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Research Article

Model for Risk Management of Critical Infrastructures of the Republic of Bulgaria

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ABSTRACT:

This paper is the first in a series that describes the Model for risk management of critical infrastructures of the Republic of Bulgaria. It focuses on activities of developing rules and proposing a mathematical apparatus for identifying critical infrastructures and their assets. Gaps in the current model for risk management of critical infrastructure are identified. A methodology based on modern scientific and analytical methods is presented to fill the identified gaps.

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Introduction

The development of a risk management methodology for critical infrastructure (CIs) assets of the Republic of Bulgaria is essential due to the inclusion in it of assets and systems that are vital for national security, the economy, health care, and the safety of citizens. It is important to protect their functioning from any threats and risks that could lead to their interruption or destruction.

Effective risk management requires the use/application of a systematic approach to the identification, assessment, and mitigation of potential threats to CIs. This includes developing strategies to prevent incidents, prepare for crisis

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response and recovery. The creation of an efficient risk management methodology will allow the relevant authorities and organizations to apply the best practices and procedures for the protection of critical infrastructure.

The development of such a methodology is key to ensuring a coordinated approach between various stakeholders, including ministries, government agencies, the private sector and international partners. This will strengthen the state's ability to deal with diverse threats, while maintaining the operation of critical infrastructure in conditions of high security and resilience. The development of a risk management methodology is a critical step to guarantee national security and the well-being of the citizens of the Republic of Bulgaria. It will help to achieve a higher level of protection and readiness of CI objects in the realization of various threats and challenges.

Model for Risk Management of Critical Infrastructures

Critical infrastructure is that national or international infrastructure, the loss of which would lead to the disruption of social and economic life. That infrastructure, the failure of which results in unacceptable losses, is defined as critical.

Critical infrastructure is a combination of:

- Infrastructure objects – these are objects with functional autonomy, i.e., their necessary conditions for functioning and the results of their operation can be determined;
- Linkages between infrastructure objects – linkages can be functional or governance.

Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of critical infrastructures and the assessment of the need to improve their protection assets that each Member State shall identify potential CIs assets that meet the horizontal and sectoral criteria and the definitions made.[1] This Directive has been transposed into Bulgarian legislation through the Ordinance on the Procedure, Method and Competent Authorities for the Identification of CIs and their assets and Risk Assessment, in force since 23 October 2012, adopted by Council of Ministers Decree No. 256 of 17 October 2012. The ordinance defines the procedure, method, and competent authorities for the identification of critical infrastructures in the Republic of Bulgaria and the risk assessment of their assets.

According to these documents, the responsible authorities shall set up permanent working groups to assist them in identifying critical infrastructures and their sites. The working groups shall develop rules for the identification of critical infrastructures and their assets in the relevant sector, which shall be approved by the competent authority. The working groups have to develop also a risk assessment methodologies for the identified critical infrastructures and their sites in the relevant sector, which shall be validated by the competent authority.

The overall process of identification and designation of critical infrastructures and the assessment of the need to improve their protection includes the following two main stages (Figure 1):

- Stage 1. Identification of critical infrastructure assets;
- Stage 2. Improve assets' protection.

The first stage includes three sequential activities. First of all, is Initial selection of infrastructures and their assets; followed by Assessment and after that is Preparation of a list of identified critical infrastructure and their assets.

The second stage includes the following activities: Identification of risk events for each critical infrastructure asset, followed by Determination of probabilities. After that takes place Identifying of vulnerabilities and Determination of the impact. Then it is executed Risk evaluation and Countering risk activities. And finally, Verification of adequacy of countermeasures is checked. (ISO 31000:2018 – Risk management)

This publication will focus on the activities of developing rules and proposing a mathematical apparatus for identifying critical infrastructures and their assets (Stage 1).

For Stage 2, another methodology was developed by the authors (Z. Zdravkov & I. Radulov) and will be presented in another publication.

Problem Description

Administrative Regulations only provide the framework for action and the criteria to be applied in identifying critical infrastructures and their assets. They do not provide ready-made solutions nor specific methods to solve the problem. This is the reason why administrations most often use a so-called desk-based approach. The working groups that have been set up make decisions based on expertise and experience, often without a clear idea of the nature of the criteria set. In order to reduce the influence of the subjective factor, a methodology for the identification and designation of critical infrastructures based on adapted scientific methods and theories is needed.

According to the mentioned above ordinance, the following takes place:

1. Working groups from each department make an initial selection of infrastructures and their assets for their own sectors. The working groups verify that these assets meet the definition of "critical infrastructure" in the law. Assets are examined on their own without taking into account their mutual influences and cascading effects of risk events occurring.

2. From the list of potential critical infrastructure assets has been drawn up from only those assets that meet the following criteria defined in the regulatory documents should be selected: [1]

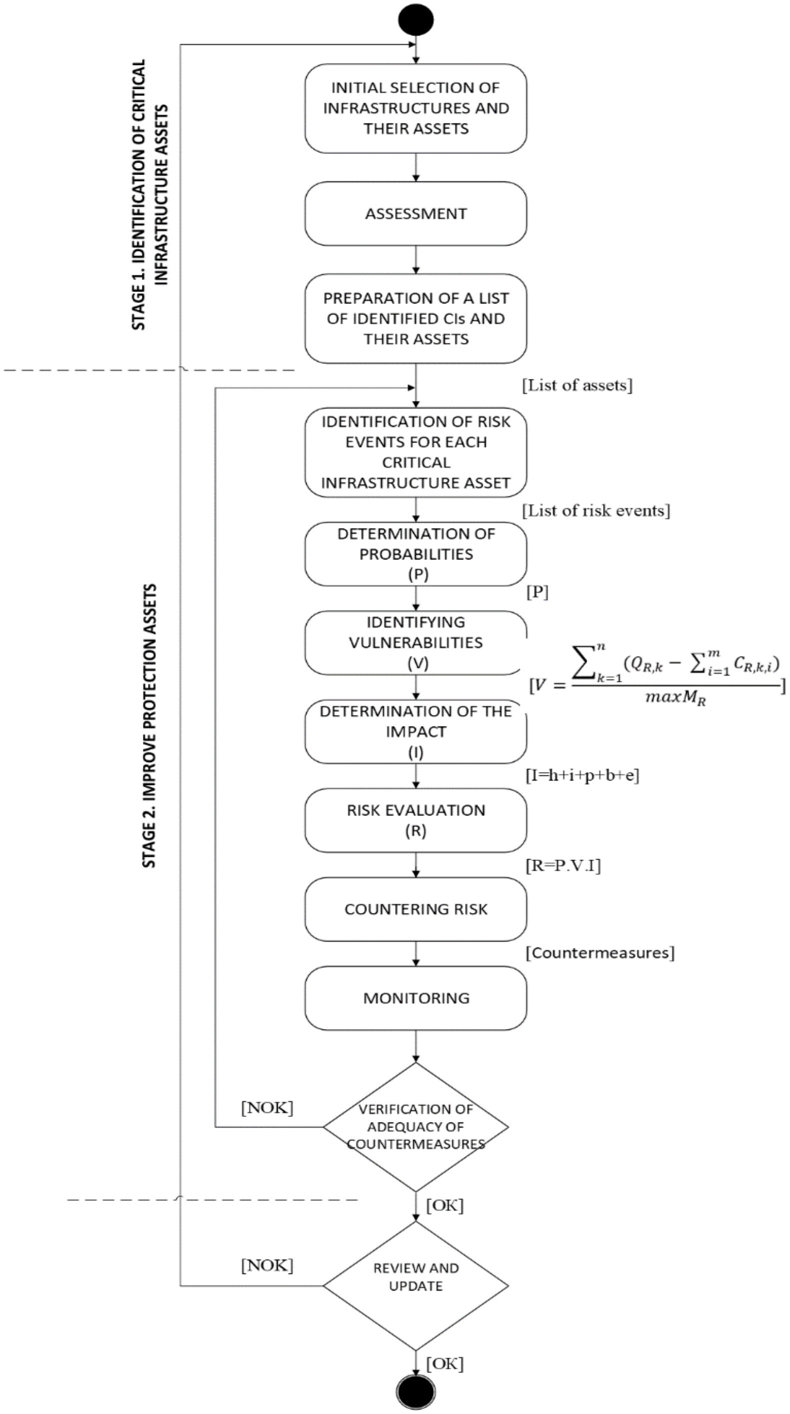

Figure 1: Model for risk management of Critical Infrastructure.

- (A_1) Casualties criterion (assessed in terms of the potential number of fatalities or injuries);
- (A_2) Economic effects criterion (assessed in terms of the significance of economic loss and/or degradation of products or services, including potential environmental effects);
- (A_3) Public effects criterion (assessed in terms of the impact on public confidence, physical suffering, and disruption of daily life; includes the loss of essential services);
- (A_4) Recovery time;
- (A_5) Alternatives to infrastructures.[1]

The threshold values of the criteria shall be established by the authorities in agreement with the Minister of the Interior.

3. Finally, a list of identified critical infrastructure and their assets should be produced. The list shall be approved by the authorities.

Methods

Under the conditions thus set, the problem reduces to solving a type of multi-criteria mathematical problem. Multi-criteria decision support problems, depending on their formal setting, can be divided into two distinct classes. In the first class of problems, a finite number of explicit constraints in the form of functions define an infinite number of admissible alternatives. These problems are called continuous multi-criteria decision support problems or multi-criteria optimization problems. In the second class of problems, a finite number of alternatives are specified explicitly in tabular form. These problems are called discrete multi-criteria decision support problems or multi-criteria analysis problems.[2, 3, 6]

On the other hand, multi-criteria analysis problems can be divided into three types: multi-criteria choice problems, multi-criteria ordering problems, and multi-criteria sorting problems.[6]

Our case falls into the first two types of problems.

There is no single best method for solving this type of problems.

Typical representatives of multi-criteria methods are weighting method – Analytic Hierarchy Process (AHP), outranking methods - PROMETHEE II, ELECTRE III, interactive method – CBIM, etc.[6] All these methods have their strengths and weaknesses. The choice of any of these is related to the nature of what is being evaluated, the nature of the evaluation, the opportunities and limitations at the time, as well as who will use the evaluation, and for what purpose so that stakeholders become aware of the potential gains and losses implied by their

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[1] Art. 7, par. 1 of the Ordinance on the procedure, method and competent authorities for the identification of critical infrastructures and their sites and risk assessment for them, in force since 23.10.2012, adopted by Decision of the Council of Ministers No. 256 of 17.10.2012.

choice. However, each technique follows a different approach to elicit human preferences.[8]

One of the most widely used compensatory weighting method is AHP. AHP is a method for organizing and analysing complex decisions, using math and psychology. It was developed by Thomas L. Saaty in the 1970s and has been refined since then. AHP provides a rational framework for a needed decision by quantifying its criteria and alternative options (in our case critical infrastructure assets), and for relating those elements to the overall goal.[4]

Stakeholders evaluate the importance of the criteria through pairwise comparisons. AHP converts these evaluations into numbers. This quantifying capability distinguishes the AHP from other decision-making techniques. In the final step of the process, numerical priorities are calculated for each asset. These numbers represent the most desired solutions based on all users' values. (Wikipedia).

The limitations of the AHP relate to the complexity of the process in a series of pairwise comparisons, which can be time-consuming and difficult to manage when there are many criteria and assets to evaluate.

Problem Solving

Calculating the weight of the criteria is the first step of the process. It is performed by the experts in the working groups. The results of the expert evaluation, related to the comparison of the criteria in order of importance, are summarized in the Comparison Matrix.[7]

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \dots \\ A_i \\ \dots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccc} A_1 & A_2 & \dots & A_j & \dots & A_n \end{array} \\ \begin{pmatrix} 1 & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2j} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ a_{i1} & a_{i2} & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nj} & \dots & 1 \end{pmatrix} \end{array}$$

For every element a_{ij} it holds:[7]

1 / a_{ij} =1 for *i=j*, (1)

2 / $a_{ij} = \frac{1}{a_{ji}}$ for $i \neq j$. (2)

The value for the element a_{ij} is obtained as follows:

a_{ij} = 1, if A_i and A_j are of an equal importance;

a_{ij} = 3, if A_i is more important in minor rate than A_j;

a_{ij} = 5, if A_i is more important in major rate than A_j;

a_{ij} = 7, if A_i is obviously more important than A_j;

a_{ij} = 9, if A_i is absolutely superior to A_j.

a_{ji} = 3, if A_j is more important in minor rate than A_i;

a_{ji} = 5, if A_j is more important in major rate than A_i;

a_{ji} = 7, if A_j is obviously more important than A_i;

a_{ji} = 9, if A_j is absolutely superior to A_i.

In the next step are calculated the „rank vector" $\overline{P}$ for the given matrix *A*. The mean geometric values for each criterion are computed and normalized (formula 3).[7]

$$P = \begin{pmatrix} p_1 = \sqrt[n]{\prod_{j=1}^{n} a_{1j}} \\ p_2 = \sqrt[n]{\prod_{j=1}^{n} a_{2j}} \\ \dots \\ p_n = \sqrt[n]{\prod_{j=1}^{n} a_{nj}} \end{pmatrix} \qquad \overline{P} = \begin{pmatrix} \overline{p_1} = p_1 / \sum_{i=1}^{n} p_i \\ \overline{p_2} = p_2 / \sum_{i=1}^{n} p_i \\ \dots \\ \overline{p_n} = p_n / \sum_{i=1}^{n} p_i \end{pmatrix} \qquad (3)$$

The vector elements give the weight coefficients for every rank. So, the element $\overline{p_1}$ is the weight coefficient of the criterion ranked at the 1-st place; the element $\overline{p_2}$ - the weight coefficient of the criterion ranked at the 2-nd place; etc. Each expert calculated the rank vector $\overline{P}$.

The following tables illustrate the derived data based on their input. In general, all of the decimals will add up to 1, and higher decimals equals a higher priority.[4]

Table 1 shows how the criteria were rated against each other.

Table 1. The value of the criteria rated against each other

GOAL	(A_1) Casualties criterion	(A_2) Economic effects criterion	(A_3) Public effects criterion	(A_4) Recovery time	(A_5) Alternatives to infrastructures	Rank
(A_1) Casualties criterion	1	3	1	2	3	**0.30**
(A_2) Economic effects criterion	0.33	1	0.25	0.5	0.5	**0.08**
(A_3) Public effects criterion	1	4	1	4	3	**0.37**
(A_4) Recovery time	0.5	2	0.25	1	1	**0.13**
(A_5) Alternatives to infrastructures	0.33	2	0.33	1	1	**0.13**

Table 2 below demonstrates the weights of each alternative/asset against the Casualties criterion.

Table 2. The weights of each alternative/asset against the casualties criterion.

(A_1) Casualties criterion	Asset 1	Asset 2	Asset 3	Asset 4	Asset 5	Rank
Asset 1	1.00	2.00	0.50	2.00	0.20	**0.15**
Asset 2	0.50	1.00	0.25	0.33	0.50	**0.08**
Asset 3	2.00	4.00	1.00	3.00	1.00	**0.34**
Asset 4	0.50	3.00	0.33	1.00	5.00	**0.22**
Asset 5	5.00	2.00	1.00	0.20	1.00	**0.21**

This would be repeated for every criterion.

Finally, the weighted importance of each criterion is then multiplied against the score of each alternative to get the weighed score (Table 3). For Asset 1's weighted casualties criterion score: 0.3*0.24=0.05. Add all new criteria numbers together to get the total score: 0.05+0.02+0.12+0.03+0.06=0.273.[5]

Table 3. Weighted score of each criterion

Synthesis	(A_1) Casualties criterion	(A_2) Economic effects criterion	(A_3) Public effects criterion	(A_4) Recovery time	(A_5) Alternatives to infrastructures	Total
	0.30	**0.08**	**0.37**	**0.13**	**0.13**	
Asset 1	0.15	0.23	0.32	0.23	0.5	**0.273**
Asset 2	0.08	0.04	0.04	0.12	0.05	**0.065**
Asset 3	0.34	0.12	0.12	0.02	0.21	**0.185**
Asset 4	0.22	0.3	0.3	0.25	0.1	**0.243**
Asset 5	0.21	0.31	0.22	0.38	0.14	**0.234**

Arrange the alternatives in ascending order, and you will get a prioritized list of critical infrastructure assets.

Experts in the working group set a threshold value for compliance. Any assets dropped below are not included in the list.

Conclusions

This publication presented the activities of developing rules and a mathematical apparatus for identifying critical infrastructures.

The proposed model sets out the general approach to risk management for identified critical infrastructures and their objects, as well as the stages through which this process takes place. A mathematical apparatus that includes multi-criteria methods such as AHP for identifying critical infrastructures and prioritizing their assets is proposed.

The presented methodology is a scientific development and does not necessarily have to be applied by stakeholders. The aim is to propose a systematic approach to risk management for critical infrastructures and their assets to cover the gaps in this area.

Certainly, other possible approaches and methods can be used to solve the identified problem.

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Disclaimer

The opinions expressed represent the personal position of the authors and should not necessarily be associated with the official position of the institutions for which they work.

References

[1] “Council Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection,” https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0114, accessed: September 04, 2024.

[2] Ward Edwards and J. Robert Newman, “Multiattribute Evaluation,” in *Judgment and Decision Making: An Interdisciplinary Reader,* edited by H. R. Arkes and K. R. Hammond (Cambridge, England: Cambridge University Press, 1986), 13-37.

[3] Ralph L. Keeney and Howard Raiffa, *Decisions with Multiple Objectives: Preferences and Value Trade-Offs* (New York, New York: Wiley, 1976), reprinted (Cambridge University Press, 1993).

[4] Passage Technology, What Is The Analytic Hierarchy Process (AHP)? www.passagetechnology.com/what-is-the-analytic-hierarchy-process, accessed May 11, 2024.

[5] Asma Bahurmoz, “The Analytic Hierarchy Process: A Methodology for Win-Win Management” *JKAU: Econ. & Adm.* 20, no. 1 (2006).

[6] Vassil Vassilev, Krassimira Genova, and Mariyana Vassileva, “A Brief Survey of Multicriteria Decision Making Methods and Software Systems,” Bulgarian Academy of Sciences, Sofia, *Cybernetics and Information Technologies* 5, no. 1 (2005).

[7] Neno Hristov, Ivo Radulov, Petko Iliev, Plamena Andreeva “Prioritization Methodology for Development of Required Operational Capabilities,” *System Analysis & Studies panel, SAS-081/RSY, NATO Research and Technology Agency (RTA)*, 26-28 April 2010, Sofia, Bulgaria, https://pdfs.semanticscholar.org/73dc/d76478a67e70d27fa3187a068fc23fa36f01.pdf.

[8] Danae Diakoulaki and Stelios Grafakos, "Final Report on Work Package 4 Multicriteria Analysis" (Contract N° ENG1-CT-2002-00609), January 2004.

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