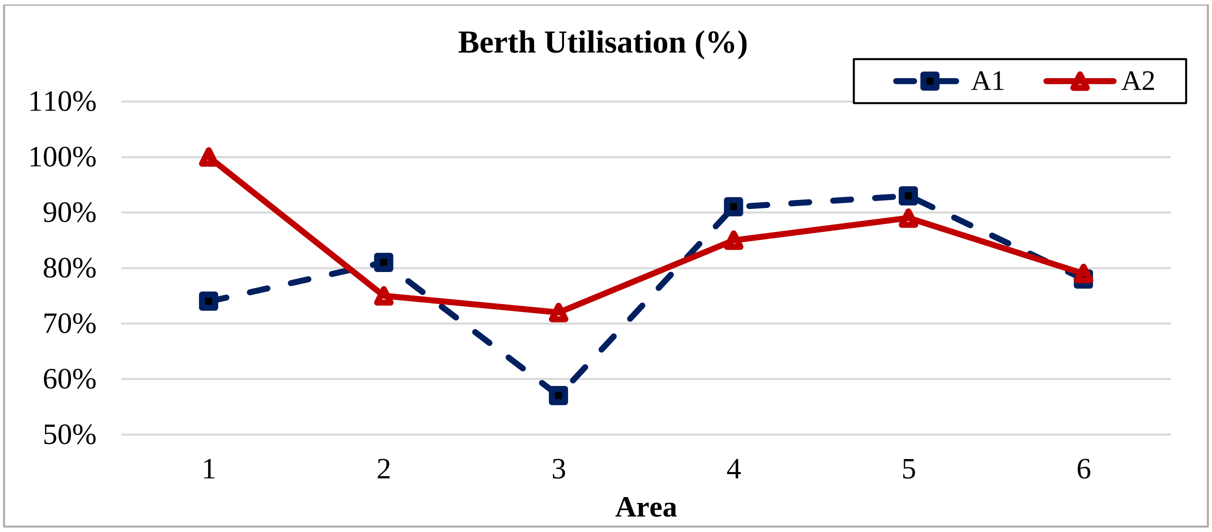


Figure 12. The Overall Berth Utilisation for A1 and A2 Approaches in S6

Analysis of Service Quality Performance

The service quality is defined by the vessel waiting time. Table 2 shows a comparison of the "Without Collaboration" approach (A1) and the proposed "With Collaboration" approach (A2) based on berth on arrival rate, the number of delayed vessels and their average waiting time. The waiting time of vessels on average was reduced by about an hour and up to about 6.9 hours. This can be explained by Figure 12, which shows that the berth utilisation in A2 is relatively more balanced than that in A1. Therefore, more vessels can be served without being queued for a particular berth. However, only in the scenarios S3 and S5 (*Low container volume scenario* and *Extremely low container volume scenario*) (on Table 2), the average waiting time slightly increased by 0.6 hour and up to 2.3 hours respectively. This is because the proposed vessel berthing strategy allows vessels to wait for their desired berth for the sake of reducing ITT.

Table 2 – Delayed Vessels

	A1 - Without Collaboration				**A2 - With Collaboration**				**Improvements With Collaboration**	
	Number of delayed vessels (>0 hour)	Average waiting time (hours)	Number of delayed vessels (>4 hours)	Estimation of the annual number of delayed vessels (>4 hours)	Number of delayed vessels (>0 hour)	Average waiting time (hours)	Number of delayed vessels (>4 hours)	Estimation of the annual number of delayed vessels (>4 hours)	Improvement of estimation of the annual number of delayed vessels (>4 hours)	Change in waiting time (hours)
S1	42	4.1	16	278	49	3.3	14	243	-35	-0.8
S2	106	4.7	46	800	115	3.8	25	435	-365	-0.9
S3	21	1.4	1	17	27	2	4	70	53	0.6
S4	224	7.6	123	2,138	204	4.9	66	1,147	-991	-2.7
S5	5	1.1	0	0	5	3.4	2	35	35	2.3
S6	667	15.6	500	8,690	676	8.7	361	6,275	-2,415	-6.9

6. Recommendations and Conclusion

6.1 Recommendations

To attain the above benefits, the implementation of the collaboration must be well planned. We identify four recommendations which could facilitate the collaboration.

i. Evaluate the ITT reduction benefits from the integrated supply chain

In the above experiment, we only calculated the tangible costs incurred for each container movement. Collaboration will enhance resource allocation and increase terminal efficiency. In addition, ITT can significantly improve supply chain efficiency and reduce the total logistics costs. As shown in the above simulation results, not only are the costs reduced, the vessel waiting times were also significantly shortened. Both liners and customers will have high confidence that vessels and containers handled by HKP can arrive and depart on time. This certainty can substantially reduce the logistics costs induced by uncertainty and risk. In the supply chain, costs associated with relevant risks include supplier delivery risk, distribution risk, delivery risk, security risk, inventory risk, financial risk, and environmental risk, which all relates to port operations. To cater for all these risks, every supply chain party tends to order more goods and estimate longer delivery time. This hinders Just-In-Time (JIT) practice and small-lot strategy. All these additional costs incurred in the supply chain should be evaluated when choosing a port for container handling. These are the intangible benefits which were not calculated above. Yet, they should be emphasised to customers.

HKP has been recognised as one of the most reliable and efficient ports in the world. The collaboration we propose would further strengthen her flexibility in tackling uncertainties, such as weather uncertainties and market dynamics, which should increase her attractiveness to shippers and liners.

ii. The operational collaboration details must be well planned

The proposed facility sharing mechanism requires collaborations among the terminals. Such collaboration covers information sharing on the operational level of supply and demand, such as real-time facilities availability status (both yard and berth), scheduling and actual arrivals of vessels, number of ITT containers, and transshipment container information. A well-planned protocol is required to facilitate information transfer among systems of different terminals. The level of detail for shared information has to be specified. Besides, the operational procedures of various terminals should be aligned, so that transshipment containers are handled similarly at all terminals.

Under the collaboration, shipping lines can gain access to port facilities irrespective of their contractual relations with terminal operators. By maximising the utilisation, all parties enjoy the cost synergies. Yet, different terminals may have different operating costs and ITT costing mechanisms. The costs for handling containers from other terminals or certain alliances must be charged under a set of agreed rates. This ensures all terminals are better-off compared with the existing practice.

iii. A healthy maritime business environment must be maintained

While this paper proposes a collaborative approach for HKP, it is important that terminal operators maintain their independence to ensure that customers have a choice, and that a good service quality can be maintained through competition. Our proposed facility sharing approach can simply help operators set more competitive prices for their customers, while also ensuring that their respective operations can be strong, independent and flexible.

iv. Establish better collaboration among terminal operators

As all the major shipping lines have formed alliances to enhance their efficiency and marketing power, terminal operators should also establish collaborations to maintain their bargaining power. Such collaboration can enhance promotion to shippers and liners, as well as strengthen competitiveness with other ports. The benefits of using HKP should be marketed to increase not only liners, but shippers' preferences. After all, the shippers are the ultimate customers to choose which port to handle their cargoes. However, the collaboration details among terminal operators need to be carefully investigated.

6.2 Conclusion

The Hong Kong maritime industry is facing severe competition from PRD ports, as well as other Asian ports. It is on a downward spiral, which is alarming to industry practitioners. The maritime industry has contributed significantly to Hong Kong's economy and society. Therefore, the industry must find ways to keep the maritime business. After reviewing the recent challenges faced by HKP, including the different operational requirements of transshipment containers, the dynamics of carrier alliances, the price competition among regional ports, as well as the complicated procedures in handling ITT, we propose a collaboration model to address these challenges.

The proposed model assumes that terminal operators collaborate with each other to share their facilities, including berths, cranes, and yards. With this collaboration, vessels with high transshipment connections are allowed to berth within the same terminal to avoid unnecessary ITT. To facilitate the vessel-berth allocation, a two-stage optimisation methodology is proposed. The majority of the data used in the simulation was real historical data collected from the KTCTs operators. The simulation results confirm that the proposed collaboration outperforms the existing home berth approach in all aspects. In terms of ITT, we can see that the total number of ITTs induced by the proposed model is significantly reduced in all six scenarios. This translates to over HK $88M of savings annually. Also, the utilisation of berths is more balanced than the existing home berth approach. The proposed collaboration can significantly save the travelling distance of transshipment. It also helps to reduce air and sound pollution. The proposed model not only benefits the KTCTs operators with lower operating costs and more efficient operations, but also the health of the people of Hong Kong.

In short, there are multiple benefits from the terminal facility sharing. However, to ensure it can be successfully implemented, careful planning and participation among all levels of management from all terminal operators is necessary. Although the ITT reduction benefits presented are not enormous, it marks the first milestone for collaboration at HKP. To stay competitive, all logistics parties should make breakthroughs in creating new value and providing value-added services for customers.

In conclusion, the ITT reduction benefits presented are significant. To survive and thrive, HKP should leverage its existing resources and facilities to overcome the challenges in the decades to come, and offer customers the best services it can provide.

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