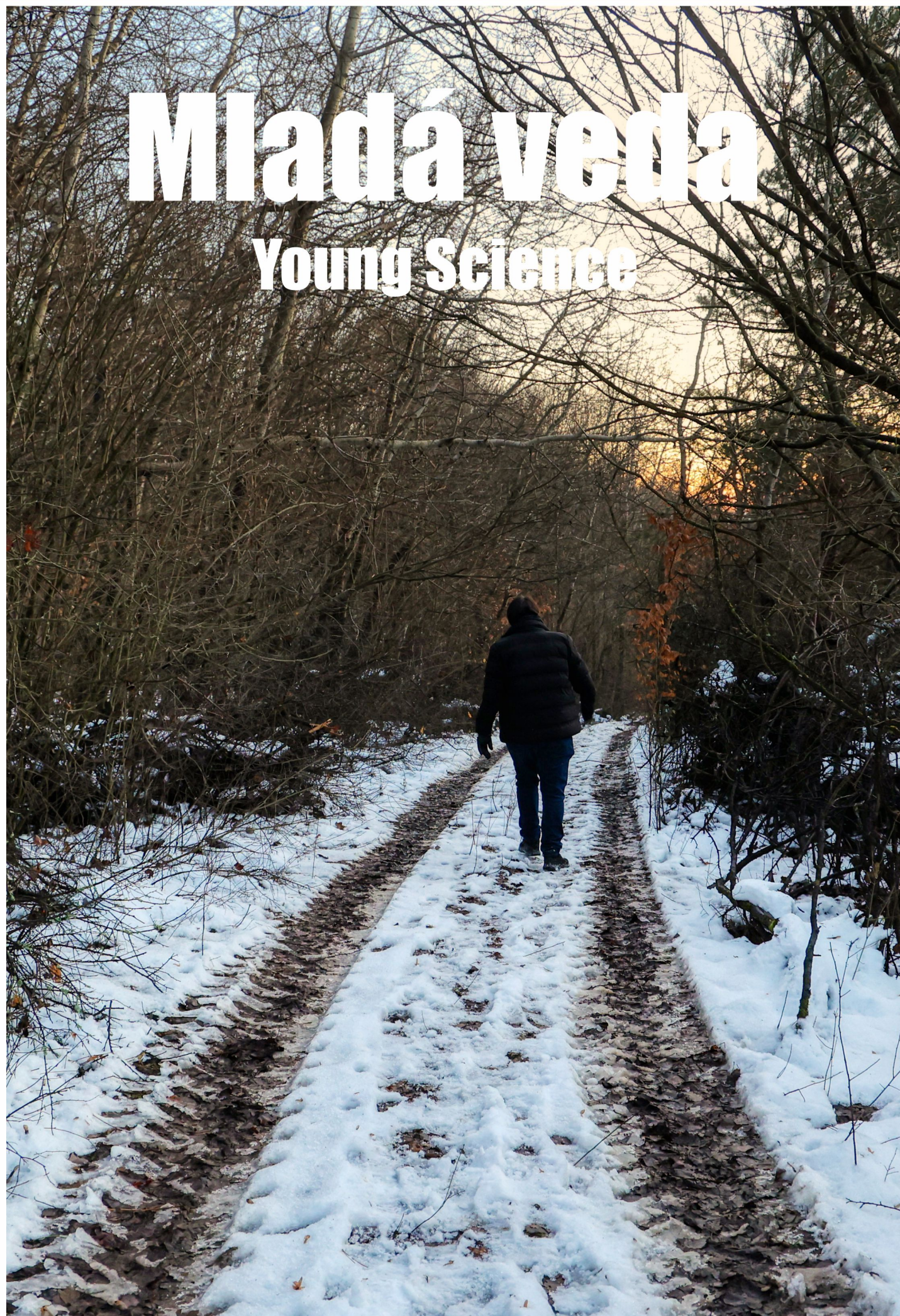


# Mladá veda

## Young Science



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# APLIKÁCIA VIACKRITERIÁLNEHO ROZHODOVANIA PRI VÝBERE SOFTVÉROVÉHO NÁSTROJA PRE MODELOVANIE POŽIARU

APPLICATION OF MULTI-CRITERIA DECISION-MAKING IN THE SELECTION OF A SOFTWARE TOOL FOR FIRE MODELING

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Dorota Hodúlová works as an internal PhD student at the Department of Fire Engineering, Faculty of Safety Engineering, University of Žilina. In her dissertation, she is working on the implementation of fire engineering into fire safety solutions for buildings. Stanislava Gašpercová is an associate professor at the Department of Fire Engineering, Faculty of Safety Engineering, University of Žilina. She focuses her research activities on the issues of materials and structures in fire safety solutions.

## **Abstract**

This paper discusses the application of selected system and operational analysis methods in fire modelling. In the first part, the paper deals with the analysis of multi-criteria decision making using the AHP and TOPSIS methods, in which each method is described. The multi-criteria decision making is based on the selection of one most suitable program for modelling confined space fires from three alternatives. These options are CFAST, PyroSim and FDS. The main objective of the paper is to select one most suitable program for modelling confined space fires from three alternatives using two multi-criteria decision making methods.

Key words: multi-criteria scheduling, AHP, TOPSIS, fire management programs, education

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## **Abstrakt**

Tento článok sa zaoberá aplikáciou vybraných metód systémovej a operačnej analýzy v modelovaní požiarov. V prvej časti sa článok zaoberá analýzou viackriteriálneho rozhodovania s použitím metód AHP a TOPSIS, v ktorých sú jednotlivé metódy popísané. Viackriteriálne rozhodovanie prebieha na základe výberu jedného najvhodnejšieho programu na modelovanie požiarov v uzatvorených priestoroch z troch variant. Týmito variantmi sú program CFAST, PyroSim a FDS. Hlavným cieľom článku je vybrať jeden najvhodnejší program na modelovanie požiarov v uzavretých priestoroch z troch alternatív pomocou dvoch metód viackriteriálneho rozhodovania.

**Kľúčové slová:** viackriteriálne rozhodovanie, AHP, TOPSIS, programy na modelovanie požiarov, vzdelávanie

## **Introduction**

Multi-criteria decision making is the consideration of multiple options for possible solutions to problems based on set criteria. When solving problems, it is always necessary to determine the weight of each criterion and then quantitatively evaluate how each solution option meets the selected criteria. We know several methods of multi-criteria decision making such as DMM - Decision Matrix Method, FDMM - Pairwise Comparison Method, AHP - Multilevel Analytical Method, TOPSIS - (Preference Ordering by Specificity Method with Ideal Solution, and many others (Máca 2023). Specifically, this paper deals with the application of two selected multi-criteria decision making methods in modeling tool selection. These methods are the AHP method and the TOPSIS method.

The AHP method is a flexible model for making decisions and clarifying problems that have multiple possible solutions. This method is considered to be one of the best quality methods as it eliminates the shortcomings of other methods, such as DMM and FDMM, while combining their advantages. AHP is carried out by two methods, namely expert and mathematical, and is also based on pairwise comparison of the degree of significance of each criterion and the degree of fulfillment of these criteria by each solution variant (Halaj 2018, Leitner 2023, Rohacova 2009).

The TOPSIS method is an objective multi-criteria method based on the selection of the variant that is closest to the hypothetical or realistic ideal variant, which achieves the best possible value in all criteria, and furthest from the hypothetical or realistic baseline variant, which scores the worst in all criteria. When applying this method, it is necessary that all criteria are maximised (Dermeková 2017, Vyhláška MV SR č. 94/2004 Z. z.).

The main of the paper is the objectification of the selection of the most suitable variant - a software tool for modelling fires in confined spaces - from a total of three variants, implemented through two of the most widespread methods of multi-criteria decision making - the AHP and TOPSIS methods.

### Material, methodology and results

The AHP and TOPSIS methods were applied to select one of the three most suitable programs for modelling confined space fires. The decision was made between CFAST, PyroSim and FDS, descriptions of each program are given in (Licensing 2023, McGrattan 2021, Peacock 2015, Peacock 2019, PyroSim 2014). The actual decision-making was based on 7 criteria:

- Acquisition price (K1)
- Difficulty of use (K2).
- Accuracy of program calculations (K3).
- Quantity of input data (K4)
- Quantity of output data (K5).
- Quality of output data (K6).
- Interoperability with other programs (K7).

Based on the information collected on the programmes from the above sources, tables with the scores for each criterion were created (Table 1, Table 2). The scores were determined on a scale ranging from 1 to 9, as the AHP method was applied using software that allows the use of a range of criteria weighting from 1 to 9. The TOPSIS method was implemented using a tool created by the authors of the paper in an Excel environment. Subsequently, a criteria-based rating of each variant was generated (Table 3). Based on the information in Table 1 - Table 3, the qualitative ratings of the variants were converted to quantitative ratings and the values were used in the application of the methods.

Acquisition price		Difficulty of use		Accuracy of program calculations	
0	1	Very low	1	Very low	1
1 - 1000	3	Low	3	Low	3
1001 - 2000	5	Medium	5	Medium	5
2001 - 3000	7	High	7	High	7
More than 3000	9	Very high	9	Very high	9

Table 1 – Criteria score 1

Source: authors

Quantity of input data and quantity of output data		Quality of output data		Interoperability with other programs	
Very small	1	Very bad	1	Yes	9
Small	3	Bad	3	No	1
Medium	5	Medium	5		
Large	7	Good	7		
Very large	9	Very good	9		

Table 2 – Criteria score 2

Source: authors

	K1	K2	K3	K4	K5	K6	K7
<b>CFAST</b>	0 €	Medium	Medium	Medium	Large	Medium	Yes
<b>PyroSim</b>	1 100 €	High	High	Very large	Very large	Very good	Yes
<b>FDS</b>	0 €	Very high	High	Very large	Very large	Very good	Yes

Table 3 – Criteria evaluation table

Source: authors

### AHP method

Program selection using the AHP method was performed with Analytic Hierarchy Process software (Analytic 2023). Within the software, the first step is to define the options between which to decide and the criteria on which to make the decision. Once the variants and criteria have been defined in the software, we apply the expert method through pairwise comparison of the significance level. Pairwise comparison was performed by determining the significance of the criteria in values from 1 to 9, as shown in Figure 1. The comparison was continued until all criteria were compared with each other. A comparison of the extent to which the evaluated variants met the criteria is shown in Figure 2.



Figure 1 – Pairwise comparison criteria

Source: authors

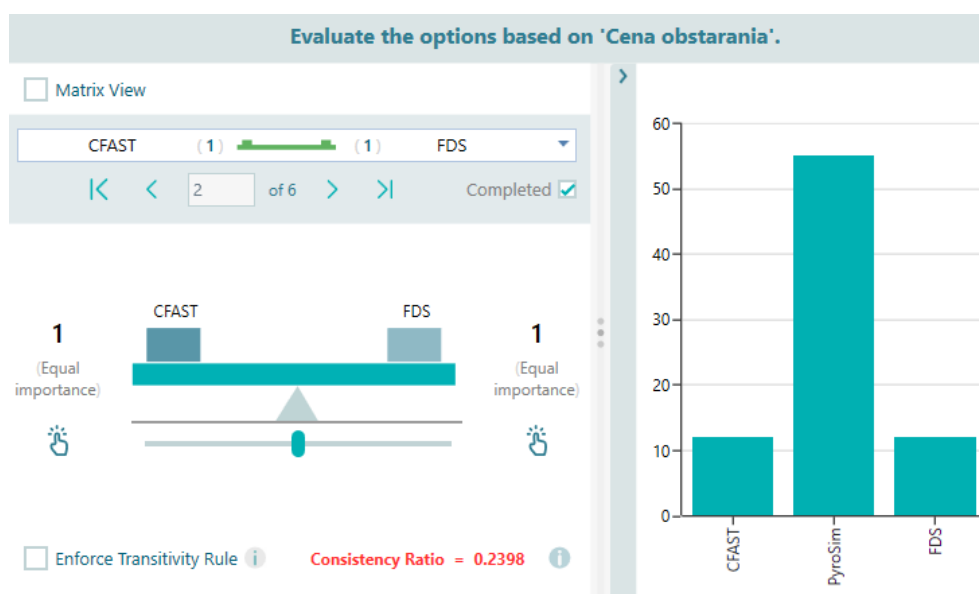


Figure 2 – Comparison of the rates of the evaluated options with respect to the criterion *Acquisition price*

Source: authors

Based on the comparison of the criteria and the variants with respect to the criteria, the program created a table (Table 4) of pairwise comparisons with the calculated weights for each criterion.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>	<b>Weight</b>
<b>K1</b>	1	1	0,25	0,5	0,25	0,25	0,333	<b>0,052</b>
<b>K2</b>	1	1	0,333	1	0,5	0,333	0,333	<b>0,069</b>
<b>K3</b>	4	3	1	3	1	1	2	<b>0,221</b>
<b>K4</b>	2	1	0,333	1	1	0,15	0,25	<b>0,086</b>
<b>K5</b>	4	2	1	1	1	1	2	<b>0,191</b>
<b>K6</b>	4	3	1	4	1	1	1	<b>0,21</b>
<b>K7</b>	3	3	0,5	4	0,15	1	1	<b>0,173</b>

Table 4 – Pairwise comparison of criteria with weights

Source: authors

Next, the program calculated the eigenvalue  $\lambda_{max}$  and the normalization vector  $a_k$  for each variant rating with respect to each criterion, but these calculations were not available. Based on the calculations, the software produced plots of the criterion weights for each variant separately, a comparison of the criterion properties for all variants (Figure 3, Table 5), and also a plot of the recommendations for each variant (Figure 4).

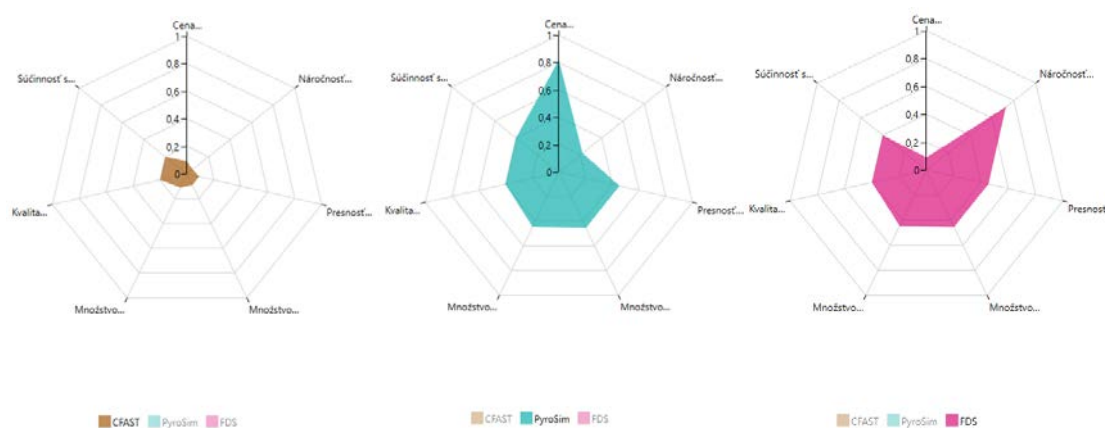


Figure 3 – Comparison of the characteristics of the criteria for each variant

Source: authors

Kritérium	CFAST	PyroSim	FDS
<b>K1</b>	0,091	0,818	0,091
<b>K2</b>	0,052	0,221	0,727
<b>K3</b>	0,091	0,455	0,455
<b>K4</b>	0,091	0,455	0,455
<b>K5</b>	0,111	0,444	0,444
<b>K6</b>	0,2	0,4	0,4
<b>K7</b>	0,2	0,4	0,4

Table 5 – Comparison of the characteristics of the criteria for each variant  
Source: authors

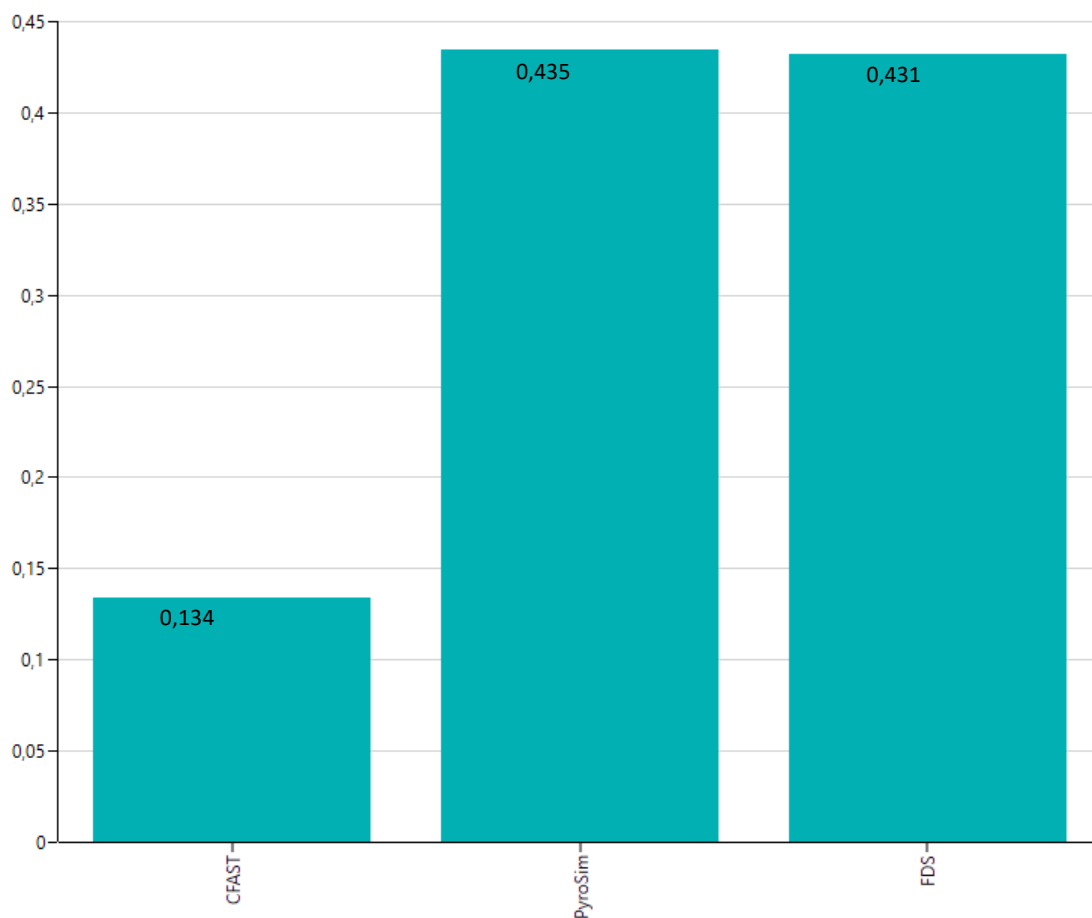


Figure 4 – Chart of recommendations of individual options  
Source: authors

As can be seen in the graph of the recommendations for each simulation program choice, the recommended program for simulating fires in confined spaces is PyroSim, which received up to 43.5%, also due to its price. It was closely followed by FDS with 43.1%. Given that the programs are almost identical, the difference being in price and difficulty, such a result is to be expected. The least recommended program is CFAST with only 13.4%, even though it is freely available, it has a few drawbacks that cannot be overlooked.



### TOPSIS method

The application of the TOPSIS method to a specific example was carried out using Microsoft Excel. The first step involved the creation of a table (Table 6) of the linkage between the options and the decision criteria, which determined whether each criterion was a minimizing or maximizing criterion, and determined the weight of each criterion. This weighting was not determined in a new way, but used data from the AHP solution.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K6</b>	<b>K5</b>	<b>K7</b>
	<b>MIN</b>	<b>MIN</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,21</b>	<b>0,191</b>	<b>0,172</b>
<b>CFAST</b>	0 €	Medium	Medium	Medium	Large	Medium	Yees
<b>PyroSim</b>	1 100 €	High	High	Very large	Very large	Very good	Yes
<b>FDS</b>	0 €	Very high	High	Very large	Very large	Very good	Yes

Table 6 – Variants and decision criteria of TOPSIS

Source: authors

Since the TOPSIS method requires that the criteria ratings for each variant be quantitative rather than qualitative, all qualitative criterion ratings were converted to quantitative ratings using Table 1 and Table 2. Table 7 shows the quantitative values of each criterion after optimisation.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K6</b>	<b>K5</b>	<b>K7</b>
	<b>MIN</b>	<b>MIN</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,21</b>	<b>0,191</b>	<b>0,172</b>
<b>CFAST</b>	1	5	5	5	7	5	9
<b>PyroSim</b>	5	7	7	9	9	9	9
<b>FDS</b>	1	9	7	9	9	9	9

Table 7 – Quantitative values of decision criteria

Source: authors

In the next step, the weighted sum method was used. Within the TOPSIS method we decide between 3 variants. To this number 1 was added, so we got the number 4, from which the individual values in Table 7 were subtracted. Finally, the sum of the values for normalization was done. The resulting table of these steps is shown in Table 8.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>
	<b>MIN</b>	<b>MIN</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>
<b>CFAST</b>	3	-1	-1	-1	-3	-1	-5
<b>PyroSim</b>	-1	-3	-3	-5	-5	-5	-5
<b>FDS</b>	3	-5	-3	-5	-5	-5	-5
<b>Sum</b>	5	-9	-7	-11	-13	-11	-15

Table 8 – Application of the weighted sum method and normalisation

Source: authors

In the next step, the individual Table 8 values were divided by the sum in the last row of the table. The resulting values can be found in Table 9.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>
	<b>MIN</b>	<b>MIN</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>
<b>CFAST</b>	0,60	0,11	0,14	0,09	0,23	0,09	0,33
<b>PyroSim</b>	-0,20	0,33	0,43	0,45	0,38	0,45	0,33
<b>FDS</b>	0,60	0,56	0,43	0,45	0,38	0,45	0,33

Table 9 – Weighted sum method

Source: authors

This was followed by maximizing the criteria that were minimized (Table 10) by putting the sign - (minus) in front of the values of the criteria that were minimized.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>
	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>
<b>CFAST</b>	-0,60	-0,11	0,14	0,09	0,23	0,09	0,33
<b>PyroSim</b>	0,20	-0,33	0,43	0,45	0,38	0,45	0,33
<b>FDS</b>	-0,60	-0,56	0,43	0,45	0,38	0,45	0,33

Table 10 – Maximising criteria values

Source: authors

In the next step, all the values of the table were multiplied by the weights of each criterion, and then the ideal and basal variants were created (Table 11). The ideal variant was created by selecting the highest value from each criterion and denoting it *H*. The basal variant was created by selecting the lowest value from each criterion and denoting it *D*.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>
	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>
<b>CFAST</b>	-0,03	-0,01	0,03	0,01	0,04	0,02	0,06
<b>PyroSim</b>	0,01	-0,02	0,09	0,04	0,07	0,10	0,06
<b>FDS</b>	-0,03	-0,04	0,09	0,04	0,07	0,10	0,06
<b>H</b>	0,01	-0,01	0,09	0,04	0,07	0,10	0,06
<b>D</b>	-0,03	-0,04	0,03	0,01	0,04	0,02	0,06

Table 11 – Formation of ideal and basal variants

Source: authors

The next step was to calculate the Euclidean distances of our real variants from the ideal and basal variants. The Euclidean distance of the real variant from the ideal was calculated by subtracting the real variant from the ideal *H* and then squaring this value.  $V+$ , which is the distance of the real variant from the ideal variant, was then calculated by summing the values of each criterion for the variants and square root this value. The Euclidean distance of the real

variant from the basal variant was calculated by subtracting the real variant from the basal  $D$  and then squaring this value. Then  $V^-$ , which is the distance of the real variant from the basal one, was calculated by summing the values of each criterion for the variants and square root this value. Table 12 and Table 13 show the calculations of the Euclidean distances.

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>	
	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>V+</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>	
<b>CFAST</b>	0,0017	0	0,0039	0,0009	0,0009	0,0058	0	0,12
<b>PyroSim</b>	0	0,0002	0	0	0	0	0	0,02
<b>FDS</b>	0,0017	0,0009	0	0	0	0	0	0,05

Table 12 – Calculation of the Euclidean distance of the real variant from the ideal  
Source: authors

	<b>K1</b>	<b>K2</b>	<b>K3</b>	<b>K4</b>	<b>K5</b>	<b>K6</b>	<b>K7</b>	
	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>MAX</b>	<b>V-</b>
<b>Weight</b>	<b>0,052</b>	<b>0,069</b>	<b>0,22</b>	<b>0,086</b>	<b>0,191</b>	<b>0,21</b>	<b>0,172</b>	
<b>CFAST</b>	0	0,0009	0	0	0	0	0	0,03
<b>PyroSim</b>	0,0017	0,0002	0,0039	0,0097	0,0008	0,00585	0	0,12
<b>FDS</b>	0	0	0,0039	0,0009	0,0008	0,0058	0	0,11

Table 13 – Calculation of the Euclidean distance of the real variant from the basal  
Source: authors

The final step was to find the final score for each variant using the formula (1).

$$\text{Resulting value} = \frac{V^-}{(V^-) + (V^+)} \quad (1)$$

After obtaining the values of each variant, the most suitable programme for modelling confined space fires was determined:

- CFAST 0,21 (21 %).
- PyroSim 0,88 (88 %).
- FDS 0,68 (68 %).

Based on the results obtained, it can be seen that PyroSim is the most suitable software variant for modelling confined space fires, scoring up to 88%. On the contrary, the least recommended variant is CFAST with 21 %.

### Discussion and conclusion

The AHP method is considered to be one of the highest quality methods of multi-criteria decision making as it combines the advantages and eliminates the shortcomings of other methods. The TOPSIS method is based on the principle of selecting the variant that results closest to the ideal variant. The results of the AHP method variants are given in decimal places or percentages, where the sum must equal 1 or 100%. The results of the TOPSIS

method variants are also given in decimal places or percentages, but unlike the AHP method, the sum of the individual values does not equal 1 or 100%, but the result tells us how suitable the variant is on a scale from 0 to 1, 0% to 100%. The higher the value of the variant, the more suitable it is.

Based on the results obtained, it can be seen that according to the AHP method, the most suitable variant of the modelling program is PyroSim with a value of 0.435, the second place is taken by the FDS program with a value of 0.431 and the last place is taken by the CFAST program with a value of 0.134. The results of the TOPSIS method do not differ from the AHP results as the best variant was the PyroSim program with a value of 0.88, then it was the FDS program with a value of 0.68 and the last one is again the CFAST program with a value of 0.21.

As can be seen, for both methods used, the PyroSim program came out as the most suitable despite its purchase price, since it combines simplicity and accuracy of calculations. The FDS program also ranked second in both cases, but only by a small margin from PyroSim, which may have been mainly due to its difficulty of use. Although CFAST is cheap and easy to use, this has a large impact on the accuracy of the results and for this reason it remains far behind PyroSim and FDS.

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