A two-phase model for dry port location with an application to the port of Dalian in China

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This paper aims to provide guidance for an optimal and reasonable dry port layout for the port of Dalian in China. We present a two-phase framework on the location of dry ports, which solves the selection of candidate inland cities and optimal dry port location choice respectively. Fuzzy C Means Clustering (FCM) is applied to select alternative cities in the vast hinterland of the seaport of Dalian, in view of identifying evaluation factors that affect the location selection decision, while a cost-minimization linear programming is proposed to choose optimal location as well as capacity level among the candidate inland cities, with the aid of Genetic Algorithm.

Keywords: Dry ports; location analysis; Fuzzy c-Means (FCM) clustering; Genetic Algorithm, two-phase model; the port of Dalian

1. Introduction

As container transport volume continues to grow, most seaports are facing the problem of a lack of space at port terminals as well as bottlenecks in the inland transportation system (Roso and Lumsden, 2009). As a result, inland distribution has become a very important part of globalization, seaborne transportation and freight distribution (Notteboom and Rodrigue, 2005). Inland access is now a cornerstone in port competitiveness (ECMT, 2001). Under these circumstances, a dry port emerges as a modern logistics centre located in an inland region. The first mention of dry ports goes back to 1980 (Munford, 1980).The development of dry ports is actually part of the port regionalization process, which is the latest stage of port and port system development and characterised by the expansion of the hinterland accessibility through market strategies and policies (Notteboom and Rodrigue, 2005).

The construction and operation of dry ports have gained great interest from port authorities, inland public bodies and market players. However, the construction boom in dry ports can result in overcapacity, duplication of facilities, low efficiency, a low utilization degree and a poor return on investment. Therefore, a need is increasingly felt in many regions around the world for seaports and investors to design a reasonable dry port layout plan aimed at allocating and utilizing all the resources in a rational way. The location decisions of dry ports can impact efficiency and smoothen the whole transportation chain. Unlike normal infrastructures and equipment which can still be altered in the intermediate term in response to the market demand and the availability of land and capital (Gujar, 2011), dry ports cannot be relocated easily, mainly because of the massive investments required and the location-bound nature of these investments. Therefore, it is pivotal to make reasonable location decisions at the very start of the dry port development process.

This paper will focus on seeking optimal location for dry port. The location decision process is divided into two parts: (1) evaluation of all inland cities in the hinterland from a macro-economic perspective, with the aim of identifying relatively developed cities as candidate location; (2) selection of optimal dry port location from the candidate inland cities from a micro-economic perspective, in order to establish cost efficient inland transportation network for the seaport. The main goal of the paper is to provide a more efficient and reasonable way for the investors to select cities for dry port development.

The paper starts with a comprehensive review of existing literature on dry port concepts, functions and classifications, as well as widely used location analysis methods. Then we introduce a brief problem description. After that, we propose the two-phase dry port location framework and corresponding solution techniques. Also a case study of port of Dalian will be presented. Finally, we present the conclusions and suggestions for future research.

2. Literature review

2.1 Dry port concept and function

The nodes in the hinterland networks of ports have been referred to as dry ports, inland terminals, inland ports, inland hubs, inland logistics centres, inland freight villages, etc… The reason for the range of terminologies lies in the multiple shapes, functions and network positions these nodes can have(Notteboom and Rodrigue, 2009), but also in differences in the preferred terminology among regions around the world(ESCAP, 2007).The dry port concept is mainly researched in relation to intermodal transport (Henttu, 2011).An early definition of the dry port concept appeared in a United Nations text of 1982. Roso and Lévêque(2002)also defined the dry port by referring to an intermodal terminal: a dry port is ‘an inland intermodal terminal directly connected to a seaport, with high capacity traffic modes, preferably rail, where customers can leave and/or collect their goods in intermodal loading units, as if directly to the seaport’.

Academic research on dry ports has grown exponentially in recent years as exemplified by the special issues on dry ports in Maritime Economics and Logistics (vol. 14, 2012) and Research in Transportation Economics (vol. 33, 2011). However, research on the classification of dry ports remains quite scarce. Based on the modes served by the dry ports, they can be classified as inland waterway ports, air cargo ports, maritime feeder inland ports and trade and transportation centres (Leitner and Harrison, 2001). In view of the distance from the seaport, dry ports can be classified as distant dry ports, mid-range dry ports and close dry ports (Woxenius et al., 2004).Notteboom and Rodrigue (2009) argue there are a number of major types of intermodal terminals each having their own locational and equipment requirements: cross-dock facilities(trucks), rail hubs, barge terminals as local ‘extended gates’ for seaport terminals(see also Rodrigue and Notteboom, 2009 and Veenstra et al., 2012) and fully-fledged inland port and logistics zones. Based on the transport function, dry ports can act as satellite terminals, load centres or transmodal centres (Rodrigue et al., 2010).Haralambides classified dry ports as gateway terminals, rail terminals and distribution centres, which is based on the accessibility of customs clearance service(Gujar, 2011).

In comparing various terms and definitions, a report of ESCAP described the following attributes of a dry port as seen in table 1.

<insert table 1 about here>

A successfully implemented dry port will influence a lot of actors in the transportation system, such as seaport, shippers, rail operators, road operators and the whole society (Roso, 2008). For the private sector, the dry port shows its location advantage by providing shippers with direct connection to international transport. Except from the traditional warehouse function namely storage, consolidation and deconsolidation, the similar-to-seaport functions of dry ports also give them accessibility to some logistics activities and services which used to be only accommodated by seaports, such as customs clearance, inspection and quarantine. With the use of advanced information systems and electronic declaration procedures (Walter and Poist, 2003), the efficiency is improved yet the transaction cost is lowered (Henttuet al., 2010). For example, companies can settle an exchange account 7 days in advance and get tax drawback at least 30 days earlier at dry port Lanzhou in China (Zhu, 2009). Furthermore, the location advantage also eliminates the possible damage caused by double inspection and loading.

A dry port can also ease various pressures and constrains faced by the seaports. The transfer of multiple activities to the hinterland increases the capacity of deep sea terminals (Slack, 1999; Notteboom and Rodrigue, 2005), allowing seaports to achieve a better accessibility to the hinterland, to deal effectively with land constrains and to maintain a high service level to shippers.

The emergence of dry ports changed transportation patterns. The congestion caused by queues and long waiting times of trucks at seaport terminals can be avoided, while the service efficiency and quality can be improved (Roso, 2007). Although road transport companies might lose a marginal market share in terms of road-kilometers, the drivers can follow driving and breaking time regulations more easily due to the shorter distances of road transport (Henttu, 2011).

The transportation sector is the only sector with increasing carbon dioxide emissions (European Commission, 2009). However, the shift of transport flows from road to intermodal solutions improves transport system’s environmental friendliness by decreasing CO_2 emissions. For example, in a case study on Finland, Henttu et al. (2010) demonstrate that the difference in CO_2 emissions between conventional road transport and dry port implemented transport can be up to 28%.The operation of dry ports can decrease external costs by approximately 35% and total costs by about 17%.

A survey among dry port managers conducted by Roso (2009) identified the most common advantages resulting from dry ports (Figure 1).

<insert Figure 1 about here>

The public sector also wants to generate benefits from the construction of dry ports. There are development goals and planning goals (Rodrigue et al., 2010). The first group refers to the aim of developing the local economy such as the investment environment, employment, taxes, and state revenues, based on the international trade function of dry ports. The second group of goals is about maintaining regulatory sustainability. Spies and Notteboom (2011) discussed the institutional and regulatory framework in relation to dry port development. They identified four specific policy tools which governments at various geographical levels can use to influence dry port development: financial intervention, public-private partnerships, land policy or spatial planning and competition policy.

2.2 Methodologies for location analysis

The early theories about location analysis were put forward by economists and regional geographers. Weber (1909) analysed the location decision for warehouses for the first time. The objective was to minimise the distance between warehouses and customers. Hotelling (1929) also developed a model to optimise the location of two competitive firms along a line of fixed length. Over the past years, a vast literature has developed to solve the problem of determining the best location for facilities. The relevant literature has been thoroughly reviewed by Owen and Daskin (1998), Hale and Moberg (2003), and ReVelle and Eiselt (2005).

Location analysis of dry ports has received considerable attention from researchers. Most traditional mathematical methods for location analysis have been successfully applied to dry ports for specific situations. Among the researches, programming methodologies such as integer programming and linear programming, as well as multi-criteria decision models such as Analytical Hierarchy Process (AHP), Fuzzy Analytical Hierarchy Process (F-AHP), and Data Envelopment Analysis (DEA) are used in solving the location problem.

James (1994) presented integer programming formulations for four types of discrete hub location problems: p-hub median problem, uncapacitated hub location problem, p-hub centre problems and hub covering problem. Rutten (1998) used existing assignment techniques and developed a conversion method called TERMINET model which can translate freight flows from tons to numbers of load-units, to determine inland terminal locations and capacities for transshipment of load-units between road vehicles and trains. Arnold (2004) established a linear 0-1 program and applied a heuristic method to solve the problem of rail/road terminals location in the Iberian Peninsula. The results showed that rail cost and track gauge were two major factors influencing modal shares. Wang (2004) solved the problem from the shippers' point of view. He took the intrinsic demand and market competitiveness of the dry port as main consideration and applied a multinomial logit model of discrete choice analysis to describe shippers' behavior and preferences when they choose dry ports. The author also compared the model with AHP and argued that a multinomial logit model is more appropriate. Yang (2006) used a two-stage model for the location selection problem. DEA was adopted in the first stage to choose effective candidate inland cities, with transportation cost, transportation time, pre-phase expenditure as input variables and the satisfaction degree of customers as output variable. AHP-F was applied in the next stage to rank the cities and choose the optimal location for the dry port. The evaluation system contained the operational environment, transportation conditions and public infrastructures as influencing factors. Wang and Wei (2008) selected natural environment, operating environment, infrastructure status and costs as main factors influencing dry port location. They relied on Analytical Network Process (ANP) to evaluate the alternative cities.

3. Problem definition

Finding an optimal location is a difficult task. The decision maker needs to select sites not only performing well according to the current situation, but also continue to be profitable in the future, even as environment changes (Owen and Daskin, 1998). Numerous factors need to be considered when making location decisions. Consequently, multi-criteria analysis is an ideal method for the evaluation of alternatives. However, the results based on this type of evaluation are not always the optimal locations. They are often ideal locations at macro-level only. From the perspective of other actors/operators in the system, there are some additional factors such as cost and efficiency that need to be considered as well.

Cost is the most important factor for stakeholders in the transport chain. Cities with a higher GDP and more foreign trade generate more cargo. However, these cities are usually also characterised by higher land rent and labour costs, which imply a higher installation and operation cost. The cost may even surpass the convenience brought for local and nearby shippers. Thus from a systematic perspective, it might be more economical to implement a dry port development in a neighbouring city characterised by low land and labour costs.

In addition, shippers focus on the total logistics costs. Since the use of a dry port typically implies a pre- and or endhaul by truck, locating a dry port close to a gateway seaport might make the intermodal option less competitive than the truck only option. As a result, shippers located in cities near the seaport are more inclined to transport their cargo directly to the seaport by truck instead of using a local dry port.

Rail operators are concerned about the operating costs of rail shuttles between the seaport and the dry ports and the efficiency of the whole network structure in terms of shuttle service frequency and costs. In case there are several candidate inland cities close to each other, rail operators might not be able in the short run to operate direct shuttles trains on a frequent basis between the seaport and all of these dry ports, given a likely lack of base volumes and thus economies of scale. From a micro-economic and operational perspective, rail operators tend to consolidate rail cargo for such group of cities to only one larger dry port instead of spreading the cargo flows over several smaller facilities. In this scenario, cargos from other nearby inland cities will be gathered in this larger dry port and transported to the seaport via rail shuttle services. As soon as volumes on the corridor pick up, operators might look for other direct dry port connections between the seaport and the urban region, thereby increasing the micro-economic feasibility of serving more dry ports in the region.

In conclusion, the decision on the optimal location of a dry port involves trade-offs between installation costs, storage costs and transportation costs. Location models should not only focus on macro-economic factors, but should also include an assessment in terms of micro-economic objectives and considerations of different stakeholders. As such, this paper proposes a two-phase framework for the location of dry ports, with the purpose of choosing cost-efficient locations for dry ports among a pool of possible candidate cities located in the hinterland. Hence, there are two problems that need solving: (1) to identify relatively developed cities in the hinterland as candidate dry port locations and (2) to determine the optimal location among the candidate inland cities in view of cost minimization.

The first phase requires an identification and evaluation of the the development status and potential of inland cities based on an array of factors. The result of this process is a list of cities which are suitable and qualified to act as inland transportation nodes.

The second phase deliversthe most cost efficient dry port location from a micro-economic perspective.

4. Two-phase location model and solving techniques

In this section, we present the two-phase location model: (a) the evaluation system for identifying candidate inland cities as alternative dry port locations and the clustering method as a solution technique; (b) the linear programming model for choosing the optimal location among the candidate inland cities from the perspective of cost minimization and a GA based solving algorithm.

4.1 Phase 1 The identification of candidate dry ports

The first phase in location decision solves the problem of inland cities assessment. The cities' resource and conditions are evaluated through certain quantitative and qualitative variables. FCM is applied to illustrate the appraisal results.

(1) Dry port location evaluation indicators system

According to a Delphi study that used aworldwide panel of experts, MacCarthy and Atthirawong (2003) found that costs, infrastructure, labour characteristics, government and political factors andeconomic factors are the top five factors that may strongly affect international location decisions.Costs were always on the top of the location decision criteria list and they are deemed as micro factors, which we will discuss in the next phase.Variables focusing on service quality and accessibility are gaining more attention from customers and decision makers, especially in the context of supply chain integration. Those variables can be quantitative or qualitative, for instance, local economy, investment climate, labour, transportation convenience, existing infrastructure, government policy and future planning in the local city.

Among the factors that may influence the location decision, human resources and service facilities can to some extent be controlled or steered by dry port investors. However, some attributes of inland cities, such as the existing transportation network and commercial conditions, cannot be altered by investors. Hence, these factors should be given priority when assessing the cities. Based on a comprehensive consideration of general factors influencing location decision and composition of a successful dry port, this paper establishes the following evaluation indicator system for candidate inland cities identification (table 2).

<insert table 2 about here>

The evaluation system contains 18 variables and 4 of them in the ‘policy environment’ category are qualitative. They are quantified according to the relevant national transportation and logistics planning. The value of the administrative attribute is 1 if the city is the provincial capital and 0 for others. The value of marshalling station level is 3 for network marshalling station; 2 for regional marshalling station; 1 for local marshalling station and 0 otherwise. Transportation environment index starts with 1 and increases by 1 each time if the city is a national railway container terminal/ a national integrated transportation hub/ connected to the seaport by rail-sea intermodal transportation. The value of logistics status index is 2 if the city is designated as national logistics node, 1 for regional logistics node and 0 otherwise.

(2) Solution technique for evaluation

Multi-criteria research, analytical hierarchy process (AHP) and Fuzzy AHP are often used in decision factors analysis. In this paper, we propose Fuzzy c-means (FCM) clustering as aid in selecting candidates. FCM was put forward based on Fuzzy Set Theory proposed by L.A. Zadeh in the middle 1960s (L.A. Zadeh,1965). The method is used to cluster objects on condition that the influencing factors and their impacts are not completely specified. Since there is some degree of uncertainty and fuzziness in the process of collecting and describing the factors that affect dry port location evaluation, FCM is quite suitable to solve the problem.

With FCM, candidate dry port selection can be described as follows.

Hypothesise there are n inland cities (x_1, x_2, ..., x_k, ..., x_n), they can be clustered to c subsets ($2 \le c < n$), according to p indicators. A criterion of FCM is to minimise *J (U, V).*

$$J(U,V) = \sum_{i=1}^{c}\sum_{k=1}^{n}(u_{ik})^m d_{ik}^2 \quad (1)$$

$$s.t. \sum_{i=1}^{c} u_{ik} = 1 \forall k \quad (2)$$

With

J objective function of FCM

U set of membership matrix

V set of clustering centres

d_{ik} distance between sample x_k and clustering centre of subset i, which means $d_{ik} = \|x_k - v_i\|$

m weighted index.

Specifically, there are six steps in FCM (Figure 2).

Step 1. Identify the amount of categories *c* and weighted index*m*.

Step 2.Initialisethe membership matrix $U^{(0)} = \left(u_{ik}^{(0)}\right)$ by choosing uniform numbers from [0, 1].

Step 3.Calculate clustering centres $v^{(l)}$.

$$v_i^{(l)} = \sum_{k=1}^{n}\left(u_{ik}^{(l-1)}\right)^m x_k \Big/ \sum_{k=1}^{n}\left(u_{ik}^{(l-1)}\right)^m, i = 1, 2, ..., c \quad (3)$$

Step 4.Correct membership matrix $u^{(l)}$ and calculate $J^{(l)}$.

$$u_{ik}^{(l)} = 1 \Big/ \sum_{j=1}^{c} \left(d_{ik}^{(l)} \big/ d_{jk}^{(l)} \right)^{\frac{2}{m-1}}, i = 1, 2, \ldots, c; k = 1, 2, \ldots, n \tag{4}$$

$$J^{(l)}(U^{(l)}, V^{(l)}) = \sum_{k=1}^{n} \sum_{i=1}^{c} \left(u_{ik}^{(l)} \right)^{m} \left(d_{ik}^{(l)} \right)^{2} \tag{5}$$

$$d_{ik} = \left\| x_k - v_i \right\| \tag{6}$$

Step 5.Iteration. If $\max\{\left| u_{ik}^{(l)} - u_{ik}^{(l-1)} \right|\} \geq \varepsilon_u$, go back to *Step 3*.

Step 6.Clustering. If $u_{jk} = \max\limits_{1 \leq i \leq c}\{u_{ik}\}$, x_k should be clustered as category *j*.

<insert Figure 2 about here>

4.2 Phase 2 Optimal location choice of dry port

In this part, a location model with multiple capacity choices considering total cost of inland transportation network is formulated. The model simultaneously determines the location of dry ports and describes the demand distributed among the selected dry ports. The problem is addressed as a two-stage logistics network flow problem as depicted in Figure 3. Moreover, GA is used to solve the model.

<insert Figure 3 about here>

(1) Optimal location model of dry ports

The objective of the model is to minimise total cost, which consists of set-up cost, storage cost at dry ports, as well as transportation costs between inland regions and seaport through dry ports. Given that capacities can have a determining impact on installation cost, as well as on transportation cost by influencing cargos allocation, they should be considered as part of the location decision process (Contreras et al., 2012).In order to solve more realistic dry port location problem, we incorporate capacity constraints in the model. A linear location model with multiple capacity choices is proposed in this phase. Each capacity level determines a specific capacity and incurs a corresponding fixed construction cost.

The parameters and variables used in the model are defined as follows:

P set of candidate locations

N set of existing dry ports

Q set of inland cities in hinterland

T set of capacity levels of candidate locations

c_{ik} fixed cost for constructing a dry port with capacity level of k at candidate location i [USD]

z_{ik} binary variable, 1 if candidate location i with capacity level of k is chosen, 0 otherwise

c_{rd} transportation cost by truck [USD/TEU-km]

l_{1ij} road distance from inland city j to candidate location i[km]

x_{1ijk} volume of containers transported from inland city j to candidate location$i$ with capacity level of k [TEU]

c_{str} storage cost at dry port [USD/TEU-day]

t_{ik} storage time of containers at candidate location *i* with capacity level of *k*[day]

T_i operational time of candidate location *i* [day]

D_i local export demand of candidate location *i* [TEU]

D_j total export demand of inland city *j* [TEU]

c_{rl} transportation cost by train [USD/TEU-km]

l_{2i} rail distance from candidate location *i* to seaport [km]

x_{2ik} volume of containers transported from candidate location *i* with capacity level of *k* to seaport [TEU]

l_{3j} road distance from inland city *j* to seaport [km]

x_{3jk} volume of containers transported directly from inland city *j* to seaport [TEU]

s_{ik} capacity of candidate location *i* with capacity level of k [TEU]

A investment limit for new dry ports [USD]

B maximum amount of new dry ports

Given the notations, the dry port location model is given below:

$$\text{Min}\, C = \sum_{i\in P}\sum_{k\in T} c_{ik} z_{ik} + \sum_{i\in P\cup N}\sum_{j\in Q}\sum_{k\in T} c_{rd} l_{1ij} x_{1ijk} + \sum_{i\in P\cup N}\sum_{j\in Q}\sum_{k\in T} c_{str} t_{ik} x_{1ijk} + \sum_{i\in P\cup N}\sum_{k\in T} c_{rl} l_{2i} x_{2ik} + \sum_{j\in Q}\sum_{k\in T} c_{rd} l_{3j} x_{3jk} \quad (7)$$

s.t.
$$t_{ik} = \frac{T_i}{S_{ik}} \quad (8)$$

$$\sum_{j\in Q} x_{1ijk} + z_{ik} * D_i = x_{2ik} \quad (9)$$

$$\sum_{i\in P\cup N}\sum_{k\in T} x_{1ijk} + \sum_{k\in T} x_{3jk} = D_j \quad (10)$$

$$\sum_{j \in Q} x_{1ijk} \leq s_{ik} z_{ik} \tag{11}$$

$$\sum_{i \in P} \sum_{k \in T} c_{1ik} z_{ik} \leq A \tag{12}$$

$$\sum_{k \in T} z_{ik} \leq 1 \tag{13}$$

$$\sum_{i \in P} \sum_{k \in T} z_{ik} \leq B \tag{14}$$

$$x_{1ijk} \geq 0 \tag{15}$$

$$x_{3jk} \geq 0 \tag{16}$$

$$z_{ik} = 0, 1 \tag{17}$$

The objective function (7) aims at minimizing total construction, storage and cargos assignment cost. Equation (8) estimates the storage time at a dry port; Constraint (9) ensures the incoming flow equals to outgoing flow at a dry port. Constraint (10) ensures the demand of each inland city is met. Constraint (11) guarantees that the dry port provides enough capacity for the demand of all the assigned inland cities. Constraint (12) represents the construction investment constraint. Constraint (13) ensures only one capacity level is chosen for each candidate location. Constraint (14) is the amount constraint for dry ports. Constraints (15) - (16) are domain constrains. Constraint (17) is the binary restrictions of the decision variables.

(2) Solving technique

The model is a linear optimization problem with discrete decision variables representing locations and capacities of dry ports. The model is also a fixed charge location model that has been proven to be NP complete. We propose the following effective global optimization technique, namely Genetic Algorithm, to obtain optimal solution for the model.

Step 1. Generate initial population of location choice. The initial population are generated randomly. We develop a two-part chromosome encoding method to describe the location choice. The first chromosome represents whether the candidate inland city is chosen as a dry port. If a city is selected to install a dry port, the corresponding gene is 1, otherwise it is 0. The second chromosome represents the capacity level of corresponding dry ports presented in the first chromosome.

For example, for the below chromosome *C*, the second, third and seventh inland cities are chosen for developing dry port, and the capacity levels are third level, second level and first level respectively.

$$C\text{: } [\{0,\underline{1},\underline{1},0,0,0,\underline{1}\},\{1,\underline{3},\underline{2},4,2,5,\underline{1}\}]$$

Step 2. Fitness function formulation. Fitness function isdefined as negative function of objective, which means

$$Fitness = -\left(\sum_{i\in P}\sum_{k\in T} c_{ik} z_{ik} + \sum_{i\in P\cup N}\sum_{j\in Q}\sum_{k\in T} c_{rd} l_{1ij} x_{1ijk} + \sum_{i\in P\cup N}\sum_{j\in Q}\sum_{k\in T} c_{str} t_{ik} x_{1ijk} + \sum_{i\in P\cup N}\sum_{k\in T} c_{rl} l_{2i} x_{2ik} + \sum_{j\in Q}\sum_{k\in T} c_{rd} l_{3j} x_{3jk}\right) \quad (18)$$

Step 3. Selection. The chromosomes are selected according to their fitness by the roulette wheel.

Step 4. Crossover. Crossover operator for the first chromosome is based on the one-point crossover strategy, and the second chromosome uses uniform arithmetic crossover operator.

Step 5. Mutation. Uniform mutation strategy is applied to perform mutation operation.

Step 6. Termination. The algorithm terminates when the generation exceeds the maximum iterated generation, otherwise go back to Step 2.

4.3 Dry port decision making framework

After discussing the phases and targets of location analysis, illustrating the corresponding techniques to solve the problem, we propose the dry port location decision making framework (Figure 4).

<insert Figure 4 about here>

When choosing optimal location for dry port, the decision maker can evaluate all the inland cities in the hinterland of seaport from the aspect of transportation infrastructure, economy development, policy availability and environmental friendliness, the dry port location alternatives in a macro level can be figured out with the aid of a clustering technique. The final locations to implement dry port are selected among the alternatives according to the cost minimization principle, based on the linear location model and GA presented in the paper.

5. Case study of the port of Dalian

5.1 General profile of the port of Dalian

The port of Dalian is an important port and shipping centre in the northeast of China. The port has the northeast of China as its hinterland, which covers three provinces: Liaoning, Jilin and Heilongjiang, as well as five northeastern cities of Inner Mongolia: XilinGol, Chifeng, Tongliao, Hinggan and Hulunbuir (Figure 5).

<insert Figure 5 about here>

Port of Dalian and Liaoning international transportation Co. Ltd constructed Shenyang goods yard in July 2003. From then on, Port of Dalian has invested more than 200 million dollars on inland node construction. Nowadays, a gradient dry ports layout has been formed; it contains three railway container terminals (RCTS) and three inland node zones.Among the several operational inland nodes, five of them have been endowed with the full function as dry ports, which are Shenyang(SY), Changchun(CC), Jilin(JL), Harbin(HB) and Muling (a country-level city belongs to Mudanjiang)(MDJ).

The start of container train operations in Northeast China in 1997, which connects Dalian and Harbin, marked the beginning of rail-sea intermodal transportation service between the port of Dalian and inland regions. From 2001 to 2011, container traffic via rail-sea intermodal transportation in the port of Dalian was the highest among all coastal ports in China (table 3).

<insert table 3 about here>

5.2 Dry port location analysis

Phase 1. The identification of candidate dry ports.

As indicated above, the hinterland of the port of Dalian covers three northeast provinces and eastern Inner Mongolia. With the exception of six seaports in Liaoning province, there are 33 cities altogether and they are the alternative cities for dry port location in phase 1. The quantitative data are collected from the statistical yearbooks of the four provinces.

Meanwhile, the parametric hypotheses of the model are as follows:

(1) The cities are classified to four categories, which means c = 4;

(2) Based on the clustering validity research, the weighted index m =2;

(3) The termination tolerance is set as follows: $\varepsilon_u = 1e - 6$ in the principle $\max\{|u_{ik}^{(l)} - u_{ik}^{(l-1)}|\} \geq \varepsilon_u$.

Using the FCM function in the Fuzzy Logic Toolbox in software MATLAB, fuzzy clustering centres of four categories and membership degrees of 33 cities are calculated and shown in table 4 and table 5.

<insert table 4 about here>

<insert table 5 about here>

The results in table 5 show that category I only includes two cities; 4 cities fall into category II; 8 cities belong to category III and the other 19 cities belong to category IV. Cities of category I represent the most developed cities in the hinterland. Undoubtedly they are the most suitable locations for dry port development. In view of the disadvantageous situation of hinterland accessibility and urgency to complete inland transportation network, the port of Dalian should also consider dry port development in the category II and category III cities. Therefore, we obtain 14 alternative locations for dry port implementation in terms of the local development aspect and transportation convenience. Five of them are existing dry ports, which suggest the results correspond to reality and the evaluation system and methodology are suitable for candidate selection. Therefore, nine other cities are included as research objects in phase 2, i.e. Tongliao (TL), Anshan (AS), Benxi (BX), Tieling (TLG), Tonghua (TH), Songyuan (SYN), Qiqiqhar (QH), Daqing (DQ) and Jiamusi (JMS).

Phase 2. Optimal location choice of dry port

In the first phase, nine cities were identified as candidates for dry port location from a macro-economic perspective. In phase 2, we will use the location decision model to figure out the optimal dry port location from a micro-economic and operational perspective.

(1) Data collection.

The amount of export cargo inthe hinterland is estimatedas follows (table6):

$$Q=V * K_1 * K_2 * \alpha \tag{19}$$

Q: Export amount (TEU);

V: Total exports (USD);

K_1: Rate of value of containerised cargo (%);

K_2: Coefficient of containerised cargo (TEU/USD);

α: Percentage of export cargo transported through the port of Dalian.

<insert table 6 about here>

Optional capacity levels and corresponding installation costs associated with each candidate inland city, as well as capacity of existing dry ports are shown in table 7 and table 8.

<insert table 7 about here>

<insert table 8 about here>

The transportation cost (USD/TEU-km) is set at 0.96 for truck and 0.24 for train; storage cost (USD/TEU-day) is 5. Operational time is set at 350 days per year. The parameters in GA are set as follows: the population size is 100; maximum calculation time is 100, with a crossover possibility of 0.7 and a mutation possibility of 0.05.

The result is shown in table 9:

<insert table 9 about here>

According to the encoding method of the algorithm, among the nine candidate inland cities figured out via FCM, the seventh and ninth cities, which are Qiqihar and Jiamusi, are optimal location of dry ports from an operational perspective. The corresponding capacity levels are level 1 and 3, which are 50000TEU and 100000TEU, and the total cost is 411.87million USD.

From the result, we can see that although nine cities fall in the desirable location categories after being evaluated from the status and potential of inland cities, only two cities are actually optimal locations from an economic perspective. The evaluation result shows three cities in Liaoning province, namely Anshan, Benxi and Tieling are appropriate locations for implementing the dry port concept, which is mainly because of the favourable policy environment that offers a strong incentive for dry port development. Nonetheless, the cities are too close to the port of Dalian. Nearby shippers sensitive to time prefer road to rail with respect to transit time cost. Moreover, there is already a dry port locates in Shenyang, where is the centre of the cities group with great location advantage. The rail operation company of the port of Dalian tends to collect cargo of the cities group to Shenyang and then transported by shuttle train to Dalian, since the volumes between the three cities and Dalian may not be enough to reach the minimal requirement of the rail operation partner—China Railway Container Transport Co, Ltd. When the volumes booms, the operators may consider to operate direct shuttle trains connect those cities and Dalian.

Tongliao, Tonghua, Songyuan and Daqing are also candidate cities for installing dry ports but fail to optimise the total cost in the system as well. The reason is the transportation cost savings for cargos gathered there cannot cover the high installation investment. Consequently, they are not optimal locations for dry port in Northeast China.

According to the optimal location choice result in table 9, the cargos allocation is shown in table 10.

<insert table 10 about here>

As shown in table 10, 145575 TEU are transported directly to the port of Dalian by truck, those cargos are mainly from southern part of northeast Inner Mongolia and sourthern part of Liaoning province, where are closer to the port of Dalian, compare to other cities in the hinterland. This demenstrates that with respect to general cost, it is more economical to consolidate vinical cargos at seaport. The dry port mode shares 88.72% of all export cargos, which are 881172 TEU in total. It can also be seen from table 10 that the two optimal dry ports locations are 'fully' used, which means the cargos collected there reach the capacity constraints. The same situation happens to dry port in Mudanjiang, Harbin, Shenyang and Changchun as well. However, only 31172 TEU are consolidated at dry port Jilin, which accounts for 51.95% of available capacity (60000TEU). That means dry port Jilin has the problem of overcapacity. The result illustrates the importance of determining optimal capacity level while deciding dry port location.

Based on the result in table 10, the distribution of export cargos of Northeast China in inland transportation network is presented in Figure 6.

<insert Figure 6 about here>

Furthermore, the optimal dry port layout of the port of Dalian can be following (Figure 7):

- Shenyang as dense dry port servicing three cities in northeast Liaoning.
- A mid-range dry port cluster containing Changchun and Jilin, with middle area of northeast Inner Mongolia, province of Jilin and two cities in Heilongjiang as hinterland.
- A distant dry ports cluster including four cities in Heilongjiang province with Harbinas the centre, and northern Inner Mongolia and Heilongjiang as hinterland.

<insert Figure 7 about here>

6. CONCLUSIONS AND FUTURE RESEARCH

This paper shed light on the optimal location for dry ports. We proposed a two-stage dry port location framework to solve the problem. In the first phase an evaluation indicator system described attributes and resources of inland cities. The system contains 18 indicators to help identify candidate cities from the perspective of transportation capacity, regional economy, policy environment and environmental friendliness. FCM was applied to classify all the cities into several categories thereby indicating the order to implement dry ports according to their performance on the indicators. In the second phase, we proposed a linear location model with multiple capacity levels, so as to select final optimal locations for dry ports by calculating the cost related to the inland transportation system, which is composed of dry port installation cost, storage cost and transportation cost.

The case study demonstrated that among the 33 cities in the hinterland of the port of Dalian, 14 cities are able to provide favorable conditions for dry port location. Except for the existing operational dry ports, there are still nine cities appropriate for location. After cost calculations, only two inland cities are identified as optimal locations with the view of total cost minimization. The capacity levels are 50000 TEU and 100000 TEU respectively. In this situation, 85.8% of export cargos of Northeast China are consolidated at dry ports by shuttle train service and then transported to the port of Dalian via truck. The rest of the cargos which are scattered in the southern part of the hinterland, are transported to Dalian directly by road. The cargo distribution results also indicate that, given the constraints of capacity and fixed costs, dry ports are more attractive for the distant hinterland, while cargos from cities close to a seaport are likely to be transported to the seaport directly. Moreover, the overcapacity situation at dry port Jilin demonstrates the great importance of deciding on a reasonable capacity level from the start of dry port development.

The issue of dry port layout can be analysed at three distinct levels: the spatial distribution plan, the strategic location and the dry port design. This paper only dealt with the location and layout problem at the first and highest level. Future research on this topic can be focused on choosing a location for a dry port in a specific city (i.e. a local location choice) or the optimal design of a specific dry port. These two research problems require a case study approach.

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Table 1. Attributes of dry ports

Geographical attributes	• linked to a sea or airport • inland-located away from traditional land, air, and coastal borders
Transport logistics attributes	• high capacity transport link(s) • more than one transport mode • intermodal transfers
Warehouse logistics attributes	• temporary storage or warehousing • consolidation and deconsolidation
International port attributes	• international trade involved • customs inspection • other services found in an international sea or airport
Value add logistics services	• freight forwarding • information systems • other value added services

Table 2. Evaluation system for inland cities identification

First-level indices	Second-level indices	Quantitative indices
Transportation condition	Traffic capacity	x_1 Road density
	Transportation demand	x_2Regional transportation volume
Regional economy	Development status	x_3GDP
	Industrial level	x_4Gross industrial output x_5 Industrial enterprises above designated size
	Commercial level	x_6Total value of wholesale and retail trade x_7Total volume of social retail sales
	Foreign trade	x_8Foreign investment in actual use x_9Total foreign trade value
	Social reproduction conditions	x_{10}Fixed investment
	Development potential	x_{11}Average increasing rate of GDP
Policy environment	Policy orientation	x_{12}The administrative attribute x_{13}Level of marshalling station x_{14}Transportation environment index x_{15}Logistics status index
Environmental friendliness	Sustainable development potential	x_{16}GDP per capita energy consumption x_{17} Investment on environmental pollution treatment-GDP ratio x_{18}Recycling rate

Table 3. Container traffic via rail-sea intermodal transportation in Dalian

(Thousands of TEU)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Total container throughput	1217	1352	1670	2202	2350	3212	3810	4500	4550	5262	6350
Growth rate	20%	11%	24%	32%	21%	21%	19%	18%	1.1%	15.6%	20.7%
Container transported by rail-sea	68	82	197	182	136	159	180	235	253	291	362
Growth rate	54.5%	20.1%	141%	-8.5%	-26%	17.1%	14%	31%	8.0%	15%	24.4%

Table 4. Fuzzy clustering centres (see Table 2 for explanation of x_1 to x_{18})

Category	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
I	0.98	11023.28	3374.38	5939.34	1713	1225.76	1309.17	8.33	128.70
II	0.69	15299.31	2168.59	2498.20	2135	941.29	575.05	8.24	33.81
III	0.47	7702.80	936.77	1336.05	773	182.91	287.34	2.01	12.07
IV	0.31	3450.85	415.49	376.72	284	70.91	129.18	0.72	8.66
Category	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}	x_{15}	x_{16}	x_{17}	x_{18}
I	2671.28	15.23	2	1.04	5.84	1.02	3.18	0.003	99.10
II	1261.94	15.33	1.04	0.04	1.22	0.05	1.30	0.001	30.50
III	653.63	15.56	1.00	0.19	0.45	0.01	1.57	0.004	66.98
IV	289.42	18.40	1.00	0.02	0.18	0.00	1.97	0.003	80.45

Table 5. Membership degrees of inland cities

City	I	II	III	IV	City	I	II	III	IV	City	I	II	III	IV
Hulunbuir	0.09	0.16	0.35	0.41	Tieling	0.13	0.27	0.37	0.23	Qiqihar	0.10	0.19	0.38	0.33
Hinggan	0.07	0.12	0.21	0.61	Chaoyang	0.08	0.15	0.35	0.43	Jixi	0.05	0.09	0.17	0.69
Tongliao	0.10	0.22	0.46	0.22	Changchun	0.77	0.09	0.07	0.06	Hegang	0.07	0.11	0.20	0.63
Chifeng	0.07	0.15	0.20	0.58	Jilin	0.13	0.42	0.26	0.19	Shuangyashan	0.04	0.07	0.13	0.77
XilinGol	0.08	0.14	0.32	0.45	Siping	0.08	0.15	0.38	0.40	Daqing	0.20	0.41	0.22	0.18
Shenyang	0.33	0.25	0.22	0.21	Liaoyuan	0.07	0.12	0.24	0.57	Yichun	0.07	0.12	0.21	0.59
Anshan	0.07	0.72	0.12	0.09	Tonghua	0.08	0.15	0.41	0.36	Jiamusi	0.05	0.09	0.48	0.37
Fushun	0.08	0.18	0.20	0.54	Baishan	0.07	0.12	0.26	0.54	Qitaihe	0.06	0.10	0.19	0.66
Benxi	0.08	0.16	0.55	0.22	Songyuan	0.07	0.15	0.58	0.20	Mudanjiang	0.09	0.16	0.44	0.31
Fuxin	0.05	0.08	0.16	0.72	Baicheng	0.05	0.08	0.15	0.71	Heihe	0.08	0.13	0.22	0.58
Liaoyang	0.09	0.17	0.24	0.50	Harbin	0.24	0.32	0.23	0.20	Suihua	0.07	0.13	0.25	0.54

Table 6. Export demand in hinterland (TEU)

City	Hulunbuir	Hinggan	Tongliao	Chifeng	XilinGol	Shenyang	Anshan
Cargo	7930	123	2480	7459	22081	162124	67368
City	Fushun	Benxi	Fuxin	Liaoyang	Tieling	Chaoyang	Changchun
Cargo	20652	65161	5149	17201	17872	10508	76431
City	Jilin	Siping	Liaoyuan	Tonghua	Baishan	Songyuan	Baicheng
Cargo	19289	2483	1778	5876	6800	3212	3365
City	Harbin	Qiqihar	Jixi	Hegang	Shuangyashan	Daqing	Yichun
Cargo	72026	19251	23523	3672	37913	18327	4097
City	Jiamusi	Qitaihe	Mudanjiang	Heihe	Suihua		
Cargo	101132	2995	133682	82342	2445		

Table 7. Capacity levels and installation costs of candidate dry ports

Dry port	Capacity level	Capacity (million TEU)	Installation cost (million USD)	Dry port	Capacity level	Capacity (million TEU)	Installation cost (million USD)
TL	1	0.03	9.6	SYN	1	0.04	11.2
	2	0.04	11.2		2	0.05	16
	3	0.05	12.8		3	0.06	20.8
AS	1	0.05	17.6	QH	1	0.05	16
	2	0.06	20.8		2	0.06	20.8
	3	0.07	25.6		3	0.07	24
BX	1	0.05	16	DQ	1	0.08	28.8
	2	0.06	20.8		2	0.1	33.6
	3	0.07	24		3	0.12	43.2
TLG	1	0.03	9.6	JMS	1	0.1	32
	2	0.04	12.8		2	0.12	41.6
	3	0.05	16		3	0.15	49.6
TH	1	0.04	11.2				
	2	0.05	16				
	3	0.06	20.8				

Table 8. Capacities of existing dry ports (million TEU)

Dry port	MDJ	HB	SY	CC	JL
Capacity	0.15	0.1	0.25	0.15	0.06

Source: the port of Dalian

Table 9. Result of GA and objective value

Chromosome	objective value
{0 0 0 0 0 0 1 0 1 1 2 2 2 1 2 1 1 3}	-4.1187e08

Table 10. Hinterland cargos allocation

	Optimal dry ports		Existing dry ports					Seaport
	QH	JMS	MDJ	HB	SY	CC	JL	DL
Hulunbuir	7930	-	-	-	-	-	-	-
Hinggan	-	-	-	-	-	123	-	-
Tongliao	-	-	-	-	-	2480	-	-
Chifeng	-	-	-	-	-	-	-	7459
XilinGol	-	-	-	-	-	-	-	22081
Shenyang	-	-	-	-	162124	-	-	-
Anshan	-	-	-	-	-	-	-	67368
Fushun	-	-	-	-	20652	-	-	-
Benxi	-	-	-	-	49352	-	-	15809
Fuxin	-	-	-	-	-	-	-	5149
Liaoyang	-	-	-	-	-	-	-	17201
Tieling	-	-	-	-	17872	-	-	-
Chaoyang	-	-	-	-	-	-	-	10508
Changchun	-	-	-	-	-	76431	-	-
Jilin	-	-	-	-	-	-	19289	-
Siping	-	-	-	-	-	2483	-	-
Liaoyuan	-	-	-	-	-	1778	-	-
Tonghua	-	-	-	-	-	5876	-	-
Baishan	-	-	-	-	-	6800	-	-
Songyuan	-	-	-	-	-	3212	-	-
Baicheng	-	-	-	-	-	3365	-	-
Harbin	-	-	-	72026	-	-	-	-
Qiqihar	19251	-	-	-	-	-	-	-
Jixi	-	4288	16318	-	-	-	2917	-
Hegang	-	3672	-	-	-	-	-	-
Shuangyashan	-	37913	-	-	-	-	-	-
Daqing	-	-	-	18327	-	-	-	-
Yichun	-	-	-	4097	-	-	-	-
Jiamusi	-	101132	-	-	-	-	-	-
Qitaihe	-	2995	-	-	-	-	-	-
Mudanjiang	-	-	133682	-	-	-	-	-
Heihe	22819	-	-	3105	-	47452	8966	-
Suihua	-	-	-	2445	-	-	-	-
Total	50000	150000	150000	100000	250000	150000	31172	145575

List of Figures