A Continuous Approximation Approach for Seaport- Dry Port Network Design

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Abstract. Dry ports development can help the freight transportation industry to find more energy efficient traffic modes that reduce the carbon emission and relieve seaports from some congestions. This paper introduces a continuous approximation model to design a seaport- dry port network with carbon emission consideration. We investigate how firms/goverments determine the service areas of dry port and joint replenishment cycle time. A nonlinear optimization technique is used to solve the seaport- dry port network design problem. The numerical examples presented herein illustrate how the solution procedure works.

Keywords: *seaport; dry port; carbon emission; network design; continuous approximation approach*

1. INTRODUCTION

Container shipping was first introduced in the 1950s and since the late 1960s has become the most common method for transporting many industrial and consumer products by sea. With the port system development, this industry must face all issues: the growth of trade, environmental considerations and community restrictions as well as the evolution of freight transportation and logistics. The idea of dry port was first introduced in the 1980s. A firm/government want to open dry ports to relieve connected seaport's pressure of overcapacity of freight and space limitation, improve the inland-port access, help develop local region's trade economy, and reduce contaminated emissions and accidents from road transport and congestion. Dry ports are responsible for integration, transshipment, temporary storage, consolidation and distribution, customers' clearance, etc. Dry port has become more and more common in today business.

Earlier research by Slack (1990) and Slack (1999) on the interior centers demonstrate the value of their improvement for multimodal transport. He also showed the role of inland part in reducing the environment effects of multimodal transport. Later the concepts of dry ports were developed by many researches: Leveque and Roso (2002), Roso (2007), and Roso et al. (2009). As such, the location of dry ports have become an import issues of research. Yang (2005) applied the method of multi-criteria decision making to the problem of locating dry ports in the states of Texas, USA. Wang and Wei (2008) provided the Analytic Network Process method to evaluate the priorities on location selection of the dry port at Tianjin, China. Li et al. (2011) proposed Affinity Propagation (AP) Clustering method to solve the location planning of dry port. Li et al. (2013) continued his research to study on dry port location problem based on AHP.

In another way, there is few research which has considered analytical models for dry port location problems. Feng et al. (2013) constructed a location-allocation model for the regional seaport-dry port network optimization problem and developed a greedy algorithm to obtain its solution. Links connect the origins of freight to seaports, either directly or through dry-ports. Crainic et al. (2015) modeled a dry-port-based freight distribution planning. A mixed integer programming mathematical formulation was proposed to solve the consider problem.

In above research, dry ports are a multi-faceted problem, the issue covers many different stakeholders and public–private-partnership needs to be taken into account when considering potential dry ports. Furthermore, dry ports are recommended to reduce carbon emission in inland transportation. It is important to understand how carbon emission cost effect to the number of dry ports and joint replenishment cycle time in practice.

This paper introduces a continuous approximation (CA) model to design a seaport- dry port network with carbon emission consideration. Our goal in this study was to investigate how firms/goverment determine the service areas of dry port and joint replenishment cycle time.

2. PROBLEM DEFINITION

This study considers a seaport-dry port network design problem related to carbon emission, which involves a seaport, a few dry port, and multiple shippers (Figure 1). The firm/governments determine the number of dry ports and joint replenishment cycle time to minimize their total cost.

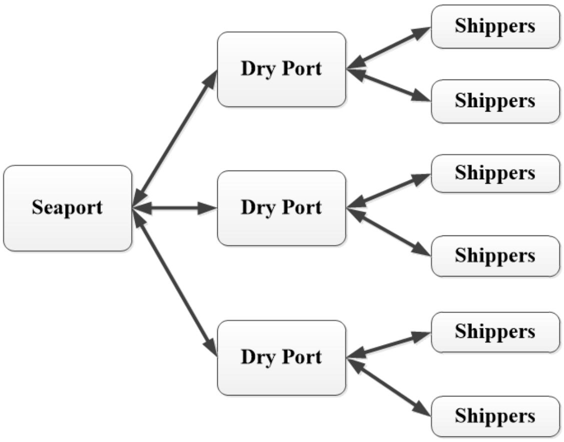

Figure 1. Container Flow

The grid cover-couple approach (Tsao et al., 2012) is used to divide the network area into cluster. The demand of shippers at each point $x \in R$ can be expressed as the shippers' density and demand rate, given as $\delta_i(x)\lambda_i(x), x \in R$. Let C_i be the sizes of area for cluster *i*, the shipper demand in the cluster *i* during the planning horizon ζ is $D_i = \zeta\delta_i\lambda_i C_i$. The number of dry ports that must operate in cluster *i* can be C_i / A_i, where A_i is the influence area of each dry port in cluster *i*.

3. MODELING

The quantity ordered during each replenishment cycle is $Q_i = T_i D_i = T_i \zeta \delta_i \lambda_i C_i$.

Cost components

Let F be the opening and operating cost for each dry port (per time), *the total facility cost*:

$$TF = \sum_{i=1}^{N} F \frac{C_i}{A_i}$$

The transportation cost from shippers to dry ports is obtained by multiplying transportation cost A^D, the average distance, $f_r\sqrt{A_i}$, and the retailer demand in cluster *i* as follows

$$\sum_{i=1}^{N}(A^D f_r \sqrt{A_i} D_i) = \sum_{i=1}^{N}(A^D f_r \sqrt{A_i} \zeta\lambda_i\delta_i C_i)$$

Let A^S be the variable cost per item for each inbound container from the dry port to the seaport. Then total transportation cost from dry port to seaport is given by

$$\sum_{i=1}^{N}(C_f + A^S Q_i)\frac{D_i}{Q_i}.$$

The total transportation cost at dry ports is

$$TT = \sum_{i=1}^{N}(A^D f_r \sqrt{A_i}\zeta\lambda_i\delta_i C_i) + \sum_{i=1}^{N}(C_f + A^S Q_i)\frac{\zeta\lambda_i\delta_i C_i}{Q_i}$$

There is no safety stock considered in our model. *The total inventory holding cost* is given by multiplying the number of dry ports, holding cost, *h* and the number of containers, as follows,

$$TH = \sum_{i=1}^{N}\frac{C_i}{A_i} h \frac{Q_i}{2}$$

Assume that the amount of carbon footprint from train is nearly to zero. In our study, we only consider the carbon footprints from warehousing at dry ports.

Let $g + g_0 Q_i$ be the amount of carbon emissions in holding Q_i containers, where *g* is the fixed carbon emissions, and g_0 is the variable emission factor in holding containers at dry port (Hua et al. 2011). The carbon footprints per unit time from warehousing is

$$g + g_0 \frac{Q_i}{2}.$$

Let C_{ce} be the carbon cost per tons per time, *the total carbon cost* at dry ports is

$$TT_{ce} = \sum_{i=1}^{N}\frac{C_i}{A_i} C_{ce}(g + g_0 \frac{Q_i}{2})$$

4. SOLUTION PROCEDURE

The model is as follows:

$$\text{Min} \quad TC(A_i, T_i)$$

where

$$TC = \sum_{i=1}^{N} F\frac{C_i}{A_i} + \sum_{i=1}^{N}(A^D f_r\sqrt{A_i}\zeta\lambda_i\delta_i C_i) + \sum_{i=1}^{N}(C_f + A^S Q_i)\frac{\zeta\lambda_i\delta_i C_i}{Q_i} + \sum_{i=1}^{N}\frac{C_i}{A_i}h\frac{Q_i}{2} + \sum_{i=1}^{N}\frac{C_i}{A_i}C_{ce}(g + g_0\frac{Q_i}{2}) \qquad (1)$$

The objective function in (1) minimizes the sum of facility cost *TF*, transportation cost *TT*, holding cost, *TH*, and carbon emission cost, TT_{ce}. There are two decision variables: the dry port influence area A_i and replenishment cycle time T_i for dry port in each cluster *i*. To achieve this, we implement the following procedure.

From total network cost function *TC*, the Hessian matrix of TC can be formulated as:

$$H=\begin{vmatrix} \frac{\partial^2 TC}{\partial (A_i)^2} & \frac{\partial^2 TC}{\partial A_i \partial T_i} \\ \frac{\partial^2 TC}{\partial T_i \partial A_i} & \frac{\partial^2 TC}{\partial (T_i)^2} \end{vmatrix} \tag{2}$$

To verify whether the matrix given in Eq. (2) is positive or not, we evaluate its principal minors:

$$D_1=\frac{\partial^2 TC}{\partial (A_i)^2}=\sum_{i=1}^{n}\frac{2FC_i}{A_i^3}+\sum_{i=1}^{n}-\frac{A^D f_r \zeta \delta_i \lambda_i C_i}{4A_i^{3/2}}+\sum_{i=1}^{n}\frac{hT_i \zeta \delta_i \lambda_i C_i^2}{A_i^3}$$
$$+\sum_{i=1}^{n}\frac{2C_{ce}C_i\left(g+\frac{1}{2}g_0 T_i \zeta \delta_i \lambda_i C_i\right)}{A_i^3}\geq 0 \forall A_i \tag{3}$$

$$D_2=\left(\frac{\partial^2 TC}{\partial (T_i)^2}*\frac{\partial^2 TC}{\partial (A_i)^2}\right)-\left(\frac{\partial^2 TC}{\partial A_i \partial T_i}\right)^2>0 A_i,T_i \tag{4}$$

Thus, we know that the Hessian Matrix is positive definite since all principle minors are positive equations (2), (3), and (4) are positive. The total cost function, TC, is convex function.

We obtain the first derivative of $TC(A_i,T_i)$ with respect to A_i and T_i; set the derivative to be zero ($\frac{\partial TC(A_i,T_i)}{\partial A_i}=0$, $\frac{\partial TC(A_i,T_i)}{\partial T_i}=0$) to obtain the optimal influence area (A_i^*) and the optimal joint replenishment-cycle (T_i^*) of each dry port in cluster i as follows.

$$A_i^*=\frac{\left(\left(2F+T_i h\zeta\delta_i\lambda_i C_i+C_{ce}\left(2g+T_i g_0 \zeta\delta_i\lambda_i C_i\right)\right)^2\right)^{1/3}}{(A^D)^{2/3} f_r^{2/3}\zeta^{2/3}\delta_i^{2/3}\lambda_i^{2/3}} \tag{5}$$

$$T_i^*=\frac{\sqrt{2A_i C_f}}{\sqrt{h\zeta\delta_i\lambda_i C_i^2+C_{ce}g_0\zeta\delta_i\lambda_i C_i^2}} \tag{6}$$

Table 1: Summary results for example

	The influence of dry port, A_i	The replenishment cycle time for each dry port, T_i
Cluster 1	2011.80	0.002024
Cluster 2	2375.77	0.003115
Cluster 3	2878.00	0.005279
Total cost	1.86164×10^8	

5. EXAMPLE

In this example, we consider the following data: F=100000, h= 6, A^D=30, A^S=55, f_r=12, C_f=8, g_0= 0.5, g= 10000, and C_{ce}= 6. Three clusters are considered with the following parameter values: C_i = (10000, 8000, 6000), λ_i = (11, 10, 9), and ∂_i=(0.07, 0.06, 0.05) with i clusters (i = 1, 2, 3).

Table 1 shows the summary results of our example. The results recommend that the company should open 5 dry ports in cluster 1, 4 dry ports in cluster 2, and 2 dry ports in cluster 3.

Based on the above numerical example, we conducted a sensitivity analysis to determine the effects of changing carbon cost, C_{ce}, on the decision variables. This analysis was conducted by fixing all of the parameters and varying them one at a time.

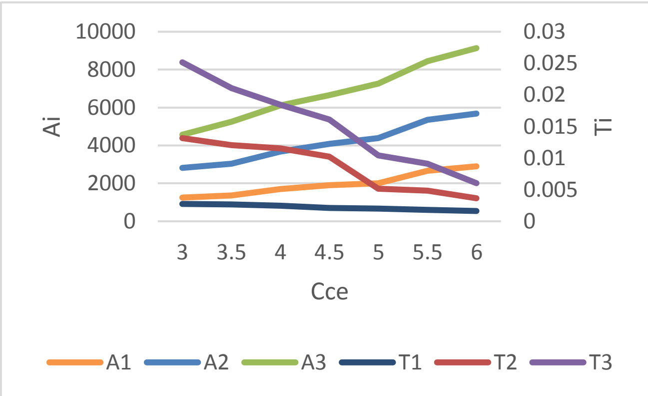

Figure 2: The influence of the carbon cost

As we seen in Figure 4, when the carbon cost increases, the influence area of dry port increases but the joint replenishment cycle time decreases. Firms should decrease the number of dry port will be opened when the carbon cost increases. However, it leads to the increasing in total network cost (Figure 5)

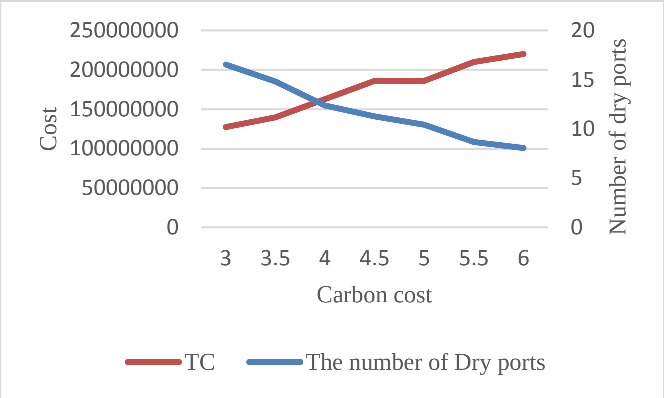

Figure 3: The influence of the carbon cost

6. CONCLUSION

In this study, we have presented a seaport- dry port network design with carbon emission considerations. A continuous approach is used to model our problem. We investigate how firms/goverments determine the service areas of dry port and joint replenishment cycle time. A nonlinear optimization technique is used to solve the seaport- dry port network design problem. Numerical example is also presented that illustrates the applicability of proposed solution procedure. The results also show that the increasing in carbon emission cost leads to the reduction of number dry port.

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