Empty container repositioning in liner shipping

Article in Maritime Policy & Management · August 2009

DOI: 10.1080/03088830903056934

Dong-Ping Song
University of Liverpool

EMPTY CONTAINER REPOSITIONING IN LINER SHIPPING[1]

[For the published version, please refer to:
Song, D.P. and Carter, J. (2009), Empty container repositioning in liner shipping, Maritime Policy & Management, 36(4): 291-307.]

Dong-Ping SONG
International Shipping & Logistics Group
Business School, University of Plymouth, Plymouth, PL4 8AA, UK
Tel: 0044 1752 285630; Fax: 0044 1752 232249
Email: dongping.song@plymouth.ac.uk

Jonathan CARTER
Department of Earth Science & Engineering
Imperial College, London SW7 2AZ, UK
Email: j.n.carter@ic.ac.uk

ABSTRACT

The efficient and effective management of empty containers is an important problem in the shipping industry. Not only does it have an economic effect, but it also has an environmental and sustainability impact, since the reduction of empty container movements will reduce fuel consumption and reduce congestion and emissions. The purposes of this paper are: to identify critical factors that affect empty container movements; to quantify the scale of empty container repositioning in major shipping routes; and to evaluate and contrast different strategies that shipping lines, and container operators, could adopt to reduce their empty container repositioning costs. The critical factors that affect empty container repositioning are identified through a review of the literature and observations of industrial practice. Taking three major routes (Trans-Pacific, Trans-Atlantic, Europe-Asia) as examples, with the assumption that trade demands could be balanced among the whole network regardless the identities of individual shipping lines, the most optimistic estimation of empty container movements can be calculated. This quantifies the scale of the empty repositioning problem. Depending on whether shipping lines are coordinating the container flows over different routes and whether they are willing to share container fleets, four strategies for empty container repositioning are presented. Mathematical programming is then applied to evaluate and contrast the performance of these strategies in three major routes.

KEYWORDS: container shipping, empty container repositioning, flow balancing, route coordination, container sharing, linear programming.

1. INTRODUCTION

Container shipping has experienced a rapid development in the last few decades. The container traffic has increased from 84.6 million TEU (twenty-foot unit) in 1990 to 362 million TEU in 2005 (www.ci-online.co.uk). The annual growth rate is about 10.2%, which is well above the average world trade growth rate 6%. There are several factors that contribute to this difference. Firstly, in recent years more and more goods have been containerised. Secondly, the deployment of mega-vessel such as Emma Maersk (which

[1] A preliminary version was presented in IAME Annual Conference at Dalian, China, April 2nd-4th, 2008.

exceeds 12,000 TEU and was launched in early 2007) reshaped the container shipping networks towards hub-and-spoke systems, which requires more transhipment in the hub ports. Thirdly, world trade becomes more imbalanced and requires more empty movements.

For example, on the Europe-Asia trade route, European ports are experiencing a high surplus of empty containers, while Asian ports are facing severe shortages. The increase in container traffic from Asia to Europe was 10 times the increase seen in the opposite direction in 2003 [1]. During 2004, about half of the boxes moving westward to northern Europe were sent back empty [2]. Drewry Shipping Consultants estimated that about 20% of all ocean container movements have involved repositioning of empty boxes since 1993 [3]. Based on the data for 2002, Song et al. [4] simulated the global container shipping business and reported that the cost of repositioning empties is just under $15 billion, which is about 27% of the total world fleet running cost. The profitability of shipping lines is highly dependent on whether, or not, the empty repositioning cost is redeemable. How to effectively and efficiently manage empty containers has been a very important problem in shipping industry. It has not only economic effect, but also an environmental and sustainablity impact.

The objectives of this paper are to:

- identify critical factors that impact empty container movements;
- quantify the scale of empty container repositioning for major shipping routes;
- evaluate and contrast different strategies that shipping lines and container operators could adopt to reduce empty container repositioning costs.

The rest of the paper is organised as follows. In section 2, the relevant literature is reviewed. In section 3 the critical factors that may impact empty container repositioning are identified. In section 4, four strategies for empty container repositioning, based on the different scopes of container flow balancing, are presented. In section 5, mathematical programming is applied to three major shipping routes to quantify the benefit of different strategies and the scale of empty repositioning. Finally, conclusions are drawn in section 6.

2. LITERATURE REVIEW

Empty container repositioning has been an on-going issue since the beginning of containerisation. But it has become more prominent in recent decades. This section will review the literature related to empty container repositioning from both the internal and external managerial points of view.

Internal efficient management

The majority of the literature focuses on the optimisation of container fleet management, with an implicit assumption that the management is done within a single company. The dynamic nature of container fleet management has been long recognised. Much of the work has taken a deterministic approach, which is essentially dynamic in time and used classical linear programming formulations (e.g. [5,6]). More recently, Bourbeau et al. [7] formulated the depot location and container allocation problem as a mixed integer program model and applied branch-and-bound parallelization strategies to find the optimal solution. Cheang and Lim [8] considered empty positioning and leasing decisions between ports using a minimum cost flow model. Erera et al. [9] developed a dynamic deterministic multicomodity network flow model for an intermodal transport network.

They considered integrated container booking and routing decisions including empty repositioning. Olivo et al. [10] presented an integer programming model for empty container management in ports and depots with multiple transport modes.

The stochastic aspects of the problem have been examined during the 1990's. Crainic [11] considered inland transportation of empty containers between ports, depots and customers. The work was further extended to multi-commodity inland transportation network [12].

Some researchers have studied empty container repositioning between ports. For example, a decision support system for empty container distribution was developed by [13]. Lai et al. [14] used a simulation model to examine empty container allocation policies, they focused on empty containers moved from ports in the Middle East to ports in the Far East. Cheung and Chen [16] developed a two-stage stochastic network model for the dynamic empty container allocation problem. Choong et al. [16] reported that a longer planning horizon could encourage the use of inexpensive slow transportation modes to reposition empties.

More recently, Li et al. [17] examined the structure of empty container allocation in a single port. Song [18] demonstrated the threshold structure of the optimal empty repositioning policy for two-depot service systems. Song and Dong [19] developed threshold type policies to reposition empties for cyclic routes. These studies show that simple inventory-based repositioning policies can perform well in some situations. Li et al. [20] extended the two-threshold policy to a multi-port system.

External effective management

Recent years have seen the emergence of external collaboration among carriers to achieve effectiveness of container operations and reduce costs. Typical examples are internet-based support systems such as SynchroNet, and InterBox. These systems, often provided by third-party vendors, can serve as a neutral platform to facilitate container sharing among shippers, forwarders, and shipping lines. The idea is gaining increasing popularity, however "*There are still pockets of resistance, but the search to reduce costs outweighs the resistance to sharing containers*" [3].

The Tioga Group [21] carried out research in the USA to identify a regional empty container logistics strategy so as to maximize the ability of the port and intermodal community to reuse empty containers for export loads and to rationalise empty container returns. The research focused on traffic and emission impacts of current industrial methodologies (e.g. reuse of empty containers, off-dock empty return depots, internet-based support systems). Hanh [22] further explored the problems in the Southern California Regional posed by empty containers, in the context of the existing international trading structures, through interviews with international marine carriers. Jula et al. [23] analysed the potential cost and congestion reductions, through the reuse of empty containers in the Los Angeles and Long Beach port area. Lopez [24] investigated the organisational choices of ocean carriers to reposition their empty containers in the USA. This paper is mainly about the carriers' relationship with inland transport companies in terms of empty container operations.

Song [25] provided a theoretical analysis, and quantified the cost savings, for a collaborative strategy between two shipping lines in a shuttle service subject to uncertain customer demands. It was found that that factors such as the fleet size, the variance of demands, the demand patterns (balanced or imbalanced), and the container dispatching policy have significant impacts on the performance of the collaborative strategy. For example, the collaborative strategy can achieve higher cost savings in situations involving smaller fleet sizes or higher degrees of uncertainty.

3. CRITICAL FACTORS THAT IMPACT EMPTY REPOSITIONING

The fundamental reason for empty repositioning is the trade imbalance, i.e. the trade in one direction is more than that in the other. Trans-Pacific and Europe-Asia are prominently imbalanced. In 2005, the trade from Asia to USA was 13.90 million TEUs, whereas it is just 4.3 million TEUs in the opposite direction. In Europe, take the UK as example, for every 2 loaded imports less than 1 loaded export is shipped out. Due to China's economic boom, there is ever increasing container traffic demand out of China, although the importing volume to China is also increasing.

Apart from the trade imbalance, there are other factors that may also affect the empty container movements, e.g. dynamic behaviour, uncertainty in demands / handling / transportation, types of equipment, blind spots in the transport chain, and a carrier's operational and strategic practices.

The dynamic behaviour of container shipping is well recognised (see the discussion in Section 2). The majority of the literature takes into account the time and place elements in managing empty containers. Clearly the geographic location of containers changes over time. The trade demands also change over time for various reasons, e.g. seasonal products like agriculture produces, special festivals such as Christmas and Chinese New Year. These demand changes, although they may be predictable to a large degree, result in a dynamic impact on the system. The demands for empty containers and the arrivals of laden containers to be reused will not match due to the time and place constraints and the volume difference. Empty containers have to be accumulated in advance to meet these expected increases in demand, or to be stored and repositioned when the demands decrease.

Uncertainty is another important factor, representing the unpredictable elements in the system. Uncertainty may exist in customer demands and container processing activities such as consolidation, movement, handling, discharge, maintenance and repair. For example, industrial action at a port may force container vessels to change their schedule. Weather conditions and traffic congestion may increase the transport time. This type of uncertainty causes either laden containers not to be delivered to customers on time, or for empty containers not to be repositioned so as to meet the demands. Therefore, the movements of containers deviate from the plan and often incur extra movements and costs. On the other hand, demand uncertainty is probably the most frequent phenomenon. In the highly competitive shipping market, shippers have more choices and become more demanding. To accommodate the uncertainty in demands, shipping lines have to invest spare capacity and reposition empties more efficiently. It has been demonstrated that even in an overall balanced trade route, if the trade demands are stochastic, empty repositioning is essential to minimize the total cost [26].

Container types also affect the empty repositioning. There are several different types of container which vary in their dimensions as well as the cargo they are designed to carry. For example, there are special containers designed to carry building materials, vehicles, lumber, chilled-frozen food, grain, powders, liquids etc. Twenty-foot unit (TEU) and forty-foot unit boxes also vary in height. Even for geographically nearby ports, they may handle significantly different volumes of 40ft and 20ft containers. For example, Yantian, in China, has a high proportion of 40ft containers in its global export driven business. For every seventeen 40ft containers there are three 20 ft containers, which gives an average box size of 1.85 TEU. Hong Kong sees sixteen 40 ft containers for every nine 20 ft containers, which gives a lower average box size of 1.64 TEU [27]. It has been observed that although some trade routes may not have significant trade imbalances, the need to transport empty containers may still be quite significant. One reason is that most types of cargo require, or it is more convenient to use, a specific type of containers [28].

Paul Crinks [29], President and CEO of International Asset Systems (IAS), stated there are blind spots when containers are moving via rail or truck, or while they are in inland terminals or at shipper/ consigner premises. Blind spots in the transport chain may prevent carriers from tracking each container's location and status in real-time, thereby challenging carriers' efforts to improve utilisation. In other words, without having timely and accurate data on container status and location, ocean carriers are unable to manage their container fleet effectively.

Carriers' operational practices are highly related to the actual empty container movements. For example, some Carriers tend to automatically return empties containers to the port as soon as they become available for immediate extraction back to Asia. Others may hold equipment for up to 30 days, in the hope that export moves will match some of their empties before they are forces to ship them empty. Apart from carriers' internal operations, their external strategies also affect their empty container movements. Some shipping lines form an alliance in which they may share vessel slots. Willingness to exchange or share containers with other carriers can provide more opportunities for container reuse and reducing empty repositioning.

For all of these factors, the trade imbalance is the root cause. Carrier's operational and strategic practices, on the one hand, affect the actual movements of empty containers; on the other hand, they represent the potential tools that carriers could use to tackle the empty container repositioning problem. In the next section, we will mainly focus on the impact of trade imbalance in a shipping network with multiple ocean carriers, and discuss a few broad-brush strategies for carriers to deal with empty container repositioning problem.

4. FOUR STRATEGIES OF EMPTY CONTAINER REPOSITIONING BASED ON FLOW BALANCING

In Section 2, we have classified previous studies related to empty container repositioning into two groups: internal efficiency oriented and external effectiveness oriented. Internal efficiency can be improved through better management at operational level [4-6,9,10] and tactical or strategic level [7,8,11,12] within a single carrier. An important mechanism to achieve better management is to coordinate the container flows over the whole network, i.e. performing coordination across different service routes rather than managing each route separately. External effectiveness can be achieved through various forms of collaborations among different carriers, e.g. sharing container fleets, sharing vessel fleets, supply chain management [3, 21-25].

Based on the above observations, we will use two important criteria: *internal coordination* and *external container sharing*, to design different strategies (propositions).

Here internal coordination refers to balancing container flows across different service routes. External container sharing refers to pooling container fleets among different ocean carriers. This paper will concentrate on tactical and strategic levels of management over a shipping network with multiple service routes involving multiple shipping companies, and will not consider the dynamic characteristics of container operations. The main purposes are to compare empty container repositioning costs in major shipping routes; and to evaluate different broad-brush strategies involving major container shipping companies.

In an ideal situation, balanced trade demands should not incur any empty movement, and imbalanced trade demands should be matched as much as possible so that the empty movements can be minimized. In other words, the empty container repositioning cost can be minimized by balancing the container flows over the global shipping network among all shipping lines.

We will use mathematical programming to evaluate the strategies. First, the following notation is introduced to formulate the empty container repositioning problem in a macro environment.

N – number of regions (or nodes) in the shipping network
L – number of global shipping lines (ocean carriers)
d_{jk}^{i} – annual trade demand volume from region j to region k for shipping line i.
c_{jk}^{i} – unit cost of repositioning an empty container from region j to region k for shipping line i.
x_{jk}^{i} – number of empty containers repositioned from region j to region k for shipping line i.
(j, k) – represent a shipping route from region j to region k.

According to whether shipping lines are coordinating the container flows over different service routes and whether they are willing to share container fleets with other companies, four strategies can be generated for empty container repositioning: container-sharing and route-coordination; container-sharing without route-coordination; route-coordination without container-sharing; and neither container-sharing nor route-coordination.

Strategy 1: Container-sharing with route-coordination

This is the most optimistic estimation of the empty container movements. It is assumed that shipping lines share their container fleets across all routes. This can be regarded as an integrated management to balance container flows worldwide ignoring individual company's identity. The shipping alliances may partially represent such practices, e.g. New World Alliance is formed by three liners: APL, Hyundai Merchant, and Mitsui OSK. It provides services for three major routes: Europe-Far East, Trans-Pacific and Trans-Atlantic. Within the alliance, although liners may not completely share their container fleets, they do share some vessel slots.

Mathematically, the objective is to minimize

$$\sum_j \sum_k \sum_i x_{jk}^{i} \cdot c_{jk}^{i} \tag{1}$$

Subject to flow balance constraints

$$\sum_k \sum_i (d_{jk}^{i} + x_{jk}^{i}) = \sum_k \sum_i (d_{kj}^{i} + x_{kj}^{i}) \quad \text{for any region } j; \tag{2}$$

$$x_{jk}^{i} \geq 0 \text{ for any } i<L \text{ and } j, k \leq N. \tag{3}$$

Where constraint (2) represents that the total flow into region j for all shipping lines should be equal to the total flow out of region j.

Under this strategy, shipping lines are virtually integrated and have achieved coordination of container flows over the whole network. The implied assumption is that all the information such as trade demands and repositioning costs are available and shared, and the allocation of containers is appropriately managed. This strategy is an ideal proposition. The total cost of moving empty containers is minimized by balancing the container flows over the entire shipping network among all shipping lines. The solution to (1)-(3) yields a lower bound for the empty repositioning cost, which can be used to estimate the scale of empty container movements.

However, it should be pointed out that in reality this strategy is impossible to implement completely because shipping lines may compete with each other and the global network is too complicated to coordinate.

Strategy 2: Container-sharing without route-coordination

This strategy assumes that shipping lines will share their containers for each route, but there is no coordination between different routes. In other words, for each individual service route, all shipping lines act as a virtual liner by pooling container fleets and vessel fleets; but different service routes are operated and managed separately.

This strategy represents some practices emerged recently. For example, the internet-based support systems such as InterBox, SynchroBox, InterExchange [21,22] provide neutral platforms to facilitate different companies to exchange containers, i.e. one company's empty containers are used to meet other company's trade demands. Therefore, one company does not need to reposition empties because they will be used by other companies to meet demands in the same service routes. By doing that, shipping companies are essentially sharing their container fleets on that route.

Mathematically, the objective under this strategy is to minimize the following cost for any given route (j, k):

$$\sum_i x_{jk}^i \cdot c_{jk}^i \tag{4}$$

Subject to flow balance constraints

$$\sum_i (d_{jk}^i + x_{jk}^i) = \sum_i (d_{kj}^i + x_{kj}^i); \tag{5}$$

$$x_{jk}^i \geq 0 \text{ for any } i<L \text{ and } j,\ k \leq N. \tag{6}$$

Where constraint (5) represents that the total flow from region j to region k for all shipping lines should be equal to the total flow in the opposite direction.

If all shipping lines have the same repositioning costs for any given shipping route (j, k), i.e. $c_{jk}^i = c_{jk}$ for $i \leq L$, then the solution to (4)-(6) satisfies:

$$\sum_i x_{jk}^i = 0, \quad \text{if } \sum_i d_{jk}^i \geq \sum_i d_{kj}^i;$$

$$\sum_i x_{jk}^i = \sum_i d_{kj}^i - \sum_i d_{jk}^i, \quad \text{if } \sum_i d_{jk}^i < \sum_i d_{kj}^i.$$

This scenario is reasonable because the repositioning costs are mainly determined by the geographic distance rather than individual company.

Clearly container sharing can go beyond a specific service route, in which case it tends to be closer to Strategy 1. It should be pointed out in reality the use of internet-based support systems is not free and other additional costs may also be incurred. However, such practice is particularly attractive to relatively small carriers [3].

Strategy 3: Route-coordination without container-sharing

This strategy assumes that shipping lines will not share their container fleets, but each of them tries to manage its empty container operations to the best by balancing container flows across different service routes. In other words, the focus is on the internal efficiency for all the services it provides rather than the external collaboration with other companies. The majority of literature can be classified into this category with an emphasis on the dynamic characteristics of the system, e.g. [5~12].

The objective under this strategy is to minimize the following cost for each shipping line i and each region j:

$$\sum_k x_{jk}^i \cdot c_{jk}^i \tag{7}$$

Subject to flow balance constraints

$$\sum_k (d_{jk}^i + x_{jk}^i) = \sum_k (d_{kj}^i + x_{kj}^i); \tag{8}$$

$$x_{jk}^i \geq 0 \text{ for any } i<L \text{ and } j, k \leq N. \tag{9}$$

Where constraint (8) represents that the total flow into region j should be equal to the total flow out of region j for each shipping line i.

This strategy focuses on internal coordination over the shipping network that a particular shipping line serves. In theory, it is more achievable than the external container-sharing strategies since business competition and data confidentiality could be resolved within a single company. In reality, for large shipping lines, the complexity of the shipping network may hinder the implementation of route coordination. For small shipping lines, their shipping network may not be wide enough to perform sufficient coordination.

Strategy 4: Neither route-coordination nor container-sharing

In this strategy, each individual shipping line has to balance its container flows for each individual service route. There is no coordination between routes and no container sharing among shipping lines. The point-to-point balancing approach used by a Chinese shipping company can be regarded as one of such practices to reposition empty containers. Mathematically, the objective is to minimize the following cost for each shipping line and each given route (j, k):

$$x_{jk}^i \cdot c_{jk}^i \tag{10}$$

Subject to flow balance constraints

$$(d_{jk}^i + x_{jk}^i) = (d_{kj}^i + x_{kj}^i); \tag{11}$$

$$x_{jk}^i \geq 0 \text{ for any } i<L \text{ and } j, k \leq N. \tag{12}$$

Where constraint (11) represents that the flow from region j to region k should be equal to the flow in the opposite direction for each shipping line i.

The solution to (10)-(12) can be easily obtained as follows:

$$x_{jk}^i = 0, \quad \text{if } d_{jk}^i \geq d_{kj}^i;$$
$$x_{jk}^i = d_{kj}^i - d_{jk}^i, \quad \text{if } d_{jk}^i < d_{kj}^i.$$

This strategy is the simplest form and is easy to implement for equipment managers. For example, some shipping lines always reposition empty containers from Europe to Asia as soon as they become available. The underlying assumption is that there will always have enough empty containers in Europe to meet trade demands from Europe to Asia. By repositioning empties back to Asia as soon as possible this will balance the container flows in the Europe-Asia route.

5. EVALUATE THE BENEFITS OF FOUR STRATEGIES AND QUANTIFY THE SCALE OF EMPTY REPOSITIONING

This section applies the above four strategies to the three major shipping routes to compare their performance in terms of the costs and volumes of empty container movements. The purpose is to evaluate their benefits and quantify the scale of empty container repositioning. This will help to identify the opportunity and scope for improvement in empty repositioning operations. Historical data from the past few years will be used in the analysis in order to demonstrate the trend in empty container movements.

The major containerised routes in the shipping network are Europe-Asia, trans-Pacific and transatlantic. These three liner routes service three broad regions: Asia, USA, and Europe (i.e. N = 3). In this section, we first discuss the available historical data and calibrate them in the form suitable for our analysis. Then we will evaluate the different strategies for managing empty containers and report the results.

5.1 Data design

The United Nation publishes an annual review of maritime transport, which lists estimated container flows on major trade routes. From year 2003 to 2007, the trade demands are summarized in table 1.

Table 1. Trade demands in three major shipping routes in million TEUs [1,2,30,31]

	Europe-Asia		Trans-Pacific		Transatlantic	
Year	Eur-Asia	Aisa-Eur	Asia-USA	USA-Asia	USA-Eur	Eur-USA
2003	4.92	7.26	10.19	4.05	1.72	2.90
2004	5.20	8.90	12.40	4.20	1.70	3.20
2005	5.60	9.90	13.90	4.30	1.80	3.30
2006	5.80	12.50	13.90	4.60	2.30	3.90
2007	6.10	14.40	14.80	5.00	2.40	3.90

Containerisation International publishes quarterly freight rates on the three major trade routes. The rates are the market averages based on six of the trades' major liner companies. We average the quarterly rates for each year to obtain the freight rates for years from 2003 to 2007 in table 2.

Table 2. Freight rates on three major routes in US$/TEU (www.ci-online.co.uk)

	Europe-Asia		Trans-Pacific		Transatlantic	
Year	Eur-Asia	Aisa-Eur	Asia-USA	USA-Asia	USA-Eur	Eur-USA
2003	749	1573	1777	833	869	1391
2004	742	1772	1896	816	801	1442
2005	816	1769	1874	803	907	1646
2006	799	1475	1744	815	1028	1819
2007	795	1803	1683	769	1090	1709

It should be pointed out that the freight rates in table 2 do not actually represent the costs of repositioning an empty container because profit margins have been included in the freight rates. We could scale down the freight rates to estimate the actual costs more closely. To simplify the data collection, we treat the freight rates as the empty repositioning costs directly. Such treatment does not affect the application of the models, and its impact on the relative merits of four strategies may be minor. On the other hand, from the business viewpoint, moving an empty container implies the loss of the revenue generated by moving a laden container. In addition, the terminal handling charges are the same for a laden container and for an empty container. Further, we assume different shipping lines have the same cost structures because transportation costs mainly depend on the geographic distance. Table 2 therefore gives the data c_{jk}^i.

In this paper, we consider an environment with multiple global shipping lines co-existing. Due to the extreme difficulty in collecting cargo volumes carried by each individual shipping line, we estimate shipping lines' cargo volumes by splitting and calibrating the total trade volumes given in table 1 according to liners' carrying capacities. This may be justified two facts: firstly, for global shipping lines, more capacity often means they carry more volume; secondly, according to the data on ci-online.co.uk, the vessel load factors (utilisations) are quite comparable for different liners in the same major route. However, it has to be pointed out that the actually carried volumes are not exactly proportional to their carrying capacities. We therefore introduce a random perturbation to the generated volumes to represent such variation.

The shipping lines' carrying capacities can be found at www.ci-online.co.uk. For example, in 2007, the top 20 shipping lines have the following shipping capacities:

Table 3. Top 20 liners' shipping capacities in 2007 (in TEU)

Ranking	Company	Shipping capacity in TEU
1	Maersk Line	11308531
2	MCS	1573551
3	CMA CGM	1019725
4	Hapag-Lloyd	517213
5	Cosco	454526
6	CSCL	390354
7	Evergreen	387168
8	APL	377334
9	Hanjin	342461
10	NYK	337378
11	Mitsui OSK	281967
12	OOCL	275057
13	K Line	267988
14	Yang Ming	240433
15	Zim Integrated	203228
16	Hamburg SDG	159039
17	Hyundai	157208
18	Pacific ILP	123084
19	CSAV NORASIA	117873
20	Wan Hai Lines	113532

Next we describe the detailed procedure to split and calibrate trade demands among multiple shipping lines. Let V_i denote the shipping capacity of shipping line i. We assume all the trade volumes in the three major shipping routes were carried by the top 20 shipping lines. This may be justified by the fact that top 20 liners form the most important part of the global shipping network. They occupy about 70% of the world total carrying capacity in 2007 and dominate the above three major shipping routes, whereas small shipping lines often focus on intra-continent routes or short-sea routes. An alternative is to introduce a virtual shipping line to represent the remaining shipping operators. Therefore, we have $L = 20$. The procedure is divided into three steps.

A procedure to calibrate trade demands among multiple shipping lines:
Step 1: (Splitting). For each route (j, k), the trade volume d_{jk} is split into smaller volumes proportional to shipping lines' carrying capacity,

$$d_{jk} = \sum_i \mu^i_{jk}; \quad \mu^i_{jk} = d_{jk} \cdot \frac{V_i}{\sum_i V_i}$$

where μ_{jk}^i represents the average annual volume carried by shipping line i.
Step 2: (Perturbation). Generating a sample of the random variable, which follows a normal distribution $N(\mu_{jk}^i, \sigma_i^2)$, where $\sigma_i = 0.3\mu_{jk}^i$. Denote its non-negative part as ξ_{jk}^i.
Step 3: (Calibration). Calibrating the split cargo volumes to preserve the total trade volume, i.e.

$$d^i_{jk} = d_{jk} \cdot \frac{\xi^i_{jk}}{\sum_i \xi^i_{jk}}$$

In the above Step 2, the parameter 0.3 represents the coefficient of variation (CV), which is defined as the ratio of the standard deviation to the mean (CV := σ/μ). For simplicity, we assume the coefficient of variation is fixed for all shipping lines. It should be noted that after perturbation in Step 2, the sum of cargo volumes in a given shipping route might not be equal to the total trade volume due to the random generation. Therefore, Step 3 is necessary to preserve the total trade volume.

5.2 Results and findings

For each year, 10 samples of the demand volume d_{jk}^i ($i \le 10$, j, $k \le 3$) are generated using the above procedure. The four strategies described in Section 4 are then applied to each sample. Note that the optimisation problem under a specific strategy is a linear programming problem with 20*3*3=180 (i.e. $L*N*N$) unknown variables (i.e. x_{jk}^i for $i \le 20$, j, $k \le 3$), the Matlab tool is used to solve these linear programming problems.

The total repositioning costs ($\sum_j \sum_k \sum_i x_{jk}^i \cdot c_{jk}^i$) averaged over 10 samples are given in table 4. These results represent the total costs incurred by repositioning empty containers on three major routes under the corresponding management strategies. To facilitate the comparison between different strategies, the percentages of cost reduction achieved by strategies 1-3 relative to Strategy 4 are given in the "% reduction" columns.

Table 4. Total costs of empty container repositioning (in million $) under four strategies

	Strategy 1	*%reduction*	Strategy 2	%reduction	Strategy 3	%reduction	Strategy 4
2003	6965	18.27%	7891	7.40%	7390	13.28%	8522
2004	9550	13.34%	10654	3.33%	9816	10.93%	11021
2005	11194	13.41%	12573	2.74%	11488	11.14%	12928
2006	12954	12.85%	14574	1.96%	13114	11.78%	14865
2007	14097	12.25%	15772	1.83%	14200	11.61%	16066

It can be seen from Table 4 that:

(a) total empty repositioning costs on the three major routes are at least 6.97, 9.55, 11.19, 12.95 and 14.10 billion dollars in years 2003 ~ 2007 respectively. This is because the results under Strategy 1 represent the most optimistic estimation of the empty container repositioning costs since it assumes route coordination and container sharing among all shipping lines over the whole network, while ignoring other factors such as dynamics and uncertainty;

(b) compared to Strategy 4, Strategy 1 saves costs 12%~18%, Strategy 3 saves costs 10%~13%, whereas Strategy 2 only saves 1.8%~7.4%. Therefore, strategies 1 and 3 achieve significantly lower costs than strategies 2 and 4. This shows that route-coordination is much more important than the container-sharing mechanism in reducing empty container repositioning costs in the given scenarios;

(c) looking at the trend from 2003 to 2007, the costs of empty container repositioning are increasing substantially. For all four strategies we see that they are all nearly doubled in five years. This reflects the increasing burden to shipping lines of repositioning empties;

(d) from 2003 to 2007, the percentage of the cost reduction achieved by strategies 1-3 from Strategy 4 is generally decreasing, which means that route-coordination and container-sharing are becoming less able to reduce empty repositioning costs compared to strategy 4.

Apart from the incurred costs, the physical volumes of empty containers to be repositioned are of interest. When the cost coefficients are difficult to quantify (as we mentioned before there is a difference between freight rates and actual repositioning costs), it is more appropriate to use the physical volumes to quantify the empty repositioning problem. Table 5 gives the corresponding optimal solutions in terms of the total volumes of empty container movements ($\sum_j \sum_k \sum_i x_{jk}^i$), which are obtained by averaging over 10 samples. Similarly, the "% reduction" columns give the percentage of empty movement reduction achieved by strategies 1-3 from Strategy 4.

Table 5. Total number of empty movements (in million TEU) under four strategies

	Strategy 1	%reduction	Strategy 2	%reduction	Strategy 3	%reduction	Strategy 4
2003	8.48	16.83%	9.66	5.26%	9.03	11.45%	10.20
2004	11.90	13.14%	13.40	2.19%	12.28	10.34%	13.70
2005	13.90	11.34%	15.40	1.77%	14.24	9.17%	15.68
2006	16.00	10.22%	17.60	1.25%	16.18	9.23%	17.82
2007	18.10	8.68%	19.60	1.11%	18.21	8.11%	19.82

Using similar arguments, it can be observed from Table 5 that: total empty repositioning volumes on the three major routes are at least 8.5, 11.9, 13.9, 16.0 and 18.1 million TEUs in years 2003 - 2007 respectively. Compared to Strategy 4, Strategy 1 can reduce the empty movements by 8.7%-16.8%, Strategy 3 can reduce the empty movements by 8.1%-11.5%, whereas Strategy 2 can only reduce the empty movements by 1.1%-5.3%. From 2003 to 2007, the volumes of empty container movements increase substantially. Using Strategy 4 as a base, the percentage volume reduction achieved by other three strategies decreases over time.

To have a clearer understanding of the scale of empty container movements, it is helpful to contrast the empty movements with the laden container movements. Table 6 gives the percentage of empties out of total movements (which includes both laden and empty movements) under Strategy 1 for the three major routes in the years 2003-2007.

Table 6. Empty movements vs. laden container movements (in million TEU) under Strategy 1

Year	Empty movements	% of total volume	Laden movements	Total movements
2003	8.48	21.46%	31.04	39.52
2004	11.90	25.05%	35.60	47.50
2005	13.90	26.38%	38.80	52.70
2006	16.00	27.12%	43.00	59.00
2007	18.10	27.98%	46.60	64.70

Table 6 reveals that the empty container movements consist of at least 21% of total container movements in 2003 for the three major routes. This steadily increases to 28% in 2007. These results are based on Strategy 1, which is the most optimistic estimation. For other strategies, e.g. Strategy 2, the percentages of empty movements become 23.73%, 27.35%, 28.41%, 29.04% and 29.61% for 2003-2007 respectively, which are about 2% higher. Further, if other factors such as dynamic behaviour and uncertainty are taken into account, the scale of empty container movements on the three major routes should be higher.

The sampling process in the trade demand calibration procedure may affect the results. To illustrate to what extent the sampling process would influence the results, table 7 shows the mean plus/minus a standard deviation of the empty container repositioning costs under four strategies based on the generated 10 samples in 2005. This reflects the variation of the costs caused by the randomness in the demand calibration procedure.

Table 7. Mean and standard deviation of empty container repositioning costs (in million $) under four strategy in 2005

	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Mean - std dev.	11193.93	12573.175	11324.74	12719.76
Mean	11193.93	12573.175	11488.05	12927.56
Mean + std dev.	11193.93	12573.175	11651.36	13135.35

Table 7 shows the standard deviation is 0 under strategies 1 and 2. This is because shipping lines are sharing their container fleets to meet trade demands and they operate like a single company. Thus, the calibration procedure does not affect the results. In other words, all samples produce the same result and lead to zero variation. For strategies 3 and 4, individual shipping line will manage their container fleets and balance trade demands independently. Different samples generate different combinations of trade demands, which lead to different results of total costs. The coefficient of variation is less than 0.02, which indicates the variation is very small and the costs are representative. Namely the results are insensitive to the sampling process.

5.3 Discussions

This research quantifies the empty container repositioning costs and empty movements under four broad-brush strategies. It was shown that route-coordination is much more beneficial than the container-sharing mechanism in reducing empty container repositioning costs. This finding may be explained by the facts that: (1) globalisation of the service network offers more opportunity to coordinate across different routes and reduce empty movements; (2) in severely imbalanced trade routes, all shipping lines have similar patterns of container surplus or deficit, which implies there is relatively limited room for reduction of empty movements by sharing containers.

The lesson for global shipping lines is that they should focus on internal route coordination first, and then turn to external container-sharing strategies for further improvement. This indeed reflects the current business perception that large ocean carriers are reluctance to join container sharing practices. For smaller shipping lines or non-vessel operating common carriers (NVOCC), due to their lack of global coverage, container-sharing strategies are probably more appropriate.

Because Strategy 1 assumes the full scale of route coordination and container sharing among all shipping lines over the entire network, it can achieve the maximum reduction of the empty repositioning costs. Therefore, the results in tables 4-6 under Strategy 1 represent the most optimistic estimations of the repositioning cost, empty movements, and the percentage of empties out of total movements. In other words, they can be used as a lower bound when estimating the scale of empty container repositioning.

Strategy 4 adopts neither route-coordination nor the container-sharing mechanism, but it still assumes perfect matching of empty containers with trade demands on each individual route for each shipping line. In reality, this is difficult to achieve due to other factors such as dynamic behaviour, uncertainty in demands / handling / transportation, types of equipment, blind spots in the transport chain, and the carrier's operational and strategic practices. In particular, the dynamic nature and external uncertainties may incur significant empty container movements even on balanced trade routes (Song, 2007ab). Therefore, the results under Strategy 4 should not be regarded as the upper bound for the scale of empty container repositioning.

From year 2003 to 2007, the costs, volumes, and percentage of empty container repositioning are increasing substantially. Compared to the base case, Strategy 4, the percentage of cost or volume reduction achieved by strategies 1-3 is generally decreasing. This indicates that the empty container-repositioning problem will become more and more challenging if the container shipping business follows the current trend (i.e. the trade becomes more and more imbalanced). Nevertheless, route-coordination and container-sharing approaches can still play a significant role since the reduction percentages from the basic case are more than 10%. Taking into account the effect of other factors such as dynamic behaviour and uncertainty, the benefits could be even higher.

In this paper we focus on the comparison of four strategies in terms of empty container repositioning costs and container movements. We did not consider the management issues about how to implement the route-coordination and container sharing. It should be pointed out that the implementation of these strategies in practice is very complicated and challenging. For example, it requires intensive information communication (e.g. container geographical location and their status) and the involvement of multiple players (e.g. port authorities, freight forwarder and inland transport companies).

The above discussions are mainly based on the trade balancing analysis among multiple shipping lines and focused on the impact of different strategies on empty container repositioning. As we pointed out earlier, apart from the trade imbalance, there are other factors that may also affect the empty movements, e.g. dynamic behaviour, uncertainty, types of containers, blind spots in the transport chain, and carrier's operational and strategic practices. To investigate the interacting impacts of these factors at the operational level, a more appropriate approach is to build a controlled simulation environment. This environment can replicate the elements of uncertainty, dynamic operations, competition, logistics strategies, and others that may be relevant to the particular situation. By monitoring the game playing over time or running purposely design scenarios, extensive data can be obtained to provide insights into the quantitative relationships between critical factors and the empty container movements.

6. CONCLUSIONS

This paper addresses the empty container repositioning problem at a macro scale from an ocean carriers' viewpoint. The critical factors that may affect empty container repositioning were identified through a literature review and industrial practice observation. Focusing on the root cause of empty repositioning, i.e. the trade imbalance, we analyse the impact of route-coordination and container-sharing on the empty container movements in a business environment with multiple ocean carriers co-existing. Different combinations of route-coordination and container-sharing produce four strategies.

Taking the three major routes (Trans-Pacific, Trans-Atlantic, Europe-Asia) as examples, we quantify the benefits of these strategies and produce a optimistic estimation of empty container movements. The strategy combining both route-coordination and container-sharing can reduce empty repositioning costs by 18% - 12% in the period 2003 - 2007 respectively, compared to using neither container-sharing nor route-coordination. Route-coordination is much more beneficial than container-sharing mechanism in reducing empty container repositioning costs. A lower bound for the empty container movements is provided. The percentage of empty movements out of total container movements is 21.46%, 25.05%, 26.38%, 27.12%, and 27.98% for the years 2003 - 2007 respectively. This quantifies the scale of the empty repositioning and indicates its trend.

Through the above discussion, it is quite clear that although route-coordination and container-sharing mechanisms can alleviate the degree of empty container movements, it cannot eliminate the empty repositioning problem. The implementation of these strategies remains a challenging issue particularly in today's dynamic and uncertain environment. With manufacturers searching for cheaper manufacturing bases, production tends to be more centralised and concentrated in a very small part of the world, which leads to a more imbalanced world trade and container shipping will have to face the challenges of empty repositioning. More research at both strategic level and operational level is required.

ACKNOWLEDGEMENTS

This work was supported in part by the Engineering and Physical Sciences Research Council (EPSRC) [grant numbers EP/E000398/1, EP/F012918/1].

REFERENCES

1. United Nations, 2004, *Review of Maritime Transport*, (Geneva: United Nations Publication).
2. United Nations, 2005, *Review of Maritime Transport*, (Geneva: United Nations Publication).
3. Mongelluzzo, B. 2004, Thinking inside the box, *The Journal of Commerce*, January 12th, 2004: 10-12.

4. Song, D.P., Zhang, J., Carter, J., Field, T., Marshall, M., Polak, J., Schumacher, K., Sinha-Ray, P., and Woods, J., 2005, On cost-efficiency of the global container shipping network, *Maritime Policy & Management*, 32: 15-30.
5. Dejax, P.J. and Crainic, T.G., 1987, A review of empty flows and fleet management models in freight transportation, *Transportation Science*, 21 (4): 227-247.
6. White, W.W., 1972, Dynamic transhipment network: an algorithm and its application to the distribution of empty containers, *Networks*, 2: 211-236.
7. Bourbeau, B., Crainic, T.G. and Gendron, B., 2000, Branch-and-bound parallelization strategies applied to a depot location and container fleet management problem, *Parallel Computing*, 26: 27-46.
8. Cheang, B. and Lim, A., 2005, A network flow based method for the distribution of empty containers, *International Journal of Computer Applications in Technology*, 22(4): 198-204.
9. Erera, A.L. Morales, J.C. and Savelsbergh, M., 2005, Global intermodal tank container management for the chemical industry, *Transportation Research Part E*, 41(6): 551-566.
10. Olivo, A., Zuddas, P., Francesco, M.D. and Manca, A., 2005, An operational model for empty container management, *Maritime Economics & Logistics*, 7: 199-222.
11. Crainic, T.G., Gendreau, M. and Dejax, P., 1993, Dynamic and stochastic-models for the allocation of empty containers, *Operations Research*, 41 (1): 102-126.
12. Crainic, T.G., Gendreau, M., Soriano, P., Toulouse, M., 1993, A tabu search procedure for multicommodity location-allocation with balancing requirements, *Annals of Operations Research*, 41: 359-384.
13. Shen, W.S. and Khoong, C.M., 1995, A DSS for empty container distribution planning. *Decision Support System*, 15 (1): 75-82.
14. Lai, K.K., Lam, K. and Chan, W.K., 1995, Shipping container logistics and allocation, *Journal of the Operational Research Society*, 46: 687-697.
15. Cheung, R.K. and Chen, C.Y., 1998, A two-stage stochastic network model and solution methods for the dynamic empty container allocation problem, *Transportation Science*, 32 (2): 142-162.
16. Choong S.T., Cole, M.H. and Kutanoglu, E., 2002, Empty container management for intermodal transportation networks. *Transportation Research Part E*, 38 (6): 423-438.
17. Li, J.A., Liu, K., Leung, S.C.H. and Lai, K.K., 2004, Empty container management in a port with long-run average criterion, *Mathematical and Computer Modelling*, 40(1-2): 85-100.
18. Song, D.P., 2007, Characterizing optimal empty container reposition policy in periodic-review shuttle service systems, *Journal of the Operational Research Society*, 58(1): 122-133.
19. Song, D.P. and Dong, J.X. 2008, Empty container management in cyclic shipping routes, *Maritime Economics & Logistics*, 10: 335-361.
20. Li, J.A., Leung, S.C.H., Wu, Y. and Liu, K., 2007, Allocation of empty containers between multi-ports, *European Journal of Operational Research*, 182: 400-412.
21. Tioga Group, 2002, *Empty ocean logistics study*. Technical Report, Submitted to the Gateway Cities Council of 541 Governments, CA, USA.
22. Hanh, Le Dam, 2003, *The Logistics of Empty Cargo Containers in the Southern California Region*, Final Report, Long Beach, CA.

23. Jula, H., Chassiakos, A. and Ioannou, P., 2006, Port dynamic empty container reuse, *Transportation Research Part E*, 42: 43-60.
24. Lopez, E., 2003, How do ocean carriers organize the empty containers reposition activity in the USA? *Maritime Policy & Management*, 30(4): 339-355.
25. Song, D.P., 2007, Analysis of a collaborative strategy in container fleet management, *11th World Conference on Transport Research*, University of California, Berkeley, June 24-28, 2007.
26. Song, D.P. and Dong, J.X., 2007, Container dispatching policies in two-terminal shipping services with uncertain demands, *International Association of Maritime Economists (IAME) Annual Conference*, Athens, Greece, July, 4-6, 2007.
27. Cochrane, R.A., 2008, The effects of market differences on the throughput of large container terminals with similar levels of efficiency, *Maritime Economics & Logistics*, 10, 35-52.
28. Branch, A., 2000, *Export Practice and Management*, 4ed. (London: Thomson Learning).
29. Crinks, P., 2000, Asset management in the global container logistics chain, *International Asset System*, (viewed 8 Nov. 2007, http://interasset.com/docs/AssetManagementWP.pdf).
30. United Nations, 2006, *Review of Maritime Transport*, (Geneva: United Nations Publication).
31. United Nations, 2007, *Review of Maritime Transport*, (Geneva: United Nations Publication).