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Multi-Criterion Decision-Making Tools for Wastewater Planning Management

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ABSTRACT

Wastewater planning management is a complex problem involving agricultural, rural and industrial interests. In countries facing rapid population growth, identifying methods that can allow them to take good decisions among several competitive alternatives is of utmost importance. The purpose of this paper is to present a methodology for a wastewater planning management system using a Multi-criterion Decision-making (MCDM) method based on utility function. It allows one to take into account a multiple conflicting multi criterion context in terms of objective specification, criteria, criterion scales and construction of a payoff matrix that consists of the alternative versus criteria array. These objectives deal with groundwater protection, effluent quality, wastewater reuse, system reliability and resources needed. A number of wastewater treatment techniques are presented as alternative action plans from which the most satisfying alternative is to be chosen. In order to select on appropriate management scheme, we propose to use the UTA (Utility Additive) method. This method is interactive and permits the decision maker (DM) to select the best solution according to his viewpoint . The UTA method proceeds in two steps: the assessment of optimal utility using piecewise linear programming techniques and sensitive analysis using a post - optimal procedure. An application of UTA method in wastewater planning management system is presented for the first time and some extensions of the method are discussed.

Keywords: Decision maker, Multi criterion utility function, Wastewater-management.

INTRODUCTION

One of the multi-criterion decision-making techniques based on utility function involves the selection of an appropriate wastewater management scheme from a finite set of feasible alternatives that have been designed to satisfy a finite set of objectives. We used the data of the twin cities of Nogales (Arizona) and Nogales Sanorn (Mexico). The case study relates back to 1951, when a wastewater treatment plant of the activated sludge type was constructed to provide primary and secondary treatment. The total capacity of that plant was 6100 m^3/day for a connected population of 20000 on both sides of the border. It served adequately well until the early 1960s, when rapid growth of the twin cities resulted in the plant being overloaded. In 1972, a new plant, the Nogales international wastewater treatment plant was designed and constructed approximately 14.2 km north of the international boundary line. The inteuded treatment capacity was 31000 m^3/day of wastewater inflow for a combined total population of 102,000. This was also found to be inadequate, because of population growth in the area. In 1985, the total population in the twin cities was estimated to be 250,000 discharging a daily average wastewater inflow of 34000 m^3/day directly into the treatment plant, 9% above design capacity. In addition, accumulated sludge deposits occupied about one third of the available pond space, making the plant operate at less than 70% of its design capacity.

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The result under current conditions is that the wastewater can not be treated according to the original design of satisfying a minimum quality requirement level before it is discharged in to the Santa Cruz river channel. In this paper, a multiple criteria methodology for selecting an appropriate wastewater management option from a set of feasible alternatives is presented. In order to select an appropriate management scheme, we propose to use the UTA (utility additive) method. This method is highly interactive and permits the decision-maker (DM) to select the best solution according to his viewpoint. Some extensions of the method are discussed.

Multi-criterion Problem Formulation

In order to evaluate a problem by using a multi-criterion procedure, the problem must be presented in a format suitable for analysis using a multi-criterion decision - making (MCDM) technique. Accordingly, to formulate the problem of wastewater management in a multi-criterion context the following six steps appear to be useful (David and Duckstein, 1979; Duckstein and Opricovic, 1980; Tecle *et al*. 1988). The steps are:

1-Defining the desired objectives to fulfill the system.

2-Identifying the mission requirements or desired specifications on the basis of such objectives.

3-Selecting evaluation criteria that relate system capabilities to specifications and hence to objectives.

4-Determing measurement scales to describe the range of possible values (quantitative) or relative positions (qualitative) an alternative system can attain in terms of a particular criterion. For the case study, steps 1-4 are summarized in Table 1.

As regards generating alternative schemes to attain the desired objectives, fifteen alternative schemes, consisting of different mixes of seven different activities are generated (Table 2). The first three mostly treat wastewater to secondary level. The four other activities are added to each of the first three, either individually or in pairs, in order to have a combined tertiary level of treatment capability.

An evaluation matrix, the elements of which represent particular values or relative positions of an alternative in terms of criteria is then formulated (see Table 3).

METHODOLOGY

There are three techniques in the MCDM method. One employs distance based techniques such as compromise programming (Zeleny, 1982). Another is based on a fuzzy outranking relationship (Roy, 1978). The third type of MCDM method assesses a utility function.

The later technique uses two approaches-multi-attribute utility theory, MAUT (Keeney and Raiffa, 1976) and utility additive, UTA (Jacquet-Lagreze and Siskos, 1982).

Table 1. Objectives specifications, criteria and criterion scales.

Objectives	Specifications	Criteria	Criterion scales
Groundwater	Pollutant Movement	Level of pollution	Ordinal (A-G)
Protection	Quality requirement	Water quality	Ordinal (A-G)
Effluent quality	Required effluent quality level	Level of treatment achieved	Ratio (0-1)
Wastewater reuse	Effluent used	Amount of effluent used	Ordinal (A-G)
System	Reliability	Compatability	Ordinal (A-G)
reliability		Flexibility	Ordinal (A-G)
Resources	Monetary cost	Capital cost	$/1000 m3/day
		O & M cost	$/1000 m3/day
	Resource need	Manpower	Ordinal (A-G)

Table 2. Generated alternatives.

Alternative	Description
A1	Facultative lagoons
A2	Aerobic lagoons
A3	Oxidation ditches
A4	A1 + chemical algae removal
A5	A2 + chemical algae removal
A6	A1 + filtration algae removal
A7	A2 + chemical algae removal
A8	A4 + nutrient removal
A9	A5 + nutrient removal
A10	A6 + nutrient removal
A11	A7 + nutrient removal
A12	A3 + land application
A13	A1 + land application
A14	A2 + land application
A15	A3 + land application

In order to select the best alternative for this case study, we use the UTA method. This method has been chosen because of the following features: (i) it has an interactive character which permits the DM to interact with the computer during the search process for the best compromise solution, and (ii) it is suited to large-scale linear problems, where other multi-objective methods would be too costly to use. The proposed approach consists of two main steps: (i) interactive assessment of a piecewise linear utility function representing a global model of the DM's preferences; and (ii) optimization of the constructed utility function in order to find the best compromise solution. The UTA method belongs to the utility / value function category of MCDM approaches. A utility function in the sense of Neumann and Morgenstern (Keeney and Raiffa, 1976) includes a notion of risk, whereas a value function is deterministic In this sense, the UTA method is a value function assessment technique, and we will use the term "value" in relation to this method. The UTA method consists of assessing a set of piecewise/ linear additive value functions using information given by a subjective preference ranking (weak order) on a set of real or imaginary actions or alternatives and the multicriteria evaluation of these actions. Although the UTA method assumes the fulfillment of utility theory axioms, it uses a completely different procedure to build marginal and global value functions. This leads to the assessment of a set of utility functions that are as consistent as possible with the DM's preferences expressed as a weak order of pre-selected actions. Real decision-making applications can be found in Siskos (1982) for evaluating a system of furniture retail outlets, in Treichel (1991) for a multicriterion analysis of rural water supply systems and Kholghi (1997) for groundwater systems and management. In this paper, we use the UTA method for the first time for selecting the best performance in wastewater system planning.

The UTA technique proceeds with the following two steps:

-Assessment of an "optimal" value function U^* (g).

Table 3. Evaluation matrix.

Criteria	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
Vulnerability to pollution	D	D	C	C	C	C	B	B	B	B	B	B	D	D	C
Level of pollution															
Water quality	D	D	C	C	C	C	C	B	B	A	A	A	C	C	B
Level of treatment	0.40	0.52	0.65	0.61	0.60	0.60	0.65	0.86	0.86	0.91	0.91	0.91	0.86	0.86	0.86
Effluent use	F	F	G	F	F	E	E	F	F	E	E	F	B	B	B
Reliability	0.71	0.66	0.46	0.66	0.63	0.71	0.63	0.63	0.57	0.71	0.60	0.50	0.710	0.69	0.50
Compatibility	E	E	D	D	D	C	C	B	B	A	A	B	A	A	B
Flexiability	D	D	B	C	C	C	C	B	B	B	B	A	B	B	B
Capital cost	0.54	0.61	1.85	0.80	0.87	0.69	0.77	1.51	1.58	1.40	1.47	1.95	0.94	1.01	2.25
O and m cost	0.21	0.37	0.38	0.28	0.44	0.24	0.39	0.45	0.61	0.40	0.55	0.48	0.26	0.42	0.43
Manpower	B	C	E	C	D	C	D	C	D	C	E	F	B	C	E

Note: Ordinal scale ranges from A-G (A= best and G = worst) , cost in dollars per m^3/day.

Table 4. Payoff matrix.

Criteria *Alternatives*	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	60	80	60	30	125	30	60	175	100	60
A2	60	80	90	30	125	30	60	175	80	50
A3	75	100	120	150	75	40	90	50	80	30
A4	75	100	120	30	125	40	75	150	100	50
A5	75	100	120	450	125	40	75	150	60	40
A6	75	100	120	30	120	50	75	175	100	50
A7	75	100	120	45	125	50	75	150	80	40
A8	90	120	180	30	125	60	90	75	60	50
A9	90	120	180	30	100	60	90	75	40	40
A10	90	140	210	45	150	70	90	100	60	50
A11	90	140	210	45	150	70	90	100	40	30
A12	90	140	210	30	100	60	105	50	60	20
A13	60	100	180	90	150	70	90	150	100	60
A14	60	100	180	90	125	70	90	125	60	50
A15	75	120	180	90	100	60	90	25	60	30

-Assessment of a set of value function by means of post-optimality analysis.

In the first step , an additive piecewise/ linear global value function is assessed:

$$U(x)=\sum^{I} i=1^{U\,i}\left[gi\,(x)\right] \qquad (1)$$

Where ui: (x) $\rightarrow ui\ \left[gi\,(x)\right]\in\left[0.1\right]$ is a monotone, piecewise/linear function (marginal value function) , and

$$u\,i\,(gi_{*})=0;\ for\ i=1,...I \qquad (2)$$

$$\sum^{I} i=1^{U\,i}\,(gi^{*})=1 \qquad (3)$$

Where gi_*, gi^* are extreme values of the criterion that correspond to the least and most preferred values of gi, respectively. The assessed value function should be as consistent as possible with a subjective ranking of several pre-selected alternatives as a reference set.

Next, in the second step, a post optimality analysis allows ambiguity zones to be delimited in the marginal value functions, for example, and the indifference relation aIb may correspond to [u (a) – u (b)] < δ rather than U (a) = U (b). For small values of δ there may be ambiguity. The mean functions are proposed, but each of the functions lying in the ambiguity zones can be considered as a value function that corresponds well to the reference set ranking.

Using (1) and the assessed marginal value functions, the global value function coefficients are calculated for each alternative under consideration, and the final ranking corresponding to these values is reached.

Application and Analysis

A computer algorithm has been used to analyse the problem. The payoff matrix in Table 4 has been used as a standard dimensionless input into the program. This payoff matrix is a quantified version of the evaluation matrix in Table 3. Its quantification is based upon the range of the scale assigned to each criterion.

In order to show the various possibilities of this method, we assume here seven cases as follows:

-Equal weighting for all criteria.

-Variable weighting.

-DM chooses a subset of the presented solution set consisting of a few relatively well known solutions or that are easy to deduc from a few relatively well known solution or that are easy to compare.

-DM changes his subset.

-DM chooses a subset and then ranks it according to subjective global judgment without being asked to explain the rule and global preference model governing the decision.

-Choosing another subset and ranking it.

Table 5. Results of seven cases.

1			2			3			4			5				6				7		
AL	UT	AL	UT	R	AL	UT	R	AL	UT	R	AL	AL	Pref	UT	R	AL	Pref	UT	R	AL	UT	R
15	0.8	1	15	0.8	1	15	0.8	1	15	0.8	1	11	1	0.5	-	12	1	0.7	1	15	0.9	1
11	0.8	2	14	0.8	2	11	0.8	1	14	0.8	2	4	2	0.5	-	15	2	0.7	2	11	0.8	2
14	0.8	3	11	0.7	3	13	0.7	3	11	0.7	3	3	3	0.5	-	3	3	0.5	3	12	0.8	3
12	0.8	4	13	0.7	4	12	0.7	4	13	0.7	4	6	4	0.5	-	14	4	0.5	4	14	0.8	4
10	0.7	5	10	0.7	5	9	0.6	5	10	0.7	5	12	5	0.5	-	7	5	0.4	5	9	0.7	5
9	0.7	6	12	0.7	6	8	0.6	6	12	0.7	6	7	6	0.5	-	2	6	0.4	6	10	0.7	6
13	0.7	7	9	0.6	7	6	0.5	7	9	0.6	7	14	7	0.5	-	11	7	0.4	7	8	0.6	7
8	0.7	8	8	0.6	8	4	0.5	8	8	0.6	8	8	8	0.5	-	5	8	0.3	8	7	0.6	8
7	0.6	9	7	0.6	9	2	0.4	9	7	0.6	9	15	9	0.5	-	9	9	0.3	9	5	0.6	9
5	0.6	10	5	0.6	10	1	0.3	10	5	0.6	10	2	10	0.5	-	10	10	0.3	10	13	0.5	10
3	0.5	11	6	0.5	11				6	0.5	11	13	11	0.5	-	8	11	0.3	11	3	0.5	11
6	0.5	12	3	0.5	12							1	12	0.5	-					6	0.4	12
4	0.5	13	4	0.5	13							5	13	0.5	-					4	0.4	13
2	0.3	14	2	0.4	14							10	14	0.4	-					2	0.3	14
1	0.2	15	1	0.3	15							9	15	0.1	-					1	0.1	15

AL (Alternative), R (Ranking), UT (Utility Function), Pref (Preference).

-Changing the weighting for the second case.

The results are given in Table 5. With these seven cases, we want to show how the final ranking of the method is influenced by varying weighting (cases 2 and 7), non-weighting (case 1) and also wigh reference to and preferences of DM. For example, in case five, the DM chose unreasonable preferences and the model can not reach a solution. In such a case , the model demands the DM to modif his preferences.

CONCLUSIONS

Wastewater is a potential nuisance that must be dealt with in the best possible way, in terms of: environmental quality; technical feasibility; economic viability; socio-politcal acceptability; resource availability; and post-treatment usability. Thus, wastewater management is a complex activity that must satisfy a host of constraints and meet a number of objectives. This procedure has motivated the use of an MCDM approach. Comparison of the potential solutions shows that the UTA method is very sensible in terms of the reference to and preferences of DM. Thus, for a real life case, the DM must have a good knowledge of the wastewater systems for taking a good initial decision in choosing his reference and preferences.

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روش تصمیم‌گیری چندمعیاره در مدیریت برنامه‌ریزی سیستم فاضلاب

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چکیده

مدیریت برنامه‌ریزی سیستم فاضلاب مسئله پیچیده‌ای است که می‌تواند در بخشهای کشاورزیء شهری و صنعتی تاثیر بسزائی بگذارد. در کشورهایی که مواجه با رشد بی‌رویه جمعیت هستند بخصوص در زمانی که گزینه‌های مختلف و گاها" بسیار نزدیک به هم مطرح می‌باشند تصمیم‌گیری مشکلتر خواهد بود. هدف از ارائه این مقاله معرفی یک متدولوژی برای مدیریت برنامه‌ریزی فاضلاب با استفاده از روش تصمیم‌گیری چندمعیاره و براساس تابع ارزش می‌باشد. این روش که معیارهای مختلف را در جهت انجام گزینه‌های متغیر در نظرگرفته و در نهایت منجر به تهیه یک جدول تصمیم‌گیری و یا جدول قضاوت می‌گردد. اهداف عبارتند از: حفاظت آبهای زیرزمینی، کیفیت آب سطحی، فاضلاب برگشتی، قابلیت اعتمادپذیری سیستم ومنابع مالی و انسانی، تعدادی تکنیک احیاء فاضلاب و اثر هر یک بر روی معیارهای مختلف برآورد شده و در نهایت گزینه‌ای که بهتر می‌تواند پاسخگو باشد انتخاب می‌گردد. به منظور انتخاب گزینه برتر ما استفاده از روش UTA را پیشنهاد می‌کنیم. مزیت این متد این است که مرتبا" با تصمیم گیرنده درحال دیالوگ است و بهترین گزینه با همکاری کامپیوترو تصمیم‌گیرنده انجام می‌شود. روش UTA دو مرحله دارد. ابتدا توسط تکنیک برنامه‌ریزی خطی چندتکه‌ای، یک ارزش بهینه برای هر گزینه محاسبه و سپس آنالیز حساسیت را در مرحله بعدی انجام داده و بهترین گزینه را پیشنهاد می‌کند. کاربرد روشUTA برای مدیریت سیستم فاضلاب برای اولین بار در این تحقیق پیشنهاد می‌شود و بعضی از کارآیی آن مورد بحث قرار می‌گیرد.