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THE USE OF THE AHP METHOD IN THE EVALUATION AND SELECTION OF CUTTING TOOLS USED IN MACHINING ON CNC MACHINES

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Abstract: *Processing on Computer Numerical Control (CNC) machines represents a cornerstone of modern industry, where the selection of cutting tools plays a critical role in ensuring machining process performance. This study presents the selection of cutting tools using the multicriteria Analytic Hierarchy Process (AHP) method, which enables a comparative evaluation of alternatives based on multiple, often conflicting criteria. The primary objective is to identify tools that maximize performance, minimize costs, and ensure process stability, considering factors such as durability, machining time, acquisition and repair costs, as well as logistical availability. By employing AHP, the study aims to provide a rigorous decision-making framework that supports informed and strategic decisions regarding the selection of CNC cutting tools.*

Keywords: *Multicriteria decision-making, Analytic Hierarchy Process (AHP) method, cutting tools.*

1. INTRODUCTION

In the context of Industry 4.0, manufacturing processes emphasize automation, connectivity, and optimization, with Computer Numerical Control (CNC) machines playing a central role by providing precision and efficiency in machining complex parts. Among other factors, their performance largely depends on the cutting tools used, which directly impact surface quality, machining time, and associated costs.

To better understand the theoretical and practical foundations of research and advancements in this vast field, it is essential to refer to the specialized literature. The bibliographic study provides insight into technological advancements, the materials used for cutting tools, and multicriteria decision-making methods, such as AHP, across various areas of application.

Regarding the selection of materials and cutting tools, several relatively recent studies have been identified.

Based on the observation that, due to the complex phenomena occurring during machining, no single cutting tool material can meet all requirements, article [1] presents a method for selecting cutting tools using Web Ontology Language and a knowledge graph (MCPKG) to identify the relationship between the structural characteristics of materials and cutting tools. Leveraging the connectivity within MCPKG, a personalized PageRank (PPR) algorithm is used for cutting tool selection. Additionally, a tool selection system based on B/S architecture and .NET MVC was developed for the classification of cutting tools.

Recognizing that machining complex parts requires a diverse range of tools, article [2] proposes an optimization method that takes into account various factors such as the machined entities, efficiency, cost, and environmental impact. The method for selecting tools is being developed, allowing the generation of efficient machining strategies. For optimization, the authors design an evolutionary algorithm that adapts to the specific characteristics of the part being machined. To validate the method, tests are conducted to identify the optimal tool configuration.

Another topic of interest is the optimization of machining processes, for which numerous studies have been conducted, some of which are mentioned here. For instance, article [3] proposes an integrated AHP-PROMETHEE method that enables the selection of sustainable machining strategies, with a focus on sustainability. Regarding sustainability criteria, cutting parameters and tool trajectories are considered. For the optimal selection of trajectories and working parameters, methods based on assigning weights to aspects related to ecological, economic, and social impacts are employed. The presented case study, focused on milling a critical area, confirms the theoretical findings regarding sustainability in the manufacturing industry.

Within the same thematic framework, study [4] presents a decision-making approach that combines three methods: experimental design and analysis, fuzzy data envelopment analysis (DEA), and fuzzy analytical hierarchy process (AHP). Based on machining parameters such as cutting speed, feed rate, depth of cut, and the number of cutting tool inserts, the study evaluates Material Removal Rate, Machining Time, and Surface Roughness. Following the experiments, rankings were generated to identify the best combination of factors. Since different rankings were obtained, the study concludes that expert opinion plays a crucial role in selecting machining parameters.

Similarly, the study [5] also focuses on optimizing machining processes but uses an optimization method based on a mathematical model designed to reduce machining time by minimizing tool changes. The proposed model determines the necessary set of tools and decreases the number of tool changes, achieving a 6.5% reduction in machining time, which represents a significant percentage in the mass production.

Regarding the use of multicriteria decision-making (MCDM) methods, article [6] presents the efficient selection of machine tools for industrial processes. The selection criteria for the machines are defined, and their weights are determined using the AHP method. By applying the VIKOR method, the most suitable machine is selected based on the previously established criteria and weights. The study explores several possibilities for cost reduction while simultaneously increasing profit by minimizing defects. The case study focuses on the selection of CNC machining tools and laser cutting machines, with practical aspects confirming the proposed methodology.

Study [7] presents an integrated approach combining the Analytical Hierarchy Process (AHP), Response Surface Methodology (RSM), and Proportional Hazards Model (PHM) to analyze the tool life of cutting tools. Starting from the observation that tool life directly impacts productivity and profitability, the AHP method is used to analyze critical factors, PHM estimates reliability, and RSM along with Weibull adjustments validate the model's predictions. The study also provides an estimation of the required tools, contributing to a reduction in machining costs.

Using multicriteria methods, study [8] focuses on the selection of processes for Non-Traditional Machining (NTM). The AHP as well as in the application of the fuzzy m-polar ELECTRE-I algorithm.

Cutting tools, such as milling cutters, drills, and reamers, are made from various materials, each with its own advantages and disadvantages. High-speed steel (HSS) tools are cost-effective but have limited durability. Carbide tools offer superior wear resistance, making them suitable for more demanding operating conditions, while carbide tools with PCD (polycrystalline diamond) inserts combine extreme durability with high performance, making them ideal for applications requiring precision and stability.

To select the most suitable cutting tool option, a systematic approach is essential, evaluating the alternatives (tool variants) based on factors such as costs, performance, process impact, and logistical availability.

This paper explores the use of the AHP method to identify the optimal solution that balances costs and performance, thereby contributing to the optimization of industrial processes.

2. METHODOLOGY

The Analytic Hierarchy Process (AHP) is a technique used for multicriteria decision-making [9]. It allows the structuring of a complex problem into a hierarchy of objectives, criteria, and alternatives, facilitating their comparison and prioritization. AHP is applied in various fields, such as management, strategic planning, engineering, and economics.

The problem is structured into a hierarchy consisting of three main levels:

- The general objective (decision goal);
- Evaluation criteria;
- Possible alternatives.

The next step involves constructing a pairwise comparison matrix. The criteria and alternatives are compared in pairs, and a score is assigned based on their relative importance, using a scale from 1 to 9 [10]. The pairwise comparison matrix is structured as follows:

$$A = \begin{array}{c} \\ C_1 \\ C_2 \\ \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & & C_n \end{array} \\ \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \end{array} \qquad (1)$$

where a_{ij} represents the relative importance of criterion i i compared to j.

The priority vector is determined by calculating the maximum eigenvalue and its associated eigenvector:

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}} \qquad (2)$$

To verify consistency, the consistency index (CI) and the consistency ratio (CR) are calculated to ensure that the judgments are coherent:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \qquad (3)$$

The consistency ratio (CR) is determined using the formula:

$$CR = \frac{CI}{RI} \qquad (4)$$

where n is the number of criteria, λmax is the largest or principal eigenvalue, and RI is the random consistency index, specific to the value of n. Consistency is considered acceptable if CR<0.1.

The final ranking of the alternatives is achieved by combining the priority weights of the criteria with those of the alternatives.

The selection of optimal cutting tools and evaluation criteria was guided by a systematic analysis of critical factors influencing machining efficiency, cost-effectiveness, and process stability. The following key criteria were prioritized based on their industrial and academic relevance: the costs, performance, impact on the process and availability and logistics. For the tool alternatives, we focused on three widely adopted and technologically distinct options, each offering unique trade-offs between cost and performance: High Speed Steel (HSS), carbide tools and carbide tools with polycrystal diamonds inserts (PCD).

Identified criteria:

C1 - Costs: Includes the purchase cost of the tools and the repair cost of worn tools.

C2 - Performance: Considers tool durability, processing time per part, and the quality of the machined surface.

C3 - Impact on the process: Includes the frequency of stops required for tool changes, the time needed for tool changes and process validation, and the ability to maintain dimensions and surface roughness within tolerance limits.

C4 - Availability and logistics: Includes the delivery time of the tools, the need for a backup stock due to long delivery times, and the impact on the process if tools are not immediately available.

Alternatives (variants):

V1 - Carbide with PCD inserts

V2 - Carbide 100%

V3 - HSS (High-Speed Steel)

The hierarchical structure is presented in Fig. 1.

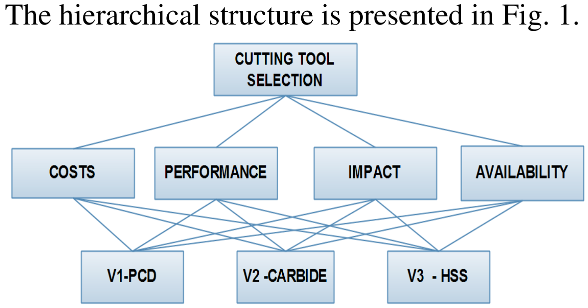

Fig. 1. AHP Structure.

3. RESULTS

Using the methodology described earlier, Table 1 presents the preference matrix for the criteria, while Table 2 shows the normalized matrix, with the last column representing the calculated eigenvector values (weights w).

Table 1

The preference matrix for the criteria.

	C1	C2	C3	C4
C1	1	1/5	1/2	2
C2	5	1	2	7
C3	2	1/2	1	4
C4	1/2	1/7	1/4	1

Table 2

Normalized matrix.

	C1	C2	C3	C4	wc
C1	0.118	0.109	0.133	0.143	0.126
C2	0.588	0.543	0.533	0.500	0.541
C3	0.235	0.271	0.267	0.286	0.265
C4	0.059	0.078	0.067	0.071	0.069

The consistency of the comparisons was determined, resulting in:

$\lambda max = 4.0122$; $CI = 0.0041$; $CR = 0.0045$

The value $CR<0.1$ certifies that the evaluations within the AHP process are consistent.

Fig. 2 presents the weight of the comparison criteria.

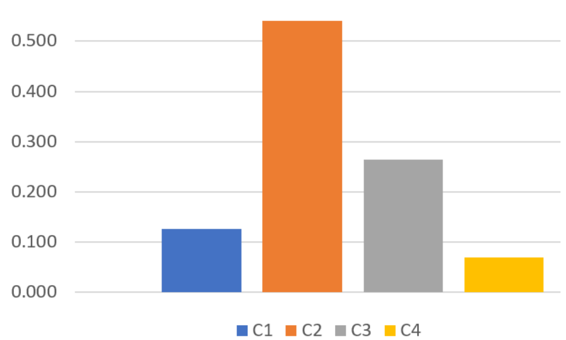

Fig. 2. The weight of the comparison criteria.

In Tables 3 – 6, the preference matrices for pairwise comparison of the alternative variants for each criterion are presented. The last column shows the calculated values for each variant. Additionally, the consistency values are also provided.

Table 3

Pairwise comparison matrix of alternatives for criterion C1 - Costs

C1	V1	V2	V3	wc1
V1	1	1/3	1/4	0.120
V2	3	1	1/3	0.272
V3	4	3	1	0.608
λmax	CI	CR		
3.0741	0.0371	0.0713		

Table 4

Pairwise comparison matrix of the alternatives for criterion C2 - Performances

C2	V1	V2	V3	wc2
V1	1	4	7	0.688
V2	1/4	1	4	0.234
V3	1/7	1/4	1	0.078
λmax	CI	CR		
3.0775	0.0387	0.0745		

Table 5

Pairwise comparison matrix of the variants for criterion C3 - Impact

C3	V1	V2	V3	wc3
V1	1	3	6	0.639
V2	1/3	1	4	0.274
V3	1/6	1/4	1	0.087
λmax	CI	CR		
3.0540	0.0270	0.0520		

Table 6

Pairwise comparison matrix of alternatives for criterion C4 - Availability

C4	V1	V2	V3	wc4
V1	1	4	4	0.655
V2	1/4	1	2	0.211
V3	1/4	1/2	1	0.133
λmax	CI	CR		
3.0541	0.0270	0.0520		

Having calculated the weights for the criteria and the weights of the alternatives for each criterion, the weight of the alternatives is determined (Table 7) and the graphical representation in Fig. 3.

Table 7

Ranking of variants

Nr.	V2	wv
1	V1 – Carbide tool with PCD	0.5181
2	V2 - 100% Carbide tool	0.2763
3	V3 - HSS	0.2056

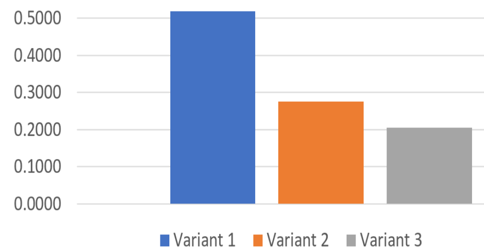

Fig. 3. Weight of the variants.

4. DISCUSSIONS

To evaluate the stability and robustness of the results, a sensitivity analysis is recommended. This aims to identify the impact of changes in input parameters (e.g., criterion preferences), the variables with the greatest influence, and the viability of the solution before implementation. A sensitivity method is proposed in [10]. The method uses a coefficient α > 0, which is used to raise the elements of the comparison matrix to the power of α without altering the criteria preferences. The coefficient α is a specific instrument of the sensitivity analysis methodology adopted from reference [10], having the role of systematically perturbing the intensity of the expressed preferences, thus allowing for the evaluation of the stability of the AHP method's results For α > 1, the weights are more dispersed, while for 0 < α < 1, they are more concentrated. The analyzed values for α are: 0.5, 0.7, 0.9, 1, 1.1, 1.3, 1.5. The results are synthesized in Table 8 and Fig. 4, and the variation of weights as a function of α is illustrated in Fig. 5.

Table 8

The sensitivity of the weight of evaluation criteria

	0.5	0.7	0.9	1	1.1	1.3	1.5
C1	0.189	0.163	0.137	0.125	0.114	0.093	0.075
C2	0.394	0.454	0.5129	0.541	0.568	0.619	0.665
C3	0.275	0.275	0.269	0.264	0.259	0.245	0.229
C4	0.140	0.106	0.079	0.068	0.058	0.042	0.030

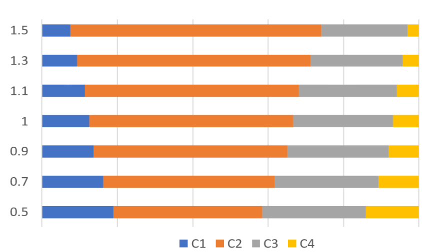

Fig. 4. Weight of the criteria based on the coefficient α.

From Fig. 4, it can be observed that the weight of the criteria does not change depending on the values of the coefficient α, and from Fig. 5, it can be noted that for different values of the coefficient α, the hierarchy of the variants does not change, which means that the analysis is robust, and variant 1 is the most favorable for the proposed purpose.

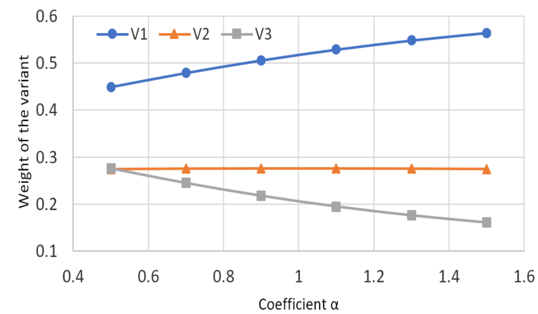

Fig. 5. Weight of the variants based on the coefficient α.

5. CONCLUSION

The study analyzes the selection of cutting tools using the AHP (Analytic Hierarchy Process) method to support decision-making in the process of acquiring a tool system. The results show that carbide tools with PCD inserts (V1) are the most suitable choice, offering a good balance between the considered criteria. The applied methodology is well-founded, and the sensitivity analysis confirms the robustness of the results, demonstrating that the hierarchy of options remains constant even under varying parameter conditions.

However, the study presents some limitations acknowledged at this time. The study is based on analyses and experiences collected from specialized firms. For this reason, a detailed economic analysis, which would include real data collected from the beneficiary, was not conducted. Secondly, the AHP method, although robust, can introduce some variability. To increase confidence in the obtained results, it is intended to complement the AHP method with another multicriteria method to confirm the ranking of the alternatives.

In the short term, the main goal of the study is the acquisition of the tool system, and the proposed methodology provides a solid framework for decision-making. In the long term, the aim is to complete the analysis with real economic calculations based on the performance of the tools in production, and to extend the study to include other optimization and validation methods.

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Utilizarea metodei AHP în evaluarea și selectarea sculelor așchietoare utilizate la prelucrări pe mașini - unelte CNC

Prelucrarea pe mașini unelte cu comandă numerică (CNC) reprezintă un pilon central al industriei moderne, iar alegerea sculelor așchietoare are un rol important în asigurarea performanței procesului de prelucrare. În acest studiu se prezintă selecția sculelor așchietoare prin utilizarea metodei multicriteriale Analytic Hierarchy Process (AHP), care permite evaluarea comparativă a alternativelor pe baza unor criterii multiple și adesea conflictuale. Scopul principal este de a identifica sculele care maximizează performanța, minimizează costurile și asigură stabilitatea procesului, ținând cont de factori pre cum durabilitatea, timpul de prelucrare, costurile de achiziție și reparație, precum și disponibilitatea logistică. Prin utilizarea AHP, se urmărește furnizarea unui cadru decizional riguros, care să asigure luarea unor decizii informate și strategice privind selecția sculelor CNC.

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