INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Selection of a site for waste disposal by means of multiattribute utility theory

Choix de site pour la décharge des déchets au moyen de la théorie d'utilité multiattributs

M. L. Galves – *Institute for Technological Research of the State of São Paulo, Brazil*
W. Hachich – *GeoExpert Polytechnic School of the University of São Paulo, Brazil*
M. E. G. Boscov – *Polytechnic School of the University of São Paulo, Brazil*

ABSTRACT: The selection of a site for waste disposal is considered in this paper as a decision problem with multiple and conflicting objectives, since it includes both economic and environmental aspects. A methodology based on multiattribute utility theory is proposed to aid the decision making process. This methodology is illustrated by an example, the geo-environmental and economic aspects of which are emphasized.

RESUME: Le choix de site pour la disposition des dechets est considéré dans cet article comme un problème de décision avec des objectifs multiples et conflitants, car des aspects économiques et environnementaux y sont inclus. Une méthodologie basée sur la théorie d'utilité multiattributs est proposée pour aider le processus de prise de décision. Cette méthodologie est illustrée avec un exemple, l'accent étant mis sur les aspects géo-environnementaux et économiques du problème.

1 INTRODUCTION

The decision problem dealt with in this paper is the selection of a site for the disposal of urban wastes. The decision maker, the city council, has to choose among three possible sites:

1. an area in the outskirts of the city, low population density, no urban facilities, hilly topography, clayey formation, shallow aquifer, low cost per square meter;
2. same as 1 but plane topography, sandy formation, shallow aquifer;
3. an area close to a densely populated city neighbourhood, high cost per square meter, small area available, clayey formation, deep aquifer.

The following objectives have been specified by the decision maker:

. satisfy the demand in a certain time horizon;
. minimize costs;
. minimize environmental impacts.

These objectives are obviously conflicting. Therefore a tool is needed to guide the decision making in such a manner that conflicts are resolved in a rational, rather than in a passional way. A methodology based on multiattribute utility theory is set forth for that purpose.

2 STRUCTURING THE PROBLEM

Before multiattribute utility theory can be applied, the decision problem must be structured. Given a set of objectives defined by the decision maker, structuring the problem basically involves characterizing the candidate sites and the landfill to be built on each site, as well as specifying the attributes.

2.1 Site and landfill characterization

Site characterization consists in identifying the physical, biological and social processes within the area of influence. This paper refers only to the physical environment and its processes, even though it is recognized that all environmental processes should be taken into account. The physical processes mostly affected by solid waste disposal are: erosion, sedimentation, surface and subsurface water flow, circulation of particles and gases in the atmosphere, and physico-chemical interactions in water and soils.

The landfill should be described in terms of its geometric and technological aspects, such as height, slope inclinations, bottom liner materials, cover material and drainage systems for surface water, leachate and gases. Although the detailed design is not available at this phase of the decision process, it is extremely important to consider those factors that may determine or prevent environmental impacts.

The relevant information required to characterize both the site and the landfill includes data on the environment, the use of natural resources and the waste, as follows:

. Environment: topography and area of the site, soil formation (clayey or sandy), wind direction, distance to water bodies (rivers, streams or lakes), flood potential, peak storm runoff, aquifer characteristics (access, thickness, transmissivity and water velocity);
. Use of natural resources: adjacent land use, including existing urban facilities, distance to city and size of city, and water body use;
. Waste: volume, type and predicted leachate and gas generation.

2.2 Specification of attributes

Once each site and the corresponding landfill have been characterized, it is possible to specify the attributes that best represent the objectives from the decision maker's viewpoint. An attribute is a measure of effectiveness that indicates the degree to which each objective is achieved.

Specification of an attribute requires the identification of a scale and the assessment of its levels for each candidate site. When no objective measure is apparent, a subjective index must be developed (Keeney and Raiffa 1976).

2.2.1 Choice of attributes

In the problem analysed in this paper, the objective of satisfying the demand is related to the capacity of each site to receive a certain volume of waste, which depends on the area of the site and the geometric characteristics of the landfill. This objective, as well as minimizing costs, will be measured by the attribute costs (X_1), composed of the following elements: buying the area for waste disposal, constructing and operating the landfill, including leachate treatment and mitigation measures for adverse impacts, and post-closing.

The objective of minimizing environmental impacts will be represented by two attributes, which reflect changes on physical processes concerning air and water:

. air quality (X_2) encompasses many elements that may be considered together, in an air quality index, or separately, depending on their relative importance for the problem:

particulates, sulfur dioxide, methane, carbon monoxide and oxygen;

. ground-water quality (X_3): refers to surface and subsurface water contamination and includes different components such as dissolved solids, heavy metals, biochemical and chemical oxygen demands, water pH and dissolved oxygen.

2.2.2 Assessment of attribute values

Attribute costs can be evaluated from the elements considered in its composition, as described in 2.2.1.

The assessment of attributes air quality and water quality is more complex because of the many aspects involved. In the case of air quality, such factors as topography, wind direction, distance to city and gas generation should be taken into account. As to water quality, relevant elements are: soil formation, distance to water bodies, depth of aquifer, water use, rainfall pattern and leachate generation.

The levels of the attributes for the three sites presented in section 1 are illustrated in Table 1. An ordinal scale has been used because quantitative data on those sites is not currently available.

Table 1. Assessed attribute levels.

Site/Attribute	Costs	Air quality	Water quality
1	B	G	A
2	A	A	B
3	A	B	G

Note: G = good; A = average; B = bad

Site 1, for instance, is considered bad on costs because of the distance, the lack of urban facilities and the topographic conditions. This site is good on air quality because it is not populated and it is distant from the city, but it is average on water quality because the aquifer is shallow.

3 MULTIATTRIBUTE UTILITY FUNCTION

Observing the attribute levels for the three sites in Table 1, one can conclude that there is no obvious best alternative. The selection of a site will be possible only by considering the decision maker's preferences regarding the achievement of the objectives.

Once certain axioms, as postulated by von Neumann and Morgenstern (1947, apud Keeney and Raiffa 1976), are satisfied, an individual's utility funtion can be obtained. This function is a formal, mathematical representation of his preference structure.

In multiattribute utility theory, the consequence vector $\underline{x} = (x_1, x_2,..., x_n)$ of implementing a particular alternative can be described in terms of the levels x_i of the attributes X_i.

To quantify preferences, the decision maker's utility function, which assigns a number u (utility) to each of the possible consequences, must be assessed. This is accomplished by eliciting the decision maker's utility for each attribute and then combining these single utilities into one multiattribute utility function. The site which provides the highest utility with respect to all the attributes is the preferred alternative.

The multiattribute utility function has two properties:

1. $u(x_1',..., x_n') > u(x_1'',..., x_n'')$ if and only if $(x_1',..., x_n')$ is preferred to $(x_1'',..., x_n'')$;

2. in situations involving uncertainty, the expected value of u is the approprate guide to make decisions.

Keeney (1974) showed that, when two basic assumptions about the decision maker's preferences are verified, the multiattribute utility funtion can be expressed in simple forms. These assumptions are:

. Preferential independence: the pair of attributes $\{X_1,X_2\}$ is preferentially independent of the attributes $\{X_3,...,X_n\}$ if preferences among $\{X_1,X_2\}$ pairs given that $\{X_3,...,X_n\}$ are held fixed do not depend on the level where $\{X_3,...,X_n\}$ are fixed.

. Utility independence: the attribute X_1 is utility independent of the other attributes $\{X_2,...,X_n\}$ if preferences among lotteries over X_1, specifying various amounts of x_1 and the probabilities of receiving them, given that $\{X_2,...,X_n\}$ are fixed, do not depend on the levels where these attributes are fixed.

The simple forms of the multiattribute utility functions are additive (1) and multiplicative(2):

$$u(x_1, x_2,..., x_n) = \sum_{i=1}^{n} k_i u_i(x_i) \quad (1)$$

$$1 + ku(x_1, x_2,..., x_n) = \prod_{i=1}^{n} [1 + kk_i u_i(x_i)] \quad (2)$$

where $u(x_1, x_2,..., x_n)$ is scaled 0 to 1, the component utility functions $u_i(x_i)$ are scaled 0 to 1, the scaling constants k_i are positive and less than one, and k is a constant calculated from the k_i's:

$$1 + k = \prod_{i=1}^{n} (1 + kk_i) \quad (3)$$

The procedures for obtaining the multiattribute utility function are described in Keeney and Raiffa (1976) and will not be presented here. They involve checking for utility and preferential independence, deciding on form of utility function (additive or multiplicative), assessing component utility functions and scaling constants (for a complete case study, see Galves 1995).

4 CONCLUSIONS

A well established methodology for decision making with conflicting objectives, namely that of maximization of utility, is shown to be directly applicable to the choice of the most preferred alternative for waste disposal. Multiattribute utility theory concepts are invoked for the assessment of the decision maker's preference or utility function.

It should be pointed out that Decision Analysis would provide a more encompassing and realistic approach, since it allows for explicit incorporation of uncertainty (something that is not done in multiattribute utility theory): a "good" site in terms of air quality, for instance, may have its bad days depending on wind direction and velocity (which are best modelled as random variables), and decisions should take these uncertainties into account.

Direct validation of such approaches is only possible, however, if a research program is conducted in which decisions are revisited a few years after they were implemented, so as to assess their correctness. The authors are not aware of any such program.

REFERENCES

Galves, M.L. 1995. *Condicionantes geotécnicos do traçado de rodovias: uma proposta metodológica de escolha baseada na Análise de Decisões com objetivos múltiplos.* Doctoral thesis, Polytechnic School of the University of São Paulo.

Keeney, R.L. 1974. Multiplicative utility functions. *Operations Research* 22: 22-34.

Keeney, R.L. & H.Raiffa 1976. *Decision with multiple objectives: preferences and value tradeoffs.* New York: Jonh Wiley & Sons.