Original Scientific Article Journal of Decision Analytics and Intelligent Computing
Vol. 3 issue 1, (2023) 286-295 https://doi.org/10.31181/jdaic10025122023b

Applying D numbers in risk assessment process: General approach

Darko Božanić[1,*], Dragan Pamučar[2] and Nenad Komazec[1]

[1] Military Academy, University of Defence in Belgrade, Belgrade, Serbia

[2] Faculty of Organizational Sciences, University of Belgrade, Belgrade, Serbia

* Correspondence: dbozanic@yahoo.com

Received 30 July 2023

Accepted for publication 17 December 2023

Published 25 December 2023

Abstract

Risk assessment is performed in different conditions and for different purposes, and very often it is followed by various types of uncertainty. Sometimes uncertainty is smaller, but usually, during risk assessment, a large number of factors appear with incomplete information to a greater or lesser extent. Risk assessment under conditions of uncertainty is less complex with the application of various mathematical fields that deal well with uncertainty. This paper presents one approach in the application of D numbers in the process of risk assessment, respectively, risk quantification. As is known, D numbers treat uncertainty very well, so this feature of them is also used in risk quantification. In this paper, first of all, basic terms related to the concept of risk, as well as D numbers, are presented. The focus of the paper is on the examples in which risk assessment is presented using D numbers. In addition to the level of risk that is defined through the application of D numbers and standard tables for risk assessment, the paper also defines the level of optimistic or pessimistic risk. Thus, in addition to the risk value, the risk interval can also be obtained, which, in conditions of uncertainty, provides a much more realistic picture of the problem.

Keywords: risk assessment, D numbers, decision-making.

1. Introduction

So far, no unique approach has been developed dealing with risk analysis, identification, assessment and management, but practice usually relies on selecting the most appropriate technique from the existing ones which is to be applied in a particular situation, or perhaps is developed a new one so as to achieve the closest determination/definition of risk and risk-related phenomena (hazards and dangers) (Božanić et al., 2015). For the purposes of risk assessment, a large number of methods and models have been developed and are still being developed (Puška, 2011; Kozarević and Puška, 2015). Such approach stems from the fact that risk management is still insufficiently explored field of human interest (Pamučar et al., 2016a). The statement mentioned is based on the fact that uncertainty is the most common feature of risk (Pamučar et al., 2011; Radovanović et al., 2023). In order to better transfer the uncertainty issue into the field of certainty, various mathematical tools are used (fuzzy

The initial version of the research was published at the 6th Security and Crisis Management - Theory and Practice (SeCMan), Belgrade, Serbia (Božanić et al., 2020).

numbers - classic fuzzy numbers, interval fuzzy numbers, Z-numbers, etc .; rough numbers - standard and interval, etc.). These are used to quantify current situation or future forecast (Dabic-Miletic and Simic, 2023).

Risk assessment aided by the application of different areas of mathematics is presented in a large number of papers. Nguyen and Macchion (2023) developed a risk assessment model based on a fuzzy synthetic evaluation approach for green building projects and presented it on a case study in Vietnam. Moreno-Cabezali and Fernandez-Crehuet (2020) used fuzzy logic to develop a model for risk assessment in additive manufacturing R&D projects. Erdem (2022) developed a fuzzy logic system for occupational safety risk assessment in a specific industrial area in Ankara. Tian and Yan (2013) use fuzzy Analytic Hierarchy Process for risk assessment in general assembling of satellite. Gogoi and Chutia (2022) use fuzzy logic for risk analysis in crop selection. Petrović et al. (2020) develop fuzzy model for risk assessment of a mobile crushing machine in the mining industry. Tepe and Kaya (2020) developed a MCDM model based on the Pythagorean Fuzzy Analytic Hierarchy Process method with cosine similarity, and also the Neutrosophic Analytic Hierarchy Process (NFAHP) to support facing uncertainty in the risk assessment process in asphalt production. In addition to the above mentioned can be found a large number of papers in which fuzzy logic is incorporated in risk assessment in various ways, and in a large number of areas of human activity.

Certain authors solved the problem of uncertainty in risk assessment by applying rough and grey set theory. That way Sarwar et al. (2023), developed, respectively, improved risk assessment model based on rough integrated clouds and the ELECTRE-II method. The application of the created model is presented in intelligent manufacturing process. Cao and Song (2016) present rough group analytic network process using it in assessing the risks of co-creating value with customers under uncertainty. Song et al. (2020) develop a comprehensive risk assessment model for identification and evaluation of failures which may occur in the clinical use of medical devices. For this purpose the authors develop a model based on failure mode and effects analysis (FMEA) approach wich is improved by rough set theory and grey relational analysis. Karimi and Yahyazade (2022) developed a risk assessment model for banking software development projects based on rough-grey set theory.

Part of the authors tries to solve the problem of uncertainty in risk assessment by applying D numbers. Liu and Deng (2019) use D numbers for risk assessment in failure mode. Khan et al. (2023) develop the framework for the assessment of Halal-related risk from a supply chain perspective. Their model is developed using the integrated approach of intuitionistic fuzzy numbers and D numbers. Zhou et al. (2020) for risk assessment combine D numbers and analytic network process approach.

As can be seen from the previous analysis, the application of different areas of mathematics which deal well with uncertainty has a significant place in the risk assessment process. This happens because risk assessments are usually accompanied by some uncertainty (Pamučar et al., 2016b; Puška et al., 2020; Tešić and Marinković, 2023). In addition to the fact that often not all the data about the problem are available, it should be borne in mind that risk assessment is carried out by people, and the decisions they make usually cannot be quantified with clear numerical values, but with different intervals of values or linguistic expressions that are closer to realistic speech (Božanić and Pamučar, 2010; Pamučar et al., 2012; Keshavarz et al., 2023). In order to bring the risk assessment as close as possible to the people who perform it, the paper presents one approach in the application of D numbers during risk assessment. The examples of risk assessment are provided for the assessment of new risks in the protection of persons, property and business, but these can be applied in a similar way in other areas of risk assessment.

In the following section, the basic theoretical provisions related to the determination of the concept of risk and D numbers are provided. Then, the method of applying D numbers in the process of risk assessment is presented, and at the end of the paper it is given a conclusion.

2. Theoretical and methodological basis of the paper

2.1 Theoretical determination of the term of Risk

The first and basic step in the risk assessment process is to define it. A large number of definitions are available in the literature, which indicates the openness of this term in its further definition, respectively, its upgrade. Avakumović et al. (2010) understand risk as the uncertainty of loss realization. Karović and Komazec (2010) define risk as probability that the potential for injury will be realized in terms of use and/or exposure, as well as possible degree of injury. According to Chapman and Cooper (1983), risk includes exposure to the possibility of economic or financial loss or gain, physical damage, injury or delay as a result of uncertainty regarding the implementation of the action. Keković et al. (2011a) point out that risk is any possibility in a specific system which with a certain probability can cause an unexpected change in quality, respectively, a change or loss of the system.

Most authors agree that risk is basically a combination of two elements - a consequence that a particular danger can produce and the probability of that danger occurring. Although reduced to only two elements, risk assessment still presents an area with a large number of more or less successful attempts to treat it. Considering the availability of information on consequences, respectively, the probability of occurrence of a certain danger, four risk states can be distinguished:

1) state of certainty - where possible consequences and the probability of occurrence of danger are known, respectively, these can be assessed;

2) state of (complete) uncertainty - where consequences and probability of occurrence of danger are unknown,

3) state of uncertainty of probability of danger occurrence - where it is possible to assess the consequences, but not the probability of danger occurrence;

4) state of uncertainty of danger consequences - where it is possible to assess the probability of occurrence, but not the consequences of danger.

The previous division can be presented graphically, as in the Figure 1.

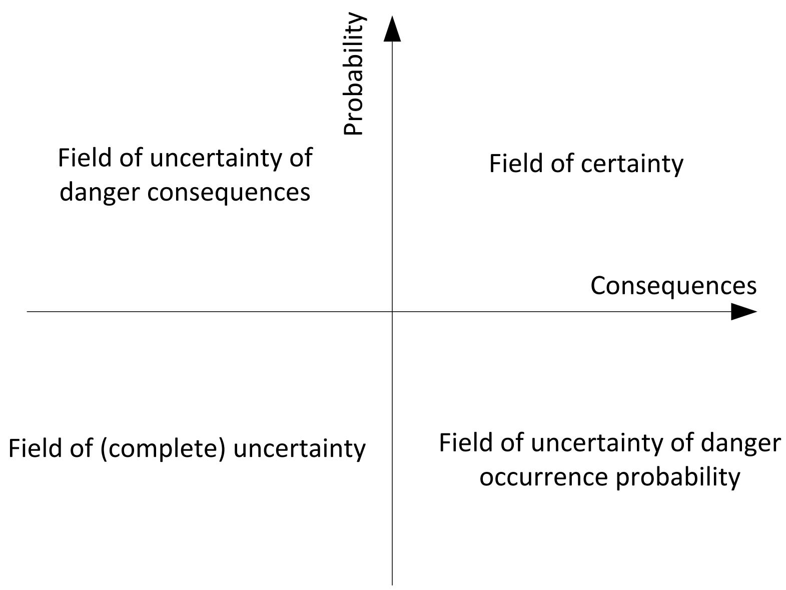

Figure 1. Graphical presentation of risk uncertainty state

As can be observed from the Figure 1, the space (field) of risk uncertainty is very wide, because the ignorance of one of the two elements significantly affects risk assessment, which further affects the quality of decisions made on the basis of risk assessment. In that sense, it is clearer why there is a large number of models that try to replicate the existing reality as realistically as possible.

Linguistic descriptions are a good basis for risk assessment - of consequences and probabilities, but without their quantification it is difficult to see the whole picture, especially in situations where risk assessment is performed by less professional and/or experienced persons, which is especially reflected in conditions of uncertainty. In that sense, different areas of mathematics are used in order to quantify linguistic descriptions, and to limit existing uncertainty to a certain extent. In this paper, uncertainties are considered using D numbers.

2.2 D numbers

D numbers present an extension of the *Dempster-Shafer evidence* theory (Deng et al., 2014a; Deng et al., 2014b). This theory, is also known as the theory of evidence, and is used to process uncertain information, which belongs to the field of artificial intelligence (Dempster, 1967; Shafer, 1976). This theory has a wide application as it allows direct expression of uncertainty by assigning probabilities to the elements that are organized into subsets within a set rather than to individual objects within the set. Due to its efficiency in processing uncertain information, it is widely used in many areas, such as pattern recognition, decision making, risk theory, *etc*.

However, there are certain limitations in classic *Dempster-Shafer evidence* theory. One of the well-known problems is the management of contradictions when the evidence are very conflicting, which is being studied in detail today. On the other hand, some other problems are given little attention. For example, *Dempster-Shafer evidence* theory implies the exclusivity of elements in discernment (Figure 2a). This limitation greatly limited practical application of the mentioned theory (Deng et al., 2014a; Deng et al., 2014b). Due to the mentioned problems, an extension of this theory was made, where D numbers were obtained, which removed certain disadvantages of the *Dempster-Shafer evidence* theory. D numbers can effectively present uncertain information, since:

1) the exclusive property of the elements in the frame of discernment is not required and
2) the completeness constraint is released if necessary (Figure 2b).

These two improvements have opened up the possibility of a wide application of D numbers in a number of real-world applications.

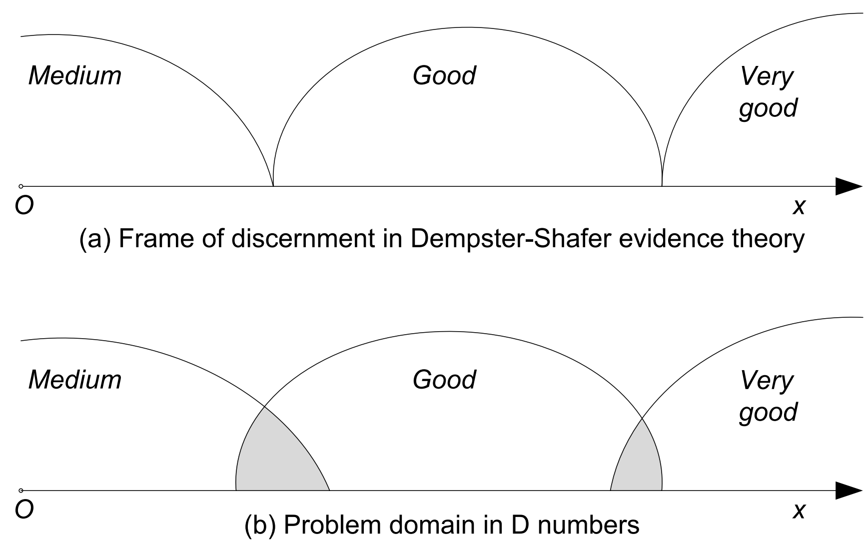

Figure 2. The frame of discernment in Dempster-Shafer evidence theory and domain in D numbers (Pribićević et al., 2020)

Basic mathematical formulations of D numbers are presented below.

Let Ψ be a finite nonempty set, and a D number is a mapping that $D:\Psi \to [0,1]$, with

$$\sum_{A\subseteq\Psi} D(A) \le 1 \;\; and \;\; D(\varnothing)=0 \tag{1}$$

where ∅ is an empty set and *A* is any subset of Ψ. In case the condition is met where $\sum_{A\subseteq\Psi} D(A) \le 1$ the information is considered complete, otherwise, the information is not complete.

In discrete set $\Psi=\{b_1,b_2,...,b_i,b_j,...,b_n\}$, where $b_i \in R$ i $b_i \ne b_j$ (when $i \ne j$), D numbers are presented as

$$D(b_1)=v_1, D(b_2)=v_2,...,D(b_i)=v_i, D(b_j)=v_j,...,D(b_n)=v_n \tag{2}$$

D numbers presented in the expression (2) can be presented in simplified way also as $D=\{(b_1,v_1),(b_2,v_2)$ ... (b_i,v_i), (b_j,v_j) ... $(b_n,v_n)\}$, where it is met the condition where $v_i>0$ i $\sum_{i=1}^{n} v_i \le 1$.

If two D numbers are provided $D_1=\{(b_1,v_1),...,(b_i,v_i),...,(b_n,v_n)\}$ and $D_2=\{(b_n,v_n),...,(b_i,v_i),...,(b_1,v_1)\}$ (b_i,v_i), (b_j,v_j) ... $(b_n,v_n)\}$, the combination of D numbers $D=D_1 \oplus D_2$ is defined as

$$\begin{cases} D(\varnothing)=0 \\ D(B)=\dfrac{1}{1-K_D}\displaystyle\sum_{B_1\cap B_2=B} D_1(B_1)D_2(B_2), \;\; B\ne\varnothing \end{cases}$$
$$with$$
$$K_D=\frac{1}{Q_1Q_2}\sum_{B_1\cap B_2=\varnothing} D_1(B_1)D_2(B_2) \tag{3}$$
$$Q_1=\sum_{B_1\subseteq\Theta} D_1(B_1)$$
$$Q_2=\sum_{B_2\subseteq\Theta} D_2(B_2)$$

If *D₁* and *D₂* are defined in frame of discernment and if $Q_1=1$ and $Q_2=1$, then the D number combination rule (3) is transformed into Dempster's rule (4).

$$m(A)=\frac{1}{1-k}\sum_{B\cap C=A} m_1(B)m_2(B)$$
$$where \tag{4}$$
$$k=\sum_{B\cap C=\varnothing} m_1(B)m_2(B)$$

where *A*, *B* and *C* are three elements of 2^{Ψ}, and *k* is a normalization constant, called the conflict coefficient between two basic probability assignment (BPA) function.

The rule for contamination of D numbers presents a mechanism allowing fusion of uncertain information presented in D numbers:

Permutation invariability: If there are two D numbers presented as $D_1=\{(b_1,v_1),...,(b_i,v_i),...,(b_n,v_n)\}$ and $D_2=\{(b_n,v_n),...,(b_i,v_i),...,(b_1,v_1)\}$ (b_i,v_i), (b_j,v_j) ... $(b_n,v_n)\}$ then $D_1 \Leftrightarrow D_2$, where „$\Leftrightarrow$" means „equal to".

Integration: For discrete D number $D=\{(b_1,v_1),(b_2,v_2)$ ... (b_i,v_i), (b_j,v_j) ... $(b_n,v_n)\}$ the integration operator can be defined as follows:

$$I(D)=\sum_{i=1}^{n} d_i v_i \tag{5}$$

where $d_i \in R^+, v_i > 0$ and *.

2.3 Application of D numbers in the risk assessment - model

According to the theoretical descriptions, in the Figure 3 are shown the basic steps of the risk assessment model using D numbers.

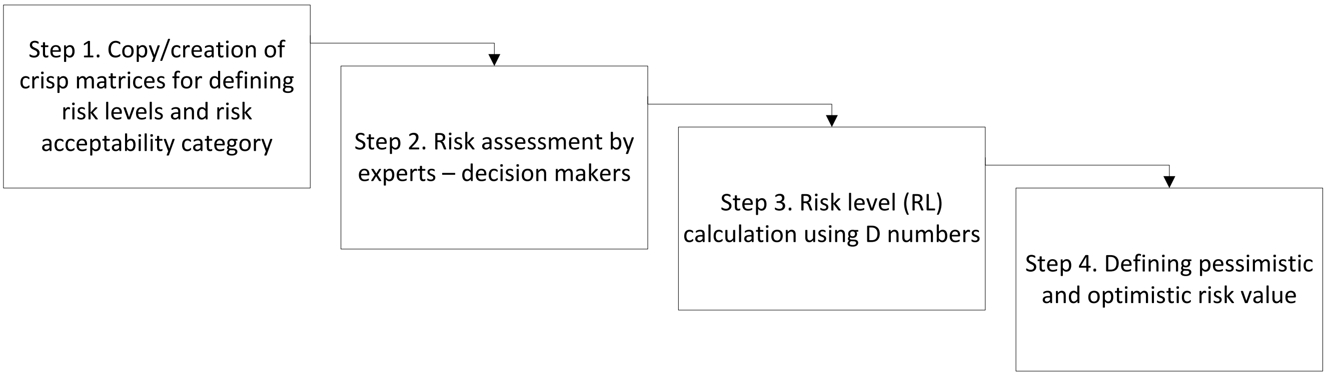

Figure 3. Flowchart of the risk assessment model by applying D numbers

In the further text, individual explanations of the steps shown in the Figure 3 are provided.

Step 1. Copy/creating of crisp matrices for defining risk levels and risk acceptability categories. As part of this step, special matrices can be defined with criteria based on which the risk level and risk acceptability categories are calculated, or such matrices can be taken from already existing risk assessment models.

Step 2. Risk assessment by experts - decision makers. Within this step, experts or decision makers are defined, who evaluate the level of risk using D numbers.

Step 3. Risk level (RL) calculation using D numbers. In this step, the experts' opinions are aggregated into one, and in the end, one crisp value is obtained.

Step. 4. Defining pessimistic and optimistic risk value. Based on the first three steps, a risk level is obtained as a certain real number within the interval [1,25]. Despite the presented mathematical apparatus, certain dilemmas related to the risk level are possible. Accordingly, in addition to the value obtained, optimistic and pessimistic risk can be defined, which, in addition to the already calculated, most realistic, level of risk, would present a total of three types of risk. Optimistic/pessimistic risk can be assessed or calculated, and these essentially represent the bottom or upper limit of the interval in which the assessed risk is located. Expressions are proposed for the calculation of optimistic and pessimistic risk:

$$RL_o = RL^*(1-\gamma) \quad (7)$$

$$RLp = RL^*(2-\gamma) \quad (8)$$

Where RL_o presents optimistic risk, RL_p presents pessimistic risk, and γ presents the coefficient of scattering. This coefficient is defined by the experts, respectively, the persons in charge of making the decision, where $1 \le RL_o, RL_p \le 25,\ \gamma \ge 1.$ The value of the scattering coefficient depends on the number of parameters in uncertain environment. Greater uncertainty - when both the consequences and the probability are uncertain requires a higher scattering coefficient.

3. Application of D numbers in Risk Assessment

The following text shows the application of the previously described model.

Step 1. The application of D numbers is presented in the matrix for determining risk level in the protection of persons, property and business, as in the Table 1.

Table 1. Matrix for determining risk level (Keković et al., 2011b)

		Consequences				
		Minimal (1)	Low (2)	Medium (3)	Serious (4)	Catastrophic (5)
Probability	Impossible (1)	1	2	3	4	5
	Improbable (2)	2	4	6	8	10
	Probable (3)	3	6	9	12	15
	Almost certain (4)	4	8	12	16	20
	Certain (5)	5	10	15	20	25

The risk level is calculated according to the expression (6) (Keković et al., 2011b):

$$RL = P * V \tag{6}$$

where RL is the value of the risk level, P is the value of the consequences and V is the probability of danger occurrence.

After the calculation of the risk level, the category and acceptability of the risk is defined, as in the Table 2.

Table 2. Matrix for defining risk category and acceptability (Keković et al., 2011b)

Risk category	Risk size	Risk level	Risk acceptability
First	Very low, negligible risk	1 and 2	Acceptable
Second	Low risk	3, 4 and 5	
Third	Moderately high risk	6, 8, and 9	Unacceptable
Fourth	High risk	10, 12, 15 and 16	
Fifth	Extremely high risk	20 and 25	

Essential application of D numbers is reflected in situations when there is uncertainty in the assessment of consequences or probabilities, or in both cases. Accordingly, the following is an example of risk assessment when the consequences are uncertain (there are no parameters on the basis of which these can be estimated), while the probability can be predicted.

The calculation of the consequences of certain danger by applying D numbers in conditions of uncertainty is based on the opinion of the persons performing the assessment (decision makers or experts). Each person declares what the consequences might be and how likely they are to occur, where it is possible that the decision makers decide on a number of different consequences, where they will assign to each one the probability of occurring.

In the following section are presented two examples. In the examples, the decision on the consequences of certain danger was made by four decision makers (experts).

Example 1:

Step 2. The decision makers declared on possible consequences in the following way:

D1={(2,0.3),(3;4,0.25),(4,0.4)},

D2={(2,0.3),(3;4,0.4),(4,0.3)},

D3={(2,0.4),(3;4,0.3),(5,0.3)},

D4={(1,0.3),(3,0.3),(5,0.4)}.

Step 3. By combining D numbers (D1 and D2; D3 and D4), the following D inter numbers are obtained:

D12={(2,0.366),(3;4,0.128),(4,0.456)},

D34={(3,0.429),(5,0.571)}.

Finally, by combining D12 and D34 it is obtained final D number for the assessment of consequences:

D1-4={(3,0.95)}.

Final value of the assessment of consequences amounts to:

P=3*0.95=2.85.

Depending on the assessment of the probability of danger occurrence, the final value of the risk assessment is obtained. If it is assumed that the decision makers have decided that a danger is likely to occur (value 3), then the final value of the risk is obtained as *RL* = 2.8 * 3 = 8.4, which is a moderately high, respectively, unacceptable risk.

Example 2:

Step 2. The decision makers declared on possible consequences in the following way:

D1={(3,0.3),(3;4,0.25),(4,0.4)}

D2={(2;3,0.3),(3,0.3),(3;4,0.3)}

D3={(1,0.4),(2,0.2),(3;4,0.35)}

D4={(2,0.3),(3;4,0.3),(5,0.4)}

Step 3. By combining D numbers (D1 and D2; D3 and D4) the following inter numbers are obtained:

D12={(3,0.584),(3;4,0.104),(4,0.271)}

D34={(2,0.345),(3;4,0.604)}

Finally, by combining D12 and D34, it is obtained final D number for the assessment of consequences:

D1-4={(3,0.555),(3;4,0.099),(4,0.258}.

Final value of the assessment of consequences amounts to:

P=3*0.555+3.5*0.099+4+0.258=3,04.

Depending on the assessment of the probability of occurrence of the danger, the final value of the risk assessment is obtained. If it is assumed that the decision makers have decided that the danger is likely to occur (value 3), then the final value of the risk is obtained as *RL* = 3.04*3 = 9.12, which is a moderately high, respectively, unacceptable risk, and tends to become high risk.

Step 4. In this particular case, if the scattering coefficient were defined as $\gamma = 0.2$, then the level of assessed risk would range within the interval:

1) for example, 1, in the interval [6.72, 15.12] and

2) for example, 2, in the interval [7.30, 16.42],

where the values 6.72 and 7.30 present the optimistic level of risk, respectively, the bottom limit of the risk level interval, and the values 15.12 and 16.42 present the pessimistic risk, respectively, the upper limit of the risk level interval.

Considering that in specific cases the risk is defined in conditions of partial uncertainty (assessment of the level of consequences), it is clear that for the final level of risk it is better to define the interval of the risk level. In both cases, it is shown that regardless of where the level of risk is actually located, at the beginning or the end of the presented interval, it is an unacceptable risk.

4. Conclusion

Assessing risk levels is a very complex process. The problem starts from the very definition of the term of risk, and continues through the selection of methods and techniques for risk assessment, as well as their subsequent application. In accordance with the stated issues, the definition of risk is first defined in the paper. Finally, it is accepted that risk assessment is a combination of the consequences and the probability of a particular danger. The uncertainty accompanying risk assessment has conditioned the existence of four states: the state of certainty, the state of uncertainty, the state of uncertainty of the probability of danger occurrence and the state of uncertainty of danger consequences. It is obvious that the field of uncertainty is the essence of risk assessment. In this context, the paper presents the basics of D numbers as an area that quantifies uncertainties relatively well.

The paper presents a possible model that could be used to quantify uncertainties when assessing risk levels. The model is based on a combination of the existing model for assessment in the protection of persons, property and business and D numbers, in order to better quantify the uncertainty. From the presented examples, it can be observed that the application of D numbers in the assessment of risk level provides data usable in later decision-making process. Since it is very difficult to eliminate uncertainty, an additional generalization is made, and in addition to the risk assessed by applying D numbers as the most probable, the most optimistic and pessimistic possible risk is defined also. Based on the obtained values, quality decisions can be made through subsequent analysis.

References

Avakumović, Č., Milinković, S., & Vujačić, N. (2010). Risk Management. The Proceedings of the International Scientific Conference Management (pp. 387-390). Kruševac, Serbia.

Božanić, D., & Pamučar, D. (2010). Evaluating locations for river crossing using fuzzy logic. Military Technical Courier, 58(1), 129-145.

Božanić, D., Pamučar D., & Komazec, N. (2020). Risk assessment by applying D numbers. The Proceedings of the 6th International scientific conference safety and crisis management -Theory and practise (SecMan) (pp. 208-215). Belgrade, Serbia.

Božanić, D., Slavković, R., & Karović, S. (2015). Model of Fuzzy Logic Application to the Assessment of Risk in Overcoming the Obstacles during an Army Defensive Operation. Vojno delo, 67(4), 240-260.

Cao, J., & Song, W. (2016). Risk assessment of co-creating value with customers: A rough group analytic network process approach. Expert Systems with Applications, 55, 145-156.

Chapman, C. B, & Cooper, D. F. (1983). Risk analysis: testing some prejudices. European Journal of Operational Research, 14, 38-247.

Dabic-Miletic, S., & Simic, V. (2023). Smart and Sustainable Waste Tire Management: Decision-Making Challenges and Future Directions. Decision Making Advances, 1(1), 10–16.

Dempster, A. P. (1967). Upper and lower probabilities induced by a multivalued mapping. Annals of Mathematical Statistics, 38, 325–339.

Deng, X., Hu, Y., & Deng, Y. (2014a). Bridge condition assessment using D numbers. The Scientific World Journal, 2014, 358057.

Deng, X., Hu, Y., Deng, Y., & Mahadevan, S. (2014b). Environmental impact assessment based on D numbers. Expert Systems with Applications, 41, 635–643.

Erdem, F. (2022). Risk assessment with the fuzzy logic method for Ankara OIZ environmental waste water treatment plant. Turkish Journal of Engineering, 6(4), 268-27.

Gogoi, M. K., & Chutia, R. (2022). Fuzzy risk analysis based on a similarity measure of fuzzy numbers and its application in crop selection. Engineering Applications of Artificial Intelligence, 107, 104517.

Karimi, T., & Yahyazade, Y. (2022). Developing a risk assessment model for banking software development projects based on rough-grey set theory. Grey Systems: Theory and Application, 12(3), 574-594.

Karović, S., & Komazec, N. (2010). Risk management as a prerequisite of the integrated management system in organizations. Military Technical Courier, 58(3), 146-161.

Keković, Z., Komazec, N., & Jeftić, Z. (2011a). Risks of non-military security threats relevant for the third mission of the Army of Serbia. Vojno delo, 63(3), 242-257.

Keković, Z., Savić, S., Komazec, N., Milošević, M., & Jovanović, D. (2011b). Risk assessment in the protection of persons, property and business (Only in Serbian: Procena rizika u zaštiti lica, imovine i poslovanja)- Belgrade: Center for Risk Analysis and Crisis Management.

Keshavarz, E., Mahmoodirad, A., & Niroomand, S. (2023). A Transportation Problem Considering Fixed Charge and Fuzzy Shipping Costs. Decision Making Advances, 1(1), 115–122.

Khan, S., Haleem, A., & Khan, M. I. (2023). Risk assessment model for halal supply chain using an integrated approach of IFN and D number. Arab Gulf Journal of Scientific Research, 41(3), 338-358.

Kozarević, S., & Puška, A. (2015). Correlation of implementation of supply chain, partnerships and competitiveness. Ekonomska misao i praksa, 2, 579-596.

Liu, B., & Deng, Y. (2019). Risk Evaluation in Failure Mode and Effects Analysis Based on D Numbers Theory. International Journal of Computers Communications & Control, 14(5), 672-691.

Moreno-Cabezali, B. M., & Fernandez-Crehuet, J. M. (2020). Application of a fuzzy-logic based model for risk assessment in additive manufacturing R&D projects. Computers & Industrial Engineering, 145, 106529.

Nguyen, H. D., & Macchion, L. (2023). A comprehensive risk assessment model based on a fuzzy synthetic evaluation approach for green building projects: the case of Vietnam. Engineering, Construction and Architectural Management, 30(7), 2837-2861.

Pamučar, D, Božanić, D., & Đorović, B. (2011). Fuzzy logic in decision making process in the Armed Forces of Serbia. Saarbrücken: Lambert Academic Publishing.

Pamučar, D., Božanić, D., & Komazec, N. (2016a). Risk Assessment of Natural Disasterts using Fuzzy Logic System Type-2. Management - Journal for Theory and Practice Management, 21(80), 23-32

Pamučar, D., Božanić, D., & Milić, A. (2016b). Selection of a course of action by Obstacle Employment Group based on a fuzzy logic system. Yugoslav Journal of Operations Research, 26(1), 75-90

Pamučar, D., Đorović, B., Božanić, D., & Ćirović, G. (2012). Modification of the dynamic scale of marks in analytic hierarchy process (AHP) and analytic network approach (ANP) through application of fuzzy approach. Scientific Research and Essays, 7(1), 24-37.

Petrović, D.V., Tanasijević, M., Stojadinović, S., Ivaz, J., & Stojković, P. (2020). Fuzzy Model for Risk Assessment of Machinery Failures. Symmetry, 12(4), 525.

Pribićević, I., Doljanica, S., Momčilović, O., Kumar, Das, D., Pamučar, D., & Stević, Ž. (2020). Novel Extension of DEMATEL Method by Trapezoidal Fuzzy Numbers and D Numbers for Management of Decision-Making Processes. Mathematics, 8(5), 812.

Puška, A. (2011). Sensitivity analysis in the function of investment decision-making (Analiza osjetljivosti u funkciji investicijskog odlučivanja). Praktični menadžment, 2(3), 80-86.

Puška, A., Šadić, S., Maksimović, A., & Stojanović, I. (2020). Decision support model in the determination of rural touristic destination attractiveness in the Brčko District of Bosnia and Herzegovina. Tourism and Hospitality Research, 20(4), 387-405.

Radovanović, M., Petrovski, A., Behlić, A., Perišić, M., Samopjan, M., & Lakanović, B. (2023). Application model of MCDM for selection of automatic rifle. Journal of Decision Analytics and Intelligent Computing, *3*(1), 185–196.

Sarwar, M., Gulzar, W. & Ashraf, S. (2023). Improved risk assessment model based on rough integrated clouds and ELECTRE-II method: an application to intelligent manufacturing process. Granular Computing, 8, 1533–1560 (2023).

Shafer, G. (1976). A mathematical theory of evidence. Princeton: Princeton University Press.

Song, W., Li, J., Li, H., & Ming, X. (2020). Human factors risk assessment: An integrated method for improving safety in clinical use of medical devices. Applied Soft Computing, 86, 105918.

Tepe, S., & Kaya, I. (2020). A fuzzy-based risk assessment model for evaluations of hazards with a real-case study. Human and Ecological Risk Assessment: An International Journal, 26(2), 512-537.

Tešić, D., & Marinković, D. (2023). Application of fermatean fuzzy weight operators and MCDM model DIBR-DIBR II-NWBM-BM for efficiency-based selection of a complex combat system. Journal of Decision Analytics and Intelligent Computing, 3(1), 243–256.

Tian, J., & Yan, Z. F. (2013). Fuzzy Analytic Hierarchy Process for Risk Assessment to General-assembling of Satellite. Journal of Applied Research and Technology, 11(4), 568-577.

Zhou, J., Su, X., & Qian, H. (2020). Risk Assessment on Offshore Photovoltaic Power Generation Projects in China Using D Numbers and ANP. IEEE Access, 8, 144704-144717.