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SIMULATION MODEL IN THE STRATEGIC DECISION-MAKING PROCESS AT THE SUBNATIONAL LEVEL USING THE AHP METHOD BASED ON THE RISK CRITERION: A CONTINUATION OF PREVIOUS RESEARCH

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In previous research, which this paper continues, a proposal was made for a possible improvement of the matrix analysis model in the function of supporting strategic decision-making at the regional level. This paper introduces the Analytic Hierarchy Process (AHP) as one of the methods of multi-criteria analysis in the final part of the decision-making process where, based on defined criteria, the optimal solution is selected from a possible number of alternative solutions. Regarding the criteria for selecting alternative solutions, risk is introduced into the process as the main criterion. Based on previously established principles, a simulation model is developed, first presenting a review of recent literature with a critical review of the main modelling methods and then determining the assumptions and limitations of modelling. The final simulation model in this paper yields satisfactory results that point to the possible application of the model in solving real problems of strategic planning in the field of regional economy. The application of the AHP method in a real decision-making environment at the subnational level of the public sector and drawing attention to the importance of public sector risk management are further highlighted as a value of this research.

Keywords: *Regional economics; Analytic Hierarchy Process (AHP); Simulation model.*

1. Introduction

In previous research, which this paper continues, a proposal was made for a possible improvement of the matrix analysis model in the function of supporting strategic decision-making at the regional level. The main open questions indicated in these studies relate to the need to introduce additional quantitative methods into the decision-making process to reduce the subjectivization of the process. This paper introduces the Analytic Hierarchy Pro-

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cess (AHP) as one of the methods of multi-criteria analysis in the final part of the decision-making process where, based on certain criteria, the optimal solution is chosen from a possible number of alternative solutions. Regarding the criteria for selecting alternative solutions, risk is introduced into the process as the main criterion.

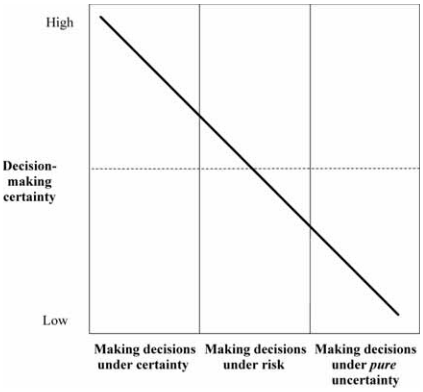
Findings from the modelling process, model discussion and open questions related to possible further research, all based on the idea of the convergence of private and public sector strategic planning tools, represent the expected main contribution of this paper.

2. Overview of literature and critical review of model methods

In previous research and the simulation model developed (Žmegač et al., 2024), which we build on in this paper, a broader overview of the literature related to situational analysis and strategic planning of the public sector is presented in the example of the subnational level. This paper aims to focus on open questions from previous research, and in this sense, a more detailed critical review of the element of the advanced simulation model related to decision-making processes, risks as a criterion for decision-making, and multi-criteria analysis as a suitable tool for providing education in a complex environment.

In the literature that deals with the problem of decision-making, one can find many definitions of decision-making, but for the purposes of this paper, we will use the approach that defines decision-making as the process of choosing between two or more possibilities (options) for solving a problem (Koontz et al., 2020; Schermerhorn, 1996). Fundamental decision-making problems are equally manifested in profit – market-oriented organizations and non-profit – public systems (public sector), of course influenced by the specificities of each organization. The main elements of the decision-making problem are: a) the goals to be achieved by the decision, b) the alternatives to be chosen in the decision-making process and c) the criteria used in the choice. Decision-making takes place in different circumstances, which can generally be favourable or unfavourable, and thus we can talk about decision-making under conditions of: a) security; b) risk and c) uncertainty (Figure 1).

Figure 1. The relationship between certainty in decision-making and circumstances



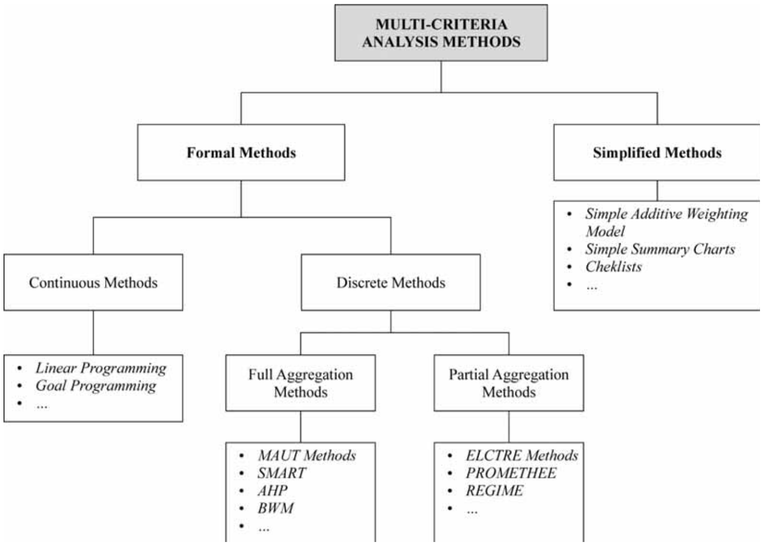
Source: Author's systematization

Figure 1 shows that the certainty of decision-making is very high in conditions when circumstances are known and safe, the certainty of decision-making decreases with the consideration of risk, while the certainty of decision-making in an environment of uncertainty is lowest. The circumstances and environment in the decision-making process therefore significantly influence the decision-making certainty of decision-makers (Sikavica et al., 1999). The most undesirable circumstance in decision-making is decision-making under conditions of uncertainty. Decision-making under conditions of safety is optimal, but decision-making under conditions of risk is the most common case of decision-making, and this is equally true for profit – market-oriented organizations and non-profit – public sector.

The Institute of Risk Management (IRM) defines risk as the combination of the probability of an event and its consequences. There are of course more risk definitions in the literature, however the IRM definition describes well the generally accepted main elements of the term. In general, risks can be divided into four categories (Hopkin, 2017): (i) compliance (or mandatory) risks; (ii) hazard (or pure) risks; (iii) control (or uncertainty) risks and (iv) opportunity (or speculative) risks. Risks are equally present in the decision-making process in both the public and private sectors. In general, economic theory indicates that in the private sector an efficient market strongly influences decision-making processes and risk management (Fone & Young, 2005), while in the public sector there are complex influences from the wider environment that is influenced by a significant number of interested parties (the local community as a separate entity, entrepreneurs, citizens, political elites...). The specificities of risk management in the public sector can be grouped as: (i) Strong influence of bureaucracy and regulation on decision-making processes; (ii) Large number of stakeholders involved who usually have opposing interests; (iii) Possible frequent changes of leadership under the influence of election cycles; (iv) Politically elected leaders are not necessarily educated for the specifics of public affairs and (v) Unrealistic goals that are communicated under the influence of political competition. In the public sector, in addition to standard risk categories, reputational risk is additionally distinguished, which is the most significant risk in the public decision-making process (Ahmeti & Besarta, 2017). The importance of reputational risk is emphasized by Fone & Young (2005) who argue that there are four types (dimensions) of risk in the public sector, namely: (i) Political dimension; (ii) Strategic and organizational dimension; (iii) Tactical dimension and (iv) Operational dimension. Drennan et al. (2024) are on this track in considering risks in the public sector, who emphasize that the main differences between the public sector and the private sector lie in: a) the range of stakeholders to which the organization is accountable, and b) the extent to which political and social dimensions impact on decisions taken.

Multi-criteria analysis (MCA) is a set of tools and structured approaches (Figure 2) used to make decisions about the most favourable outcomes based on defined alternatives and their preferences that are ranked according to different criteria.

Figure 2. Classification of MCA methods



Source: (Dean, 2022)

According Vaidya & Kumar (2006), Analytic Hierarchy Process (developed by Thomas L. Saaty in the 1970s) is one of the most widely used multiple criteria decision-making tools. The foundation of AHP decision-making are mathematics and psychology (Saaty, 2008). Short summary of the advantages and disadvantages of the method is presented in Table 1.

Table 1. AHP Method Strengths and Weaknesses

Strengths	**Weaknesses**
Flexibility of the method and the possibility of checking for inconsistencies.	In a complex problem, there are many pairs to compare.
Reducing decision-making problems to consistent fragments that enable a better understanding.	Achieving consistency can be time-consuming and complex.
The AHP method includes both qualitative and quantitative decision-making parameters.	The artificial limitation of the scale to nine values can create a problem in decision-making.
A significant number of software that support the AHP method.	The methodology does not guarantee decisions as completely correct due to the subjective approach of the AHP process.

Source: Author's systematization

Result of comparison AHP method and other selected decision-making methods is presented in Table 2.

Table 2. AHP compared to other selected decision-making methods

Other decision-making methods	AHP Comparison
Simple Additive Weighting (SAW) **Advantages**: Easy to understand and implement; requires fewer comparisons than AHP. **Disadvantages**: Lacks the hierarchical structure of AHP, which can limit its ability to handle complex problems.	**AHP** is more suitable for complex decisions involving multiple criteria and sub-criteria, while SAW is better for simpler problems.
Weighted Sum Model (WSM) **Advantages**: Straightforward and intuitive; easy to apply in situations with well-defined criteria. **Disadvantages**: May oversimplify complex decisions; does not provide a consistency check like AHP.	**AHP** offers a more structured and rigorous approach, especially when dealing with subjective judgments and inconsistencies.
Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) **Advantages**: Considers both the best and worst alternatives. **Disadvantages**: Requires a normalization process, which can be complex; sensitive to the choice of criteria weights.	**AHP** provides a more intuitive pairwise comparison process, whereas TOPSIS focuses on closeness to ideal and anti-ideal solutions.
4. Multi-Attribute Utility Theory (MAUT) **Advantages**: Incorporates risk preferences and utility functions; can handle trade-offs between criteria. **Disadvantages**: Requires detailed knowledge of utility functions; more complex to implement than AHP.	**AHP** is generally easier to use and more accessible to non-experts, while MAUT is more suitable for decision-makers with a strong understanding of utility theory.

Source: Author's systematization

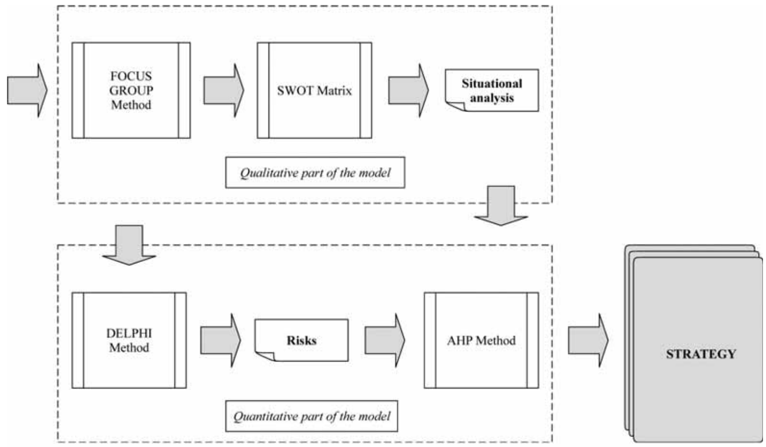
AHP excels in scenarios that require detailed pairwise comparisons and a hierarchical breakdown of complex decision problems (Forman & Gass, 2021). It provides a robust framework for both quantitative and qualitative criteria and includes a consistency check. However, it can be more time-consuming and complex to implement compared to simpler methods. AHP is widely used in various fields, including business, government, engineering, healthcare, and education, to make informed and rational decisions. Some specific contexts where AHP is appropriate method: (1) Strategic Planning and Priority Setting; (2) Project Selection and Portfolio Management; (3) Supplier and Vendor Selection; (4) Resource Allocation; (5) Performance Evaluation and Benchmarking; (6) Policy and Decision Making in Public Sector and (7) Risk Assessment and Management.

The method is explained in more detail in the next chapter which is dealing with the methodology for creating the model.

3. Methodological framework

The methodology and structure of the decision-making model at the subnational level using the AHP method based on risk criteria is shown in Figure 3.

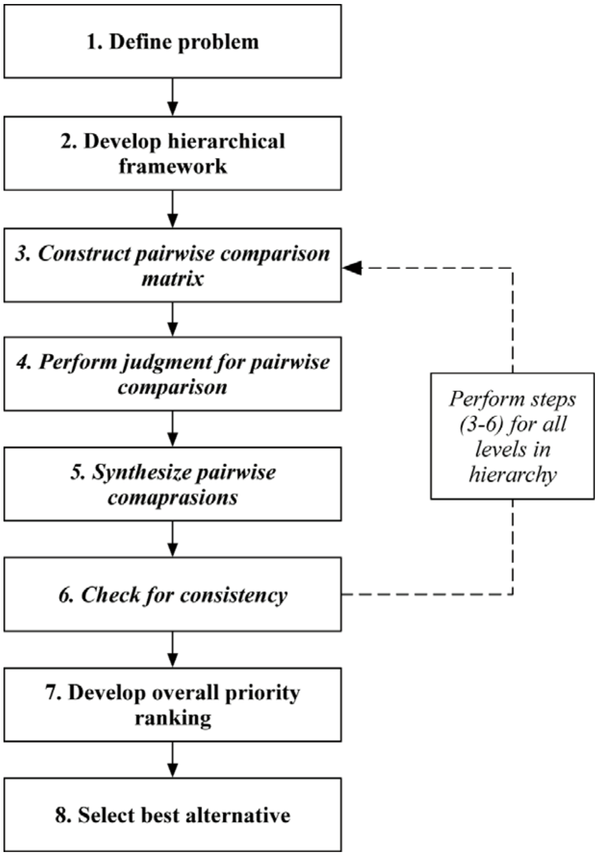
Figure 3. Structure of the new model



Source: Author's systematization

It is evident from Figure 3 that first a SWOT/TOWS analysis of regional self-government will be created in the basic form using the FOCUS group method – the qualitative part of the model. This part of the model will provide a situational analysis with possible strategies, after which we seek an answer to the question – Which strategy should we choose in order to reach the new desired state of the system? In this part of the process, we come to the question of risk management in relation to the chosen strategy for reaching the set goal. Determining the expected risks for the implementation of the process is done using the DELPHI method, based on which we arrive at a list of possible risks. The key risks are then quantified using the AHP method (Figure 4) and a result is obtained that describes which of the possible SWOT strategies has the highest probability of success.

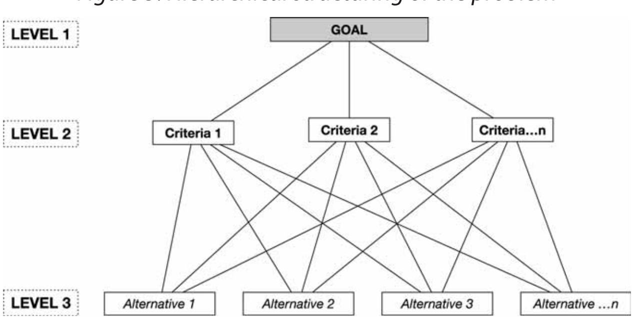
Figure 4. Steps of the Analytical Hierarchy Process (AHP)



Source: Author's systematization

In Figure 4, we see the systematized main steps in performing the AHP method, where it is emphasized that the procedure must be performed for each of the levels in the set hierarchy of problems (Figure 5).

Figure 5. Hierarchical structuring of the problem



Source: Author's systematization

In Figure 5, we see the hierarchical structure of a specific problem divided into three levels. Level 1 represents the goal of the model. Level 2 is multi-criteria (it can consist of several specific sub-criteria), while level 3 is composed of alternative choices (solutions) as a function of level 1. The lines between the levels indicate the relations between the objective, criteria and alternative solutions.

The AHP method is performed using a standard procedure known in the literature, which is processed in matrix form, all based on the comparison of the elements being compared, preference levels according (Saaty, 1977) and calculations of the values of (1) CI (Consistency index) and (2) CR (Consistency ratio).

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (1)$$

where n is the dimension of the matrix; λ_{max} is maximal eigenvalue.

$$CR = \frac{CI}{RI} \qquad (2)$$

where RI is the random index

3.1. Simulation model assumptions and limitations

As previously mentioned, this work is a continuation of the research, and the modeling assumptions and limitations (Table 3) are identical to the initial work to which we refer here (Žmegač et al., 2024).

Table 3. Model assumptions

Model component	Assumptions and limitations	Source in the real system
Modelling objective	Author's systematization	Public-sector problems and needs
Situational analysis	Author's systematization	FOCUS group; SWOT and TOWS method
Weighted key risks	Author's systematization	DELPHI method; AHP method

Source: Author's systematization

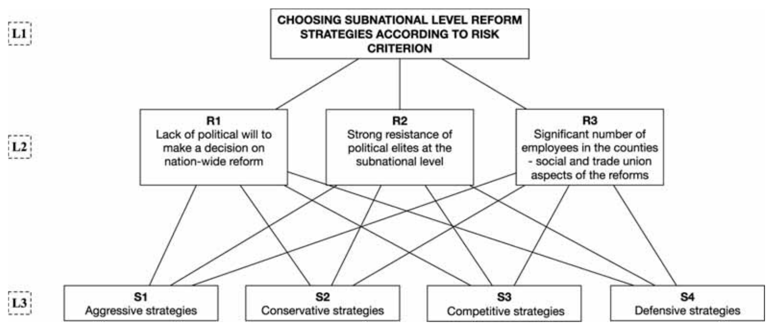
4. Modelling

We start with the creation of a simulation model using the adopted methodology and assumptions of the model. We will implement the model through eight steps that are grouped according to the connection of the procedures.

STEP 1-2: Define problem; Develop hierarchical framework

The problem that we solve with this simulation model refers to deciding about which of the available and proposed strategies to apply in order to implement the reform of the reorganization of the subnational level of the state – the goal of the model. From the previously defined problem, we create a representation of the hierarchical structure of all model elements and their mutual relations (Figure 6).

Figure 6. Hierarchical structure of the problem and goal of the model



Source: Author's systematization

As can be seen in Figure 6, the determined goal of the model (Level 1) is observed through the risk functions R1, R2 and R3 (Level 2) which influence which of the possible alternatives S1, S2, S3 and S4 (Level 3) to choose as optimal solution to the problem.

STEP 3-6: Construct pairwise comparison matrix; Perform judgment for pairwise comparison; Synthesize pairwise comparisons; Check for consistency (for all levels in hierarchy)

In steps 3 to 6, for each of the levels of the established hierarchical structure of the problem (Figure 6), a comparison is first performed according to the degrees of preferences, after which a comparison matrix is created. In the last step, through the normalization of the matrix, we arrive at the value of the Priority Vector. Tables 4 to 6 show the procedure for Level 2 in relation to the goal (Level 1).

Table 4. Level 2 – Pair wise comparison with respect to the goal (Level 1)

Factor	More importance than				Equal	*Less importance than*				Factor
R1	9	[7]	5	3	1	*3*	*5*	*7*	*9*	**R2**
R1	9	7	[5]	3	1	*3*	*5*	*7*	*9*	**R3**
R2	9	7	5	3	1	*[3]*	*5*	*7*	*9*	**R3**

Source: Author's systematization

Table 5. Level 2 – Paired comparison matrix with respect to the goal (Level 1)

	R1	R2	R3
R1	1,00	7,00	5,00
R2	*0,14*	1,00	0,33
R3	*0,20*	*3,00*	1,00
∑	**1,34**	**11,00**	**6,33**

Source: Author's systematization

Table 6. Level 2 – Normalized Relative Weight of Matrix and Priority vector

	R1	R2	R3	∑	Priority Vector
R1	0,74	0,64	0,79	**2,17**	**0,7235**
R2	0,11	0,09	0,05	**0,25**	**0,0833**
R3	0,15	0,27	0,16	**0,58**	**0,1932**

Source: Author's systematization

After adopting the Priority Vector value, we calculate the CI (Consistency Index) and finally check the consistency through the CR (Consistency Ratio) value.

$$\lambda_{max} = (0{,}7235)(1{,}34) + (0{,}0833)(11{,}00) + (0{,}1932)(6{,}33) = 3{,}1115$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{0{,}1115}{2} = 0{,}0557$$

$$CR = \frac{CI}{RI} = \frac{0{,}0557}{0{,}58} = 9{,}61\% \quad (CR < 10\%, \textit{acceptable})$$

According to the adopted procedure, Tables 7 to 9 show the procedure for Level 3 in relation to the first element R1 in Level 2.

Table 7. Level 3 – Pair wise comparison *with respect to Level 2 R1*

Factor	More importance than				Equal	*Less importance than*				Factor
S1	9	7	5	3	1	*3*	*5*	*7*	*9*	**S2**
S1	9	7	5	3	1	*3*	*5*	*7*	*9*	**S3**
S1	9	7	5	3	1	*3*	*5*	*7*	*9*	**S4**
S2	9	7	5	3	1	*3*	*5*	*7*	*9*	**S3**
S2	9	7	5	3	1	*3*	*5*	*7*	*9*	**S4**
S3	9	7	5	3	1	*3*	*5*	*7*	*9*	**S4**

Source: Author's systematization

Table 8. Level 3 – Paired comparison matrix with respect to Level 2 R1

R1	S1	S2	S3	S4
S1	**1,00**	3,00	3,00	5,00
S2	*0,33*	**1,00**	3,00	1,00
S3	*0,33*	*0,33*	**1,00**	1,00
S4	*0,20*	*1,00*	*1,00*	**1,00**
∑	**1,87**	**5,33**	**8,00**	**8,00**

Source: Author's systematization

Table 9. Level 3 – Normalized Relative Weight of Matrix and Priority vector (R1)

R1	S1	S2	S3	S4	∑	Priority Vector
S1	0,54	0,56	0,38	0,63	**2,10**	**0,5246**
S2	0,18	0,19	0,38	0,13	**0,87**	**0,2165**
S3	0,18	0,06	0,13	0,13	**0,49**	**0,1228**
S4	0,11	0,19	0,13	0,13	**0,54**	**0,1362**

Source: Author's systematization

After adopting the Priority Vector value, we calculate the CI (Consistency Index) and finally check the consistency through the CR (Consistency Ratio) value.

$$\lambda_{max} = (0,5246)(1,87) + (0,2165)((5,33) + (0,1228)((8,00) + (0,1362)(8,00) = 4,2054$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{0,2054}{3} = 0,0685$$

$$CR = \frac{CI}{RI} = \frac{0,0685}{0,9} = 7,61\% \quad (CR < 10\%, acceptable)$$

According to the adopted procedure, Tables 10 to 12 show the procedure for Level 3 in relation to the second element R2 in Level 2.

Table 10. Level 3 – Pair wise comparison *with respect to Level 2 R2*

Factor	More importance than				Equal	*Less importance than*				Factor
S1	9	7	**5**	3	1	*3*	*5*	*7*	*9*	**S2**
S1	9	7	**5**	3	1	*3*	*5*	*7*	*9*	**S3**
S1	9	**7**	5	3	1	*3*	*5*	*7*	*9*	**S4**
S2	9	7	5	**3**	1	*3*	*5*	*7*	*9*	**S3**
S2	9	7	5	**3**	1	*3*	*5*	*7*	*9*	**S4**
S3	9	7	5	3	**1**	*3*	*5*	*7*	*9*	**S4**

Source: Author's systematization

Table 11. Level 3 – Paired comparison matrix with respect to Level 2 R2

R2	S1	S2	S3	S4
S1	**1,00**	5,00	5,00	7,00
S2	*0,20*	**1,00**	3,00	3,00
S3	*0,20*	*0,33*	**1,00**	1,00
S4	*0,14*	*0,33*	*1,00*	**1,00**
∑	**1,54**	**6,67**	**10,00**	**12,00**

Source: Author's systematization

Table 12. Level 3 – Normalized Relative Weight of Matrix and Priority vector (R2)

R2	S1	S2	S3	S4	∑	Priority Vector
S1	0,65	0,75	0,50	0,58	**2,48**	**0,6204**
S2	0,13	0,15	0,30	0,25	**0,83**	**0,2074**
S3	0,13	0,05	0,10	0,08	**0,36**	**0,0907**
S4	0,09	0,05	0,10	0,08	**0,33**	**0,0815**

Source: Author's systematization

After adopting the Priority Vector value, we calculate the CI (Consistency Index) and finally check the consistency through the CR (Consistency Ratio) value.

$$\lambda_{max} = (0{,}6204)(1{,}54) + (0{,}2074)(6{,}67) + (0{,}0907)(10{,}00) + (0{,}0815)(12{,}00) = 4{,}2250$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{0{,}22250}{3} = 0{,}0750$$

$$CR = \frac{CI}{RI} = \frac{0{,}0750}{0{,}9} = 8{,}33\% \quad (CR < 10\%, acceptable)$$

According to the adopted procedure, Tables 13 to 15 show the procedure for Level 3 in relation to the third element R3 in Level 2.

Table 13. Level 3 – Pair wise comparison *with respect to Level 2 R3*

Factor	More importance than				Equal	*Less importance than*				Factor
S1	9	7	5	**[3]**	1	*3*	*5*	*7*	*9*	**S2**
S1	9	7	5	**[3]**	1	*3*	*5*	*7*	*9*	**S3**
S1	9	**[7]**	5	3	1	*3*	*5*	*7*	*9*	**S4**
S2	9	7	5	**[3]**	1	*3*	*5*	*7*	*9*	**S3**
S2	9	7	5	**[3]**	1	*3*	*5*	*7*	*9*	**S4**
S3	9	7	5	**[3]**	1	*3*	*5*	*7*	*9*	**S4**

Source: Author's systematization

Table 14. Level 3 – Paired comparison matrix with respect to Level 2 R3

R3	S1	S2	S3	S4
S1	**1,00**	3,00	3,00	7,00
S2	*0,33*	**1,00**	3,00	3,00
S3	*0,33*	*0,33*	**1,00**	3,00
S4	*0,14*	*0,33*	*0,33*	**1,00**
∑	**1,81**	**4,67**	**7,33**	**14,00**

Source: Author's systematization

Table 15. Level 3 – Normalized Relative Weight of Matrix and Priority vector (R3)

R3	S1	S2	S3	S4	∑	Priority Vector
S1	0,55	0,64	0,41	0,50	**2,10**	**0,5261**
S2	0,18	0,21	0,41	0,21	**1,02**	**0,2555**
S3	0,18	0,07	0,14	0,21	**0,61**	**0,1516**
S4	0,08	0,07	0,05	0,07	**0,27**	**0,0668**

Source: Author's systematization

After adopting the Priority Vector value, we calculate the CI (Consistency Index) and finally check the consistency through the CR (Consistency Ratio) value.

$$\lambda_{max} = (0,5261)(1,81) + (0,2555)(4,67) + (0,1516)(7,33) + (0,0668)(14,00) = 4,1912$$

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{0,1912}{3} = 0,0637$$

$$CR = \frac{CI}{RI} = \frac{0,0637}{0,9} = 7,08\% \quad (CR < 10\%, acceptable)$$

STEP 7-8: Develop overall priority ranking; Select best alternative

As we can see, the value of the priority vector of the factor R2 during the calculation in Step 1-2 is less than 10%, while the factor R1 is at a level of over 70% respectively R3 at almost 20%. Therefore, we can ignore the R2 factor because it will not have an impact on the result but retrospectively the weight of factor R1 and R3 must be adjusted (the sum must be 100%):

$$Adjusted\ weight\ for\ factor\ R1 = \frac{72,35}{91,67} = 0,7893$$

$$Adjusted\ weight\ for\ factor\ R3 = \frac{19,32}{91,67} = 0,2107$$

Then we calculate the total composite weight of each alternative (Table 20).

$$S1=(0,7893)(52,46)+(0,2107)(52,61)=52,49$$

$$S2=(0,7893)(21,65)+(0,2107)(25,55)=22,47$$

$$S3=(0,7893)(12,28)+(0,2107)(15,16)=12,88$$

$$S4=(0,7893)(13,62)+(0,2107)(6,68)=12,15$$

Table 16. Best alternative

	R1	R3	Composite weight
Adjusted weight	*0,7893*	*0,2107*	
S1	52,46%	52,61%	52,49%
S2	21,65%	25,55%	22,47%
S3	12,28%	15,16%	12,88%
S4	13,62%	6,68%	12,15%
	100,00%	100,00%	100,00%

Source: Author's systematization

As we can see in Table 16, the result indicates that solution S1 (Aggressive Strategies) is the best solution. The second-best solution is S2 (Conservative Strategies), while S3 and S4 solutions are the worst alternatives considering the risk criteria R1, R2 and R3. When we compare the two best solutions, we see that the S1 solution is almost 2.5 times better than the second-best solution S2, based on which the S1 solution (Aggressive Strategies) can be taken as final.

Finally, by summing all levels we can check the overall consistency of hierarchy ($\overline{CR}$).

$$\overline{CR}=\frac{(0,0557)(1)+(0,0685)(0,7893)+(0,0637)(0,2107)}{(0,58)(1)+(0,9)(0,7893)+(0,9)(0,2107)}=\frac{0,1232}{1,4800}=8,32\%$$

$$\overline{CR}<10\% \quad (acceptable)$$

5. Research results and discussion

The goal of this paper, which continues previous research, is to consider possible improvements to the standard process of strategic planning in the regional economy, in the first phase – strategy formulation. For the purposes of the research, the first part of the simulation model was performed, with which possible strategies were arrived at, after which the question arises as to which of the possible solutions (strategies) to choose. Based on the previous results, in this continuation of the research, the AHP method is introduced into the decision-making process as a multi-criteria decision-making model based on the risk criterion. As in the previous paper, the limitations of the model were determined in this paper, and the final simulation model was derived based on the established methodology.[2] The final simulation

[2] The full simulation model includes the model derived in this paper and the first part of the model from previous research: Žmegač, D., Čolig, M., & Drezgić, S. (2024). Simulation model of the quantified SWOT/TOWS matrix on an example of situational analysis at subnational level. *Zbornik Veleučilišta u Rijeci*, 12(1), 23–35.

model in this paper shows satisfactory results that point to the possible application of the model in solving real problems of strategic planning in the field of regional economy. The application of the AHP method and drawing attention to the importance of public sector risk management is additionally emphasized as the value of this research.

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