AN INTERMODAL CONTAINER FLOW SIMULATION MODEL AND ITS APPLICATIONS

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ABSTRACT
This paper develops a container flow simulation model incorporating shippers, carriers, and port operators for intermodal freight transportation systems. This model consists of the components as follows: inland intermodal container transportation involving different inland transport modes, liner shipping services provided by various carriers, competition between carriers in terms of freight rate, transit time and service capacity, utility-based path choice principle for shippers, and discrete event simulation procedure. It is also implemented by using the object-oriented programming language C++ to facilitate the analysis of various scenarios. Finally, the developed program is applied to predict the increased revenue and market share of a liner shipping company if it introduces a new liner service route and to estimate quantitatively the impact on the container throughput of Singapore port that Maersk shifted its Southeast Asian hub from Singapore to Tanjung Pelepas.

KEY WORDS
Intermodal Transportation; Container Flow; Liner Shipping; Discrete Event Simulation
INTRODUCTION

Globalization is leading a steady growth in international seaborne trade. Liner shipping represents around a quarter of total volume of cargo transported in the whole maritime freight transportation market (1). Containerization has revolutionized the maritime transportation by minimizing cargo handling cost and time. By the end of 2007, the global containership fleet has reached a total of more than 25 million twenty-foot equivalent units (TEUs), an increase of more than 50 per cent since the end of 2002 (1).

Shippers, carriers, and container terminal operators (or port operators) are major players in the container cargo market. A shipper is a person or a company that has cargo to be shipped from an origin to a destination, or an intermediary broker or a third-party logistics (3PL) company governing and coordinating the whole shipment delivery process for cargo owners. A carrier is a company which provides transportation services. A container terminal operator serves liner shipping companies through container handling, storage, and bunkering. As this paper focuses solely on the container operations at ports, we use the term port operators and container terminal operators interchangeably. Shippers choose carriers according to their freight rate, transit time, reliability, and reputation. A shipper chooses more than one carrier to transport containers from origin to destination: Inland carriers transport containers from origin to export port or from import port to destination by truck, rail, barge, or their combinations. Liner shipping companies are the carriers which provide maritime transportation services. In order to efficiently deploy the containerships, a liner shipping company seeks to forecast its container shipment demand quantitatively while taking into account the competition with other companies.

Due to the acquisition, merger, and alliance within the liner shipping industry, liner shipping companies are becoming larger and facing cut-throat competitions. To decrease the operating cost, liner shipping companies usually adopt the hub-and-spoke shipping network by deploying large containerships on trunk routes to reap the benefit of economies of scale. For example, APL uses Singapore port as its hub for the Southeast Asian region (2). Consequently, major ports in the same region are struggling to be the hub of the region to increase the throughput of transshipped containers. In order to retain existing carriers and attract carriers from other ports, port operators are building new berths to alleviate port congestion, dredging water to accommodate larger containerships, purchasing new cranes to increase the container handling efficiency, expanding container yard to store more containers, and improving intermodal facilities to minimize the dwell time of cargo. All these constructions and improvements are extremely costly. A quantitative estimation of the future container throughput is a precondition for making the right construction and improvement decisions.

The purpose of this study is to develop an intermodal container flow simulation model to predict the container shipment demand for each carrier and throughput for each port and thus to assist the decision-making of carriers and port operators in a competitive context. The aggregated origin-destination (O-D) container shipment demand can be forecasted from the world economy development (1). To allocate this aggregated demand among carriers and ports, shippers’ choice behavior must be accounted for. In other words, the competition between carriers and the competition between ports must be examined.

Literature Review

A number of efforts have been devoted to the liner shipping fleet size and mix, fleet deployment, and service network design problems (3). Most of these studies assume that the container shipment demand is deterministic. Service factors such as the transit time and competition between liner shipping companies are excluded in these models.

There are also studies on evaluating attractiveness factors of ports. One line of this research (4-7) employs survey method to identify factors affecting port competitiveness, such as inland distance, oceanic distance, and intermodal connection. However, the conclusions of different research are not the same, mainly because of different population targeted for survey (8-
9) and limited sample size. The other line of research has sought to investigate quantitatively the significance of each selection factor and whether two factors are correlated by using discrete choice model (10-11) or regression model (7). Nevertheless, these models focus on one or a few ports and their applicability to a global liner shipping network is unclear.

Some researchers have integrated the selection of both carriers and ports into a single container cargo flow simulation model. The first stream of the container cargo flow model (12-13) aims to obtain the equilibrium between shippers and carriers. The selection of port is implicitly included in the selection of liner service routes. At the equilibrium, shippers cannot reduce their cost by unilaterally choosing another carrier and carriers cannot reduce their cost by changing the liner services. One major drawback of this approach is ignorance of the volatility of liner shipping market, since the system parameters have already changed before the ideal equilibrium is reached. The second stream of the container cargo flow simulation model (14) calculates the container cargo flow for the present liner shipping network. This approach takes into account the liner services provided, freight rate, ship capacity and transshipment cost. However, the model in (14) does not incorporate the effect of transit time on shippers’ choices. Moreover, this model investigates the container flow from one country to another, and hence neglects the impact of inland intermodal transportation on the choice of export/import port. Thirdly, containers are allowed to be transshipped at most one time, which is not representative in liner shipping practices.

Objectives and Contributions
The objective of this study is to develop an intermodal container flow simulation model for the current container transport systems in order to assist the decision-making of carriers and port operators in a competitive context. To achieve this goal, it first introduces an important concept of segment-based path to facilitate the representation of transshipment and the generation of candidate paths for an origin-destination pair. This paper proceeds to employ the utility-based discrete choice model to formulate shippers’ choice behavior. The utility definition explicitly contains the effect of transit time by using the value of time (VOT) of shipments. In addition, an inland intermodal operating network is proposed to calculate the transfer cost and time between different transport modes. Finally, this paper applies the discrete event simulation technique and develops a computer program with the object-oriented programming language C++ to simulate the container flow in the inland and maritime transportation networks. The container flow is allocated to each liner service route. Therefore the container shipment demand for each liner shipping company and the container throughput for each port can be easily derived. This paper contributes to the literature in that it simulates the container flow whilst capturing major characteristics of the practical intermodal transportation system: (i) Both the inland and maritime transportation networks are investigated in the container flow model; (ii) The competition between liner shipping companies is formulated by considering shippers’ utility-based choice principle; (iii) The concept of segment-based path allows for the representation of transshipment at sea ports more than one time. The proposed model is applied to the container flow on the Asia-Europe trade lane. This application predicts the increased revenue and market share of a liner shipping company if it introduces a new liner service route and estimates quantitatively the impact on the container throughput of Singapore port that Maersk shifted its Southeast Asian hub from Singapore to Tanjung Pelepas.

PROBLEM DESCRIPTION
Consider an intermodal container transportation system comprising the inland intermodal transportation network and the maritime transportation network. The origin and destination of containers flowing in the system are located in inland areas. Containers from an inland origin are first transported by available modes in the inland intermodal transportation network, such as truck, rail, barge, or their combinations, to an export port, where containers are loaded onto ships
deployed on liner shipping service routes operated by different liner shipping companies and transported to the import port. From the export port to the import port, ships may visit many intermediate ports while these containers stay on board, and these containers can also be transferred at transshipment ports to other ships. After arriving at the import port, containers are discharged from ships and reloaded onto truck, rail, or barge, and delivered to the inland destination.

Figure 1 depicts an intermodal transportation system and the container flow from Beijing to Berlin. This intermodal container transportation system consists of two inland intermodal networks (from the origin Beijing to the export port Qingdao and from the import port Rotterdam to the destination Berlin) and one maritime network (from Qingdao port to Rotterdam port). An inland intermodal network is defined by a set of nodes, denoted by \( N \) and a set of arcs \( A \). There are three types of nodes: area \( N^a \), port \( N^p \), and intermodal freight terminal \( N^i \). Area nodes are locations of inland origins and/or destinations. Cargo can also be transferred from one transport mode to another, e.g., truck to rail, at area nodes if there are such transshipment facilities. Port nodes can be cargo origins and destinations. Cargo can also be transshipped at port nodes. Intermodal terminals are locations without cargo demand or supply and solely used for cargo transshipment. The arcs between nodes are the inland transportation services, namely, truck \( A^t \), rail \( A^r \) and barge \( A^b \). The transportation of containers in the inland network involves different transport modes. For instance, containers from Beijing are firstly loaded onto a barge and shipped to Jinan. In Jinan these containers are transferred to rail and transported to Qingdao port. The maritime transportation network contains only the liner shipping services. Nevertheless, the port to port transportation may be served by more than one carrier. For example, containers from Qingdao port to Rotterdam port are transshipped at Singapore port and two different liner shipping companies are in charge of the transportation of Qingdao-Singapore and Singapore-Rotterdam, respectively. It should be noted that a liner ship carrying containers from one port to another port, for example, from Qingdao to Singapore, might call at other ports whereas these containers stay on board.

Given the aggregated container shipment demand from shippers for each O-D pair in the intermodal container transportation system, this paper aims to develop a model that can simulate the movement of these containers by taking into account shippers’ route choice behavior and carriers’ service level. This container flow simulation model can be used by liner shipping companies to quantitatively analyze the profitability of opening a new liner shipping service route. Also, it can be used by port operators to estimate port throughput.
CONTAINER FLOW SIMULATION MODEL

Segment-based Paths between an O-D Pair

In order to facilitate model formulation whilst not missing major characteristics of a container flow path from origin to destination, we propose the concept of segment-based path. The segment-based path formulation for the flow in Figure 1 is: Beijing→Qingdao port→Singapore port→Rotterdam port→Berlin, where Qingdao port is the export port, Rotterdam port is the import port and containers are transshipped at Singapore port. Thus, this segment-based path is composed of a series of segments: Beijing→Qingdao port, Qingdao port→Singapore port, Singapore port→Rotterdam port, and Rotterdam port→Berlin. Namely, a segment is from the origin to the export port or from the import port to the destination, or from a loading port to a discharge port. The first two types of segment are called inland segment and the segment from port to port is referred to as maritime segment. Transshipment ports can easily be derived from the definition of segment-based path. The term path mentioned in the remainder of the paper refers to segment-based path.

Utility-Based Path Choice Model for Shippers

Shippers can choose different carriers for different segments in a path. Without loss of generality, we assume that the load and discharge cost at both ends of a segment is included in the freight rate of the transportation service for the segment. It is possible that containers are stored at ports for some time as liner ships have fixed schedules, and the storage cost at port should be accounted for. A shipper may have more than one batch of containers to transport, e.g., one batch in January and another batch in May, or one batch every week. Here we simply consider those different batches as from different shippers. Thus, one shipper has exactly one batch of containers (referred to as a shipment hereafter).
From the origin to the destination, shippers have many candidate paths to choose. For instance, another possible path in Figure 1 is Beijing→Tianjin port→Busan port→Hamburg port → Berlin. When facing with the path choice, each shipper’s individual preference can be described by a utility function in terms of cost and time of the path (5) defined below:

\[ V(r,s) = -(C_r + VOT_s \times T_r), r \in R_{od}, s \in S_{od} \]  

where \( R_{od} \) is the set of candidate paths from origin \( o \) to destination \( d \); \( S_{od} \) is the set of shippers who have container shipment demand from origin \( o \) to destination \( d \); \( C_r \) is the total charge paid by the shipper who chooses path \( r \) (USD/TEU), including the freight rate and storage cost; \( VOT_s \) is the value of time of the shipment for shipper \( s \) (USD/TEU-hour). \( VOT_s \) is mainly a reflection of the inventory cost of the cargo in the containers; \( T_r \) is the transit time (hours) from origin to destination on path \( r \). Due to various unobservable factors, the real utility of a path to shipper \( s \), denoted by \( U(r,s) \), equals the observed utility \( V(r,s) \) plus an error term \( \varepsilon(r,s) \) (15). The probability that a shipper \( s \) chooses a certain path \( r^* \) among a set of candidate paths \( R_{od} \) is the probability that path \( r^* \) has the largest utility, namely,

\[ \Pr(r^*, s) = \Pr\{U(r^*, s) \geq U(r, s), \forall r \in R_{od}\}, r \in R_{od}, s \in S_{od} \]  

Logit model and probit model are the most commonly used models in practice. Carriers publish the information on the freight rate and schedule of their services, and thus to model the container flow according to the utility-based discrete choice model, we need to find the set of candidate paths.

Generation of Candidate Paths for an O-D Pair

Theoretically there are infinite paths for an O-D pair because containers can be transshipped many times at ports. However, only a small subset of these paths is used in practice. Take Figure 1 as an example, one hardly considers Xiamen port as the export port for containers from Beijing to Berlin because of the long inland distance between Beijing and Xiamen. To generate the practical paths, we propose two concepts: export/import ports for an O-D pair and transshipment ports for a pair of ports. The combination of these two concepts together with the concept of segment-based path facilitates the generation of all practical candidate paths for an O-D pair. Note that the generated paths in the model are based on the paths that are in operation in practice. In other words, whether a port is qualified to be an export/import/transshipment port depends on whether in practice it plays the role of export/import/transshipment port. As for the O-D of Beijing-Berlin in Figure 1, it is reasonable to assume the export port is one of Qingdao port and Tianjin port, and the import port is one of Rotterdam port and Hamburg port. Similarly, containers cannot be transshipped at any port in maritime transportation. Hence we also define the transshipment ports for each port pair. An illustrative definition for some ports in Figure 1 in provided in Table 1. Note that Table 1 is only an example to clarify the concept of transshipment ports rather than an enumeration of all transshipment ports. By the introduction of the concept of segment-based path, export/import ports for an O-D and transshipment ports for a port pair, we can list all the candidate paths for the O-D Beijing-Berlin, as shown in Table 2.

<table>
<thead>
<tr>
<th>No.</th>
<th>Port Pair</th>
<th>Transshipment Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tianjin, Hamburg</td>
<td>Singapore</td>
</tr>
<tr>
<td>2</td>
<td>Tianjin, Singapore</td>
<td>Busan</td>
</tr>
<tr>
<td>3</td>
<td>Tianjin, Rotterdam</td>
<td>Singapore</td>
</tr>
<tr>
<td>4</td>
<td>Qingdao, Hamburg</td>
<td>Singapore</td>
</tr>
<tr>
<td>5</td>
<td>Qingdao, Rotterdam</td>
<td>Singapore</td>
</tr>
</tbody>
</table>

TABLE 1 Transshipment Ports for Some Port Pairs

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TABLE 2  Candidate Paths for the O-D Beijing-Berlin

<table>
<thead>
<tr>
<th>No.</th>
<th>Segment-Based Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Beijing→Tianjin→Hamburg→Berlin</td>
</tr>
<tr>
<td>2</td>
<td>Beijing→Tianjin→Rotterdam→Berlin</td>
</tr>
<tr>
<td>3</td>
<td>Beijing→Tianjin→Singapore→Hamburg→Berlin</td>
</tr>
<tr>
<td>4</td>
<td>Beijing→Tianjin→Singapore→Rotterdam→Berlin</td>
</tr>
<tr>
<td>5</td>
<td>Beijing→Tianjin→Busan→Singapore→Hamburg→Berlin</td>
</tr>
<tr>
<td>6</td>
<td>Beijing→Tianjin→Busan→Singapore→Rotterdam→Berlin</td>
</tr>
<tr>
<td>7</td>
<td>Beijing→Qingdao→Hamburg→Berlin</td>
</tr>
<tr>
<td>8</td>
<td>Beijing→Qingdao→Rotterdam→Berlin</td>
</tr>
<tr>
<td>9</td>
<td>Beijing→Qingdao→Singapore→Hamburg→Berlin</td>
</tr>
<tr>
<td>10</td>
<td>Beijing→Qingdao→Singapore→Rotterdam→Berlin</td>
</tr>
</tbody>
</table>

Inland Intermodal Operational Network

An inland segment is within an inland intermodal network comprising transport modes such as truck, rail or barge or their combinations. In our approach, the inland is divided into many areas and all containers originated from the area are assumed to be located at the central city of the area. Normally there are numerous inland carriers providing various transportation services and it is difficult to trace each one of them. In addition, the inland transportation takes much shorter time compared with the maritime transportation. Thus, it is reasonable to assume that in the inland transportation network, there is at most one carrier providing service for each mode between two nodes and this service has an unlimited capacity and is available at any time. For instance, in the inland intermodal transportation network in Figure 2 there are truck and rail services between node 1 and node 6; each service has a given freight rate and transit time. Note that directions for the arcs in Figure 2 are not drawn as all the arcs are bi-directional in the inland intermodal transportation network.

FIGURE 2  Inland intermodal transportation network.

The container flow in the inland intermodal transportation network is different from the traditional network flow in that the transshipment cost and time are incurred at a node if the incoming arc and the outgoing arc are of two types (transport modes). In order to use any shortest path algorithm to calculate the utility of an inland segment, we transform the inland intermodal transportation network into an equivalent inland intermodal operational network with cost or time exclusively associated with arcs. The corresponding operational network for the inland intermodal transportation network of Figure 2 is shown in Figure 3. In the inland intermodal operational network, one node $i \in N$ in the transportation network is represented by at most 5 nodes: origin $n_i^o$, destination $n_i^d$, truck terminal $n_i^t$, railway terminal $n_i^r$ and port terminal $n_i^p$ (both inland port terminal and sea port terminal). There are inland transportation arc
(including truck, rail and barge), transshipment arc (transferring cargo between two transport modes) and origin/destination arc (arc from origin to terminal and from terminal to destination). The transshipment arc is not drawn for the ease of readability and cargo can be transferred from one terminal to another in the same location. The inland transportation arc and transshipment arc are bidirectional and have fixed cost and transit/transfer time. The origin/destination arcs are unidirectional and associated with no cost or transit/transfer time. We can use the utility definition equation (1) to calculate the utility of each arc, and thus employ the shortest path algorithm to find the utility of an inland segment. For instance, the optimal segment from origin to its export port in the transportation network in Figure 2 corresponds to the shortest path from $n_i^o$ to $n_i^p$ in the operational network of Figure 3.

![FIGURE 3 Inland intermodal operational network.](image)

**Maritime Transportation Network**

Determining the utility of a maritime segment is straightforward. As a maritime segment has defined the load port and the discharge port, we look up all the liner shipping services provided by different carriers. By comparing the freight rate and transit time of these services, we can choose the one with maximum utility. It should be noted that as a liner shipping service has its fixed schedule, containers might need to be stored at ports for some time and wait for the shipping service. To find the optimal liner service, we should take into consideration the storage cost and wait time at port. For instance, in the path of Beijing→Qingdao port→Singapore port→Rotterdam port→Berlin, we define the segment Singapore port→Rotterdam port as from the arrival at Singapore port to the arrival at Rotterdam port. In other words, the storage time and cost at Singapore port are included in the segment Singapore port→Rotterdam port. Therefore which liner service is the optimal for the segment Singapore port→Rotterdam port depends on the arrival time at Singapore port. In other words, it depends on the choice of service for the former segment Qingdao port→Singapore port.

To determine the utility of a path, i.e., to obtain the optimal combination of the services on each segment, we can employ the dynamic programming procedure as the utility of a service on the latter segment depends solely on the choice of service for the former segment.

**Discrete Event Simulation**

Given the inland intermodal operational network and the maritime transportation network, we use the discrete event simulation technique to simulate the container flow within a certain time period (e.g. one year). The flowchart of the simulation process is shown in Figure 4. We simply assume that the time interval between two adjacent shipments is exponentially distributed and each shipment has a constant batch size (number of containers). A larger batch size leads to fewer shipments, and thus reduces the simulation time. However, large batch size may decrease the
simulation accuracy, depending on the aggregated container number for each O-D and the ship
capacity. Besides, the distribution of VOT for the shipments is estimated based on the commodity
type and value. With these settings, we can generate all the shipments for a given aggregated O-D
container shipment demand.

At the beginning of the simulation, we assume that all ships are empty. To reduce the
posed simulation error, we add a warm-up period (e.g., 2 months). Shipments for the warm-up
period are also generated and processed in the same manner as normal shipments, whereas they
are not summarized for conclusions.

A shipper chooses a segment-based path according to the utility-based discrete choice
model. After that the available capacity of ships on the path is updated. For example, if the
shipment is 100 TEUs and the original available ship capacity is 120 TEUs on a certain segment
in the path, then after processing the shipment, the available ship capacity is 20 TEUs. If the next
shipment is 100 TEUs, the current available ship capacity is not large enough to accommodate the
shipment and hence this shipment cannot be delivered by the ship.

**Implementation Using C++**

The proposed container flow simulation model has been implemented using programming
language C++ and MySQL database. It has three modules as shown in Figure 5: the input and
output modules, which are interactive with users, and the process module. The “Simulate” block
in the process module represents the steps shown in Figure 4.
APPLICATIONS

There are three major container cargo transportation routes internationally: the transpacific, which is between Asia and North America, the transatlantic, which connects North America and Europe, and the Asia-Europe lane, which has the largest container flow volume. In 2007, container flows from Asia to Europe and from Europe to Asia are estimated at 17.7 and 10 million TEUs respectively (1). We thus employ the proposed model to analyze the container flow on the Asia-Europe lane in 2008. We consider three liner shipping companies, APL, OOCL and Maersk. Asia-Europe routes and 3 intra-Asia routes are selected for each company. These 15 liner service routes are modified by deleting the ports which are not in our case and adding a dummy port if necessary in order to make the round-trip time be an integer number of weeks. APL and OOCL take Singapore port as the Southeast Asian transshipment hub (2, 16), and Maersk uses Tanjung Pelepas (17). The cargo flow from Asia to Europe is assumed to be from the 13 provinces of Mainland China with the largest GDP in 2008 (18) to Rotterdam port. The capital cities of these provinces are Guangzhou, Jinan, Nanjing, Hangzhou, Zhengzhou, Shijiazhuang, Shanghai, Shenyang, Chengdu, Wuhan, Changsha, Fuzhou and Beijing, shown in Figure 1. The cargo flow from Europe to Asia is assumed to be from Rotterdam port to 7 of the top 9 ports regarding the number of TEUs handled in 2007 (19) in Mainland China. These 7 ports are Dalian, Tianjin, Qingdao, Shanghai, Ningbo, Fuzhou, Xiamen and Shenzhen; Yingkou port and Guangzhou port are not included because the selected 15 liner service routes do not call at these two ports. The total number of TEUs in the two directions between Asia and Europe are adjusted proportionally to fit the transportation capacity of the liner service routes. For each O-D pair, the number of TEUs is proportional to the GDP of the origin Chinese province (from Asia to Europe) or the number of TEUs handled at the destination Chinese port (from Europe to Asia). There are also 4 intermodal stations (Qinhuangdao, Dezhou, Xuzhou and Zhangping) in the inland transportation network in Mainland China, and 7 transshipment ports (Hong Kong, Kaohsiung, Pusan, Kobe, Port Klang, Tanjung Pelepas and Singapore). Thus, there are a total of 3 carriers, 15 liner routes, 13 areas, 4 intermodal stations, 17 ports (including a dummy port) and 20 O-D pairs, as shown in Figure 1.

The cost and time of inland transportation are calculated according to (20). The transshipment cost is assumed to be 50 USD and the time is 1 hour between any two inland transportation modes. The storage cost is 1 USD/TEU•day (21). The freight rate for maritime transportation is estimated from the report of UNCTAD (1). The VOT (USD/TEU•h) distribution is estimated by the commodity types and the value of commodity shipped from Asia to US in 2004 (22).

As in this study the wait time at transshipment ports is considered, it is difficult to quantify the correlation of the utilities of two paths. Hence we simply use the multinomial logit

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**FIGURE 5** Structure of the container flow simulation program.
model \((15)\) to express the probability that a shipper \(s\) chooses a certain path \(r\) among a set of candidate paths \(R_{sd}\), namely,

\[
Pr(r^*, s) = \frac{e^{\mu U(r^*, s)}}{\sum_{r \in R_{sd}} e^{\mu U(r, s)}}, r^* \in R_{sd}, s \in S_{sd}
\]

where \(\mu\) is the scale parameter. The scale parameter \(\mu\) in the multinomial logit discrete choice model is assumed to be 0.005, which means that if there are only two services and the first has 200 USD more utility than the second, then the probability that shippers will choose the first service is \(\exp(1)/[\exp(1)+\exp(0)] = 73\%\). The study period is 1 year and the warm-up period is 2 months. The batch size of each shipment is 100 TEUs.

Next, we analyze two scenarios to illustrate how the model can be used as a quantitative analysis tool to assist the decision-making for carriers and port operators.

**Introduction of a New Liner Service Route**

APL observes that ships have a very high loading factor on the legs of Rotterdam-Singapore and Singapore-Rotterdam through simulation. Therefore APL considers chartering more ships to provide a new liner service route between Rotterdam and Singapore. The simulation results are shown in Figure 6. After introducing the new liner route, it is estimated that APL will increase its revenue by 431 million USD and raise its market share from 34\% to 43\% (Here the market share is defined as the ratio of one carrier’s revenue to the sum of all carriers’ revenues). By comparing the operating cost of the new liner route with the increased revenue and taking into account its marketing strategy, APL can make the decision whether to introduce this new liner service route or not.

In this scenario, the freight rate of the new service is the same as existing services. There are two reasons for the volume shift to APL. One is the availability of slots. The other is the more frequent services, in other words, the container wait time at ports is shortened due to more frequent services. Two managerial insights can be correspondingly obtained. First, some liner shipping companies share slots on ships (slot charter). For example, a ship has the capacity of 4000 TEUs and is shared by 2 liner shipping companies. Each company manages 2000 TEUs. In this case, it might be possible that each company has 100 TEUs’ free slots, while a potential shipment is 150 TEUs. Consequently it is suggested that the ship capacity be flexibly allocated to these two companies. If one company uses more than half the capacity, it should compensate the other company. The flexible capacity allocation strategy dominates the rigid slot allocation. Second, liner shipping companies try to provide fast services by visiting as few intermediate ports as possible. From this model, to increase the service frequency can be considered as another alternative. Of course, increasing the service frequency requires to deploy more ships. Whether increasing the service frequency is justifiable should be examined on a case-by-case basis.
Maersk Shifted Its Southeast Asian Hub

A major concern for port operators is to retain their existing customers (carriers). Thus, we analyze the impact of Maersk’s South Asian hub shift. Before the year 2000, Maersk used Singapore port as its transshipment hub. The comparison of the container throughput for some ports between the current situation (with Tanjung Pelepas as the hub) and the case that Maersk would still use Singapore port as its hub is provided in Figure 7. Results indicate that Singapore’s container throughput decreases by 14.5% as a result of Maersk’s hub shift. This underscores the importance of retaining large liner shipping companies for a port.

We provide insights pertaining to the choice of hub port by analyzing these two case studies. In the first case, APL, OOCL and Maersk roughly provide the same services (each has 2 Asia-Europe routes and 3 intra-Asia routes), whereas from Figure 6 (a), the market share of Maersk is significantly smaller than the other two companies. This is due to the more frequent shipping services at Singapore port. In other words, cargo from Asia to Europe and transshipped at Singapore port wait shorter time because there are 4 liner service routes from Singapore to Europe (Tanjung Pelepas has only two services to Europe). In other words, Singapore port has better connectivity. As a result, more shippers choose to transship at Singapore port. Similarly, in Figure 6 (b), when APL introduces a new service connecting Singapore and Europe, the benefit of transshipping at Singapore is more evident. Hence, OOCL also benefits from this new service to some extent. The market share of OOCL drops because the competition of APL’s new service outweighs the facilitation of transshipment. Maersk suffers the most in this case because both the competition of APL’s new service and the facilitation of transshipment at Singapore are detrimental to it. We can also explain the interesting result in Figure 7 that the container throughput of Singapore when Maersk had not shifted its hub is even larger than the sum of the container throughputs of both Singapore and Tanjung Pelepas after the hub shift. This result is now intuitive, because when one hub is divided into two, the ship calling frequency decreases and thus the benefit of transshipment is reduced. In this case, more containers are shipped from Asia to Europe without transshipment. Therefore, liner shipping companies, especially small liner shipping companies, should choose the hub port with many existing liner services. Also, from the perspective of port operators, once a port has enough liner services calling, liner shipping companies would naturally choose it as the hub. Therefore the foremost task for port operators is to retain the global liner shipping companies or liner shipping alliances.
CONCLUSIONS
This paper has investigated the container flow in an intermodal transportation network with the discrete event simulation technique. The characteristics of the practical intermodal transportation network are taken into account, including inland intermodal and maritime transportation networks, competitions between liner shipping companies, and cargo transshipment. With these practical considerations, the model can be employed as a useful and practical quantitative analysis tool to assist the decision-making for liner shipping companies and port operators, such as predicting the increased revenue and market share of a liner shipping company if it introduces a new liner service route and estimating the impact on the container throughput of Singapore port that Maersk shifted its Southeast Asian hub from Singapore to Tanjung Pelepas. Further applications include: (i) to assess the profitability of slot-sharing among liner shipping companies; (ii) to analyze the viability of deploying mega-containerships; (iii) to predict the consequences of unexpected incidents, e.g., a strike at port; and (iv) to estimate the hinterland of an export/import port.

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REFERENCES


