OPTIMIZATION OF EMPTY CONTAINER MOVEMENTS USING “STREET-TURN” STRATEGY: APPLICATION TO METRO VANCOUVER AREA

by

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Abstract

This paper focuses on the regional empty container repositioning problem. We propose a more practical model to optimize regional empty container movements. With the framework, we evaluate the effectiveness of “street-turn” strategy and provide insights on “street-turn” operation in Metro Vancouver area. We conduct interviews with local industry professionals to collect information about current empty container operations.

The major findings from this research are: (1) “Street-turn” strategy reduces empty container repositioning cost majorly from transportation and gate fees. (2) “Street-turn” strategy is more effective in trade-balanced environment than trade-imbalanced environment. (3) The number of participants in the transport network has a positive impact on the feasibility and effectiveness of “street-turn” strategy. (4) The variance in the supply and demand of empty containers increases the variance in the effectiveness of “street-turn” strategy. (5) Container users have higher incentive to promote “street-turn” operations than shipping lines. (6) “Street-turn” strategy has been conducted jointly by a few importers and exporters in Metro Vancouver area. The major challenge is that container information is not shared among participants. (7) Unlike the situation in LA/LB port region, shipping lines have not yet taken the initiative to promote “street-turn” interchanges in Metro Vancouver area.

The successful implementation of “street-turn” strategy depends on the participation of each player. With a high level of information visibility, the proposed model can be employed as a decision support tool to identify “street-turn” opportunities and optimize empty container movements within the system.
Preface

This thesis is original, unpublished, independent work by the author, Hanxing Zhang. It is edited based on helpful comments from Garland Chow, Daniel Ding, and Tom Culham. I am responsible for developing the mathematical analysis. The modelling is conducted using YALMIP Optimization Toolbox created by Johan Löfberg. This thesis also has benefited from practical insights provided by local industry professionals from Port Metro Vancouver, shipping lines, and drayage companies.
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Lastly, my enduring gratitude also goes to my parents, whose have supported me throughout my years of education, both morally and financially.
Dedication

To my parents
Chapter 1: Introduction

Empty container repositioning is a major issue for shipping companies to achieve cost efficiency and to maintain high level of customer satisfaction. In 2009, global expense for empty container repositioning is up to 30.3 billion dollars, which is around 19% of the global maritime industry income (Sterzik, 2013). According to De Brito and Konings (2011), around 20%-25% of the general expense for a shipping company comes from empty container management. Moving empty containers generates no revenue but increases operation cost; however, empty container repositioning is unavoidable at various geographical levels in order to fulfill the demand of empty containers.

The root cause of empty container repositioning is global trade imbalance (Boile et al., 2004). For example, China imports raw materials as bulk cargo and exports manufactured products in containers to developed countries such as the United States. However, the volume of exported containers is much fewer than imported containers in developed countries. Therefore, Asian countries always face a lack of containers for export cargos, whereas empty containers are accumulated in North America (Song and Panayides, 2012). To mitigate the impact of trade imbalance, shipping companies reposition empty containers from importing regions to exporting regions by sea or by railway at the global and inter-regional level (Theofanis et al., 2009).

At a regional level, shipping companies make decisions on when and where to position empty containers between marine terminals, off-dock depots, importers (consignees), and exporters (shippers). The objective of regional repositioning is to minimize unproductive movements while satisfying local export demand and the need from global repositioning (Braekers et al., 2009).
Poor empty container management generates unnecessary truck trips, worsens traffic congestion, and contributes to excessive inventory at wrong locations (Theofanis and Boile, 2007). According to Sterzik (2013), regional empty container movements contribute to 40%-50% landside container flows, whereas the proportion of empty containers in sea segment is only around 20%. Therefore, an efficient regional repositioning strategy is crucial for shipping companies to reduce container operating cost and increase container utilization.

Regional empty container repositioning strategy depends on the local trading environment. For example, shipping lines prioritize global empty container repositioning in the import-dominant region such as LA/LB port region. Imported containers are returned to marine terminals and shipped back to Asia after unloaded at customer’s site. In the trade-balanced region, shipping lines encourage reusing imported containers for local export cargos. Empty containers reuse is an effective method to reduce regional repositioning cost and to eliminate outbound non-revenue trips.

Researchers paid limited attention to regional empty container repositioning problems in the past. Although some mathematical models are proposed recently to rationalize regional empty container movements, it is still challenging to develop a realistic framework due to the complex relations between shipping companies, terminal operators, and hinterland logistics providers. Hence, it is crucial to build up a practical framework to optimize regional empty container movements and identify the appropriate repositioning strategy based on the local trading environment.

This research focuses on the regional empty container repositioning problem. The main purpose is to propose a more practical model to optimize regional empty container movements. With this
framework, we evaluate potential benefits of implementing “street-turn” strategy, a special regional repositioning strategy. From the model analysis, we examine the effectiveness of “street-turn” strategy and provide insights on “street-turn” operations in Metro Vancouver area.

The optimization model is established based on actual practice in Metro Vancouver area. We collected insights from local industry professionals regarding current empty container operations. Unlike the majority of port regions in North America, Metro Vancouver port area has a relatively balanced trading environment, in which case, is favorable for empty container reuse strategy.

The rest of the thesis is organized as follows. Section 2 reviews the related literature. It provides the background of empty container repositioning problem. In particular, regional repositioning strategy is specified. Also, this section summarizes the mathematical models and methodologies dealing with empty container repositioning problem. Section 3 illustrates current empty container operations in Metro Vancouver area. Section 4 describes the proposed framework, and Section 5 shows main findings from the model analysis. Section 6 concludes our work.
Chapter 2: Literature Review

2.1 Background introduction

2.1.1 Problem context

The fundamental step to understand empty container management is to identify major players in empty container logistics. The main owners of marine containers are shipping company and container leasing company. Container depots and some main shippers may own a few containers. Shipping companies manage containers as transportation equipment and the main goal is to minimize transportation cost and container operating cost. Container leasing companies lease out containers as assets to make profit. Shipping companies nowadays tend to increase the ownership share of containers to have better control of container movements (Boile et al., 2004).

As stated in the Gateway Cities Council Study, “A suitable container must be in the right place at the right time” (The Tioga Group, 2002). In general, empty container repositioning is implemented at three geographical levels, namely global, inter-regional, regional level (Boile et al., 2008) — as shown in Figure 1.
At a global level, empty containers are repositioned over sea between two foreign ports, usually from a surplus area to a deficit area. Global repositioning considers global liner network design, vessel schedules and ship capacity (Furió et al., 2013). It is managed directly by shipping lines to reverse container imbalance and to fulfill demands within the worldwide network. At an inter-regional level, empty containers are repositioned between a region of importation and a region of consumption by railway or long haul trucking. For example, a large percentage of marine containers in New York region comes from West Coast by intermodal transportation mode. After unloaded, containers are repositioned back by train to LA/LB port area instead of staying in New York region (Boile et al., 2008). Likewise, loaded containers from Asia that enter Canada from Halifax, after unloaded in Toronto, are delivered to Vancouver as part of inter-regional
repositioning instead of returned to Halifax. Similarly, a number of containers entered Toronto by rail from Western Canada, are reloaded with export cargos and shipped to Europe or Asia.

At a regional level, shipping companies reposition empty containers between port terminals, off-dock container depots, and container users. Empty container repositioning strategy depends on the local trading environment. For example, shipping lines tend to prioritize global/inter-regional empty container repositioning in the import-dominant region. Commonly, shipping companies ship empty containers back to the deficit areas as soon as possible instead of reusing them (Boilé and Aboobaker, 2006). For example, the number of imported containers in LA/LB port region is around 6 million TEUs more than exported containers in 2004, contributing to a substantial empty container stock at port area. If containers are not sent to deficit areas in a timely way, it leads to a significant cost to replenish containers in deficit regions. It costs significantly to rent empty containers in deficit areas.

2.1.2 Regional container movement patterns

A typical container flow within a region involves seaports, container depots, importers, and exporters. In general, there are five regional repositioning strategies (Furió et al., 2013), which are shown in Figure 2.
Pattern A and Pattern B are defined as “empty repositioning” operation, indicating that empty containers are returned to the port of origin as part of global repositioning. Under this strategy, importers return the containers to a marine terminal (Pattern A) or to an off-dock container depot (Pattern B) after unloading process. The containers are then shipped out for global repositioning.

Pattern C, Pattern D, and Pattern E are known as “match-back” operation (empty container reuse), where reusing imported containers for local export cargos. This practice eliminates
outbound non-revenue movements (movement 4 in Pattern A and B). In Pattern C, imported containers are returned and stored at marine terminal after unloaded (movement 3), and will be delivered to an exporter site for loading (movement 4). Pattern D is called “depot-direct” strategy, which employs off-dock depots to add buffer capacity for empty container storage (The Tioga Group, 2002). Pattern E is called “street-turn” strategy, representing that empty containers can be sent directly from an importer to an exporter without first returning to the marine terminal. “Street-turn” strategy reduces unproductive container movements and relieves traffic congestion (Hanh, 2003).

2.1.3 Applications of empty container reuse strategy

Figure 3 illustrates possible regional empty container flows among multiple facilities. Empty containers enter regional transportation system from global repositioning and from inter-regional repositioning by sea and railway. Also, local importers collect a number of empty containers after unloading the full containers. Empty containers are repositioned within the region to fulfill local export loads and to meet the need of global repositioning.
The objective of regional repositioning is to eliminate unproductive truck trips and reduce excessive inventory at wrong locations while satisfying demand within the region. Empty container reuse is an effective repositioning method to minimize unnecessary container movements and to improve container utilization. Traditionally, importers return empty containers to a marine terminal or to an off-dock container depot after unloading imported containers. “Street-turn” strategy allows importers send empty containers directly to local exporter sites, which potentially reduces the operating cost for both parties.

Most recently, researchers have started to look into empty container repositioning problem of a specific port region and evaluate the feasibility of implementing “street-turn” strategy. Below provides a review of related studies and projects.
In 2006, the Victorian Government offered Murray Goulburn Co-operative, one of the largest exporters in Victoria, $75,000 grant to test the feasibility of implementing “street-turn” strategy in Port of Melbourne. This study showed some concerns to apply “street-turn” strategy more widely to improve the overall efficiency (Connect Freight, 2006). For example, container surveying, repairing, and cleaning processes are omitted in “street-turn” interchanges. These processes are essential to keeping container cleanliness to meet special condition classifications such as food grade quality.

Islam et al. (2010) investigated several possible strategies to reduce empty container movements at Ports of Auckland. This study addressed that “street-turn” strategy has high potential to eliminate unproductive truck trips. Off-dock container depots can be integrated into “street-turn” operation as a neutral container interchanging point. Wolff et al. (2012) analyzed empty container flows between the port of Hamburg and the Baltic Sea region. Port of Hamburg suffers from high empty container repositioning cost because local export loads are much smaller than the volume of import containers. The study revealed that the share of “street-turn” strategy has increased from 5% to 10%. Also, both shipping lines and forwarding companies have recognized the effectiveness of “street-turn” strategy to improve container utilization. Quality control of containers is handled carefully by shipping lines due to the absence of checking process under “street-turn” strategy.

To facilitate regional empty container repositioning, information technology is applied to improve the trucking appointment system and terminal gate entrance (Islam et al., 2013). Also, RFID and GPS are employed to better trace container flows. What is more, a new Web-based platform called “Virtual Container Yard” (VCY) is designed to share container information and
to increase regional “street-turn” interchanges between importers and exporters. The status and location of containers are posted and shared on the platform, which enables players to plan ahead and quickly identify “street-turn” opportunities. Theofanis and Boile (2007) investigated the feasibility of establishing a VCY in the NY-NJ port region. In this report, the authors emphasized that VCY requires collaborations among multiple parties such as ocean carriers and drayage companies.

Researchers also looked into several possible methods for shipping lines to cooperate. One option is container sharing (or “Grey box pools”), which means that shipping lines share containers and collaborate on container fleet management. Another method is “Box swapping”, which allows a shipping company to borrow containers from other shipping companies that under the same container interchange scheme (Boilé and Aboobaker, 2006). Although shipping lines have shown reluctance to cooperate and share equipment and information, VCY now has been successfully implemented in LA-LB port region and Port of Oakland (Sterzik et al., 2012).

The next section reviews previous literature related to empty container repositioning problem.

2.2 Review of mathematical models

2.2.1 Global repositioning problem

Braekers et al. (2011) identified two research streams regarding global empty container repositioning problem: mathematical programming and inventory theory perspective. A broad range of approaches can be found in existing literature. For example, Moon et al. (2010) developed a mixed integer deterministic model to minimize unproductive container movements within a multiple-port network. Li et al. (2004) applied inventory theory to empty container
allocation problem from a single port perspective. Shipping companies need to determine the number of empty containers to send to the seaport for future export demand, as well as the number of empty containers to send out in a certain time period. The objective of this research is to find an optimal policy \((U, D)\) to manage empty container flows, which is, bringing in empty containers up to \(U\) when the inventory level at the port is smaller than \(U\) or shipping out empty containers when the stock exceeds \(D\). This study was extended to a multiple-port system by Li et al. (2007), aiming to minimize empty container repositioning cost while satisfying the demand of empty containers at each port.

Regional repositioning problem receives limited attention comparing to global repositioning problem. However, these two problems are indivisible and some methodologies are applicable in both cases. For example, Yun, Lee, and Choi (2011) incorporated inventory theory into inland empty container repositioning problem based on previous studies on global repositioning problem. The objective is to find an optimal inventory control policy to store empty containers at regional container depots (both on-dock and off-dock). Furthermore, empty container reuse has been applied to global repositioning problem. De Brito and Konings (2011) proposed to make use of reverse logistics such as recycling flows to reduce empty container movements on the backhaul trips by sea. Likewise, Veenstra (2005) evaluated the possibility of incorporating empty container repositioning with short sea trade at Port of Rotterdam. By doing so, outbound empty trips could be eliminated by reloading the empty containers with cargos for coastal trade. Other issues existing in both problems include repositioning cost metrics, uncertainty in container supply and demand, and container leasing.
2.2.2 Regional repositioning problem

At a regional level, shipping lines determine when and where to reposition empty containers to fulfill the demand of local exporters and the demand from global repositioning (Di Francesco, 2007). Braekers et al. (2011) classified regional empty container repositioning problem into three categories, namely strategic, tactical, and operational planning.

2.2.2.1 Strategic/Tactical level planning

Strategic/tactical planning incorporates empty container balancing strategy with regional transportation network design, such as location selection of inland container facilities. Traffic distribution, terminal policy, and vehicle and crew planning are considered at this planning level (Crainic, 2000). In other words, strategic/tactical planning determines network configuration by specifying the quantity and location of inland container facilities, the allocation of customers to container depots, and the local container balancing flows (Crainic et al., 1993).

Bourbeau et al. (2000) considered balancing requirements and applied branch-and-bound parallelization strategy to the network design problem. The objective of the model is to determine the location of container depots with minimal operating cost. Empty containers are collected at importer sites after unloaded and then delivered to a container depot for future demand. Both fixed cost for opening container depots and variable costs from container traffic flows are considered. Lei and Church (2011) conducted a study aiming to determine where to locate off-dock storage yards in LA/LB port area. A family of mixed integer programming models were developed to optimize the placement of off-dock storage depots. The reduction of daily empty containers transport distance was calculated based on real GIS data.
Another case study focuses on regional empty container repositioning in New York/New Jersey port region. Boile et al. (2008) aimed to determine the optimal configuration of inland container depots, with minimal empty container repositioning cost. The authors proposed an optimization model to reduce total cost including fixed cost and empty container operating cost in a 10-year planning horizon. Based on this study, Mittal et al. (2013) improved the framework by adding system uncertainty to this problem. In addition, social cost associated with traffic congestion and pollution is added into the two-stage stochastic model.

2.2.2.2  Operational level planning

Operational planning focuses on day-to-day container operation. Optimal flow management aims to reduce unnecessary container flows while fulfilling the demand for empty containers from local exporters (Song and Panayides, 2012). At this level, Crainic et al. (1993) divided empty container repositioning problem into two optimization sub-problems: container allocation problem and vehicle routing problem.

The objective of container allocation model is to optimize the distribution of empty containers to satisfy both known and future demands; whereas the vehicle routing model aims to minimize total transportation cost of regional container movements. The majority of literature focuses on improving mathematical models and methodologies from a theoretical perspective. Recently, some researchers have started to investigate regional empty container repositioning in a specific port area. In addition, some researchers have shown interest in regional empty container reuse strategy. Some scholars have collaborated with shipping lines and developed decision support tools to improve regional empty container repositioning operations (Cimino et al., 2010).
Crainic et al. (1993) first considered time factor in the empty container allocation problem. The authors aimed to determine when and where to position empty containers based on past and future demand in a certain planning horizon. They proposed a general dynamic framework with consideration of container types, container substitution, container leasing, and customer delivery window. However, no solution is proposed in the study due to the complexity of model formulation and computation. In this research, two deterministic dynamic optimization models are presented respectively regarding single and multiple container type scenarios. The time step in this model is one day, with a planning horizon of one or two weeks. Also, the authors proposed a single-commodity stochastic model that accounts for the uncertainty in container demand and supply.

Di Francesco et al. (2006) improved Crainic et al. (1993)’s work by proposing a deterministic dynamic model with solutions. The objective is to minimize total repositioning cost in a 15-days planning horizon. To simply the problem and to obtain feasible solutions, the authors excluded delivery window and container leasing issues in this model. However, storage capacity limit at container facilities is taken into account in order to make the model more realistic.

Moreover, Bandeira et al. (2009) provided a decision support system incorporating both empty container and full container flows. This decision support system is based on two sub-models. The first model is a Single-commodity static model, which allocates both full and empty containers in each instant time t. The second model is a dynamic model, which controls and updates the future demand and supply of containers using a heuristic method. The major improvement of this work is to that it integrates allocation decision of both full containers and empty containers. However,
there is still space to adjust the framework to be more practical. For example, inventory capacity limit and delivery window can be considered.

As mentioned above, a group of researchers focus on empty container repositioning in a specific port region. In general, this type of study obtained support from the local port authority to testify the model with real data. Here we introduce some successful studies in this criteria.

Olivo et al. (2005) proposed a deterministic dynamic model to minimize empty container repositioning cost over a weekly planning horizon. The model is verified through a case study of the Mediterranean basin. The authors pointed out that technology nowadays allows real-time information transition, therefore, changing the time step from daily to hourly makes the model more accurate and responsive. In this research, terminal and container depot storage capacity limit is added to the model. Container leasing and delivery window issue are not considered to simplify the problem.

Jula et al. (2003) looked at empty container operations in Los Angeles and Long Beach port complex. LA/LB port region suffers from heavy container traffic and congestion problem at marine terminals. One of the root causes is the inefficient regional repositioning strategy, which generates unnecessary container movements. Traditionally, after unloaded at importer sites, imported containers are returned to marine terminals waiting to be shipped back to Asia. Local exporters pick up empty containers from marine terminals. Namely, it is a default practice to return and collect empty containers at the marine terminal. In this study, the authors evaluated the possibility of reusing imported containers for local export demands in LA/LB port region. They compared the efficiency of different empty container repositioning strategies according to the current situation of LA/LB port region. This case study provided evidence on expected cost
reduction by using empty container reuse strategy ("depot-direct" and "street-turn"). System uncertainty, inventory capacity limits, and container substitution are excluded in the model. Also, the planning horizon is set as 8 hours only. Customer delivery window is only modelled in the dynamic formulations. In this research, four scenarios are considered:

- Single-commodity, base scenario

  Only one container type is considered. Containers are returned and stored at marine terminals once unloaded at importer’s sites.

- Single-commodity, “street-turn” scenario

  Empty containers can be delivered directly from local importers to exporters without first returning to the marine terminal.

- Single-commodity, “street-turn, depot-direct” scenario

  Empty containers can be stored at both marine terminals and off-dock container depots.

- Multi-commodity, “street-turn, depot-direct” scenario

  Multiple container types are considered.

Jula et al. (2006) and Ioannou (2008) conducted more simulations to evaluate the effectiveness of "street-turn" and "depot-direct" strategy based on the single-commodity dynamic model proposed by Jula et al. (2003). Also, Chang et al. (2006) improved Jula et al. (2003)’s work in two aspects. Firstly, they added container substitution rules to the Multi-commodity static model. That is, the demand of a certain type of container can be fulfilled by another type of container.
The simulation result indicated that container substitution further reduces container repositioning cost. Secondly, the authors improved the Single-commodity static model by including demand uncertainty. The problem is modelled as a two-stage stochastic program and solved by Monte Carlo simulation. Chang et al. (2008) then improved the work by employing a heuristic method to solve the model with higher solution quality and less computing time. Chassiakos et al. (2006) considered stochastic element in the supply and demand of empty containers. The probability distributions are generated from historical data. The authors modeled the problem as a one-stage stochastic program and solved the model using Monte Carlo sampling methodology.

Poor empty container repositioning is time-consuming and leads to high operating cost. Shipping companies are desirable to find effective Decision Support System (DSS) to optimize empty container flows, especially to better implement “street-turn” strategy (Di Francesco, 2007). Two research papers are found from the literature that proposed tailor decision support system for the shipping companies and verified the model with real container data. These two studies are introduced as follows.

Deidda et al. (2008) proposed a static deterministic optimization model for a shipping company to compare the efficiency of “street-turn” strategy with current repositioning strategy. This study concluded that “street-turn” strategy can reduce both transportation distance and transportation time. However, further work needs to incorporate more factors such as time constraint, container types, and uncertainty.

Most recently, Furió et al. (2013) developed a decision support system to evaluate potential benefits of implementing “street-turn” strategy in Valencia port region in Spain. A dynamic optimization model is developed to make daily decisions on local empty container repositioning.
Multiple container types and container depots capacity limit are considered in this framework. The proposed model is tested and verified with real data provided by a local shipping agency. However, the authors did not consider container substitution, delivery window, and uncertainty.

2.2.3 Summary

In general, the majority of researchers aim to develop a dynamic framework to rationalize empty container flows in a certain planning horizon. Some authors such as Deidda et al. (2008) developed a static model to simplify the problem. Only Furió et al. (2013) chose 14 days as the planning horizon, which is in accordance with actual practice.

With regard to uncertainty, Crainic et al. (1993) first proposed a Single-commodity stochastic model but no solution was provided. In recent decades, Chassiakos et al. (2006) added uncertainty issue to the framework and solved the model using Monte Carlo simulation. In addition, researchers use transportation cost and storage cost to measure empty container repositioning cost. Other cost such as container handling cost, substitution cost, and penalty cost for unsatisfied demand are discussed in a few literature. Specifically, there are two common ways to estimate transportation cost. In the LA/LB port region study, researchers use travel distances as measure transportation cost; whereas Deidda et al. (2008) calculated transportation time as total transportation cost.

In terms of realism, only Deidda et al. (2008) and Furió et al. (2013) obtained support from shipping lines and got access to real data to verify their framework. Olivo et al. (2005) generated model input data according to Mitsui O.S.K Lines 2001 annual report. The study of LA/LB port region container repositioning problem estimated container traffic using the aggregated container
statistics available in port authority publications. In particular, Jula et al. (2003) incorporated the agreement issue between marine terminals and shipping lines into the framework. It is based on actual practice in LA/LB port region, for example, shipping lines pick up/drop off containers only at the terminals they contract with.

What is more, delivery time window is only considered by Crainic et al. (1993) and by Jula et al. (2003). Storage capacity limit of marine terminals and off-dock depots is barely considered until recent years. Olivo et al. (2005), Di Francesco et al. (2006), and Furió et al. (2013) added storage capacity constraint into their model. Container substitution is considered by Crainic et al. (1993), Di Francesco et al. (2006), and Chang et al. (2006) in their static framework. Container leasing is only included into the framework by Crainic et al. (1993). The necessity of container short-term leasing varies among port regions. For instance, shipping lines in general do not borrow containers from outside the system in surplus areas. In addition, container repairs and discards issue is commonly excluded by researchers in this field. A more detailed classification of mathematical models regarding regional empty container repositioning is presented in Appendix A.

2.3 Main contributions

This research aims to provide a more realistic framework to optimize regional empty container flows and evaluate potential benefits of implementing “street-turn” strategy. An optimization model is developed to determine daily empty container movements while matching container availability with local export demands. The model is developed according to actual practice in Metro Vancouver region, and is further employed to examine the effectiveness of “street-turn”
strategy in different trading environments. The major improvements of our proposed framework are in the following aspects:

1. In previous literature, it is a common assumption that empty containers can only be stored at marine terminals and off-dock depots. However, in reality, importers and exporters sometimes hold the containers for a few days to achieve “street-turn” interchange jointly. Therefore, we assume that empty containers can be stored at customer sites for temporary storage.

2. In the Valencia port region study conducted by Furió et al. (2013), exporter demands have to be fulfilled within one day. However, in reality, exporters accept empty containers within a time range rather than on a fixed day only. Thus, we assume that exporters accept empty containers within a delivery time window to fulfill the demand.

3. In the LA/LB port region study, the authors considered transportation cost as empty container repositioning cost. The model assumed that daily supply of empty containers is always more than the demand, based on the fact that LA/LB port area is an import-dominant region where always holds excessive empty containers. By the same token, container safety stock at marine terminals and off-dock depots is not taken into consideration. Our model includes safety stock and storage capacity limits to make the framework more general and applicable.

4. As for empty container repositioning cost, our model considers container shortage cost and gate fees in addition to transportation cost and container storage cost. Container shortage cost is added considering the unsatisfied demand in the system. It can be regarded as container short-term leasing cost, because shipping lines tend to rent empty containers for temporary use from local container leasing companies when facing container deficit. To our best
knowledge, our research is the first work that incorporates both container shortage cost and gate fee to this problem.
Chapter 3: Empty Container Operations in Metro Vancouver Area

3.1 Background on container transportation in Metro Vancouver area

Port Metro Vancouver (PMV) is the busiest port in Canada, ranking the fourth largest tonnage port in North America. Its jurisdiction covers more than 600 kilometers coastline. Port Metro Vancouver was formed in 2008, from the amalgamation of three Port Authorities: Vancouver Port Authority, Fraser River Port Authority and North Fraser Port Authority. It has four deep-sea container terminals, with about 20 different lines calling at the port. 158 local drayage companies and more than 50 off-dock container facilities operate in its hinterland (Asia Pacific Gateway Skills Table, 2013). 95% of port businesses is served for Canadian import/export markets. PMV facilitates trade with more than 160 countries and a wide range of domestic locations, generating considerable contributions to the economy. According to the economic impact study conducted by InterVISTAS Consulting Inc. (InterVISTAS Consulting Inc, 2013), Port Metro Vancouver contributed $9.7 billion in GDP to the economy across Canada in 2012. Container traffic is one of the major contributors to the port economy. In 2011, total GDP impact of container traffic logistics system is around $2.3 billion.

BC’s Lower Mainland is the largest gateway for international container traffic of Canada. Philip Davies (2006) concluded that Metro Vancouver Area provides a more favorable environment to implement empty container reuse strategy comparing to LA/LB port region. Table 1 below lists the ratio of inbound and outbound laden container volumes of some major port regions on the west coast of North America. This ratio indicates the trading environment of a port region. For example, the volume of import full containers is almost doubled the volume of export full
containers in LA/LB port area, which means that LA/LB port region is an import-dominant region. On the other hand, the ratio of Metro Vancouver area is only around 1.2 to 1.3 on average, implying that trading environment of Metro Vancouver region is more balanced than LA/LB port region. Therefore, this data provided evidence that empty container reuse strategy is more achievable in Metro Vancouver area.

<table>
<thead>
<tr>
<th>Year</th>
<th>Port Metro Vancouver</th>
<th>Port of LA</th>
<th>Port of LB</th>
<th>Port of Oakland</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>1.353</td>
<td>2.322</td>
<td>1.89</td>
<td>0.874</td>
</tr>
<tr>
<td>2009</td>
<td>1.088</td>
<td>2.112</td>
<td>1.875</td>
<td>0.726</td>
</tr>
<tr>
<td>2010</td>
<td>1.31</td>
<td>2.158</td>
<td>2.003</td>
<td>0.84</td>
</tr>
<tr>
<td>2011</td>
<td>1.235</td>
<td>1.928</td>
<td>2.008</td>
<td>0.802</td>
</tr>
<tr>
<td>2012</td>
<td>1.287</td>
<td>2.003</td>
<td>1.988</td>
<td>0.803</td>
</tr>
<tr>
<td>2013</td>
<td>1.26</td>
<td>2.07</td>
<td>2.027</td>
<td>0.792</td>
</tr>
<tr>
<td>Average</td>
<td>1.256</td>
<td>2.099</td>
<td>1.965</td>
<td>0.806</td>
</tr>
</tbody>
</table>

Table 1 Import-Export container gap

Source: Calculated from container statistics published on port authority official websites

In LA/LB port region, around 40% to 50% of the imported containers are required to be returned to Asia as empty containers. Therefore, repositioning empty containers to off-dock container depots for future demand rather than keeping the containers at marine terminals would generate unproductive truck trips (Hanh, 2003).
Metro Vancouver area can be considered as a trade-balanced region, as is shown in Figure 4. Figure 4 illustrates the inbound and outbound container traffic of Port Metro Vancouver from 2008 to 2014. Laden container flow indicates the trading environment of a region, and the empty container flow reflects the global repositioning policy applied to this region. As it shown below, the gap between inbound full containers and outbound full containers is relatively small. The volume of outbound empty containers is in general greater than the inbound empty containers, which can be explained by the nature of global trade imbalance. The figure also shows an ascending trend of the overall container volume, implying that port congestion problem can be worsen if regional container repositioning is not under good control.

![Port Metro Vancouver Monthly Container Statistics (2008 to 2014)](image)

Figure 4 Port Metro Vancouver 2008-2014 container statistics

Source: Port Metro Vancouver Website

In 2003, Port Metro Vancouver decided to move 50% of the empty containers to off-dock storage in order to relieve terminal congestion. However, this adjustment generated additional
non-revenue truck trips among the facilities, contributing to extra container repositioning cost for shipping companies and drayage companies. Currently, only several industrial reports evaluated the effectiveness of inland container depots in BC Lower Mainland (Hatch Mott MacDonald and IBI Group, 2006; Davies, 2007). However, no study investigates “street-turn” operations in Metro Vancouver area. Therefore, this research intends to fill the gap and evaluates the implementation of “street-turn” strategy in Metro Vancouver area.

3.2 Findings from company visits

We interviewed some industry professionals from Port Metro Vancouver, shipping companies, and drayage companies. The list of companies that we have visited is shown in Appendix B. From company visits, we collect information to better understand local empty container operations and current “street-turn” programs. We summarize the following insights from interviews.

First, “street-turn” strategy has been recognized as an effective method to reduce repositioning cost and to improve container utilization. By interchanging empty containers directly “on the street”, shipping lines avoid container storage cost and gate fees charged at marine terminal and off-dock container facilities. Drayage companies reduces unnecessary truck trips to and from marine terminals and off-dock container depots. Importers and exporters pay drayage companies to move containers, and thus “street-turn” strategy benefits container users indirectly.

In Metro Vancouver area, shipping lines do not arrange “street-turn” interchanges. Importers and exporters take the initiative to seek for “street-turn” opportunities and submit their request to shipping lines after they find a match. Shipping lines normally make container repositioning plan
around two weeks in advance, and adjust repositioning plan on a daily basis according to the
requests from container users. “Street-turn” strategy currently has been experimented jointly by a
few importers and exporters. The main obstacle is that information is not transparent across all
players. For example, an importer returns empty containers to the marine terminal or an off-dock
container depot if the importer is unable to find an exporter to perform “street-turn” interchange
with. Upon arriving to the terminal, an exporter also arrives to pick up empty containers. If
information is shared, containers can be sent directly from the importer to the exporter instead of
making the extra trips to the terminal.

More importantly, professionals from shipping lines and drayage companies have expressed their
willingness to encourage “street-turn” interchange. Several professionals call for shipping lines
to take initiatives to establish an information platform such as Virtual Container Yard, where all
the parties get access to container information. It would facilitate “street-turn” interchanges by
providing up-to-date information.

Some professionals also elaborated their concerns and identified some key challenges to
implement “street-turn” strategy. The primary issue is time match. The time gap between the
supply of empty containers by an importer and the request for empty containers from an exporter
should be within a reasonable range. The second concern is container ownership or “color
match” issue. Currently, shipping lines do not share containers among each other. In other words,
“street-turn” interchange is allowed only between importers and exporters who use containers
from the same shipping company. This restriction cuts down a number of potential “street-turn”
opportunities. In addition, “street-turn” strategy requires that the supply and demand of empty
containers must be the same container type. Container substitution among different sizes of
containers is uncommon in Metro Vancouver area. It is allowed occasionally between 40ft standard containers and 40ft high cube containers. Another concern is related to container condition. Usually the containers used for “street-turn” interchange do not go through inspection or repair processes. Thus, the containers might get rejected by the exporters after delivered to the facility.
Chapter 4: Model Formulation

4.1 Model description

In our dynamic framework, we consider empty container flows among marine terminals, off-dock container depots, importers, and exporters. In a certain planning horizon, shipping lines bring in and ship out empty containers following their global container repositioning policy. Importers collect a number of empty containers after unloading the imported containers. Exporters pick up containers from marine terminals, off-dock depots, or importer sites for export cargos. Commonly, empty containers are stored at marine terminals and off-dock container depots temporarily for future needs. In each time period (usually one day in actual practice) of the planning horizon, the following processes occur:

- The importers acquire a certain number of empty containers after unloading imported laden containers;
- The exporters request a certain number of empty containers to load export cargos;
- A certain number of empty containers arrive at marine terminal by vessel from global repositioning;
- A certain number of empty containers are required to be shipped out at marine terminal for global repositioning;
- Empty containers are repositioned within the region to fulfill demand at various locations;
- The shipping company rents extra empty containers from container leasing companies if there is unsatisfied demand;
• The inventory level of empty containers at each location (marine terminal, off-dock container depots, and customer sites) is updated at the end of each time period;

The proposed optimization model aims to determine empty container repositioning plan on a daily basis, with minimal total repositioning cost in a planning horizon. To evaluate the effectiveness of “street-turn” strategy, two scenarios (with and without “street-turn” strategy) are modeled separately and total repositioning cost in each scenario is compared. The two scenarios are defined as following:

1. Base scenario (without “street-turn” strategy)
   This represents the current practice that importers and exporters drop off/pick up empty containers at a marine terminal or an off-dock depot as a default option.

2. “Street-turn” scenario
   In this scenario, empty containers collected at importer premises can be delivered directly to an exporter site without first returning to a marine terminal or an off-dock container depot.

4.1.1 Model assumption

Model assumptions are made based on literature and company visits. The assumptions are summarized below:

1. The planning horizon is 14 days, and each time period is set as one day. 14 days is considered as a reasonable planning cycle according to both academic literature and industry practices. In actual practice, exporters book containers in advance based on the published vessel schedule. Shipping lines make regional container repositioning plan two weeks ahead
with the information of container bookings. The container repositioning plan is then implemented and adjusted on a daily basis. Besides, researchers in this field commonly use two weeks as the length of planning horizon.

2. The number of empty containers provided by importers and the number of empty containers requested by exporters in each time period is known at the beginning of planning horizon. As explained above, shipping lines have the container transaction information around two weeks ahead because customers normally book containers in advance.

3. The number of empty containers arrived at terminals and the number of empty containers needed to be shipped out in each time period is known at the beginning of the planning horizon. Inbound and outbound empty container flows are determined by global repositioning policy, which is a strategic decision made by the shipping line headquarter. In actual practice, empty container traffic from global repositioning is known when making the regional container repositioning plan. Thus, it is reasonable to assume that this information is given at the beginning of the planning horizon.

4. Only one container type is considered. Container substitution is not a common issue in Metro Vancouver area, thus repositioning plan for different type of containers is designed independently. Hence, we do not specify different container types in this framework. Container substitution rules can be taken into consideration for future research.

5. Empty containers can be stored at terminals, off-dock container depots, and exporter premises. In previous studies, researchers assume that empty containers cannot stay at customer facilities for temporary storage. In other words, importers get rid of empty
containers immediately once they have any, and exporters do not hold empty containers in advance for future demand. In actual practice, importers or exporters sometimes keep empty containers for extra days to achieve “street-turn” interchange. Therefore, we improve the model by assuming that empty containers can also be stored at customer sites. In terms of modelling, holding empty containers at importer sites or at exporter sites is mathematically equivalent. For this reason, we assume that empty containers can be stored at exporter sites but not at importer sites to simplify math formulas.

6. Exporters start to accept empty containers two days in advance from the latest receiving day. In our model, we add a three-day delivery window to the exporter demand, considering that exporters mostly accept containers within a time range rather than on a fixed day in actual practice. This is a key assumption that makes the proposed model more practical.

7. Regional truck trips can be completed within one day. In other words, trips between any two facilities within the region can be completed within a day.

8. Marine terminal has a limited capacity to store empty containers.

9. Empty container repositioning cost consists of transportation cost, container storage cost, gate fees at both terminal and off-dock depots, and container shortage cost. The proposed framework improves previous work by incorporating considering gate fees and container shortage cost. In this model, we assume that unit gate fee is a fixed price. Sensitivity analysis of gate fees is conducted to test how gate fees affect the effectiveness of “street-turn” strategy. Terminal gate fee can be specified to day-gate fee and night-gate fee in future research.
10. Transportation cost of a trip is a function of the travel distance between the origin and destination and a fixed unit transportation cost. In previous literature, transportation cost is measured by travel distance or by travel time. Here we use travel distance to calculate transportation cost based on the insights from local industry professionals.

11. Empty container storage cost is a function of the quantity of empty containers and the constant unit container storage cost. Unit storage cost is measured as the cost per container per day. This assumption is made according to the interview results from industry. Given a storage charge rate at a container facility, total storage cost is determined by the quantity of containers and the length of storage time.

12. There is a container shortage cost as a penalty for unsatisfied demand. It is seen as the cost of bringing in extra empty containers to satisfy unfulfilled demand. From company visits, we verified that shipping lines rent empty containers for short-term use from container leasing companies when facing container deficit.

13. No repairs or discarded containers are considered in this model. In other words, empty containers are always ready to be used. This assumption is a common assumption that can be found in most related literature.

4.1.2 Model formulation

With information about the supply and demand of empty containers, the mathematical model determines the optimal daily repositioning plan with minimal total repositioning cost in the 14-day planning horizon. The required notation is introduced below.
Model Indexes

T: Length of the planning horizon (t=1, 2, 3... T)

P: The set of marine terminals in the region (p=1, 2... P)

Q: The set of off-dock container depots in the region (q=1, 2, 3… Q)

I: The set of supply customers (importers) that hold empty containers after unloading cargos
   (i=1, 2, 3… I)

J: The set of demand customers (exporters) with requests of empty containers (j=1, 2… J)

Model Parameters

Supply and demand

$S'_t$: The number of empty containers provided by importer i at time period t

$D'_j$: The number of empty containers requested by exporter j, which has to be fulfilled by time
     period t as the latest receiving day. Empty containers arrived before period t have to stay at the
     exporter’s site.

$S'_{tp}$: The number of empty containers arrived at terminal p and available to be picked up at time
       period t; it represents the inbound empty containers flow from global repositioning.

$D'_{tp}$: The number of empty containers requested to be shipped oversea from terminal p at time
       period t; it represents the outbound empty container flow for global repositioning.

Stock data

$SL^\text{max}_{tp}$: The maximum number of empty containers can be stored at marine terminal p
\( \text{SL}_p^0 \): Initial stock of empty containers at marine terminal \( p \) at time period 0

\( \text{SL}_q^0 \): Initial stock of empty containers at off-dock container depot \( q \) at time period 0

Cost information

\( c_{od} \): The transportation cost from origin node \( o \) to destination node \( d \) \((o,d \in P \cup Q \cup I \cup J)\), which is measured by travel distance (km) multiplied by unit transportation cost (\$/km).

\( \alpha \): Unit storage cost of empty containers at marine terminals (\$/container/day)

\( \beta \): Unit storage cost of empty containers at off-dock container depots (\$/container/day)

\( \gamma \): Unit storage cost of empty containers at exporter premises (\$/container/day)

\( g_r \): The gate fee at marine terminals (\$/container)

\( g_s \): The gate fee for empty containers to get in and out off-dock container depots (\$/container)

\( c_s \): Container shortage cost in term of unfulfilled demand (\$/container)

Decision Variables

Figure 5 demonstrates regional empty container flows and corresponding decision variables. For example, decision variables \( v_{ip} \) and \( v_{iq} \) represent the number of empty containers that importers return to the marine terminal and to off-dock container depots respectively. Variables \( v_{pj} \) and \( v_{qj} \) each denotes the number of empty containers that moved from the marine terminal and off-dock depots to exporter sites. Accordingly, variables \( v_{pq} \), \( v_{qp} \) and \( v_{qq} \) illustrate empty
container interchanges among the marine terminal and off-dock depots. Movement $V_{ij}$ represents “street-turn” movements, which are not considered in the base scenario.

![Figure 5 Regional empty container flows](image)

The detailed description of decision variables is as following.

**Base scenario**

$V_{ip}^t$: The volume of empty containers moved from importer i to terminal p at period t

$V_{iq}^t$: The volume of empty containers from importer i to depot q at period t

$V_{pj}^{t,s}$: The volume of empty containers moved from terminal p to exporter j at period t to fulfill the demand at period s ($s = t, t+1, t+2$)
\( V_{t,ij} \): The volume of empty containers moved from depot q to exporter j at period t to fulfill the demand at period s (s= t, t+1, t+2)

\( V_{t,pq} \): The volume of empty containers moved from terminal p to depot q at period t

\( V_{t,qp} \): The volume of empty containers moved from depot q to terminal p at period t

\( V_{t,qq} \): The volume of empty containers moved from depot q to depot q’ at period t

“Street-turn” scenario

Additional variable \( V_{t,ij} \): the volume of empty containers sent directly from importer i to exporter j at period t to fulfill the demand at period s (s= t, t+1, t+2)

State variables

\( SL_{t,p} \): The stock level of empty containers at terminal p at the end of period t

\( SL_{t,q} \): The stock level of empty containers at depot q at the end of period t

\( SL_{t,j} \): The stock level of empty containers at exporter j at the end of period t

\( UD_{t,p} \): The level of unfulfilled demand of empty containers at terminal p at period t. We assume that shipping lines bring in additional empty containers at the marine terminal from other sources.

\( UD_{t,q} \): The level of unfulfilled demand of empty containers at depot q at period t. We assume that shipping lines bring in additional empty containers at off-dock container depot from other sources.
Objective function

The objective is to minimize total empty container repositioning cost in the 14-day planning horizon. Empty container repositioning cost consists of transportation cost, storage cost, gate fees, and shortage cost.

Model formulation

Base Scenario

Minimize

\[
\sum_{t=1}^{T} \left( \sum_{i=1}^{I} c_{vi} + \sum_{j=1}^{J} \sum_{s=1}^{S} c_{vj} + \sum_{q=1}^{Q} \sum_{i=1}^{I} \sum_{s=1}^{S} c_{vi} + \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} c_{vj} + \sum_{q=1}^{Q} \sum_{i=1}^{I} \sum_{s=1}^{S} c_{vi} + \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} c_{vj} \right)
\]

\[
+ \sum_{t=1}^{T} \left( \alpha SL_{pi} + \beta SL_{qi} + \gamma SL_{ij} \right)
\]

\[
+ \sum_{t=1}^{T} \left[ g \left( \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} v_{pq} + \sum_{q=1}^{Q} \sum_{i=1}^{I} \sum_{s=1}^{S} v_{iq} + \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} v_{pq} \right) + g \left( \sum_{i=1}^{I} \sum_{s=1}^{S} v_{iq} + \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} v_{ij} + \sum_{q=1}^{Q} \sum_{i=1}^{I} \sum_{s=1}^{S} v_{iq} + \sum_{q=1}^{Q} \sum_{j=1}^{J} \sum_{s=1}^{S} v_{ij} + 2 \sum_{q=1}^{Q} \sum_{i=1}^{I} \sum_{s=1}^{S} v_{iq} \right) \right]
\]

\[
+ c \left( \sum_{t=1}^{T} UD_{pi} + \sum_{q=1}^{Q} UD_{iq} \right)
\]

(3.1)

Constraints

Constraint 1. Importer supplies

In each time period \( t \), the number of empty containers provided by importer \( i \) at period \( t \) equals to the number of empty containers that moved out from importer \( i \) at period \( t \).

\[
v_{iq} + \sum_{q=1}^{Q} v_{iq} = S_{pi}^t \quad \forall i \in I
\]

(3.2)

Constraint 2. Exporter demands

The volume of empty containers requested by exporter \( j \) at period \( t \) equals to the accumulated number of empty containers exporter \( j \) receives within the time window \([t-2, t]\).

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\[\sum_{q_i \in \{x, y\}} v_{qj}^{r,s} + \sum_{r \in \{x, y\}} v_{rj}^{r,s} = D_j^*, \forall j \in J\]  

(3.3)

Constraint 3. Empty container flow balance at terminal

The container flow balance equation for terminal \( p \) is written as: the stock level at the end of period \( t = (\text{the stock level at the end of period } (t-1) + \text{the number of empty containers entered the facility in period } t - \text{the number of empty containers left the facility in period } t) + \text{the unfulfilled demand of empty containers in period } t\)

We add an extra term representing unfulfilled demand to the right-hand side of this equation to make the model feasible. The value of unfulfilled demand is zero when the stock of empty containers is sufficient to the demand; the value of unfulfilled demand equals to container shortage when the stock of empty containers is smaller than the demand.

\[
SL_j^p = \left\{ \begin{array}{ll}
SL_j^{r-1} + (\sum_i v_i^j + \sum_q v_q^j) + S_j^r - (\sum_i v_i^r + \sum_q v_q^r) - D_j^r \geq 0 \\
\max (0, \sum_i v_i^j + \sum_q v_q^j + S_j^r - (\sum_i v_i^r + \sum_q v_q^r) - D_j^r) < 0
\end{array} \right.
\]

(3.4)

Container shortage cost is calculated by the volume of total unfulfilled demand and unit shortage cost. The model objective is to minimize total repositioning cost, thus the volume of unfulfilled demand is minimized. Considering that both container stock levels and the unsatisfied demands are constrained as non-negative values in the framework, we can thus omit the second constraint. Likewise, we did the same adjustment to Constraint 4.

Constraint 4. Empty container flow balance at off-dock container depots
The container flow balance equation for off-dock container depot q is written as: the stock level at the end of period t = (the stock level at the end of period (t–1) + the number of empty containers entered the facility in period t – the number of empty containers left the facility in period t) + the unfulfilled demand of empty containers in period t

\[
SL_{q}^{t} = \left[ SL_{q}^{t-1} + \left( \sum_{i} v_{iq}^{t} + v_{pq}^{t} + \sum_{q} v_{qq}^{t} \right) - \left( \sum_{j} \sum_{q} v_{qj}^{t,s} + v_{qp}^{t} + \sum_{q} v_{qq}^{t} \right) \right] + UD_{q}^{t}, \forall q \in Q
\]

(3.5)

Constraint 5. Stock capacity limit

The inventory level in each period t at the marine terminal should not exceed the capacity limit.

\[
SL_{p}^{t} \leq SL_{p}^{\text{max}}
\]

(3.6)

Constraint 6. Non-negativity

All decision variables and state variables represent the quantity of empty containers, thus they are constrained as non-negative values.

Constraint 7. Integer

All variables must be integer because the quantity of empty containers cannot be a non-integral value.

“Street-turn” Scenario

An additional variable \(v_{ij}^{t,s}\) is added to the basic optimization model, representing the “street-turn” interchanges between importers and exporters. Total transportation cost of “street-turn” movements is added to the objective function.
Minimize

\[
\sum_{t=1}^{T} \left( \sum_{i=1}^{I} c_{ii} v_{ip}^t + \sum_{j=1}^{J} \sum_{q=1}^{Q} c_{pq} v_{jq}^t + \sum_{i=1}^{I} \sum_{s=1}^{S} c_{is} v_{is}^t + \sum_{j=1}^{J} \sum_{s=1}^{S} c_{js} v_{js}^t + \sum_{q=1}^{Q} \sum_{r=1}^{R} c_{qr} v_{qr}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} c_{qs} v_{qs}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} c_{qs} v_{qs}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} c_{qs} v_{qs}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} c_{qs} v_{qs}^t \right) \\
+ \sum_{j=1}^{J} \left[ \alpha S_{ij}^t + \beta \sum_{q=1}^{Q} S_{ij}^t + \gamma \sum_{j=1}^{J} S_{ij}^t \right] \\
+ \sum_{j=1}^{J} g_{p} \left( \sum_{i=1}^{I} v_{ip}^t + \sum_{j=1}^{J} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{r=1}^{R} v_{qr}^t + \sum_{q=1}^{Q} v_{qr}^t \right) + g_{q} \left( \sum_{q=1}^{Q} \sum_{r=1}^{R} v_{qr}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t + \sum_{q=1}^{Q} \sum_{s=1}^{S} v_{js}^t \right) \\
+ c \sum_{t=1}^{T} \left( U_{ip}^t + \sum_{q=1}^{Q} U_{ip}^t \right) 
\]

(3.7)

Constraints

Constraint 1. Importer supplies

In each time period \( t \), the number of empty containers provided by importer \( i \) at period \( t \) equals to the number of empty containers moved out at importer \( i \) at period \( t \). Importers can deliver empty containers to exporter sites directly in this scenario.

\[
v_{ip}^t + \sum_{q} v_{iq}^t + \sum_{j \in \{i+1, j+2\}} v_{ij}^t = \frac{S_{i}^t}{\forall i \in I}
\]

(3.8)

Constraint 2. Exporter demands

The volume of empty containers requested by exporter \( j \) at period \( t \) equals to the accumulated number of empty containers received by exporter \( j \) within the time window \([t-2, t]\). In this scenario, exporters can choose to pick up empty containers from the marine terminal, off-dock container depots, and local importers.

\[
\sum_{i \in \{i-2, i\}} v_{ip}^t + \sum_{q} \sum_{r} v_{iq}^t + \sum_{j \in \{j-2, j\}} v_{ij}^t = D_j^t \quad \forall j \in J
\]

(3.9)
The rest of constraints listed below is the same as the base scenario.

Constraint 3. Empty container flow balance at terminal

The container flow balance equation for terminal p is written as: the stock level at the end of period t = (the stock level at the end of period (t–1) + the number of empty containers entered the facility in period t – the number of empty containers left the facility in period t) + the unfulfilled demand of empty containers in period t

\[
SL_p^t = SL_p^{t-1} + (\sum_i v_{ip}^t + \sum_q v_{qp}^t) + S_p^t - \left(\sum_j \sum_s v_{js}^t + \sum_q v_{pq}^t\right) - D_p^t + UD_p^t
\]  
(3.10)

Constraint 4. Empty container flow balance at off-dock container depots

The container flow balance equation for off-dock container depot q is written as: the stock level at the end of period t = (the stock level at the end of period (t–1) + the number of empty containers entered the facility in period t – the number of empty containers left the facility in period t) + the unfulfilled demand of empty containers in period t

\[
SL_q^t = SL_q^{t-1} + (\sum_i v_{iq}^t + \sum_j v_{pq}^t) - \left(\sum_j \sum_s v_{qs}^t + \sum_q v_{qq}^t\right) + UD_q^t, \forall q \in Q
\]  
(3.11)

Constraint 5. Stock capacity limit

The inventory level in each period t at the marine terminal should not exceed the capacity limit

\[
SL_p^t \leq SL_p^{\text{max}}
\]  
(3.12)

Constraint 6. Non-negativity
All decision variables and state variables represent the quantity of empty containers, thus they are constrained as non-negative values.

Constraint 7. Integer
All variables must be integer because the quantity of empty containers cannot be a non-integral value.

4.2 Application to the case of Metro Vancouver region

The input data was collected from publicly available source because container information is highly confidential for shipping lines and port authority. We found “Port Metro Vancouver Container Statistics Report 2008-2014” on Port Metro Vancouver official website (Port Metro Vancouver, n.d.). Based on the monthly container traffic statistics from 2008 to 2014, we calculated the average daily supply and demand of empty containers within the region.

The basic transport network is composed by one marine terminal, two off-dock container depots, ten importer sites and ten exporter sites. Facility locations are identified and transportation distances are measured on Google Map.

The value of model parameters is determined based on practical insights provided by local professionals. Table 2 lists the value of unit transportation cost, unit container storage cost, and gate fees we chose. Here we assume that unit storage cost at the marine terminal is zero. In actual practice, storing empty containers at the marine terminal within certain days is free for shipping lines. The proposed framework considers 14 days as the planning horizon, which does not exceed the time limit. Therefore, it is reasonable to assume terminal storage cost is zero. In terms of storage cost at exporter site, exporters usually store empty containers using their own storage
space. Thus, we assume storage cost at exporter site is zero. Exporters normally keep containers only for a few days to avoid the detention fee charged by shipping lines.

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit transportation cost</td>
<td>$6/km</td>
</tr>
<tr>
<td>Unit storage cost at terminal</td>
<td>$0/container/day</td>
</tr>
<tr>
<td>Unit storage cost at off-dock depot</td>
<td>$1.2/container/day</td>
</tr>
<tr>
<td>Unit storage cost at exporter site</td>
<td>$0/container/day</td>
</tr>
<tr>
<td>Terminal gate fee</td>
<td>$50/container</td>
</tr>
<tr>
<td>Off-dock depot gate fee</td>
<td>$40/container</td>
</tr>
</tbody>
</table>

Table 2 Value of model parameters

4.3 Methodology

The integer Programming (IP) problem is coded in Matlab using YALMIP Optimization Toolbox and solved by a freeware called LPSolve. We evaluate the effectiveness of “street-turn” strategy in three trading environments (import-dominant, trade-balanced, export-dominant environment). Sensitivity analysis is conducted to verify model outputs.

In terms of input data, we estimated daily supply and demand of empty containers based on monthly container traffic statistics of Port Metro Vancouver. This set of values is used as the model input of trade-balanced case. The value of average daily supply and demand of empty containers is further adjusted to simulate the export-dominant environment and the import-dominant environment. We keep the sum of empty container supply and demand the same in three trading circumstances to compare the effectiveness of “street-turn” strategy. What is more,
we use the same global repositioning strategy in three cases to better examine the impact of trade balance.

For each trading circumstance, we calculate and compare total empty container repositioning cost in base scenario and “street-turn” scenario. To evaluate the effectiveness of “street-turn” strategy, we identify several performance metrics. One is total cost saving percentage, aiming to compare the cost saving from “street-turn” strategy with total container repositioning cost in base scenario (without using “street-turn” strategy). We also look at the percentage of “street-turn” trips to evaluate the implementation of “street-turn” strategy. The results are validated by simulation.
Chapter 5: Main Findings

From Port Metro Vancouver monthly container traffic statistics, we identified that the volume of yearly import full containers and export full containers is relatively equal. From company visits, we learnt that local export demand is strong enough to balance import container flows, regardless of the inter-regional container flows to and from Eastern Canada. Hence, it is plausible to conclude that Metro Vancouver region is a trade-balanced environment. In addition, the volume of outbound empty containers is around three times of the inbound empty container traffics, indicating that the supply of empty containers from global repositioning is smaller than the demand for global repositioning.

We test the effectiveness of “street-turn” strategy in trade-balanced case using the estimated values based on PMV container traffic statistics. Also, we evaluate the implementation of “street-turn” strategy in export-dominant case and import-dominant case. Here we define the three trading environments as: Export-dominant region, where empty container supply is smaller than demand (e.g. marine terminals in East Asia); Trade-balanced region, where empty container supply relatively equals to demand (e.g. Metro Vancouver region); and Import-dominant region, where empty container supply is bigger than demand (e.g. most of the port regions in North America).

Total empty container repositioning cost in base scenario and “street-turn” scenario is compared in three circumstances respectively. The effectiveness of “street-turn” strategy is measured by total cost saving percentage. Model outputs and analysis results majorly provide four insights, which are illustrated as follow.
5.1 Insight 1 – The impact of trade balance on “street-turn” strategy

“Street-turn” strategy reduces empty container repositioning cost. In particular, “street-turn” strategy is most cost-effective in trade-balanced environment.

Here we use boxplot\(^1\) to summarize the result from 50 replications. The boxplot of both total cost saving percentage and percentage of “street-turn” trips is presented in Figure 6. “S” in Figure 6 represents the average daily supply of empty containers within a region; “D” represents average daily demand of empty containers within a region. Export-dominant case is noted as “S<D”; trade-balanced case is represented by “S=D”, and “S>D” stands for import-dominant case.

Figure 6 shows that total cost saving percentage is positive in all cases, from which we prove that “street-turn” strategy reduces empty container repositioning cost. What is more, total cost saving percentage reaches its highest point in the trade-balanced case, implying that “street-turn” strategy is most cost-effective in trade-balanced environment.

\(^1\)A boxplot graphically depicts groups of numerical data through their quartiles. The bottom and top of the box are always the first and third quartiles, and the band inside the box is always the second quartile (the median). The ends of the whiskers represent the minimum and maximum of all of the data.
Both the percentage of “street-turn” trips and total cost saving percentage are low in the export-dominant environment. “Street-turn” strategy is not very applicable in export-dominant environment because there are few empty containers available for regional repositioning. More than likely, shipping lines bring in extra empty containers outside the regional transport network to fulfill local demand. As local supply of empty containers catches up to local export demand, more empty containers are available to be transferred “on the street”. As is shown in Figure 6, the percentage of “street-turn” trips increases when container supply becomes more comparable to export demand, as well as the total cost saving percentage.

Total cost saving percentage starts to go down when the supply of empty containers becomes redundant for local demand. The number of “street-turn” opportunities is restrained to local export loads in the import-dominant environment, leading to the decrease in the percentage of “street-turn” trips. Furthermore, cost saving from “street-turn” interchanges is insignificant.
compared to the cost caused by excessive empty container inventory. As a result, total cost saving percentage is lower when the supply of empty containers is excessive for local export use.

The percentage of “street-turn” trips follows a similar pattern as total cost saving percentage. The percentage of “street-turn” trips is maximized when local empty container supply level and demand level is the same. However, total cost saving percentage reaches its peak when local empty container supply is slightly bigger than local empty container demand. To explain the inconsistency, we need to look at the definition of these two indicators.

The percentage of “street-turn” trips is determined by the number of “street-turn” opportunities between local importers and exporters. Namely, it is decided by the supply and demand of empty containers from local participants. Total cost saving percentage considers overall supply and demand of empty containers within the region, including empty container traffic from global repositioning. In our framework, we assume that the volume of outbound empty containers is three times the volume of inbound empty containers, which simulates the global repositioning policy employed at Metro Vancouver region. Therefore, the highest total cost saving percentage point is different from the percentage of “street-turn” trips.

To verify this reasoning, we adjust the inbound empty container flows to the same level as the outbound empty container flows. The result is shown in Figure 7. Both total cost saving percentage and “street-turn” trip percentage is the highest when local empty container supply equals to local demand. In addition, we conduct sensitivity analysis of global repositioning policy, considering the fact that global repositioning policy varies among regions in reality. Different values of inbound and outbound empty container flows are examined, and the test result shows that Insight 1 is still valid.
What is more, we assume that daily supply and demand of empty containers follow normal distribution in our model. Here we change the distribution of daily empty container supply and demand to Poisson distribution to testify the validity of Insight 1. We choose Poisson distribution because researchers in this field commonly use Poisson distribution to represent container traffics. Model output is shown in Figure 8, which is consistent with the results we acquired above.
To examine Insight 1, we conduct sensitivity analysis of each model parameter such as unit storage cost, unit transportation cost, and gate fees. We select a range of plausible values for each model parameters according to actual practice. Here we present some major results from sensitivity analysis.

When unit storage cost at the marine terminal varies from $0 to $5 per container per day, model outputs remain the same in all three cases. One of the possible reasons is that storage cost at the marine terminal only contributes to a small part of repositioning cost, and thus small changes in unit terminal storage cost do not affect empty container repositioning decisions.

As for unit storage cost at off-dock depots, Figure 9 shows that total cost saving percentage remains the same when unit depot storage cost changes from $0.5 to $5 per container per day in
the trade-balanced and the export-dominant circumstance; whereas total cost saving percentage drops slightly in the import-dominant circumstance.

![Depot storage cost sensitivity analysis — Total cost saving percentage](image)

This difference can be explained by looking at the percentage of “street-turn” trips. As is shown in Figure 10, the percentage of “street-turn” trips in the trade-balanced environment goes up slightly as unit depot storage cost changing from $0.5 to $5. The increase in the number of “street-turn” trips increases the cost saving, which enables total cost saving percentage maintaining at the original level when total repositioning cost in base scenario increases.
In the import-dominant environment, the number of “street-turn” trips remains the same when unit depot storage cost changes, implying that “street-turn” opportunities have been maximized. “Street-turn” interchange is restrained to local export demand when the supply of empty containers is redundant. Hence, the cost saving from “street-turn” movements is limited, resulting in the decrease in total cost saving percentage.

Likewise, in the export-dominant environment, “street-turn” opportunity is limited to the quantity of containers available in the system. The figure below indicates that local supply of empty containers cannot satisfy export demand, and only around 50% of empty containers is repositioned using “street-turn” strategy. Container storage cost is trivial compared to container
shortage cost in the export-dominant case. Hence, the change in total cost saving percentage is unnoticeable.

With regard to unit storage cost at exporter sites, Figure 11 reveals a slight decline in total cost saving percentage in both trade-balanced and import-dominant case as unit exporter storage cost increases. The increase of unit storage cost at exporter sites does not have an impact on the base scenario but leads to higher cost to perform “street-turn” interchange. Correspondingly, cost saving from “street-turn” strategy decreases. In other words, “street-turn” strategy is less effective if unit storage cost at exporter sites becomes more expensive.

![Figure 11 Exporter storage cost sensitivity analysis — Total cost saving percentage](image)

However, total cost saving percentage in the export-dominant case remains unchanged. The reason is that the cost saving from “street-turn” strategy is trivial compared to container shortage cost, which is the major component of repositioning cost. Therefore, the changes in unit storage
cost at exporter sites do not have a noticeable impact on the effectiveness of “street-turn” method percentage wise.

Moreover, from Figure 12 we deduce that “street-turn” strategy is no longer a cheaper substitution for the traditional repositioning method for some container movements. As is shown in below, the percentage of “street-turn” trips decreases in both trade-balanced and import-dominant case. In order words, the number of “street-turn” trips reduces as unit storage cost at exporter site increases.

![Figure 12 Exporter storage cost sensitivity analysis — Percentage of “street-turn” trips](image)

Model sensitivity to unit transportation cost is also taken into consideration. We test the model by adjusting unit transportation cost from $1.5 to $7.5 per container per kilometer. The changes in total cost saving percentage in three trading environments are presented in Figure 13.
As is shown from Figure 13, total cost saving percentage has a decreasing trend in trade-balanced and import-dominant circumstance; whereas total cost saving percentage in the export-dominant case goes up as the unit transportation cost increases. We need to look at the percentage of “street-turn” trips to explain the difference, which is shown in Figure 14 below.
Figure 14 Transportation cost sensitivity analysis — Percentage of “street-turn” trips

In the trade-balanced case, the percentage of “street-turn” trips drops slightly, indicating that “street-turn” method is no longer preferable for some container movements. In other words, “street-turn” method becomes more costly than traditional repositioning method. What is more, total empty container repositioning cost goes up significantly as unit transportation cost increases. In a word, the decrease of “street-turn” interchanges and the increase of total repositioning cost together contribute to the decline in total cost saving percentage in trade-balanced case.

There is no noticeable changes in the percentage of “street-turn” trips in both import-dominant and export-dominant circumstance, implying that the optimal repositioning solution is insensitive to this change in unit transportation cost. However, transportation cost makes up the largest
proportion of total repositioning cost in the import-dominant case, thus the effectiveness of “street-turn” strategy decreases percentage wise as unit transportation cost increases.

As for the export-dominant case, total cost saving percentage shows an upward trend as the increase of unit transportation cost. Transportation cost is a crucial part of the cost saving from “street-turn” strategy. Hence, cost saving increases as unit transportation cost changes from $1.5 to $7.5. However, total repositioning cost in export-dominant case majorly comes from container shortage, which means that this change in unit transportation cost does not have a significant impact on total repositioning cost. Therefore, total cost saving percentage goes up.

In addition, we examine model sensitivity in terms of gate fees. We test both terminal gate fee and depot gate fee ranging from $15 to $65 per container. The results indicate that the model is insensitive to the changes in gate fees. Other model parameters such as container shortage cost, initial stock levels at marine terminal and off-dock depot, and terminal storage limit are examined as well. The analysis result shows that these factors do not affect model outputs when they vary within a reasonable range according to actual practice.

5.2 Insight 2 – The cost saving from “street-turn” strategy

Transportation cost, gate fees, and shortage cost are the major parts of total empty container repositioning cost. “Street-turn” strategy mainly saves costs from transportation cost and gate fees.
To identify how “street-turn” strategy saves empty container repositioning cost, we compare the repositioning cost in base scenario and in “street-turn” scenario. Figure 15 presents the components of total repositioning cost.

![Figure 15 Total cost in base scenario and "street-turn" scenario](image)

As is shown in Figure 15, there is a distinguishable cost reduction by using “street-turn” strategy. “Street-turn” strategy allows empty containers being sent directly to exporter sites without firstly returned to off-dock depots or the marine terminal; whereas empty containers can only be stored at off-dock depots or the marine terminal in base scenario. Therefore, transportation cost and gate fees are overall lower in “street-turn” scenario than base scenario.
From Figure 15 we can also conclude that transportation cost, gate fees, and shortage cost are the major components of empty container repositioning cost. Storage cost holds a small proportion of repositioning cost in this problem. The proportion of each component varies depending on the trading environment. In the export-dominant circumstance, container shortage cost contributes to a substantial part of the total cost. In the trade-balanced and the import-dominant circumstance, repositioning cost mainly comes from transportation and gate fees. Transportation cost and gate fees overall are higher in the import-dominant case than in the trade-balanced case. The cost difference is mainly caused by excessive empty containers that have to be moved to and from off-dock depots or the marine terminal.

What is more, Figure 15 indicates that “street-turn” strategy is least effective in export-dominant circumstance. In the export-dominant case, empty container repositioning cost majorly comes from container shortage, which cannot be reduced by “street-turn” strategy. Also, cost saving from “street-turn” method is trivial compared to the significant cost of bringing in extra empty containers. Therefore, “street-turn” interchange is not a key issue in an export-dominant environment.

We also conduct sensitivity analysis to examine how model parameters affect the cost saving from “street-turn” strategy. As we mentioned above, the model is insensitive as we adjust unit terminal storage cost and unit depot storage cost from $0 to $5 per container per day respectively. Therefore, here we focus on unit storage cost at exporter sites. Figure 16 shows the change in total cost saving as unit exporter storage cost ranging from $0 to $6 per container per day. Total cost saving in trade-balanced and import-dominant case is shown respectively in Figure 16. The export-dominant case is not shown because the model is insensitive to this
change. The bar chart below proves that cost saving mainly comes from transportation cost and gate fees.

From Figure 16 we observe that cost saving from container storage cost becomes negative after unit exporter storage cost is more than $2.5 per container per day. The reason is that increasing unit storage cost at exporter sites does not affect the base scenario but increases total storage cost.
in the “street-turn” scenario. In addition, Figure 16 shows that total cost saving is higher in trade-balanced case than in import-dominant case, indicating that “street-turn” strategy is more effective in trade-balanced environment.

We also test the model sensitivity to unit transportation cost and gate fees respectively considering that they are the major components of cost saving.

Figure 17 summarizes the change in total cost saving as unit transportation cost ranging from $1.5 to $7.5 per container per kilometer. As is shown below, cost saving from transportation goes up accordingly in all three cases when unit transportation cost increases. Cost saving from gate fees decreases slightly in trade-balanced case, implying that the number of “street-turn” trips reduces. In other words, some “street-turn” trips are switched back to traditional repositioning method after increasing unit transportation cost. Cost saving from gate fees remains unchanged in import-dominant and export-dominant case, indicating that the optimal empty container repositioning solution is insensitive to this change.

Additionally, Figure 17 shows that “street-turn” strategy achieves the highest cost saving in trade-balanced case. Again it provides evidence that “street-turn” strategy is more cost-effective in trade-balanced environment than trade-imbalanced environment.
Figure 17 Transportation cost sensitivity analysis — Total cost saving
Next, we adjust depot gate fee from $15 to $65 per container and look at the changes in total cost saving in three trading environments. From Figure 18 below, we observe that cost saving from gate fees increases correspondingly as unit depot gate fee goes up. Yet, there is a noticeable increment in the cost saving from transportation when unit depot gate fee drops down to $25 per container and under.

When unit depot gate fee is smaller than $25, some participants choose to reposition empty containers to/from off-dock depot instead of the marine terminal to avoid high gate fee. In this case, it costs less to get/drop off empty containers at an off-dock depot for some participants even they are geographically closer to the marine terminal. For this reason, transportation cost in both base and “street-turn” strategy increases, and the cost saving from gate fees decreases. However, the change in depot gate fee has a stronger impact in the base scenario than “street-turn” scenario. As a result, cost saving from transportation is higher and saving from gate fee is lower when unit depot gate fee is below $25.

Cost saving from transportation remains the same as unit depot gate fee exceeds $25, indicating that the optimal container repositioning solution does not change with this adjustment. Sensitivity analysis of terminal gate fee is conducted as well, and the result is consistent with above findings.
Figure 18 Depot gate fee sensitivity analysis — Total cost saving
5.3 Insight 3 – The impact of the number of participants on “street-turn” strategy

The number of participants in the transport network has a positive influence on implementing “street-turn” strategy. A transport network with fewer participants tends to have fewer “street-turn” opportunities, and thus restrains the effectiveness of “street-turn” strategy.

Here we examine how the number of participants within the regional transport network affects the effectiveness of “street-turn” strategy. In the basic framework, we created a transport network with 10 importers and 10 exporters. Here we test different number of participants in the system and evaluate its impact on the effectiveness of “street-turn” strategy.

We conduct five experiments to test model sensitivity and the result is shown in Figure 19 and Figure 20 below. Figure 19 presents the percentage of “street-turn” trips and total cost saving percentage separately. Figure 20 provides more information about total repositioning cost.
From Figure 19, we notice that the percentage of “street-turn” trips increases in both trade-balanced and import-dominant case as more participants involved in the transport network. This change indicates that a transport network with more participants tends to have more “street-turn”
opportunities, which makes “street-turn” strategy more applicable. Total cost saving percentage increases correspondingly, as is shown in Figure 19.

The number of participants does not have a noticeable impact on “street-turn” interchanges in the export-dominant case. One of the root causes is the insufficient supply of empty containers. The number of empty containers available to perform “street-turn” is very limited. With the same level of empty container supply, increasing the number of participants cannot encourage “street-turn” interchanges effectively. To explain the increase in total cost saving percentage, we need to look into more details about the total repositioning cost as is illustrated in Figure 20.

Figure 20 Sensitivity analysis of the number of participants —— Total cost (Trade-balanced case)

Figure 20 gives an example of the trade-balanced case to demonstrate the changes in total repositioning cost. The findings below are consistent in all three cases. From Figure 20 we conclude that empty container repositioning cost is lower in a transport network with more
participants. For this reason, total cost saving percentage goes up in all three cases as the number of participants increases, even though cost saving in the export-dominant case does not change.

Figure 20 also shows that total transportation cost decreases in both scenarios as there are more participants in the system, which implies that more repositioning alternatives become available. Participants are able to choose a shorter route for some movements to save transportation cost. Likewise, the number of participants has a negative impact on gate fees in the “street-turn” scenario. In a transport network with more participants, more empty containers are able to be delivered directly to an exporter site instead of being sent to depots or the marine terminal. Hence, container repositioning cost from gate fees reduces.

5.4 Insight 4 – The impact of variance on “street-turn” strategy

Higher variance in supply and demand of empty containers increases the variance in the effectiveness of “street-turn” strategy.

Here we focus on the variance in the supply and demand of empty containers. We identified two type of variances, namely, time-wise variance and location-wise variance. Time-wise variance makes the supply or demand from a certain container user varies on a daily basis. Location-wise variance reflects the distinction among the supply and demand provided by each container user in the transport network.

In the above analysis, we assume that all importers’ daily empty container supply follow a same distribution, and all exporters follow a same demand distribution. Considering the actual practice, we add a variance to the average daily empty container supply and demand level in
terms of different locations, i.e., the location-wise variance. Simply put, daily supply and
demand level among participants is non-homogenous in this experiment.

The result of sensitivity analysis regarding location-wise variance is summarized in Figure 21
below. It shows the changes in percentage of “street-turn” trips and total cost saving percentage
respectively. From the Figure 21, we find that the percentage of “street-turn” trips decreases in
trade-balanced case as with the increase of location-wise variance; whereas it goes up in import-
dominant and export-dominant case.
In the trade-balanced case, daily supply and demand of empty containers among participants are approximately balanced. Increasing location-wise variance reduces a number of “street-turn”
opportunities. Correspondingly, the percentage of “street-turn” trips and total cost saving percentage decreases. In an import-dominant or an export-dominant environment, there is a significant gap between daily supply and demand of empty containers among participants. Therefore, some exporters and importers identify new opportunities to perform “street-turn” interchange as location-wise variance increases.

Moreover, it is noticeable that the variance of total cost saving percentage increases as location-wise variance changes from 0 to 85 units. To better illustrate the changes in total cost saving percentage, we need to look at total empty container repositioning cost in both base and “street-turn” scenario. Figure 22 summarizes the changes in total empty container repositioning cost in three trading environments.
As is shown in the first chart above, container shortage appears and leads to the increase in total repositioning cost as location-wise variance becomes bigger in the trade-balanced case. “Street-turn” strategy cannot reduce container shortage cost, thus the uprising container shortage cost impairs the effectiveness of “street-turn” strategy percentage-wise.

Moreover, higher location-wise variance increases the difficulty to perform “street-turn” interchanges, making off-dock depots more favorable to store empty containers as a buffer. Consequently, total repositioning cost in “street-turn” scenario goes up and the cost saving goes down. To conclude, the increase in total repositioning cost and the decrease in cost saving leads to the decline in total cost saving percentage.
Likewise, the occurrence of container shortage contributes to the increase in total repositioning cost in the import-dominant case, as is shown in Figure 22. The changes in cost saving are trivial compared to the substantial shortage cost, resulting in the decrease in total cost saving percentage. In the export-dominant case, more “street-turn” interchanges are achieved as location-wise variance increases, which leads to the increase in cost saving. In addition, the decrease in container shortage cost reduces total repositioning cost, and thus total cost saving percentage goes up.

We also examine the impact of time-wise variance on the effectiveness of “street-turn” strategy. We adjust the time-wise variance from 10 to 60 units, and the result is presented in Figure 23. From Figure 23, we conclude that the optimal empty container repositioning solution generated from the model is insensitive to this change, but the variance in the effectiveness of “street-turn” strategy increases.
5.5 Summary

In this research, we evaluate the effectiveness of “street-turn” strategy in three trading environments: trade-balanced environment, import-dominant environment, and export-dominant environment. We came to four insights from the above analysis.

Insight 1: “Street-turn” strategy reduces empty container repositioning cost. In particular, “street-turn” strategy is more effective in trade-balanced environment than trade-imbalanced environment.

In trade-imbalanced case, the number of “street-turn” opportunities is restrained to local available empty containers (export-dominant case) or to local export demand (import-dominant case).
case). Moreover, “street-turn” interchange cannot reduce the cost generated by container shortage or excessive container stocks. Thus, “street-turn” strategy is less effective in trade-imbalanced environment.

From the sensitivity analysis, we observe that the increase of unit storage cost at exporter sites and unit transportation cost discourages implementing “street-turn” strategy. “Street-turn” interchange becomes more expensive as unit exporter storage cost or unit transportation cost goes up. Consequently, potential cost saving from “street-turn” strategy decreases and “street-turn” strategy is no longer a cheaper alternative for traditional repositioning method for some movements.

Insight 2: “Street-turn” strategy mainly reduces empty container repositioning cost from transportation and gate fees.

“Street-turn” strategy allows container users to interchange empty containers directly “on the street”, which minimizes transportation cost and eliminates gate fees and storage cost charged at off-dock container depots and marine terminals. From sensitivity analysis, we find that cost saving from container storage drops down to negative values when unit storage cost at exporter sites becomes higher. Moreover, when depot gate fee becomes relatively low to the terminal gate fee, some participants decide to reposition empty containers to/from off-dock depot rather than the marine terminal to avoid high gate fee.

Insight 3: Street-turn” strategy is more effective in a transport network with more participants.

From the above analysis, we conclude that the number of participants in the transport network has a positive influence on implementing “street-turn” strategy. Empty container repositioning
cost overall is lower in a transport network with more participants. In the “street-turn” scenario, more route alternatives among container users become available as the number of participants increases, which potentially reduces repositioning cost from transportation and gate fees. Therefore, the more participants join the network, the more incentives to implement “street-turn” strategy.

Insight 4: Higher variance in supply and demand of empty containers increases the variance in the effectiveness of “street-turn” strategy.

We examine both location-wise variance and time-wise variance of daily supply and demand of empty containers. The analysis result proves that the variance in supply and demand of empty containers has a positive correlation to the variance in total cost saving percentage.
Chapter 6: Conclusion

The main contribution of this research is to develop a more realistic framework to optimize regional empty container movements and to evaluate the effectiveness of “street-turn” strategy. We first conducted interviews with local industry professionals regarding current empty container operations. Their practical insights helped this research to examine and verify the effectiveness of implementing “street-turn” strategy in Metro Vancouver area. We also provide a comprehensive review on the literature that deals with empty container repositioning problem.

The model analysis provides evidence that “street-turn” strategy reduces empty container repositioning cost mainly from transportation and gate fees. Also, we conclude that “street-turn” strategy is more effective in the trade-balanced environment. In a trade-imbalanced environment, empty container repositioning cost majorly comes from container shortage or excessive stock of empty containers, which cannot be reduced by “street-turn” strategy. In addition, this research indicates that the successful implementation of “street-turn” strategy depends on the participation of each player. “Street-turn” opportunities can be quickly identified when container information is shared among the participants in the network. With real time information about container availability and port terminals gate operations, our model can be applied to determine “street-turn” opportunities and optimize empty container flows.

Metro Vancouver area has high potential to benefit from “street-turn” strategy due to its trade-balanced environment. Our model analysis shows potential benefits of implementing “street-turn” strategy in an ideal scenario. In reality, there are some other factors limit the implementation of “street-turn” strategy. For example, the agreements and contractual
relationship between container users and trucking companies add a barrier for players to cooperate. In addition, there is a time window constraint at the marine terminal gates, which limits the availability of trucks and container supply. From company visits, we find that only several importers and exporters have collaborated to conduct “street-turn” programs. The major challenge to perform “street-turn” interchange is that container information is not shared among participants. Shipping lines, who possess all the container information, do not arrange “street-turn” interchanges and have not yet taken the initiative to establish an information platform to facilitate “street-turn” movements in Metro Vancouver area.

Our research provides some insights to the current situation. We discover that “street-turn” strategy has been recognized as an effective method to lower container operating cost by local industry professionals. The cost benefit of “street-turn” strategy for each stakeholder is illustrated in Table 3. For shipping line, “street-turn” interchange reduces container storage cost and gate fees charged at marine terminal and off-dock container depots. “Street-turn” strategy potentially helps drayage company eliminate empty truck trips and needless loaded trips to and from marine terminals or container depots, which reduces container repositioning cost and eventually benefits container users.

| The cost saving from “street-turn” strategy | Stakeholder |
| --- | --- | --- | --- |
| **Cost** | Shipping line | Drayage company | Container user (importers and exporters) |
| Transportation cost | | ✓ | ✓ |
| Gate fee | ✓ | | ✓ |
| Container storage cost | ✓ | | |

Table 3 The cost saving from “street-turn” strategy
From the model analysis, we observe that “street-turn” strategy saves repositioning cost primarily from transportation and gate fee; whereas container storage cost is an insignificant part of the cost saving. We thus infer that container users have higher incentive to advocate “street-turn” strategy than shipping lines. This finding explains why shipping lines have not yet take the plunge to promote “street-turn” strategy. Our research also indicates that “street-turn” strategy has indirect benefits to shipping lines. In today’s highly competitive market, shipping lines can build competitive advantage by providing a more efficient land transportation solution to container users. An efficient regional repositioning system helps container users reduce cost and customer satisfaction will increase in the long run.

On the other hand, professionals express their concerns about “street-turn” strategy. One of the key requirements for “street-turn” interchange is time match. Simply put, the time gap between the supply and demand of empty containers must be within the free time for both container users. Otherwise, shipping lines will charge detention fee, making “street-turn” interchange more costly than traditional repositioning method. Container ownership is another concern to perform “street-turn” strategy. Currently, “street-turn” interchange is only allowed between container users of the same shipping company. This restriction creates a barrier to implementing “street-turn” strategy. Also, “street-turn” strategy normally applies to the same type of containers only. Container substitution is not a common practice in Metro Vancouver area. Additionally, container maintenance and repair process is bypassed in “street-turn” interchange, increasing the risk of container condition problem.

This research improves modeling with consideration of the time match requirement in actual practice. To make the framework more applicable, we add delivery window constraint to the
model and assume that empty containers can be stored temporarily at customer sites. Another improvement is that we incorporate gate fee and container shortage cost into our model.

Our proposed framework has several limitation that can be improved by future research. Firstly, we use public data to estimate daily empty container traffic, which cannot accurately simulate actual empty container flows. To better model regional empty container flows, researchers can collaborate with shipping lines and obtain data from them. Secondly, we consider gate operations at the marine terminal by adding gate fees to the model. In actual practice, marine terminals conduct day-gate operation and night-gate operation separately in recent years. Incorporating terminal gate operations into the regional empty container repositioning problem will be an important progress. Thirdly, future research employ simulation techniques to incorporate stochastic elements in the supply and demand of empty containers such as last-minute booking and cancelation of container booking. Furthermore, exporters may reject the empty containers delivered directly from importers due to container condition issue. Thus, the probability of “street-turn” interchange failure can be considered in future research. Lastly, researchers can further evaluate potential benefits of implementing container sharing among shipping lines and container substitution.
References


Appendices

Appendix A : Appendix for Chapter 2

We classified the related literature based on model characteristics. Table 4 below is a summary of available frameworks focusing on regional empty container repositioning problem.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Case study</th>
<th>Time dependency</th>
<th>Cost metrics</th>
<th>Consideration of “street-turn” strategy</th>
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<tbody>
<tr>
<td>(Crainic et al., 1993)</td>
<td>No (no solution provided)</td>
<td>Dynamic daily</td>
<td>Transportation cost, Storage cost, Container leasing cost</td>
<td>No</td>
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<td></td>
<td>Dynamic daily</td>
<td>transportation cost, Storage cost, Container leasing cost</td>
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<td>Static N/A</td>
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<td>Dynamic hourly 8h</td>
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<td>Static N/A</td>
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<tr>
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<td>Mediterranean basin</td>
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<tr>
<td>(Deidda et al., 2008)</td>
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<td>Dynamic daily</td>
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<td>Static N/A</td>
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<td>Dynamic daily 2 weeks</td>
<td>Transportation cost, Storage cost</td>
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<tr>
<td>Paper</td>
<td>Consideration of uncertainty</td>
<td>Delivery window</td>
<td>Storage capacity limit</td>
<td>Container type</td>
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<tr>
<td>----------------------------</td>
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<td>----------------</td>
<td>------------------------</td>
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<td>No</td>
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<td>No</td>
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<td>(Chang et al., 2006)</td>
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<tr>
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<td>(Furio et al., 2013)</td>
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**Table 4 Classification of literature**
Appendix B: Appendix for Chapter 3

Table 5 is a list of companies that we have visited to collect information for this research.

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<th>Visit Date</th>
<th>Company Name</th>
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<td>Port Metro Vancouver</td>
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<td>2014-12-03</td>
<td>Canadian Tire Corporation’s Vancouver Operations Division</td>
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<td>Evergreen Shipping (America) Corp. (Vancouver Office)</td>
<td>Shipping line</td>
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<td>Shipping line</td>
</tr>
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<td>Drayage company</td>
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<td>2014-12-22</td>
<td>Aheer Transportation Group</td>
<td>Drayage company</td>
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Table 5 List of companies