

**Empty Container Management for Container-on-Barge (COB) Transportation:  
Planning Horizon Effects on Empty Container Management  
in a Multi-Modal Transportation Network**

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**Abstract**

We present a computational analysis of the planning horizon effects on empty container management for multimodal transportation networks. A distinctive aspect of our analysis is that we consider three different modes explicitly, namely truck, rail and river barge. The barge mode makes the network structure and underlying operational problem interesting, since it is the slowest and cheapest of the three modes. To analyze how the planning horizon affects the empty container flows in such a multimodal network, we develop an integer programming model. We discuss the sensitivities of initial inventory at each container pool, number of container pools in the system, and transport mode usage to the length of planning horizon. We conduct controlled experiments using the actual Mississippi River basin network. Our results show that the application of long planning horizon (used on a rolling basis) can give a better empty container distribution for the earlier periods. The longer horizon allows better management of container outsourcing and also encourages use of cheaper but slower transportation modes, such as barge. However, the advantages of using a rolling horizon might be small for a system that has a sufficient number of container pools since such a system has small end-of-horizon effects. We finally discuss related issues that one needs to consider when determining the length of planning horizon.

**Keywords:** Transportation, Logistics, Integer Programming,

## 1. Introduction and Background

This paper addresses the planning horizon problem related to the tactical management of empty containers for intermodal container-on-barge transportation networks. A key advantage of containerization is that it will enable fuller use of existing river resources and reduce traffic pressure on highways and railroads. Figure 1 shows a potential network based in the Mississippi River basin. In order for such a network to become a reality, the problems of empty container management must be solved.



Fig. 1. Mississippi River Network

The availability of barge transport adds interesting possibilities for addressing the well-known empty container management problem. Within barge capacity limits, empty containers

can be "piggy-backed" onto existing barge tows of loaded containers at very low cost. Thus, the cost of moving empty containers can be negligible in a network with barge links. The chief trade-off is the relatively slow speed of barge transport. The slow speed necessitates careful consideration of the planning horizon length.

While there is a much literature about planning horizon effects in production planning and control, comparatively little has been written on this subject in relation to empty container management. The following summarizes recent relevant papers.

Florez (1986) presents a profit optimization model for the problem of empty container repositioning and leasing for ocean-going ships. The author discusses the sensitivity of the model to the length of planning horizon, and finds that the solution of the case study is not affected much by the changes in the length of planning horizon. The author also notes that the conclusion cannot be generalized to other cases because the determination of an adequate planning horizon basically depends on the concentration of activities in the network under consideration.

Dejax, et al. (1992) present a general framework for a combined container routing – vehicle itinerary building model. They suggest that the planning horizon should be long enough to include the next set of arrivals and departures, and to allow the consistent, and system wide building of vehicle itineraries. On the other hand, labor contracts, safety regulations, and other practical considerations limit the actual length of vehicle itineraries and thus of the planning horizon. The authors give an example of an appropriate length limitation and discretization, i.e., 7 to 10 days long with 1 or 0.5 day periods, without any experimental results.

Crainic, et al. (1993) propose models for empty container allocation and distribution between a land transportation system and international maritime shipping network. The authors state that, to get valid solutions, the length of planning horizon and the end-of-horizon conditions

should be determined carefully. In real-life application of the models, it is suggested to limit the length of planning horizon to between 10 and 20 periods since the number of decision variables in any period will be fairly large. The information available on the future supply and demand of empty containers should also be considered when selecting the proper length of the planning horizon. For specifying the end-of-horizon conditions, they suggest forcing reasonable values for the empty container stocks in each depot at the end of planning horizon or including a salvage value term in the holding cost functions for the last period to account for containers at each depot. Furthermore, they advise to exclude the demands in split delivery windows (i.e., delivery windows that fall partly within the planning horizon and partly outside of it) and to slightly adjust the lower bounds of the empty container stocks at the depots from which these demands should be satisfied later on. The authors do not present any experimental results.

Cheung and Chen (1998) compare a two-stage stochastic model with a two-stage deterministic model for the dynamic empty container allocation problem. The authors perform some experiments with rolling horizons and conclude that a longer planning horizon is not necessarily better than a shorter one. When the planning horizon is lengthened, solutions in some of the test cases improve; however, solutions in other test cases worsen. The authors do not discuss the factors (difference in the number of ports, the number of voyages, the transportation times between ports, etc.) that might explain the observations.

In the general transportation area, Holmberg, et al. (1998) evaluate the impacts of planning horizon length on a model for empty freight car distribution at Swedish State Railways. The authors propose a multicommodity network flow model with integer requirements. The model aims to minimize total cost, consisting of transportation cost and shortage cost, while satisfying customer demands. In the experiments, a rolling horizon is used to simulate empty

freight car distribution for 10 consecutive days. The results show that the outcome of the proposed model depends on the length of the planning horizon. The authors suggest that the planning period should be longer than the longest transportation time in the system in order to achieve a low car shortage level.

The length of planning horizon, especially when used in a rolling horizon environment, is an important issue not only for transportation operations, but also in production planning. For instance, significant literature on production planning discusses the impact of planning horizon on the lot-sizing decisions and selection of the lot-sizing methods. Bregman (1991) evaluates the performance of seven ordering procedures when the planning horizons are of a shorter, more realistic duration. The author demonstrates that the length of planning horizon can significantly affect the choice among alternative discount ordering procedures.

De Matta and Guignard (1995) study lot-sizing and changeover decisions in production schedules that are used on a rolling horizon basis. The authors examine the effects of the length of planning horizon, the starting inventory, and the demand fluctuation on the schedules. The experimental results show that the changeover cost decreases while the holding cost increases when the planning horizon is extended. The authors also show that beyond a certain length of planning horizon, the savings in the annual production cost is minimal; at that point it no longer pays to obtain additional information about the future demand.

Russell and Urban (1993) investigate the effects of forecast length and accuracy in extending the planning period beyond the frozen horizon of rolling production schedules. They compare the performances of the Wagner-Whitin algorithm and the Silver-Meal heuristic for different length and accuracy of horizon extensions. The experimental results show that horizon

extension is worthwhile for relatively large forecast errors and that Wagner-Whitin improves in more cases than previously thought.

Section 2 presents a model for managing empty containers in a single commodity (single container type), multimodal transportation network over a given planning horizon. Section 3 explains the computational setup and the factors considered in the experiments. Section 4 discusses the experimental results. Section 5 presents summary conclusions and potential future research.

## **2. Empty Container Management Model**

### **2.1. Problem Statement and Assumptions**

Efficient management of empty containers is an important part of a successful implementation of containerized shipping. Typically, logistics managers want to minimize costs related to empty containers since their main concern is the transportation of loaded containers. Ideally, logisticians would prefer to ignore empty containers completely, but this is not possible since real-world container networks usually require empties to account for imbalances in loaded flows.

The goal of the math model is to minimize the total cost of managing empty containers while satisfying customer demand for timely availability of empty containers. The basic structure of the model is adapted from the deterministic single commodity model described by Crainic, et al. (1993). Crainic's model is modified to include multiple modes, storage capacity, and transportation mode capacity. The new model, however, does not include delivery windows. Containers are assumed to be delivered to the customer site in the time period in which they are needed. Crainic, et al. (1989) select the transportation mode prior solving their static, multimode

and multicommodity model. Since they assume linear cost and unlimited capacity for each transportation link, the mode or combination of modes can be selected based on the lowest unit transportation cost. The same technique cannot be applied to the model in this research since the least expensive mode (barge) is capacitated.

In this research, leased containers (short-term or long-term) are modeled in the same way as company-owned containers. No cost is incurred on a leased container until it actually enters the transportation network. The model does not consider returning leased containers to the lessor. It is assumed that a lease term does not expire in the planning horizon. This is the case if the lease term is much longer than the planning horizon, which is usually less than a month. This assumption should not cause a significant effect on the optimum solution value because the savings on storage cost when containers are returned to the lessor are relatively small compared to other cost components in the network. We also make the following assumptions, all of which are standard in majority of models in the literature:

1. The number of loaded containers that arrive at a location in a certain time period is known (i.e., the number of empty containers available is known).
2. The number of loaded containers that depart from a location in a certain time period is known (i.e., the number of empty containers required is known).
3. As soon as a shipment arrives at a customer site, the commodity is unloaded immediately, and the empty container becomes available.
4. To simplify the modeling, empty containers are not allowed to be stored at the supply customer sites. After unloading the commodity, containers are hauled away immediately to demand customers and/or container pools. To represent the situation where a supply customer wants to keep the empty containers for later use, a dummy container pool can

be located adjacent to that supply customer site. A dummy container pool has zero transportation cost, zero transit time (from its associated supply customer site), a certain amount of holding cost, and a maximum number of containers that can be stored.

5. Empty containers will not be shipped early to demand customers to meet the demand of future periods. Demand customers will not store extra empty containers for later time periods.
6. Only one type of container is used, i.e., this is a single commodity model.
7. No backorders are allowed.
8. The number of empty containers left from the previous planning horizon at a container pool is known. The stock is considered as the initial inventory of the container pool at the beginning of the current planning horizon. The initial inventory may include both company-owned and leased containers.
9. Containers can be rented, purchased, or borrowed at any container pool in any time period.
10. Three types of transportation modes are considered: truck, rail, and barge.
11. Transportation mode can be changed only at a container pool location.
12. All transit times are independent of their starting and arriving periods. In reality, the transit times could be dependent on the periods because of the water level (for barge) and traffic (for truck) at a certain period or season.
13. All costs are independent of time periods. This assumption can be relaxed if necessary without sacrificing from model simplicity and computational burden.
14. Storage capacity of container pools is independent of time periods. This assumption can also be adjusted if necessary.

15. Containers are ready to be used, and no repairs or discards of containers occur.

## 2.2. Mathematical Model

We model the empty container management problem as an integer program, using the notation in the appendix. The decision variables in the model denote the empty container flows between the nodes of the underlying space-time network. There are four main types of decision variables that define where the flows originate and how the empty containers are used.

(1) Vector  $u$  denotes flows that originate from a supply customer.  $u_{sim}^t$  denotes the number of empty containers to be moved from supply customer  $s$  to demand customer  $i$  for arrival in period  $t$  via transportation mode  $m$ . Similarly,  $u_{sjm}^t$  denotes the flow from  $s$  to container pool  $j$ .

(2) Vector  $v$  denotes the flows that originate from a container pool.  $v_{jim}^t$  denotes the number of empty containers to be moved from container pool  $j$  to demand customer  $i$  for arrival in period  $t$  via transportation mode  $m$ . Similarly,  $v_{jkm}^t$  denotes the flow from  $j$  to container pool  $k$  where  $k \neq j$ .

(3)  $v_{jj}^t$  denotes the number of empty containers available at container pool  $j$  at the end of period  $t$ .

(4)  $w_j^t$  denotes the number of empty containers to be brought in from outside the system (leased, borrowed, or newly purchased) to container pool  $j$  for arrival in period  $t$ .

The remainder of this section introduces the model and details the objective function and constraints

$$\begin{aligned} \text{Minimize } & \sum_t \left[ \sum_s \sum_i \sum_m C_{sim} u_{sim}^t + \sum_s \sum_j \sum_m C_{sjm} u_{sjm}^t \right] + \\ & \sum_t \left[ \sum_j \sum_i \sum_m C_{jim} v_{jim}^t + \sum_j \sum_k \sum_m C_{jkm} v_{jkm}^t \right] + \sum_t \sum_j H_j v_{jj}^t + \sum_t \sum_j R_j w_j^t \end{aligned} \quad (1)$$

**Subject to**

$$\sum_m \sum_{s \in S_{im}^t} u_{sim}^t + \sum_m \sum_{j \in J_{im}^t} v_{jim}^t = X_i^t \quad \forall i, t \quad (2)$$

$$\sum_m \sum_{i \in I_{sm}^t} u_{sim}^{t+\tau_{sim}} + \sum_m \sum_{j \in J_{sm}^t} u_{sjm}^{t+\tau_{sjm}} = Y_s^t \quad \forall s, t \quad (3)$$

$$v_{jj}^t = v_{jj}^{t-1} + \left( \sum_m \sum_{s \in S_{jm}^t} u_{sjm}^t + \sum_m \sum_{k \in \bar{K}_{jm}^t, \neq j} v_{kjm}^t \right) + w_j^t - \left( \sum_m \sum_{i \in I_{jm}^t} v_{jim}^{t+\tau_{jim}} + \sum_m \sum_{k \in K_{jm}^t, \neq j} v_{jkm}^{t+\tau_{jkm}} \right) \quad \forall j, t \quad (4)$$

$$v_{jj}^t \leq SL_j \quad \forall j, t \quad (5)$$

$$\sum_i \sum_{s \in S_{i3}^t} u_{si3}^t + \sum_j \sum_{s \in S_{j3}^t} u_{sj3}^t + \sum_i \sum_{j \in J_{i3}^t} v_{ji3}^t + \sum_j \sum_{k \in \bar{K}_{j3}^t, \neq j} v_{kj3}^t \leq BL^t \quad \forall t \quad (6)$$

$$u_{sim}^t, u_{sjm}^t, v_{jim}^t, v_{jkm}^t, v_{jj}^t, w_j^t \geq 0, \text{ integer} \quad (7)$$

The objective of the model is to minimize the total cost of empty container management over a given planning horizon. The total cost (1) includes cost of moving empty containers between locations, cost of holding empty containers at container pools, and cost of bringing in containers from outside the system (leasing, buying, or borrowing containers). At container pools, holding cost is incurred only on non-moving empty containers that remain at the end of a period. To prevent containers from being moved just to avoid staying at the container pool over the period and being charged a holding cost, the model could be modified to add holding cost to the moving cost for the moving containers.

Constraint set (2) states that all demands must be met by empty containers from supply customers and/or container pools. Container pools have the option of getting more containers by leasing, buying, or borrowing from sources outside the system.

Constraint set (3) indicates that all containers must be moved from supply customer sites to demand customers and/or container pools.

Constraint set (4) shows the stock of empty containers available at container pools at the end of each period. The empty container stock at a container pool is derived from the previous period stock (or initial inventory for the first period) plus inflow of containers from supply customers and other container pools plus the number of containers that are brought in from outside the system minus outflow of containers to demand customers and other container pools.

Constraint set (5) ensures that the stock of empty containers at a container pool at the end of a period cannot exceed the storage limit of the container pool. The storage capacity of a container pool is often large, however.

Constraint set (6) states that the total number of empty containers transported by barge during a time period may not exceed a limit set by the barge company. Since a barge is best utilized when carrying loaded containers, it is more profitable to carry as many loaded containers as possible. If there are free spaces on the barge, they may be used for moving empty containers at very low marginal cost. Since loaded flows are assumed known, the barge limit for carrying empty containers can easily be determined by taking the difference between the barge capacity and the number of loaded containers to be transported for that time period. The capacity for taking empty container may be different for each period depending on the loaded flow for that period.

Constraint set (7) indicates that all decision variables can only take nonnegative integer values. This ensures that fractional containers will not be considered in the optimum solution.

### **3. Experimental Factors**

This section details a case based on potential container-on-barge activities in the Mississippi River basin. The number and locations of customers are as shown in Figure 1. The experiments consider a number of factors. The first factor is the number and the locations of the container pools. We consider three “levels” of this factor: 3, 5, and 7 container pools. Table 1 lists the customer locations and these container pools that are used in the experiments. The twelve customer locations are port cities that are located in the Mississippi River basin. Note that the container pools are located adjacent to the corresponding customer locations. These pool locations are chosen because of their seemingly strategic locations on the network and their overall traffic as customer locations. One can use another optimization model (e.g., a location-allocation model) to locate the pools on the network. This is a subject for future research.

The distances between locations via each transportation mode, and average speed and costs for each transportation mode are obtained from Trusty and Malstrom (1998) (see Table 2). Future data sets should probably consider the asymmetry in the transportation times for the barge modes due to speed difference depending on which direction the move occurs (upriver versus downriver).

Table 1

## Customer Locations and Container Pools for the Experiments

Customer Location	Number of Container Pools		
	3	5	7
St. Paul (STP)	-	-	-
Omaha (OMH)	-	-	-
Chicago (CHG)	-	-	CHG_P
Pittsburgh (PTB)	-	-	-
Cincinnati (CIN)	-	CIN_P	CIN_P
St. Louis (STL)	STL_P	STL_P	STL_P
Memphis (MEM)	MEM_P	MEM_P	MEM_P
Little Rock (LR)	-	LR_P	LR_P
Mobile (MBL)	-	-	-
New Orleans (NO)	NO_P	NO_P	NO_P
Houston (HTN)	-	-	HTN_P
Brownsville (BRW)	-	-	-

Table 2

## Average Speeds and Costs

Transportation Mode	Speed (Miles per hour)	Cost (\$ per mile)
Truck	42	0.90
Rail	37	0.351
Barge	6	0.1234

Additional factors include barge limit and initial empty container inventories at the pools. We consider three levels of the barge limit (BL): 5%, 10%, and 20% of total loaded containers per day. The initial inventory at each container pool is set to 0.5 (InvH), 1 (Inv1), or 2 (Inv2) times of average total daily empty flow (ATDEF). Along with these factors, we did preliminary experiments to see if the pool storage capacity, holding costs, and the outsourcing cost affect the planning horizon's impact on the solutions. Seeing that they were not significant, we set each pool's storage capacity to 5 times the average total daily empty flow. We keep holding cost

constant at \$5 per container per day, and outsourcing cost at \$1,000 per container per planning horizon.

Our main factor of interest is the planning horizon. Due to observations we have from the literature review, we investigate two levels of the planning horizon: 15 days and 30 days. Our main expectation is that the longer planning horizon should lead to higher utilization of slower modes of transportation.

The net supply/demand of empty containers at each customer location can be easily derived from the loaded container flows. To have a relatively unbalanced network that would necessitate empty container management, we generated loaded flows in a controlled manner: 30% of the loaded container flow data are zero flows, and the remaining 70% are uniformly distributed between 20 and 80. Since most of the origin/destination pairs require long transit time via barge, an extra 30 days of departure data are added before day one of the assumed planning horizon. This denotes loaded container transactions that occur prior to the beginning of the planning horizon but that may arrive some time during the planning horizon.

At the beginning and end of the planning horizon, however, the net values for some of the customer locations may need to be modified in order to have a feasible solution. The constraints of the mathematical model require that all demands be met and that all empty containers be moved from supply customer sites. At the very beginning or end of the time horizon, there may be some customer locations that are “unreachable”. For example, suppose there is a customer location that does not have a container pool at its location, and it cannot be reached from any other customer location or a container pool within a day. On day one of the planning horizon, if the location has a demand of empty containers, the demand cannot be satisfied from any available sources, and thus the model is infeasible. On the other hand, if the location has a supply

of empty containers on the last day of the planning horizon, the containers cannot be moved to other locations within a day, and thus a feasible solution cannot be found. Although there might be other strategies to handle the infeasibilities (such as adding a dummy supply node, etc.), we chose to change net value for the “unreachable” location to zero, i.e., the location will not request or provide empty containers. Fortunately, only a very small portion of the data required adjustment. For example, in the experiments, 10 out of 180 net demand data (for the 15-day planning horizon model) and 13 out of 360 net data (for the 30-day planning horizon model) are changed to zeros. Hence, we do not expect this modification of the data would cause a significant effect on the optimum solution value or the model’s behavior.

#### **4. Experimental Results**

We used the AMPL modeling language (Fourer, et al., 1993) and the CPLEX solver to solve the problem instances associated with each combination of factors.

To evaluate the sensitivity of the model to the length of planning horizon, we compare a 15 day horizon to a 30 day horizon. The net demand/supply data for the first 15 days of the 30-day model are the same as those in the 15-day model, while the remaining data are generated as discussed in Section 3. Although the numbers of variables and constraints for the 30-day planning horizon model (e.g., 30,549 variables and 587 constraints) are almost double of those for the 15-day planning horizon model, each problem is solved within six seconds on a 600 MHz Pentium III computer.

Comparing the results of the first 15 days of the 30-day model indicates that the length of planning horizon has an effect on the empty container allocation planning for the first 15 days.

For the 3-container pool cases, Figures 1 to 4 show the comparison of total cost and its cost elements between (1) the 15-day model and (2) the first 15 days of the 30-day model. (A barge limit of 5% is used in the following discussion.)

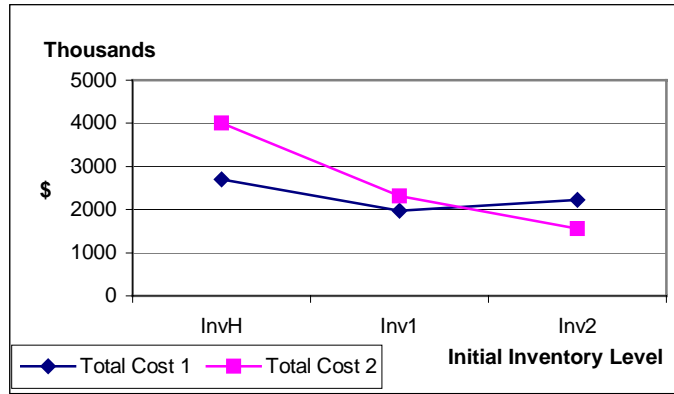


Fig. 2. Total cost comparison – 3 container pools

Figure 2 shows the total cost of the first 15 days of the 30-day model (Total Cost 2) is higher than that of the 15-day model (Total Cost 1) except when Inv2 is used. The higher total cost (Total Cost 2) is solely caused by high outsourcing cost (Out Cost 2, Figure 3).

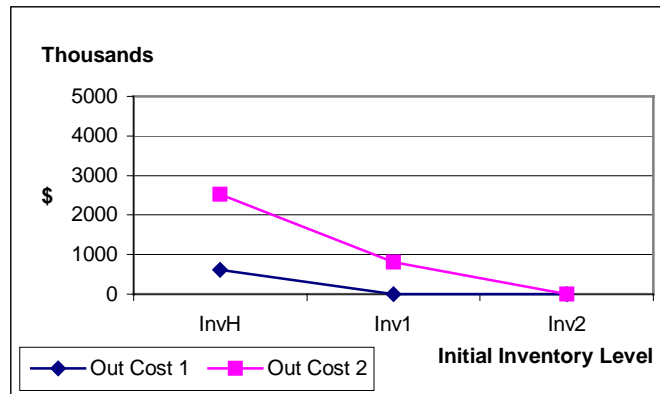


Fig. 3. Outsourcing cost comparison – 3 container pools

The solution of the 30-day model shows that most of the outsourced containers are obtained during the first 15 days. These empty containers are brought in not only to satisfy the demands in the first 15 days, but also to meet the demands in the second 15 days. Since

outsourcing cost is incurred only once for each empty container brought into the system, an outsourced container can be used to meet a demand at an early period and then be kept in the system for future use until the lease term expires. Another reason for bringing in outsourced containers early is that the outsourced containers can then be moved via a cheaper, slower mode (barge) to meet the demands in the later periods. When barge limit increases, the model brings in all outsourced containers that are needed for the entire 30-day planning horizon during the first 15 days. Bringing in containers during the earlier periods to utilize the barge mode can reduce the total cost for the second 15 days in the 30-day model.

The length of planning horizon affects the travel mode usage in the first 15 days. Table 3 shows an example of travel mode usage in the first 15 days for the test case with 3 container pools, barge limit 5%, and low initial inventory level.

Table 3.

Travel Mode Usage Comparison – 3 Container Pools

BL 5%, InvH	Truck Usage (%)	Rail Usage (%)	Barge Usage (%)
15-day model	5.950	74.794	19.256
1st 15 days of 30-day model	0.027	68.643	31.330

The truck usage is very low during the first 15 days of the 30-model. One of the reasons is that, for the 30-day model, empty containers (which are not needed for meeting the demands) from a supply customer location can be transported via a slower travel mode (barge) and reach a container pool after day 15. For the 15-day model, a faster travel mode (truck) has to be used in order to reach the container pool within 15 days. Since the truck usage is lower and the barge usage is higher for the first 15 days of the 30-day model than for the 15-day model, the total

moving cost of the first 15 days of the 30-day model (Moving Cost 2) is lower than that of the 15-day model (Moving Cost 1) (see Figure 4).

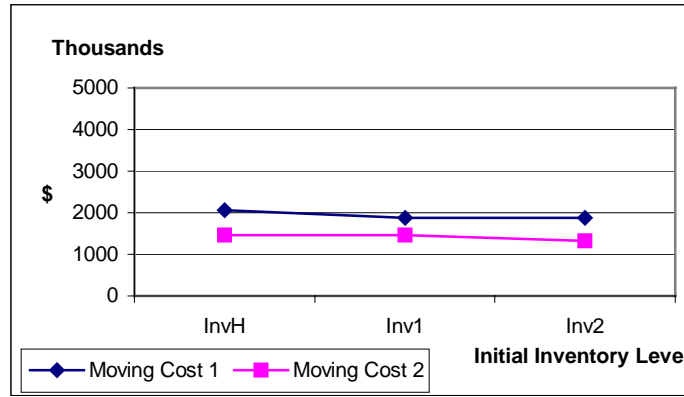


Fig. 4. Moving cost comparison – 3 container pools

In addition to changes in travel mode usage, the lower moving cost (Moving Cost 2) is also caused by the initial inventory. The number of empty containers at an initial inventory level in the 30-day model is slightly higher than that in the 15-day model because the 30-day model has a higher average total daily empty flow (ATDEF), which is included in the calculation of initial inventory. Table 4 shows the initial inventory of each model.

Table 4

*Initial Inventory of 15-day and 30-day Models*

	ATDEF	InvH	Inv1	Inv2
15-day model	1127.2	563	1127	2254
30-day model	1188.8	594	1188	2377

With a higher initial inventory at the container pools, the demands may be satisfied from a nearer container pool in the 30-day case, thus resulting in lower total moving cost.

Figure 5 shows that the holding cost for the first 15 days of the 30-day model (Holding Cost 2) is lower than that of the 15-day model (Holding Cost 1). Fewer containers are stored at a container pool during the first 15 days because the available empty containers are distributed to

other container pools or customer locations to meet the demands in the second 15 days of the 30-day model.

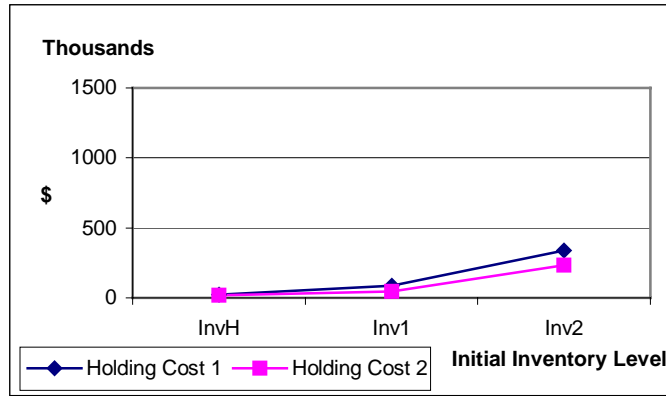


Fig. 5. Holding cost comparison – 3 container pools

Figure 6 shows cost comparisons for the 5-container pool cases. During the first 15 days of the 30-day model, the number of outsourced containers becomes zero at Inv1, which is a lower inventory level than that in the 3-container pool cases (Inv2). Therefore, a lower total cost for the first 15 days can be seen at a lower initial inventory level (Figure 6) compared to the 3-container pool case (Figure 2).

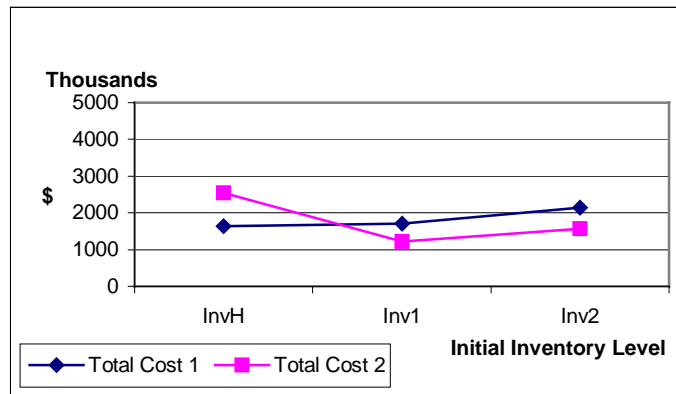


Fig. 6. Total cost comparison – 5 container pools

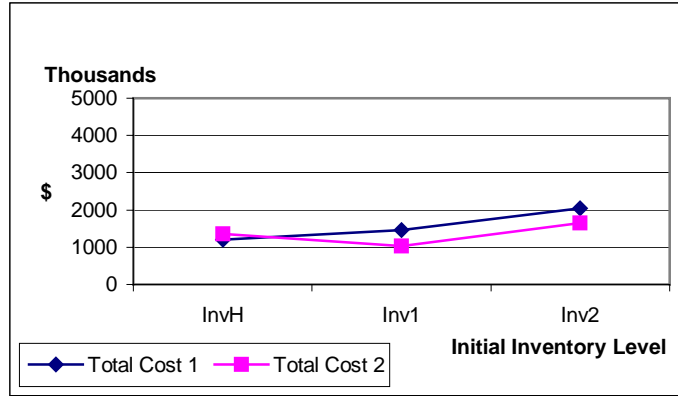


Fig. 7. Total cost comparison – 7 container pools

Figure 7 shows that, for the 7-container pool cases, the difference in total cost between the first 15 days of the 30-day model (Total Cost 2) and the 15-day model (Total Cost 1) is not as large as that in the 5-container pool cases (Figure 5). Since a 12-customer location system with 7 container pools gives a shorter travel distance between locations, the end-of-horizon effect is not as significant as in the 3- or 5-container pool cases. In the 7-container pool cases, empty containers from a supply customer location are able to reach a container pool before the end of 15-day planning horizon even by the slower travel modes (rail and barge). Thus, an extension in the planning horizon does not have much effect on the travel mode usage for the first 15 days (compare Table 5 to Table 3).

Table 5.

Travel Mode Usage Comparison – 7 Container Pools

SL 5%, InvH	Truck Usage (%)	Rail Usage (%)	Barge Usage (%)
15-day model	0.000	59.592	40.408
1st 15 days of 30-day model	0.018	52.881	47.101

Due to the small changes in travel mode usage when the planning horizon is extended to 30 days, the savings in moving cost (and thus total cost) for the first 15 days in the 7-container pool cases are not as large as in the 5-container pool cases.

Although the solution of the first 15 days changes when the length of planning horizon changes, the 30-day planning horizon seems to give a better plan for the first 15 days. This can be seen from the fact that, for the first 15 days, the total moving cost and holding cost are lower than in the 15-day model. For cases with the absence of outsourced containers in the system, the total cost for the first 15 days of the 30-day model will likely be lower than that of the 15-day model. For the cases considered, since the supply and demand data are deterministic, a rolling horizon of 30 days can be used, in which the model is solved for the 30-day planning horizon but only the solution for the first 15 days is implemented. The model can then be re-solved with the third 15-day data to obtain the solution for the second 15 days, and so on. For systems with sufficient number of container pools, however, the advantages of using a rolling horizon might be small since such systems have small end-of-horizon effects.

## **5. Conclusions and Future Research**

This paper discusses the planning horizon effects on empty container management for multimodal transportation networks. Although the appropriate length of planning horizon depends on the network under consideration, a longer planning horizon (used on a rolling basis) can give better empty container distribution plans for the earlier periods. The longer horizon allows better management of container outsourcing and encourages use of slower cheaper transportation modes. However, the advantages of using a rolling horizon might be small for a

system that has a sufficient number of container pools since such a system has small end-of-horizon effects.

When the information for future periods is not available, a shorter planning horizon is preferred. If the information for the future periods is known but only imperfectly, a rolling horizon can be used, where only the solution for the earlier periods are implemented. The problem should be re-solved when more accurate information is obtained for the later periods.

For a network with a barge transportation mode, the planning horizon should be long enough for the model to have a chance to consider using the slower cheaper barge mode. One rule of thumb is to consider use the most frequently used barge transit time to help determine the planning horizon. In the test cases, there are two barge transit times that are equally used most frequently: 12 and 19 days. So, the lengths of planning horizon considered (15 days and 30 days) are most likely appropriate for the test cases.

The impact of choosing a planning horizon that is too short depends on three conditions.

*1. Concentration of the activities in the network:*

If the periods immediately following the short planning horizon are very active (i.e., customers have high supplies and demands), a longer planning horizon might give a better solution. Extending the planning horizon might enable the model to utilize slower, cheaper transportation modes.

*2. Transit time of the container movements:* A system that has long transit times may need a longer planning horizon to allow that model to select slow, cheap modes that work well in the real-world's infinite horizon.

*3. End-of-horizon effects:* A small end-of-horizon effect may reduce the significance of lengthening the planning horizon. The test cases indicate that the end-of-horizon effect is smaller

when the average travel distance in the system is short or the initial inventory at each container pool is high.

There are several possibilities for future research. One can integrate the loaded and empty container flow decisions in a single model. Since the location and number of container pools has significant impact on the solutions, it might be worthwhile to look at location-allocation models along with the planning horizon considerations. Another future research endeavor could be to consider uncertain nature of the demand and/or supply in the container management problem.

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## Appendix: Notation

This appendix describes the sets and parameters of the model. The decision variables are described in the main text. All of the notation described here is based on Crainic, *et al.* (1993).

### Sets and Indices

I - Demand customers, indexed by  $i = 1, 2, \dots, I$

J, K - Container pools, indexed by  $j = 1, 2, \dots, J$ ,  $k = 1, 2, \dots, J$

S - Supply customers, indexed by  $s = 1, 2, \dots, S$

T - Length of planning horizon, indexed by  $t = 1, 2, \dots, T$

M - Transportation modes, indexed by  $m = 1, 2, 3$  (Truck, Rail, Barge)

### Subsets

These subsets ensure that no empty containers are shipped before the first time period or after the last time period in the planning horizon. The length of the planning horizon and the transit time between two locations ( $\tau$ ) determine these subsets.

$I_{sm}^t$  - The set of all demand customers  $i$  which may be satisfied from supply customers by a movement of empty containers, via transportation mode  $m$ , that starts in period  $t$  and arrives in period  $t + \tau_{sim}$ . Similarly  $I_{jm}^t$  denotes demand customers that can be satisfied from container pool  $j$  with transit time  $\tau_{jim}$ .

$J_{sm}^t$  - The set of all container pools  $j$  which may be satisfied from supply customer  $s$  by a movement of empty containers, via transportation mode  $m$ , that starts in period  $t$  and arrives in period  $t + \tau_{sjm}$ . Similarly,  $K_{jm}^t$  is the set of container pools that can be satisfied from container pool  $j$  with transportation time  $\tau_{jkm}$ .

$S_{im}^t$  - The set of all supply customers  $s$  from which demand customer  $i$  may receive empty containers (this as an “inverse” set of  $I_{sm}^t$ ). The movement of empty containers, via transportation mode  $m$ , arrives in period  $t$  and starts in period  $t - \tau_{sim}$ . Similarly  $J_{im}^t$  is the set of container pools that can satisfy customer  $I$  using transit time  $\tau_{jim}$ .

$S_{jm}^t$  - The set of all supply customers  $s$  from which container pool  $j$  may receive empty containers. The movement of empty containers, via transportation mode  $m$ , arrives in period  $t$  and starts in period  $t - \tau_{sjm}$ . Also,  $\bar{K}_{jm}^t$  is the set of container pools that can send empty container to container pool  $j$  using the transit time  $\tau_{kjm}$ .

## Parameters

### 1. Known demands and supplies

$X_i^t$  - Demand at customer  $i$  in period  $t$ .

$Y_s^t$  - Supply at customer  $s$  in period  $t$ .

### 2. Initial inventory

$v_{jj}^0$  - Initial inventory at container pool  $j$  at the beginning of planning horizon.

### 3. Costs

$C_{sim}$  - Cost (dollars per container) to move an empty container from supply customer  $s$  to demand customer  $i$  via transportation mode  $m$ . Similarly costs are  $C_{sjm}$  (cost of unit flow between supply customer  $s$  to container pool  $j$ ),  $C_{jim}$  (cost of unit flow between container pool  $j$  and demand customer  $i$ ), and  $C_{jkm}$  (cost of unit flow between container pools  $j$  and  $k$ ). The latter is zero for  $j = k$ .

$H_j$  - Holding cost (dollars per container per period) at container pool  $j$ .

- $R_j$  - Cost (dollars per container) of bringing in an empty container from outside the system (leasing, purchasing new container, or borrowing from partner companies) at container pool  $j$ .
4. Transit time,  $\tau_{\eta\mu m}$ , includes the loading time at origin and unloading time at destination, plus the travel time between the two points. The origin  $\eta$  and the destination  $\mu$  may represent supply customers, demand customers, or container pools. The transportation mode  $m$  is truck (1), rail (2), or barge (3). If there is no existing route between two locations, the transit cost is set to a large number that represents the cost of building the route, and the transit time is set to a reasonable number. This expensive transit cost will prevent the model from selecting the arc between those two locations as the optimum solution unless absolutely necessary.
5. Capacity
- $SL_j$  - Maximum number of empty containers that can be stored at container pool  $j$ .
- $BL^l$  - Maximum number of empty containers that can be moved by barge per period (barge limit)