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Using multi-criteria decisions for the selection of computer-aided manufacturing software using the AHP method

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Abstract. In the context of Industry 4.0, selecting the right Computer-Aided Manufacturing (CAM) software is crucial for optimizing production processes. This article delves into the fundamental aspects of CAM software, selection criteria, and the application of the Analytic Hierarchy Process (AHP) in multi-criteria decision-making. CAM software is an essential tool that facilitates the transformation of Computer-Aided Design (CAD) models into precise machine instructions, contributing to production efficiency and quality. 1 Key selection criteria for CAM software include functionality, compatibility with existing equipment, implementation and maintenance costs, and technical support. These criteria are often complex and interconnected, necessitating a systematic approach to the decision-making process. The AHP method is an efficient tool for structuring and evaluating these criteria. The article highlights the importance of applying AHP in multicriteria decisions, demonstrating how it can facilitate the choice of CAM software that best meets the specific needs of an organization.

Keywords: multi-criteria decisions, manufacturing technologies.

1. Introduction

The transition to digital manufacturing, characteristic of the current development period, is essential for companies aiming to streamline production. Computer Aided Manufacturing (CAM) applications generate tool paths for machining on numerically controlled machine tools. CAM applications facilitate the transition from the virtual product, created during the design phase with the help of Computer Aided Design (CAD) applications, to the manufacturing phase of CNC (Computer Numerical Control) machine tools. In the context of Industry 4.0, this CAD-CAM-

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CNC integration enables process optimization and reduces the time-to-market for products.

For companies aiming to optimize production and improve efficiency, selecting CAM software products is a complex process influenced by multiple variables. Decisions regarding the choice of CAM software not only affect initial costs but also have long-term implications on operational efficiency, product quality, and customer satisfaction.

There is a wide variety of CAM software on the market, each with specific features and functionalities. From simple solutions focused on basic machining to advanced applications that integrate artificial intelligence and data analysis, choosing an appropriate product can significantly influence a company's performance. This diversity necessitates a careful evaluation of the available options to identify the most suitable solution for each organization's specific needs. Decisions regarding the selection of CAM software have long-term implications, as, in addition to initial costs, there may also be costs related to usage efficiency, product quality, customer satisfaction, and the benefits provided.

According to [1], for the selection of software products, given the large number of options, it is necessary to use multicriteria decision-making methods. One of the methods recommended in this article is the Analytic Hierarchy Process (AHP). The method used to quantify the weights of decision criteria through pairwise comparisons is a structured technique for organizing and analyzing complex decisions [2].

The specialized literature records a series of case studies that illustrate the use of the AHP method in solving multicriteria decision-making problems.

In article [3], an algorithm based on the Analytic Hierarchy Process (AHP) is proposed to evaluate software functionality. Software functionality refers to the product's ability to perform various functions. Two options are examined: the first involves a pairwise comparison using three functionality criteria and three alternatives to determine which criterion is superior, while the second option extends the analysis to five software programs, five functionality criteria, and five alternatives, thus identifying the superior criterion and the best software. This approach ensures the correct and precise functioning of the program, as supported by experience and obtained results.

Article [4] proposes a new approach to the AHP method for evaluating environmental impact. Using the AHP method, which offers the flexibility to integrate both quantitative and qualitative factors, manage diverse groups of stakeholders, and combine opinions expressed by multiple experts, a case study is addressed that focuses on evaluating economic impact. In this study, AHP was used to capture stakeholders' perceptions regarding the relative severity of various socio-economic impacts on the environment for the purpose of mitigating negative effects.

Starting from the observation that, in a complex economic context, when applying the AHP method, the number of criteria can become very large, complicating the decision-making process, in the author [5] explores methods to reduce the number of factors considered in the decision-making process by using geopolitical determinants as criteria. The importance of the quality of final decisions is emphasized, which should not be affected by the limitations on the quantity of criteria analyzed. This approach helps ensure an efficient and well-founded decision-making process.

In an organization, the management of the information system plays an essential role in conducting activities, as it ensures the rapid and accurate transmission of information. In article [6], the use of the AHP method is proposed for analyzing the criteria for selecting the information system in a manufacturing company. The necessity of information transfer, management, and information systems lies in identifying and reviewing criteria to ensure flexibility and quality of the process. In addition to the criteria for choosing an information system, it is also important to protect informational assets, which involves identifying and analyzing risk criteria related to the security of selected processes.

To establish a connection with customers, various software solutions are used; however, selecting the best option represents a multicriteria decision-making problem. Article [7] presents an integrated model based on one of the most effective decision-making methods, the Analytic Hierarchy Process (AHP), combined with the Quality Function Deployment (QFD) tool. This combination is a structured method for translating customer requirements into technical specifications and implementing them in products and services. Integrating these two methods allows for the creation of a reliable model to assist in complex decisions that can determine the success or failure of a new venture.

Another use of the AHP method for evaluating and selecting forecasting software is presented in the study [8]. To streamline the effort associated with the calculations of this method, the authors use a commercial software called Expert Choice. The article also presents sensitivity studies that confirm the accuracy of the calculations.

The process of selecting the right software is vital for a company's future growth and competitiveness. Additionally, the choice of project management software has a significant impact on the successful operation and control of projects. Project management software is essential for organizations, helping them manage projects efficiently, reduce costs, shorten delivery times, and better meet customer requirements. Article [9] presents the selection of project management software using the AHP method. Experts identified selection criteria for three widely used project management software packages: HP-PPM, MS-Project, and Primavera. These criteria were evaluated by five project managers from different companies for the three tools. The results indicated which option was the most suitable among the three of the interviewed companies.

The study [9] analyzes the efficiency of the Analytic Hierarchy Process (AHP) in the selection of project management software for a technology company. Essential criteria for choosing project management software are identified and examined, utilizing evaluations from industry experts and conducting pairwise comparisons. The methodology uses the perspectives of management professionals to determine the most relevant criteria, which include functionality, usage patterns, costs and pricing, integration capabilities, and support reliability. The results suggest that functionality and usability are the most influential criteria guiding the selection process. The application of AHP allowed for a quantitative evaluation of different software options, ultimately recommending a specific tool that best aligns with organizational needs and enhances operational efficiency. The study concludes that the AHP method provides a robust framework for making informed decisions, suggesting its extended applicability in similar decision-making scenarios.

Selecting the appropriate CAD software for product design is a crucial issue faced by companies. Considering the numerous criteria involved in the selection process, such as the cost of the package, ease of use, software popularity, offered functionalities, and system requirements, choosing the right CAD software is not an easy task. The difficulty is amplified by the availability of a large number of commercial packages on the market. Selecting the most suitable software application represents a multicriteria decision-making problem, which is addressed using the AHP method. Given that CAD software can be highly specialized and vary significantly depending on the field of application, this study will focus on CAD software intended for mechanical design applications, analyzing some of the most popular CAD packages [11].

From the analysis of the presented studies, it can be concluded that the AHP (Analytic Hierarchy Process) method is used due to its ability to structure and simplify complex decisions. The article presents a case study for selecting CAM software for a research laboratory in the field of manufacturing. Research laboratories face high demands for efficiency and precision in their activities.

2.Method

According to [2], the Analytic Hierarchy Process (AHP) is a technique for organizing and analyzing complex decisions, developed by Thomas Saaty in 1980. AHP is based on a well-defined mathematical structure and allows for the ranking of decision alternatives and the selection of the best option when the decision must be made based on multiple criteria. After defining the criteria, an important aspect is how to define the weights for each of the selected criteria according to their importance. In the AHP method, criteria are compared in pairs, which makes the method more reliable than assessing the importance and weight of criteria as a whole

According to [13], the main steps involved in applying the method are:

- defining the structure to be analyzed: establishing criteria and subcriteria, and determining the variants (alternatives)
- hierarchizing the criteria by comparing them in pairs
- hierarchizing by pairwise comparison of the alternatives based on each criterion
- obtaining the performance matrix, calculating the final score, and making the decision.

The preference matrix is created by pairwise comparison of two criteria or two alternatives, assigning scores from 1 to 9 (table 1).

Table 1. A pairwise comparison scale
used for ranking in the AHP method [2]

Scor	Description
1	Equally preferred
2	Equal to moderate
3	Moderately preferred
4	Moderate to strong
5	Strong favorite
6	Strong to very strong
7	Very strongly preferred
8	Very strong to extremely preferred

The preference matrix has the form:

$$\begin{matrix} & & C_1 & C_2 & & C_n \\ C_1 & & & & & \\ C_2 & A= & & & & \\ \\ C_n & & & & & \end{matrix} \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

- C_1, C_2,...C_n - The criteria to be compared
- a_{ij} - the importance given to criterion Ci (row i) compared to criterion Cj (column j)
- for $i=j$ a criterion is compared with itself (diagonal of the matrix), as a result the value is 1

Basically, the matrix A is defined by the ratio between the preference of criterion *"i"* and the preference of criterion *"j"*, that is:

$$a_{ij} = \frac{c_i}{c_j} \text{ (2)} \quad (2)$$

c_i and c_j represent the preferences of criterion C_i and criterion C_j, respectively.

$$A = \begin{bmatrix} \frac{c_1}{c_1} & \frac{c_1}{c_2} & \dots & \frac{c_1}{c_n} \\ \frac{c_2}{c_1} & \frac{c_2}{c_2} & \dots & \frac{c_2}{c_n} \\ \dots & \dots & \dots & .. \\ \frac{c_n}{c_1} & \frac{c_n}{c_2} & \dots & \frac{c_n}{c_1} \end{bmatrix} \quad (3)$$

In the Analytic Hierarchy Process (AHP) method, preferences are reciprocal. If criterion C_i is *'x'* times more important than criterion C_j (meaning element $a_{ij} = x$), then criterion C_j (row *j*) has a value of *1/x* relative to criterion C_i (meaning element $a_{ji} = 1/x$).
The values of the elements below the diagonal of the comparison matrix are the reciprocals of those above the diagonal.

$$A = \begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ \dfrac{1}{a_{12}} & 1 & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ \dfrac{1}{a_{n1}} & a_{n2} & \ldots & 1 \end{bmatrix} \tag{4}$$

Once the comparisons between criteria are finalized, they are standardized using the normalized arithmetic mean method [2]. This results in matrix B, with elements calculated as follows:

$$b_{ij} = \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}} \tag{5}$$

The resulting matrix has the form:

$$B = \left| \begin{array}{cccccc} \dfrac{a_{11}}{\sum_{i=1}^{n} a_{n1}} & \dfrac{a_{12}}{\sum_{i=1}^{n} a_{n2}} & \dfrac{a_{13}}{\sum_{i=1}^{n} a_{n3}} & \dfrac{a_{14}}{\sum_{i=1}^{n} a_{n4}} & & \dfrac{a_{1n}}{\sum_{i=1}^{n} a_{nn}} \\ \dfrac{a_{21}}{\sum_{i=1}^{n} a_{n1}} & \dfrac{a_{22}}{\sum_{i=1}^{n} a_{n2}} & \dfrac{a_{23}}{\sum_{i=1}^{n} a_{n3}} & \dfrac{a_{24}}{\sum_{i=1}^{n} a_{n3}} & & \dfrac{a_{2n}}{\sum_{i=1}^{n} a_{nn}} \\ \dfrac{a_{31}}{\sum_{i=1}^{n} a_{n1}} & \dfrac{a_{32}}{\sum_{i=1}^{n} a_{n2}} & \dfrac{a_{33}}{\sum_{i=1}^{n} a_{n3}} & \dfrac{a_{34}}{\sum_{i=1}^{n} a_{n4}} & \ldots & \dfrac{a_{3n}}{\sum_{i=1}^{n} a_{nn}} \\ \dfrac{a_{41}}{\sum_{i=1}^{n} a_{n1}} & \dfrac{a_{42}}{\sum_{i=1}^{n} a_{n2}} & \dfrac{a_{43}}{\sum_{i=1}^{n} a_{n3}} & \dfrac{a_{44}}{\sum_{i=1}^{n} a_{n4}} & \ldots & \dfrac{a_{4n}}{\sum_{i=1}^{n} a_{nn}} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \dfrac{a_{n1}}{\sum_{i=1}^{n} a_{n1}} & \dfrac{a_{n2}}{\sum_{i=1}^{n} a_{n2}} & \dfrac{a_{n3}}{\sum_{i=1}^{n} a_{n3}} & \dfrac{a_{n4}}{\sum_{i=1}^{n} a_{n4}} & \ldots & \dfrac{a_{n}}{\sum_{i=1}^{n} a_{nn}} \end{array} \right| \tag{6}$$

The calculation of the relative priority (weight) (wi) is done with the relationship indicated in [14]:

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{7}$$

where *n* represents the number of crisscrosses (or alternatives)

This calculation method gives very good results but requires high consistency of pairwise comparisons. The calculation of relative priority is validated after analyzing the consistency of opinions. This analysis is necessary because there may be criteria whose preference value has been erroneously indicated.

The value of the eigenvector λ_{max} is calculated

$$\lambda_{\max} = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{(A \cdot W)_i}{w_i} \tag{8}$$

where *A* is the criteria comparison matrix, and *W* is the relative priorities matrix formed by the w_i elements.

The Relative Consistency Index (CI) is determined with the relationship:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{9}$$

The consistency ratio is determined with the relationship:

$$CR = \frac{CI}{RI} \tag{10}$$

RI stands for the Random Value of the Consistency Index which is tabularly determined according to the number of criteria (table 2) [15].

Table 2. The values of the random variable (Random Index Value)

N	1	2	3	4	5	6	7	8	9	10
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

If CR<0.1 it is considered that the evaluation is consistent, in this case the decision matrix (*X*) of the form can be determined:

$$X = C \cdot W \tag{11}$$

where:

C is the matrix of the relative weights of the variants according to each criterion

W is the matrix of priorities relative to the pairwise comparison of the criteria.

3. Choice of comparison criteria

In defining the evaluation criteria, we started from the observation that the research laboratory requires software solutions that enable the testing of products, equipment, and manufacturing processes, optimize the quality of results, but also allow for further development and facilitate innovation to remain competitive in a constantly changing environment

The definition of comparison criteria for the mentioned software was influenced by the evaluations on the G2 platform. This is because they represent the direct opinions of users who have experienced these software products in their work environment, referring to aspects such as integration with other CAD/CAM systems, support for different types of processing, etc. These reviews allow for obtaining information about the behavior of each software and its performance in practice, which helps to identify relevant comparison criteria based on real experiences rather than subjective impressions, contributing to a more informed selection of software. The selected criteria are as follows:

- C1. CAD-CAM Import:
- *C2. CAM Data Exchange*
- *C3. CAD/CAM Compatibility*
- *C4. CNC Workflows*
- *C5. CNC Feature Recognition*
- *C6. Programming Control*
- *C7. Job Set-up*
- *C8. Operations*
- *C9. Tooling and Toolpaths*

It is appreciated that a CAM software that offers advanced functionality can reduce tool wear and improve the quality of manufactured parts.

4. Choosing the variants (alternatives) to compare

As previously mentioned, selecting software is a complex process influenced by numerous factors. Choosing the right software involves evaluating multiple criteria such as ease of use, offered functionalities, compatibility with existing equipment, and technical support.

Another important aspect is the software's ability to facilitate collaboration between different research teams in interdisciplinary projects. The easy integration and sharing of data and results among teams can significantly improve collaboration efficiency. The market offers a variety of software packages dedicated to manufacturing, each with its own advantages and disadvantages. Choosing the right software requires a detailed analysis of the available options, comparing functionalities, and selecting the solution that best aligns with specific needs.

From the multitude of CAM applications available on the market, due to their popularity and extensive capabilities in the manufacturing and computer-aided design industry, Siemens NX CAM, Fusion 360, SolidCAM, and SolidWorks CAM have been selected for comparison. These applications provide a balanced comparison between top industry solutions.

- *V1 - NX CAM* is renowed for its advanced machining capabilities and tight integration with other Siemens solutions, providing a robust platform for manufacturing and engineering. It is widely used in industries such as aerospace and power generation. It offers comprehensive solutions for CNC programming, simulation, and manufacturing process integration. [18, 19, 20].
- *V2 - Autodesk Fusion 360* provides a comprehensive cloud-based CAD/CAM solution, offering accessibility and flexibility to users. It is appreciated for its intuitive interface and low licensing costs. [21, 22]
- *V3 - SolidCAM* is integrated with SolidWorks, providing machining functionality and support for various CNC machining operations, even 5-axis machining [22], [23].
- *V4 - SolidWorks CAM* is an extension of SolidWorks, with which it forms an integrated solution for design and machining. It is ideal for users who want to stay in the SolidWorks system. [22]

These software applications are the top four ranked on the G2 platform, based on reviews and opinions from users in mid-sized companies (up to 1000 employees). G2 is an independent review site that compares software applications based on various criteria, providing insights into the advantages and disadvantages of each.
When selecting a CAM application for the research laboratory, reviews provided by mid-sized companies (up to 1000 employees) were considered relevant. This segment represents a significant portion of the industry and has complex needs regarding integration with other software systems (ERP or CAD) as well as CNC machine tool processing. It was assessed that evaluating a CAM software intended for this segment of companies accurately reflects the needs of most industrial users.

5. Results

Fig.1 shows the hierarchical structure for the AHP method. The objective, criteria and software variants (alternatives) are defined.
According to the presented methodology, the criteria are compared pairwise based on their assigned importance. The results of these comparisons are presented in the preference matrix (matrix A) in Table 3. Table 4 presents the normalized matrix B after performing the calculations imposed by relation (6). The last column represents the calculated values of the eigenvector (weight w).

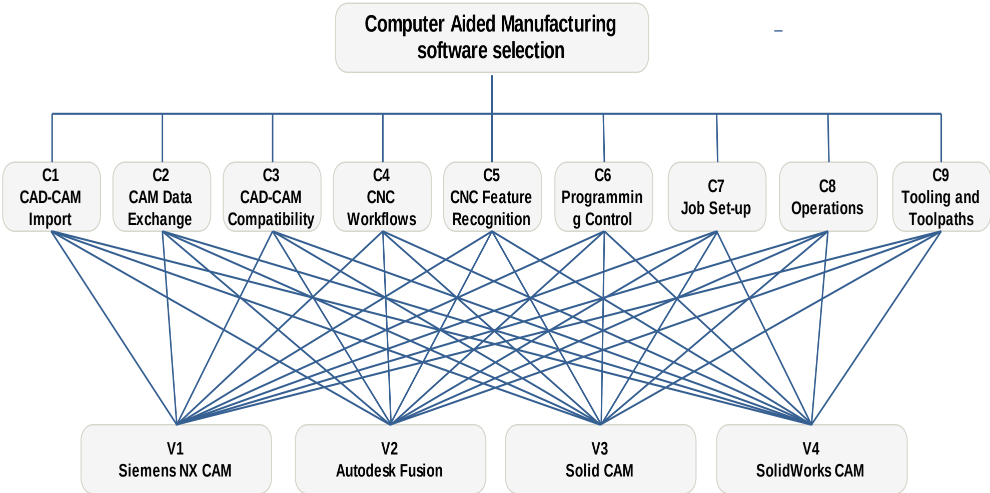

Fig. 1. Hierarchical structure.

Table 3. Preference matrix (matrix A)

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
C1	1	2	2	5	5	4	7	7	9
C2	1/2	1	1	3	4	3	5	6	8
C3	1/2	1	1	2	3	2	4	7	9
C4	1/5	1/3	1/2	1	1	1	2	3	5
C5	1/5	1/4	1/2	1	1	1	2	2	4
C6	1/4	1/3	1/2	1	1	1	2	3	6
C7	1/7	1/5	1/4	1/2	1/2	1/2	1	3	3
C8	1/7	1/6	1/7	1/3	1/2	1/3	1/3	1	1
C9	1/9	1/8	1/9	1/5	1/4	1/6	1/3	1	1

Table 4. Normalized matrix (matrix B)

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**w**
C1	0.3282	0.3698	0.3331	0.3563	0.3077	0.3077	0.2958	0.2121	0.1957	0.3007
C2	0.1641	0.1849	0.1666	0.2138	0.2462	0.2308	0.2113	0.1818	0.1739	0.1970

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**w**
C3	0.1641	0.1849	0.1666	0.1425	0.1846	0.1538	0.1690	0.2121	0.1957	0.1748
C4	0.0656	0.0616	0.0833	0.0713	0.0615	0.0769	0.0845	0.0909	0.1087	0.0783
C5	0.0656	0.0462	0.0833	0.0713	0.0615	0.0769	0.0845	0.0606	0.0870	0.0708
C6	0.0821	0.0616	0.0833	0.0713	0.0615	0.0769	0.0845	0.0909	0.1304	0.0825
C7	0.0469	0.0370	0.0416	0.0356	0.0308	0.0385	0.0423	0.0909	0.0652	0.0476
C8	0.0469	0.0308	0.0238	0.0238	0.0308	0.0256	0.0141	0.0303	0.0217	0.0275
C9	0.0365	0.0231	0.0185	0.0143	0.0154	0.0128	0.0141	0.0303	0.0217	0.0207

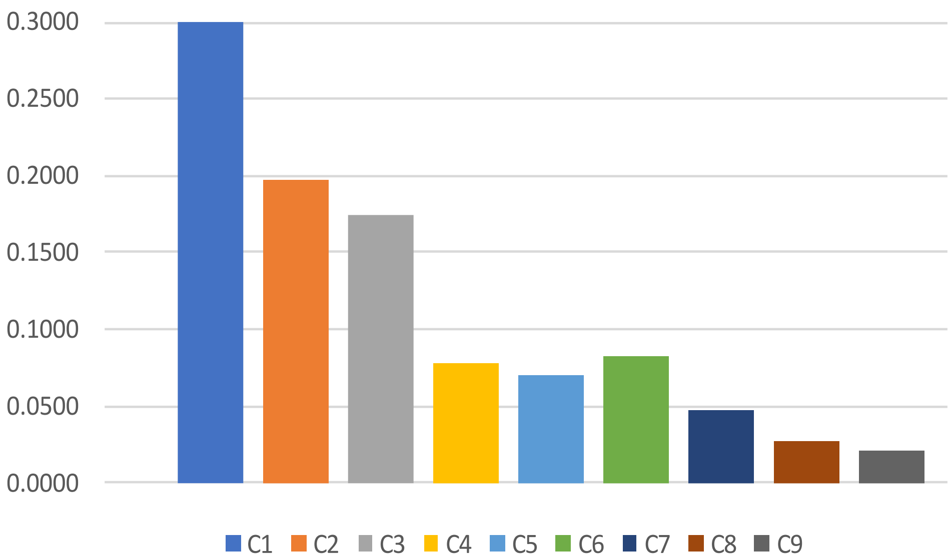

Fig. 2. The weight of the comparison criteria

The consistency of the comparisons was determined using relations (8), (9), (10), obtaining:

$$\lambda_{max} = 9.27212; CI = 0.03402; CR = 0.02346$$

It is observed that the *CR* value is less than 0.1, confirming that the evaluations within the AHP process are consistent, and the obtained results are reliable to support selection decisions.

Tables 5 to 13 present, for each criterion, the preference matrices used for pairwise comparisons of the evaluated software alternatives. The last column contains the calculated weight values. Below each table, the calculated consistency values (λ_{max}, *CI*, *CR*) are indicated.

Table 5. Results of the pairwise comparison of the variants according to the C1 criterion

C1-CAD-CAM Import	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	4	4	5	0.589
AutodeskFusion	1/4	1	1	1	0.139
SolidCAM	1/4	1	1	1	0.139
SolidWorksCAM	1/5	1	1	1	0.132
Lambda	**CI**	**CR**			
4.01	0.002078	0.002334			

Table 6. The results of the pairwise comparison of the variants according to the C2 criterion

C2-CAM DataExchange	SiemensN XCAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	4	5	5	0.607
AutodeskFusion	1/4	1	1	1	0.136
SolidCAM	1/5	1	1	1	0.129
SolidWorksCAM	1/5	1	1	1	0.129
Lambda	**CI**	**CR**			
4.01	0.002077	0.002334			

Table 7. The results of the pairwise comparison of the variants according to the C3 criterion

C3-CAD-AM Compatibility	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	3	3	6	0.538
AutodeskFusion	1/3	1	1	3	0.200
SolidCAM	1/3	1	1	2	0.179
SolidWorksCAM	1/6	1/3	1/2	1	0.082
Lambda	**CI**	**CR**			
4.02	0.006895	0.007747			

Table 8. The results of the pairwise comparison of the variants according to the C4 criterion

C4-CNCWorkflows	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	3	3	4	0.513
AutodeskFusion	1/3	1	1/2	1	0.135
SolidCAM	1/3	2	1	2	0.227
SolidWorksCAM	1/4	1	1/2	1	0.125
Lambda	**CI**	**CR**			
4.05	0.015277	0.017166			

Table 9. Results of the pairwise comparison of the variants according to the C5 criterion

C5- CNC Feature Recognition	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	3	3	4	0.513
AutodeskFusion	1/3	1	1/2	1	0.135
SolidCAM	1/3	2	1	2	0.227
SolidWorksCAM	1/4	1	1/2	1	0.125
Lambda	**CI**	**CR**			
4.05	0.015277	0.017166			

Table 10. Results of the pairwise comparison of the variants according to the C6 criterion

C6- Programming Control	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	2	2	2	0.394
AutodeskFusion	1/2	1	1/2	1/2	0.141
SolidCAM	1/2	2	1	1	0.233
SolidWorksCAM	1/2	2	1	1	0.233
Lambda	**CI**	**CR**			
4.06	0.020236	0.022738			

Table 11. The results of the pairwise comparison of the variants according to the C7 criterion

C7- JobSet-up	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	3	3	3	0.491
AutodeskFusion	1/3	1	1/2	1/2	0.118
SolidCAM	1/3	2	1	1	0.195
SolidWorksCAM	1/3	2	1	1	0.195
Lambda	**CI**	**CR**			
4.06	0.020237	0.022738			

Table 12. The results of the pairwise comparison of the variants according to the C8 criterion

C8- Operations	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	2	1	4	0.377
AutodeskFusion	1/2	1	1	2	0.226
SolidCAM	1	1	1	3	0.296
SolidWorksCAM	1/4	1/2	1/3	1	0.101
Lambda	**CI**	**CR**			
4.05	0.015276	0.017164			

Table 13. The results of the pairwise comparison of the variants according to the C9 criterion

C9- Tooling and Toolpaths	SiemensNX CAM	Autodesk Fusion	SolidCAM	SolidWorks CAM	Priority w
SiemensNXCAM	1	2	4	9	0.532
AutodeskFusion	1/2	1	3	4	0.288
SolidCAM	1/4	1/3	1	2	0.117
SolidWorksCAM	1/9	1/4	1/2	1	0.063
Lambda	**CI**	**CR**			
4.02	0.007459	0.008381			

An overview of the weights of the software variants according to the selection criteria is presented in fig.3...fig.11.

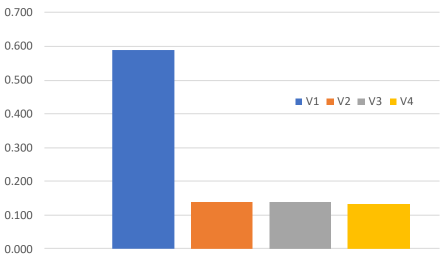

Fig. 3. Weight of variants according to C1

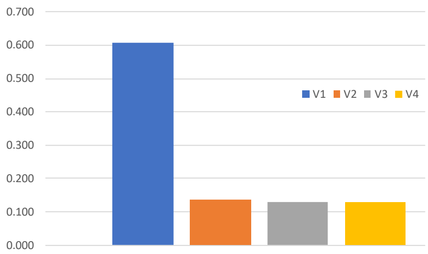

Fig. 4. Weight of variants according to C2

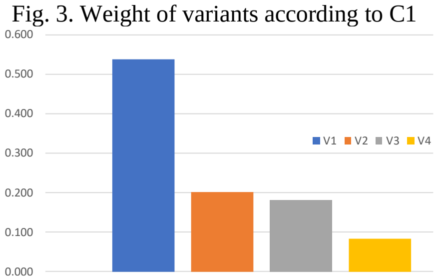

Fig. 5. Weight of variants according to C3

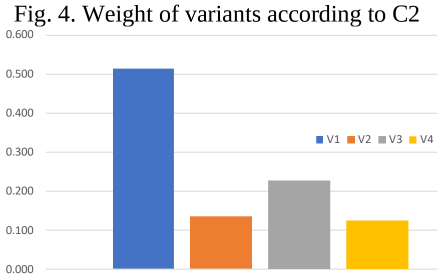

Fig. 6. Weight of variants according to C4

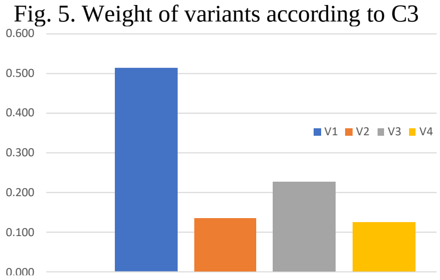

Fig. 7. Weight of variants according to C5

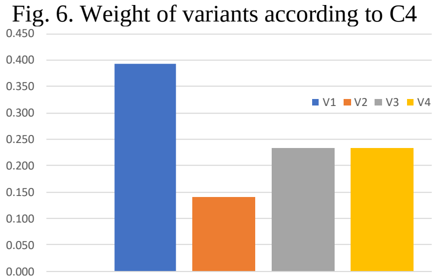

Fig. 8. Weight of variants according to C6

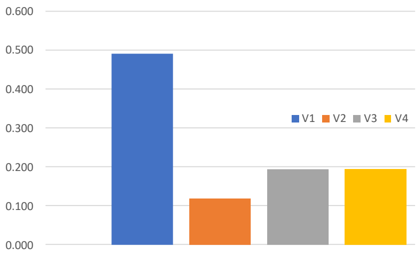

Fig. 9.Weight of variants according to C7

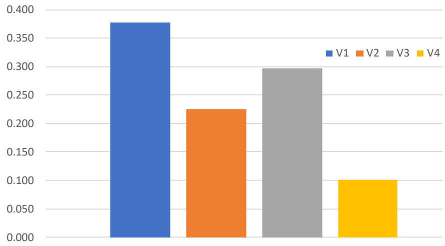

Fig. 10. Weight of variants according to C8

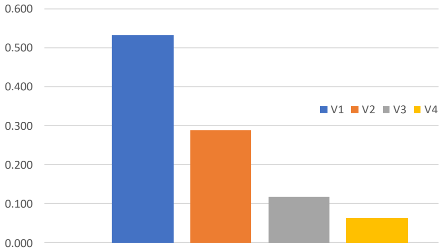

Fig. 11. Weight of variants according to C9

Tables 5...13 allow the formation of matrix C from relation (11). Matrix C represents the weight values obtained by comparing the variants according to the selection criteria.

$$C = \begin{bmatrix} 0.5890 & 0.6069 & 0.5384 & 0.5126 & 0.5126 & 0.3937 & 0.4915 & 0.3770 & 0.5321 \\ 0.1394 & 0.1361 & 0.2003 & 0.1354 & 0.1354 & 0.1413 & 0.1184 & 0.2260 & 0.2877 \\ 0.1394 & 0.1285 & 0.1795 & 0.2274 & 0.2274 & 0.2325 & 0.1951 & 0.2965 & 0.1175 \\ 0.1321 & 0.1285 & 0.0819 & 0.1246 & 0.1246 & 0.2325 & 0.1951 & 0.1005 & 0.0627 \end{bmatrix}$$

$$W = \begin{bmatrix} 0.3007 \\ 0.1970 \\ 0.1748 \\ 0.0783 \\ 0.0708 \\ 0.0825 \\ 0.0476 \\ 0.0275 \\ 0.0207 \end{bmatrix}$$

The decision matrix is obtained using relation (11):

$$X = \begin{bmatrix} 0.5445 \\ 0.1534 \\ 0.1716 \\ 0.1305 \end{bmatrix}$$

Fig. 12 shows the weights of the analyzed software variants.

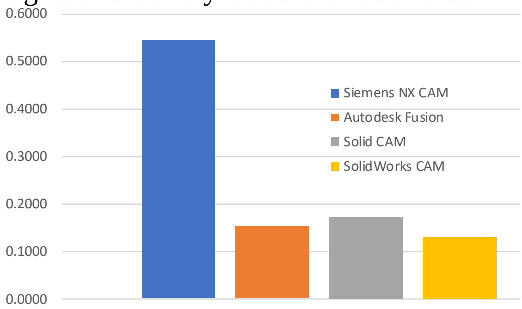

Fig. 12. The weights of the variants of the analyzed software variants

From the analysis of the graph, the ranking of the variants can be achieved (table 14), the software application that has the highest score is Siemens NX CAM.

Table 14. Ranking of variants in terms of weight

Ranking	Alternative	Soft
1	V1	SiemensNXCAM
2	V3	SolidCAM
3	V2	AutodeskFusion
4	V4	SolidWorksCAM

6. Sensitivity analysis

Although the final result of the pairwise comparisons is consistent with expert preferences, a sensitivity analysis is recommended to evaluate the stability and robustness of the obtained results. This analysis aims to identify: how certain changes in input parameters (e.g., preferences assigned to criteria) affect the final results; the variables that most influence the outcome; and the viability of the proposed solution before implementation.
A sensitivity analysis method is mentioned in [16] and described in [17]. The idea consists in using a coefficient $\alpha > 0$ and studying the weights in the situation where the elements of the comparison matrix are raised to the power of α, without changing the value of the preferences for criteria. For $\alpha > 1$, the weights are more dispersed, and for $0 < \alpha < 1$, more concentrated weights are obtained [17].
For the analysis, it was considered that the values of the coefficient α are: 0.5, 0.7, 0.9, 1, 1.1, 1.3, 1.5. The analysis involves a large volume of calculations, their result being synthetically presented in table 15 and graphically in fig.13. In fig. 14.

the variation of the weight of the variants is presented when the "α" coefficient changes.

Table 15. The results of the sensitivity analysis regarding the weight of the evaluation criteria

	α=0.5	α=0.7	α=0.9	α=1	α=1.1	α=1.3	α=1.5
C1	0.1984	0.2386	0.2799	0.3007	0.3213	0.3618	0.4007
C2	0.1609	0.1777	0.1914	0.1970	0.2018	0.2088	0.2128
C3	0.1514	0.1632	0.1718	0.1748	0.1771	0.1795	0.1794
C4	0.1010	0.0927	0.0832	0.0783	0.0733	0.0636	0.0545
C5	0.0961	0.0865	0.0760	0.0708	0.0656	0.0556	0.0465
C6	0.1034	0.0960	0.0872	0.0825	0.0778	0.0685	0.0597
C7	0.0778	0.0648	0.0530	0.0476	0.0427	0.0342	0.0272
C8	0.0595	0.0444	0.0324	0.0275	0.0233	0.0164	0.0115
C9	0.0513	0.0362	0.0251	0.0207	0.0171	0.0115	0.0077
λ	11.07	9.92	9.36	9.27212	9.32	9.80	10.862
CI	0.26	0.11	0.04	0.03402	0.04	0.10	0.233
CR	0.18	0.08	0.03	0.02346	0.03	0.07	0.161

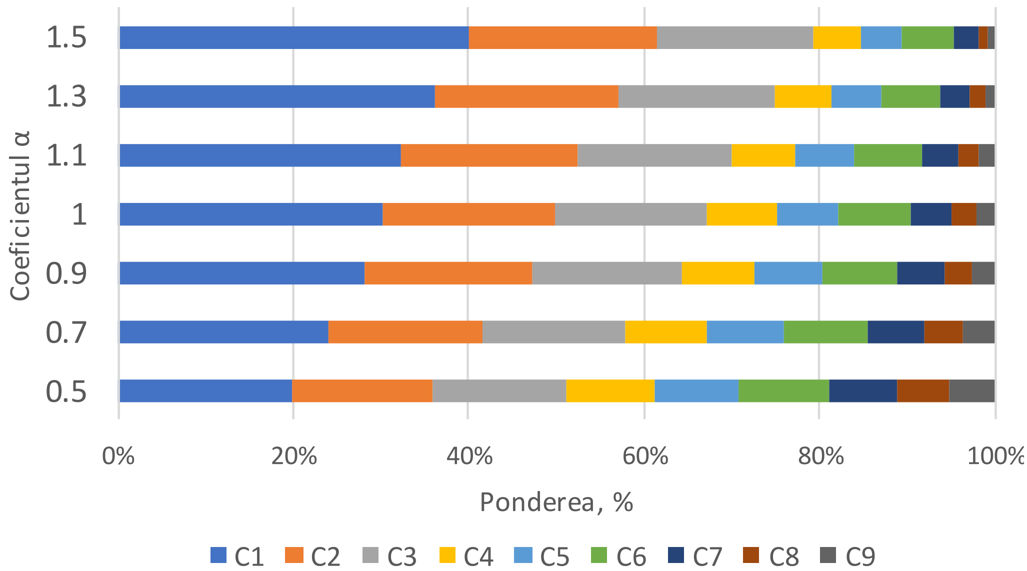

Fig. 13. The weight of the criteria according to the coefficient α

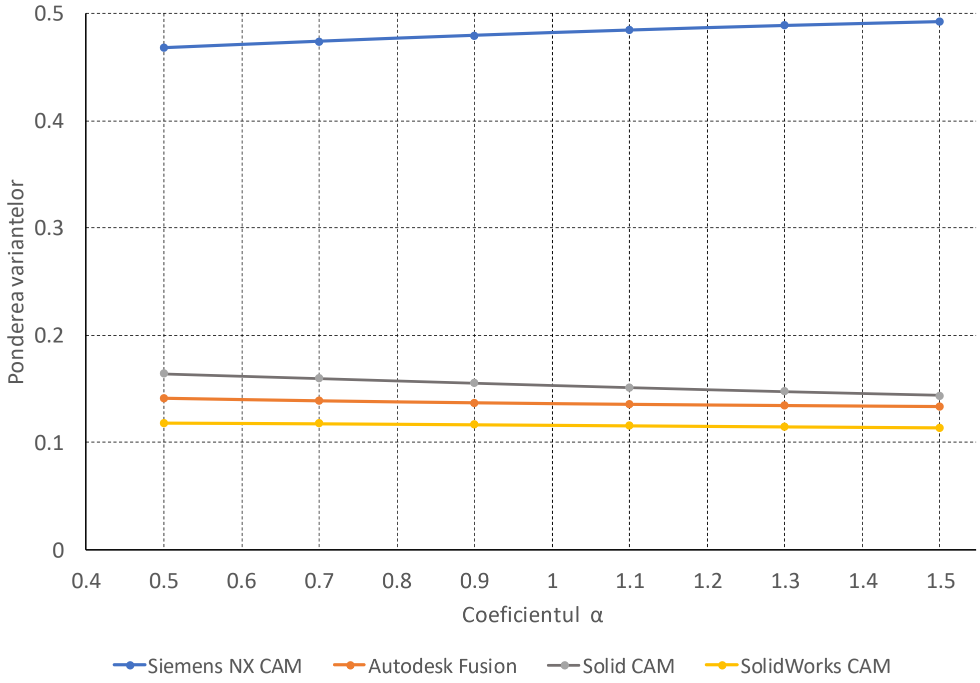

Fig. 14. The influence of the coefficient "α" on the weights of the variants.

As can be seen from fig.14, the modification of the weights of the variants in the project corresponding to the different values of the α coefficient do not change the hierarchy of the variants.

7. Cost-benefit analysis

The cost of the software variants was not included in the list of comparison criteria in order to be used in a cost-benefit analysis regarding the economic efficiency of the CAM software acquisition.

To conduct a cost-benefit analysis, the benefits and costs of each software solution are compared [24]. For the benefit, the previously obtained values are considered."

Prices for the analyzed software could not be obtained from the suppliers, as each company sets its own prices based on feature packages, licensing, and other business considerations. Comparing prices for CAD/CAM software licenses is complex, but a general estimate can be made based on price information from general comments in dedicated forums [25], [26], [27], [28], [29], [30], [31], [32], [33].

Siemens NX CAM is one of the most expensive options, for which a reference price of 100% is considered. Autodesk Fusion represents a much more affordable option, costing approximately 40% of the price of a Siemens NX CAM license. SolidCAM is situated somewhere in the middle, with a price of approximately 70% of the price of a Siemens NX CAM license. SolidWorks CAM is also more affordable than Siemens NX CAM, with a price of approximately 60% of the price of a Siemens NX CAM license. Figure 15 presents the Cost-Benefit graph for the evaluated CAM software variants. As a benefit, the values obtained through calculation in the decision matrix "X" were considered. In fig. 15 shows the Cost-Benefit graph for the evaluated CAM software variants. The values obtained by calculation in the decision matrix "X" were considered as benefit.

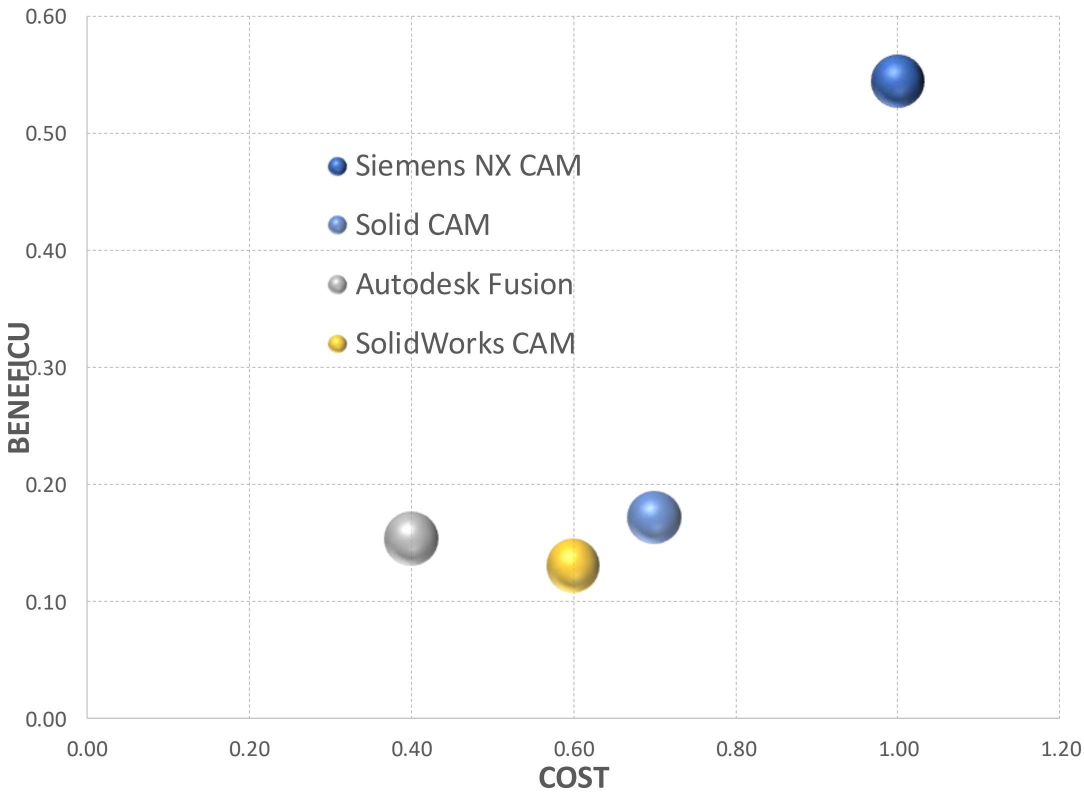

Fig. 15. Cost-Benefit Diagram.

Table 16 shows the results of the Benefit/Cost ratio according to the indications in [24]

Table 16. Results of the Benefit/Cost report.

Software	Benefit	Cost	Benefit/Cost
Siemens NX CAM	0.54	1	0.545
Autodesk Fusion	0.15	0.4	0.384
Solid CAM	0.17	0.7	0.245
SolidWorks CAM	0.13	0.6	0.217

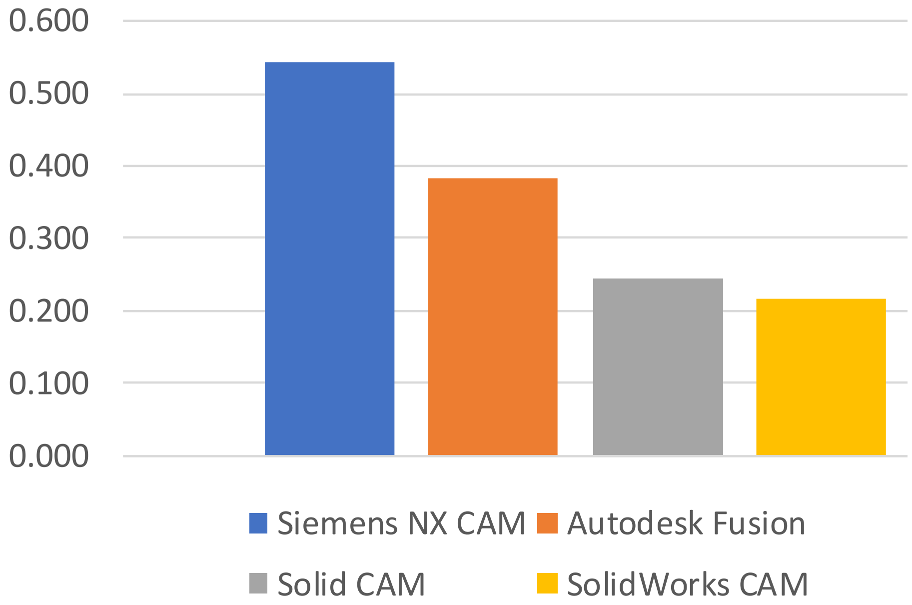

Fig. 16. Benefit/Cost Ratio

The cost-benefit analysis (Fig. 16) shows that Siemens NX CAM is the most efficient option, even though it has the highest cost, due to significantly greater benefits. Autodesk Fusion proves to be a viable alternative, while Solid CAM and SolidWorks CAM have a lower cost-benefit ratio, making them less attractive."

8. Conclusions

Acquiring CAM software is a complex task due to the multitude of offers and evaluation criteria. Prioritizing key selection factors involves making multicriteria decisions. This research paper presents a method to assist in the selection process of a software product. The selection of software variants and selection criteria was made taking into account the rankings and opinions of industry users expressed on specialized platforms and websites.

Utilizing the specialized platform G2, which presents a ranking based on user reviews of CAM software from mid-sized companies (up to 1000 employees), four CAM application variants ranked highest were selected for comparison. Selection criteria considered important from a functional performance standpoint were established.

The AHP method was employed to select the optimal CAM software variant, enabling the consideration of all evaluation criteria for the analysis. The decision-making process was based on pairwise comparisons, both between criteria and between variants. To minimize subjectivity in the decision-making process, comparative data from specialized forums and websites was used when assigning values to the elements of the preference matrices for the analyzed criteria and variants.

All stages of the AHP process recommended in the literature were followed, resulting in a final ranking that indicates the most technically beneficial option. A comparative Benefit-Cost analysis highlighted the optimal variant from an investment efficiency perspective.

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