Foundation of Collective Decisions by Evaluating Risks and Perspectives

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Prijatie kolektívneho rozhodnutia zhodnotením rizík a perspektív

There are several methods for dumping waste in the earth's crust. Consequently, prior to such an activity decisions have to be made about the methods to be applied and the parameters in every case. These decisions cannot be made without the analysis of the expected consequences of dumping. The preparation of impact studies is a prerequisite required by law for any such activity to be permitted. The decision about waste dumping in the earth's crust can be regarded multiattributal because the decisionmaker(s) must have several aims in view at the same time. Prior to the decision the fulfilment of economic, safety and environment protectional objectives should be assessed for every possible and feasible solution. It is also evident that the implementation will affect a large number of people, bigger communities both directly and indirectly. Thus the decision is to be made collectively by the parties concerned by taking into account the foreseeable implementation of common objectives as well as the extent of its predictable impacts. This presentation is about a method suitable for the design of waste dumping processes and the collective, multipurpose assessment of the risks involved in dumping, complying with the abovementioned requirements.

Theoretical background

There are generally several ways to solve any problem arising in a smaller or bigger community or to achieve an objective formulated. Through the choice between the different ways of solution or implementation (i.e. decisionmaking) we decide to perform concrete activities. Each of these activities will have consequences affecting the decisionmaker. These may be favourable (assessed as positive) or unfavourable (assessed as negative) for the decisionmaker, and on the other hand, they may be causal or stochastic. If, prior to decision, the weight (extent) of all the j consequences ($j=1,\ldots,s_i$) belonging to every possible i way of solution or implementation ($i=1,\ldots,r;\geq 2$) is assessed on the basis of the decisionmaker's criteria, then s_i possible consequences can be attached to every i alternative. If the consequence is sure to be realized (probability of occurrence: $P=1$) and is assessed as positive, then we speak about an **advantage**, if it is assessed as negative, then we speak about a **disadvantage.** In other words, we are concerned with an advantage or disadvantage if consequence j is related to activity i causally. Let us mark its weight (value) with $k_{i,j}$.

If, however, a consequence is imaginable but its occurrence and impact on our objectives are uncertain, then the weight (value) of the consequences can be regarded as a probability variable, a stochastic value.

Values of stochastic consequences can be discrete and continuous. The interpretation of risk is often limited to such cases in literature where the $k_{i,j}$ consequence values that can be attached to a decision in a given time interval are probability variables of discrete distribution.

In reality, the weight of consequences is generally not a concrete value that can be given in advance but in most cases any value can be imagined within a given interval.

For the sake of simplicity, however, the present paper also follows the practice that it takes only two (discrete) values of the weight of a consequence into account: one is 0, the other is $k_{i,jmax}$. If the probability of $k_{i,jmax}.P(k_{i,jmax})=P_{i,j}$ and $P(O)=1-P_{i,j}$, then the expected value of the weight of the given consequence $k_{i,j}$.is:

$$k_{i,j}.=p_{i,j}\cdot k_{i,jmax}+(1-p_{i,j})\cdot O=p_{i,j}\cdot k_{i,jmax}.$$

If $k_{i,jmax}.(<0)$is a discrete value of damage with an occurrence probability of $p_{i,j}$, then $k_{i,j}$ gives the value of **risk**; but if $k_{i,jmax}.\ (>0)$ denotes the extent of some concrete benefit, then $k_{i,j}$ gives the value of **chance**.

If consequence values are continuous, then the expected $k_{i,j}$ values must be determined in a set of continuous distribution. In this case the $k_{i,j}$ extent of consequences can be regarded as a variable of $F_{i,j}(x)$ distribution within a fixed time interval:

$$F_{i,j}(x)=P(k_{i,j}<x)$$

The $k_{i,j}$ extent of risk or chance is the expected value of a probability variable of $F_{i,j}$ distribution in this case.

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$$k_{i,j}=\int_{x=-00}^{+00} x\cdot dFi,j(x)$$

In other words if the benefit or the damage is the causal consequence of the decision, then $k_{i,j}$ is a value expressing their extent, whereas in the case of a benefit or damage of uncertain extent $k_{i,j}$ is their expected value. If we form their sums,

$$Si=\sum_{j=1}^{si} k_{i,j}$$

the suitable solution is the one where S has maximum value.

In the preparation of decisionmaking, the expected extent of the predictable advantages and disadvantages, chances and risks should therefore be determined for each of the solutions envisaged. Here the greater difficulty is surely involved in the assessment of chance and risk.

Measurement of chance and risk

The previous analysis of the terms ‘risk’ and ‘chance’ makes it clear that both have two components: the value of activity consequence and its occurrence probability. By the numerical definition of these two attributes of consequences, it is possible to determine the parameter representing the cumulative (aggregated) extent of the chances and risks involved in our decisions, which is suitable for the characterisation of the expected consequences of possible decisions.

In the relevant literature the quantitative interpretation of chance and risk is sometimes sharply criticized. Here we should like to remark that a responsible engineer’s attitude requires the assessment of all the expected consequences of our work and decisions prior to both implementation and decisionmaking. Although neither measurements nor the numerical definition of values are necessary for decisionmaking, it is simpler if such a characterization is possible. If for example it is possible for us to do A, B or C, and our analyses show that the consequences of action plan B are undoubtedly more favourable than those of action plan A, and action plan C is more promising than action plan B, it is evident that the C alternative should be selected. It is absolutely clear, too, that this decision of ours will not become objective just because we estimate the expected values k of the consequences of the particular action plans and express them in numerical values: k_A=-2, k_B=20 and k_C=21. These three numbers, however, reveal much more about our assessment than the words: ‘undoubtedly more favourable’ and ‘more promising’.

The more generally accepted judgements (e.g. measured values, expenses or prices) the three numbers express, the more true this latter statement will become.

As regards this problem area, it can so far be stated that the more divergent the consequences involved in a particular decision are, the more necessary it is to analyse the situation thoroughly considering every important aspect for a good decision. The result of the analyses is best expressed with a parameter gained through the aggregation of numerical risk and chance values.

In a society which has adopted the principle of the cautious treatment and protection of natural environment (environmentally oriented society) a consensus must be attained as to the risks of both individual and collective activities. In the course of this, such general questions arise as the expectability of (taking) risks along with special ones like the distribution of risks among citizens and the problems of fairness involved.

This problem is aggraveted by the fact that the sources often do not make a distinction between a subjective sense of risk (supposed risk) based on no realistic reasons whatsoever, and risk assessment arising from thorough and circumspect analyses based on up-to-date scientific knowledge.

Now let us examine which is the best decisionmaking process in waste dumping issues. In this case, too, it is useful to assess the consequences of the possible options (action plans) and select the proper solution on the basis of this.

In this case the assessment of chances and risks will be different from what has been presented before in that it must be performed on the basis of several different objectives, interests and criteria.

It is feasible if prior to decisionmaking the common objectives, the extent of the realization of which gives the extent of chances and risks, are defined.

In general terms such decisions are characterized by the following:

- there are several possible action plans, i.e. there are several co-existent o_i(i=1,….,m; m>1) options,
- the decision is of a multiattribute character as the decisionmaker(s) want(s) to pursue several different aims z_j(j=1,…,n; n>1) simultaneously,
- the decision is not made by one person or group of people having the same objectives, interests and judgements, but by several ones. Let us mark them with m_k(k=1,…,r; r>1).

The m_k persons or groups pursuing different aims are hereinafter called parties. A party m_k may denote one or more persons alike.

Based on the aforementioned, the fact that the selection of an option involves risks or chances means that the realization of a state $S_g(g=1,\ldots,0)$ arising later from the selected activity is not automatic, i.e. the p_g probability of the occurrence of S_g is less than 1. The K_g consequence descriptions (values) include the assessment of an S_g state, the occurrence of which is realistic after the selection of a particular option, according to the realization of the set objectives.

Multiattribute collective decisionmaking involving risk assessment therefore requires the definition of a set of shared objectives, that of the possible options, an estimate of the possible related processes and an evaluation of the states that may realistically come into being. Let us now consider these tasks one by one.

Definition of a set of objectives

Selection of objectives

In the concrete cases a collective set of objectives must be defined from the parties' own sets. This is indispensable for the assessment of the consequences of the particular action options as it involves the evaluation of how a possible state corresponds to the shared objectives.

The starting point should be that every $m_j \in M$ party has its own objectives which make up a Z_j set. The first step is to define and collect these objectives. Secondly, it must be examined whether there are any two objectives which directly contradict each other. These contradictions must be eliminated by negotiating strategies.

If contradictions are done away with, there are two possible procedures to follow:

1. Every Z objective set is incorporated in one common set of objectives. This has the advantage that in this phase of investigation no need arises for negotiations within the group. Furthermore, no party feels to be discriminated against as every party's objectives are taken into account. This involves that in a later phase of the procedure when objectives are weighted, every party should accept the use of O weight with which a given party can express that it does not share the objectives of other parties at all. This procedure has the disadvantage that the parties must define and assess the occurrence of consequences on the basis of the set of objectives shared by the group. Thus the parties are obliged to define the extent of realization and benefits of objectives that they do not share.
2. The group strives to set up a common Z set of objectives in consensus through counselling, negotiations and reconciliation. In this procedure counselling and negotiations have an outstanding importance. These must lead to a compromise that every party is content with.

Structuring objectives

If we have a set of objectives based on consensus, the next step is to define the impact of consequences on the basis of the objectives. For this, attributes on a scale are attached to the objectives. A y_i attribute is attached to every z_i member of the Z set of objectives. These are stored in the A set of attributes

$A=\{y_1,\ldots, y_n\}$

This way every consequence can be determined on the basis of the fulfilment of objectives.

Proper care should be taken to formulate objectives concretely enough so that attributes can be attached to them and no useless results should be yielded by decision assessment due to a lack of information concerning set (followed) objectives.

It is also of help if objectives are not only formulated as guidelines but if already in the phase of the formulation of objectives it is indicated when an objective is actually achieved. This will make it simpler for the group to decide about the extent of objective fulfilment. On the other hand, if the objective has only been formulated as a general guideline, opinions may differ greatly about how much a set objective has been achieved. (E.g. opinions can be very different about what is expensive.)

Definition of options

Before the prognostication of the decisionmaking process it must be made sure that every possible option is taken into account. This aspect can gain special importance in environmental issues.

Should further investigations prove some options to be unimportant e.g. because they have a O probability of occurrence or there is a minimum degree of objective achievement, then it may be suggested that they be excluded from later procedure. This must be preceded, however, by the compilation of the possible options and the analysis of their consequences, as options initially considered to be hopeless may later prove to be promising. An expert team of the given field can be entrusted with the defintion of a complete set of possible options.

(It is by the way the first task to be solved in impact studies, which requires an analysis of the possible technical alternatives.)

Prognostication – progress of events

Once the objectives supplied with attributes as measuring tools are available, conditions are given for the definition of the progress of events. This includes the calculation/estimate of the extent of consequences per objective as well as the estimate of the probability of their occurrence.

As in cases involving e.g. the introduction of new technologies, there are very often neither practical experience nor objective probabilities available, subjective probabilities must be relied on. These are generally defined by the Delphi process on the basis of expert team estimates.

Experts define both the probabilities and the extent of consequences provided that a suitable scale is available for this. The Delphi process ensures the maximum exploitation of the expertise of experts involved in the investigation.

In the case of constructed attributes which have no objectively measurable scale, not experts but the parties themselves must be involved in the estimate of the degree of objective achievement.

If every consequence has been defined with regard to the degrees of objective achievement and probabilities of occurrence, then the investigations concerning the extent of consequences should be carried out. For this, there is not just one value but as many as there are objectives. The measuring units are also different for them, depending on the scale used in measurements. In a given S_g state of an O_q option consequences can be expressed with a vector:

$$K=(x_{qg1},\dots,x_{qgn})$$

where the values of x_{qgi} mean the value of attribute y_i within the relevant scale. In other words, the value within the relevant scale must be defined for every attribute of every consequence.

Assessment

The theory of multiattribute utility is used to ensure commensurability. First, an individual u_i utility function with values between 0 and 1 is drawn up for every y_i attribute. This will ensure commensurability, as every x_{qgi} degree of objective achievement can now be constructed as an individual u_i (x_{qgi}) value of utility. As the next step, the importance of objectives will be determined with the help of the λ_i weight factors. Both the individual utility function and the λ_i weight factors are determined according to the preferences of the parties. The components described give the full utility values of the consequences in the following way:

$$u(K)=\sum_{i=1}^{n} \lambda_i * u_i\,(x_{qqgi})$$

$$(q=1,\dots\dots,m;\ g=1,\dots\dots O)$$

Group decisions are rendered more difficult by the fact that the group must arrive at a common individual utility function and a common weight for every attribute.

Assessment of hazardous decisions

Besides uncertainties, the total utility values must also be weighted with occurrence probabilities in decisionmaking. This must be done even if there is no opportunity to define objective probabilities but only subjective probabilities can be relied on.

In Figure 1 a random branch point can be seen in the path of strategy(O_1 & O_3). As it cannot be defined with certainty what consequences this strategy will have, an expected benefit (the expected value of utility), a value calculable from probabilities and benefits is defined. The expected utility (EU) of an option/strategy is the sum product of the utility values of the consequences and their occurrence probabilities:

$$EU(Oq)=\sum_{g=1}^{O}\Big[\, p_g * \Big(\sum_{i=1}^{n} \lambda_i * u_i(x_{qgi})\Big)\Big]$$

where $q=1,\dots,m$

Here the rationality requirement (postulate of rationality) is valid for decisionmakers: select the strategy where the expected utility is the highest.

The expected utility of strategy (O_1 & O_3) can be calculated in the following way:

$$EU(O_1\&O_3)=p_1*(\sum_{i=1}^{n}\lambda_i*u_i(x_{(1,3)1i}))+(1-p_1)*(\;*(\sum_{i=1}^{n}\lambda_i*u_i(X_{(1,3)2i}))=$$

$$=p_1*u(K_1)+(1-p_1)*u(K_2)$$

The expected utility of strategy (O_1&O_4) can be given with certainty as:

$$EU(O_1\&O_4)=u(K3)=\sum_{i=1}^{n}\lambda_i*u_i(x_{(1,4)1i})$$

If $EU(O_1\&O_3) > EU(O_1\&O_4)$, then the strategy ($O_1$&$O_3$) should be chosen and option O_4 should be excluded in accordance with the postulate of rationality.
The expected value of O_2:

$$EU(O_2)=p_3 * u(K_4) + p4 * u(K_5) =$$

$$= p3 * (\sum_{i=1}^{n}\lambda_i*u_i(x_{(2,3)1i}) + p4 * (\sum_{i=1}^{n}\lambda_i*u_i(x_{(2,4)2i}))$$

If $EU(O_2)>EU(O_1\&O_3)$, then the postulate of rationality requires the choice of option O_2.

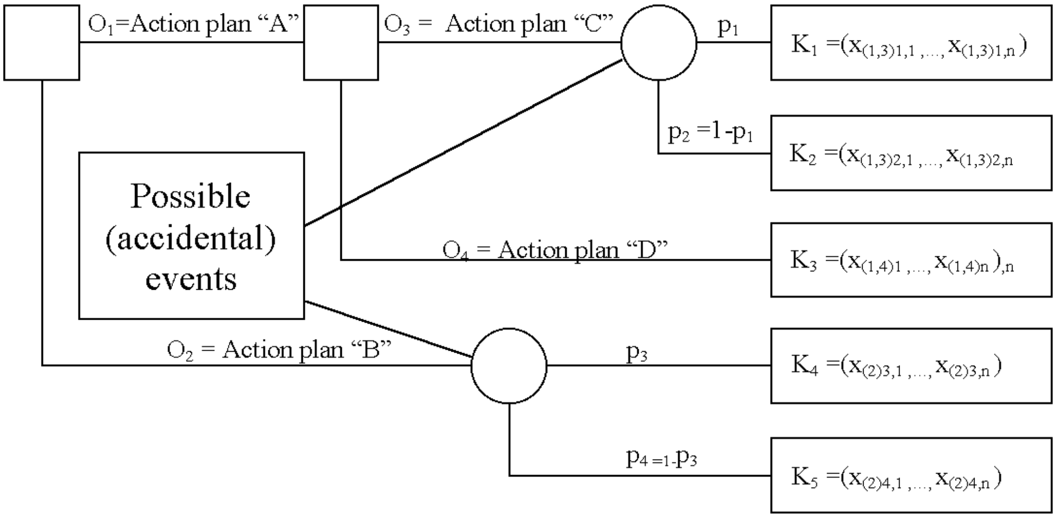

Fig.1.

Sensitivity studies

As the last step it can be investigated how and to what extent the features of the problem and the parties' value judgements have affected the choice. The rationale for such an investigation (check) can e.g. be that the expected values of two options, which the parties intuitively judge to be of very different utility, are very close to each other, in fact. In reconsidering the value judgements of the parties, the sensitivity (change in extent) of the results can be analysed by changing e.g. the weight factors or other parameters, as the function of these changes.

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