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Further Analysis on Cumulative and Synergic Effect of Risks and Hazards on Selected Protected Object

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The multi-risk and multi-hazard analysis replace the single processes analysis as a natural continuation of risk perception in risk management. The separation of hazards is substituted by pooling the hazards into the categories based on various criteria. This transition from understanding the hazards as interrelated subjects raise numerous questions, for example: Based on what criteria should hazards be separated? Is it the obvious interconnection of action and reaction or should they be sorted by the risk level? In our article, we focus on description of mutual hazards' relationships that can be studied by their cascade and synergy effects if they manifest.
This approach allows to consider multiplied impact of hazards manifested in some protected area. The consideration of the cascade and synergy effects illustrate the force of some particular hazard on the network of its impact. Relations are determined ad hoc, by means of estimations made by experts. Subsequently, there is calculated the average of thus obtained values and used as an activity, respectively a passivity coefficient. This way each risk connected with particular hazard is enriched with two values, which should clarify its impact. Obviously, there are two main insufficiencies. First, the usage of any estimation carries out subjectivity of experts that needs to be treated in proper way. Secondly, computing the average of given values does not include any information about the importance, meaning or weight of grouped hazards.

1. Introduction

The elimination of the deficiencies from above can be partially removed by application of selected methods of multiple objective optimization. The most often used method of multiple – criteria decision analysis is a method proposed by Fuller. This easy comparing of two selected objects brings nice results but for larger tasks requires comparison of $\binom{k}{2}$ combinations, where k equals the number of compared objects. Even more input data is required by the Saaty method which can be considered as a enlarging of the Fuller method. The less accurate but simpler methods are the Ranking method and the Scoring method which is similar as in previous enlarging of the Ranking method. All these methods, along with the method of the Weight estimation method, are useful tools for risk and hazards analysis and bring mathematical approach into the risk management. Nevertheless, all these methods are formed on estimations. Experts may make these estimations but it is not enough of them or they do not particularly focus on given topic, and thus burden their estimates with subjective errors.
In our article we attempt to properly describe all the above-mentioned methods for weight determination considering the cumulative and synergic effect of risks and hazards on selected protected object. There are interpreted selected subsidies in context of critical infrastructure. The article provide multiple examples of modifications of these methods. There is illustrated the table of different calculations leaning on estimates which were made by various experts in order to show modifications that can be done at same model just by keeping multiple estimations. Furthermore, in the article there is drafted the analysis of the effect of subjective experts' estimates on perception of multi-risk assessment and multi-hazards analysis. At the end of the article there is proposed the frame of approach that can be used to improve the method intended for detection the cumulative and synergic effect. This method is based on correcting the initial estimates made by experts. The

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initial estimates made by experts are altered with the observations which can be entered into the description of the cumulative and synergic effect of risks and hazards on selected protected object.
Authors of the article build their work on mathematical instruments used in risk management as well as the newest principles of hazard identification.
The problem of understanding the possible threats in the context of critical infrastructure was already study in (Lovecek et al. 2016). Analyse of domino and synergic effects of 58 selected threats on particular electric station is described in the following text. At the beginning there were listed the possible threats in the risk catalogue, as it is common in Risk management. There were recognized 59 threats of different kinds like anthropogenic, natural, economical, software related, etc. In general, there can be n potential threats: $h_1, \dots, h_n$. Based on the Rehak et al. (2016a; 2016b) or Hromada and Lukas (2012) it is possible to define two types of coefficients: Activity Coefficient C_A and Passivity Coefficient C_P.

2. Activity and Passivity Coefficients

The Activity Coefficient is created by consideration of the influence of the thereat A on the other threats. In other words, if the threat A is able to initiate (activate) another threat B, then this the relation ρ can be written as $(A\rho B) = 1$. In case when the threat A is unable to initiate (activate) another threat C, then this the relation ρ can be written as $(A\rho C) = 0$. By assumption that any already activated threat cannot be reactivated by itself, the relation $(A\rho A) = x$, meaning the relation does not exist. The activity coefficient for particular h_i threat is then defined as the sum of the relations for the particular threat divided by the number of all other threats:

$$C_{A_i} = \frac{\sum_{j=1}^{n} \rho_{ij}}{n-1} \text{ for } \forall\, j \neq i \tag{1}$$

Following the same principle, the Passivity Coefficient represents the vulnerability of some particular threat A to be activated by another threat B. If the threat A can be caused by the threat B this relation σ can be written as $(A\,\sigma\,B) = 1$. In case where A cannot be initiated by C this relation σ can be written as $(A\,\sigma\,C) = 0$. Similarly the relation $(A\rho A) = x$, not exist. The passivity coefficient for particular h_j threat is then defined as the sum of the relations for the particular threat divided by the number of all other threats:

$$C_{P_j} = \frac{\sum_{i=1}^{n} \sigma_{ij}}{n-1} \text{ for } \forall\, j \neq i \tag{2}$$

For example, both coefficients can be easily find out from the Table 1.

Table 1: Table of active ρ and passive σ relations

	Threat A	Threat B	Threat C	$\boldsymbol{C_{A_i}}$
Threat A	x	1	0	1/2
Threat B	0	x	0	**0**
Threat C	1	1	x	1
$\boldsymbol{C_{P_j}}$	1/2	1	**0**	

The reader could object to this “average type” of methodology. Indeed, it is obvious that this approach has one great imperfection: it does not consider the occurrence, effect, or importance of the threat. One cannot perceive each threat in the same way. For example, the occurrence of the nuclear accident is much lower than occurrence of common operational accident. Moreover, the consequences significantly differ. To overcome the inadequacy there should be introduced some criteria for further evaluation of the threats. layout of the pages must follow the current format - do not modify the page setup – including the header.

3. Modification of the original approach

Domino and synergy effects described by the Activity and Passivity Coefficients are based on the average effect over all criteria. Following modification takes into account different way how one threat effect other expressed by the criteria.

3.1 The Criteria

In general, there may exist *m* different criteria $c_1, \dots, c_m$, for example: prediction [time], expected appearance [frequency], recovery [time], resources for recovery [finance], prevention measures [finance].
Activity Coefficient or Passivity Coefficient can be enriched by the impact of these criteria. Therefore, the Activity Coefficient (Passivity Coefficient) will be multiplied by the value of the given criteria for each threat separately. In this way, the coefficient of activity (passivity) is enriched by perception of a given threat on the

basis of a given criterion. The evaluation (EHC_{ij}) of the given threat particular h_i under criterion c_j is thus determined by:

$$EHC_{ij} = c_j \cdot C_{A_i} \quad (3)$$

This threat evaluation under the given criteria will generate the as many evaluations as the number of the threats in. This way it is possible to create a cumulative coefficient of the give threat that will be based on the Multiple-criteria decision analysis. This can be done by using the weighting criteria.

3.2 Weithing Criteria

The classical approach of Saaty method (Saaty et al., 1982) to determine criteria weights $w_1, \ldots, w_m$ was used here. The expert estimated the ratio criteria. Table 2 show the mutual ratio of the selected criteria:

Table 2: Saaty method – criteria ratio (rc_i)

	Prediction	Expected appearance	Recovery time	Resources for recovery	Preventive measures
Prediction	1,00	0,33	0,20	0,25	0,50
Expected appearance	3,00	1,00	0,20	0,33	0,50
Recovery time	5,00	5,00	1,00	1,00	0,50
Resources for recovery	4,00	3,00	1,00	1,00	1,00
Preventive measures	2,00	2,00	2,00	1,00	1,00

Based on the mutual ratio of the criteria the weights of the criteria were calculated by the relations of Saaty method and are fully described in Table 2 and Table 3:

$s_i = \prod_{i=1}^{m} rc_i$, where rc_i is the criteria ratio (4)

$R_i = \frac{s_i}{m}$, where m is the number of weights (5)

$$w_i = \frac{R_i}{\sum_{i=1}^{m} R_i} \quad (6)$$

Weighs of the criteria can be found by any other suitable method, also just by estimation of the expert but it is needed that $\sum_{i=1}^{m} w_i = 1$. The method is based on determining the ratio ($\mathrm{rc_i}$) between the criteria and their normalisation into the $\langle 0,1 \rangle$ interval, by applications of the expressions (4)-(6). As it is described in the Table 3.

Table 3: Saaty method – weights (w_i)

	s_i	R_i	w_i
Prediction	0,01	0,38	0,07
Expected appearance	0,10	0,63	0,11
Recovery time	12,50	1,66	0,28
Resources for recovery	12,50	1,64	0,28
Preventive measures	8,00	1,52	0,26

After considering the weights into threat assessment, we get a comprehensive concept that takes into account the threat activity (passivity) for all criteria (Weight evaluation threat criteria $WEHC_{ij}$ of the given threat particular h_i under criterion c_j is thus determined by:

$$WEHC_{ij} = w_j \cdot c_j \cdot C_{A_i} \quad (7)$$

The Weight Evaluation Threat Criteria $WEHC_{ij}$ is a value that more fully describes of the threat effect in view according to various criteria. These criteria and weights are estimated by experts and can be chosen specifically for the situation. This allows customizing the model for different situations.
Correspondingly, the Weighted Evaluation of the Threat:

$$WEH_i = \sum_{j=1}^{m} w_j \cdot c_j \cdot C_{A_i} \quad (8)$$

is the value of the estimation of the given threat h_i under all criteria c_j. This value fully describe the threat as a whole under all criteria in one value. This value is more accurate description of the potential of given threat than the original value of Active (Passive) Coefficient was since it takes into account the inner connections between threats and manifestations of the hazards themselves as well as their potential after the manifestation and consequences.
Mentioned analysis can be based either on the observation or on the estimations made by experts. Since it is more extended to use estimations made by experts, following text is devoted to this approach.

4. Estimations made by experts

Estimations made by experts has a wide interpretation in the analysis of environmental threats as it can be found in (Kampova et al., 2010). Using this method in the combination with estimations made by experts is possible to improve the original estimation. Therefore, this method can be also applied on cumulative probabilities from (Lovecek et al., 2013). Combination of estimations made by experts with synergic effect and this new approach can be done by the following procedure:

- The experts were asked to estimate the coefficients (activity or passivity) under the mentioned criteria (Prediction, Expected appearance, Recovery time, Resources for recovery, Preventive measures) on a scale from 0 to 10 (see Table 4).

Table 4: Meaning of the criteria scale

Criteria	Meaning of 0	Meaning of 10
Prediction	Easily predicted	Impossibly predicted
Expected appearance	Can be predicted in long term	Cannot be predicted in long term
Recovery time	Very short recovery time	Very long recovery time
Resources for recovery	Resource-less	Resource-intensive
Preventive measures	Undemanding	Consuming

- Estimates made by experts were normalized to the interval ⟨0;1⟩.
- Calculation of the indicators.
- The results were interpret in the charts.
- The analysis of the estimations and modifications of original values of the Active (Passive) Coefficient was made.

Each expert made their estimation for a given threat under the given criteria. In the following graph (Figure 1) can be found the estimations of activity made by 1st, 2nd, and 3rd expert for the given threat:

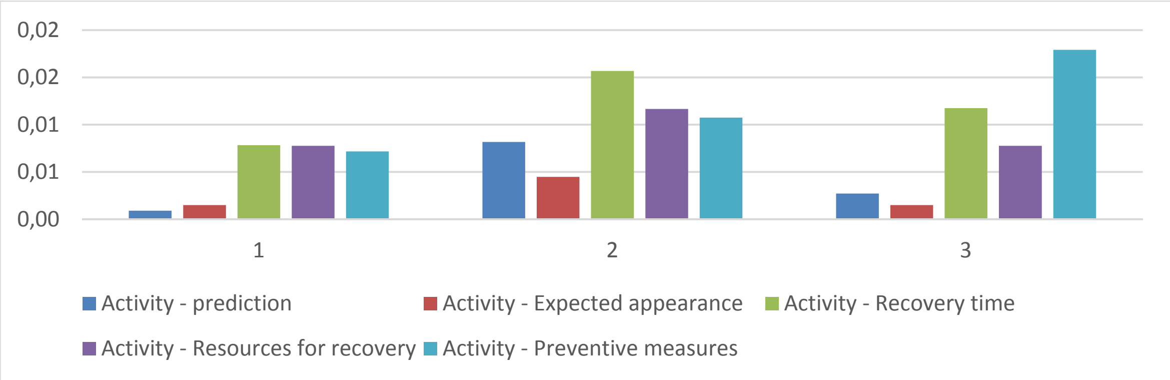

Figure 1: Estimation of Activity

Final evaluation of modified coefficients can be observed from the graphs. Original estimation of coefficients are represented by the blue dots and the bars in the red, orange, and purple colour depending on the expert (1st, 2nd, and 3rd respectively) represent modified values in the Figure 2:

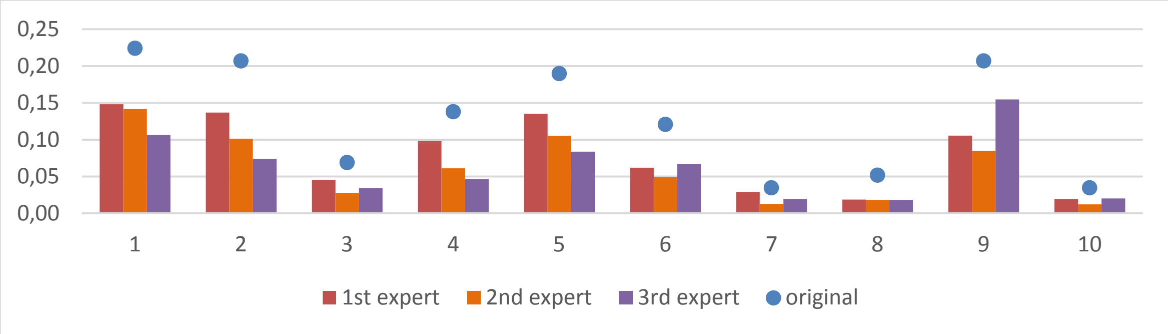

Figure 2: Estimation of Activity

For some threats is the improvement bigger than for the others. This fact depends on the estimations made by the experts. The estimations can improve the original value and be more accurate as the number of the estimations made by experts increase. On the other hand, results of this method can help identify these experts who's estimations are inadequate. This can be done simply by calculation of the error function for each expert.
Obviously, the estimations can be modified by the observations or bigger number of the estimations made by experts. With more data, it is practical to introduce some probability distribution with its expected value and variance. Therefore, this approach has a wider application also into the work of Prieto et al. (2017) where estimations made by experts can be replaced by the measurements. For example, for the values that depend on many factors like manifestation of the hazards it is practical to use an arithmetic mean as an expected value and the normal distribution as an expected probability distribution. The traditional expression (Medhi et al., 1992) for an arithmetic mean adjusted for the method used in this article is:

$$\overline{WEH_i} = \frac{\sum_{k=1}^{l} WEH_{ik}}{l} \tag{8}$$

Where $\overline{WEH_i}$ is an arithmetic mean of the Weighted Evaluation of the Threat (for the give threat h_i) for all estimations made by l experts, WEH_{ik} is the Weighted Evaluation of the Threat calculated for the threat h_i based on the estimation made by k expert, and l is the number of experts. The arithmetic mean value $\overline{WEH_i}$ allows comparison of the original the Active (Passive) Coefficient with just one value which is a result of the method given above. The difference of the modified Activity coefficient and the original one can be found in the Figure 3 above. In this graph are missing some bars (eg. bar 40) since experts did not find the threat 40 relevant for the given situation. Also, the estimation of the Activity all threats is reduced because in the modified values it is also important "how much the threat" is active not only if as it was in the original model.

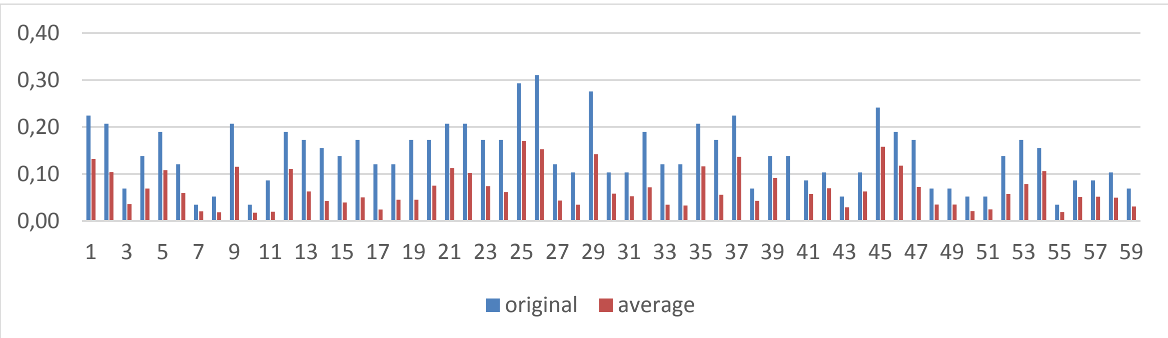

Figure 3: Comparison for Activity of the Threat

This value ($\overline{WEH_i}$) serves for the better orientation of the assessor and helps with crisis management decision making.

5. Conclusions

The method explained in this paper describes the synthetic of the synergistic effects method proposed in Rehak's work, the multi-decision making, and the application of the estimations made by experts. This method provide a deep analysis of the inner connection between the threats and the synergic effect of their manifestation with analysing the threats independently and analyse of their connections by parts. The benefits of this approach are: a simplicity in partial steps, a usage of commonly understandable statistical methods, an easy graphical interpretation of the results, and particularly the retrospective evaluation of the estimations made by the experts through the error function.

The greatest benefit of here presented method is that in the original approach there was only relevant if the threat can activate another threat and now, also the potency of this manifestation is taken into account. The original model is based on the knowledge that if manifestation of the threat with small effect and activate the threat with big effect, it is important to pay attention also to the threat with a small effect. New, approach deals with the question how much will this threat with a small effect influence threats with its activation. This correction can lead to better understanding of cumulative and synergic effects in the crisis management and risk assessment of the manifestation of the hazard in the critical infrastructure and further.

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