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RISK ANALYSIS OF CRITICAL INFRASTRUCTURES USING FUZZY COPRAS

ABSTRACT

Critical infrastructures play a significant role in countries because of the essentiality of nation security, public safety, socioeconomic security, and way of life. According to the importance of infrastructures, it is a necessity to analyze the potential risks to do not allow these risks be converted into events. The main purpose of this paper is to provide a developed framework with the aim to overcome limitations of the classical approach to build a more secure, safer, and more resilient critical infrastructures in order to develop, implement, control. The proposed framework extends conventional RAMCAP (Risk Analysis and Management for Critical Asset Protection) through introducing new parameters the effects on risk value. According to the complexity of problem and the inherent uncertainty, this research adopts the fuzzy COPRAS (COPRAS-F) as a fuzzy multi criteria decision making technique to determine the weights of each criterion and the importance of alternatives with respect to criteria. Case analysis is implemented to illustrate the capability and effectiveness of the model for ranking the risk of critical infrastructures. The proposed model demonstrates a significant improvement in comparison with conventional RAMCAP.

***Keywords**: Fuzzy COPRAS, COPRAS-F, Risk analysis, Criticalinfrastructures, RAMCAP*

***JEL Classification:** C53, C54, C61, C63.*

1. INTRODUCTION

The countries of all around the world were recently faced with several events generated by various causes in the critical infrastructures sector(Too, 2011, Rudock et al. 2010, Miao et. al. 2010, Darby, 2008, Little, 2005, Yusta et al. 2011, Tofani et al. 2010). They have led to a lot of casualties and major damageto human, machinery, and environment. That is demonstrated by many events which risk connected with security, safety, health, and environment cannot be perfectly avoided.Therefore, miscellaneous methodologies were developed in order to analyze and rank the existing risks (Hsueh et al. 2007, Manik et al. 2008, Zavadskas et al. 2010, Perera et al. 2009,JaskovskiandBiruk, 2011, Kheirkhahet al. 2009).Risk Analysis and Management for Critical Asset Protection (RAMCAP) methodology is one the most well-known methods in this field that were presented by the Department of

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Homeland Security. The RAMCAP method is a function of three components threat (T), vulnerability (V), and consequence (C) (Brashear et al., 2007; ASME-ITI, 2006; Cox, 2009).

Regardless of the relative importance weights of the evaluation criteria, it appearsto be an urgent need for critical infrastructuresto develop a risk assessment methodology to manage the effectivecomponents.

COPRAS(COmplex PRoportional ASsessment) isone of the most application multi criteria decision making (MCDM) methods,which assigns the best alternative among a pool of feasible alternatives by determininga solution with the ratio to the ideal solution and the ratio with the ideal-worst solution (Zavadskas and Kaklauskas, 1996).This technique is employed by various researchers to solve the decision making problems.

Kaklauskas et al. (2006) applied COPRAS to select low-e windows in retrofit of public buildings. Banaitiene et al. (2008) used COPRAS to evaluate the life cycle of buildings. Chatterjee et al. (2011a) developed two COPRAS and evaluation of mixed data methods for materials selection. This paper presents two examples which prove that these two MCDM methods can be effectively applied to solve the real time material selection problems. Zavadskas et al. (2010) used COPRAS for risk assessment of construction projects. Mazumdar et al. (2010) used COPRAS for evaluation appraisal of teacher performance, Karbassi et al. (2008) – for energy savings decisions. Ginevicius et al. (2010) used COPRAS for the model of forming competitive strategy of an enterprise under the conditions of oligopoly market.Podvezko et al. (2010) used COPRAS method for complex evaluation of contracts for construction. Podvezko (2011) compared SAW and COPRAS methods.

Zavadskas et al. (2008) proposed COPRAS-G method in order to select construction project managers.They considered the application of grey relations methodology for defining the utility of alternatives. Madhuri et al. (2010) selected the best web site by applying COPRAS-G method.Zavadskas et al. (2011) COPRAS-G method used for assessment the indoor environment of dwelling houses. Chatterjee et al. (2011b) used COPRAS-G for material selection.

Zavadskas and Antucheviciene (2007) applied fuzzyfied COPRAS method for analysis of regeneration alternatives of derelict buildings of regeneration alternatives of derelict buildings in Lithuania rural areas. Antucheviciene et al. (2011) compared fuzzy COPRAS, TOPSIS and VIKOR methods. Fuzzy logic is able to model theexistinguncertainty.This technique uses linguistic variable instead of traditional quantitative expression, which is a very helpful concept for dealing with situations which are too complex or not well-defined enough (Zadeh, 1965).Therefore, COPRAS-F is developed in order to solve different aspects of priority issues.

In this paper, we extend the approach of COPRAS to develop a risk-based methodology under fuzzy environment. COPRAS-F is adopted because of its capability and efficiency in handling uncertainty, simultaneous consideration of the ratio to the ideal solution and the ratio with the ideal-worst solution, and logical concepts.

The rest of the paper is organized as follows: In Sections 2, the basic structure of the RAMCAP methodology is introduced. Section 3 describes fuzzy theory, including fuzzy logic, fuzzy set, and fuzzy number. In section 4, COPRAS-F is presented. The proposed framework is summarized in Section 5, including risks identification, selection of criteria, and risk evaluation. In Section 6, study for risk evaluation in an illustrative case is presented. The comparison of the proposed model with the conventional RAMCAP is implemented and results are discussed in Section 7. Conclusions are discussed and some shortages of the conventional RAMCAP are listed in Section 8.

2. THE BASIC CONCEPTS OF RAMCAP METHODOLOGY

The RAMCAP methodology provides a systematic process to identify and analyze the significance of potential events associated with critical infrastructures. The RAMCAP process is comprised of seven steps as follows (ASME-ITI, 2006; Brashear et al., 2007):
(1)Asset characterization and screening, (2) Threat characterization, (3) Consequence analysis, (4) Vulnerability analysis, (5) Asset attractiveness and threat assessment, (6) Risk assessment, and (7) Risk management. This steps are depicted in Fig. 1.

Figure. 1. Process of RAMCAP technique

The benefits of conventional RAMCAP, but are not limited to, include (Brashear & Jones, 2010): (i) More efficient management of capital and human resources, (ii) Ability to identify the assets with the greatest need and value of improvement, (iii) rational allocation of resources to maximize the security and resilience enhancement within a finite budget.
According to the conventional RAMCAP technique, risk (R) is determined by the intersection of consequences of the attack (C), the threats of the attack (T) and vulnerabilities to the attack (V). More specifically, risk is formulated as Eq. (1):

(1)

$$R= C \times T \times V$$

3. FUZZY THEORY

Adequate knowledge and comprehensive data base on a number of different problems are requested to analyze critical infrastructures. There are a close relationship between complexity and certainty, so that; increasing the complexity lead to decrease the certainty. Fuzzy logic –introduced by Zadeh (1965) - can take into account uncertainty and solve problems where there are no sharp boundaries and precise values. Fuzzy logic provides a methodology for computing directly with words (Zadeh, 1996).

Fuzzy set is a powerful mathematical tool for handling the existing uncertain in decision making. A fuzzy set is general form of a crisp set. A fuzzy number belong to the closed interval 0 and 1, which 1 addresses full membership and 0 expresses non-membership. Whereas, crisp sets only allow 0 or 1.There are different types of fuzzy numbers that can be utilized based on the situation. It is often convenient to work with triangular fuzzy numbers (TFNs) because they are computed simply, and are useful in promoting representation and information processing in a fuzzy environment (Torlak et al, 2011).

A fuzzynumber $\tilde{A}$ on R can be a triangularfuzzynumber (TFN)ifitsmembershipfunction $\mu_{\tilde{A}}(x): R \rightarrow [0,1]$ be definedasfollows (SeeFig. 2):

(2)

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \le a \\ (x-a)/(b-a), & a \le x \le b \\ (c-x)/(c-b), & b \le x \le c \\ 0, & \text{otherwise} \end{cases}$$

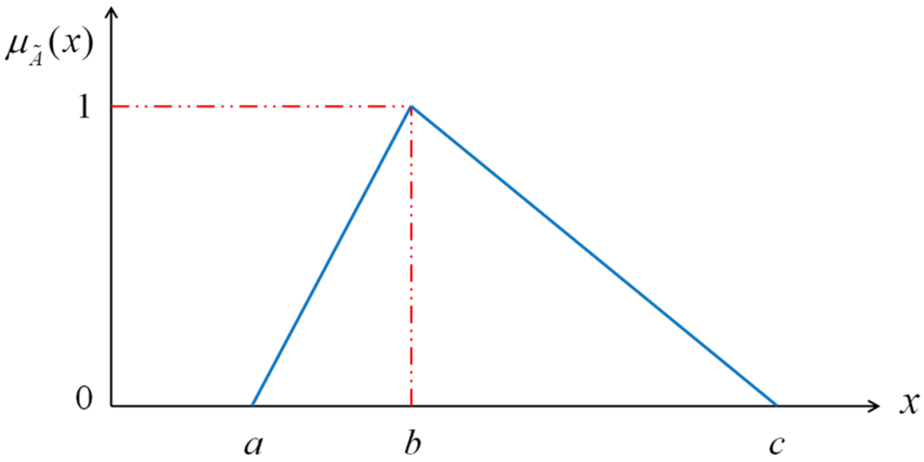


Fig.2. Membershipfunctionof a triangularfuzzynumber $\tilde{A} = (a, b, c)$

4. FUZZY COPRAS APPROACH

The COPRAS (*CO*mplex*PR*oportional*A*ssessment) method was first introduced by Zavadskas and Kaklauskas (1996). The COPRAS method determines a solution with the ratio to the best solution. This method assumes direct and proportional dependence of the significance and utility degree of investigated versions on a system of criteria adequately describing the alternatives and on values and weights of the criteria. COPRAS-F method was first introduced by Zavadskas and Antucheviciene (2007).

In conventional COPRAS, the weights of the criteria and the ratings of alternatives are taken into account as crisp numerical data. However, under many conditions crisp data are insufficient to handle real world decision problems andon the other hand perfect knowledge is not easily obtained. These make decision imprecise and inaccurate. Consequently, COPRAS-Fis proposedwhere criteria weights and alternative ratings are given by linguistic terms that are addressed using fuzzy numbers.

The mathematics concept of COPRAS-F can be described as follows:

Step 1: Choose the linguistic ratings for criteria and alternatives with respect to criteria.

In this step, the importance weights of evaluation criteria and the ratings of alternatives are considered as linguistic terms to assess risk under fuzzy environment. Linguistic values for importance weight of each criterionare shown in Table 1 and Fig. 3, andlinguisticvalues for preference rating of each alternative are presented in Table 2 and Fig. 4.

Table 1. Linguistic terms for criteria

Linguistic terms	Fuzzy number
Very low (VL)	(0.0,0.0,0.25)
Low (L)	(0.0,0.25,0.5)
Medium (M)	(0.25,0.5,0.75)
High (H)	(0.5,0.75,1.0)
Very High (VH)	(0.75,1.0,1.0)

Table 2. Linguistic rating for alternatives

Linguistic terms	Fuzzy rating
Very Poor (VP)	(0.0,0.0, 2.5)
Poor (P)	(0.0,2.5,5.0)
Fair (F)	(2.5,5.0,7.5)
Good (G)	(5.0,7.5,10.0)
Very Good (VG)	(7.5,10.0,10.0)

Figure 3.Linguistic values for importance weight of each criterion

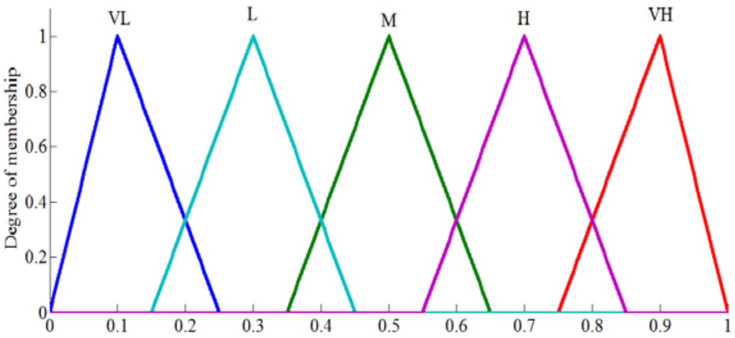
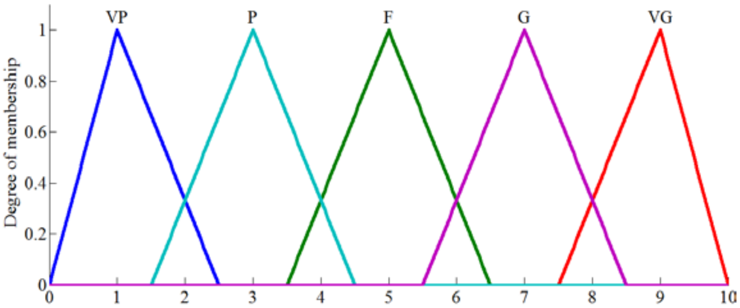


Figure 4. Linguistic values for preference rating of each alternative



Step 2. Construct the fuzzy decision matrix.

If assume that the number of criteria is *n* and the count of alternatives is *m*, fuzzy decision matrix will be obtained with *m* rows and *n* columns as following matrix:

(3)

$$\tilde{D} = \begin{array}{c c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} & \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & & \tilde{x}_{mn} \end{bmatrix} & \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \end{array}$$

And criteria are constructed as follows:

(4)

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, ..., \tilde{w}_n)$$

Defuzzify the fuzzy decision matrix and fuzzy weight of eachcriterion into crisp values. In order to deffuzzify fuzzy decision matrix and fuzzy weight of each criterioninto crisp values, the authorsusedthe centre of area (COA) method. This method is a simple and practical without the need to bring in the preferences of any evaluators (Wu *et al*. 2009). The BNP value for the fuzzy number $\tilde{R}_i = (L\tilde{R}_i, M\tilde{R}_i, U\tilde{R}_i)$ can be found using the following equation:

$$BNP_i = [(U\tilde{R}_i - L\tilde{R}_i) + (M\tilde{R}_i - L\tilde{R}_i)]/3 + L\tilde{R}_i \tag{5}$$

4. Normalization of the defuzzieddecision-making matrix $\overline{X}$. The normalized values of this matrix are calculated as:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}; \; i = \overline{1,n} \; and \; j = \overline{1,m} \; . \tag{8}$$

After this step we have normalized decision-making matrix:

$$\overline{X} = \begin{bmatrix} \bar{x}_{11} & \bar{x}_{12} & \cdots & \bar{x}_{1m} \\ \bar{x}_{12} & \bar{x}_{22} & \cdots & \bar{x}_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \bar{x}_{n1} & \bar{x}_{n2} & \cdots & \bar{x}_{nm} \end{bmatrix} . \tag{9}$$

5. Calculation of the weighted normalized decision matrix $\hat{X}$. The weighted normalized values $\hat{x}_{ij}$ are calculated as:

$$\hat{x}_{ij} = \bar{x}_{ij} \cdot q_j ; \; i = \overline{1,n} \; and \; j = \overline{1,m}. \tag{10}$$

In formula (10) q_j is weight of the $j-th$ attribute.

After this step we have weighted normalized decision-making matrix:

$$\hat{X} = \begin{bmatrix} \hat{x}_{11} & \hat{x}_{12} & \cdots & \hat{x}_{1m} \\ \hat{x}_{21} & \hat{x}_{22} & \cdots & \hat{x}_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ \hat{x}_{n1} & \hat{x}_{n2} & \cdots & \hat{x}_{nm} \end{bmatrix}; \; i = \overline{1,n} \; and \; j = \overline{1,m}. \tag{11}$$

6. Sums P_j of attributes values which larger values are more preferable (optimization direction is maximization) calculation for each alternative (line of the decision-making matrix):

$$P_i = \sum_{j=1}^{k} \hat{x}_{ij} \; . \tag{12}$$

In formula (6) K is number of attributes which must to be maximised (it is assumed that in the decision-making matrix columns first of all are placed attributes with optimization direction maximum and ones with optimization direction minimum are placed after).

7. Sums R_i of attributes values which smaller values are more preferable (optimization direction is minimization) calculation for each alternative (line of the decision-making matrix):

$$R_i = \sum_{j=k+1}^{m} \hat{x}_{ij} . \tag{13}$$

In formula (13) $(m-k)$ is number of attributes which must to be minimized.

8. Determining the minimal value of R_i :

$$R_{\min} = \min_i R_i ; \; i = \overline{1,n}. \tag{14}$$

9. Calculation of the relative weight of each alternative Q_i :

$$Q_i = P_i + \frac{R_{\min} \sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \frac{R_{\min}}{R_i}} . \tag{15*}$$

Formula (15) can to be written as follows:

$$Q_i = P_i + \frac{\sum_{i=1}^{n} R_i}{R_i \sum_{i=1}^{n} \cdot \frac{1}{R_i}}. \tag{15}$$

10. Determination of the optimality criterion K:

$$K = \max_i Q_i;\ i = \overline{1,n}. \tag{16}$$

11. Determination of the priority of the project. The greater weight (relative weight of alternative) Q_i, the higher is the priority (rank) of the project. In the case of $Q_{\max}$, the satisfaction degree is the highest.

12. Calculation of the utility degree of each alternative:

$$N_i = \frac{Q_i}{Q_{\max}} 100\%, \tag{17}$$

where Q_i and $Q_{\max}$ are the weight of projects obtained from Eq. (15).

5. THE PROPOSED FRAMEWORK

The proposed framework for ranking risk in critical infrastructures has followingthree phases:
1. Identify the existing risks.
2. Select the evaluation criteria.
3. Evaluate the identified risks using the COPRAS-F procedure.

5.1. RISKS IDENTIFICATION

In the risk identification phase, threats and hazards which could disrupt the critical services and products should be identified. One of the simplest method of identifying and analyzing the risks in a infrastructure is by asking questions such as which assets are most critical, which assets are more exposed to danger, and getting the right answers.

5.2. SELECTION OF CRITERIA

Selection of criteria is the first step for evaluating risk of critical infrastructures.The parameters of the RAMCAP methodology were identified as a part of evaluation criteria. Since these criteria are not enough to cover all aspects of risks; new criteria for a more precise, accurate, and sure risk analysis are developed. These criteria are presented in Table 3. As shown in Table 3, the first three criteria (i.e. C1, C2, and C3) are the cost type criteria (the lower, the better). The remaining criteriaare the benefit type criteria (the higher, the better).

Table 3. Evaluation criteria for analyze risk

Criteria	Definition	Type of criterion
Threat (C1)	Threat is defined as an event with an undesired impact	Cost
Vulnerability (C2)	Any weakness of an asset that can convert it into an event or disaster by one or more threats	Cost
Consequence (C3)	Consequence is defined as the effect of an event or incident	Cost
Detectability (C4)	The capability and potential for identification and elimination of the weakness	Benefit

Reaction against event (C5)	The capability of an appropriate response in order to reduce or limit the effect of an event after happening or prevent against the development of casualties, damage, and loss	Benefit

5.3. EVALUATING THE EXISTING RISKS USING THECOPRAS-F PROCEDURE

In the third phase, evaluating risks is determined by using theCOPRAS-F technique. Linguistic terms are utilized for evaluating the ratings and importance weights of alternatives and criteria.The definition of linguistic terms and triangular fuzzy numbers are presented in Tables (1) and (2).

6. CASE ANALYSIS

The proposed modelis utilized to rank the existing risk in a critical infrastructure in order to demonstrate the potential applications of the model. A rail transportation example is adopted from API & NPRA (2004). The example is of a fictitious hydrocarbon tank truck transportation system, which includes the tank truck, inventory of flammable liquids and the route specific variables such as the type of road, population centers and environmental receptors, and any stops.

6.1. RISKS IDENTIFICATION

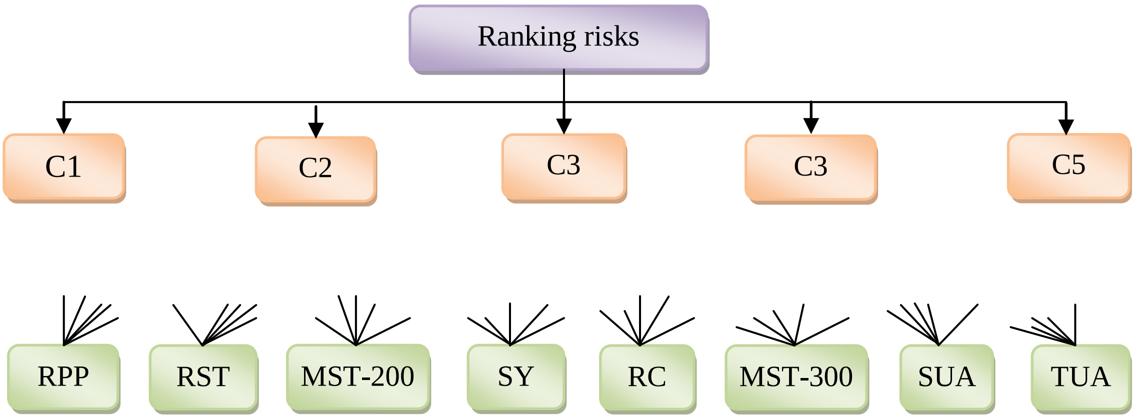
In our case, eight critical assets were identified as risky assets to be analyzed by the model. These assets include25 railcars of petroleum products (RPP), rural section of track to switch yard - 25 miles from shipper's site (RST), mainline section of track in rural area - 200 miles (MST-200), switch yard (SY), river crossing (RC), mainline section of track in urban area - 300 miles (MST-300), siding in Urban Area (SUA), and tunnel in Urban Area (TUA).

6.2. SELECTION OF CRITERIA

From above discussion, evaluation criteria to utilize in the proposed model comprise Threat (C1), Vulnerability (C2), Consequence (C3), Detectability (C4), andReaction against event (C5). Thus, the decision hierarchy is structuredas depicted in Fig. 5.

The decision problem consists of three levels: the objective of the problem is situated at the highest level, while in the second level, the criteria are presented, and the last level belongs to the alternatives.

Figure 5. The structure of decision



6.3. EVALUATING THE EXISTING RISKS USING FUZZY COPRAS PROCEDURE

Regarding the evaluation of the identified risks, 8 decision makers with minimum 5 years experience were invited to evaluate the weights of criteria and alternatives with respect to each criterion by using linguistic variables given in Table 1 and Table 2. For achieving the aim, two questionnaires are designed; one of them is to obtain the weights of criteria and other is to acquire the importance of alternatives with respect to criteria. To determine the fuzzy weight of each criterion, linguistic variables are converted into triangular fuzzy numbers as shown in the third column of Table 4. The crisp weights are calculated by Eq. (5) and are presented in the last column of Table 4.

Table 4. Fuzzy weights of criteria

Criteria	Linguistic term	Fuzzy weight	Crisp weight
C1	M	(0.25,0.5,0.75)	0.5
C2	H	(0.5,0.75,1.0)	0.75
C3	VH	(0.75,1.0,1.0)	0.916
C4	L	(0.0,0.25,0.5)	0.25
C5	M	(0.25,0.5,0.75)	0.5

Then, decision makers were asked to form fuzzy evaluation matrix by linguistic variables presented in Table 2. It is constructed by comparing eightpotential risks under five criteria separately. The fuzzy decision matrix is presented in Table 5. After constructing the fuzzy decision matrix, fuzzy values are converted into crisp values through Eq. (5).

Based on the fuzzy COPRAS procedure, the decision matrix formed in Table 5 needs to be normalized. Then, the weighted decision matrix for the existing alternatives is calculated by multiplying the weights of criteria with the normalized decision matrix as depicted in Table 6.

Table 5. Fuzzy decision matrix

	C1	C2	C3	C4	C5
RPP	G (5.0,7.5,10.0)	F (2.5,5.0,7.5)	G(5.0,7.5,10.0)	VG(7.5,10.0,10.0)	F (2.5,5.0,7.5)
RST	F (2.5,5.0,7.5)	G(5.0,7.5,10.0)	F (2.5,5.0,7.5)	P (0.0,2.5,5.0)	P (0.0,2.5,5.0)
MST-200	F (2.5,5.0,7.5)	F (2.5,5.0,7.5)	P (0.0,2.5,5.0)	VG(7.5,10.0,10.0)	G(5.0,7.5,10.0)
SY	G (5.0,7.5,10.0)	VP (0.0,0.0, 2.5)	P (0.0,2.5,5.0)	F (2.5,5.0,7.5)	VG(7.5,10.0,10.0)
RC	F (2.5,5.0,7.5)	G(5.0,7.5,10.0)	P (0.0,2.5,5.0)	F (2.5,5.0,7.5)	VG(7.5,10.0,10.0)
MST-300	VG(7.5,10.0,10.0)	F (2.5,5.0,7.5)	F (2.5,5.0,7.5)	P (0.0,2.5,5.0)	G(5.0,7.5,10.0)
SUA	VP (0.0,0.0, 2.5)	P (0.0,2.5,5.0)	G(5.0,7.5,10.0)	VG(7.5,10.0,10.0)	G(5.0,7.5,10.0)
TUA	G (5.0,7.5,10.0)	G(5.0,7.5,10.0)	F (2.5,5.0,7.5)	P (0.0,2.5,5.0)	F (2.5,5.0,7.5)

Table 6. Weighted normalized fuzzy decision matrix

	C1	C2	C3	C4	C5
RPP	0.078947	0.091837	0.183333	0.050926	0.046875
RST	0.052632	0.137755	0.122222	0.013889	0.234375
MST-200	0.052632	0.091837	0.061111	0.050926	0.351563
SY	0.078947	0.015306	0.061111	0.027778	1.289063
RC	0.052632	0.137755	0.061111	0.027778	1.575521
MST-300	0.096491	0.091837	0.122222	0.013889	1.289063
SUA	0.008772	0.045918	0.183333	0.050926	1.054688
TUA	0.078947	0.137755	0.122222	0.013889	0.703125

Then for the eight alternatives, the relative weight of each alternative is calculated. As mentioned above, C1, C2, and C3 are cost criteria whereas C4 and C5 are benefit criteria. Finally, the utility degree of each alternative is computed as presented in Table 7.

Table 7. Fuzzy COPRASoutput

	Q	***N***	Rank based on security
RPP	0.290986	52.52115	6
RST	0.256163	46.2358	8
MST-200	0.454007	81.94529	2
SY	0.554037	100	1
RC	0.385727	69.62121	4
MST-300	0.304489	54.95828	5
SUA	0.408648	73.75836	3
TUA	0.262609	47.39924	7

According to CC_i values, therisk rankingindescendingorder is SY, MST-200, SUA, RC, MST-300,RPP, TUA, and RST. Therefore, the riskiest asset is RST and the securest asset is SY.

7. COMPARE THE PROPOSED MODEL WITH THE CONVENTIONAL RAMCAP

In this subsection, in order to show the capability and suitability of the risk evaluation model proposed in this paper, a comparison of the model with conventional RAMCAP is presented. For this aim, we fulfill the risk analysis by using the conventional RAMCAP for previous case. Based on RAMCAP, risk is a function of only three components threat, vulnerability, and consequence magnitude.An evaluation scale withfive judgments {1, 2, 3,4, and 5} was applied, where 1 represents minimum judgment level and 5means the maximum as depicted in Table 8. The results of evaluator team for assets are presented in Table 9. For the aim of comparison, the output of fuzzy COPRAS is shown in the last column of Table 9.

Table 8. Definition of the RAMCAP components

	Components		
Rating	Threat (C1)	Vulnerability (C2)	Consequence (C3)
1	Very Poor (VP)	Very Poor (VP)	Very Poor (VP)
2	Poor (P)	Poor (P)	Poor (P)
3	Fair (F)	Fair (F)	Fair (F)
4	Good (G)	Good (G)	Good (G)
5	Very Good (VG)	Very Good (VG)	Very Good (VG)

Table 9. RAMCAP matrix

	C1	C2	C3	Risk value	Rank based on security	
					RAMCAP result	Fuzzy COPRAS result
RPP	4	3	4	48	7	6
RST	3	4	3	36	5	8
MST-200	3	3	2	18	3	2
SY	4	1	2	8	1	1
RC	3	4	2	24	4	4
MST-300	5	3	3	45	6	5
SUA	1	2	4	8	1	3
TUA	4	4	3	48	7	7

As can be easily seen, the final classification showssignificant differences between the results of RAMCAP and fuzzy COPRAS. According to the output of RAMCAP, the risk value belong to a limited set and never takes into account values such as 7, 11, 13, 14, 17, 19, 21. Furthermore, from a computational point of view, there is a reduction in the capability of the conventional RAMCAP methodology to define a precise and accurate rank, then grouping the critical assets into a fewcategories and allocating similar rank to different assets. This should be considered that organizations are forced with two main limitations finance and time. The allocation of resources for unnecessary activities leads to waste opportunities. Besides different sets of vulnerability, threat, and consequence may generate an identical value of risk; however, the risk implication may not necessarily be the same.For example, two assets RPP and TUA have values of 4, 3, 4 and 4, 4, 3 for C1, C2 and C3 respectively. Both these assets will have a risk value of 48; however, the risk implications of these two assets may be completely various. Other example is two assets SUA and SY, which have values of 1, 2, 4 and 4, 1, 2 for C1, C2 and C3 respectively, with similar risk value 8; nevertheless, the risk implications of these two assets may be entirely different. Finally, the relative importance among C1, C2 and C3 are not considered. This may not be accurate in real world problems. Therefore, the outputs of proposed model are more accurate. This may result a more precise, accurate and sure risk analysis for protection.

8. CONCLUSION

In response to the rapid growth of military industries and increasing the capability of terrorists to carry out destructive work, particularly for the critical infrastructures,the need for assets controls and risk measures has caught much time and attention of governments and responsible sectors. On the other hand, the measurement of risk is difficult for decision makers to be precisely and accurately measured because of the intangible nature of dangerous and threats. Most previous studies only used the RAMCAP parameters to evaluate risk. In this paper, a new framework for evaluating risk in critical infrastructures is introduced and developed. The model proposed extends the conventional RAMCAPthrough introducing new parameters the effects on risk level to obtain a more precise classificationof the existing risks.

According to the complexity of the proposed model due to exist different criteria, which are in conflicting with each other, a multi-criteriadecision makingmethod based on the fuzzy logic theory is described to also handle the uncertainty of decision making problem. This technique helps decision maker to specify relative importance of criteria and to determine judgments by means of linguistic variables.A case study is presented in order to demonstrate the potential applications of this methodology. Then a comparison between the proposed model and conventional RAMCAP is fulfilled. The results of the comparison show some shortages of the conventional RAMCAP as listed in the following:

(1) The values of risk evaluation belong to a limited set,
(2) Grouping the assets into a few categories,
(3) Allocating similar rank to different assets,
(4) Neglecting the relative importance of criteria.

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ANALIZA RIZIKA KRITIČNIH INFRASTRUKTURA POMOĆU NEIZRAZITE COPRAS

SAŽETAK

Kritične infrastrukture imaju važnu ulogu u zemljama radi same važnosti nacionalne sigurnosti, javne sigurnosti, društveno-ekonomske sigurnosti i načina života. S obzirom na važnost infrastruktura potrebno je analizirati potencijalne rizike kako se isti ne bi ostvarili. Svrha ovog rada je ponuditi razvijeni okvir u cilju prevladavanja ograničenja klasičnog pristupa izgradnji sigurnijih i izdržljivijih kritičnih infrastruktura s ciljem razvoja, primjene i kontrole. Predloženi okvir proširuje konvencionalni RAMCAP (Analiza i upravljanje rizikom za zaštitu ključnih faktora) uvođenjem novih parametara učinka na vrijednost rizika. S obzirom na složenost problema i inherentnu nesigurnost, istraživanje koristi neizrazitu (fuzzy) COPRAS (COPRAS-F) kao neizrazitu multi kriterijsku tehniku donošenja odluka kako bi se odredila težina svakog kriterija i važnost alternativa u odnosu na kriterije. Koristi se analiza slučajeva kako bi se prikazala sposobnost i efikasnost modela za rangiranje rizika kritičnih infrastruktura. Predloženi model prikazuje značajan napredak u usporedbi s konvencionalnim RAMCAP-om.

Ključne riječi: *Neizrazita (fuzzy) COPRAS, COPRAS-F, analiza rizika, kritične infrastrukture, RAMCAP*

JEL klasifikacija*: C53, C54, C61, C63.*