Port dynamic empty container reuse

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Abstract

In this paper, empty container movements in the Los Angeles and Long Beach (LA/LB) port area are studied in an effort to reduce congestion by optimizing the empty container reuse. The dynamic empty container reuse is modeled analytically, and techniques are developed to optimize empty container operations. Several case studies based on current and projected demand in the LA/LB port area are used to evaluate the proposed techniques. Simulation results demonstrate that significant cost and congestion reductions can be achieved in the area, through reuse of empty containers.

Keywords: Dynamic optimization; Empty container reuse; Los Angeles and Long Beach port area

1. Introduction

The Los Angeles and Long Beach (LA/LB) port complex, located in San Pedro Bay, is the largest US ocean freight hub and its busiest container port complex. It consists of fourteen individually gated terminals, and serves as a crucial node in the regional supply chain (Mallon and
During 2000 alone, the combined ports handled 9.5 million Twenty-foot Equivalent Units (TEUs). This figure implies that almost 5.1 million full containers were handled during 2000 in the LA/LB port complex. Over the period of 1990–2000, the growth in container traffic in the LA/LB port was significant. With an average annual growth of 9.2%, this figure surpasses the forecasted annual growth of 6.2%, which had been the basis of the 2020 Seaport Plan and much of the regional economic and infrastructure planning (Mallon and Magaddino, 2001; The Tioga Group, 2002). Assuming a modest 6.2% annual growth, the estimated container traffic in 2020 will be around 28 million TEUs or almost 15.1 million containers. Thus, by 2020 the volume of containers moving through the combined LA/LB ports will be at least triple the current volume (Mallon and Magaddino, 2001).

As a consequence of this unanticipated growth, port generated traffic has emerged as a major contributor to regional congestion. The unanticipated growth in LA/LB port activity suggests that the levels of predicted traffic (50,000 truck and 100 train movements per day) will be met in 2010, a full 10 years earlier than planned (US Maritime Administration, 1999). Empty containers have the highest average dwell time in container terminals and are probably the single largest contributor to the congestion at and around marine ports (Mallon and Magaddino, 2001). Current practices, regarding the movement of empty containers, involve trucking empties for export loads from container terminals, while returning emptied import containers to the terminals. The emptied import containers, however, can be reused for export loads without first being returned to the marine terminals. The development of optimization techniques for exchanging empty containers in and out of the marine ports will help reduce congestion around the terminals especially in areas where land scarcity limits further terminal expansion.

Surprisingly, research on empty container reuse is scant. As noted by Dejax and Crainic (1987), the work on developing models related to the container transportation problems is very limited. In their seminal paper, Crainic et al. (1993) proposed dynamic and stochastic models for empty container allocation in a land distribution and transportation system. The work, however, did not address empty container exchange, nor did it develop any optimization technique for handling empties.

In this paper, the empty container movement problem in the LA/LB port area is studied. The main objective of this paper is to model empty reuse in a dynamic environment analytically and develop optimization techniques to minimize the cost of dynamic empty reuse. The techniques developed are evaluated and compared with the cost of the current practices using case study sim-

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Typically a container could be 20 ft or 40 ft in length, but the vast majority of containers are 40 ft. It is estimated that on an average, a random container would correspond to 1.85 TEU (The Tioga Group, 2002).
ulation scenarios generated in the LA/LB port area. In an effort to reduce the number and cost of truck trips in the LA/LB port area, two empty container reuse methodologies are considered: street-turn and depot-direct. Each reuse methodology is investigated in-depth, and it is shown that with a careful selection of reuse cost function, the emphasis can be shifted between street-turn and depot-direct reuse methodologies.

The paper is organized as follows: In Section 2, the current empty container movements and flows in the Los Angeles and Long Beach (LA/LB) port area are briefly reviewed and studied. In Section 3, the dynamic empty container reuse problem is modeled mathematically and an optimization technique is developed. Section 4 is devoted to case studies in the LA/LB port area. These case studies are then used for simulation experiments and cost comparisons between the empty container reuse and current practices. Finally, Section 5 concludes this paper.

2. Empty container flows in the LA/LB port area

Empty containers move both to and from the container terminals. Generally speaking, local container movements at any marine terminal can be divided into two major categories: import and export movements.

The import container movements, demonstrated in Fig. 1, can be briefly described as follows: a truck is dispatched to pick-up a loaded import container from the terminal (move 1); the truck then delivers the loaded container to its designated local consignee (move 2); if an empty container is available at the time of delivery, the truck takes it back to the terminal (move 5), and then goes to its tracking company or another assignment (move 6). If an empty container is not available, the truck goes back to its trucking company or another assignment after delivering the loaded im-

![Fig. 1. Import container movement.](image-url)
When the emptied container becomes available at the local consignee, a truck is dispatched to take it back to the terminal (move 4).

Likewise, export container movements, shown in Fig. 2, are as follows: a truck is dispatched to pick up an empty container from the terminal (move 1); the empty container is trucked to a designated local shipper for loading (move 2); if a loaded container is available at the time of the empty delivery, the truck returns it to the terminal (move 5), and finally the truck goes back to its trucking company or another assignment (move 6). If the loaded container is not available, the truck goes back to its company or another assignment after delivering the empty container (move 3), and when the loaded container becomes available, a truck is dispatched to take it from the local shipper to the terminal (move 4).

Over the last decade, the growth in container movements in and out of the Los Angeles and Long Beach (LA/LB) port complex has been impressive. In 2000, almost 716,000 empty containers were trucked out of the LA/LB container terminals to local shippers, local container depots, and intermodal container terminals. Among these, 77% of empties were moved to local shippers to be stuffed with exports. During the same period, 1.9 million empties were returned to terminals from local consignees, local container depots, and intermodal container terminals by trucks. Almost 58% of returned empties were trucked back from local consignees (The Tioga Group, 2002).

It is predicted that by 2020 the number of empties trucked back from local consignees to the LA/LB container terminals would be more than 4,585,000 containers (i.e., 63% of all empties trucked to the terminals). At the same time local shippers will be in need for 1,900,000 empty containers (i.e., 72% of all empties moved by trucks out of the terminals) for loading export goods (The Tioga Group, 2002). These numbers indicate that the local businesses (local consignees and shippers) will be the largest contributors to empty flows in the region, and consequently, to the congestion at and around the LA/LB container terminals.

In a recent study, Barber and Grobar (2001) found that 40% of trucks visiting LA/LB terminals are involved in more than 2 h waiting time, with almost a quarter of the transactions involving a wait in the range of 2–3 h. In addition to driver inefficiency, traffic congestion and long queues at the gates of the LA/LB terminals are a main source of air pollution (especially diesel toxins),
wasted energy, and increasing maintenance cost imposed by the volume of trucks on the roadway (Barton, 2001). Moreover, a study by the California Highway Patrol (2000) freeways reveals that the main artery to the LA/LB terminals, the I-710 freeway, topped the list of freeway collisions on two measures, the highest proportion of truck-involved collisions, 31%, and truck-caused collisions at 16%.

With huge number of empty containers in the LA/LB port area, a small percentage reduction in empty repositioning traffic can be reflected in significant congestion reduction and improved operational costs. The idea of “reusing” empties is an effort to reduce empty repositioning around the ports. It consists of using empty import containers for export loads without first returning them to the marine terminal. Generally speaking, two major methodologies can be considered for empty container reuse: depot-direct, and street-turn.

Depot-direct: In addition to the marine terminals, empty containers can be stored, maintained, and interchanged at off-dock container depots. The potential benefits of depot-direct are: establishing a supply point for reusable empties, facilitating empties drop-off and pick-up when terminal gates are congested or closed, and adding buffer capacity to the marine terminals.

Street-turn: In street-turn, the empty container is directly moved from local consignees to local shippers. The potential benefits of street-turns are enormous, including: reducing the number of truck trips and consequently reducing the traffic congestion, noise, and emissions, and saving driving times to and from marine terminals by avoiding the congested areas around the gates.

The general local container flows in the LA/LB port area can be illustrated by Fig. 3, where empty truck moves are eliminated for the sake of simplicity. As demonstrated in Fig. 3, by forwarding empties from local consignees to local shippers directly, the empty street-turn reuse eliminates two empty moves to and from the terminals (move 5 in Fig. 1, and move 2 in Fig. 2), and adds one off-port empty move.

The idea of empty reuse is desirable by all parties involved, yet hard to achieve. Several key issues limit the ability to make the empty reuse possible, including operational (e.g., import/export timing and location mismatch, ownership mismatch, container type mismatch), and legal issues (e.g., off hiring of leased containers). Before the empty reuse idea can be fully implemented, these barriers must be addressed and transitions must be made to create a fast, reliable, efficient, and seamless system for empty container reuse outside the terminals.

![Fig. 3. Local container flows in the LA/LB port area: (—) loaded flows, (---) empty flows.](image-url)
Assuming that all other barriers (legal, insurance, etc.) have been addressed, this study investigates the operational issues of empty container reuse. Our focus will be on addressing import/export timing and location mismatch. We analytically model empty container reuse, and develop an optimization technique to minimize the number and cost of truck trips. It is widely expected that optimization techniques and the use of Information Technologies (IT) will play a major role in removing some of the non-operational and operational barriers. Presently, studies have been conducted to use IT in addressing these barriers in the LA/LB port area (The Tioga Group, 2002; Hanh, 2002; Mallon, 2001).

3. Modeling and optimization

3.1. Modeling

We consider single commodity empty container movements in a deterministic and dynamic environment. In other words, we assume that all containers belong to a single class of containers. We also assume that all information regarding the location and the time of requests for empties at shippers, and supplies of empties at consigneves are known a priori.

Fig. 4 shows schematically all possible moves in the dynamic empty container reuse scenario. The empty reuse is demonstrated in two dimensions: time, and space (location). The time axis is divided into \( T \) periods, where \( T \) is the planning horizon. At each period \( k, k = 1, \ldots, T \), the locations of consigneves, where the supplies of empties are available, are unfolded and shown by single circles on the space axis. For instance, at period \( k = 1 \), consigneves 1 and 2 have supplies of empties, while at time \( k = T - 1 \) only consignee \( i \) has empties available for pick-up. Likewise, at each period \( k, k = 1, \ldots, T \), the locations of shippers are unfolded and shown by double circles on the space axis. For instance, at periods \( k = 2 \) and \( k = T \), shipper 1 has demands for empties.

For the sake of simplicity, Fig. 4 shows only one container terminal (port) in the region. Dashed lines in Fig. 4 demonstrate the moves of empties from consigneves to port, consigneves
to shippers, and port to shippers. As seen, a move may need more than one time period to be com-
pleted. That mainly depends on the distance between the geographical locations of shippers, con-
signees and the port. In congested areas, such as the LA/LB port area, the time needed to 
transport a container between its origin and destination may also depend on traffic conditions, 
and consequently on the time the move was initiated.

In this study, we assume that all processing of empties occurs within the planning horizon \( T \). In 
other words, we assume that no movement starts before time period \( k = 1 \), or ends after \( k = T \). 
For the purpose of empty container movement in relatively small regional transportation net-
works, such as the LA/LB port area, the assumption is realistic since all local empty container 
movements can be performed within a single working day (i.e., \( T < 24 \) h). We also assume that 
all depots and ports can process the empties throughout the time horizon, \( T \).

For modeling the dynamic empty container reuse, we adopt the following notation:

\[
\begin{align*}
T & \quad \text{length of the planning horizon} \\
I & \quad \text{set of consignees with excess of empties in horizon } T \\
J & \quad \text{set of shippers with requests for empties in horizon } T \\
P & \quad \text{set of depots and ports. Hereafter, called the set of “depots” for simplicity} \\
x^{kk'}_{ij} & \quad \text{number of empties moved from consignee } i \in I \text{ at time } k \text{ to shipper } j \in J \text{ to satisfy the} \\
& \quad \text{demand at time } k' \\
c^{kk'}_{ij} & \quad \text{cost of moving an empty container from consignee } i \in I \text{ at time } k \text{ to demand } j \in J \text{ in order} \\
& \quad \text{to satisfy the request at time } k' \\
\ell^{kk'}_{ij} & \quad \text{time needed to move an empty between consignee } i \in I \text{ and shipper } j \in J \text{ initiated at time} \\
& \quad k. \text{This time includes the pick-up time at consignee and drop-off time at shipper. We} \\
& \quad \text{assume that this time depends solely on the time when the move initiated} \\
x^{k}_{ip} & \quad \text{number of empties moved from consignee } i \in I \text{ at time } k \text{ to depot } p \in P \\
c^{k}_{ip} & \quad \text{cost of moving an empty container from consignee } i \in I \text{ at time } k \text{ to depot } p \in P \\
x^{k'}_{pj} & \quad \text{number of empties moved from depot } p \in P \text{ to shipper } j \in J \text{ to satisfy the demand at time} \\
& \quad k' \\
c^{k'}_{pj} & \quad \text{cost of moving an empty container from depot } p \in P \text{ to shipper } j \in J \text{ to satisfy the demand} \\
& \quad \text{at time } k' \\
s^{k'}_{j} & \quad \text{number of empties available at consignee } i \in I \text{ at time } k \\
d^{k'}_{j} & \quad \text{number of empties requested by shipper } j \in J \text{ to be fulfilled by time } k'.
\end{align*}
\]

Let us also define the following two time index generators:

\[
\begin{align*}
U(x^{kk'}_{ij}) &= k \\
D(x^{kk'}_{ij}) &= k'
\end{align*}
\] (1)

where \( U \) returns the earliest pick-up time and \( D \) generates the latest delivery time of the variable 
\( x^{kk'}_{ij} \), respectively. The dynamic single commodity empty reusing scenario can be mathematically 
modeled as follows:
We propose a two-phase optimization technique for solving the dynamic empty container reuse model presented in (3)–(7). In phase one, the model is transformed into a bipartite transportation network. In phase two, the best match between supply and demand of empties in the transportation network is found that solved the optimization problem presented in (3)–(7).

Phase I: Generating the bipartite network. Let $I^k$ denote the set of consignees with supplies of empties at period $k$. $I^k$ is defined as follows:

$$I^k = \{i^k | i \in I, s^k_i > 0\}, \ \forall \ k = 1, \ldots, T$$

(8)

where in (8) $i$ is the index of consignee, and $k$ is the index of time period. Likewise, $J^{k'}$ denotes the set of shippers with demands for empties at period $k'$. The set is defined as follows:

$$J^{k'} = \{j^{k'} | j \in J, d^{k'}_j > 0\}, \ \forall \ k = 1, \ldots, T$$

(9)

where in (9) $j$ is the index of shipper, and $k'$ is the index of time period. Let also $I$ and $J$ be the supply and demand sets in horizon $T$ defined respectively as

$$I = \{I^1, I^2, \ldots, I^T, P\}$$

(10)

$$J = \{J^1, J^2, \ldots, J^T, P\}$$

(11)
The bipartite network $G(N,A)$ is generated as follows: $N = I \cup J$ is the node set, $A = \{(v,w) | v \in I, w \in J \}$ is the arc set, and $c_{vw}$ is the cost associated with each arc $(v,w) \in A$.

To calculate the cost $c_{vw}$, we define the following functions:

- Time period generators $\Pi : I \rightarrow \{1, \ldots, T\}$ and $\Delta : J \rightarrow \{1, \ldots, T\}$, which return the time index $k$ and $k'$, respectively, when operated on members of supply and demand sets.
- Node index generators $\sigma : I \rightarrow \{I,P\}$ and $\delta : J \rightarrow \{J,P\}$, which return the supply and demand node indexes, respectively.

The cost $c_{vw}$ is calculated as follows,

$$
c_{vw} = \begin{cases} 
  c(\Pi(v), \delta(w)) & \text{if } \delta(w) \in P, \sigma(v) \notin P \\
  c(\sigma(v), \delta(w)) & \text{if } \sigma(v) \in P, \delta(w) \notin P \\
  c(\sigma(v), \delta(w)) & \text{if } \Pi(v) + I(\Pi(v)) \leq \Delta(w), \delta(w) \notin P, \sigma(v) \notin P \\
  M & \text{otherwise}
\end{cases}
$$

(12)

where $M$ is a big number. To reduce the computational time, we prune the network $G$ through eliminating arcs $(v,w) \in A$ if the cost $c_{vw} = M$.

**Phase II:** The outcome of the Phase I is a bipartite network $G$ with node set $N$ and arc set $A$. Associated to each arc in $A$ is a cost calculated in (12), which determines the cost of empty movement along the arc in $A$. The bipartite network $G$ is indeed an integer Transportation Problem (TP), in which all decision variables $x_{vw}$’s are integer representing the number of empties moved from supply node $v$ to demand node $w$. The supply and demand of empties at nodes $v$ and $w$ (except the depots) are, respectively

$$
s_v = s^I_{\sigma(v)}
$$

(13)

$$
d_w = d^I_{\delta(w)}
$$

(14)

Since all supply of empties at consignees $(s^k, i \in I, k = 1, \ldots, T)$ and all demands at shippers $(d^k, j \in J, k' = 1, \ldots, T)$ are integer numbers, the values of supplies, $s_v$, and demands, $d_w$, are integers too. Therefore, the integer Transportation Problem (TP) formed by bipartite network $G$ can be solved to optimality using Linear Programming (LP) techniques (Rockafellar, 1984).

Note that the above argument is valid as long as the costs of moving empty containers to node $w \in J$ on separate arcs are different. That is, given nodes $w \in J, v_1, v_2 \in I,$ and arcs $(v_1,w),(v_2,w) \in A$ where $v_1 \neq v_2$, the optimal integer values of $x_{vw}$’s are guaranteed to be integer numbers if $c_{v_1w} \neq c_{v_2w}$. If the above condition does not hold, one may add a small real number $\epsilon > 0$ to any of the moving costs $c_{v_1w}$ or $c_{v_2w}$ to find the optimal integer solution.

4. Experimental results

A series of case studies are generated in the San Pedro Bay area located in Southern California containing the twin ports: Los Angeles and Long Beach. Current and projected data are used to
generate scenarios and to evaluate the costs associated with the empty container reuse methodology developed in Section 3.

The geographical area shown in Fig. 5 bounded from the West and South by the Pacific Ocean, from the East by freeway I-15, and from the North by freeway I-210 is considered for the case study simulation scenarios. For the sake of simplicity, the area is referred to as the LA/LB port area.

The LA/LB port area, including the transportation network, was created in the ArcView Geographic Information System (GIS). On top of the ArcView GIS, we employed the “ArcView Network Analyst” to find the shortest distance and associated path between each pair of origin and destination (OD). In our study, origins are places where the empty containers are picked-up and destinations are those where empties are dropped-off. Shown in Fig. 5 is the transportation network in the LA/LB port area, which consists of regional freeways, major avenues and main streets. Freeways I-110, and I-710 are the two arterial freeways carrying almost all containers into and out of LA/LB ports.

The case studies consist of 12 consignees (supply of empties), 8 shippers (demand for empties), 2 local container depots, and one container terminal. The various symbols in Fig. 5 represent the following entities:

- **Consignees**: The consignees are represented by circles in Fig. 5 and labeled one to twelve. Many consignees were chosen to represent existing businesses. For instance, the first five locations (i.e., consignees 1–5) are the most active local importers in the LA/LB port area according to (The Tioga Group, 2002). The other consignees’ locations were distributed randomly throughout the region under study.

Fig. 5. Transportation network and the basic layout for the empty container movement in the LA/LB port area.
The degree of activity among the consignees is variable. To each consignee $i$ a weight $w_{ci}$ is associated which indicates its relative activity at that location compared to other consignees in the region. Vector $W_C$ below, shows the degree of activity at each consignee relative to other consignees.

$$W_C = [15 \ 9 \ 7 \ 7 \ 13 \ 3 \ 2 \ 1 \ 2 \ 1 \ 2 \ 3]$$

For instance, vector $W_C$ indicates that the degree of activity at Consignee 1 is 15 times more than that of Consignee 10. For the first five most active consignees in (15), the data were acquired from the terminal surveys conducted by The Tioga Group (2002). Since The Tioga Group (2002) study does not include the low-active consignees, the degree of activity at consignees 6 to 12 was randomly assigned by generating a random number between 1 and 3.

**Shippers:** The shippers are represented by squares in Fig. 5 and labeled one to eight. Likewise, to each shipper $j$ a weight $w_{sj}$ is associated which indicates its relative activity at that location compared to other shippers. The degree of activity at shippers is shown in vector $W_S$ below.

$$W_S = [5 \ 4 \ 1 \ 2 \ 1 \ 1 \ 1 \ 2]$$

Similarly, the data of the most active exporters were acquired from The Tioga Group (2002). These data indicate that the first two locations are the most active local exporters in the LA/LB port area. For the other locations (i.e., shippers 3–8), random numbers were assigned.

It should be noted that the difference between the higher number of consignees and the lower number of shippers represents an imbalance between the number of import and export container carriers in the region.

- **Inland container depots.** The inland container depots are represented by pentagons in Fig. 5 and labeled one to two. According to The Tioga Group (2002), most existing container depots are located about 4 miles from the twin ports and 1 to 2 miles from freeways I-110 and I-710. The study identifies 10 depot locations in this area, among which we selected two without loss of generality. Depot 1 is the location of the Intermodal Container Terminal Facility (ICTF) located in the Los Angeles area.

- **Container terminal.** The container terminal's location is shown by a star in Fig. 5 which represents the physical location of Pier G terminal which is one of the most active container terminals in the LA/LB port complex.

### 4.1. Simulated operations

Two operations are considered and compared in this paper: base and reuse operations.

#### 4.1.1. Base operation

The base operation replicates the current practices in the LA/LB container terminals. In this operation, emptied import containers at consignees are moved back to terminals and, upon receiving requests, empty containers are trucked for loading from terminals to shippers.

Using the notation presented in Section 3.1, the total cost of empty container movements in the dynamic base operation is considered as follows:
\[ \sum_{k=1}^{T} \sum_{i \in I} c_{ik}^k \cdot s_i^k + \sum_{k'=1}^{T} \sum_{j \in J} c_{jp}^{k'} \cdot d_j^{k'} \] (17)

Note that (17) gives the total cost to/from the single terminal \( p \) assumed in this study. We assume that the cost of moving an empty to/from the container terminal is equal to the traveling distance and that this cost is independent of the time the move was initiated. More precisely, we assume \( c_{ip}^k = c_{ip} \) and \( c_{pj}^{k'} = c_{pj} \), where the cost \( c_{ip} \) is equal to the shortest distance between consignee \( i \) and Pier G, and \( c_{pj} \) is the shortest distance between Pier G and shipper \( j \).

4.1.2. Empty reuse operation

The dynamic empty container reuse was discussed in detail in Sections 2 and 3. Using the notation presented in Section 3, we assume the following empty moving costs between supply and demand nodes:

\[ c_{ij}^{k'} = c_{ij} + \alpha (k' - k) \quad \forall \ i \in I, j \in J \]

\[ c_{ip} = c_{ip} \quad \forall \ i \in I, p \in P \]

\[ c_{pj}^{k'} = c_{pj} \quad \forall \ j \in J, p \in P \] (18)

where \( c_{ij} \) is the traveling distance between consignee \( i \) and shipper \( j \), \( c_{ip} \) is the traveling distance between consignee \( i \) and depot \( p \) (including Pier G terminal), and \( c_{pj} \) is the traveling distance between depot \( p \) and shipper \( j \). The design parameter \( \alpha \geq 0 \) is to avoid stocking empties in one location and to force early movement of empties between supply and demand nodes. Note that the first row in (18) consists of two terms: \( c_{ij} \) and \( (k' - k) \). The latter represents the extra cost introduced by the difference in times when demand should be satisfied, \( k' \), and when the supply is ready to be picked up, \( k \). If \( \alpha = 0 \), the algorithm in Section 3.2 would find the closest (in space) match between demand and supply of empties without taking into account the time difference \( (k' - k) \). That is some empties may be stayed in one location for a long period of time before being moved or loaded. As the parameter \( \alpha \) increases, more weight will be placed on the time difference \( (k' - k) \) forcing the algorithm in Section 3.2 to find a solution to move and load empty containers as soon as possible.

In this section, we also assume that the transport time between origin node \( i \) and destination node \( j \), \( t_{ij} \), is independent of starting time and is given by

\[ t_{ij} = \frac{d_{ij}}{v} \] (19)

where \( d_{ij} \) is the traveling distance between supply node \( i \) (including consignees, depots and the terminal) and demand node \( j \) (including shippers, depots and the terminal), and \( v \) is the average traveling speed in the LA/LB port area assumed to be 25 mph, which is very close to the real life scenario. A detailed sensitivity analysis to study the effect of the variation of average inner-city speeds on the reuse cost is conducted later in the paper.

4.2. Case studies

In this study, we generate a series of case studies using current and projected data for the Los Angeles and Long Beach port area (Mallon and Magaddino, 2001; The Tioga Group, 2002).
Case Study 1: (Status quo) During 2000, almost 45% of trucks passing through the inbound gates of the LA/LB container terminals were delivering or picking up empties (Mallon and Magaddino, 2001). Among all empties delivered to the LA/LB terminals, 24% were trucked from local shippers (The Tioga Group, 2002). At the same time 49% of all empties picked up at terminals were destined for local consignees. These data are used to generate the following three case studies to simulate the current practices:

(1-A) Quiet day: During a relatively quiet day at a LA/LB container terminal in 2000, almost 250 trucks passed through the terminal’s gates (aggregated inbound and outbound trucks) (Mallon and Magaddino, 2001). This can be translated to 14 demanded empties at local shippers and 28 empties supplied from local consignees.

(1-B) Average day: During a regular day in 2000, about 107 empty containers were picked up per container terminal for local shippers, and about 219 empties were delivered from local consignees (The Tioga Group, 2002).

(1-C) Busy day: In an extremely busy day in 2000, almost 5000 trucks were served at the inbound and outbound gates at a LA/LB terminal (Mallon and Magaddino, 2001). This translates to 267 empties trucked to local shippers and 547 empties delivered from local consignees.

Case Study 2: (2010 projection) In this scenario, we use the projected figures for the empties demand and supply for 2010. It is expected that in 2010 the number of export and import loads in the LA/LB port area will be about 2.0 and 1.8 times more than those in the year 2000, respectively (The Tioga Group, 2002). Thus, considering the worst-case scenario presented in Case Study 1-C, the number of empties demanded by shippers will be around 534, and the number of empties supplied by consignees will be about 985 containers per day in 2010. These figures are used as the Case Study 2 in this paper.

Case Study 3: (2020 projection) The estimated number of empty container demand and supply for 2020 are used for Case Study 3. It is anticipated that by 2020, the number of export and import loads in the LA/LB port area will increase by 3.4 and 4.0 compared to 2000, respectively. That is for the worst-case scenario, in 2020 the number of empties demanded by shippers will be about 908, and the number of empties supplied by consignees will be about 2188 containers per day.

4.3. Simulation scenarios

The simulation programs are coded in Matlab 6.5 developed by The MathWorks, Inc., and tested on an Intel Pentium 4, 2.2 GHz.

Simulation Scenario 1: In this simulation scenario, the cost of empty container reuse is compared with the cost of the base operation. We assume that the design parameter $a$ in (18) is 1, and the planning horizon is 8 h, i.e. $T = 8$, which is divided into 8 periods. Each period represents an hour of operation. The total daily number of empties supplied and demanded by all consignees and shippers are assumed to be given by case studies in Section 4.2. To determine the number of empties supplied by each consignee and demanded at each shipper, we randomly distribute the total daily numbers among consignees and shippers according to their degrees of activity presented in (15) and (16), respectively. In other
words, given the case study, the daily number of empties requested by each shipper and the number
of empties supplied by each consignee in Fig. 5 is determined randomly based on their degrees
of activity. Moreover, the supply and demand of empties for each consignee and shipper at each
period of time \( k = 1, \ldots, 8 \), is calculated by evenly distributing the empties at each location in the
planning horizon.

For each case study, the simulation program was tested 10 times. Table 1 shows the average
result of the simulations based on the results of 10 trials.

It is not straightforward to compare the cost of the reuse scenario with that of the base oper-
ation. Note that the cost of the base operation in (17) is solely the sum of empty traveling dis-
tances. However, the cost of empty reuse consists of two elements: empty traveling distances,
and an extra cost introduced by the design parameter \( z \) in (18) which forces early pick-up and
delivery of empty containers. Even though, \( z \) introduces some additional cost, the cost of empty
reuse is almost half of the cost of the base operation, as demonstrated in Table 1.

Table 1 also shows more than 50% reduction in the empty trip activity around the port and
depots in the reuse operation (note: in Fig. 5 depots are located very close to the port) compared
to that of the base operation. This can be translated into significant reduction in the traffic and
congestion around the port and therefore, a reduction in noise and emissions.

**Simulation Scenario 2:** In this simulation scenario, we investigate the sensitivity of the reuse cost
to changes in the average inner-city speeds, i.e., \( \bar{v} \) in (19). We consider case study 1-C discussed in
Section 4.2. The scenario not only replicates the current worst-case scenario in the LA/LB termi-
nals, but it also provides a good approximation of the average empty container movement sce-
nario predicted for 2010.

We vary the average inner-city speed from 5 to 50 miles/h in steps of 5 miles/h. For each speed,
the simulation program was tested 10 times on 10 sets of data, which were initially generated ran-
domly. For the purpose of cost comparison, the same generated sets of data were used for all sim-
ulation trials. For each data set, we distribute the supply and demand of empties among
consignees and shippers using the same technique discussed in Simulation Scenario 1. Moreover,
we assume that the design parameter \( z \) is 1 and the length of the time horizon is 8 h, which consists
of 8 one-hour time periods. Table 2 shows the average cost for each inner-city speed based on the
results of the 10 trials.

<table>
<thead>
<tr>
<th>Case study</th>
<th>No. of time periods</th>
<th>No. of empties at consignees</th>
<th>No. of empties at shippers</th>
<th>Base operation</th>
<th>Reuse operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cost</td>
<td>Total no. of empty trips</td>
</tr>
<tr>
<td>1-A</td>
<td>8</td>
<td>28</td>
<td>14</td>
<td>694</td>
<td>42</td>
</tr>
<tr>
<td>1-B</td>
<td>8</td>
<td>219</td>
<td>107</td>
<td>5483</td>
<td>326</td>
</tr>
<tr>
<td>1-C</td>
<td>8</td>
<td>547</td>
<td>267</td>
<td>13,832</td>
<td>814</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>985</td>
<td>534</td>
<td>25,568</td>
<td>1519</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>2188</td>
<td>908</td>
<td>52,857</td>
<td>3096</td>
</tr>
</tbody>
</table>
Table 2 demonstrates that as the speed increases, the reuse cost decreases. This indicates that, as the average inner-city speed increases, there is a higher probability of street-turn empty reuse, which results in a decrease in the number of trips to the ports and depots and hence a reduction in the reuse cost.

**Simulation Scenario 3:** In this simulation scenario, we investigate the sensitivity of the reuse cost to changes in the time horizon. We still consider the case study 1-C and distribute the supply and demand of empties among consignees and shippers using the same technique discussed in Simulation Scenario 1.

We assume that the design parameter $a$ is 1 and that the length of each time period is 1 h. We vary the length of the planning horizon $T$ to determine the sensitivity of the reuse cost to the variation of time periods. Similarly, the simulation program is tested 10 times, and the results in Table 3 show the average of the results of the 10 trials.

Table 3 indicates that as the number of time periods increase, the reuse cost drops. At the same time, the number of street-turn empty reuse increase. This reduces the total number of empty trips as well as the number of truck trips to the port and depots. These benefits, however, are gained at the price of dramatically increasing the size of the bipartite transportation network discussed in Section 3.2 as indicated by Column 9 in Table 3. As a consequence of increasing the number of nodes and arcs in these networks, the CPU-time to find the optimum reuse solution increases sharply. Table 3 also demonstrates that the pruning condition in (12) was effective in reducing the number of arcs of the networks.

**Simulation Scenario 4:** The design parameter $a$ in (18) plays a key role in determining the cost of empty reuse. As discussed in Section 2, empty container reuse consists of two parts: street-turn, and depot-direct. Selecting a relatively low value for $a$ emphasizes the street-turn container movement. Note that the supplies available at early periods stay at consignees for the best match throughout the time horizon. On the other hand, selecting a relatively large value for $a$ forces the empties to be moved as soon as they appear. This shifts the empty reuse towards the depot-direct methodology. Note, in this paper we assumed that the port and depots are processing the empties at all periods of time.

<table>
<thead>
<tr>
<th>Average speed (miles/h)</th>
<th>No. of time periods</th>
<th>Base operation</th>
<th>Reuse operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cost</td>
<td>Total no. of empty trips</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>25</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>30</td>
<td>8</td>
<td>13,790</td>
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<tr>
<td>35</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
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<tr>
<td>40</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>45</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
<tr>
<td>50</td>
<td>8</td>
<td>13,790</td>
<td>814</td>
</tr>
</tbody>
</table>
In this simulation scenario, we investigate the sensitivity of the cost of empty reuse to changes in the design parameter \( a \). We again consider the case study 1-C and distribute the supply and demand of empties among consignees and shippers using the same technique discussed in Simulation Scenario 1. The time horizon is assumed to be 8 h which consists of 8 time periods—1 h long each. We vary the value of \( a \) from 0.01 to 100. The simulation program is tested 10 times, and the results are averaged and presented in Table 4.

As seen in Table 4, as the value of parameter \( a \) increases the cost of reuse operations as well as the total number of trips to the port and depots increases sharply. This result verifies our intuition that relatively large value of \( a \) forces empties to be moved according to the depot-direct methodology.

### 5. Summary and conclusions

In this paper, empty container movements in the Los Angeles and Long Beach port area are studied. In particular, we considered the operational issues that appear in dynamic empty container reuse. We modeled the dynamic empty container reuse analytically, and developed an optimization technique to minimize the number and the cost of truck trips. Based on current and
projected data for the next 20 years, we developed several realistic case studies in the Los Angeles and Long Beach port area. Experimental results show that the empty container reuse reduces costs and congestion significantly.

Empty container reuse consists of two methodologies: street-turn and depot-direct. We showed that with a careful selection of the reuse cost function, weights can be adjusted to put more emphasis on either the street-turn or depot-direct. Basically, when time is critical, empty reuse is shifted towards depot-direct, since the waiting time is minimal in this methodology. On the other hand, when the traveling cost and traffic congestion are the important factors, street-turn methodology provides the best match between supply and demand of empties.

Considering the large number of empty containers in the LA/LB port area, empty container reuse would have an enormous impact on the local economy. As a consequence of reducing the number of truck trips to and from the container terminals, empty container reuse will have significant environmental effects. It will reduce the traffic and congestion around the ports, which in turn reduce noise and emissions. It will save time, energy and cost for both truckers and port operators.

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