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An inland-depots-for-empty-containers-model for the hinterland

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Abstract

Purpose – The purpose of this paper is to figure out in which way a hinterland-based inland depot model can help a shipping company in solving the empty container problem at a regional level. The repositioning of empty containers is a very expensive operation that does not generate profits. Consequently, it is very important to provide an efficient empty container management.

Design/methodology/approach – In this paper, the empty container problem is discussed at a regional repositioning level. For solving this problem, a mixed-integer linear optimization model is developed and validated by using the German hinterland as a case.

Findings – The findings show that the hinterland-based solution is able to reduce the total system costs by 40 per cent. In addition, total of truck kilometres could be reduced by more than 30 per cent too.

Research limitations/implications – This research is based on German data only.

Originality/value – This paper closes the gap in empty container repositioning research by looking at the hinterland dimension from a single shipping company point of view.

Keywords Optimization problem, Container management, Empty container problem, Hinterland, Modified IDEC

Paper type Case study

Introduction

The implementation of reusable containers in 1965 has revolutionized the international exchange of goods (Kendall and Buckley, 2001; Vojdani and Lootz, 2011). Between 2000 and 2010, the global container traffic in form of port throughput has more than doubled, starting with 236.7 million twenty-foot equivalent unit (TEU) in 2000 and rising to 548.5 million TEU in 2010 (Drewry Shipping Consultants, 2011). According to the United Nations Conference on Trade and Development (UNCTAD) Review of Maritime Transport (2014), the world container port throughput surpassed 651 million 20-ft containers in 2013. The rate of empty containers in the total container amount has only minor fluctuations and remains in the past five years at an average of 21.3 per cent (Drewry Shipping Consultants, 2011). This induces the question of how to manage empty containers as the use of containers in trade requires these empties to be available at the right time at the right place in the right condition for being used again (Vojdani *et al.*, 2010). Thus, the overall objective of empty container management is to make containers available for reload while minimizing transport costs and maximizing benefits.

The transport of empty containers is often inevitable, as the place where containers are discharged and the place where the loading takes place are generally not the same. Efficient empty container management is therefore very important for shippers because

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the transportation of empty boxes causes substantial costs, which are nearly as high as the transportation of full containers. Consequently, shippers can generate profits when delivering a full container, but they cannot generate any profit by repositioning of empty containers (Exler, 1996).

According to Drewry Shipping Consultants (2011), each repositioning amounts to US$400 per container. Overall, most of the empty containers are transported over land (Konings, 2005) and it is often assumed that a container remains empty for more than half of its useful economic life, being under repair, maintenance or in transit (De Brito and Konings, 2008). Apart of this, there are also 1.5 to 2.5 million TEUs stored in the hinterland of seaports so that there is also a high space requirement, often resulting in a shortage of storage areas in ports (Vojdani and Lootz, 2011). "For the benefit of port operators, shippers and carriers, the number of empty boxes sitting at the terminals should ideally be nil or very few" (Boile *et al.*, 2004). By looking closer at the cost structure in container traffic (Exler, 1996), we can further see that hinterland transportation has the biggest share on those costs, thus it offers the highest potential for cost savings.

In this paper, we are going to propose a model of inland-depots-for-empty-containers (IDEC) by positioning the container depot in the hinterland of a port. By doing so, we expand the notions of Mittal (2008) by looking at this particular problem from a more realistic single-company point of view. Thus, the purpose of this paper is to figure out in which way our suggested model is able to improve the efficiency of empty container management from the perspective of the shipping company.

The paper is organized as follows: The first section of this paper introduces the process and related costs of repositioning empty containers. Afterwards the paper presents the results of a critical review of operations research (OR) related literature, which deals with the empty container problem in general as well as from the perspective of hinterland. Then, the inland depot model that solves the empty container problem in the hinterland of ports by considering regional repositioning is developed. This also includes an empirical validation by simulation on the ground of a case study. The paper ends up with a critical conclusion and an outlook for future research.

Repositioning of empty containers

The management and organization of repositioning

The whole process of container logistics starts with discharging at an importer's place and ends with the positioning of containers at an exporter's location (Furio *et al.*, 2009). The repositioning of empty containers is understood as the transfer of a discharged container to a place where it can be refilled with cargo (Theubert, 2010). Usually, every full container movement is followed by an empty transport to meet subsequent orders. Thus, the process of repositioning is thus unavoidable (Mittal, 2008; Vojdani and Lootz, 2011).

The process of container repositioning can be accomplished at a local, interregional or global level (Mittal, 2008).

Repositioning at a global level is a very complex process and is mostly done by shippers (Furio *et al.*, 2009). Figure 1 shows the return of empty containers at this level is between two foreign seaports. Typically, this process happens often between regions with an empty container surplus and container demanding regions to offset the imbalance (Boile *et al.*, 2008; Furio *et al.*, 2009; Mittal, 2008). Suppose port A is located in a so-called supply region and port C in a demand region. After having transported of a full container from port C to port A, the return is often done immediately by sea to port C (Mittal, 2008).

In case of repositioning at an interregional level, the repositioning of empty containers between two regions is done by land route. This type of reposition is necessary when the importing region and the consuming region are not the same. In the case where a full container is imported through port B and the consumer is located in port A, transportation by land route is inevitable for a transport of a full and an empty container (Boile *et al.*, 2008; Mittal, 2008). Here, transportation is mainly done by trucks, trains and barges (Mittal, 2008; Notteboom and Rodrigue, 2007).

The repositioning at local or regional level takes place between importers, exporters, ports and depots (Boile *et al.*, 2008; Notteboom and Rodrigue, 2007). Here, the truck is mainly used. Rail transport is an inefficient method of transportation in this case, due to terminal and drayage costs (Resor and Blaze, 2004). Contrary to the literature, regional repositioning in Germany is also been done by truck, train and barge (Bruns, 2012).

The costs of repositioning

The transportation costs of an empty container are similar to the costs of a loaded one. Whereas in a full container transport a carrier bears the resulting costs, it is the shipper who pays the costs in case of an empty transport.

To identify cost savings potentials in container traffic and repositioning, it is necessary to look at the cost structure of a supply chain in international container traffic. However, Stopford (2009) argues that it is difficult to find an equal cost allocation in container transport for the ocean carriers as the cost structures of different carriers are not similar and not very transparent. Due to this, it is necessary to generate an overview of the cost structure, which can be generally classified into four main groups (Breitzmann *et al.*, 1993; Exler, 1996; Malchow and Schulze, 1993):

(1) transport costs of initial and final trips in hinterland;
(2) costs of container throughput;
(3) costs of main run (sea transport); and
(4) other costs.

Transport costs in hinterland consists of the costs of carriage in inland from source to port and from port to sink by using a transportation mode like truck, train or barge (Exler, 1996; Konings, 2005). In addition, the costs for the container chassis belong to this group too. The costs of container throughput consist of charges for container storage and all other expenses in handling between fore-run and main run and main run and back-run. Movement costs arise while the container is on sea and are considered to be time- and travel-dependent operating costs. Travel-dependent costs include port and canal fees, costs for tugboats and pilots, as well as fuel costs. The expenses for the crew,

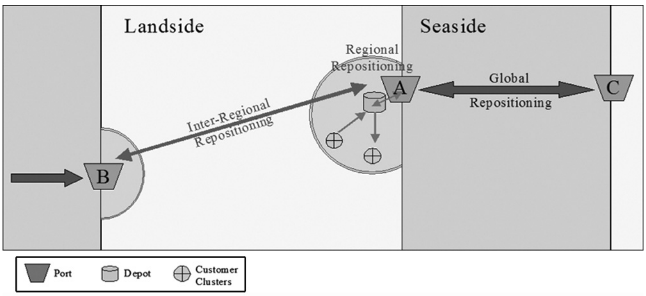

Figure 1.
Types of repositioning

Source: Mittal (2008)

insurance, equipment, repairs and maintenance are among the time-dependent operating costs (Stopford, 2009). Other costs refer to expenses like costs of sales and marketing, administrative costs, various repair and maintenance costs of the container and documentation costs (Pawlik, 1999).

The ratio of these individual costs in relation to the total costs is difficult to be quantified and they often vary. Exler (1996) pointed out that the inland costs represent 60 per cent of the total costs, while Hastings (1997) presents a ratio of about 50 per cent and Schwarz (2006) presented an empirical ratio of even 70 per cent. The share of sea transport is between 25 and 35 per cent depending on the covered sea distance and the travelled distance in hinterland (Notteboom, 2002; Schwarz *et al.*, 2006; Stopford, 2002). The costs for container throughput are estimated by around 20 per cent (Lun *et al.*, 2010; Stopford, 2002) and the rest is allotted to other costs.

Overall, the share of hinterland costs in relation to total costs show its importance as well as opportunities for significant cost savings.

State of the art of solving the empty container management problem

Table I shows an overview to operations research (OR)-related research in the area of empty container management. The literature has also been viewed from the point of view of whether the hinterland aspect has been (explicitly or implicitly) addressed.

Even though the repositioning of empty containers is considered to be a highly relevant problem in the industry, there is a lack of relevant research in this area.

One of the early works is by Florez (1986) who addressed the problem of repositioning and leasing of empty containers from the viewpoint of ocean-going vessels by setting up a profit optimization model.

Dejax and Crainic (1987) were the first who published an overview article focusing on empty flow management. The authors used several criteria to "classify the problems and models on empty freight vehicle travel" (Dejax and Crainic, 1987). They differ between policy models and operational models and they used criteria to define the problem like the type of flow, the transportation mode and so on. Dejax and Crainic (1987) also deducted criteria for defining the methodological approach such as modelling assumption and solution techniques. By means of these criteria, an overview of the state of the art has been done and in the end of the paper current research trends are derived (Dejax and Crainic, 1987).

Crainic *et al.* (1993) then developed a model for distribution and allocation of empty containers between land transportation and maritime shipping transportation by interpreting the problem as a minimum cost network flow problem.

To improve the repositioning of empty and full containers in liner shipping, Cheung and Chen (1998) suggested a two-stage stochastic network. Jula *et al.* (2006) focuses on regional repositioning and its optimization by setting up a network problem.

To reduce total transportation costs in empty container transportation, Mittal (2008) developed a warehouse-location model. This model opens new depots next to customers to reduce empty transportation routes driven by trucks and in addition to reduce the congestion near the ports by adding new space in hinterland.

In the paper by Furio *et al.* (2009), a network flow problem is presented that should reduce the land transportation costs and in addition it should minimize storage costs. The optimization of the provision of empty containers at seaports is the subject of the work by Vojdani (2010). She builds up his model by the principle of grey boxing and adds an integer linear optimization problem taking the shippers' perspective (Vojdani, 2010). Furthermore

Author	Theme aspect	Used method/sort of problem
Empty container repositioning in hinterland		
Florez, 1986	Container repositioning and leasing	Profit optimization model
Dejax and Crainic (1987)	Fleet management in container transport	Theoretical
Crainic *et al.*, 1993	Distribution and allocation of empty containers	Minimum cost network flow problem
Cheung and Chen (1998)	Repositioning in liner-shipping	Two-stage stochastic network
Jula *et al.*, 2006	Regional repositioning of empty containers	Network problem
Mittal, 2008	Regional repositioning of empty containers	Warehouse-location-problem
Furió *et al.*, 2009	Reduction of land transportation costs and storage costs	Network flow problem
Vojdani, 2010	Container pooling	Linear optimization problem
Sterzik, 2013	Container sharing	Vehicle routing problem
Empty container management and hub and spoke network		
Meng and Wang (2011)	Liner shipping service network, hub and spoke, multi-port calling option	Mixed-integer linear programming model
Empty container management in practice		
Hanh, 2003	South California	Overview of practice
Mittal, 2008	New York New Jersey	Overview of practice
Hüttmann 2013	North Range	Analyses of empty container management
Intermodal transport in empty container management		
Choong *et al.*, 2002	Intermodal container transport in hinterland, focus barge	Integer optimization problem
Olivo *et al.*, 2005	Interregional repositioning in Mediterranean area	Mixed-integer optimization problem
Wang and Wang (2007)	Empty container repositioning	Integer optimization problem
OR models with real applications		
Olivo *et al.*, 2005	Interregional repositioning in Mediterranean area	Mixed-integer optimization problem
Jula *et al.*, 2006	Regional repositioning of empty containers	Network problem
Mittal, 2008	Regional repositioning of empty containers	Warehouse-location problem

Table I.
Literature overview

Meng and Wang (2011) deal with a hub-and-spoke network for empty container repositioning when multiple ports are called.

Some of the identified papers are embedded in an empirical setting such as Mittal (2008) who describes in her dissertation the empty container management in the port region of New York/New Jersey or by Hanh (2003) who examines the Southern California Region. In these two works, empty containers are always repositioned over the port and thus a high number of empty runs are generated.

Only a few articles could be identified which have the subject of empty container management and intermodal transport. Here, Choong *et al.* (2002) developed an integer model for the intermodal transportation of empty containers in hinterland. The author regards intermodal transportation, but the focus of their model is the barge. Olivo *et al.* (2005) focused on an interregional repositioning of empty containers in the Mediterranean area by examining all three types of transportation, truck, train and barge. Overall, Olivo *et al.* (2005) want to reduce total transportation costs by using a mixed-integer optimization model. Wang and Wang (2007) also developed an integer optimization model for solving the empty container problem by using intermodal transport for reducing the transportation costs between port-to-port, port-to-exporter and importer-to-port.

Sterzik (2013) showed in his dissertation how trucking companies could improve their routes when container sharing between different companies is allowed. Therefore, he formulated two exact mixed-integer-programming (MIP) models for this problem. In the first scenario, the operating companies are not allowed to make street turns and they "only have access to its own empty containers" (Sterzik, 2013), and in the second scenario, container sharing is allowed and the company participates in such a concept. In a last step, he formulated a tabu-search heuristic several trucking companies and not only for one like in the MIP.

Hüttmann (2013) though wrote in her dissertation about the major problems in empty container repositioning. She analysed the determinants in empty container flows first in theory and second she formulated "an augmented gravity model within panel data framework" (Hüttmann, 2013) with which the determinants can be analysed and empirically verified.

Overall, it is particularly noticeable that only few contributions deal with the empty container management in practice and therefore depict reality. So far, this topic is only devoted by Hanh (2003) and Hüttmann (2013) in detail and partially by Mittal (2008). Also, only few sources were identified that address intermodal transport in their proposed solutions for hinterland. Only Choong *et al.* (2002), Olivo *et al.* (2005) and Wang and Wang (2007) consider in their essays all modes of transportation, with the exception of the aircraft.

The literature review revealed that most of the proposed solutions dealing with the optimization of empty container management are purely theoretical. A real-life implementation, or a case study on the developed models, can only be found in the works by Jula *et al.* (2006), Mittal (2008) and Olivo *et al.* (2005). This paper shall close this research gap by introducing a model with a possible scenario for optimizing the empty container repositioning in Germany's hinterland.

Suggesting an IDEC model for the hinterland

The starting point of the considerations is the IDEC model presented by Mittal (2008), who developed a model which minimizes the total transport costs and adds additional space for storing containers in the hinterland by opening new depots next to customer destinations.

Mittal's (2008) model is based on the following assumptions:

- *A1*. there is no direct empty container transport between the importers and exporters in the region;
- *A2*. there is no transport of empty containers between the depots in the region;
- *A3*. all incoming empty containers arrive at the depot at the beginning of a time period t, and all outgoing containers leave the depot at the end of a time period t;
- *A4*. transport costs are linear costs;
- *A5*. operating costs for a depot do not vary between depots and are considered to be the same for every location, as depots are located in the same region;
- *A6*. customer locations as well as their agglomerations remain in the future the same;
- *A7*. a shipper can only receive/send a container from/to one depot to which the shipper is assigned to and if it is according to trading agreements; and
- *A8*. all variables that are not included in the formulation are set to 0.

Mittal (2008) formulated her model as "an inventory-based capacitated depot location problem under deterministic […] demand patterns" (Mittal, 2008) with a planning horizon of 10 years.

In this paper, modifications were done for the purpose to define a model, which minimizes the total transport costs in the hinterland. Using the case of a German port's hinterland shall validate the proposed model. Hinterland is here defined as the area, which is served with goods by a port (Notteboom and Rodrigue, 2007).

To deal with this, Mittal's (2008) approach was adapted in some points while keeping the original assumptions A1 to A2 as well as A4 to A8.

However, in the presented model, containers are considered to arrive and to leave the depot at the same time (= modification of A3).

The time horizon is limited to one single period instead of the planning horizon of 10 years. By doing this, this model does not include the time variable t as t = 1. This modification was done to exclude uncertainty as well as to maintain a more realistic scenario as compared to a time horizon of 10 years that requires the forecast of a lot of data that do not contain in a realistic manner certain developments in data progression as for example (f.e.) the development of property prices or fuel price developments as well as extrapolations of empty container demand and supply. In addition, it is difficult to foresee which clients exit and enter the market.

Furthermore, a more micro-perspective was introduced to the model by looking at the optimization of the network of one single shipping company and not the networks of different companies. As such, Mittal's (2008) variable I can be ignored.

The shipping company is going to work with one single depot operator whereby d = 1 is valid. Due to the single operator condition, variable d can be omitted.

Each import and each export client delivers to only one depot. To achieve a better clarity, we waive the labels l ∈ L, j∈ Imp and k ∈ Exp and so on. Therefore, we can summarize as follows:

- there are no direct transports between an importer and an exporter;
- there are no transports between the depots in a region;
- the cost structure is linear where operating costs at each depot are equal;
- a shipper can get a container out of a depot, if assigned to it;
- each exporter and importer is also assigned to only one depot; and
- variables, which are not in the formulation, have to be zero.

Following parameters are used for model development:

- i: Depot, $i'(i \in F)$;
- F: Set of depot facilities in the region $(F = EF \cup NF)$;
- EF : Set of existing depot facilities $(i \in EF)$;
- NF : Set of potential depot facilities $(i \in NF)$;
- Exp : Set of export customers $(k \in Exp)$;
- Imp : Set of import customers $(j \in Imp)$;
- H : Set of Ports $(h \in H)$;
- S_j : Supply of empty containers from importer, $j'(j \in Imp)$;
- D_k : Demand of empty containers by exporter, $k'(k \in Exp)$;
- S_h : Supply of empty containers from port, $h'(h \in H)$;

- D_h : Demand of empty containers by port, h' $(h \in H)$;
- K_i : Storage capacity of the depot, i' $(i \in F)$;
- f_i : Fixed cost of opening depot, i' $(i \in F)$;
- $d_{ik}, d_{ji}, d_{ih}, d_{hi}$: Distances between respective nodes;
- $c_{ik}, c_{ji}, c_{ih}, c_{hi}$: Transport costs between respective nodes;
- x_{ji}: Volume of empty containers, transported from importer, j' to depot, i' $(i \in F, j \in Imp)$;
- x_{ik} : Volume of empty containers, transported from depot, i' to exporter, k' $(i \in F, k \in Exp)$;
- x_{ih} : Volume of empty containers, transported from depot, i' to port, h' $(i \in F, h \in H)$;
- x_{hi} : Volume of empty containers, transported from port, h' to depot, i' $(i \in F, h \in H)$;
- V_i : Inventory of empty containers in depot, i' $(i \in F)$;
- $y_i : \begin{cases} 1, \textit{if depot'i'will be opened} \\ 0, \textit{otherwise} \end{cases} (i \in F)$;
- z_{ji} : Decision variable for the assignment of importer, j' to depot, i' . z_{ji} is a dummy variable and could be 0 or 1;
- $z_{ji} = \begin{cases} 1, \textit{if Importeur'j'is assigned to depot'i'} \\ 0, \textit{otherwise} \end{cases} (i \in F, j \in Imp)$;
- z_{ik} : Decision variable for the assignment of depot, i' to exporter, k' . z_{ik} is a dummy variable and could be 0 or 1;
- $z_{ik} = \begin{cases} 1, \textit{if exporteur'k'is assigned to Depot'i'} \\ 0, \textit{otherwise} \end{cases} (i \in F, k \in Exp)$.

The objective function is the following:

$$Z = min \sum_{i \in F} f_i \times y_i + \sum_j \sum_i (S_j \times x_{ji} * c_{ji}) + \sum_i \sum_k (D_k \times x_{ik} \times c_{ik}) \\ + \sum_i \sum_h (x_{ih} \times c_{ih}) + \sum_h \sum_i (x_{hi} \times c_{hi}) \quad (1)$$

The first term presents the fixed costs for opening a depot. The following terms two to five stand for transportation costs within the network. For example, the second and the third term are transportation costs between importer and depot, respectively, exporter and depot. At fourth and fifth place, the costs between port and depot or rather depot and port are shown. Besides the objective function, there are some constraints

$$\sum_i x_{hi} = S_h; \forall h \in H \quad (2)$$

$$\sum_i x_{ih} = D_h; \forall h \in H \quad (3)$$

$$\sum_i x_{ji} = 1; \forall j \in Imp \quad (4)$$

$$\sum_i x_{ik} = 1; \forall k \in Exp \quad (5)$$

$$z_{ji} \leq y_i; \forall i \in F, j \in Imp \tag{6}$$

$$z_{ik} \leq y_i; \forall i \in F, k \in Exp \tag{7}$$

$$\sum_i \sum_j x_{ji} \times S_j = \sum_j S_j \times z_{ji}; \quad \forall i \in F, j \in Imp \tag{8}$$

$$\sum_i \sum_k x_{ik} \times D_k = \sum_k D_k \times z_{ik}; \quad \forall i \in F, k \in Exp \tag{9}$$

$$V_i + \sum_h x_{hi} + \sum_j x_{ji} \times S_j - \sum_k x_{ik} \times D_k - \sum_h x_{ih} \leq K_i \times y_i; \quad \forall i \in F \tag{10}$$

$$V_i + \sum_h x_{hi} + \sum_j x_{ji} \times S_j - \sum_k x_{ik} \times D_k - \sum_h x_{ih} \geq 0; \qquad \forall i \in F \tag{11}$$

$$y_i = 1; \forall i \in EF \tag{12}$$

$$x_{ji} \geq 0; \forall i \in F, j \in Imp \tag{13}$$

$$x_{ik} \geq 0; \forall i \in F, k \in Exp \tag{14}$$

$$x_{ih} \geq 0; \forall i \in F, h \in H \tag{15}$$

$$x_{hi} \geq 0; \forall i \in F, h \in H \tag{16}$$

$$V_i \geq 0; \forall i \in F \tag{17}$$

$$x_{ji}, x_{ik}, x_{ih}, x_{hi}; \ \in \mathbb{N} \tag{18}$$

$$0 \leq y_i \leq 1; \forall i \in NF, \ y_i \in \{0, 1\} \tag{19}$$

$$0 \leq z_{ji} \leq 1; \forall i \in F, j \in Imp, \ z_{ji} \in \{0, 1\} \tag{20}$$

$$0 \leq z_{ik} \leq 1; \forall i \in F, k \in Exp, \ z_{ik} \in \{0, 1\} \tag{21}$$

Constraints (2)-(5) are presenting the demand and supply of empty containers by the port, the exporter and the importer (Mittal, 2008). Each importer can be assigned to a depot, where it is open (6). The same for exporters means constrain (7) (Jacquemin, 2006). Constraints (8) and (9) ensure that the whole transport volume uses the same link. The first one belongs to the link importer to depot and the second one to the link depot to exporter (Jacquemin, 2006). To make a container go into a depot and also to go out of a depot at the same time is fixed with the constraint (10). Constraint (11) ensures that not more containers can go out of a depot, as containers are inside. With constraint (12), all already existing depots are kept open (see Mittal, 2008). All decision variables are defined as continuous and non-negative by equations (13)-(17). Constraint (18) defines the variables as integer, and constraints (19)-(21) define the variables as a dummy variable, so they are binary and can be only 0 or 1.

To illustrate the efficiency of the modified IDEC, an empirical case study by comparing two scenarios is going to be examined. The first scenario refers to a network with three depots in a radius of 180 km around a port and the port. In this scenario, all importers and exporters are assigned to these three depots. In the second scenario, the modified IDEC will be used. In this case, the same setting like in the first one is used, but additionally seven possible inland depot locations are introduced, which can be opened. The port of Bremerhaven and its hinterland represent the case study region. The necessary empirical data (e.g. customer and facility locations of customers) were collected through several interviews with the Inland Operations Manager of a shipping company and some additional data were collected by literature.

Empirical assessment of the modified IDEC

For each depot and their customers, the transport volume x_{ji}, x_{ik}, x_{hi}, x_{ih} and the storage capacity K_i are needed. The number of containers was assessed based on the size of companies and their sales volume. The data for the storage capacity for each depot were collected from existing homepages of depot facilities.

The distances between each depot and each customer d_{ik}, d_{ji}, d_{ih}, d_{hi} were calculated with Google maps. The transportation cost c_{ik}, c_{ji}, c_{ih}, c_{hi} of a container (TEU) per km is based on a study of truck toll by Rhenus Logistic (2003). The indicated costs in the study were supplemented by current average price of diesel fuel as well as current tolls.

The location opening costs for each depot include the land price, costs for the infrastructure, as well as investment costs for the equipment and clearance costs as suggested by Mittal (2008).

For finding an exact solution for this problem, a branch-and-bound algorithm was applied by using software Lingo 8.0. The overall results are shown in Table II.

The solution of scenario A is shown in Figure 2. Here the identified total system costs amount 267,194,523 € and the total driven kilometres by truck are 180,536,840 km. The driven distance is composed of the sum of travelled distance between customer locations and depots and in addition between depots and port.

The locations of the importers are represented in Figure 2 by diamonds and the locations of the exporters by triangles. The port is characterized through a square and the depots by a circle. White arrows indicate the flow of empty containers from an importer to a depot or from a depot to an exporter. The empty container flow from and to the global repositioning is symbolized by grey arrows.

Figure 2 shows clearly that nearly all container movements are done by the depot of Bremen. The depot of Bremerhaven, only one customer is assigned, and to the one in Hamburg, five customers are allocated. Containers for global repositioning only went out of the depot in Bremerhaven, and the containers from global repositioning are distributed to Bremerhaven and Bremen.

The result of scenario B is shown in Figure 3. The total system costs are estimated in this case at 106,881,095 €. Thereby, 90,428,000 € is the transportation cost, and 16,453,095 € is the cost of opening new depots. The total distance driven by trucks is 61,100,000 km.

From scenario B, it is evident that the depot locations of Duisburg, Nürnberg, Augsburg, Halle, R üsselsheim and Fürstenwalde are opened. In addition, each depot location is assigned a certain number of customers. Only the depot in Bremerhaven is not used for regional repositioning, as it is exclusively used for global repositioning. Next to this depot, the depot of Hamburg and Bremen are also involved here.

Scenario	Total system costs in €	Total driven km by truck	No. of used depots in network
Scenario A	267,194,523	180,536,840	3
Scenario B	106,881,095	61,100,000	9

Table II.
Solution overview

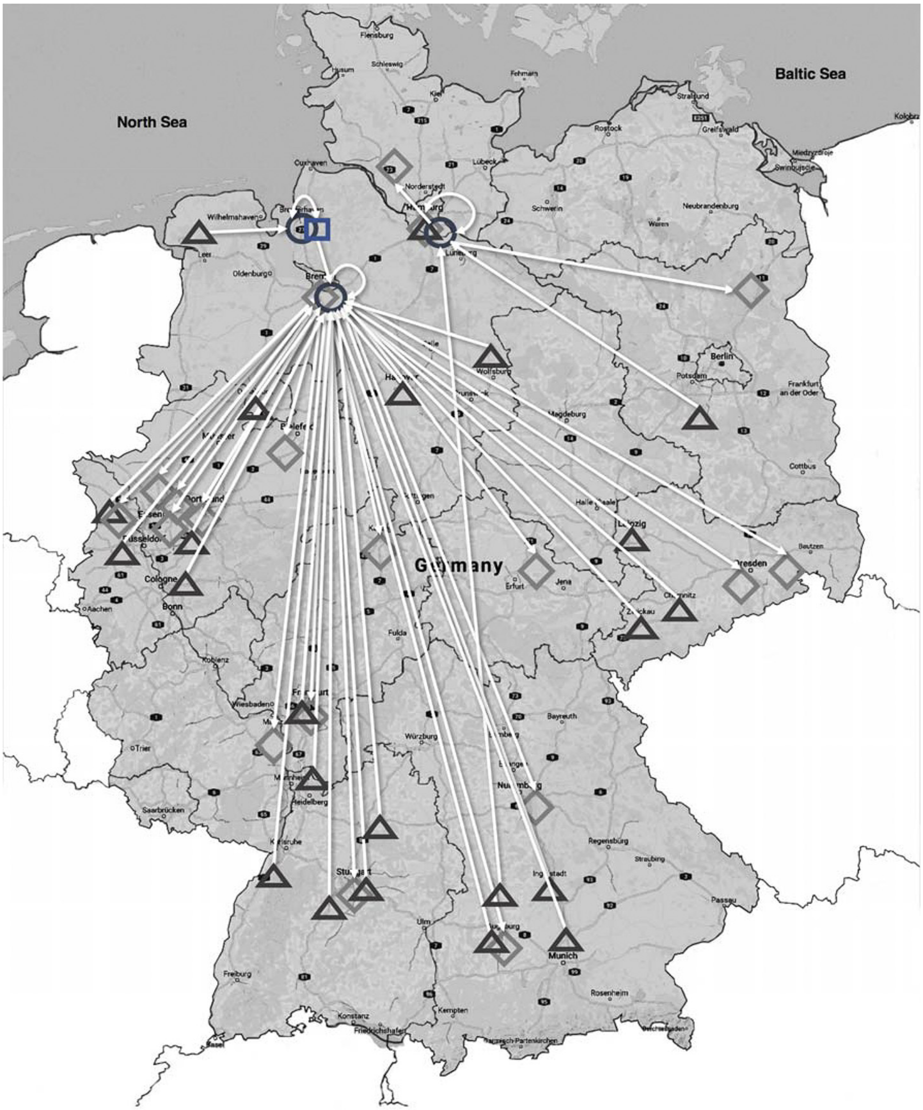

Figure 2.
Solution of case A

Discussion, limitations, conclusion and outlook

The contribution of this paper was to show how the implementation of a modified inland depot model can help to reduce the total system costs in empty container management on a regional level.

Our modified model came up with reduced total system costs as well as decreasing number of empty runs. The total number of kilometres in scenario B showed a reduction by nearly a one-third as compared to scenario A. The newly opened depots and the allocation of

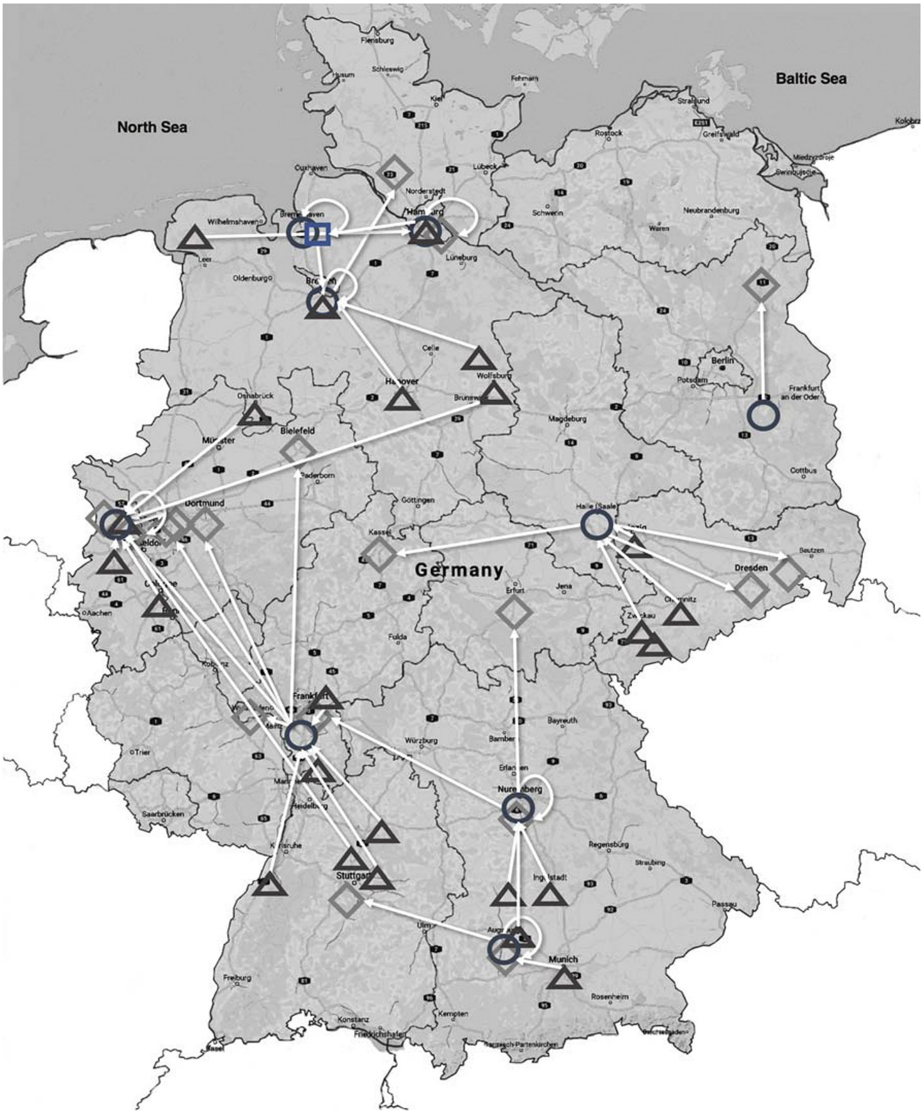

Figure 3.
Solution of case B

customers to depots in proximity of customer can justify this, as total costs were even reduced by 40 per cent.

Our case study has shown how effective inland depots can be in terms of reduction of total operating costs as well as of covered distances by trucks. Figure 3 shows that the reduction in the covered distances is mainly due to the reduction of empty runs that can be explained by the opening of new depots and the allocation of customers to these depots on the basis of their distance to the depot. Besides cost reductions, reduction of emissions can also be expected.

To proof viability of this approach, sensitivity analysis needs to be performed; however, this may lead to a complex re-calculation, as the insertion and/or exclusion of importers and exporters to the model can change the whole model approach. In addition, a change in the costs for opening and closing a depot can also impact the model results as well as our time horizon assumption and assumption towards cost linearity. Nevertheless, when diesel prices are going to change according to the past developments (Destatis, 2012), our model leads to additional cost savings. A price increase of 10 €-cent per litre will increase transportation cost from 1.48 €/km to 1.52 €/km per litre and consequently improve the cost advantage of the modified IDEC from about 160m € to 165m €. While transport prices changed by 2.70 per cent, the cost advantage of the modified solution changes by 2.98 per cent.

The introduction of inland depots for empty container repositioning can therefore be welcomed, as repositioning operations at the port site are more expensive than in the hinterland (Bruns, 2012). Any capacity extension of container storage in the hinterland can lead to a relief of limited capacity at the port site.

Nevertheless, the presented model has some limitations and disadvantages. First of all, it is limited to the truck as transport mode. In future research, barge and train as additional transport mode should expand the model. Furthermore, the modified IDEC concentrates on the regional level in empty container repositioning and it is not invented for global repositioning.

In theory, a hinterland-based depot for distribution of empty containers reduces the total costs significantly and probably enhances environmental sustainability by having lower CO_2 emissions. In a real-life setting, there might be some barriers in its application, as f.e. standard rail connections go via the port and the chartering of transverse special train connections is very expensive and thus not profitable. This may also be due to lacking supply and demand as the example of the connection between Munich and Dusseldorf shows. The operation of transverse connections by trucks is also very cost intensive, which is why repositioning is still done through the port.

A model like IDEC or modified IDEC assumes a shipping company to have at each point in time full information on the exact location and loading condition of containers. This is in practice also very difficult to achieve so that shipping companies only have a low share of door-to-door transports as well as hinterland transports. Empty container transports are typically released by the port and operated by freight forwarders. This leads to a minimized disposal of the container and its location by the shipping company (Bruns, 2012).

Besides that, it may also be difficult to identify adequate locations for new depots due to the landscape or other soft location factors as objections by residents. Additionally, the exclusive observation of single depot connections may not be ideal, as the total network needs to be examined to achieve a total optimum.

In future, it is possible to add a multiple planning horizon to the model to have a more realistic case study or to formulate the model for more than one shipper and depot operator. Another possible extension could be the extension of the model by the consideration of handling costs in inland depots.

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