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RESEARCH OF THE CRITERIA FOR EFFICIENCY AND OPTIMALITY OF THE CRITICAL INFRASTRUCTURE PROTECTION MANAGEMENT

Lyubomir I. Pashov

MUNICIPAL COUNCIL OF SHUMEN

ABSTRACT*: In this work, the risk categories are investigated by use of efficiency criteria. For that purpose, the maximum value of each efficiency criterion is determined on grounds of the available determined uncontrollable factors. Particular attention is paid to the transition from quantitative criteria to qualitative criteria. The results from the research on the risks for the individual processes in infrastructure are represented graphically.*

KEY WORDS: *efficiency criteria, optimality, management, protection, critical infrastructure*

The definition of efficiency criteria in the process of operations research involves comparison of different risk categories and selection of the one that is most likely to occur. The risk categories are compared with each other by use of an efficiency criterion which has been introduced for the purpose. The model we use aims to establish the maximum value of the efficiency criterion. However, the efficiency criterion can be used when there are determined uncontrollable factors only. If there are random or undetermined uncontrollable factors, it will not be possible to compare the risk categories by use only of the efficiency criterion. To be able to compare the risk categories, they have to be expressed as values. All values defined over a set of risk categories can be summarized as an efficiency estimate [1].

If we presume that there are only determined uncontrollable factors, then the efficiency criterion W will be a function only of X, since the determined uncontrollable factor Y^0 is known to us. Indeed, W = F (X, Y^0), so we can denote this function as $f_{0}\_$ (X). The $f_{0}\_$ (X) function can be used to estimate the risk category. When comparing two different risk categories, X_1 and X_2, better will be the one which has a lesser value of the $f_{0}\_$ (X) function. Thus, we shall be able to determine the best or optimal risk category X_0 for which $f_{0}\_(X_0) \geq f_{0}\_(X), \forall XX$. If presume that the risk category depends on undetermined uncontrollable factors, then for each fixed category X* the efficiency criterion W = (X*,Y) will be a function of the factor Y, and not a fixed number, so the efficiency cannot be estimated. Thus, each category will no longer correspond to a single value only, and the comparison of the risk categories by use of an efficiency criterion will bring uncertain results.

There are operations in which two different risk categories coexist and where X_2 and $F(X_2,Y) > F(X_1,Y)$ for each undetermined and uncontrollable factor.

In such case risk category X_1 is definitely worse than risk category X_2. Such situations occur occasionally. In fact, efficiency estimate can be achieved in different ways. Efficiency estimate is calculated by the operating party. The efficiency together with the optimality is a part of the problem formulation when performing a research of the risk categories. We have to point out, that although interconnected the efficiency estimate and optimality of a risk category are not absolute values. Therefore, when we say that a rick category is optimal, we have to necessarily specify in what sense we understand optimality.

Selection of one or another efficiency estimate would depend on the involved uncontrollable factors. When an undetermined uncontrollable factor is a random variable and the distribution function for the factor is known, then the efficiency estimate shall be the mathematical expectation of the efficiency criterion resulting from the following expression:

$$\square F(X,Y)G(dY)$$

The function $f_0(X) = \square F(X,Y)G(dY)$ is an estimate in the sense of an mean value of the risk category. The use of such estimate does not prevent the risk from achieving worse results in the progress of operation than the estimated mean value. Only numerous repetitions of an operation can give us grounds to conclude that the value of a certain risk category corresponds to the estimated mean value.

It is possible to research risk categories which are functions of random uncontrollable factors. To be able to estimate the efficiency In such cases, we can use the mathematical expectation $f(\tilde{x})=\square F(\tilde{x}(Y),Y)G(dY)$. where the mean value of the probable distribution G(Y), $\tilde{x}$ is the function of the random uncontrollable factor Y.

The estimate (mean) value will correspond to the optimal (mean) value:

$$f(\tilde{x}^0) \geq f(\tilde{x}), \ \forall \bar{x} \bar{X}$$

where $\tilde{x}^0$ is the optimal (mean) value in a set. Therefore, when the risk categories X are constant, then X^0 is the optimal, i.e. mean value in the set of risk categories X, if

$$f(x^0) \geq f(x), \forall xX$$

In this case the random uncontrollable factor has two values. By use of the mathematical expectation definition of the estimate, i.e. the mean value of X_1 and X_2 we get:

$$f(X_1)=0{,}9.10+0{,}1=10=10$$

$$f(X_2)=0{,}09+0{,}1.110=11$$

Our goal is to minimize the risk category, so the X_1 risk category is better than X_2. Due to the fact that there is no other risk category apart from X_1 and X_2, we come to the conclusion that X_1 is more optimal, i.e. less risky.

When there are undetermined uncontrollable factors, we know only the set Y of the possible values of Y, so for the risk category X the criterion will have values within the [A,B] interval, where

$$A = \min_{y = Y} F(x,y) \text{ and } B = \max_{y = Y} F(x,y)$$

It is reasonable to accept A as an efficiency estimate of X, i.e.

$$F_r(X) = F(x,y)$$
$$y \in Y$$

Such estimate is called guaranteed efficiency estimate. With reference to this estimate, we shall introduce the term *optimal risk category*, i.e. X^0, where:

$$F_r(X^0) \geq f_r(X), \ \forall x \in X$$
$$\text{or } \min_{y \in Y} F(x^0,y) \geq \min_{y \in Y}(x,y), \ \forall x \in X$$

By analogy, we shall introduce the term guaranteed efficiency estimate and optimality in the sense of a guaranteed efficiency estimate of the risk categories $\tilde{x}$(y) of the uncontrollable factors:

$$f_r(x) = \min F(\tilde{x}(y),y)$$
$$f_r(\tilde{x}^{\,0}) \geq f_r(\tilde{x}), \ \forall \ \tilde{x} \in \tilde{x}$$
$$x \in X \quad , \quad y \in Y$$

The value $F_r(x)$ = maxmin f(x,y) is called maximum guaranteed result over the set of x. By analogy, we introduce the function $F_r(x)$.

Despite the challenges of the undisturbed factors, we have considered so far some general types of operations with a single efficiency criterion. In the more complex operations, the efficiency could not be characterized by a single efficiency criterion. For the cases when more than one efficiency criterion exists, we shall introduce the term multi-criterion research of the risk categories. While defining (estimating) the risk categories, it is possible to have criteria for which we shall seek the maximum value, and others for which we shall seek the minimum value.

We shall introduce a single efficiency criterion W, which summarizes the remaining criteria $W_1, W_2, \dots W_n$ and which we shall call convolution of criteria. The general expression of the convolution will be:

$$W_0 = f\,(W_1, W_2, \dots . W_n),$$

where f is an arbitrary function.

When we select efficiency criteria, we are subjective in our research. Therefore, by the introduction of the f function through which convolution of the various criteria is performed, we have a great variety which is generalized by W_0.

We shall consider the most common way of convolution of the efficiency criteria – that of summarizing the criteria with coefficients. The general criterion W_0 will be:

$$W_0 = \sum_{i=1}^{n} \lambda i W i,$$

where λi is weighed coefficient with the following condition: λi≥0, i=T,u

$$u \sum_{i=1}^{u} \lambda i = 1$$

Transition from quantitative criteria to qualitative criteria

In this case for each criteria there is a limit $W^0{}_i$, $i=\overline{1,n}$

Then

$$W_0 = \{ \frac{1, if Wi > \mathrm{Wi}^0, i = \overline{1,n}}{0 otherwise}$$

The risk category can only be accepted, if the values of all criteria exceed the limits.

Often, in the research process, it is possible to solve the direct problem i.e. by using certain solutions to calculate the values of the multidimensional criteria. As a result of this, during the direct comparison of the multidimensional criteria some of the possible risk categories may be discarded from the set x as entirely irrelevant, because all the remaining categories are much better in any respect. We shall presume that we have to solve a multi-criterion problem of defining the risk categories by estimating n criteria W_1, $W_2, \ldots W_n$, all of them preferably at their maximum value.

Let x_1 and x_2 be two possible risk categories, and all efficiency criteria $W_i, i=\overline{1,n}$ of the category x_2 be greater or equal to the respective criteria of category x_1. Let us presume that there is an inequality in at least one of the criteria. We usually say that risk category x_2 dominates over x_1. That is why we shall subtract x_1 from all dominant risk categories. As a result of this rejection of all dominant risk categories, the set of dominant risk categories is significantly poorer than the source set. The dominant risk categories are also known as Pareto categories or Pareto optimality.

We shall consider vectors from the efficiency criterion $(W_1(x), W_2(x), \ldots W_n(x))$. We presume that the criteria $W_i(x)$, $i = \overline{1,n}$ depend only of the risk category 1, i.e. there are no uncontrollable factors. The point X_0 is called effective point or optimal point according to Pareto $x \in X$ risk category, and the vector $(W_1(x), W_2(x), \ldots W_u(x))$ is the effective value of the criteria vector, if there is no point for which $W_i(x) > W_i(x_0)$, $i = \overline{1,n}$, while at least one value of i_0 meets the strict inequality $W_{i0}(x) > W_{i0}(x0)$.

If x_0 is the effective point at $W_i(x_0) > 0, I = \overline{1,n}$, then there are such coefficients where $\lambda i => 0, i=\overline{1,n} \sum_{i=1}^{n} \lambda i=1$, so the general criterion W_0 of W_0 of $W_0(x) = \min \lambda i W i(x)$,

$1 \leq I \leq n$

Point x_0 is the maximum of set x,

$$W_0(x_0) \geq W_0(x), \ \forall x \in X.$$

Hence, the optimal Pareto risk category is an ordinary point of the general criterion W_0. As a rule, there are many effective points and setting of the λi coefficients leads to a simple identification of x_0 as the maximum of X. The set of all effective points of the vector is called a Pareto set.

Let us presume that n = 2 for each of the criteria W_1 and W_2 and that we are looking for the maximum. Furthermore, let us presume that the X set contains a finite number of risk categories x_1, x_2 ... x_n. For each solution there are two values of the criteria W_1 and W_2 which we can mark as a point having coordinates W_1 and W_2. The points marked on the coordinates of the risk categories will be numbered. In this case effective solutions are x_2, x_7 and x_1. For any other solution there is at least one dominant point for which either W_1, or W_2, or both are greater. The figure demonstrates that risk category x_7 is the best one under the W_2 criterion, while x_1 is the best one under the W_1 criterion. When decision is to be taken, we shall choose of either x_7 or x_1 depending on which of the W_1 and W_2 criteria is more adequate.

Thus, by rejecting of the risk categories dominated by the set x, we can select only the effective points.

The selection of an operation to minimize the risk category is manual operation. Only a man can compromise when selecting an operation in order to minimize the risk in view of the available effectiveness criteria.

Sometimes it is possible a decision-making procedure to be repeated on multiple occasions, which on the other hand provides an opportunity to develope some formal rules and reduce the risk categories without participation of the man when solving multi-criterion problems investigating the risk categories at various conditions. Based upon the collected statistics, we can find the coefficients λ1, λ2, ... λn of the general criterion $W_0 = \sum_{k=1}^{n} \lambda k W k$. A coefficient depends on the conditions and the possible solutions. Therefore, by use of the general efficiency criterion we can take decisions without human intervention.

In practice, we use a different approach to reduce a multi-criterion problem into a single-criterion one. We select one of the parameters W_1, i $= \overline{2,n}$ as a major one and have to find its maximum, while the remaining parameters should meet the condition $W > W_i$, i = $\overline{2,n}$. The selection of the minimums (lower limits) is in a way arbitrary.

We shall consider one more method for finding a compromise solution, namely the method of successive concessions. We presume, that the efficiency parameters W_i, i = $\overline{1,n}$ are lined down in a decreasing importance order. Initially, we seek a solution which reaches its maximum at $W_1 = W_2^*$, after which a concession from the maximum value of the parameter W_1 is made by Δ W_1 to find the maximum of the parameter W_2 at the condition that $W_1 > W_{1-\Delta}^*$ W_1. Again, we make a concession from the parameter W_2 by Δ W_2 to find the maximum of the parameter W_3. By this way of finding compromise solutions, we can see at what concession of one of the parameters we can find the maximum of the next parameter.

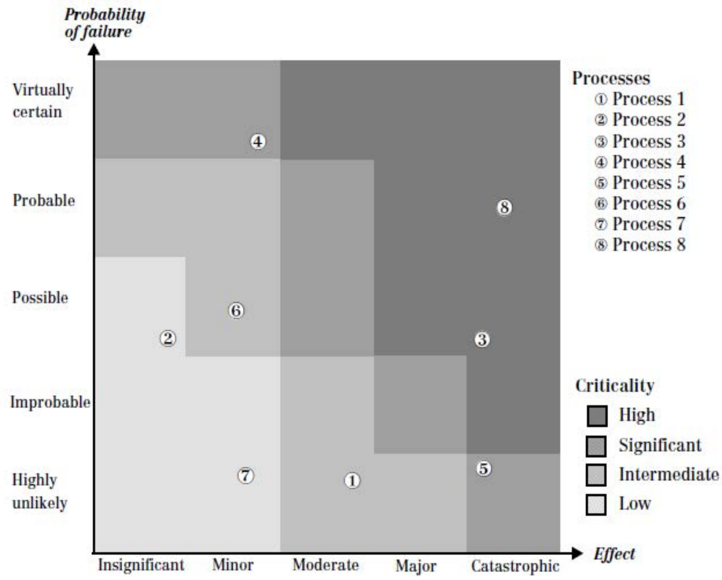

Figure 1 Determination of risk for individual processes in the infrastructure

Estimates for identification and prioritizing of the measures to mitigate the risk are used:

- to identify the methods/ways for mitigation of risk in the critical infrastructure;

- to develop strategies for identification and localization of risk, i.e. definition of priorities and measures to localize the risk within a strategy;

The below methodology has got seven key elements which are interrelated at logical and informative level:

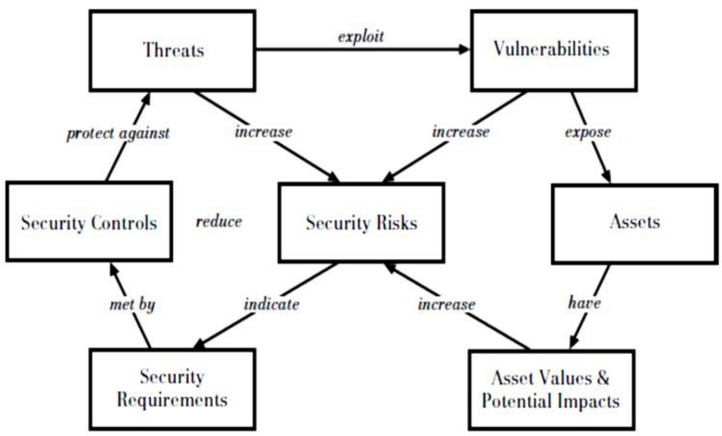

Figure 2 Informative interconnections between the key elements of methodology

The analytical activities concerning the planning of critical infrastructure protection are performed cyclically within the limits of a single process

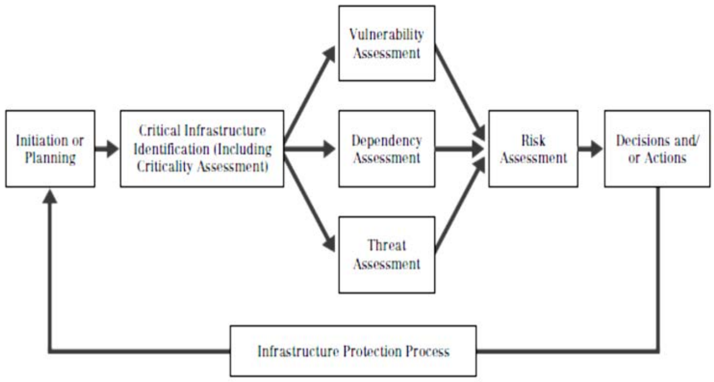

Figure 3 The Critical Infrastructure Protection Process

Finally, we would like to note, that in view of the growth of terrorism worldwide, the critical infrastructure that deserves special attention in terms of security is that of the energy sector because its vulnerability to terrorist attacks. The critical infrastructure marking is very important [3], taking into account the increased number of breakdown cases, the adverse weather conditions and natural disasters.

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