EJTIR

Issue 13(3), 2013
pp. 184-200
ISSN: 1567-7141
www.ejtir.tbm.tudelft.nl

A DEA-inspired approach to selecting parking areas for dangerous-goods trucks

Caro-Vela[1], M.D, Paralera[2], C. and Contreras[3], I.
Departamento de Economía, Métodos Cuantitativos e Historia Económica. Universidad Pablo de Olavide de Sevilla.

The transport of dangerous goods by trucks requires special conditions for rest areas. By considering the set of existing service areas, the present work develops a procedure for selecting the subgroup of the most suitable service areas for modification in order to provide a service to dangerous-goods transporters. Under multiple criteria, a new DEA-inspired model is developed that uses the main characteristics of the problem under study with the goal of selecting the best locations. Through the application of this model to Spanish territory with the help of Geographical Information Systems, various solutions are suggested. The final decision on the number of areas to be located depends on corresponding authorities, whose main priority is to satisfy economic criteria.

Keywords: Dangerous goods, DEA, selection, road freight transport, parking areas.

---

1. Introduction

Dangerous goods can be defined as those materials or products involving a danger for people or the environment in contact with them (Gorys, 1990). Approximately 4.5 per cent of goods transported by road across the European Union (EU) in 2010 were dangerous goods, although in countries like Spain the rate exceeded 5 per cent (Data from Eurostat statistics, 2012).

The risk presented by carriers of dangerous materials has raised the awareness among public administrations of the need to define criteria and establish norms whose aim is to prevent the danger associated to the transportation of these kinds of goods.

In Europe, the basic legislation on this matter is regulated by the "European Agreement concerning the International Carriage of Dangerous Goods by Road" (ADR), developed in accordance with the recommendations of the United Nations Economic Commission for Europe (UNECE, 2010). In addition to most European countries, some Asian and Northern African countries have also subscribed to this agreement.

The norms are applicable to these kinds of vehicles both when they are on the move and when they are parked. Concerning this second situation, the ADR defines a number of safety measures affecting the surveillance of these vehicles. This norm establishes as a priority the obligation to

---

[1] Ctra. Utrera Km.1, 41013 Sevilla, Spain, T:+34 954 34 89 81, F: +34 954 349 339, E: mdcarvel@upo.es,
[2] Ctra. Utrera Km.1, 41013 Sevilla, Spain, T:+34 954 34 91 70, F: +34 954 349 339, E: cparmor@upo.es
[3] Ctra. Utrera Km.1, 41013 Sevilla, Spain, T:+34 954 34 93 55, F: +34 954 349 339, E: iconrub@upo.es

park these vehicles in parking areas that are watched by security agents who have been previously informed about the nature of the goods and can locate the driver at all times. As a second option, the vehicles must be parked in public or private parking areas where they are protected from any possible damage by other vehicles. In the absence of these two possibilities, a suitable open area located away from major public roads and inhabited places is recommended, that is neither a meeting point nor a place of passage, (UNECE, 2010).

The drivers of heavy vehicles transporting dangerous goods are obliged by law to make rest stops along the route during their journeys. These drivers consequently need appropriate places to carry out these rest stops.

In Spain, both quantitative and qualitative shortages have been detected in the safety of parking areas (see RACC, 2010, and Ministry of Public Works, 2006). There is a need to create a network of parking areas which can satisfy drivers' demand for rest in compliance with the legal norms and can prevent danger to society and the environment.

To this end, a tool is required that enables institutions in charge of planning and managing service areas to select a network of these areas which can be adapted under objective criteria to fulfil the rest requirements of dangerous-goods carriers so that any investments made have a greater impact on the community.

To select the set of feasible areas, several criteria are considered in order to guarantee that the candidate areas can provide an adequate service to dangerous goods transport. One compulsory condition is the inclusion of the area into RIMP (Network of Dangerous-Goods Transport Routes in Spain). This is the network of routes of dangerous goods (mainly highways), to which all dangerous-goods transportation is bound under Spanish law.

This set is composed of 89 parking areas that comply with a series of requirements concerning location, minimum area, and safe distance from the road, as recommended by the Ministry of Public Works. After an initial study of the 89 candidate areas, only 66 have available data (in most cases, the studied areas are not currently fully operative). It is important to bear in mind that the proposed procedure developed in the following sections strives to obtain the best locations by considering this set of existing and available alternatives exclusively. That is, the possibility of new locations is rejected, due to economic factors, which explains why certain zones contain no selected areas. The solution obtained must be seen as the best solution for when only existing areas are considered.

In the process of locating those areas, the main criteria include the need to respond to demand, both regards the quantity (to cover the needs of the highest number of dangerous freight carriers) and the quality of the services provided, and the prevention of the social and environmental risks associated to this kind of parking areas.

Another aspect to be considered in this study is the amount of resting time required by the drivers of vehicles transporting goods. The drivers are obliged to respect certain minimum stops and rest periods during the exercise of their activity. These stops are regulated and it is established that, after a driving period of four and a half hours, drivers have to make an uninterrupted stop of at least 45 minutes. This stop can be substituted by a short pause of at least 15 minutes followed by another pause of at least 30 minutes, alternating with the driving activity so that the above-mentioned dispositions are met,(Regulation (EC) 561/2006).

Given that the maximum speed allowed for vehicles carrying dangerous goods in Spain is 80 km/hour on highways, 70 km/hour on main roads, and 60 km/hour or less on the remaining roads, even a non-stop route of 360 km is currently allowed. Nevertheless, traffic authorities recommend a pause after each two hours of driving, or after every 150-200 Km, in order to prevent fatigue (González et al. 2002). This distance is also justified by safety recommendations of the National Traffic Agency (see Gonzalez-Luque and Alvarez-Gonzalez, 2002). Then the estimation is that there must be a rest area every 150-200 Km of the RIMP to enable drivers to make the statutory pauses during the execution of their activity. It is interesting to point out that the case of double-driver use, the use of another driver in the same vehicle, has not been considered. In contrary case, the distance should be reconsidered.

2. Precedents of the problem and selection of the criteria

Location theory has traditionally studied the best location for service areas in order for them to achieve a specific series of objectives. Problems associated to the location of facilities include a broad range of situations, and hence are widely studied in the field of Operations Research. Examples of this type of problem are found in the location of public services, such as hospitals, schools, ambulance services, fire stations, gas pipelines, and warehouses. In specialised literature, many studies have focused on the location of plants; among them, those that discuss the problem of maximal coverage (see Murray et al., 2010). The Maximal Covering Location Problem (MCLP) restricts the number of plants to be installed to a finite number of locations that maximise the amount of demand covered. Among the first research into maximal covering location, that by Church and ReVelle (1974) formulated the problem clearly. Later on, many other studies set out the problem in relation to the location of various facilities, such as emergency centres (Current and O'Kelly, 1992), new parks in urban areas (Molano et al., 2009), and service stations (Upchurch et al., 2009).

Certain studies have integrated Geographic Information Systems (GIS) in order to analyse different problems associated to location, such as maximal coverage, maximal coverage with capacity restrictions, and the p-median. In particular, work by Murray (2005), and by Alexandris and Giannikos (2010) present maximal covering location models that apply different GIS functions.

Recent work by Caro and Paralera (2011a, 2011b) has focused on the location problem associated to parking areas for dangerous goods carriers. Their studies have analysed the need for the availability of this kind of parking area and have determined, with the help of GIS, the demand covered by the current network of parking areas in Spain. A maximal covering location model is proposed that strives to cover the highest possible demand with a fixed number of facilities.

The present work analyses the problem under a totally different light. Other criteria that may be influential at the moment of selecting the best location for the various service areas are hereby considered, rather than just coverage of the carriers' demand. These other criteria include: the services provided at the rest areas; the social risk associated to this type of area; and their collective disutility.

The main contribution of the present paper is twofold. On one hand, a new methodology is proposed for the optimal location of parking areas of dangerous goods. Taking previous work as the starting point, a new procedure inspired in DEA is developed specifically to solve the problem studied here. The considerations of multiple criteria and of a non-subjective weighting vector constitute the main features of the proposed procedure. On the other hand, the procedure is applied to a real case. By considering the data on transport and existing rest areas of Spain, optimal solutions are obtained for a variable number of newly modified parking areas.

In order to measure the coverage of the demand in this case, and given that data on the operating routes of dangerous-goods transportation remain unavailable for the determination of the points of demand, the average daily traffic density (ADT) of dangerous-goods carriers along stretches of the Spanish road network as reflected in the Traffic Map of the Ministry of Public Works (2009) is used. In their study on the location of petrol stations, Goodchild and Noronha (1987) also choose traffic flows to measure demand, due to the difficulty of finding origin-destination matrices for carriers.

Since the purpose of this work is to solve the problem in those areas where demand currently remains to be covered, a map showing the areas that are covered is generated as a first step. A total number of 3,638 stretches of road with available ADT data, and the 10 existing service areas already adapted for dangerous-goods carriers have been considered. In order to select and allocate the demand nodes (stretches with ADT data) to the various locations, ArcGIS 9.3 functions (ESRI, 2008) have been applied. This software enables the handling of geo-referenced databases of existing service areas, the average daily traffic of dangerous-goods vehicles and the RIMP.

The information layer showing the kilometre posts along Spanish roads indicates the location of the 10 service areas presently adapted for dangerous-goods carriers and, subsequently, the stretches of road located less than 150 km away (radius of coverage) from these 10 service areas are selected. In this way, the demand covered by the 10 existing service areas is obtained.

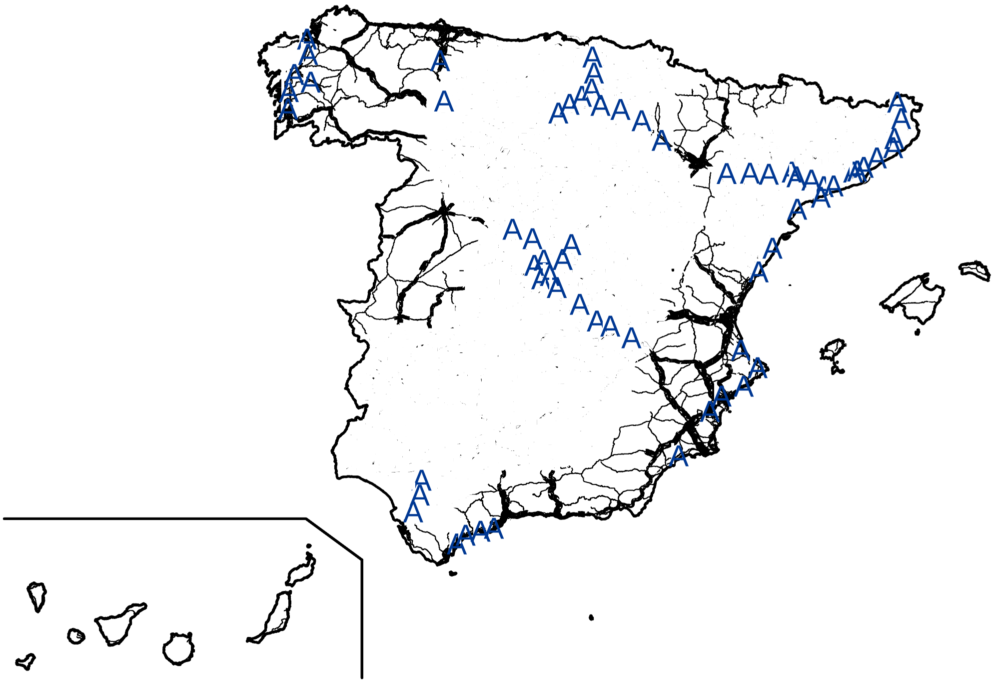

Figure 1. Demand remaining uncovered and 66 possible locations

A layer of information reflecting the 66 suggested locations is then placed on the map showing the demand which still remains uncovered. The coverage of the demand by these service areas is thus evaluated in the same way as that of the first 10 areas.

In general, parking areas usually provide basic services such as petrol pumps, cafeterias, shops, telephone booths and toilet facilities. These services may be sufficient for a carrier to make a short stop; however, if a longer stop is required, the drivers will need a place to sleep, something that is not available at all service stations. A small garage, where quick repairs could be made if required, would also be a convenient service to be supplied at this kind of rest area.

In order to discriminate between the different parking areas, it should be taken into account that the most appropriate areas are those which provide a wider range of services, including specific services such as a garage and accommodation facilities. The inclusion of the number of services provided by each area is therefore justified as a criterion for their selection.

Operations involving the transportation of waste and, in particular, hazardous materials, imply a risk that is usually met by rejection from the population. The incorporation of this risk into location models has been made in various ways, for instance in relation to the population exposed to the risk (Giannikos, 1998; Santos et al., 2001; Caballero et al., 2007), the probability of an accident actually happening (Erkut and Verter, 1995, 1998) and the dangerousness of the goods transported (Martínez-Alegría et al., 2003).

Studies on dangerous-goods transportation approach risk assessment in various ways. The evaluation is sometimes made through the separate valuation of the vulnerability of the population and of the environment (Martínez-Alegría et al., 2003). In other work, the probability of an accident is determined by estimating the severity level of any potential accident and the magnitude of its consequences in relation to the people and the environment (Zhang et al., 2000).

In this paper, social risk is determined by the ADT (average daily traffic) of vehicles per kilometre that might be affected by an accident involving a dangerous-goods carrier in the stretch of road where the service area is located.

Another social criterion that we find in specialised literature is the so-called collective disutility, which reflects the rejection from nearby populations of the place where a specific, probably undesirable facility is to be located. Collective disutility is considered an increasing function of the size of the facility to be installed and a decreasing function of the distance from the facility to the corresponding urban centre (Erkut & Neuman, 1992; Giannikos, 1998; Santos et al., 2001). In Caballero et al. (2007), it is defined by the number of inhabitants of nearby towns or cities, the capacity of the facility in question, and the distance between those urban areas and the facility.

In the present study, collective disutility is measured through the sum of population of nearby villages divided by the distance to the service area. In this way, the importance of the population decreases in terms of the distance to the potential danger. Following (Vílchez et al. 2001), we consider that three kilometres is the maximum distance that can be affected and hence, if the town or city is situated further away from the service area, then that aspect of social rejection will not be taken into account. Population at a distance of one, two, and three kilometres has been considered in the measurement of this criterion.

3. Methodology

For the resolution of this problem a new methodology is proposed. This methodology enables the best set of areas to be determined from a large set of possible locations valued in relation to multiple attributes, or to variables and those characteristics described below. This new methodology is developed for this particular problem in an effort to determine the best subgroups of locations from a set of feasible alternatives.

The methodology proposed is inspired by Data Envelopment Analysis (DEA) and adapted to the characteristics that are typical of the problem in question. DEA (Charnes et al., 1978) is a non-parametric analysis technique originally conceived to measure the efficiency of a set of units that, starting from multiple inputs, are capable of producing multiple outputs. The objective of the original model was limited to measuring the efficiency of each individual unit through the aggregate value ratio of outputs and inputs. The main characteristic of DEA is the free selection of the vector of weights by each alternative. More specifically, each evaluated unit is allowed to select its own vector of weights so that its efficiency can be measured in the best possible situation through the output/input ratio. Thus, if one unit does not reach the possible maximum value, then the cause will not be the arbitrary selection of weights. The application of DEA has outgrown the objectives for which it was originally conceived, and a great number of applications have been generated and numerous models have been inspired whose common characteristic is the endogenous determination of the weights: the weights of criteria or variables are obtained during the procedure and not exogenously obtained in accordance with the preferences of the analyst or of the deciding agents. In this case, the vector of weights is determined by the evaluation of each alternative with respect to each variable or criterion.

From among all the DEA-inspired procedures, this work focuses attention on those models known under the name of common-weight models. This family of models, which are closer to traditional valuation models, determines only one vector of weights that is shared by all the alternatives, instead of determining one for each alternative. Nevertheless, the original idea of establishing the weights of inputs and outputs as a problem variable is preserved.

This type of model strives to overcome the main criticism against DEA-based procedures. The possibility of each unit selecting a vector of its own generates a double conflict. On the one hand, the difficulty of comparing the units on a common basis is exacerbated. There are several authors (Seydel, 2006) who argue that, in applications where the purpose is to organise or compare the units, it is not suitable for each variable or criterion to be valued differently depending on the unit that is being evaluated, as is carried out in traditional DEA models. On the other hand, the application of this methodology often results in multiple ties, in particular between those units reaching the maximum value, that is, between efficient units. This, in turn, restricts discrimination between alternatives, by hindering, for example, the construction of a complete order of units.

The main innovation of the procedure here presented is that an objective valuation objective is established. In contrast to the optimisation of individual valuations established by traditional DEA models and of the majority of the models derived from this methodology, the model herein strives to maximise the optimisation of the whole set that is finally selected. In other words, even if the characteristics of all the possible locations are considered for the resolution of the problem, only the valuation of the areas finally selected is taken into account in the objective function of the problem, as shown below in the description of the proposed procedure.

Let a set of n alternatives be considered, from which a subset with the best e units is to be selected with $(e < n)$ so that the joint valuation of the selected subset is optimised. In this context, a DEA-inspired model with a free selection of weights is proposed, which, although it considers the value of the n alternatives for the selection of the vector of weights, takes into account the valuation of only those units selected for the achievement of its maximisation objective.

Each unit i $(i = 1, \ldots, n)$ is to be evaluated in relation to m criteria or variables; the evaluation of each unit i with respect to criterion or variable s $(s = 1 \ldots. m)$ is denoted as y_{is}. All the variables are considered to be of the kind "the more, the better"; something that can be achieved with a preliminary rescaling procedure (which can be completed with the normalisation of the units of measurement, although if it is rendered unnecessary since DEA models are independent of the units). The valuation of each alternative is made through the aggregate value of the individual valuations, namely $\sum_{s=1}^{m} w_s \cdot y_{is}$, where $w = (w_1, \ldots, w_m)$ denotes the vector of weights which is common to the n alternatives.

The following model is proposed in Equation (1) for the selection of the set of the e best alternatives with a single vector of weights w for the whole set of n alternatives.

The di variables measure the distance from the maximum value (fixed at 1) that the aggregate value of each unit can reach. Obviously, when $d_i = 0$, then the alternative reaches the maximum aggregate value (and would be qualified as efficient in DEA terminology). The difference $1 - d$ quantifies the inefficiency of the *i-th* unit or, in other words, the distance from the unit to the maximum possible value.

$$
\begin{array}{llll}
min & F(d_i) & & \\
s.a. & \sum_{s=1}^{m} w_s \cdot y_{is} \le 1, & i=1,\dots,n; & (R1) \\
 & \sum_{s=1}^{m} w_s \cdot y_{is} + d_i + (1-t_i) \ge 1, & i=1,\dots,n; & (R2) \\
 & \sum_{i=1}^{n} t_i = e, & & (R3) \\
 & t_i \in \{0,1\}, w_s \ge 0. & & (R4)
\end{array}
\qquad (1)
$$

$F(d_i)$ represents the function of distances that quantifies the global valuation of the selected set. It enables different objectives to be considered for the quantification of the joint evaluation of the selected units, which will depend on the preferences of the analyst or on the context or problem in question. In the present work, two objectives are considered: the total value of the distances, which is equivalent to the minisum solution and is denoted as $F(d_i) = \sum_{i=1}^{n} d_i$; and the minimum efficiency within the set, which is equivalent to the minimax solution denoted as $F(d_i) = \max_{i=1,\dots,n}\{d_i\}$. Both solutions allow a linear expression, which is immediate in the case of the first solution. On the other hand, the second solution requires the inclusion of a set of restrictions to the problem such that $D \ge d_i, \ \forall i = 1,\dots,n$.

In this case, the objective of the problem will be to minimise the value of D, an auxiliary variable included to measure the maximum value of di. Compromise solutions between these two values may be proposed, as those suggested by González-Pachón and Romero (1999), as either an alternative or a complementary objective, in order, for example, to discriminate between the units in the case of ties.

The first set of restrictions (R1) guarantees that the aggregate value of all these units is limited by 1. It is interesting to remark how all units, whether selected or not, intervene in the determination of the optimum vector of weights, in the sense that they participate at the level of the aggregate value. Nevertheless, as shown below, only selected units have a direct influence on the objective function.

Binary variables t_i are used in the identification of the alternatives that are finally selected. When $t_i = 1$, alternative i is selected. In order to understand how the model functions, the second set of restrictions must be studied (R2). When $t_i = 0$, the difference $1 - t_i$ equals 1 and the corresponding restriction to this alternative is redundant. All the variables are non-negative; therefore, the condition established is verified, without having assigned any value to the variable d_i. On the other hand, if $t_i = 1$, then the difference $1 - t_i$ i equals 0 and, consequently, the restriction is activated. Either the aggregate value reaches the maximum, fixed in the previous set of restrictions at 1, or it will be necessary to assign a specific value to variable d_i in order to verify the restriction. As far as the objective is to minimize the values assigned to d_i, only the best alternatives are selected so that just the lowest possible amount is accumulated.

The third set of restrictions (R3) guarantees that the desired number of alternatives is selected and that it is denoted by e. A simple variation of the model enables the maximum number of efficient alternatives to be obtained or the number of alternatives to be selected through another limitation to be determined (such as a budget restriction).

It is interesting to highlight how the optimum weighting vector is selected. The best alternative (that which achieves the value 1) determines the vector w; note that the normalization restriction implies that the aggregate value is lower than or equal to the unity. In those cases in which this vector is a singleton, this optimum vector is the same for all the subgroups, independent of the size established (value of parameter e). However, in those cases in which multiple vectors can be obtained (as often occurs in DEA models), the optimum vector will be selected by considering the value of the remaining alternatives of the subgroup.

It is evident that the model proposed has a solution and that, when $e = n$, i.e. when the total number of units evaluated is selected, the solution is equivalent to that suggested by Li and Reeves (1999) for the case in which the evaluated alternatives produce multiple outputs with a single common input and all the units are valued with the same vector of weights.

When various units reach the maximum value or, in other terms, $d_i = 0$, then multiple solutions may arise. In particular, if the number of efficient units is higher than the number of units to be selected, then the optimum solution will be 0, but the combination of units selected will not be the only one with this value. In this case, it will be necessary to include additional information, or to consider any of the procedures applied in specialized literature to discriminate between efficient units (see Adler et al., 2002).

The proposed model allows the incorporation of additional information, when required, for its application to real situations. In particular, two possibilities are considered: restrictions on the possible value of vector w, and restrictions on the combination of alternatives that may be selected.

As the model suggests, the vector of weights can be freely chosen: the only restriction being that the aggregate value of each alternative should not exceed 1. The DEA literature provides numerous methods to restrict the value of the vector of weights, which, although originally designed for traditional models in which each unit is evaluated with its own vector of weights, can be directly adapted to common weight models, as is the model proposed here.

As regards the limitations on the possible combination of alternatives, it is natural to think that, in the case in question, the aim is to select alternatives that differ sufficiently in geographical terms. Let a selection of two alternatives be supposed that is restricted such that alternatives i and j cannot be simultaneously selected. There is no objection if only one is selected or, obviously, if none is selected at all. The limitation is activated only when both i and j are selected, something that can be measured through their corresponding binary variables.

To identify the pairs of linked alternatives, a binary matrix A is considered in which

$$a_{ij} = \begin{cases} 1 & \textit{if the selection of } i \textit{ and } j \textit{ is } \lim \textit{ited,} \\ 0 & \textit{otherwise} \end{cases} \tag{2}$$

When there is a conflictive situation, namely, when both units are simultaneously selected, the following set of restrictions is applied:

$$\begin{aligned} & t_i + t_j - \alpha_{ij} \leq 1, \forall i \neq j, \\ & \alpha_{ij} \in \{0,1\}. \end{aligned} \tag{3}$$

This set of restrictions enables the alternatives to be compared in pairs through their associated binary variables. Values are assigned to a_{ij} as shown on Table 1.

Table 1. Values of variable a_{ij}

Selection	t_i	t_j	a_{ij}
Both *i* and *j*	1	1	1
Alternative *i*	1	0	0
Alternative *j*	0	1	0
Neither	0	0	0

In order to guarantee that limited pairs are not selected, the following restriction is incorporated into the original problem:

$$\alpha_{ij} \cdot a_{ij} = 0, \ \forall i \neq j. \tag{4}$$

As can be observed, in order for this restriction to be activated, both $\alpha_{ij} = 1$ and $a_{ij} = 1$ have to be true at the same time. If not, the restriction will be redundant. It is important to underline that this restriction can transform the problem into an unfeasible problem. The inclusion of a high number of restrictions, which reduces the number of feasible alternatives to a lesser number than intended, will hinder the resolution of the problem.

Through a set of similar restrictions, positive synergies derived from the selection of a specific pair of alternatives may also be included; even the selection of a specific unit may be imposed. It must be borne in mind, however, that in this case the selection of the vector of weights will need to be adapted to the pre-selected unit in order to guarantee a sufficiently high valuation.

4. Application of the model

The methodology described above is used for the resolution of the proposed problem since it enables the best set of parking areas to be determined from a large set of possible locations evaluated in relation to multiple attributes. As mentioned before, the selected criteria are, in this case, the coverage of the drivers' demand, the provision of services in the parking areas, social rejection, and collective disutility. The coverage of the drivers' demand is measured through the daily average intensity of the dangerous-goods vehicles in sections of 150 kilometres of the RIMP network. The provision of services by the service areas is obtained as the number of services that the area offers to the clients (cafeteria, beds, etc). In this case, social risk is determined by the average daily traffic (ADT) of vehicles per kilometre that might be affected by an accident of a dangerous-goods carrier in the stretch of road where the service area is located. Finally, collective disutility is measured as the sum of the population of nearby villages divided by the distance to the service area, considering the population placed within a distance of one, two or three kilometres. In this way, the importance of every collective is considered proportional to its distance to the potential danger.

The purpose of applying the model detailed in Section 3 is to select, from the 66 possible parking areas, a subset containing those areas that are considered the *best* according to the proposed valuation and to the selection criteria specified above.

In this model, the variables denoted as y_{is} represent the valuations of location i $(i = 1, \ldots 66)$ in relation to criterion s $(s = 1, \ldots, 4)$. The numeric values reached by the various alternatives with respect to the different criteria are summarized in Table 2. Detailed information on the units can be consulted in the Appendix. Before applying the model here described, it is necessary to normalise these values in order to adapt them to the characteristics of the procedure, by making, for instance, all variables respond to the criterion "the more, the better". It is important to underline that, while DEA-based models do not require the use of normalised variables (it is enough that they are rescaled), the fact that solutions are independent from the units of measurement used means that the solution found here is equal to that which would be obtained with non-normalised values: the only change is that of the scale in which the vector of weights is measured. The valuation of each alternative is obtained as the weighted addition of y_{is} with the optimum vector of weights selected by the procedure itself.

Table 2. Descriptive statistics of the criteria

	CRITERIA			
	Social rejection (Average daily traffic in the stretch of road covered by service area)	**Collective disutility (Population divided by the distance)**	**Demand coverage (Average daily traffic density)**	**Services provided (Number of services)**
Minimum	0.00	3.00	646,415.03	0.00
Maximum	37,134.00	9.00	46,707,955.03	221,465.50
Mean	7,743.41	6.36	9,244,952.28	7,367.92
Standard Deviation	9,718.09	1.24	8,494,814.21	29,589.00

As seen above, the described procedure enables additional information to be included. In this work, two types of additional restrictions have been considered. In the first place, there is a limitation imposed on the combinations of alternatives that may be selected. There is no sense in selecting two parking areas that are very close together since their services would overlap. It is natural to think that the optimum solution must imply the selection of a network of service stations that are evenly distributed across the geographical area under study. To this end, the restrictions described in Section 3 are implemented, thus preventing the selection of two alternatives considered to be incompatible. In this case, a minimum separation distance of 150 km is established since it is a reasonable distance between rest stops.

In the second place, the selection of the vector of weights is also limited. As seen in Section 3, one of the characteristic features of both DEA and the aforementioned procedure is the free selection of weights. This freedom can often lead to the optimum vector of weights reaching extreme values, in the sense of containing just a few components with non-null values. This means that only those criteria whose components are not null are taken into account for the valuation of the alternatives. To prevent this situation from arising, a minimum level is imposed on the components of vector w to guarantee that all criteria are directly represented in the solution.

The last variable that needs to be fixed is the size of the set to be selected. First of all, it is necessary to know the maximum possible size, which can be determined by the number of alternatives that cannot be selected simultaneously (those areas that are located less than 150 Km away from each other). In this case, the number is 11, and for this reason all problems dealing with a subset of alternatives which contains more than 11 units will be unfeasible. Taking this solution as a maximum, the number of service areas to be located will depend on the decision of the corresponding authorities on the matter and, most probably, on various economic criteria. The location of more service areas would entail a greater economic cost, since it would mean adapting the existing stations so that they could function as parking areas for dangerous-goods vehicles. This adaptation would include, among other things, the provision of specialised surveillance by security personnel specifically trained in guarding dangerous goods, apart from the installation of specific signalling and the creation of a self-protection plan.

In particular, it is considered that the subset of locations may have three possible sizes: 5, 7, and 11 alternatives. The Figure 2 shows the locations obtained with the 5-alternative solution:

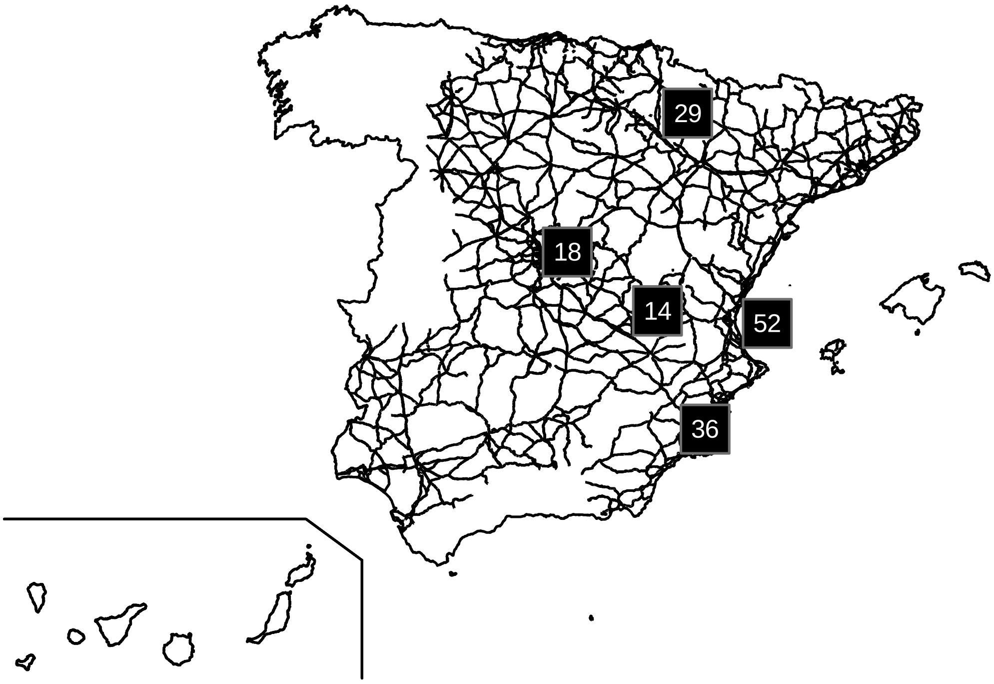

Figure 2: Locations of the 5-unit solution

Table 3 reflects the aggregate values of the 66 units (service areas) considered in this solution. The 5 units selected to form the subset are marked as number 1 in bold in the corresponding column.

Units 36 and 37 have the maximum aggregate value. However, only one of them is selected because they are less than 150 km apart and their joint selection would not comply with the restriction imposed on the problem. In the case of units 54 and 56, their aggregate value is very similar, but only number 54 is selected because the distance between them is again too short.

Table 3. Aggregate values of the 5-unit subset

Unit	Subset of 5	Aggregate values	Unit	Subset of 5	Aggregate values	Unit	Subset of 5	Aggregate values
1	0	85.7300	23	0	85.5018	45	0	85.1290
2	0	86.0085	24	0	88.0908	46	0	84.1133
3	0	87.1368	25	0	85.0875	57	0	74.0550
4	0	88.1634	26	0	88.3279	58	0	59.7988
5	0	89.5280	27	0	90.5263	48	0	87.1691
6	0	87.0756	28	0	82.7706	50	0	90.2336
7	0	90.6854	29	**1**	**91.0625**	51	0	92.5689
8	0	87.4492	30	0	78.8524	54	**1**	**96.3956**
9	0	85.7305	31	0	89.7564	55	0	87.5107
10	0	86.2074	32	0	95.2185	56	0	96.1740
11	0	91.4823	33	0	81.1753	59	0	90.5546
12	0	92.8854	34	0	87.7335	60	0	88.5918
13	0	93.3533	35	0	83.7988	61	0	88.7563
14	**1**	**94.8168**	36	**1**	**100**	62	0	89.6340
15	0	87.0752	37	0	100	63	0	85.5730
16	0	86.9888	38	0	68.2914	64	0	87.8244
17	0	88.4744	39	0	87.6686	65	0	85.5961
18	**1**	**100**	40	0	90.3169	66	0	87.8710
19	0	90.4553	41	0	90.5743	67	0	87.3562
20	0	86.4423	42	0	88.3387	68	0	87.2914
21	0	88.0456	43	0	86.7528	69	0	11.3790
22	0	89.2190	44	0	81.3224	70	0	89.9837

The 5-unit subset has been obtained with an optimum vector of weights $w_1 = 0.1,\ w_2 = 0.1175,\ w_3 = 0.1376,\ w_4 = 0.7685$, which correspond to the criteria of demand coverage, service provision, social rejection and collective disutility, respectively. As can be observed, the most discriminating criterion is collective disutility and those that have a greater weight in the process of selecting the units are the social criteria: social rejection and collective disutility. Figure 3 and 4 present the locations for the 7-unit and 11-unit (a unit being a parking area) solutions of the problem. The geographical areas covered by these locations are also shown together with that covered by the 10 current service areas adapted for dangerous-freight carriers. It is worth noting that these two solutions are obtained with a different vector of weights, w=(0.1, 0.1, 0.1263, 0.7864).

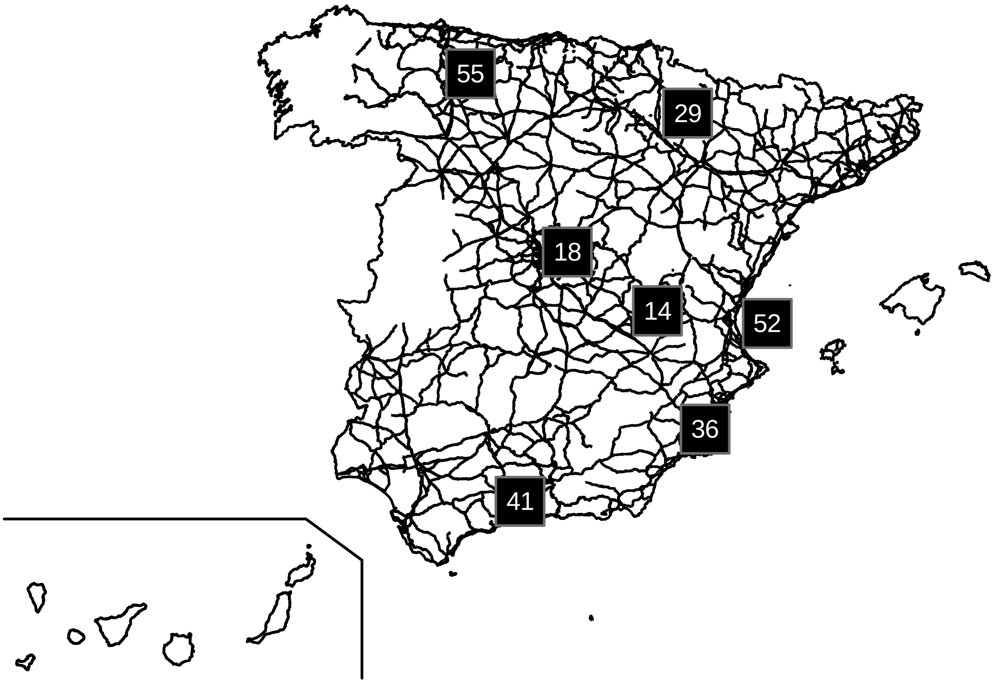

Figure 3: Locations of the 7-unit solution

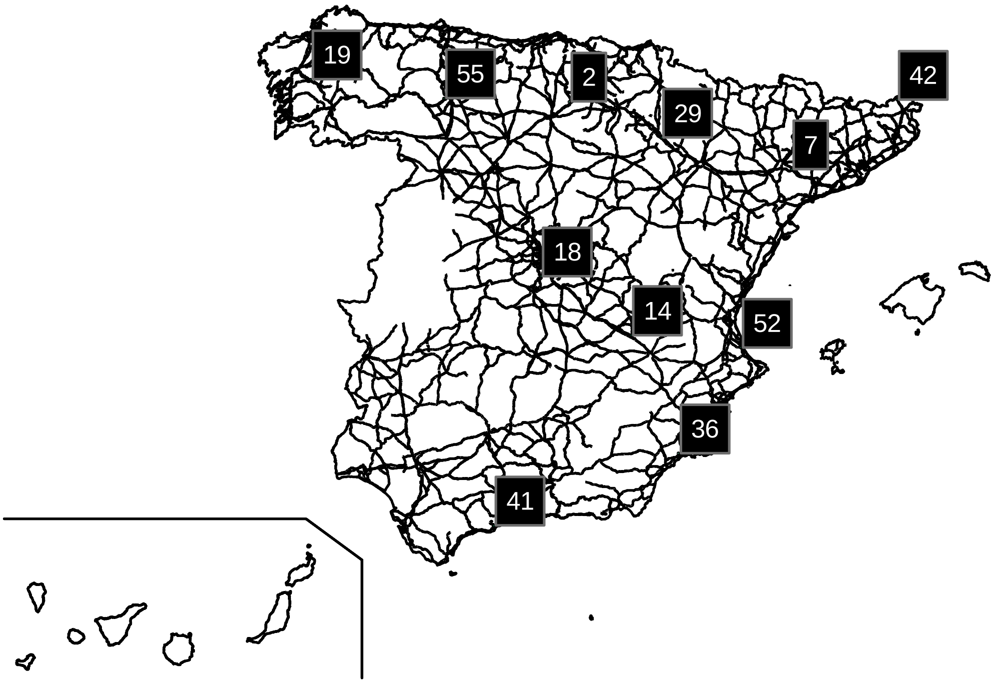

Figure 4: Locations of the 11-unit solution

It is interesting to observe that even the location of 11 new service areas, in addition to existing areas, would not fully cover the demand. The north of the province of Cáceres and the whole province of Salamanca (along the so-called "Ruta de la Plata") would still not be covered in this last scenario. As far as it is known by the authors, no service area in this region is included in the network of routes for the transport of dangerous goods, RIMP, a fact that leads the authors to consider the pertinence of considering the opening of a new service area in this region. The economic cost of this rest area would probably be much higher, since it would imply the construction of a new area and not merely an adaptation of one of the 66 existing service stations.

5. Conclusions

This work discusses the problems affecting the location of parking areas for dangerous-goods trucks in Spanish territory. European regulations on transportation force drivers to make specific rest stops along their route and give priority to the parking of dangerous-goods vehicles in service areas with special characteristics.

The work, therefore, underlines the need for a network of parking areas adapted for dangerous-goods trucks that satisfies the drivers' rest requirements in accordance with the law, prevents social risk, and minimises the collective rejection that a potential accident involving any of these vehicles might cause.

A new methodology is proposed, a DEA-based model that enables the best set of areas to be determined from the 66 possible locations, which are valued in relation to four attributes or variables.

The three best solutions are offered for cases in which 5, 7, and 11 service areas are to be located, under the limitation that 11 is the maximum number of locations that can be established if the restriction of locating areas no less than 150 km apart is to be respected. The choice of these three options as possible solutions is merely illustrative, since it will remain the responsibility of the corresponding authorities on the matter to decide on the final number of locations, probably upon the basis of economic criteria.

The problem thus solved provides a helpful tool for the decision-making process concerning the location of this kind of service area.

Not only do drivers find their necessities for longer rest stops to be satisfied, but this methodology also minimises both the exposure to potential accidents involving dangerous-goods vehicles, and the social rejection that the location of specially adapted parking areas might cause among the population.

Acknowledgements

The authors would like to thank the reviewers for their comments that help improve the manuscript. Financial support from Ministerio de Ciencia e Innovación ECO2011-29801-C02-02 and from Junta de Andalucía SEJ-7782 is gratefully acknowledged.

References

Adler, N., Friedman, L., and Sinuany-Stern, Z. (2002). Review of ranking methods in the data envelopment analysis context. *European Journal of Operational Research*, 140, 249-265.

Alexandris, G., and Giannikos, I. (2010). A new model for maximal coverage exploiting GIS capabilities. *European Journal of Operational Research*, 202, 328-338.

Caballero, R., González, M., Guerrero, F.M., Molina, J., and Paralera, C. (2007). Solving a multiobjective location routing problem with metaheuristic procedure. Application to the case of Andalusia. *European Journal of Operational Research*, 177, 1751-1763.

Caro, M.D., and Paralera, C. (2011a). Analysis of the need for a network of service/resting areas especially adapted to the transport of dangerous goods by means of a maximal covering location model. *Journal of Transportation Security*, 4, No. 3, 187-200.

Caro, M.D., and Paralera, C. (2011b). Una propuesta para la localización de áreas de servicio/descanso adaptadas al transporte de mercancías peligrosas mediante un modelo de optimización. Aplicación al territorio español. *Journal of Quantitative Methods for Economics and Business Administration*, 11, 17-32.

Charnes, A., Cooper, W.W., and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, 2, 429-444.

Church, R. and ReVelle, C. (1974). The maximal covering location problem. *Papers of the Regional Science Association*, 32, 101-118.

Current, I. and O'Kelly, M. (1992). Locating emergency warning sirens. *Decisions Sciences*, 23, 221-234.

Gonzalez-Luque and Alvarez-Gonzalez (2002), La fatiga, ¿cada cuanto hay que descnasar. Salud Vial, DGT www.dgt.es/revista/archivo/pdf/num152-**2002**salud.pdf.

Erkut, E., and Verter, V. (1995). Hazardous Materials Logistics. In Drezner, Z. (Ed.), *Facility Location: A Survey of Applications and Methods*. Springer, Heidelberg.

Erkut. E., and Verter, V. (1998). Modeling of Transport Risk for Hazardous Materials. *Operations Research*, 46, 5, 625-642.

EUROSTAT. 2012. *Data Base* (online). http://www.eurostat.org. Last accessed on May 7, 2012.

Giannikos, I. (1998). A multiobjective programming model for locating treatment sites and routing hazardous wastes. *European Journal of Operational Research*, 104, 333-342.

González, J. C., and Álvarez F.J. (2002). La Fatiga: ¿Cada cuánto hay que descansar?. Salud Vial. Dirección General de Tráfico, 152, 32

González-Pachón, J., and Romero, C. (1999). Distanced-based consensus methods: a goal programming approach. *Omega-The International Journal of Management Science*, 27(3), 341-347.

Goodchild, M.F., and Noronha, V.T. (1987). *Location–Allocation and impulsive shopping in the case of gasoline retailing. Spatial Analysis and Location–Allocation Models*. Van Nostrand Reinhold, New York. 121-136.

Gorys, J. (1990). *Transportation of dangerous goods in the province of Ontario*. Transportation Research Record 1264. Transportation Research Board, National Research Council, Washington,

Li, X-B., and Reeves, G.R. (1999). A multiple criteria approach to data envelopment analysis. *European Journal Operation Research*, 115, 507-517.

Martínez-Alegría, R., Ordóñez, C., and Taboada, J. (2003). A conceptual model for analyzing the risks involved in the transportation of hazardous goods: Implementation in a geographic information system. *Human and Ecological Risk Assessment*, 8, 857-873.

Ministerio de Fomento (2006). Coordinación del Transporte de Mercancías Peligrosas. Estacionamientos para vehículos de Mercancías Peligrosas. http://www.fomento.es/MFOM/LANG_CASTELLANO/DIRECCIONES_GENERALES/ORGANOS_COLEGIADOS/CCTMP/ListadoEstudio.htm Accessed October 21, 2010.

Molano, A.M., Medaglia, A.L., Sarmiento, O. L., and Sefair, J.A. (2009). Modelo de planeación de áreas urbanas para construir nuevos parques vecinales en Bogotá. *Revista Planeación y Desarrollo*, 39(2): 140-173.

Murray, A. (2005). Geography in coverage modeling: Exploiting spatial structure to address complementary partial service areas. *Annals of the Association of American Geographers*, 95(4), 761-772.

Murray, A.T. and Tong, D. (2007). Coverage optimization in continuous space facility siting. *International Journal of Geographical Information Science*, 21(7), 757-776.

RACC (2010). Proyecto LABEL: European Truck Parking Areas. http://w3.racc.es/index.php?mod=fundacion&mem=EPTodos&relmenu=31. Accessed September 21, 2010.

RACE (2008). La fatiga en la conducción, http://www.fatigayconduccion.com/estudios/informe_encuesta_fatiga08.pdf

Regulation (EC) No 561/2006 of the European Parliament and of the Council of 15 March 2006

Resolución de 25 de enero de 2010, de la Dirección General de Tráfico. BOE Nº 40 de 15/02/2010, 13.538.

Santos, D.R., Suárez-Vega, R., and Dorta, P. (2001): Un modelo de decisión multicriterio para localización de centros de tratamientos de residuos. *Estudios de Economía Aplicada*, 17, 163-182.

Seydel, J. (2006). Data Envelopment Analysis for decision support. *Industrial Management and Data Systems*, 106(1), 81-95.

UNECE (United Nations Economic Commission for Europe) (2010). European agreement concerning the international carriage of dangerous goods by road (ADR) (applicable as from 1 January 2011).

Upchurch C., Kuby, M., and Lim, S. (2009). A model for location of capacitated alternative-fuel stations. *Geographical Analysis*, 41, 85-106.

Vílchez J.A., Pérez-Alavedra X., Arnaldos J., Amieiro C., and Casal J. (2001). A New Concept When Designing Parking Areas for Lorries Carrying Dangerous Goods: the Dynamic Segregation. *Loss Prevention and Safety Promotion in the Process Industries*, 983-991.

Zhang J. Hodgson J., and Erkut, E. (2000). Using GIS to assess the risks of hazardous materials transport in networks. *European Journal of Operational Research*, 121, 316-329.

Appendix

Units	Area	Social rejection (Average daily traffic in the stretch of road covered by service area)	Collective disutility (Population divided by the distance)	Demand coverage (Average daily traffic density)	Services provided (Number of services)
1	Quintanapalla	8,636.995	0	34	6
2	Briviesca	8,636.995	2.993	75	7
3	Desfiladero	7,990.580	0.00	98	7
4	Pina de Ebro	6,101.340	0.00	7,480	6
5	Monegros	5,588.515	0.00	7,200	7
6	Fraga	4,930.784	0.00	7,005	5
7	Lleida	4,565.785	0.00	5,324	8
8	Les garriges	4,745.730	0.00	3,281	6
9	Montblanc	4,555.565	2.844	273	6
10	Alt Camp	5,924.680	0.00	55	6
11	Corral de Almaguer	1,792.880	0.00	1,942	7
12	Mora del Cuervo	1,640.675	0.00	5,443	7
13	Las Pedroñeras	1,692.505	0.00	7,797	7
14	San Clemente	1,889.970	0.00	15,271	7
15	Los Palacios	11,647.150	0.00	10,867	5
16	Cerro Fantasma	10,656.905	4.366	11,059	6
17	El Cuadrejón	8,174.540	0.00	10,008	6
18	Numancia	646.415	0.00	890	7

19	Silleda	2,161.530	0.00	10,971	5
20	Villalba	15,076.690	10.543	3,349	9
21	Villacastín	11,055.120	0.00	4,619	7
22	Caldas de Luna	3,944.555	0.00	13,289	5
23	Arrigorriaga	14,075.860	3.279	40	7
24	Altube	11,824.175	0.00	131	8
25	Igay	5,355.645	0.00	154	5
26	San Asensio	3,983.610	0.00	362	7
27	Logroño	4,074.130	0.00	3,860	8
28	Calahorra	3,195.210	18.925	6,917	6
29	Tudela	4,719.450	0.00	6,960	8
30	Gallur	3,195.210	18.925	6,917	3
31	Sobradiel	4,719.450	0.00	6,960	7
32	El Realengo	8,406.315	0.00	35,163	6
33	El Llobregat	34,497.610	10.874	0	6
34	Penedés	20,983.485	0.00	24	8
35	Médol	21,495.580	0.00	0	5
36	Mazarrón	906.660	0.00	25,260	5
37	Agost	3,298.870	0.00	37,134	8
38	Manilva	6,473.640	60.816	12,369	6
39	Rio castor	6,480.940	6.654	14,535	6
40	Altos de Marbella	7,019.680	0.00	16,185	6
41	Arroyo de la Miel	7,019.680	0.00	17,141	6
42	La Jonquera	8,590.640	0.00	0	8
43	Emporda	11,771.615	0.00	0	7
44	Gironés	16,185.925	0.00	0	3
45	La Selva	20,307.870	0.00	0	6
46	Montseny	24,901.395	2.694	0	6
47	Vallés	46,707.955	27.434	0	5
48	Bellaterra	34,871.735	76.228	0	7
49	L'hospitalet	9,577.235	0.00	903	7
50	Benicarló	6,810.170	0.00	10,881	7
51	La Ribera	7,770.120	0.00	15,302	8
52	La Safor	10,990.515	0.00	35,608	7
53	San Antonio	9,129.015	8.388	32,211	3
54	La Marina	12,432.265	0.00	35,134	7
55	Robledo de la Valdoncina	2,173.940	0.00	11,427	5
56	O Burgo	21,178.760	1.845	10,453	7
57	Ameixeira	7,758.075	0.00	10,838	6
58	Compostela	9,270.635	0.00	9,942	7
59	Sainés	8,805.260	0.00	9,223	4
60	San Simón	13,007.870	0.00	9,096	6
61	Meco	3,833.595	8.006	211	7
62	Támbora	4,980.790	0.00	326	7
63	Seseña	3,526.995	0.00	530	6
64	Ocaña	3,519.695	0.00	270	6
65	Polvoranca	4,343.135	221.465	698	7
66	Los Vegones	3,940.540	0.00	1,570	8