LOCATION OF SPECIFIC RISK MATERIAL INCINERATION PLANTS IN ANDALUCÍA USING A MULTICRITERIA APPROACH

Flor Mª Guerrero and Concepción Paralera, Pablo de Olavide University, Seville, Spain
Rafael Caballero[1], Department of Applied Economics (Mathematics), Faculty of Economics, Campus El Ejido, University of Malaga, Spain
Mercedes González and Julián Molina, Málaga University, Málaga, Spain

ABSTRACT
We analyse the problem of choosing the location of incineration plants for the disposal of solid animal waste from preestablished sites in Andalucia. The waste collected by lorries from slaughterhouses should arrive at such plants once a week. Given the nature of the problem, we used multicriteria techniques for its solution. On the one hand, we have to take into account economic criteria such as start-up, maintenance, and transport costs; and on the other, social issues such as social rejection by towns on the lorry route, maximum risk as an equity criterion, and the negative implications for towns close to the plant.

Key words: SRM Waste, Location, Multiobjective, Metaheuristic.

MSC: 90C29, 47N10.

RESUMEN
La problemática que analizamos en este trabajo es la localización de incineradoras de residuos sólidos animales entre lugares preestablecidos de Andalucía. A dichas incineradoras llegarían los deshechos semanales de mataderos, los cuales deben ser recogidos mediante camiones. Para resolver el problema que se nos plantea utilizamos técnicas multicriterio, puesto que contamos con múltiples criterios siendo algunos económicos, como el coste de instalación de la incineradora, el de mantenimiento y el de transporte y otros sociales como el rechazo social de los distintos pueblos por donde pasarían los camiones en sus rutas, el riesgo máximo como criterio de equidad y la desutilidad de las poblaciones cercanas a la incineradora.

1. INTRODUCTION

In recent years interest has increased regarding analysing the effects of waste contamination and studying the policies required to deal with it. An example of this is the enforcement of regulations in industrialized countries to protect the natural environment and reduce ecological and personal damage derived from certain hazardous processes. Some environmental legislation deals with transportation and waste storage, as well as its transformation or disposal. A particular case of this in the European Union is the management of animals with mad cow disease (**BSE)**.

Most livestock activity and use involves the disposal of animal remains due to death or other causes. These remains cannot be classified as urban or hazardous disposal, so the producers are confronted with a service gap that must be filled.

In Spain, the tissues and organs of bovine, ovine, and caprine species are considered Specific Risk Materials (SRM) and as such their disposal is regulated, meaning that certain procedures have to be followed.

The disposal of SRM aims at the complete destruction of risk tissues to avoid their introduction into the human and/or animal food chain, although this is an expensive process. The most feasible, economic, and viable way to do this, and remain compliant with waste legislation, is the incineration process.

This work presents a model to find the best location for up to two incineration plants shared between five preestablished locations in Andalucía that will be used to dispose of solid animal waste. We deal with two scenarios. In Stage 1 we consider the location of a single plant, and in Stage 2 analyze the location of two plants. The model required for the location of more than two plants can be extrapolated from the latter.

E-mail: [1]rafael.caballero@uma.es

The following towns were chosen as candidates for plant location: 1) Antequera, as this town is the geographical centre of Andalucía; 2) Aznalcóllar and Alquife, since they have a large number of unemployed people - mainly lorry drivers and machine engineers - due to relatively recent mine closures; and 3) Olvera and Alcalá la Real, because of their proximity to several Andalucian provinces.

As we have to take into account different factors when evaluating potential locations for the new plants, we are dealing with a multicriteria problem. The literature offers various examples of the multicriteria approach being used to solve problems regarding the location of plants for the disposal of hazardous or unwanted substances (Erkut and Neuman, 1989, Giannikos, 1998, and Santos, Suárez-Vega and Dorta, 2001).

The aim, on the one hand, is to minimize start-up and maintenance costs, which are clearly economic criteria. At the time of our study, there were 161 slaughterhouses in Andalucia generating SRM waste which has to be completely incinerated according to the law. Therefore, our location model has to take into account the weekly collection and transportation by lorry of the waste produced by these slaughterhouses. Thus, to the two previous economic factors we have to add the minimization of transport costs. We expressed the three types of costs involved in weekly periods for reasons of homogeneity.

The disposal of this type of waste has an associated risk. This gives rise to social rejection which can be incorporated into the model in different ways. We can find different definitions of perceived risk in the literature. Thus, Erkut and Pour (1995, 1997) define it as individual risk multiplied by the power of the number of inhabitants in the given town, where individual risk can be expressed in relation to the probabilities of incidents and their consequences. For Giannikos (1998) perceived risk is expressed as the amount of product transported per town.

In our model, we tried to minimize social rejection, which was divided into two aspects. On the one hand, we took into account rejection by towns that lorries passed through on their way to the incineration plant. This was obtained by multiplying the number of lorries passing through a given town by the number of its inhabitants. The other aspect referred to rejection by towns near the incineration plant, which we called collective disutility, and which is an increasing function of town size and a decreasing function of distance from the plant to the nearby town.

We also have to take into account equity criteria in these types of problems, referring to the equitable distribution of damage between the towns involved (Marsh and Schilling, 1993). Thus, as a measure of equity we minimized maximum social rejection corresponding to the town most affected by waste transportation.

In short, we are faced with a six-objectives problem that includes economic criteria -start-up, maintenance, and transport costs -and social criteria- social rejection due to transportation and incineration of waste. Some of these objectives are clearly in conflict, which makes the multiobjective nature of the problem explicit.

In the following section we describe our model. In Section 3 we apply it to real data by looking for the best location for a single incineration plant, while in Section 4 we handle the problem of finding the best location for two plants.

2. DESCRIPTION OF THE MODEL

Our problem involves collecting SRM waste generated by n elements belonging to a set I of slaughterhouses, and transporting it to incineration plants located in some of the s candidate sites. These sites are set J. Transport passes through q towns, which are elements of the set H.

Our model includes binary variables, y_j, which take value 1 if the plant is installed in site j, $j \in J$, and 0 otherwise. The other variables, x_{ij}, are also binary and take value 1 if slaughterhouse i, $i \in I$, delivers its waste to plant j, and 0 otherwise.

The aims of the model are as follows:

1) Minimizing start-up costs

$$\text{Min} \sum_{j=1}^{s} \xi_j y_j$$

For each potential location, we consider the start-up costs of an incineration plant ξ. This includes cost of the site and the land around it, building costs, machinery and transport, furniture, materials and refrigerating chambers for the correct operation of the plant, and technical services and licence costs.

2) Minimizing maintenance costs

$$\text{Min} \sum_{j=1}^{s} v_j y_j$$

This includes expenditures involved in the maintenance of the plant ν_j, such as repairs, parts, checking, and so on, both inside and outside the actual site, and the costs of maintenance staff.

3) Minimizing transport costs

$$\text{Min} \sum_{i=1}^{n} \sum_{j=1}^{s} c r_{ij} \delta_{ij} y_j$$

This was calculated by taking into account the distance from each of the 161 centres generating waste to each possible location for the plant δ_{ij}, the number of lorries needed for transportation, r_{ij}, which, due to the amount of waste generated weekly in each slaughterhouse, is only one lorry, and the cost per kilometre travelled, c, set at 1€/km.

4) Minimizing social rejection

$$\text{Min} \sum_{h \in H} \sum_{j \in J} \omega_h R_{hj} y_j$$

where R_{hj} is the individual risk measured as the number of lorries that go through town h to the plant j, and ω_h is the number of inhabitants in h. Thus, to calculate social rejection we took into account the towns the waste passed through. We calculated the number of lorries going through a town weekly, and this was multiplied by the number of inhabitants in such a town.

5) Risk distribution criterion (minimizing maximum risk)

$$\text{Min Max} \sum_{j \in J} \omega_h R_{hj} y_j$$

To find out which of the towns that the lorries pass through gives the highest maximum risk value, we considered the one with greater social rejection.

6) Minimizing collective disutility

$$\text{Min} \sum_{h \in H} \omega_h E_h \qquad \text{where} \qquad E_h = \sum_{j \in J} \frac{\gamma y_j}{\delta_{hj}}, \quad \delta_{hj} \le \theta_1$$

This expresses social rejection from the towns near the plant. We consider that a town is nearby if its distance from the plant is equal to or less than θ_1. The threshold was set at 10 km, and thus if the town is further away then the social rejection factor is not taken into account. Consequently, collective disutility is an increasing function of the capacity of plant γ, and a decreasing function of the distance from the plant to the actual town δ_{hj}.

With regard to the model's constraints we assume the following:

$$\sum_{j=1}^{s} y_j \le p$$

$$\sum_{i \in I} \tau_i x_{ij} \le \gamma y_j \quad \forall j \in J$$

$$\sum_{j \in J} x_{ij} = 1, \quad \forall i \in I$$

$$x_{ij} \in \{0,1\}, \forall i \in I, \forall j \in J \qquad y_j \in \{0,1\} \quad \forall j \in J$$

The first constraint refers to the maximum number of incineration plants we want to install, p. The second constraint is the amount of waste burned in site j, which cannot exceed the capacity of the incineration plant, and where τ_i is the amount of weekly waste from slaughterhouse i. The other constraint arises from the fact that every slaughterhouse has to be allocated to an incineration plant. Finally, we deal with the binary condition of variables x_{ij} and y_j.

3. APPLICATION OF THE MODEL TO ONE INCINERATION PLANT

Although we are dealing with a multicriteria problem, only one incineration plant is to be installed. Thus, this is a discrete problem and we only have to calculate variables y_j. The binary variables x_{ij} are known because all the waste has to be disposed of in just one plant, thus all slaughterhouses are allocated to the same plant. Consequently, in this first stage, we will find the best location for a single incineration plant where all the waste will be disposed of. We also assume just one lorry per slaughterhouse which would go directly from the slaughterhouse to the incineration plant, without collecting any more waste on the way.

The information needed to solve this problem is shown in Table 1. The costs are expressed as weekly costs and the start-up costs have been spread over fifteen years (a reasonable estimate for the lifetime of the incineration plant) at 52 weeks per year.

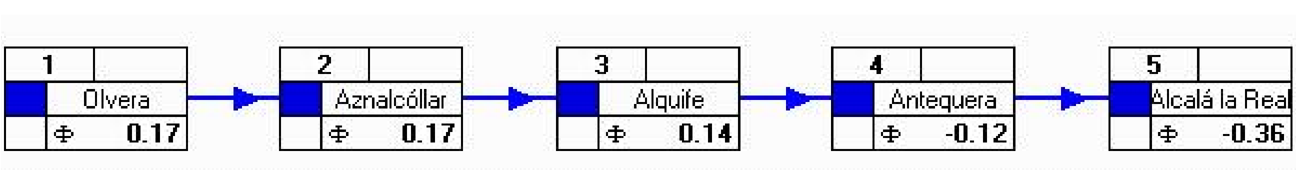
Table 1.

	Start-up Cost	Maintenance Cost	Transport Cost	Social Rejection	Maximum Risk	Collective Disutility
Aznalcóllar	1541.06	5778.96	30788.40	5232610	1139412	2977
Antequera	1926.32	6356.86	27470.80	2957654	1246832	8087
Alcalá la Real	1772.22	6125.70	30898.80	7563493	2805372	4304
Olvera	1695.16	6010.12	27389.60	4434927	1246832	4738
Alquife	1464.00	5547.80	42263.90	4091317	1246832	3057

Thus, we are dealing with a discrete multicriteria problem with 5 alternatives and 6 quantitative criteria. This problem can be solved in several ways, but we have chosen two specific ones, the outranking relation and the multiattribute utility approaches, to ensure a consistent analysis.

First, we applied the Promethee method using Decision Lab software. This method requires inputting several decision parameters, such as the preference and indifference thresholds for each criterion and their weights.

To select these thresholds, we looked into the variation range for each criterion and chose accordingly. Regarding weighting, we gave more importance to economic criteria than to any others, assigning four times more weight to economic costs than to the rest of the criteria, thus obtaining the following with this ranking:



The town chosen using these criteria is Olvera, but this is closely followed by Aznalcóllar, there being very little difference between them. Therefore, we carried out a sensitivity analysis on the weights, with the first two alternatives unchanged. In this case, the amplitude of the sensitivity ranges was large, but when we swapped the order of the first two towns, the range became very small. This led us to study the discrete problem using the multiattribute utility approach, which involves transforming the data for each criterion into utilities for the decision-maker. The town with the greatest weighted sum of utilities will thus provide the required solution.

To obtain the monoattribute utility functions from our data we used linear functions, with values in the ranging of [0,10]. The results are shown in Table 2:

Table 2.

	Start-up Cost	Maintenance Cost	Transport Cost	Social Rejection	Maximum Risk	Collective Disutility	WEIGHTED SUM
Aznalcóllar	4.5894	4.80693	7.1058	5.0316181	9.30294	9.205	5.969873
Antequera	0.7368	0.95426	8.7646	9.1679018	8.76584	0.6883	4.029649
Alcalá la Real	2.2778	2.4953	7.0506	0.793649	0.97314	6.993	3.737004
Olvera	3.0484	3.26586	8.8052	6.4819509	8.76584	6.27	5.466377
Alquife	5.36	6.348	1.36805	7.1066963	8.76584	9.0716	5.149893
Weights	0.26	0.26	0.26	0.06	0.06	0.06	

This table shows both the utilities and the weights of the different criteria, which are the same as the ones used in the previous method. The last column shows the weighted sum for each location, with Aznalcóllar being the chosen solution, followed by Olvera, Alquife, Antequera, and finally, Alcalá la Real.

Comparing this ranking to the one obtained with the outranking method, the only change involves swapping the first and second positions. However, with this second approach, the difference between Aznalcóllar and Olvera is greater, and so taking both methods into account we opted for Aznalcóllar as the location for the incineration plant. It should be borne in mind that the first method, based on outranking relations, measures the preferred intensities of a given alternative in relation to another by assigning it a maximum value of 1, even if the difference between the alternatives is very significant, whereas in the multiattribute utility theory these differences are always expressed.

In short, the problem of finding a location for a single incineration plant can be solved with different discrete multicriteria methods, each with different nuances.

4. APPLICATION OF THE MODEL TO THE LOCATION OF TWO INCINERATION PLANTS

Given the maximum capacity of incineration plants and the amount of waste produced in Andalucía, a single incineration plant would be sufficient to dispose of the weekly waste from Andalucian slaughterhouses. However, it might be cost-effective to install a second one to reduce economic and social costs, and offer incinerating services to neighbouring regions, which would yield some economic benefits.

Thus, we decided to adapt our model to the location of up to two incineration plants. In this case, the discrete character of the problem is lost because of the number of possible combinations available regarding distributing the waste of 161 slaughterhouses between the two potential incineration plants.

From a mathematical standpoint, we are dealing with a multiobjective binary problem. Specifically, it is a location and allocation problem with more than 800 binary variables, and thus the use of an exact method is not advisable.

For example, CPLEX -currently one of the most efficient programs for the exact resolution of linear binary problems- needs more than one hour to obtain a single efficient solution for the problem with the weighting method. This means that with CPLEX we would need a disproportionately large computation time to obtain an approximation to the efficient boundary. Furthermore, it is well-known that we cannot obtain non-supported efficient solutions with the weighting method. In order to do so, we have to use more complex algorithms that add constraints to the model and, in most cases, increase its computational cost. In short, solving this problem with an exact method is computationally too expensive. For this reason, we opted for a metaheuristic algorithm -the MOAMP method (Caballero, Gandibleux and Molina, 2003)- which is a metaheuristic algorithm for multiobjective binary programming, based on Taboo search.

Regarding the data used to solve the problem, we combined the start-up and maintenance costs under the common denominator of costs. Transport costs, social rejection, and maximum risk had to be taken into account for each route from the slaughterhouses to possible locations for the incineration plants, while disutility was the same as in the previous case.

Some of the efficient solutions obtained are shown in Table 3.

Table 3.

Sol	Costs	Transport	Rejection	Max Risk	Disutility	Sum	Max	Aznalc.	Anteq.	Olvera	Alcalá	Alquife
**						0.00%	0.00%	6	2	0	1	2
sol9	0.00	1.00	0.69	1.00	0.01	269.89%	100.00%	0	0	0	0	161
sol4	0.96	0.00	0.66	0.67	0.53	281.03%	95.52%	85	0	0	76	0
sol69	1.00	0.32	0	0.00	1.00	232.21%	100.00%	30	131	0	0	0
sol6	1.00	0.27	0.01	0.00	1.00	227.42%	100.00%	36	125	0	0	0
sol3	0.04	0.52	1	0.71	0.00	226.85%	71.11%	161	0	0	0	0
sol152	0.85	0.38	0.10	0.00	0.38	**171.04%**	85.20%	75	0	0	0	86
sol3	0.04	0.52	1	0.71	0.00	226.85%	**71.11%**	161	0	0	0	0

The first six columns of the table show examples of efficient solutions and standardized values for each objective in each solution. Value 0 represents the minimum scope of the objective, that is the ideal value, while value 1 expresses the anti-ideal value.

Thus, solution 9 (sol9) minimizes costs (start-up and maintenance); sol4 minimizes transport costs; sol69, social rejection; sol6, maximum risk; and sol3, disutility.

The middle two columns show the sum of the deviations from the ideal levels for each solution and the maximum deviation from such levels, respectively. The last two solutions, (these values are shaded), provide minimum values for some of the two factors. Sol152 yields the minimum value of the sum of deviations from ideal values, and sol3 the minimum of the maximum deviation.

The right-most columns show five candidate locations, the number of slaughterhouses delivering waste to each location, and the number of incineration plants installed in each efficient solution. Thus, in sol9 a single incinerator is installed in Alquife, while in sol3 one is installed in Aznalcóllar. Other efficient solutions yield two incineration plants; for example, in sol4, 85 slaughterhouses take their waste to Aznalcóllar, and 76 to Alcalá la Real.

5. CONCLUSIONS AND FUTURE LINES OF WORK

This work is an attempt to establish the best location for up to two incineration plants of solid animal waste which are chosen from five preestablished areas. The weekly waste from 161 official slaughterhouses in Andalucía would be delivered to them by lorry.

In regard to decision-making, we have to deal with economic and social criteria, which are sometimes antagonistic to each other; thus, this is a multiobjective problem. We solved this by using two different methods. In the first, we identified the location of a single plant and so this was a discrete problem. In the second, we studied the location of two incineration plants, and thus the problem was solved with metaheuristic methods.

Our further aim is to solve the problem under more realistic conditions. It is not very logical for a lorry to collect waste from a single slaughterhouse and then go to the plant with half a load, while passing other slaughterhouses. It would make more sense for a lorry to collect waste from several slaughterhouses, bearing in mind lorry capacity and the working hours of the drivers.

Thus, in future research, we will try locate more than one incineration plant, and at the same time allow a single lorry to pick up waste from several slaughterhouses before arriving at the plant. We therefore intend to organize the routes for each lorry taking the chosen plant as the start and finish point.

This complicates the problem considerably because we have to take into account the distances, not only between each slaughterhouse and each plant, as we have done up to now, but also between each slaughterhouse. We also have to bear in mind the time needed to travel these distances as we have to consider the working hours of the lorry drivers.

Furthermore, there are a vast number of possible combinations that considerably increase the dimensions of the problem and this makes the acquisition of the data necessary to solve it difficult. For example, when calculating the social rejection of each location, we are faced with the need to take into account all the towns the lorries might pass through on the potential routes that can be created by combining 161 slaughterhouses.

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REFERENCES

CABALLERO, R.; X. GANDIBLEUX and J. MOLINA (2003): "MOAMP - A Multiobjective Meta-heuristic using an Adaptative Memory Procedure", **European Journal of Operational Research**. Submitted for publication.

ERKUT, E. and S. NEUMAN (1989): "Analytical Models for Locating Undesirable Facilities", **EJOR**, 40, 275-291.

ERKUT, E. and V. VERTER (1995): **Hazardous Materials Logistics**. En **Facility Location. A Survey of Applications and Methods**. Springer, Heidelberg.

______________________ (1997): "Modeling of Transport Risk for Hazardous Materials". **Operations Research**, 46(5), 625-642.

GIANNIKOS, I. (1998): "A Multiobjective Programming Model for Locating Treatment Sites and Routing Hazardous Wastes", **EJOR**, 104, 333-342.

MARSH, M. and D.A. SCHILLING (1993): "Equity Measurement in Facility Location Analysis: A review and Framework", **EJOR**, 74, 1-17.

SANTOS, D.R.; R. SUÁREZ-VEGA and P. DORTA (2001): "Un Modelo de Decisión Multicriterio para Localización de Centros de Tratamientos de Residuos", **Estudios de Economía Aplicada**, 17, 163-182.