Siting a university kindergarten in Madrid

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Abstract

In this paper we present a real-life multicriteria decision making problem of choosing the site for a university kindergarten in Madrid. The largest private university of Madrid, San Pablo CEU, needs to build a kindergarten for personnels children. This study consists of two phases. In the first phase an approximative model was presented to the decision makers in order to motivate re-activating the process. In the second phase, a more detailed model with new alternatives was introduced. The criteria measurements as well as the preferences contain large uncertainties. Therefore, the problem is solved by using the SMAA-III software that allows to model uncertainties through joint probability distributions. We present the complete case study in which the preference parameters as well as the criteria measurements are modelled with various types of uncertainties.

Keywords: Site location problem; Decision analysis; Multicriteria; SMAA

1 Introduction

Choosing a site for a new facility is among the traditional multiple criteria decision making problems. This type of problems typically consist of a finite set of alternative sites that are evaluated in terms of multiple criteria. The criteria often take into account socio-economical, logistical, and environmental aspects of the problem setting. Although the ultimate goal is to choose the site to build in, it is common to use a ranking method to obtain also some backup alternatives, in the case that the most preferred one cannot be implemented. Many modern multiple criteria ranking methods have been applied in such problem setting, see e.g. Barda *et al.* (1990); Erkut & Moran (1991); Hokkanen *et al.* (1999); Hokkanen & Salminen (1997); Karagiannidis & Moussiopoulos (1997); Karkazis (1989); Keeney (1980);

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Lahdelma *et al.* (2002); Norese (2006); Partovi & Burton (1992); Queiruga *et al.* (2006).

In this paper we present a real-life case study of siting a university kindergarten. The Fundación Universitaria San Pablo - CEU (abreviated just as CEU from now on) is among the largest universities in Madrid, Spain. It has received a petition from the teachers and other personnel of the university to arrange a kindergarten for the personnels children. This petition was received already in 1996, but the project was frozen because no agreement for the location could be reached. In early 2007, a two-phase decision making process for choosing the site was initiated by the university professors. In the first phase, an initial analysis was made in order to motivate re-activation of the project without requiring interaction from the Decision Makers (DMs). In the second phase the model was revised and the DMs gave more precise preference information so that the most preferred alternatives could be recognized.

The case study considered in this paper had a preliminary phase in which PROMETHEE method (Brans & Vincke, 1985) and generalized criteria were used (Barberis & Rodenas, 2006). Equal weights were considered in the preliminary phase without justification. In the face of ignorance about preferences, it is advisable not to use geometrical or other means to model ignorance, because even small alterations of the weights might cause different results. This is especially the case with outranking methods (see e.g. Figueira *et al.*, 2005b), because their preference model containts many non-linearities. For an example of alteration of results in the light of small changes in weights, see Tervonen *et al.* (2007).

The problem consists of ordinal and imprecise cardinal criteria measurements and partially missing preference information. Stochastic Multicriteria Acceptability Analysis (SMAA) methods have been used succesfully in such type of siting problems, see e.g. Hokkanen *et al.* (1999); Lahdelma *et al.* (2002), or Tervonen & Figueira (2006) for a full survey on SMAA methods. These problems have included environmental and/or socio-economical criteria, that are also present in this study. ELECTRE methods are used widely in discrete decision making problems (e.g. Figueira *et al.*, 2005b; Hokkanen & Salminen, 1997; Karagiannidis & Moussiopoulos, 1997; Norese, 2006). They have the advantage that a utility or a value function does not need to be defined, therefore requiring less interaction with the DMs. Our problem has these characteristics: the criteria measurements are uncertain and preferences cannot be elicited in the first phase because we need results to motivate the DMs. Therefore, we have chosen to analyze the problem with SMAA-III (Tervonen *et al.*, 2007). It allows to apply ELECTRE III with imprecise values for the model parameters. We also cross-validate the results by applying SMAA-3 (Hokkanen *et al.*, 1998) that uses a less discriminative maximin exploitation rule.

SMAA-III applies probability distributions to model imprecision. Although we believe that the approach taken in SMAA-III is the most appropriate one for this study, we note that there are also other approaches. These include entropy methods (Abbas, 2006), interval methods (Mustajoki *et al.*, 2005), Dempster-Shafer theory (Beynon *et al.*, 2000), rough sets and fuzzy sets (Figueira *et al.*, 2005a). An important reason for choosing the method is also that the analysts (us) are more familiar with SMAA-III than with the other pre-mentioned methods, therefore lowering the risk of imprecision of analysis from misunderstanding the model.

This paper starts by presenting the applied method, SMAA-III, in Section 2. The case study is presented in Section 3, followed by a discussion of the results in Section 4. Conclusions end the paper in Section 5.

2 SMAA-III

SMAA-III (Tervonen *et al.*, 2007) is designed to solve a discrete ranking problem that consists of a set of alternatives evaluated in terms of multiple criteria. It is based on ELECTRE III (see e.g. Belton & Stewart, 2002; Figueira *et al.*, 2005b) for constructing a ranking of alternatives, extending it by allowing imprecise parameter values. ELECTRE III has two phases. In the first phase, an outranking relation between pairs of alternatives is formed. When an alternative outranks another, it is considered "as good as or better one". The second phase consists of exploiting this relation, producing a final partial pre-order and a median pre-order.

ELECTRE III applies pseudo-criteria in constructing the outranking relation. A pseudo-criterion is defined with two thresholds: an indifference threshold for defining the difference in a criterion that the DM deems insignificant, and a preference threshold for the smallest difference that is considered absolutely preferred. Between these two lies a zone of "hesitation" of indifference and strict preference. ELECTRE III also defines a third threshold, the veto threshold. It is the smallest (negative) difference that completely nullifies (raises "veto" against) the outranking relation. In addition to the thresholds, preferences are quantified through a weight vector $w = (w_1, \dots, w_j, \dots, w_n)$. Without loss of generality, we assume that $\sum_j w_j = 1$.

For more details on how ELECTRE III constructs the ranking, see e.g. Belton & Stewart (2002). In the original ELECTRE III, a median pre-order is computed based on the two complete pre-orders and the final partial pre-order. The median pre-order removes the incomparabilities in the final partial pre-order.

SMAA-III applies simulation and studies the effect of changing parameter values and criteria evaluations on the results. The imprecision of the parameters is quantified in theory through joint density functions, but in practice simple linear intervals or Gaussian distributions are used. Monte Carlo simulation is used in SMAA-III to compute three types of descriptive measures: rank acceptability indices, pair-wise winning indices, and incomparability indices.

The *rank acceptability index* measures the share of feasible weights that grant an alternative a certain rank in the median pre-order by taking into account simultaneously imprecisions in all parameters and criteria evaluations. It represents the share of feasible parameter combinations that make the alternative acceptable for a particular rank, and it is most conveniently expressed percentage-wise. The most acceptable ("best") alternatives are those with high acceptabilities for the best ranks. Evidently, the rank acceptability indices are within the range [0,1], where 0 indicates that the alternative will never obtain a given rank and 1 indicates that it will always obtain the given rank with any feasible choice of parameters. Thus, the rank acceptability indices are a measure of robustness.

The *pair-wise winning index* describes the share of weights that place an alternative on a better rank than another one. An alternative that has a pair-wise winning index of 1 with respect to anohter one always obtains a better rank, and can thus be said to *dominate* it in a wide sense. The pair-wise winning indices are especially useful when trying to distinguish between the ranking differences of two alternatives. Because the number of ranks in the median pre-order of different simulation runs varies, two alternatives might obtain similar rank acceptabilities although one is in fact inferior. In these cases looking at the pair-wise winning indices between this pair of alternatives can help to determine whether one of the alternatives is superior to the other or if they are equal in "goodness".

Because median pre-orders are used in computing the rank acceptability indices, it is not anymore possible to model incomparability. For this reason, SMAA-III includes an *incomparability index* that measures the share of feasible parameter values that cause two alternatives to be incomparable.

When the criteria measurements and other parameters are imprecise, the three different indices can be used to measure robustness of the analysis. For example, pair-wise winning indices show how the mutual goodness of a pair of alternatives changes with different feasible parameter values. If an alternative is deemed the preferred one and still has a relatively low (less than 60%) pair-wise winning index with another alternative, the parameters should be defined more precise. Sometimes this is not possible, and less crucial decisions can be made based on such imprecise conclusions. With decisions having larger impact, the process should be iterated until sufficient pair-wise winning indices are obtained.

3 Case study

The CEU has received a petition from the teachers and other personnel of the university to arrange a kindergarten for the personnels children within the universitys premises. CEU has various installations dispersed widely in Madrid. The future location for the kindergarten can be chosen within these installations, or in the residential zones west of Madrid. The choice of location has clearly multi-dimensional effects; not only the accessability and the price of construction and maintenance have to be taken into account, but also the possible size of the kindergarten and the effects to the surrounding city view.

The original petition was received already in 1996, but as no agreement was reached over the location, the project was frozen for more than 10 years. Lately the University Board of Directors has received a large amount of requests from the teachers and employees concerning building the kindergarten. In order to reactivate the project, we first did an initial, imprecise analysis for motivational purposes. We used for it old criteria measurements and possible locations from 10 years ago. There was no preference information available as the DMs were not consulted. To probe for good compromise alternatives and raise discussion, we used weight lower bounds of 0.1 to avoid extreme weight combinations. There were total 5 criteria used, therefore the weights were modelled with a joint uniform distribution bounded within 0.1 – 0.6 for each weight.

The initial phase resulted in a decision to re-activate the project and to do a more through analysis. We then re-evaluated the alternatives, and found that one of them did not belong to CEU anymore. A residential zone alternative was split into three different locations. All the criteria measurements were updated to correspond with the current situation. In this manner we formed a multiple criteria decision making problem in which 7 alternatives were to be ranked with respect to 5 criteria. The criteria were the same that were used in the first phase of the study, chosen after discussions with different educational bodies of the CEU. In their opinion, these 5 criteria take into account all relevant aspects of the problem:

- ACC: accessability to the center of city. Measured in minutes by public transportation
- SIZ: size of the kindergarten to built. Measured in the number of day-care places
- COP: land and construction price. Measured in euros
- EFF: effects to the city landscape. Measured as an ordinal criterion
- MAC: maintenance cost of the facility. Measured in euros

The 7 alternative locations for the kindergarten are all located in the west side of the centre of Madrid. Figure 1 shows a map of the locations. Notice that two alternatives are so close to each other that they are shown in the map as a single location: Campus Moncloa and San Dominique. These reside within 50 meters in the same street.

The criteria measurements revised for the second phase of the study are presented in Table 1. The accessability criterion (ACC) is measured in minutes by public transportation from the Avenida América metro station. This metro station is a major transport hub for central Madrid. It incorporates train, bus, and metro stations, and is used by large amount of commuting workers to arrive to the central Madrid area. For defining measurements for the accessability criterion, faculty staff accustomed to travel in Madrid approximated the mean times to travel from the Av. América metro station to the desired location during a weekday. Separate approximations were done for 6 different time slices: 6:30-10, 10-13, 13-16, 16-19, 19-21, and 21-24. After this, we calculated the mean and standard deviations for each alternative based on these approximations, and modelled the criteria measurements as Gaussian distributed values. It should be noted, that although the uncertainties of the measurements are correlated in the approximations, probably

Figure 1: Alternative locations in the map.

the real values underlying these means are not correlated. Therefore we do not model the criterion through a multivariate Gaussian distribution as has been done in, for example, Tervonen *et al.* (2008).

Table 1: Criteria measurements.

Alternative	ACC	SIZ	COP	EFF	MAC
	min	max	min	rank	min
Campus Montepríncipe	52.5 ± 5.24	234	3937880	3.	39000–48000
Campus Moncloa	39.17 ± 5.85	159	4729000	7.	26000–32000
Campus Argüelles	36.67 ± 6.06	167	5238520	5.	28500–35000
San Dominique	38.33 ± 6.06	134	4068450	6.	23500–29000
Majadahonda	46.33 ± 3.83	159	3146000	4.	27500–33500
Pozuelo	42.83 ± 3.19	167	3317270	1.	28500–35000
Las Rozas	49 ± 3.52	201	3904800	2.	34000–42000

For measuring the size of the kindergarten (SIZ), we calculated the number of kindergarten places that would be available in the final installation. In Spain there are two government rules that regulate the amount of children allowed in kindergartens (BOE, 2007a,b). These divide the kindergarten education into two cycles and take into account the age of children. For the first cycle, we have three age classes: 0-1 years, 1-2 years, and 2-3 years. The regulated amount of children in the classroom for these are 8, 12-14, and 16-20, respectively. The second cycle comprises of children of ages 3-6. For children of these ages there can be between 20 and 25 in a classroom.

The size of the kindergarten as well as the construction costs depend on the number of classrooms. Our estimates for these numbers are presented in Table 2. We model the number of children with exact value that is the maximum number of children allowed with this amount of classrooms. For example, for Campus Montepríncipe, the SIZ is $4 \times 8 + 4 \times 14 + 3 \times 20 + 3 \times 25 = 223$ children.

Table 2: The number of different classrooms for each alternative.

Alternative	0-1 yrs	1-2 yrs	2-3 yrs	3-6 yrs
Campus Montepríncipe	4	4	3	3
Campus Moncloa	2	2	2	3
Campus Argüelles	3	2	2	3
Zona Residencial	3	3	3	3
San Dominique	2	2	2	2
Majadahonda	2	2	2	3
Pozuelo	3	2	2	3
Las Rozas	3	3	3	3

The minimum infrastructure for each building is a W.C., a multiple purpose room, a playground, and a classroom for every group of children. The sizes of classrooms are regulated by two government orders. These obligate two square meters for each children, and a minimum size of 30 square meters for a classroom (BOCM, 2004; BOE, 2005). Therefore the sizes are 30m^2 for classrooms of children of 0-1 and 1-2 years, 40m^2 for 2-3 years and 50m^2 for 3-6 years. The infrastructure requirements are used to estimate the total land area required by the alternatives. We use Gaussian distribution for the land and construction price (COP). Standard deviation is set to 5% of the mean value, so that the 95% confidence intervals are mean $\pm 10\%$. The land prices were obtained from the El País newspaper for second hand housing mean prices in the corresponding areas (El País, 2007). The estimated construction prices were obtained from (Madrid, 2007).

Effects to the city landscape (EFF) measure both the effect during construction as well as the possible negative effect after completion. We chose to measure the effect as an ordinal criterion: the alternatives were ranked based on expert views. It would have been quite hard to come up with a cardinal values to measure the effects, similarly that has been reported in the literature when measuring effects on the landscape or environment (e.g. Hokkanen & Salminen, 1997; Lahdelma *et al.*, 2000; Martin *et al.*, 2007).

The DMs provided us with imprecise weight information: the ACC and COP criteria were considered to be the most important ones with approximated weights of 0.3. After them, the next important one was considered to be SIZ with a weight of 0.2. EFF and MAC were considered the least important ones with estimated weights of 0.1. Although the DMs provided these exact weight values, they showed uncertainty about the values. To model this behaviour, we considered the weights to be uncertain with linear intervals. For each weight a +-0.05 uncertainty is considered. This enforces weight bounds as shown in Table 3. It should be noted, that these weight bounds preserve the ordinal information present in the original weights; for example, ACC and COP can never have lower weights than the rest of the criteria. We have estimated preferences also in terms of imprecise thresholds. For all cardinal criteria except the maintenance cost we use direct imprecise thresholds. For maintenance cost the threshold is defined as imprecise percentage of the value. The thresholds are presented in Table 3.

Table 3: Imprecise weights and thresholds.

Criterion	ACC	SIZ	COP	EFF	MAC
Weight	0.25–0.35	0.15–0.25	0.25–0.35	0.05–0.15	0.05–0.15
Indif TH	6.5 ± 1.5	1.5 ± 1.5	10000 ± 5000	-	$3\% \pm 2\%$
Pref TH	12.5 ± 2.5	3 ± 1	100000 ± 50000	-	$8\% \pm 2\%$

We executed the analysis with SMAA-III and cross-validated the results with a modified SMAA-3 method. It takes into account all ranks and produces rank acceptability indices with a meaning similar to those of SMAA-III, but uses a less discriminative maximin exploitation rule. This was done because up to our best knowledge SMAA-III has not been used before in real-life decision making contexts as it the case with SMAA-3. The cross-validation gave additional security in the results. Both of these analyses were done with 10000 iterations, which gives sufficient accuracy for the indices (Tervonen & Lahdelma, 2007). The rank acceptability indices and pair-wise winning indices of SMAA-III analysis are shown in Figures 2 and 3, respectively. The incomparability indices are not presented as they are not relevant in this study. Neither are presented the rank acceptability indices of the modified SMAA-3 analysis, because the results are similar to those of the SMAA-III analysis.

4 Discussion

The resulting indices of the analysis give quite high first rank acceptability to Campus Argüelles and Pozuelo. But as we are using quite uncertain criteria measurements as well as thresholds and weights, all alternatives that obtain significant first rank acceptabilities should be taken into account. This means, that Monteprincípe, Moncloa, and Las Rozas are viable choices as well. As it can be seen from the pairwise winning indices, all of them obtain higher ranks than Argüelles and Pozuelo with a reasonable share of parameter combinations. Therefore the “true” parameters might as well lie in these, relatively small sets of parameter values.

Rank acceptability indices

Rank	1	2	3	4	5	6	7
Monteprincipe	13	19	19	19	17	10	2
Moncloa	9	15	17	16	17	17	10
Arguelles	36	16	14	12	12	7	2
San Dominique	3	10	16	22	22	19	8
Majadahonda	4	9	14	19	22	20	12
Pozuelo	37	23	16	11	7	4	1
Las Rozas	18	25	20	17	12	7	1

Figure 2: Rank acceptability indices of SMAA-III analysis.

Pair-wise winning indices

	Monteprincipe	Moncloa	Arguelles	San Dominique	Majadahonda	Pozuelo	Las Rozas
Monteprincipe	0	57	36	64	66	28	39
Moncloa	38	0	28	52	55	22	31
Arguelles	60	67	0	74	74	45	53
San Dominique	32	44	23	0	50	15	24
Majadahonda	29	40	21	45	0	15	22
Pozuelo	67	72	50	82	81	0	58
Las Rozas	53	65	41	73	73	36	0

Figure 3: Pair-wise winning indices of SMAA-III analysis.

Although the results contain high uncertainties, recommendations have to be given. Pozuelo and Campus Argüelles seem to be the "best" alternatives with no further information. There is a clear "trade-off" between the two alternatives: Pozuelo is a residential zone alternative away from the city center, while Campus Argüelles resides in the center of Madrid. An interesting fact is that they are equal in size, both being good compromise alternatives in that aspect. Campus Argüelles is more accessible alternative, but also expensive and causing possibly high effects to the city landscape. For deciding between these two, we presented the results to the University Board of Directors.

The University Board of Directors examined carefully the results. During several meetings of the Board, discussions took place with respect to measuring their preferences. They reckoned that the problem of weighting decision criteria is hard. Furthermore, they acknowledged the fact that in the case of collective decisions it is very difficult to achieve consensus. As they acknowledged the hardness of making group decisions with highly imprecise data, the results of the analysis were accepted and discussion continued about the results.

Between the two "best" alternatives, Pozuelo and Campus de Argüelles, the Board considered that Pozuelo is more preferred one in the current situation. The most important reason for this was that at present it is hard to have access to the land in the central area of Madrid where Campus Argüelles is situated. The question of buying property is currently complicated in Spain because of the state of markets. Buying centrally situated property would imply extra financial uncertainties not taken into account by the model.

Even though the Board agreed on choosing Pozuelo for the location of building the kindergarten, the project was postponed due to ongoing change of members in the University Board. The decision making process ended with these conclusions. The initial enthusiasm and the decision to re-activate the project because of structured decision analysis not requiring too much interaction from the DMs was in the end overtaken by the current administrative situation. We believe that taking into account the importance of the problem presented in this paper, the forthcoming new members of the University Board will show sensibility in relation with the crucial social problem and re-activate the project again in the near future.

5 Conclusions

In this paper we presented a real-world case study of choosing a location for a kindergarten of the largest private university of Madrid. The study contained some important particularities: the initial phase of the process was to re-activate the project without requiring interaction from the Decision Makers (DMs). The SMAA-III ranking method was chosen because it allows the analysis to be done with imprecise criteria measurements and missing preference information. Initial phase of the project was considered a success: the University Board of Directors decided to re-activate the process and the model was revised with up-to-date data. New alternatives were also discovered and old ones not viable anymore removed from the model. In the second phase, more preference information was included in the model as well. In the end of the process, the DMs could identify the most preferred alternative. However, the implementation is delayed because of changes in the university administration.

The initial phase of re-activation of the process without requiring interaction from the DMs could be applied similarly in other decision making contexts as well. Whenever older, more imprecise data is available, a possible initial phase with an uncertain model can allow savings to be obtained. Although in this case study the analysts had no extra salary outside their university payment, commonly companies offering decision analysis charge high costs per hour. This type of two-phase decision analysis could be used in wide range of decision making problems, possibly allowing implementation as a company policy to gain competitive advantage in the market of consulting services.

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