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A fuzzy approach to the location of depots for returned maritime containers

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Abstract: The container depot location problem is usually treated as a cost minimization problem due to the impact of container depots on logistic costs. But these depots, that store the returned empty maritime containers until they are needed, have also an environmental impact in the areas where they are located. In this paper a biobjective model is considered for designing a depots network in a hinterland. The two objectives used are the total cost of the network and the environmental impact generated by the commissioning and maintenance of the container depots and by the transport operations in and out of the depots. As the capacity of a depot is not an exact value, they have been modeled as a fuzzy restriction. An additive fuzzy multiobjective optimization approach has been used to solve the problem. Results were applied to the case of the Port of Valencia, Spain.

Keywords: maritime transportation, empty containers, depots location, environmental impact, fuzzy multiobjective optimization

1. INTRODUCTION

During the last decades maritime container shipping has grown considerably. Containers have become a basic tool for all maritime logistic operations. Once a ship arrives to port and containers are transported to the consignees, the goods are unloaded and the empty containers sent to a depot. In the depots, the containers are stored until shippers need them to export their own goods. As in many regions the amount of imports is much greater than that of export it is necessary to store the resulting empty containers somewhere.

There are multiple reasons that require the storage of containers (Furió 2005): the number of containers in the world doubles the total capacity of ships; the import and export operations are not balanced; the variability in the contents of the containers and the difficulty of the coincidence in time and place of the offer and the demand. Since container terminal storage capacity is limited and expensive other facilities are required for container storage. Also containers require some intermediate operations after they are unloaded by the consignees until a shipper requests them for shipping their own products.

Container depots are generally large facilities in the vicinity of ports and are divided in different zones in which different activities are performed, e.g. the reparation zone; the cleaning zone; the storage zone. The activities performed in these places have an impact in the environment of the area due the pollution, noise and other externalities they produce.

Moreover, the location of a depot involves a large number of heavy transport operations. These operations have also an environmental impact due to externalities like atmospheric, visual and noise pollution, traffic congestion and accidentality rate.

Probably the most important feature of a container depot is its capacity. This feature does not depend exclusively on the area available. The manipulation technologies used, the internal organization of the depot and the stacking height of containers are other factors that need to be taken into account.

In addition to their capacity, an important decision variable is where to locate the empty container depots. In this paper, we propose a multiobjective approach based on the Multicommodity Capacitated Location Problem with Balancing Requirements. The goal is not only to minimize costs but also to minimize the environmental impact due to the setting up and maintenance of the container depots, and to the transport operations in and out of these depots. The capacity of the depots is considered as a fuzzy constraint and a fuzzy optimization approach is used to solve the problem. The proposed approach is applied to the case of the Valencia's hinterland

The organization of this paper is the following: in section 2, a brief review of the relevant literature is presented; section 3 formulates the proposed mathematical model; in section 4, a description of the fuzzy multiobjective optimization approach used to solve the problem is presented and the results of its application applied to Valencia's hinterland; finally concluding remarks are made in section 5.

2. PREVIOUS WORK

2.1 Depot location problem

The Multicommodity Capacitated Location Problem with Balancing Requirements (MCLB) was introduced by Crainic et al. (1989). This problem arises from the need to store empty containers once they are unloaded by the consignees until shippers require them to export their own products. These authors also introduced capacities at the depots, giving the problem a more realistic view. These capacities are an estimate of the number of empty containers that a depot can

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handle. The problem is thus to minimize the total cost which includes the cost of opening the depots and the transportation costs. Several methods have been used to solve this problem. Thus, Crainic et al. (1993) used a branch-and-bound method and later a tabu search while Gendron and Crainic (1995) used a branch-and-bound algorithm.

Gendron et al. (2003) showed that large-scale instances of the MCLB problem cannot be solved efficiently by mixed-integer programming solvers. They combined tabu search with slope scaling obtaining good solutions in this kind of problems. They considered a network G=(N,A) where N represents the set of nodes and A the set of arcs. They used two types of nodes, customers and depots, and each arc determines the existence of commodity flows between nodes. The aim of the problem is to minimize the total cost of the network satisfying the demand of each node.

Li et al. (2004) showed that there exists an optimal pair-critical policy (U, D) for the management of empty containers in a port with stochastic demand. That is, if the number of empty containers is less than U, then containers are imported up to U. Also, if the number of empty container is more than D, the containers are exported down to D. In any other case, do nothing. They also extended the problem for multi-ports applications.

All these papers consider the depot location problem as a cost minimization problem. In this paper, we transform the problem into a biobjective optimization problem introducing the criterion of minimizing also the environmental impact of the depots construction and operation.

2.2 Analytic Hierarchy Process

The Analytical Hierarchy Process (AHP) was introduced by Thomas L. Saaty in the 70's. In the AHP methodology the decision maker inputs a crisp matrix containing pair-wise comparisons between different alternatives. However, many times these comparisons have a degree of uncertainty due to the difficulty to quantify relations with a precise value (Lee et al. 2005) making a fuzzy approach an interesting option.

As in our case obtaining impact data is a difficult task, we decided to use the Fuzzy AHP methodology to take into account the degree of uncertainty in the decision makers comparisons. Fuzzy AHP has been applied to many decision making problems using different techniques (e.g. Chen, 1996, Chang 1996, Csutora and Buckley, 2001, Lee et al., 2005, etc). Thus, to obtain weights for the alternatives Buckley (1985) proposed to extend to fuzzy matrices the geometric mean method used with crisp matrices. To determine the importance weights for the customer requirements Kwong and Bai (2003) used fuzzy AHP with triangular fuzzy numbers for the pairwise comparisons.

2.3 Fuzzy goal programming

Introducing fuzzy set theory in Goal Programming (GP) was first considered by Narasimhan (1980). The main difference between fuzzy goal programming (FGP) and GP is that in FGP the values for the objectives to achieve are specified in an imprecise way. Tiwari et. al. (1987) presented an additive (weighted and preemptive) model to solve fuzzy goal programming using arithmetic addition to aggregate the fuzzy goals.

Chen et. al. (2001) proposed a model based in the additive approach of Tiwari but using lower bound thresholds for the goal membership values instead of weights. They also show that this additive model obtains better results than the original fuzzy optimization approach proposed by Zimmerman (1978). They presented a preemptive goal programming version too.

In this paper we propose a biobjective optimization model for empty container depots location and solve it using an additive fuzzy optimization method. We also used Fuzzy AHP to obtain the impact associated with the transport operations and the setting up and maintenance of each depot. We used LINGO as optimization software.

3. PROBLEM MODELING

The model considered in this paper is based in the model proposed by Gendron et al. (2003). The main difference is that we consider two objective functions instead of one, i.e. we include the environmental impact generated by the depots as the second objective function. Another difference between their model and ours is that we consider three kinds of nodes instead of two: we have shippers/consignees (subindex s), depots (subindex d) and terminals (subindex t). We also consider that any depot or terminal can work with any shipper/consignee. The notation used is shown in Table 1.

Data	
I_{st}	Containers imported by consignee s through terminal t every year.
E_{st}	Containers exported by shipper s through terminal t every year.
K_d	Flow capacity limit of depot d.
K_t	Flow capacity limit of terminal t.
C_d	Storage capacity of depot d.
f_d	Fixed operation cost of depot d.
c_{st}^{ST}	Unit transport cost between shipper/consignee s and terminal t.
c_{sd}^{SD}	Unit transport cost between shipper/consignee s and depot d.
c_{td}^{TD}	Unit transport cost between terminal t and depot d.
w_d	Environmental impact per unit flow from/to depot d.
v_d	Environmental impact per stored unit in depot d.
β	Relation between depot impact and transport impact.
Variables	

x_{st}^{ST}	Container flow from shipper/consignee s to terminal t.
x_{ts}^{TS}	Container flow from terminal t to shipper/consignee s.
x_{sd}^{SD}	Container flow from shipper/consignee s to depot d.
x_{ds}^{DS}	Container flow from depot d to shipper/consignee s.
x_{td}^{TD}	Container flow from terminal t to depot d.
x_{dt}^{DT}	Container flow from depot d to terminal t.
δ_d	Binary variable that indicates if depot d opens or not.

Table 1. Notation for model data and variables

The problem can be formulated as:

$$\min \sum_d f_d \delta_d + \sum_s \sum_{t \in T(s)} c_{st}^{ST} (x_{st}^{ST} + x_{ts}^{TS}) + \\ + \sum_t \sum_{d \in D(t)} c_{td}^{TD} (x_{td}^{TD} + x_{dt}^{DT}) + \\ + \sum_s \sum_{d \in D(s)} c_{sd}^{SD} (x_{sd}^{SD} + x_{ds}^{DS}) \qquad (1)$$

$$\min \ 2\sum_d w_d \left(\sum_{s \in S(d)} x_{sd}^{SD} + \sum_{t \in T(d)} x_{td}^{TD} \right) + \beta \sum_d C_d v_d \delta_d \qquad (2)$$

s.t.

$$\sum_{s \in S(t)} x_{st}^{ST} + \sum_{d \in D(t)} x_{dt}^{DT} + \sum_s E_{st} = \\ = \sum_{s \in S(t)} x_{ts}^{TS} + \sum_{d \in D(t)} x_{td}^{TD} + \sum_s I_{st} \qquad \forall t \qquad (3)$$

$$\sum_{s \in S(d)} x_{sd}^{SD} + \sum_{t \in T(d)} x_{td}^{TD} = \sum_{s \in S(d)} x_{ds}^{DS} + \sum_{t \in T(d)} x_{dt}^{DT} \quad \forall d \qquad (4)$$

$$\sum_{t \in T(s)} x_{st}^{ST} + \sum_{d \in D(s)} x_{sd}^{SD} = \sum_{t \in T(s)} I_{st} \quad \forall s \qquad (5)$$

$$\sum_{t \in T(s)} x_{ts}^{TS} + \sum_{d \in D(s)} x_{ds}^{DS} = \sum_{t \in T(s)} E_{st} \quad \forall s \qquad (6)$$

$$\sum_{s \in S(t)} x_{st}^{ST} + \sum_{d \in D(t)} x_{dt}^{DT} + \sum_{s \in S(t)} x_{ts}^{TS} + \sum_{d \in D(t)} x_{td}^{TD} \le K_t \quad \forall t \qquad (7)$$

$$2\left(\sum_{s \in S(d)} x_{sd}^{SD} + \sum_{t \in T(d)} x_{td}^{TD} \right) \le K_d \delta_d \quad \forall d \qquad (8)$$

$$\delta_d \in \{0,1\} \quad \forall d \quad \text{(plus non-negativity)} \qquad (9)$$

The first objective function is the cost function. It includes the cost of maintenance and setting up of the depots and the total costs of the transport operations between each shipper/consignee, depot and terminal. The second objective function is the impact function. It includes the maintenance and setting up impact and the transport operations impact. The values of parameter β captures whether the transport operations impact is more, equal or less important than the setting up and maintenance impact of the depot.

Regarding constraints, (3) assures that the number of containers received in a terminal is equal to the number of containers that leave same terminal; constraint (4) imposes that the number of containers received in a depot is equal to the number of containers that leave same depot; constraint (5) guarantees that each container imported by a consignee is stored in a depot or a terminal; constraint (6) assures that each container exported by a shipper is received from a depot or a terminal; constraint (7) imposes that the number of container movements in a terminal does not exceed the container movements capacity of that terminal; constraint (8) guarantees that the number of container movements in a depot does not exceed the container movements capacity of that depot. Note that constraints (8) implicitly consider that the total number of container movements in a depot is double the number of containers received; this is applied also to the objective function (2).

As, in many cases, the amount of imports is higher than that of exports, it can be considered that the surplus of containers that arrive to the terminal are exported from the terminal to other ports as empty containers.

The number of variables used in this model is $d + 2\cdot(s\cdot t + d\cdot t + s\cdot d)$ and the total number of constraints is $3d+2\cdot(t + s)$.

It is important to note that our model is static so long term it should be stable. For this reason, it is supposed that exists a balance of the number of containers moving on the network.

Since we propose to use a fuzzy multiobjective optimization approach, constraint (8) may be replaced by two new constraints (the first one to soften the constraint by allowing a certain tolerance and the second to prohibit movements to/from the depot when the depot is not opened):

$$2\left(\sum_{s \in S(d)} x_{sd}^{SD} + \sum_{t \in T(d)} x_{td}^{TD} \right) \le \tau K_d \quad \forall d \qquad (8')$$

$$2\left(\sum_{s \in S(d)} x_{sd}^{SD} + \sum_{t \in T(d)} x_{td}^{TD} \right) \le \tau K_d \delta_d \quad \forall d \qquad (8'')$$

where τ determines by how much the capacity of a depot could be increased (for instance, τ=1.15 means up to an additional 15% container traffic over the nominal capacity could be handled by the depot).

Let us call $f_1(x,\delta)$ and $f_2(x,\delta)$ respectively the two objective functions (1) and (2). For i={1,2} let be z_1^- the optimal objective function value of the model min $f_i(x,\delta)$ s.t. (3)-(7), (8''), (9); and, analogously, let be z_1^+ the optimal objective function value of the model max $f_i(x,\delta)$ s.t. (3)-(7), (8''), (9).

Now consider the following fuzzy multiobjective optimization (FMO) model in which the cost membership function λ_1 and the environmental impact membership function λ_2 have the same importance.

$$\max \sum_{i=1}^{2} \lambda_i \tag{10}$$

s.t.

$$\lambda_i \le \frac{z_i^+ - f_i(x,\delta)}{z_i^+ - z_i^-} \quad \forall i=1,2 \tag{11}$$

$$\gamma_d \le \frac{\tau K_d - g_d(x,\delta)}{(\tau - 1)K_d} \quad \forall d \tag{12}$$

Constraints (3)-(7), (8''), (9)

$$\lambda_i, \gamma_d \in [0,1] \tag{13}$$

where $g_d(x,\delta)$ is the left hand side of constraint (8'). The optimal solution (x^*, δ^*) has an associated cost $f_1(x^*,\delta^*)$ and an environmental impact $f_2(x^*,\delta^*)$. With these values we solve again the above model changing its objective function to $\max \sum_d \gamma_d$, removing constraints (11) replacing them by new constraints imposing that the values of the total cost and environmental impact cannot be worse than $f_1(x^*,\delta^*)$ and $f_2(x^*,\delta^*)$ respectively. The solution to this second optimization model is the final solution obtained.

Apart from this, the model can be solved using a certain value α as lower bound on the membership functions λ_i. Varying α different solutions can be obtained.

4. APPLICATION TO HINTERLAND OF VALENCIA

The Port of Valencia (Spain) is the biggest Spanish port in the Mediterranean Sea, with an important volume of maritime container traffic. Due to this, we have considered the hinterland of Valencia as our application case. We have used a sample of the largest 357 shippers/consignees in the area.

The hinterland of Valencia currently has eight depots open in the regions of Valencia and Murcia regions with different (between 50,000 and 125,000 container movements per year) flow capacities. In addition to these eight depots and taking into account the location of the shippers/consignees considered we have considered eleven new potential locations for a new depot (see Figure 1).

The flow capacity of these potential locations is 95,000 movements of containers per year. The estimation for the fixed cost of a depot is about 1,000,000€ for a depot processing about 250,000 container movements per year. For a depot with 95,000 container movements per year the fixed cost is assumed to be 380,000€. To estimate the costs per unit flow we calculate the distance (km.) between each pair of nodes of our network and make the product with the unit transport cost per km. of a container transport vehicle (1.152€/km according to Ministerio de Fomento, 2012).

Figure 1. Current depots (1-8, circled) and potential new depots (9-19).

4.1 Impact estimation using Fuzzy AHP

Obtaining data about the impact generated by the transport operations of a depot and by its setting up and maintenance is a difficult task. We have asked three logistic experts about five externalities produced by the transport operations, namely atmospheric (a.p.), visual (v.p.) and noise pollution (n.p.), traffic congestion (t.c.) and accidentability (acc.). Each expert was asked to define a Fuzzy AHP matrix comparing the five effects, and its consistence was checked. The three final matrices are:

$$M_1 = \begin{pmatrix} <1,1,1> & <\frac{1}{5},\frac{1}{4},\frac{1}{3}> & <1,2,3> & <5,6,7> & <5,6,7> \\ <3,4,5> & <1,1,1> & <6,7,8> & <8,9,9> & <8,9,9> \\ <\frac{1}{3},\frac{1}{2},1> & <\frac{1}{8},\frac{1}{7},\frac{1}{6}> & <1,1,1> & <2,3,4> & <3,4,5> \\ <\frac{1}{7},\frac{1}{6},\frac{1}{5}> & <\frac{1}{9},\frac{1}{9},\frac{1}{8}> & <\frac{1}{4},\frac{1}{3},\frac{1}{2}> & <1,1,1> & <1,1,2> \\ <\frac{1}{7},\frac{1}{6},\frac{1}{5}> & <\frac{1}{9},\frac{1}{9},\frac{1}{8}> & <\frac{1}{5},\frac{1}{4},\frac{1}{3}> & <\frac{1}{2},1,1> & <1,1,1> \end{pmatrix}$$

$$M_2 = \begin{pmatrix} <1,1,1> & <\frac{1}{9},\frac{1}{8},\frac{1}{7}> & <1,2,3> & <\frac{1}{7},\frac{1}{6},\frac{1}{5}> & <\frac{1}{8},\frac{1}{7},\frac{1}{6}> \\ <7,8,9> & <1,1,1> & <8,9,9> & <4,5,6> & <4,5,6> \\ <\frac{1}{3},\frac{1}{2},1> & <\frac{1}{9},\frac{1}{9},\frac{1}{8}> & <1,1,1> & <\frac{1}{9},\frac{1}{8},\frac{1}{7}> & <\frac{1}{8},\frac{1}{7},\frac{1}{6}> \\ <5,6,7> & <\frac{1}{6},\frac{1}{5},\frac{1}{4}> & <7,8,9> & <1,1,1> & <1,1,2> \\ <6,7,8> & <\frac{1}{6},\frac{1}{5},\frac{1}{4}> & <6,7,8> & <\frac{1}{2},1,1> & <1,1,1> \end{pmatrix}$$

$$M_3 = \begin{pmatrix} <1,1,1> & <\tfrac{1}{8},\tfrac{1}{7},\tfrac{1}{6}> & <6,7,8> & <3,4,5> & <\tfrac{1}{5},\tfrac{1}{4},\tfrac{1}{3}> \\ <6,7,8> & <1,1,1> & <8,9,9> & <7,8,9> & <3,4,5> \\ <\tfrac{1}{8},\tfrac{1}{7},\tfrac{1}{6}> & <\tfrac{1}{9},\tfrac{1}{9},\tfrac{1}{8}> & <1,1,1> & <\tfrac{1}{3},\tfrac{1}{2},1> & <\tfrac{1}{9},\tfrac{1}{8},\tfrac{1}{7}> \\ <\tfrac{1}{5},\tfrac{1}{4},\tfrac{1}{3}> & <\tfrac{1}{9},\tfrac{1}{8},\tfrac{1}{7}> & <1,2,3> & <1,1,1> & <\tfrac{1}{9},\tfrac{1}{8},\tfrac{1}{7}> \\ <3,4,5> & <\tfrac{1}{9},\tfrac{1}{8},\tfrac{1}{7}> & <7,8,9> & <7,8,9> & <1,1,1> \end{pmatrix}$$

The consensus matrix M_c is calculated using the geometric mean of each component of the fuzzy numbers (lower, medium, upper) of the values provided by each expert.

$$M_C = \begin{pmatrix} <1,1,1> & <0.14,0.16,0.2> & <1.82,3.04,4.16> & <1.29,1.59,1.91> & <0.5,0.6,0.73> \\ <5.01,6.07,7.11> & <1,1,1> & <7.27,8.28,8.65> & <6.07,7.11,7.86> & <4,5.13,6> \\ <0.24,0.33,0.55> & <0.12,0.12,0.14> & <1,1,1> & <0.42,0.57,0.83> & <0.35,0.41,0.49> \\ <0.52,0.63,0.78> & <0.13,0.14,0.16> & <1.20,1.75,2.38> & <1,1,1> & <0.48,0.5,0.83> \\ <1.37,1.67,2> & <0.17,0.19,0.25> & <2.03,2.41,2.88> & <1.20,2,2.08> & <1,1,1> \end{pmatrix}$$

This matrix is transformed to a crisp matrix to check its consistence using the method proposed by Kwong and Bai (2003) in which each element of the matrix is calculated as: $m_{ij} = (m_{ij}^{-} + 4m_{ij} + m_{ij}^{+})/6$. Once the consistence was checked we used the geometric mean to obtain the weights for each alternative and determine the environmental impact per transported unit at each depot. To assess the environmental impacts of each depot we used the "ratings mode" considering three categories (low, medium, high) for each criterion. These ratings and the resulting relative impacts (r.i.) of each potential location are shown in Table 2.

Locat.	a.p. (0.117)		n.p. (0.597)		v.p. (0.055)		t.c. (0.085)		acc. (0.146)		r.i.
D 1	M	0.464	M	0.333	M	0.464	A	1	M	0.333	0.443
D 2	L	0.215	M	0.333	M	0.464	L	0.215	L	0.111	0.276
D 3	H	1	H	1	H	1	H	1	H	1	1
D 4	H	1	H	1	H	1	H	1	H	1	1
D 5	H	1	H	1	H	1	H	1	H	1	1
D 6	M	0.464	M	0.333	L	0.215	L	0.215	M	0.333	0.327
D 7	H	1	H	1	H	1	H	1	M	0.333	0.893
D 8	H	1	H	1	H	1	H	1	M	0.333	0.893
D 9	M	0.464	M	0.333	M	0.464	H	1	M	0.333	0.443
D 10	M	0.464	M	0.333	M	0.464	H	1	M	0.333	0.443
D 11	M	0.464	M	0.333	L	0.215	H	1	M	0.333	0.428
D 12	H	1	H	1	H	1	H	1	H	1	1
D 13	M	0.464	M	0.333	M	0.464	H	1	M	0.333	0.443
D 14	M	0.464	M	0.333	L	0.215	M	0.464	M	0.333	0.359
D 15	M	0.464	M	0.333	M	0.464	L	0.215	M	0.333	0.342
D 16	M	0.464	M	0.333	M	0.464	M	0.464	M	0.333	0.374
D 17	H	1	H	1	H	1	H	1	H	1	1
D 18	M	0.464	M	0.333	L	0.215	M	0.464	M	0.333	0.359
D 19	M	0.464	M	0.333	M	0.464	M	0.464	M	0.333	0.374

Table 2. Impact per flow unit at each depot

Also, we consider three criteria in relation to the impact generated by the depot itself, namely its setting up (s.u.), visual impact (v.i.) and operations pollution (o.p.). The corresponding ratings and resulting relative impacts of each potential location are shown in Table 3.

Locat.	s. u. (0.2)		v.i. (0.08)		o.c. (0.72)		r.i.
D 1	H	0.215	M	0.464	M	0.333	0.320
D 2	U	1	L	0.215	L	0.111	0.297
D 3	U	1	H	1	H	1	1
D 4	H	0.215	M	0.464	H	1	0.800
D 5	M	0.464	H	1	H	1	0.893
D 6	M	0.464	M	0.464	M	0.333	0.370
D 7	M	0.464	H	1	H	1	0.893
D 8	M	0.464	H	1	H	1	0.893
D 9	M	0.464	M	0.464	M	0.333	0.370
D 10	H	1	M	0.464	M	0.333	0.477
D 11	H	1	L	0.215	M	0.333	0.457
D 12	M	0.464	H	1	H	1	0.893
D 13	L	0.215	H	1	M	0.333	0.363
D 14	H	1	L	0.215	M	0.333	0.457
D 15	H	1	L	0.215	M	0.333	0.457
D 16	H	1	L	0.215	M	0.333	0.457
D 17	M	0.464	H	1	H	1	0.893
D 18	H	1	M	0.464	M	0.333	0.477
D 19	M	0.464	L	0.215	M	0.333	0.350

Table 3. Fixed impact per stored unit at each depot

4.2 Optimization results

The first step is to obtain the extreme values for the two objective functions in our model. The minimum and maximum cost values obtained (in thousand euros) are z_1^{-} =1212.98 and z_1^{+} =9614.51 respectively. For the environmental impact objective function, the minimum and maximum values are z_2^{-} =21342.68 and z_2^{+} =94150.98.

With these extreme values the FMO model, changing in the objective function and constraints every λ_i for a unique λ, was solved obtaining λ*= 0.973. The cost value for this solution is 1442.668 thousand euros and its environmental impact is 23333.17. This solution opens seven depots, three of them corresponding to currently opened depots (1, 6, 7) and the other four to new ones (9, 13, 15, 18).

After that, we solve several times the FMO model including as a constraint that $\lambda_i \geq \alpha$. The first value for α is the λ* value we obtained before, that is, initially α=0.973. After that α is decreased by 0.0005 in each iteration. For $\lambda \leq 0.9665$ the solution does not change any more. All the different solutions found are shown in Figure 2.

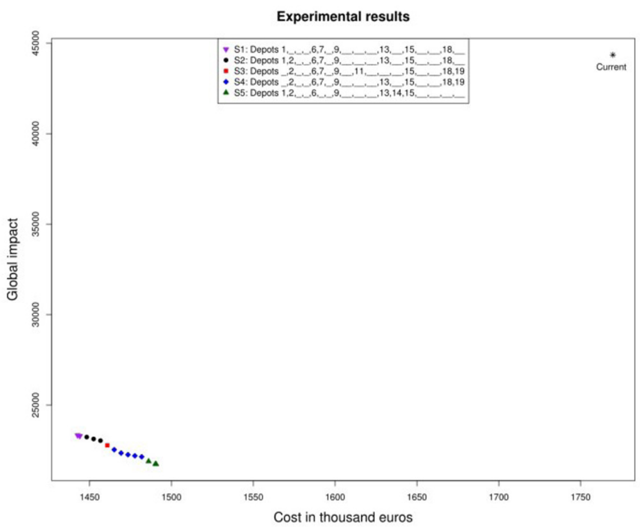

Figure 2. Solutions for model [FMO]

We have also solved the problem forcing that the open depots are exactly the eight depots actually operating. The resulting minimum cost for the current situation is 1769.698 thousand euros and its impact is 44355.57. This current solution is absolutely dominated by all the solutions we have found. The best cost solution we have found in our experiments is about 18% better than the current one and the best impact solution we have found improves about 51% the current configuration of opened depots (see Figure 2).

It can be also noted that depots 6, 9 and 15 are open in every solution while depots 3, 4, 5, 8, 10, 12, 16 and 17 are not selected for any solution (see Figure 3).

Figure 3. Depots that are never opened (X) and those opened in all obtained solutions (□)

5. CONCLUSIONS

In this paper a new bicriteria optimization model is presented to determine the best location of empty container depots in a hinterland. This model takes into account the total operation costs as well as the total environmental impact generated by the heavy transport operations in and out of the depots network as well as by the depots setting up and maintenance. Due to the uncertainty of the data needed fuzzy multiobjective optimization was used to solve the problem. Fuzzy-AHP was also used to obtain the environmental impact data. The results in the hinterland of Valencia have provided a set of potential solutions that are clearly much better than the current situation for both objective functions.

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