Applied Computer Science, vol. 18, no. 4, pp. 116–129
doi: 10.35784/acs-2022-32

Submitted: 2022-11-04 | Revised: 2022-12-17 | Accepted: 2022-12-27

Keywords: accessability, efficiency, production process, maintenance, AHP, Fuzzy AHP

Piotr WITTBRODT [0000-0002-6377]*, *Iwona ŁAPUŃKA* [0000-0003-1472-1477] **, *Gulzhan BAYTIKENOVA****, *Arkadiusz GOLA* [0000-0002-2935-5003]****, *Alfiya ZAKIMOVA******

IDENTIFICATION OF THE IMPACT OF THE AVAILABILITY FACTOR ON THE EFFICIENCY OF PRODUCTION PROCESSES USING THE AHP AND FUZZY AHP METHODS

Abstract

Maintenance has a key impact on the efficiency of the production processes because the efficiency of the machines determines the ability of the system to produce in accordance with the assumed schedule. The key element of the system performance assessment remains the availability of technological equipment, which directly translates into the efficiency and effectiveness of the performed production tasks. Taking into account the dynamic nature of manufacturing processes, the proper selection of machinery and equipment for the implementation of specific production tasks becomes an issue of particular importance. The purpose of this research was to determine the impact of technical and non-technical factors on the material selection of machine tools for production tasks and to develop a method of supporting the selection of production resources using the AHP and Fuzzy AHP methods. The research was carried out in a manufacturing company from the automotive industry.

* Department of Management and Production Engineering, Faculty of Production Engineering and Logistics, Opole University of Technology,Poland, p.wittbrodt@po.edu.pl
** Department of Management and Production Engineering, Faculty of Production Engineering and Logistics, Opole University of Technology, Poland, i.lapunka@po.edu.pl
*** School of Business and Entrepreneurship, D. Serikbayev East Kazakhstan Technical University, Kazakhstan, gbaytikenova@mail.ru
**** Department of Production Computerisation and Robotisation, Faculty of Mechanical Engineering, Lublin University of Technology, Poland, a.gola@pollub.pl
***** School of Business and Entrepreneurship, D. Serikbayev East Kazakhstan Technical University, Kazakhstan, azakimova@edu.ektu.kz

1. INTRODUCTION

Current market requirements result in an increase in demand for personalized products with unique features and functionalities tailored to specific customer needs (Zubrzycki et al., 2021; Relich & Świć, 2020). Providing a wide range of products is a huge challenge for manufacturing companies, which determines the nature of the organization's activities and functioning, and above all, the type and structure of the manufacturing system (Gola, 2014). Appropriate preparation of this type of production in terms of construction, technology or organization is a significant challenge – moreover, it is not easy to control and manage such type of production (Pizon, Kulisz & Lipski, 2021; Szabelski, Karpiński & Machrowska, 2022).

In general, the implementation of production activities is carried out in two ways: in steady-state and transient conditions (Burduk et al., 2019). In the first case, it is possible to determine future production levels with high probability, and thus it is possible to develop scenarios of remedial actions for potential threats to production (Bałdowska-Witos et al., 2020). In the second case, when working conditions are unstable, it is impossible to develop action scenarios due to the variety of disruptive factors, e.g. damage to equipment and machines (Varela et al., 2018). Currently, due to changing market requirements, the second type of production dominates in enterprises. The reasons for this situation are: (1) a customer who expects personalized products - requires focusing the company's attention on trends in society, responding to the customer's wishes, suggestions and comments, and time pressure - producing the product in the shortest possible time (Swic & Gola, 2013). Meeting the requirements is an indicator of the existence of the company on the market (Vollman et al., 2005; Madu, 2000). The lack of repeatability of the series results in the lack of organizational patterns of the production structure and the accumulation of errors in its organization and management. Therefore, solutions supporting and eliminating these disturbances should be sought (Rakyta et al., 2015). Unfortunately, in enterprises, when considering and trying to prevent faults in unstable production conditions, the aspect of maintenance is often overlooked (Kosicka, Gola & Pawlak, 2019). The role it plays in the enterprise is important, because with the proper functioning of maintenance services, it is possible to both maximize the use of available machine resources and determine their actual states (technical diagnostics of objects), as well as to obtain new data that can be input data, supplementing control systems and production management (advisory systems, expert systems). Supporting production with such systems makes flexible production have the characteristics of mass production, stable and predictable.

The implementation of modern machinery and equipment in the production system of the company (implementation of technical solutions, e.g. automation and robotization, flexible production systems) as well as the introduction of various production philosophies (e.g. Just-in-Time (JiT) or Lean Manufacturing) improved the use of available resources. Despite these activities, the area of maintaining the machine park in constant readiness leaves you unsatisfied, because technical equipment is of key importance for the efficient and effective functioning of production processes and quick order fulfillment (Crespo Márquez et al., 2009; Al-Najjar, 2007).

The purpose of this article is to analyze the impact of technical and non-technical indicators on the material selection of technological equipment for specific production purposes and to present the method of supporting decisions in the selection of resources for the needs of production tasks using the AHP and Fuzzy AHP methods.

2. THE IMPORTANCE OF MAINTENANCE IN A MANUFACTURING COMPANY

The growing pressure to shorten production cycles means that the readiness to work of machines and technical devices remains the key factor determining the possibility of timely execution of orders, which consequently increases the role and importance of maintenance services (Aspinwall & Elgharib, 2013). Therefore, maintenance has an increasing impact on the efficiency and profitability of the company. Production lost due to unplanned machine downtime will never be recovered without additional cost. Disruptions in production processes caused by a failure of a machine or device not only reduce productivity and increase the cost of the product, but also cause the loss of the ability to produce products on time, which in turn translates into the loss of the company's image.

The importance of maintenance is growing due to its role in the maintenance and availability of the machine park and the efficiency of its operation. Traditionally, the approach to maintenance is considered to be an area of additional costs for the enterprise, however, research shows the positive impact of maintenance on the efficiency of the enterprise, its profitability and productivity (Al-Najjar & Algabroun, 2018; Azizi, 2015; Maletic et al., 2014).

It is believed that by applying an effective maintenance policy, production deficiencies and failures can be reduced to a minimum level, the economic indicator of which is acceptable to the company. In the perspective of long-term goals, this type of action can bring significant savings to the organization (Al-Najjar, 2007).

Maintenance is a strategy that involves the identification, investigation, and implementation of many repair, replacement, and inspection decisions. In the initial scope of its operation, it was based on a reactive approach, where no action is taken to prevent failures or detect the beginnings of failures, and the device must be repaired when it fails. It was assumed that the costs related to traffic maintenance are high in relation to its functioning. When mechanization elements were introduced to the industry, the approach to maintenance changed to a preventive approach. Inspections of machines and devices were carried out at specific time intervals (e.g. number of shifts) or other criteria aimed at reducing the probability of failure or deterioration of efficiency (e.g. number of manufactured products). In the following years, when the share of automated and robotic processes increased significantly, the maintenance approach changed to a predictive approach. A number of IT systems for maintenance management based, for example, on monitoring the technical condition of the facility with the use of vibroacoustic signals, have been developed. Currently, due to globalization, dedicated IT systems are not sufficient in the effective use of maintenance. Supporting solutions were and are still being sought, consisting in combining the maintenance department and other departments necessary for the proper functioning of the company (e.g. supply departments, production optimization, organization and management of the company). This approach is called a process-oriented approach. Although different approaches have been developed at different times, in practice more than one approach can be used at the same time, as well as many 'customized maintenance strategies'. Therefore, from the point of view of the user of these systems, it is very important to know which of the available approaches to maintenance is the most cost-effective and corresponds to the technical system in the company's operational activities. The strategies discussed can be found in many scientific publications, and various maintenance concepts have been developed on their basis, e.g.: Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM), Condition-Based Maintenance (CBM) and Integrated Logistics Support (ILS) (Sagar & Singh, 2012; Ahmad & Kamaruddin, 2012).

Systemically, the maintenance process is currently perceived as supporting the main processes implemented in the company - mainly production and its cost. However, the complexity of modern production systems and their dependence on a large number of internal and external factors forces a change in the approach to maintenance to a process-oriented approach (Blanchard, 2004). Identification of these factors and determining their importance is one of the basic activities enabling the construction of a model for assessing the added value through the maintenance of the system, organization and management of a production company (Al-Najjar, 2007).

3. ESSENCE AND CHARACTERISTICS OF AHP AND FUZZY AHP METHODS

Analytic Hierarchy Process (AHP) is an effective decision support tool. Using the AHP method, a problem can be solved in a hierarchical manner, where the decision is based on criteria (usually multiple criteria) (Saaty, 1980). The AHP method is based on the concept of a hierarchy of goals and creating binary comparisons between goals of the same level (determining the ranking of the analyzed solutions). The construction of the hierarchy diagram strictly depends on the type of problem under study and maps the hierarchy of goals of this problem. If the problem is complex and contains a number of alternative paths, the structure is more complex, which makes solving the problem more difficult. Most often, a simplified structure is sought, which contains, for example, three levels, where the first level contains only one element, the decision problem. The second level consists of elements - decision criteria, and the third level contains the characteristics of the tested object. A typical, hierarchical structure of the AHP method is shown in Fig. 1.

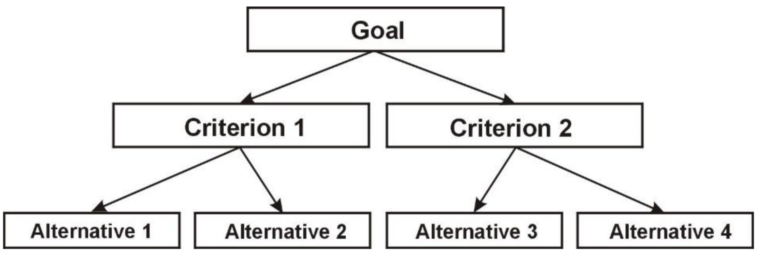

Fig. 1. Typical hierarchy structure of the Analytic Hierarchy Process method

In mathematical terms, the record of a decision problem presents the so-called decision matrix (1).

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{1n} \\ x_{21} & x_{22} & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix} \quad (1)$$

where: X – action, strategy, alternative decision or decision,
$x_{mn} -$ the measure of the variant W_m according to the K_n criterion,
m – value of m variant,
n – value of n variant.

Decision matrix is a description of individual variants along with criteria describing those variants to which weight should be assigned (usually in the form of a numerical value). The numerical value of the criterion is a measure of the implementation of the assumed tasks and objectives of individual variants. The scale of the point value is ambiguous and a point scale from 0 to 5 is adopted in simplified tasks, and from 0 to 10 in exact solutions. The assumption of the point criterion is that the minimum value is the worst grade, while the maximum value is the best grade. For example, a comparative rating of 1 might mean "equal", a value of 3 for "slightly greater", a value of 9 for "extremely greater". To solve a decision problem using the AHP method, four steps must be taken. It is necessary to specify the decision problem with its description (hierarchy of the problem), make a comparison in pairs in relation to the criteria, and criteria in relation to the goal (evaluation of the criteria). Then set preferences with regard to the priority of criteria and decision variants and choose the best variant (analysis of results). As a result of the analysis, we obtain the highest ranking value, which is considered to be a solution to the decision problem and is a compromise between different goals or criteria (Bayzit, 2005).

The assessment of the solution made by the decision-maker is ambiguous, depending on his attitude to the task, personal characteristics, function performed, knowledge, data and skills. The result of such an approach is a multifaceted approach to the decision-making problem. The AHP method has a wide and varied application, and the availability of examples in the literature is considerable (Das & Chattopadhyay, 2003).

The Fuzzy Analytic Hierarchy Process (FAHP) method is similar in terms of methodology. Unlike the classical AHP method, it enables a more accurate assessment of linguistic criteria and is similar to human reasoning. It is characterized by the use of fuzzy sets in relation to linguistic criteria and membership functions. Membership functions can take various forms, e.g. triangular or trapezoidal, but in practical applications the first one is most often used – the triangular membership function. The fuzzy values correspond to the start, middle, and end of the triangle, respectively. The fuzzy triangle (TNF) scores for the FAHP method are presented in Table 1.

Tab. 1. Values of fuzzy evaluation triangles (Kutlu, 2012)

Linguistic assessment	Fuzzy value TNF	AHP classic equivalent
Absolute preference	(2; 5/2 ;3)	9
Very clear preference	(3/2; 2; 5/2)	7
Clear preference	(1; 3/2; 2)	5
Slight preference	(1; 1; 3/2)	3
Equal preference	(1; 1; 1)	1
Slight inferiority	(2/3; 1; 1)	1/3
Clear inferiority	(1/2; 2/3; 1)	1/5
Very clear inferiority	(2/5; 1/2; 2/3)	1/7
Indisputable inferiority	(1/3; 2/5; 1/2)	1/9

The calculation scheme is similar to the classic AHP method, except that fuzzy evaluations should be used for pairwise evaluation.

4. FORMULATION OF THE RESEARCH PROBLEM

The entity in which the research was carried out was a manufacturing company belonging to the SME sector, dealing in the production of metal and metal-rubber elements used in the automotive industry. The assortment of manufactured products includes over 300 different products, on average twice a month a new product is launched. The large number of products offered resulted in the problem of the appropriate selection of production stations along with their availability (efficient and ready to work machines and production equipment) so that the production process ran smoothly and efficiently. For the planner, it involves a number of actions and decisions that must be made.

The basic information for production planning must be individual data on the availability of production resources - machines and devices. At a later stage of planning, economic and technological factors of production should be taken into account. Based on this data, the planner selects the optimal solution from among many available other solutions, assessing their impact on the organization and management of the enterprise.

The production system of the enterprise works on the basis of the technological principle. This means that the production space consists of separated, separate technological cells with the same type of machines and production devices (high operational interchangeability). It is possible to distinguish turning, milling, drilling, grinding and manual machining (locksmith) production units, combined with a product assembly station. In addition, the cells were divided into rough and fine machining stations. Individual production stations in a cell show differences in terms of efficiency, cost-intensity and availability. Availability of machines or devices is limited by readiness for operation, planned repairs and unexpected breakdowns. These factors cause disruptions that ultimately affect the organization and proper management of the enterprise.

In order to determine the impact on the enterprise and eliminate disturbances in the availability of machinery and equipment, and to support the planner (often inexperienced) in selecting the appropriate resource for a given technological operation, the state of affairs (resource failure rate) was analyzed and an attempt was made to support the decision-making process using the AHP method (as the basic approach), as well as in its extended variant – FAHP. The goal was to select a resource available immediately and meeting the criterion of failure-free working time for the assumed time frame of expected work in unit production. The technological and economic aspects were omitted, as the available resources are at a similar level of technical advancement in individual production units (small differences in efficiency). As a result, the financial aspect can also be omitted in this example, because the lack of availability of the resource (too long waiting time for the product to be put into production) as well as failures compensate for the potential profit.

In order to check the assumptions of the conducted research, one group of machine tools was selected. The selection was made from a group of 10 machines for milling processing, characterized by comparable technical and economic properties and technical wear (data obtained from the maintenance department). A monthly period of work (twenty working days) was taken into account, in which the machines were used in three shifts, five days a week (the working time fund of a single resource was therefore 2,400 hours).

5. METHOD AND OBTAINED RESULTS

The analysis of the operation of machines in the analyzed period allowed to conclude that the availability of individual machine tools was extremely different, as shown in Table 2 and Figure 2. The fourth column of Table 2 presents an indicator that shows the monthly availability of a given resource. Based on the obtained data, an attempt was made to search for the causes that were responsible for the downtime of the machine tools.

Tab. 2. Machine availability indicators

Resource (milling machine)	Working time [%]	Downtime [%]	Availability indicator
M1	90	10	0,9
M2	89	11	0,89
M3	96	4	0,96
M4	76	24	0,76
M5	85	15	0,85
M6	92	8	0,92
M7	97	3	0,97
M8	69	31	0,69
M9	87	13	0,87
M10	88	12	0,88

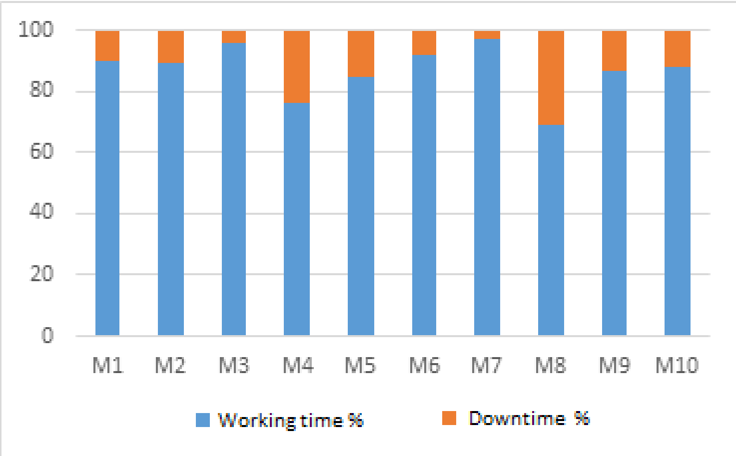

Fig. 2. Percentage of machine downtime in the analyzed period

After determining the reasons for the downtime of the machines, the aspects that had an impact on the organization and management of the company were identified. These reasons have been grouped into areas that include:

- Technical area:
  - failure (mechanical, electrical, hydraulic or pneumatic),
  - change in the quality of the input material of the same production batch,
  - quality of tools used during production tasks,
  - service errors (programming errors or settings),

  – machine degradation,
  – quality of products,
  – work safety,
- non-technical area:
  – the availability of spare parts to remove the failure,
  – the availability of a maintenance worker (mechanic or electrician),
  – the date of completion of the products,
  – the cost of maintaining the machine (e.g. depreciation, inspections, service),
  – work safety.

It was decided that the listed factors will constitute the basic criteria that can be identified with the impact on the enterprise. The planner also has such data and should be guided by the selection of the appropriate workstation for production tasks. For the available criteria, weights were assigned on a scale from 1 to 10 (Table 3). The weight values were consulted with a group of planners and the maintenance department. The individual criteria and the values assigned to them are presented in Table 4.

Tab. 3. Machine availability indicators

Criterion			**The value of impact on organization and management**
Technical	A1	failure	10
	A2	change in the quality of the input material of the same production batch	3
	A3	quality of tools used during production tasks	2
	A4	service errors	1
	A5	machine degradation	6
	A6	quality of products	4
	A7	work safety	5
Non-technical	P1	the availability of spare parts to remove the failure	8
	P2	the availability of a maintenance worker	5
	P3	the date of completion of the products	3
	P4	the cost of maintaining the machine	3
	P5	work safety	5

The last level of the decision tree – level 3, defines the alternatives. The dilemmas were the available set of machines, defined as M1, M2, ..., M10, forming a decision tree, the solution of which is the appropriate selection of the workplace with the least impact (the least downtime) on the enterprise organization and management system.

The solution to the research problem was carried out using the Matlab program. Due to the large size of the matrix of pairwise comparisons of the AHP and FAHP methods as well as the m-code calculation functions, partial calculations and results are presented (Fig. 3 – AHP method, Fig. 4 – FAHP method, Fig. 5 – synthetic TNF values for criterion A1).

a)

```
function [machine_selection] = Art_AHP()
%% Method analytical hierarchy process (AHP)
%   AUTHOR:
%           P. Wittbrodt, I.Łapuńka, A. Gola
%   CREATED:
%           March, 2022
%% Problem:
% Situation: Select the most suitable machine from the available M1, M2, ..., M10 according to technical and non-technical criteria.
% I will use % AHP with the following:
%         alternatives:  M1, M2, ..., M10
%         criteria:      A1 Malfunction
%                        A2 Change in the quality of input material within the same production batch
%                        A3 Quality of tools used for manufacturing
%                        A4 Operational errors
%                        A5 Machine degradation
%                        A6 Product quality
%                        A7 Occupational safety
%                        P1 Availability of replacement parts needed to repair a malfunction
%                        P2 Availability of maintenance staff
%                        P3 Manufacturing deadline
%                        P4 Machine maintenance costs
%                        P5 Occupational safety
%%-----------------------------------------------

%% Problem formulation:
clear all; close all; clc;
%% Step 1
% Using Scale:
% Weight - numerical scale       Weight - verbal scale
%        1                       equally important
%        3                       little more important
%        5                       much more important
%        7                       far more important
%        9                       absulutely more important
%      2, 4, 6, 8                intermediate values ?
%      1/2, 1/3, 1/4, 1/5,          for inverse relations
%      1/6, 1/7, 1/8, 1/9
```

b)

```
%% Step 2

%% Compare A1
disp('A1');

%     M1    M2    M3    M4    M5    M6    M7    M8    M9    M10
A1 = [1     3     5     5     1     3     3     1/3   5     1    ; ...
      1/3   1     3     5     1/7   3     1/3   3     1/5   1/3  ; ...
      1/5   1/3   1     1/7   1/3   3     5     1     7     1/5  ; ...
      1/5   1/5   7     1     3     1/5   1/3   3     1/5   1/3  ; ...
      1     7     3     1/3   1     1/5   5     1/5   3     5    ; ...
      1/3   1/3   1/3   5     5     1     1/5   5     1/5   1    ; ...
      1/3   3     1/5   3     1/5   5     1     1/3   1/3   3    ; ...
      3     1/3   1     1/3   5     1/5   3     1     1     5    ; ...
      1/5   5     1/7   5     1/3   5     3     1     1     1/7  ; ...
      1     3     5     3     1/5   1     1/3   1/5   7     1    ];

eA1 = calc_eig(A1);
%%
```

c)

```
%% Step 3:
% matrix of eigenvectors calculated above for each criteria eigenvectors: A1, A2, A3, A4, A5, A6, A7, P1, P2, P3, P4, P5
eM  =   [eA1   eA2   eA3  eA4  eA5  eA6  eA7  eP1  eP2  eP3  eP4  eP5];

% obtain scores for each najlepiej dostosowanej maszyny spośród dostepnych M1, % M2, ..., M10 on criteria and maszyn comparisons
disp('Scores for: M1, M2, M3, M4, M5, M6, M7, M8, M9, M10')
machine_selection = eM * eC;

%% sub-function on calculating eigenvectors
    function [eigvect ] = calc_eig(M) ...

%% sub-function to normalise a vector (0-1)
    function [normvect ] = calc_norm(M) ...

end
```

Fig. 3. A part of m-code of the AHP method: a) formulation of the problem, b) matrix of pairwise comparisons for criterion A1, c) computational function

a)

```
function [ weights CompMat fuzzyTFN ] = FuzzyAHP( CompMat )
%% Method analytical hierarchy process (AHP)
%    AUTHOR:
%             P. Wittbrodt, I.Łapuńka, A. Gola
%    CREATED:
%             March, 2022
% fuzzy tfn and inverse fuzzy tfn constants
fuzzyTFN = {[1     1     1  ]   [1      1     1  ]
            ...                                  ]};

....
....
%%
% find sum of every l,m,u values for triangular fuzzy number
for i=1:m ...

vec = [mExtendAnalysis{1,:}];
mExtendAnalysisSum = sum(reshape(vec,3,[])');

for i=1:m ...

%%
% degree of possibility calculation
%              /---
%              | 1    if m2>=m1
%              |
%              | 0    if l1>=l2
% V(M2>=M1) = <
%              |     l1-u2
%              | --------------- otherwise
%              | (m1-u2)-(m1-l1)
%              \---
```

b)

```
%%
% normalized weight calculation
weights = zeros(1,m);
for i=1:m, ...
weights = weights/sum(weights);

end
```

Fig. 4. A part of m-code of the FAHP method: a) the sum of l, m, u values for a triangular fuzzy number, b) calculation of weights

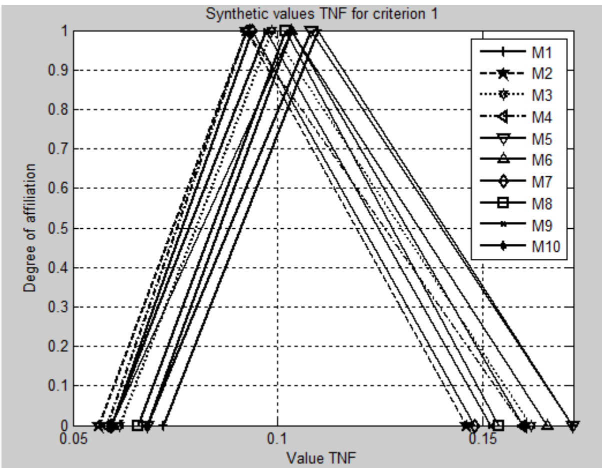

Fig. 5. Synthetic THF values for criterion A1

As shown in Figure 5 – for the A1 criterion, the M5 machine tool is the preferred machine resource, because its values are the largest and the span (width of the set) is the largest.

As a result of the calculations carried out in the Matlab package with the use of m-codes presented in Figures 3–4, a set of values was obtained (for all criteria) for the one-level structure of the problem, which are presented collectively in Table 4 and graphically in Figure 6.

Tab. 3. Comparison of the obtained results with the choice made by the decision maker, using the AHP and FAHP methods

Machine tool	Decision maker	AHP		FAHP	
	Position	Weight	Position	Weight	Position
M1	2	0,111	1	0,119	1
M2	10	0,093	9	0,085	10
M3	6	0,104	5	0,092	8
M4	9	0,073	10	0,090	9
M5	3	0,108	3	0,095	7
M6	8	0,098	7	0,099	5
M7	7	0,096	8	0,097	6
M8	5	0,102	6	0,103	4
M9	4	0,106	4	0,109	3
M10	1	0,109	2	0,111	2
Sum		1,000		1,000	

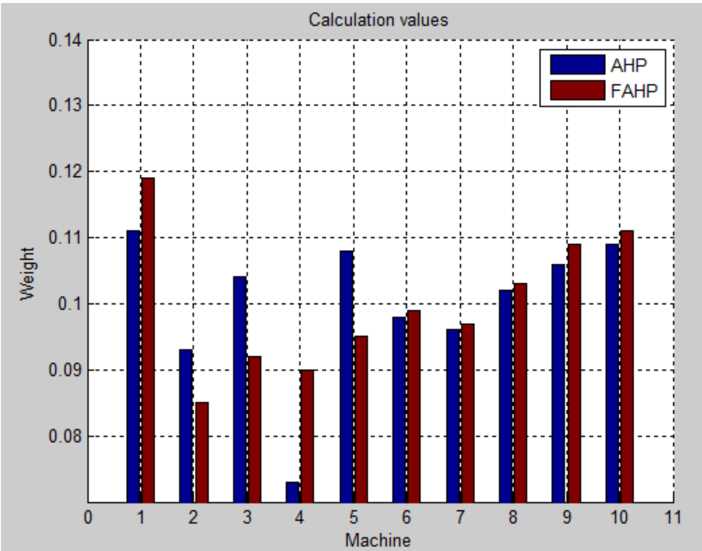

Fig. 5. Bar graph of the results obtained using the AHP and FAHP methods

As shown in Table 5, in the analyzed case, the machine resource M1 should be assigned to the production task in the first place (this results from both the use of the AHP and FAHP methods). The decision maker placed this resource as the second position, preferring the choice of the M10 resource. Nevertheless, the action of the decision-maker and the methods used should be determined at a satisfactory level, as the presented results are largely convergent. Differences in the obtained results result from the adopted small differences in the values of the criteria weights. The lowest values occur in the M2 and M4 resources, which is caused by the strong impact of the A4 criterion, whose impact on organizations and management is at level 1.

6. CONCLUSIONS

Maintenance is of key importance from the point of view of the efficiency of production processes, and its proper functioning improves the productivity of the company, increases production efficiency, stabilizes the quality of products and timeliness. At the same time, maintenance as a function supporting production reduces downtime and extends the life of production machines and equipment.

This study shows that the decision maker who has the given criteria has the ability to identify faults caused by maintenance for the proper functioning of production and determine the breakdown schedule in the enterprise for individual machines. The correct correlation of the planner's activities and the AHP and FAHP methods allows us to conclude that less experienced employees, based on the support methods, will be able to take corrective actions, preventive actions in the pre-emergency time (before the failure occurs), develop a scenario of actions and appropriately plan the use of production resources. The reaction of maintenance services in such a case is planned and better organized and managed, ensuring minimization of costs for the company and increasing the efficiency of operations. Proper maintenance practice can therefore keep production assets in reliable condition, thereby minimizing production inefficiencies, product defects, downtime, etc.

Maintenance activities are costly, but the lack of these activities is more costly for the company. Companies that will be equipped with a decision support system (e.g. based on the AHP or FAHP method) will be able to improve their maintenance systems and improve their performance. It is important to develop a system supporting the decision-making process, because such a system is the foundation for the efficient and trouble-free operation of the production system, its organization and management.

The research results have a potential practical application, which is demonstrated by a practical example, which is why research on a multidimensional model, taking into account a wider range of criteria and factors, is continued. In the future, the decision support system will be expanded with other decision support methods.

Funding

This work is supported by Lublin University of Technology under grant no. FD-20/IM-5/2022.

Conflicts of Interest

The authors declare no conflict of interest regarding this paper.

REFERENCES

Ahmad, R., & Kamaruddin, S. (2012). An Overview of Time-Based and Condition-Based Maintenance in Industrial Application. *Computers & Industrial Engineering*, *63*(1), 135–149. https://doi.org/10.1016/j.cie.2012.02.002

Al-Najjar, B. (2007). The lack of maintenance and not maintenance which cost: A model to describe and quantify the impact of vibration-based maintenance on company's business. *International Journal of Production Economics*, *107*, 260- 273. https://doi.org/10.1016/j.ijpe.2006.09.005

Al-Najjar, B., & Algabroun, H. (2018). A Model for Increasing Effectiveness and Profitability of Maintenance Performance: A Case Study. In: M. Zuo, L. Ma, J. Mathe & H. Z. Huang (Eds.), *Engineering Asset Management 2016. Lecture Notes in Mechanical Engineering* (pp. 1–12). Springer. https://doi.org/10.1007/978-3-319-62274-3_1

Aspinwall, E., & Elgharib, M. (2013). TPM Implementation in Large and Medium Size Organizations. *Journal of Manufacturing Technology Management*, *24*(5), 688-710. https://doi.org/10.1108/17410381311327972

Azizi, A. (2015). Evaluation Improvement of Production Productivity Performance Using Statistical Process Control, Overall Equipment Efficiency, and Autonomous Maintenance. *Procedia Manufacturing*, *2*, 186–190. https://doi.org/10.1016/j.promfg.2015.07.032

Bałdowska-Witos, P., Piotrowska, K., Kruszelnicka, W., Błaszczak, M., Tomporowski, A., Opielak, M., Kasner, R., & Flizikowski, J. (2020). Managing the uncertainty and accuracy of life cycle assessment results for the process of beverage bottle molding. *Polymers*, *12*(6), 1320. http://doi.org/ 10.3390/polym12061320

Bayazit, O. (2005). Use of AHP in decision-making for flexible manufacturing system. *Journal of Manufacturing Technology Management*, *16*(7), 808–819. https://doi.org/10.1108/17410380510626204

Blanchard, B. (2004). *Logistic Engineering and Management. 5th Ed*. Prentice Hall Inc.

Burduk, A., Musiał, K., Kochańska, J., Górnicka, D., & Stetsenko, A. (2019). Tabu search and genetic algorithm for production process scheduling problem. *Logforum*, *15*(2), 181–189. http://doi.org/10.17270/J.LOG.2019.315

Crespo Márquez, A., Moreu de León, P., Gómez Fernández, J. F., Parra Márquez, C., & López Campos, M. (2009). The maintenance management Framework. A practical view to maintenance management, *Journal of Quality in Maintenance Engineering*, *15*(2), 167–178. https://doi.org/10.1108/13552510910961110

Das, S., & Chattopadhyay, A. B. (2003). Application of the analytic hierarchy process for estimating the state of tool wear. *International Journal of Machine Tools & Manufacture*, *43*(1), 1–6. https://doi.org/10.1016/S0890-6955(02)00168-2

Gola, A. (2014). Economic aspects of manufacturing system design. *Actual Problems of Economics*, *156*(6), 205–212.

Kosicka, E., Gola, A., & Pawlak, J. (2019). Application-based support of machine maintenance. *IFAC-PapersOnLine*, *52*(10), 131–135. http://doi.org/10.1016/j.ifacol.2019.10.033

Kutlu, A. (2012). Fuzzy failure modes and effects analysis by fuzzy TOPSIS-based fuzzy AHP. *Experts Systems with Application*, *39*(1), 61-67. https://doi.org/10.1016/j.eswa.2011.06.044

Madu, C. (2000). Competing through maintenance strategies. *International Journal of Quality and Reliability Management*, *17*(9), 937–948. https://doi.org/10.1108/02656710010378752

Maletic, D., Maletic, C., Al-Najjar, B., & Gomiscek, B. (2014). The Role of Maintenance in Improving Company's Competitiveness and Profitability: A Case Study in A Textile Company. *Journal of Manufacturing Technology Management*, *25*(4), 441–456. https://doi.org/10.1108/JMTM-04-2013-0033

Pizon, J., Kulisz, M., & Lipski, J. (2021). Matrix profile implementation perspective in Industrial Internet of Things production maintenance application. *Journal of Physics: Conference Series*, *1736*(1), 012036. http://doi.org/10.1088/1742-6596/1736/1/012036

Rakyta, M., Fusko, M., Haluska, M., & Grznar, P. (2015). Maintenance support system for Reconfigurable manufacturing systems. *Annals of DAAAM and Proceedings of the International DAAAM Symposium* (pp. 1102–1108). DAAAM International. http://doi.org/ 10.2507/26th.daaam.proceedings.155

Relich, M., & Świć, A. (2020). Parametric estimation and constraint programming-based planning and simulation of production cost of a new product. *Applied Sciences*, *10*(18), 6330. http://doi.org/10.3390/APP10186330

Saaty, T. (1980). *The analytic hierarchy process*. McGraw–Hill.

Sagar, M. K., & Singh, D. (2012). Supplier Selection Criteria: Study of Automobile Sector in India. *International Journal of Engineering Research and Development*, *4*(4), 34–39.

Swic, A., & Gola, A. (2013). Economic analysis of casing parts production in a flexible manufacturing system. *Actual Problems of Economics*, *141*(3), 526–533.

Szabelski, J., Karpiński, R., & Machrowska, A. (2022). Application of an artificial neural network in the modelling of heat cutting effects on the strength of adhesive joints at elevated temperature with imprecisive adhesive mix ratios. *Materials*, *15*(3), 721. http://doi.org/10.3390/ma15030721

Varela, M. L. R., Putnik, G. D., Manupati, V. K., Rajyalakshmi, G., Trojanowska, J., & Machado, J. (2018). Collaborative manufacturing based on cloud, and on other i4.0 oriented principles and technologies: a systematic literature review and reflections. *Management and Production Engineering Review, 9*(3), 90–99. http://doi.org/10.24425/119538

Vollmann, T. E., Berry, W. L., Whybark, D. C., & Jacobs, F. R. (2005). *Manufacturing Planning and Control for Supply Chain Management. 5th Ed*. McGraw- Hill/Irwin.

Zubrzycki, J., Świć, A., Sobaszek, Ł., Kovac, J., Kralikova, R., Jencik, R., Smidova, N., Arapi, P., Dulencin, P., & Homza, J. (2021). Cyber-physical systems technologies as a key factor in the process of Industry 4.0 and smart manufacturing development. *Applied Computer Science, 17*(4), 84–99. http://doi.org/10.23743/acs-2021-31