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A BILEVEL CHOICE METHOD OF ECOLOGIC – ECONOMIC MODERNIZATION PROJECTS

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Abstract: The most common decision methods in choosing one of more projects is in terms of money expenditure efficiency. We consider that more criteria should be taken into account, looking not only to costs but also to the implications of social, ecological, human, ethical, etc. nature. More, based on ethical reasons, we introduce a hierarchy of criteria, grouping them in two levels of importance. We present a manner of deducing *a cost-quality ecologic-economical decision method*, based on an as thorough as possible description of the consequences of the project, together with the expenditure. It provides the decision maker with an inner characterization of the project, depending both on the results of the project itself and its costs. Two examples of projects are analyzed: choosing the policy of reducing the temperature within a company in Arad County during the summer time and ecological modernization of the railway transport system. The paper is supported by the Romanian Education and Research Ministry, within the Research Project ID-1239/2007.

1. INTRODUCTION

The process of selecting a project of modernization arises many ethical issues due the conflict among the necessity of carefully looking to the effects on mankind, society, environment, health, etc. and the limitation of funds. The need of economic-ecologic efficiency of a modernization project is often mentioned both in technical and in scientific literature. A method of assessing the ecologic-economic efficiency of an environmental policy is described in our paper [4], based on multiple criteria optimization techniques from [3] and [5].

There are specific extra-economic possibilities of describing the efficiency of an ecology activity, as discussed in [1]. The relationship between industry, transport system, etc. and environment should receive considerable attention from two points of view: within the organization and between the organization and the society and nature. So, a method of assessing the efficiency of the investment policy from a complex of points of view is necessary. Also, the financial aspect should be not omitted, but its importance within the choice process should be diminished, out of ethical reasons, by considering more criteria referring to the effects of the project. Our aim is to study few possibilities of solving this problem and to develop a bilevel approach to the economic-ecologic effectiveness in the process of choice of a project. The research resulting in this paper is part of the Research Project ID-1239/2007, funded by the Romanian Education and Research Ministry.

2. LEVEL ONE – CHOICE BASED ON EXTRA-FINANCIAL CRITERIA

The aim of this section is to obtain a practical and useful possibility of characterizing the effect of an ecologic modernization policy, using multiple criteria programming. We take into account more points of view in the further research: effectiveness, side effects and their seriousness, etc. We suppose that there are more possible projects of ecologic modernization. For each project we study two points of view: if the modernization is performed or not. So, we have to study firstly what does living first without the modernization project mean and secondly after performing it, changing the environment according to the project. We take into account more different aspects referring to the human life, environment, health care, concentration of various substances affecting the environment's health.

First, let us deal with the set of criteria measured behaviour. It is known that the value of criterion k, for $k \in \{1, 2, \ldots, n\}$ is p_{Nk}.

After a known period of time,

- out the environment non-submitted to the modernization project, p_k is the value of criterion k, for $k \in \{1, 2, \ldots, n\}$;
- out the environment submitted to the modernization project, p_{Ek}% is the value of criterion k, for $k \in \{1, 2, \ldots, n\}$.

The following costs are known:

- c_k the cost of the pollution by increasing the value of criterion k if the modernization project is not applied;
- c_E the total cost of applying the modernization project;
- c_{Rk} the cost of the total recovery of the normal value of criterion k if the modernization project is applied;
- c_A the cost of treating the negative reactions or side effects if the modernization project is applied.

The main purpose is to elaborate a method of choosing a modernization project such as to bring criterion as close to its normal level as possible. The ecologic-economic efficiency of the modernization project should be studied in these conditions. For this purpose, a mathematical model is attached to this problem, in terms of a multiple criteria programming problem in variables *0* and *1.* These values are meant to express the preference for a type of action, meaning that two binary variables, x_1 and x_2 are introduced, having the following significance:

- $x_1 = 1$ means that the modernization project is used;
- $x_1 = 0$ means that the modernization project is not used;
- $x_2 = 1$ means that no modernization project is preferred;
- $x_2 = 0$ means that the modernization project is preferred.

Of course, $x_1 + x_2 = 1$, since an modernization project may be only accepted or rejected. The objective functions are f_1: $\{0,1\}\times\{0,1\} \to \mathbf{R}$, f_2: $\{0,1\}\times\{0,1\} \to \mathbf{R}$ and f_3: $\{0,1\} \times \{0,1\} \to \mathbf{R}$, defined, for every $(x_1, x_2) \in \{0,1\} \times \{0,1\}$ by:

$$f_k(x_1, x_2) = (p_{Nk} - p_{Pk})\, x_1 + (p_{Nk} - p_k)\, x_2, \text{ for } k \in \{1, 2, \ldots, n\},$$

Then, the solution comes from finding the min-efficient points of the following vectorial programming problem, denoted by (PE):

$$(PE) \quad ((p_{N1} - p_{P1})x_1 + (p_{N1} - p_1)x_2, \ \ldots , (p_{Nn} - p_{Pn})x_1 + (p_{Nn} - p_n)x_2) \to v\text{-}min$$

when $x_1 + x_2 = 1$, $(x_1, x_2) \in \{0,1\} \times \{0,1\}$.

In order to solve problem (PE), we use the pounds $\lambda_k > 0$, for $k \in \{1, 2, \ldots, n\}$, to introduce the synthesis function F: $\{0, 1\}\times\{0, 1\} \to \mathbf{R}$, getting

$$F(x_1,x_2) = \sum_{k=1}^{n} \lambda_k f_k(x_1, x_2).$$

With this function, problem (PE) turns into the following problem (P):

$$F(x_1,x_2) = \sum_{k=1}^{n} \lambda_k \left[\left((p_{Nk} - p_{Pk})x_1 + (p_{Nk} - p_k)x_2\right)\right] \to min,$$

when $x_1 + x_2 = 1$, $(x_1, x_2) \in \{0,1\} \times \{0,1\}$. By elementary calculus one gets

$$F(0,1) = \sum_{k=1}^{n} \lambda_k \left(p_{Nk} - p_k\right),$$

$$F(1,0) = \sum_{k=1}^{n} \lambda_k \left(p_{Nk} - p_{Pk}\right)$$

and, as consequence,

$$F(1,0) - F(0,1) = \sum_{k=1}^{n} \lambda_k \left(p_k - p_{Pk}\right).$$

If $F(1,0) - F(0,1) \leq 0$ then one can decide that the modernization project is profitable. Also, a modernization project is better than another one if its $F(1,0) - F(0,1)$ is the lowest one (i. e. its absolute value is the greatest one). This result is the reason of using the difference $F(1,0) - F(0,1)$ as a method of making the decision, when the choice of a modernization project is under debate.
Further we investigate the properties of the difference $F(1,0) - F(0,1)$ and the manner in which it is able to turn into a decision making tool in the process of choosing a modernization project.
Definition 1. *The effectiveness index of a modernization project is the number*

$$Ef = \sum_{k=1}^{n} \lambda_k \left(p_k - p_{Pk}\right).$$

As one can remark, this index provides an inner characterization of the effect of a modernization project on the environment under treatment, since it does not depend on costs, taking into account the effects of the project. The monotony property of this index is: *Ef* decreases when the modernization project brings the criteria to their normal level.
As consequence, one can say that:
Property 2. *A modernization project is more efficient than another one if it has a lower negative Ef.*
On another hand, it depends on the social or moral system of values of the decision makers: the pounds λ_k are chosen according to the importance given to each criterion f_k within a company or the whole society. According to the conditions established by the decision maker, the number *Ef* becomes a measure of the improvement gained by means of each modernization project.

3. LEVEL TWO – CHOICE BASED ON FINANCIAL CRITERIA

After ranking based on extra-financial criteria, the next step of the choice process is to take into account financial aspects involved in project development. We consider two decision functions, built based on the same the binary variables as on level one:

$$f_1(x_1, x_2) = x_1 \left|\frac{Ef}{\alpha_E}\right| + x_2,$$

$$f_2(x_1, x_2) = x_1 + \frac{\alpha}{\alpha_E} x_2,$$

where $\alpha = \sum_{k=1}^{n} c_k$ and $\alpha_E = c_E + c_A + \sum_{k=1}^{n} c_{Rk}$. The problem to solve on level two is also a vectorial optimization one:

$$\begin{cases} f_1(x_1, x_2) \to \max \\ f_2(x_1, x_2) \to \min \end{cases}$$

The goal on level two is to maximize the effect gained by using the project and to minimize the expense. The solution to this problem is able to give the decision maker the most accurate information on the development and effect of the modernization project.

4. APPLICATIONS

Example 4.1. This choice technique was tested as a decision method in investing on reducing the temperature within a company in Arad County during the summer time. The increase of the temperature at more than 35^o C had severe consequences not only by drastically decreasing the work efficiency of the employees but also on their momentary health condition. All the effects of the increase of the temperature on employees will be referred in what follows as disease. Therefore, a policy of reducing the temperature within the company was urgently applied, choosing it by some rules of thumbs. The unit of the company, we have been allowed to study, has 2540 employees, having no healthy issues in normal conditions (average temperature of 24^{o}C). The total cost of the complete recovery per one season is 6000 €, the total cost of treating the complications is 10000 € and the total cost of treating the side effects of the environmental policy is 15000 € for the entire personnel per season. Before taking action for reducing the temperature, the behaviour of the company employees working within the unit under investigation was recorded as follows:

After a known period of time:

If the modernization project is applied then out of the personnel of the company:

- p_{EN} % are healthy;
- out of the employees having some disease:
  - p_{ED} % died;
  - p_{ER} % completely cured;
  - p_{EC} % have complication;
- p_{EA} % have adverted reaction to the modernization project itself.

If the modernization project is not applied then out of the personnel of the company:

- p_N % are healthy;
- out of the employees having some disease:
  - p_D % died;
  - p_R % completely cured;
  - p_C % have complications.

The following costs are known:

- c_E the cost of the project application / person;
- c_R the cost of complete recovery / person if the project is performed;
- c_C the cost of treating the health complications and death compensations / person if the project is performed;
- c_A the cost of treating the negative reactions / person if the project is performed.

So, p_D = 0, p_N = 15%, p_C = 80%, p_R = 5%. Therefore, α_N = 433.1. Three solutions to reduce the temperature were presented to the company. The estimated consequences of each policy are presented in table 1.

PROJECT	REDUCED TEMPERATURE	TOTAL COST (€)	P_{EN} %	P_{ER} %	P_{ED} %	P_{EA} %	A_E
1	28° C	45600	80	10	0	5	1861.1
2	30° C	250000	70	15	0	7	9952.75
3	22° C	490000	100	0	0	0	19291.34

Table 1.

Taking the pounds $\lambda_1 = \lambda_2 = 2$ and $\lambda_3 = 1$ (according to the opinion of company's staff) and computing the ecologic-economical effectiveness index of each environmental policy, we got

$$Ef(\text{project1}) = -129.24,$$
$$Ef(\text{project2}) = -109.04,$$
$$Ef(\text{project3}) = -169.02.$$

It shows that Project 3, which reduces the temperature at 22° C, is the most efficient from the point of view of the employees' behaviour at their workplace. If we apply the level two of the choice procedure also pounding, by giving the importance $\lambda_1 = 100$, $\lambda_2 = 1$, one can find also the third project as the best one. If $\lambda_1 = \lambda_2 = 1$, then, obviously, project 1 comes first.

Example 4.2. Environment indicators in the domain of railway transport are defined under the International Union of Railways (UIC) (http://www.uic.asso.fr) and the project RAVEL funded by the European Union **(**RAVEL – Sustainable Mobility – Railway in the future – Projects) (http://www.uic.asso.fr), in order to diminish the impact of the railway transport on the environment. The Working Group UIC on environment presented the *Guide to establish the indicators of environment for the railways* ([9]) that is updated each year and is included in the technical portfolio of the Committee C6 UIC (dealing with economy, finance and environment protection). From technological point of view, there are the following possibilities to ecologically modernize the railway transport system.

- **Project P1)** Ecological modernization of the *box of the railway vehicle* – in order to improve the travelers' comfort, basically on high speed (V > 160 km/h);
- **Project P2)** Modernization of the *drive system of the railway vehicle* to allow the use of non-conventional fuel (especially bio-fuel);
- **Project P3)** Optimization, from constructive point of view, of the *Lifting structure of the railway vehicle*, especially of the bogie frame and tread apparatus, for avoiding shocks and transversal or longitudinal vibrations, which are source of major travelers' discomfort;
- **Project P4)** Modernization of braking systems of railway vehicles, in order to produce as soft as possible breaking, with deceleration allowed by the human body (af < 0,8 m/s2), in established braking way.

According to [9], the following criteria are taken into account:

Criterion 1) Concentration of CO_2 in the air:

Normal: 0,03% from the atmosphere
Actual: 1,68 g/km
Estimated after improvement: 1 g/km

Criterion 2) Level of noise:

Normal: 50 dB(A) (STAS 10009-88 and STAS 6161/1-79);
Actual: 125-130 dB(A) (Noise produced by wagons);
Estimated after improvement: 60-70 dB(A).

Criterion 3) Energy consumption:
Normal: 4,5 t/day over 1 million tones x km;
Actual: 4,05 t/day over 1 million tones x km;
Estimated after improvement: 3,85 t/day over 1 million tones x km.
Criterion 4) Annual number of accidents:
Normal: 0
Actual: 2900 dead/year;
Estimated after improvement: max. 1500 dead/year.

As we see, this problem involves linear preference criteria with indifference zones. They are independent. As consequence, we can study the four projects from the Ef point of view.

Project	CO_2	Noise	Energy	Accidents	Cost
1	0	0	7.5%	87	1.5 million lei / wagon
2	0	32.5%	10%	0	750 000 lei / drv. Sys.
3	0	40%	17%	58	500 000 lei / bogie
4	44%	30%	3%	1015	250 000 lei / br. Sys.

Table 2.

Table 2 contains the percentages of variation (p_k - p_{Pk}). Table 3 contains various possibilities of taking into account the projects based on the importance of criteria. First, the environment criteria are the most important, the second study takes into account both the environment and the human factor, the third approach looks to the energy consumption without ignoring the behaviour within a human environment and the fourth approach is very attentive to the level of noise. The hierarchy of the projects and the best one are given on the last two columns. Let us remark that the costs are not taken into account since an evaluation of the side effects and the damage was not available. The last column of table 2 presents only the costs of the technical improvement of one wagon.

Weights	Ef Proj.1	Ef Proj.2	Ef Proj.3	Ef Proj.4	Order	Best
$\lambda_1=\lambda_2=10$ $\lambda_3=\lambda_4=1$	94.5	326	475	1758	P1<P2<P3<P4	P4
$\lambda_1=\lambda_2=5$ $\lambda_3=1, \lambda_4=10$	877.5	172.5	815	10523	P2<P3<P1<P4	P4
$\lambda_1=\lambda_2=1$ $\lambda_3=10, \lambda_4=2$	259	132.5	790	2134	P2<P1<P3<P4	P4
$\lambda_1=\lambda_3=\lambda_4=1$ $\lambda_2=100,$	94.5	3260	4075	4062	P1<P2<P4<P3	P3

Table 2. Ranking based on Ef

Level two of the decision process, with pounds equal to one, also reveals project P4 as the best one.

According to our opinion, the use of a decision technique of this kind instead of the known ones, referring mainly to costs and benefits, when an environment strategy is discussed, is an ethical option. As one can see, in this method of approaching the problem, the costs may be present as auxiliary parameters, having as important impact on the decision making process as the ethics of the decision maker allows. But the decision makes looks to all the results of the modernization project.

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