INFORMATION TECHNOLOGY SESSION

MULTI-CRITERIA ASSESSMENT OF RESILIENCE DIMENSIONS IN EDUCATIONAL SYSTEMS

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Abstract:

Modern educational systems are highly dependent on information and communication technologies. Due to this fact, they often face technical, organizational and security challenges, so special attention should be paid to the issue of the resilience of these systems. The aim of this paper is to identify and rank the key dimensions of the resilience of the educational system, in order to grasp their relative contribution to the stability and continuity of the educational process. The paper analyzed five different dimensions of resilience: technical, pedagogical, organizational, social and economic. The PIPRECIA-S method of multi-criteria decision-making, based on expert evaluation, was applied to determine the relative importance of each dimension of resilience. The results show that technical resilience has the greatest impact on overall system resilience (0.262), followed by pedagogical (0.230), social (0.198), organizational (0.163) and economic (0.146). The proposed model enables a systematic overview different dimensions of the resilience of the educational system. This model can serve as a basis for improving the management of the educational system in the digital environment.

Keywords:

Educational System Resilience, Technical Resilience, PIPRECIA-S Method, Multi-Criteria Decision-Making, Educational Information Systems.

INTRODUCTION

Modern education systems are highly dependent on information and communication technologies [1, 2]. Educational system resilience is very important [3] to ensure the continuity, stability and safety of the educational process. The resilience of the educational system represents the ability of the system to function in conditions of various disturbances, to adapt to changes and to recover after crisis situations, while preserving the quality of education [3, 4]. According to [3], the educational system's resilience becomes a key element of modern education and enables both students and institutions to maintain purpose, coherence and creativity due to rapid changes.

The infrastructure on which teaching and the management of educational institutions are based is becoming more and more complex due to the digitization of education, the development of online platforms and the ever-widening application of educational information systems [5, 6].

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In such conditions, technical, organizational and security disturbances can significantly affect the functioning of the educational system [7, 8].

Although there are many published works dealing with the digitization of education and the application of information technologies in teaching, a small number of researchers are focused on the analysis of the resilience of educational systems through several related dimensions. How different aspects of resilience contribute to the stability and sustainability of the education system has not been sufficiently explored. Therefore, there is a need to develop a model which allows the identification and ranking of different dimensions of resilience for a better understanding of their relative importance in the overall resilience of the system.

The goal of the research is to identify the key dimensions of the educational system's resilience and to assess their share of overall resilience. The assessment of the importance of individual dimensions of resilience requires the application of methods that enable systematic analysis and comparison of different criteria. Considering the complexity of the educational system's resilience, multi-criteria decision-making was applied, which enabled the quantification of the subjective assessments of experts and the determination of the relative weights of the observed criteria - dimensions of resilience. The obtained results enable a better understanding of the structure of the educational system's resilience and the identification of the dimensions that have the greatest impact on the stable functioning of modern educational systems.

2. DIMENSIONS OF THE RESILIENCE OF THE EDUCATIONAL SYSTEM

The criteria used in this research were defined based on a review of relevant literature regarding system resilience, educational information systems and risk management. Resilience is viewed in modern research as a multidimensional concept that includes technical, organizational and social aspects of system functioning [9, 10]. In this context, technical and cyber resilience refers to the reliability of information and communication infrastructure and the system's ability to respond to security threats [11, 12], while organizational resilience includes the ability of institutions to adapt to changes and disruptions in work [13, 14].

In the context of educational systems, the pedagogical and social dimensions of resilience are particularly significant, which relate to the continuity of the teaching process and the ability of the system to respond to the needs of users in crisis situations [15, 16]. Economic resilience is also an important aspect, as it relates to the availability of resources and the sustainability of the system in conditions of limited financial capacity.

Based on the above, five basic dimensions of resilience are defined in this paper: technical, pedagogical, organizational, social and economic. Each of these dimensions of resilience affects the overall ability of the system to respond to challenges and to ensure the continuity of the teaching process even in the face of various disruptions.

The first dimension of resilience refers to the technical resilience of the educational system. In modern education, a large part of teaching activities relies on digital infrastructure and various information systems. Therefore, the continuity of the teaching process depends on the stability and reliability of technical resources. Technical resilience refers to the ability of information systems, network infrastructure and digital learning platforms to ensure stable operation, data protection and availability of educational content even when technical problems or security incidents occur [12, 17].

The second dimension of resilience refers to pedagogical resilience, which represents the ability of adaptation of the teaching process to changes while preserving the quality of education. This dimension of resilience includes the ability to develop new approaches to teaching and adapt teaching methods to different environments. The key factors that influence the pedagogical dimension of resilience are the digital competences of teachers, the flexibility of teaching methods, as well as the adaptation of teaching materials in case of various disorders [18].

The third dimension of resilience is the organizational resilience of educational institutions. This dimension of resilience represents the ability of educational institutions to effectively manage changes, plan their work in case of crisis situations and adapt their processes to new working conditions. Institutions that have a risk management plan and a work continuity plan more easily overcome challenges and maintain the stability of the educational process [19].

The fourth dimension of resilience is social resilience. This dimension of resilience refers to the ability of the system to ensure the availability of education to all participants in the educational process and for the

reduction of the negative consequences of social and technological inequalities. Solving the problem of the digital divide is a special challenge [20].

The fifth dimension of resilience is the economic resilience of the system. This dimension refers to the financial stability of educational institutions and their ability to provide the necessary resources for the functioning of the educational system. A prerequisite for the long-term sustainability and resilience of the educational system involves investment in infrastructure, technology and the development of digital educational platforms [21].

3. METHODOLOGY

To determine the relative contribution of the dimensions of the educational system's resilience the PIPRECIA-S (Pivot Pairwise Relative Criteria Importance Assessment – Simplified) method is used. This method represents an improved and simplified version of the PIPRECIA approach. It is suitable for situations where the assessment is based on expert knowledge, with less cognitive effort compared to classical pairwise comparison methods [22, 23]. The advantages of the PIPRECIA-S method are: it does not require complete matrices of pairwise comparisons, enables a flexible choice of reference criteria, reduces the burden on experts during assessment, and is suitable for group decision-making.

In education, the PIPRECIA-S model has so far been used to evaluate various criteria in the context of choosing optimal solutions for the selection of electronic learning materials [24], for the selection of AI tools in education [25], for the selection of an operating system in education [26].

Within this research, the dimensions of the resilience of the educational system are viewed as criteria whose relative importance needs to be determined. The procedure for determining weight coefficients of criteria using the PIPRECIA-S method consists of five steps [27].

After defining the criteria $C_j, j = 1,\ldots,n$, where n is the number of criteria, experts evaluate the relative importance of each criterion in relation to the reference criterion C_1 by determining the relative importance of criterion s_j based on Equation (1).

$$s_j = \begin{cases} 1, & C_j = C_1 \\ [0{,}6,\ 1{,}4], & C_j \neq C_1 \end{cases}$$

Equation 1. Relative importance value s_j based on C_j

In this research, the range of the criteria's real importance is limited to [0,6, 1,4]. This way avoids extreme assessments that could damage the stability of the model and lead to a disproportionate influence of certain criteria. Values greater than 1 indicate that the criterion is more important than the reference, and values less than 1 indicate a criterion of less importance.

Based on these estimates, the coefficient k_j is calculated, which is then used to determine the preliminary weights of criteria q_j. The method of determining the values of k_j is shown by Equations (2).

$$k_j = \begin{cases} 1, & j = 1 \\ 2 - s_j, & j > 1 \end{cases}$$

Equation 2. Calculation of the coefficient k_j

The method of determining the values q_j is shown by Equations (3).

$$q_j = \begin{cases} 1, & j = 1 \\ \frac{q_{j-1}}{k_j}, & j > 1 \end{cases}$$

Equation 3. Calculation of the coefficient q_j

In the next step, the preliminaries are normalized in order to obtain the final weights of the criteria w_j. The normalization of criteria weights is calculated based on Equation (4).

$$w_j = \frac{q_j}{\sum_{i=1}^{n} q_i}$$

Equation 4. Calculation of the relative weight of criterion w_j

The sum of the weights of all observed criteria is equal to one. The obtained weights reflect the relative importance of individual dimensions of resilience within the educational system.

4. EXPERT SAMPLE AND EVALUATION METHOD

Given that the resilience of the educational system depends on a combination of pedagogical, organizational and technological factors, the expert sample was composed of university professors, researchers in the field of information systems and experts who have experience in the implementation of digital educational platforms. The group of experts is composed of ten members.

In the first step, the experts made a consensus decision on the choice of the reference criterion. In this way, the choice of the reference criterion is based on collective professional opinion. The remaining dimensions of resilience were observed in relation to the reference criteria, with experts assessing their relative importance.

During the evaluation process, each expert gave an assessment of the relative importance of the observed dimensions of resilience. The obtained estimates are aggregated using the arithmetic means. The stability of expert ratings was checked by analyzing the dispersion of the obtained values. Based on the aggregated assessments of experts and the conducted analysis procedure, the final weights of the dimensions of the educational system's resilience were calculated.

5. RESEARCH RESULTS

Within the research, five key dimensions of the resilience of the educational system were analyzed, which at the same time represent criteria in the multi-criteria analysis: C_1 – Organizational resilience (reference criterion); C_2 – Technical resilience; C_3 – Pedagogical resilience; C_4 – Social resilience; C_5 – Economic resilience.

Table 1. Expert assessments of the relative importance of criteria

Experts	s_1	s_2	s_3	s_4	s_5
Expert 1	1,0	1,4	0,8	0,8	0,6
Expert 2	1,0	1,4	1,0	0,8	0,6
Expert 3	1,0	1,4	0,8	0,8	0,6
Expert 4	1,0	1,4	1,0	1,0	0,6
Expert 5	1,0	1,4	0,8	0,8	0,8
Expert 6	1,0	1,4	0,8	0,8	0,6
Expert 7	1,0	1,2	0,8	0,8	0,6
Expert 8	1,0	1,4	0,8	0,8	0,6
Expert 9	1,0	1,4	1,0	0,8	0,6
Expert 10	1,0	1,4	0,8	0,8	0,6

Table 2. Results of PIPRECIA-S calculation of criteria weight coefficients

C_j	$\overline{s_j}$	k_j	q_j	w_j	*Rank*
C_1	1,00	1,00	1,000	0,163	4
C_2	1,38	0,62	1,613	0,262	1
C_3	0,86	1,14	1,415	0,230	2
C_4	0,84	1,16	1,220	0,198	3
C_5	0,62	1,38	0,884	0,145	5

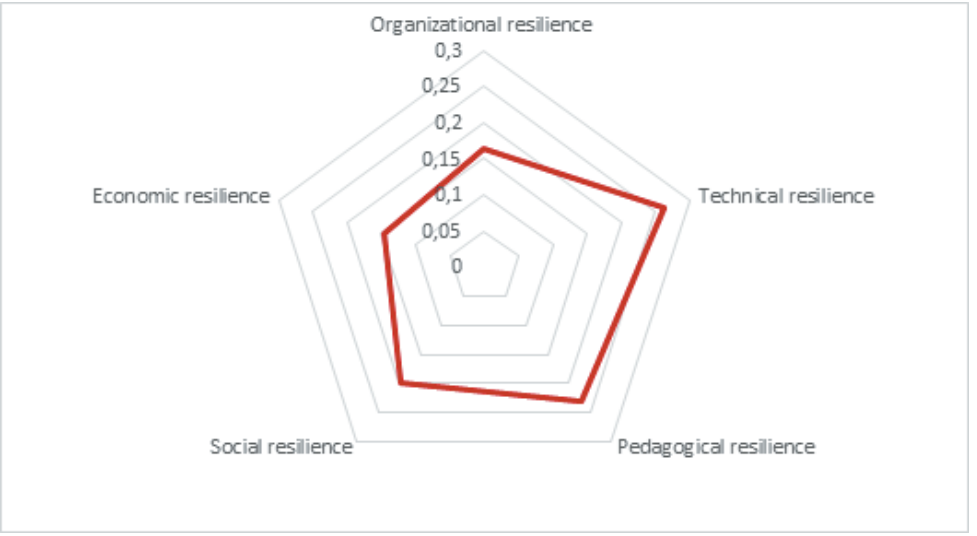

Figure 1. Radar display of the relative importance of dimensions of resilience in the education system

The experts determined the reference criterion by consensus, while they gave marks to the remaining criteria using a discrete scale of values from 0,6 to 1,4 in steps of 0,2. The results of expert evaluations are shown in Table 1. For each criterion, the value of the coefficient of relative importance assigned by each expert is shown. The obtained standard deviation values are significantly less than 0,2, which indicates a high level of expert consensus.

Based on the average values of the coefficients of relative importance, a complete PIPRECIA-S calculation was performed and the ranking of the criteria was determined. The results of this calculation are shown in Table 2.

Table 2 - Results of PIPRECIA-S calculation of criterTo show more clearly the relative importance of the individual dimensions of resilience, the obtained weighting coefficients of the criteria are presented using radar graphics in Figure 1.

Figures should be centred, with captions below them in the figure caption style, as in Figure 2. Make sure to refer to each figure in the paper and explain it in the text. If a figure is not strictly necessary, consider not using it.

6. DISCUSSION

The analysis of the obtained weight values shows that technical resilience occupies the largest part in the total resilience of the educational system, with a weight of 0,262. Experts emphasized that the preservation of the continuity and quality of the educational process is directly influenced by the speed of response, the reliability of infrastructure solutions and the effective protection of digital resources. Therefore, technical resilience is a dominant factor in the overall evaluation.

The pedagogical aspect also shows a significant impact on the resilience of the system. The quality of the teaching staff, flexibility in the approach to education and the ability to adapt to different situations enable the optimal use of technical resources. The results indicate that pedagogical resources and technical infrastructure function in synergy. Technical resilience without pedagogical adaptability would not be sufficient to preserve the continuity and quality of education.

Organizational resilience with a weight of 0,163 proves an important role in the overall resilience of the system. A good organization includes clearly defined procedures, distribution of responsibilities and continuity plans, which allows for the reduction of the risk of non-compliant activities. Expert assessments show that even when technical and pedagogical resilience functions optimally, without a solid organizational framework, their effect can be reduced.

Social resilience emphasizes the importance of interpersonal connections, community support, and the involvement of all participants in the educational process. The results indicate that the educational system cannot be fully resilient only through technical and pedagogical resources, but also requires the ability to adapt to the wider social context, such as cooperation with parents, the local community or other educational institutions.

Economic resilience shows that financial capacity and the availability of funds, although less influential compared to the technical and pedagogical components, represent the basis for the sustainability of all other types of resilience. Lack of adequate budget, investment in technology and teacher training can have the effect of reducing the overall resilience of the system.

A limitation of this study is the relatively small expert sample, which may restrict the external validity of the results and introduce potential selection bias. Although the experts were carefully selected based on their expertise in educational information systems and decision-making methods, future research should include a larger and more diverse expert group with clearer demographic and disciplinary stratification.

A limitation of this study is the absence of empirical validation through a case study, external dataset, or outcome-based performance metrics. The model is currently based on expert judgment and multi-criteria evaluation, and future research should focus on its validation in real-world educational environments and comparison with measurable system performance indicators.

The present study does not explicitly integrate broader socio-technical resilience frameworks from computer science and information systems, such as network resilience or cyber-physical system resilience models. While the proposed approach focuses on educational system dimensions, future research should explore its alignment with quantitative, metric-driven resilience frameworks in order to improve cross-domain applicability and comparability.

7. CONCLUSION

The analysis of the resilience of the education system shows that technical resilience is dominant. This means that technical infrastructure and digital security play a key role in preserving the teaching process. Pedagogical, organizational, social and economic factors contribute to overall resilience, but their effectiveness depends on a stable technical base of the system. Expert assessments emphasize that the synergy between different dimensions of resilience enables adequate adaptability and sustainability of the system in complex situations.

Given that the role of technical resilience is dominant, further research should focus on detailed analysis of technical components, including specific technologies, network infrastructure, security protocols and crisis management scenarios.

For future research, expansion of the expert group in order to ensure greater representativeness and increase the reliability of the assessments is recommended. Also, the inclusion of quantitative data from the real system would allow additional validation of the proposed model. Based on the received weighting coefficients of the dimensions of resilience, it would be possible to develop an overall index of resilience of the educational system, which would enable a quantitative assessment of its stability and ability to respond to various types of disturbances. In addition, it would be useful to investigate in more detail the interdependencies between different dimensions of resilience, which would contribute to the development of an educational system that is more resilient to technical, organizational, pedagogical, social and economic risks.

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