PREVENTIVE MAINTENANCE IN THE 3D ATOMIC IV PRINTER MACHINE USING THE ANALYTIC HIERARCHY PROCESS

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ABSTRACT

Preventive maintenance (PM) of equipment is a crucial aspect of effective manufacturing systems, as inadequate PM can lead to various negative issues, such as quality, productivity cost, customer cost, and maintenance costs. This paper presents a case study approach using the Analytic Hierarchy Process (AHP) and ranking of critical elements for the PM equipment of a 3D Atomic IV printer machine at The Instituto Tecnológico de Ciudad Juárez. AHP was used to find the equipment problem sensors and determine all the criteria weights and rank elements. The principal methodology is applied to a 3D Atomic IV printer to formulate a critical PM strategy.

Keywords: MCDM, AHP, critical weights, PM, printer machine, sensors, decision-making, maintenance, manufacturing, elements

Recibido: 29-junio-2024 / Aprobado: 31-julio-2024
Mantenimiento Preventivo en la Impresora 3D Atomic IV utilizando el Proceso de Jerarquía Analítica

RESUMEN

El mantenimiento preventivo (MP) de los equipos es un aspecto crucial de los sistemas de fabricación eficaces, ya que un MP inadecuado puede provocar diversos problemas negativos, como la calidad, el costo de productividad, el costo del cliente y los costos de mantenimiento. Este artículo presenta un enfoque de estudio de caso utilizando el proceso de jerarquía analítica (AHP) y la clasificación de elementos críticos para el equipo de MP de una impresora 3D Atomic IV en el Instituto Tecnológico de Ciudad Juárez. Se utilizó AHP para encontrar los sensores del problema del equipo y determinar todos los pesos de los criterios y clasificar los elementos. La metodología principal se aplica a una impresora 3D Atomic IV para formular una estrategia crítica de MP.

Palabras clave: MCDM, AHP, pesos críticos, MP, impresora, sensores, toma de decisiones, mantenimiento, fabricación, elementos
INTRODUCTION

Effective preventive maintenance (PM) of equipment is paramount in manufacturing systems because the absence of PM can detrimentally impact the overall maintenance performance of all equipment and productivity costs. The cost of a manufacturing system, including its production rate, quality, and cost, depends predominantly on the type of PM implemented (Al-Najjar, B. and Alsyouf I. 2003 and Alsyouf, I. 2004). Moreover, PM significantly influences a company’s global competitiveness by enhancing its production process, optimizing machine utilization, increasing production output, and enhancing system flexibility. However, given the extensive range of available equipment, selecting equipment for a given production problem is challenging (Alsyouf, I. 2009 and Atmani, A., & Lashkari, R. S. 1998). Although PM plays a crucial role in the design of effective preventive systems in manufacturing, studies on this subject are scarce (Ayag, Z., & Ozdemir, R. G. 2006 and Barba-Romero S. y Pomerol J. C. 1997). Studies in this domain often focus on machine selection. Other studies have proposed models and algorithms to address flexible manufacturing system machine maintenance and operation problems (Bertolini and Bevilacqua, M. 2006) Bevilacqua and Braglia, 2000). Various studies have discussed PM equipment decisions (Caputo, pelagagge, and Salini, 2013., Chan and Lau, 2001), given the finite number of alternatives in equipment PM problems, ranking them based on relevant criteria as a multi-criteria method. Several multi-criteria methods (Chatterjee and Chakraborty, 2012 and Chan., Lau, H. 2001), with scoring models and the Analytic Hierarchy Process (AHP) being among the most popular. The best multi-criteria method depends on the problem, real alternatives, critical criteria, and data uncertainty levels (Chen, 1999, Fouladgar, Yazdani-Chamzini, Lashgari, Zavadskas, and Turskis, 2012).

In this study, an analytic hierarchy process (AHP) algorithm was used to identify critical PM equipment elements, and its implementation was explained using a 3D Atomic IV printer machine as an example. This study presents a methodology for predicting PM on additive manufacturing equipment using AHP, aiming to: (a) integrate an MCDM methodology to identify principal PM sensors in a 3D Atomic IV printer machine; (b) find a weighting calculation alternative incorporating knowledge from literature.
reviews and expert judgments; and (c) present a research model illustrating hierarchical factors and their corresponding scoring values for establishing concrete strategies (Fraser, Hvolby and Tseng, 2015).

We proposed some research questions:

1. How could the AHP method find the most critical PM sensors in a 3D Atomic IV printer machine?
2. Could the AHP algorithm be used to obtain all weighting values for each criterion, integrating acquired knowledge and judgment evaluation by experts?
3. Can the obtained results be compared with other MCDM methods of calculating weighting values and final ranking?

Thus, the proposed AHP methodology for criteria weight determination would be evaluated by the next hypothesis: "All weighting values for each criterion based on the AHP method result provide us a Consistency Index Ratio (CIR) coefficient lower than 0.10 using the Saaty method on Adding Manufacturing Problem."

This study is structured under six sections.

1. Introduction: This section introduces the problem under study.
2. Principles of AHP: This section outlines the methodology issue.
3. Proposed AHP: Details regarding the proposed approach are provided here.
4. A Theoretical Application of the Proposed AHP Approach: A theoretical example demonstrating the application of the proposed approach is presented.
5. Results: The outcomes of the theoretical application are discussed.
6. Conclusion: A summary of the findings and concluding remarks are provided.

**Literature Assessment**

This section is divided into the following subsections: literature review on PM equipment, MCDM method research, and identifying gaps concerning additive manufacturing equipment PM.

Critical Equipment:
The critical equipment that is vital for the continuous operation of a process is discussed here. Researchers have employed various methodologies to identify critical equipment based on factors such as risk-based inspection, generation loss, maintenance costs, availability, and MTBF.

**MCDM Methods research**

This subsection discusses the significance of MCDM methods in decision-making, particularly in situations with numerous alternatives and criteria. It outlines the main steps involved in the MCDM process, and highlights the efficiency of these methods in selecting the ranking of a set of alternatives.

**Identified Gap from the Literature Reviewed:**

A gap was identified in the literature concerning the additive manufacturing equipment of the Atomic IV printer machine at Instituto Tecnológico de Ciudad Juárez using the AHP method.

**Analytic Hierarchy Process AHP**

The analytic hierarchy process (AHP) proposed by Saaty (1980) has been introduced in recent decades as one of the most widely used Multi-Criteria Decision Analysis (MCDA) methods for many complex problems. AHP aids decision-makers in assigning comparisons by employing pairwise comparisons and assigning weights to criteria based on the decisions of all alternatives.

The AHP algorithm is integrated into three fundamental principles: the global problem, the judgment of all alternatives by experts and criteria, and the finding of the best priorities for all criteria. AHP converts the problem into a hierarchical structure consisting: of objectives, criteria, and alternatives. The pairwise comparison matrices are then found to show us the best criteria within each level of the problem decomposition, employing the comparison value scale illustrated in Table 1.

**Table 1. The nine-point Intensity of importance Scale (Saaty, 1980)**

<table>
<thead>
<tr>
<th>Definition</th>
<th>Intensity of importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally important</td>
<td>1</td>
</tr>
<tr>
<td>Moderately more important</td>
<td>3</td>
</tr>
<tr>
<td>Strongly more important</td>
<td>5</td>
</tr>
<tr>
<td>Very strongly more important</td>
<td>7</td>
</tr>
<tr>
<td>Extremely more important</td>
<td>9</td>
</tr>
<tr>
<td>Intermediate values</td>
<td>2, 4, 6, 8</td>
</tr>
</tbody>
</table>
The method’s fundamental algorithms are as follows:

Algorithm 1: Decomposition of the problem into three levels:

1. Goal of the problem solution.
2. Judgment for all criteria and all alternatives by experts.
3. Making a hierarchy tree diagram.

Algorithm 2: Defining the importance score scale for each criterion by table 1.

Algorithm 3: Construct a comparison matrix between a set of criteria and alternatives.

Algorithm 4: Convert the comparison matrix into a normalized matrix. Suppose $X$ is the comparison matrix $X = [x_{ij}]$, where $i$ represents the equipment $(i = 1, \ldots, n)$ and $j$ represents the criteria $(j = 1, \ldots, m)$.

Then, the normalized matrix from $X$ can be obtained as:

$$X = [x_{ij}]$$

where $i$ represents equipment $(i = 1, \ldots, n)$ and $j$ represents the criteria $(j = 1, \ldots, m)$. Then, the normalized matrix from $X$ can be obtained by:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}, j = 1, 2, \ldots, m$$

Algorithm 5: A vector $CR = \{CR_j | j = 1, 2, \ldots, n\}$ I defined as the all criteria. The result of the pairwise comparison of $n$ criteria can be shown in an $(n \times n)$ evaluation matrix $A$, where every element $a_{ij} (i, j = 1, 2, \ldots, n)$ is the quotient of the weights of the criteria, as shown in equation 1:

$$A = \begin{bmatrix}
    a_{11} & a_{12} & \cdots & a_{1n} \\
    a_{21} & a_{22} & \cdots & a_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    a_{n1} & a_{n2} & \cdots & a_{nn}
\end{bmatrix}, a_{ii}=1, a_{ij}=1/a_{ij}, a_{ij}\neq 0$$

Thus, $a_{ij} > 0$, $a_{ij} = 1/a_{ji}$, and $a_{ij}$ represents the user-defined rating of the relative importance of criterion $i$ to criterion $j$. When $i$ and $j$ have equal relative importance, $a_{ij} = a_{ji} = 1$. 

Revista Científica y Académica. Vol. 4, No. 2, Abril, Junio Año 2024
The relative rankings, denoted by $a_{ij}$, can be determined based on the following assumptions.

- If criterion $i$ and $j$ are equally important then is equal to 1.
- If criterion $i$ is slightly more important than criterion $j$ then is equal to 3.
- If criterion $i$ is significantly more important than criterion $j$ then is equal to 5.
- If criterion $i$ is strongly more important than criterion $j$ then is equal to 7.
- If criterion $i$ is extremely more important than criterion $j$ then is equal to 9.

Numbers 2, 4, 6, and 8 were used for intermediate comparisons.

Algorithms 6 and 7 determine the mathematical operations to normalize the comparison matrix and determine the weights for each matrix element. These weights were determined using the right eigenvector ($w$) corresponding to the largest eigenvalue ($\lambda_{\text{max}}$), as expressed in equation 2:

$$A_w = \lambda_{\text{max}}w$$  \hspace{1cm} (2)

Then, if the pairwise comparison matrices are completely consistent. Then, matrix $A'$ has a rank of 1 and $\lambda_{\text{max}}$ equals $n$. Therefore, all weights can be derived by normalizing any of the rows.
We need to know that the effectiveness of the AHP results directly depends on the consistency of the pairwise comparison matrix values. Consistency is determined by the relationship between the entries of $A'$: $a_{ij} \times a_{jk} = a_{ik}$. The consistency index ($CI$) is given by Equation 3:

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

Next, we compute the matrix $R$ to show the significance of all criteria and for all alternatives.

$$R = \begin{bmatrix}
  w_1 & w_2 & \ldots & w_j & \ldots & w_n \\
  C_1 & C_2 & \ldots & C_j & \ldots & C_n \\
  A_1 & \begin{bmatrix}
    r_{11} & r_{12} & \ldots & r_{1j} & \ldots & r_{1n} \\
    r_{21} & r_{22} & \ldots & r_{2j} & \ldots & r_{2n} \\
    \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\
    r_{i1} & r_{i2} & \ldots & r_{ij} & \ldots & r_{in} \\
    r_{m1} & r_{m2} & \ldots & r_{mj} & \ldots & r_{mn}
  \end{bmatrix} \\
  A_2 & \ldots \\
  A_i & \ldots \\
  A_m & \ldots
\end{bmatrix}$$

The Consistency Index Ratio value of the (CIR), determines the adequacy of the consistency of the evaluation and is computed by dividing the value of $CI$ by the random index value of (RI), as shown in Equation 4.

$$CIR = \frac{CI}{RI}$$

Thus, The RI is the Random Index, as shown in Table 2.

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
</tr>
<tr>
<td>n</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>RI</td>
<td>1.45</td>
<td>1.49</td>
<td>1.51</td>
<td>1.48</td>
<td>1.56</td>
<td>1.57</td>
<td>1.59</td>
<td></td>
</tr>
</tbody>
</table>

Finally, when we found a CIR below 0.10, we used the calculated eigenvectors as the relative weights of the criteria to determine the weighted values for each alternative. Thus, overall weighted scores and rankings were determined.
Thus, the threshold of 0.1 serves us as the upper limit for the CIR. If the final Consistency Ratio is above this value, the evaluation process fails to enhance the consistency. Assessing consistency can be beneficial for evaluating the hierarchical consistency of decision-makers.

**AHP Approach for 3D Atomic IV Printer Machine**

The AHP methodology for addressing the 3D Atomic IV equipment PM problem has three objectives:

1. Data from the equipment.
2. AHP algorithm computations.
3. Decision-making results.

Initially, a decision hierarchy is formed. Subsequently, decision-making experts endorse the decision diagram hierarchy tree. Following approval, our AHP algorithm was used to assign all weights to the criteria used in our 3D Atomic IV printer equipment PM. This involves forming pairwise comparison matrices and eliciting individual evaluations from decision-making experts as indicated by the scale in Table 1. Consensus is sought to determine the final comparison matrix, from which all criteria weights are computed.

The priorities of PM of 3D Atomic IV equipment sensors are established by decision-making experts, and upon their endorsement, each equipment element is selected based on expert expertise, Figure 1 provides a block diagram of the proposed problem research.
The Proposed Approach

To demonstrate the proposed methodology, we used a 3D Atomic IV printer, as shown in Figure 2. Maintenance management systems offer a range of strategies that are, typically classified into two principal groups: corrective and preventive. Therefore, in corrective maintenance issues, maintenance activities are performed after a failure occurs. However, maintenance managers often seek more reliable strategies because of the narrow profit margins and increased competition.

**Figure 2.** The 3D machine printer research proposed
METHODOLOGY

In this section, the MCDM method is discussed. After reviewing the literature, it was observed that various methods such as TOPSIS, VIKOR, PROMETHEE, MOORA, ELECTRE, and Fuzzy AHP are widely used in different problems of multi-criteria decision-making. However, for this research goal, we chose the AHP because of its simplicity and suitability for hierarchically structured problems.

AHP Method Process

AHP is an algorithm used to select only one alternative from a given set of alternatives, involving all decision criteria, and rank these alternatives based on quantitative comparison issues.

The algorithms of the AHP method are as follows:

Algorithm 1: The problem is divided into three levels, goal, judgment criteria, and alternatives, and a hierarchical tree diagram is created. Figure 3 provides the necessary information for our problem, and Table 3 presents the equipment nomenclature used in the tree diagram.

Table 3. The Nomenclature of 3D Equipment Elements on the AHP Diagram

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Principal Elements of 3D Atomic IV printer machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Axis_x</td>
</tr>
<tr>
<td>E2</td>
<td>Axis_y</td>
</tr>
<tr>
<td>E3</td>
<td>Axis_z</td>
</tr>
<tr>
<td>E4</td>
<td>Fan_Heat</td>
</tr>
<tr>
<td>E5</td>
<td>Temp_Nose_Feeder</td>
</tr>
<tr>
<td>E6</td>
<td>Temp_Base</td>
</tr>
<tr>
<td>E7</td>
<td>Feeder_Material</td>
</tr>
</tbody>
</table>

W_Score  Rank

7  0.0625  0.156862745  0.148148148  0.10170831
6  0.0625  0.156862745  0.111111111  0.10096493
5  0.0625  0.156862745  0.185185185  0.10552313
3  0.1875  0.078431373  0.074074074  0.14661755
1  0.2500  0.137254902  0.333333333  0.21777871
2  0.28125 0.137254902  0.074074074  0.20669554
4  0.09375 0.176470588  0.074074074  0.11871183

0.549
Figure 3. The AHP Hierarchy Tree Diagram of Critical Elements of Equipment.

Algorithm 2: Define the values for the Criterion Score.

Algorithm 3: Calculate a Comparison Matrix of all criteria versus all alternatives.

Algorithm 4: Transform the Comparison Matrix results into a Normalized Matrix for the problem.

Algorithm 5: Obtaining Pairwise Comparison Matrix.

Algorithms 6 and 7: Evaluate the Consistency result of the Pairwise Comparison Matrix and calculate all weights of each criterion in our problem.

Problem Description and Analysis

In additive manufacturing facilities at Instituto Tecnológico de Ciudad Juárez, numerous 3D Atomic IV printer machines are utilized, with some being particularly vital from a manufacturing standpoint. Their significance can be assessed based on the following criteria

1. Customer Inconvenience upon Equipment Failure
2. Downtime Impact when Equipment Fails
3. Maintenance Cost of the Equipment
4. Quality Cost of the Finished Product

This study aims to comprehensively address various scenarios that arise during equipment failure. Although the data for preventive maintenance are theoretical, conducting a thorough analysis of the problem is indispensable and cannot be overlooked.
Establishing Scales for Scoring Different Criteria

Four criteria were examined for criticality analysis, with a 1 to 9 Saaty scale used to assign scores to each criterion. These criteria include:

1. **(ID)** Impact of Downtime: A Saaty scale ranging from 1 to 9 was employed to encompass all possible downtime values, as shown in Table 4.

2. **(CI)** Customer inconvenience due to Failure: Equipment failures can result in customer inconvenience and loss. A value based on the generation loss owing to equipment failure was sold to quantify the level of inconvenience experienced by the customer, as illustrated in Table 4.

3. **(MC)** Maintenance Cost of the Equipment: Equipment failures necessitate maintenance activities, incurring certain costs. This value is based on the average maintenance cost of the equipment and represents various possible maintenance expenses (Table 4).

4. **(QC)** Quality Cost: It is imperative to maintain control over the quality costs associated with the finished product (Table 4).

**Table 4.** The Score Table or Comparison Matrix for the Equipment elements by experts

<table>
<thead>
<tr>
<th>Sensor</th>
<th>System</th>
<th>ID</th>
<th>CI</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Axis_x</td>
<td>2</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>E2</td>
<td>Axis_y</td>
<td>2</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>E3</td>
<td>Axis_z</td>
<td>2</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>E4</td>
<td>Fan_Heat</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>E5</td>
<td>Temp_Nose_Feeder</td>
<td>8</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>E6</td>
<td>Temp_Base</td>
<td>9</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>E7</td>
<td>Feeder_Material</td>
<td>3</td>
<td>9</td>
<td>2</td>
</tr>
</tbody>
</table>

Analysis of the problem

A 3D Atomic IV printer machine is comprised of numerous functional components, each of which plays a crucial role. We identified equipment elements that directly affected the occurrence of failures. It is imperative to analyze the criticality of these equipment elements. The necessary score table,
formulated based on the assigned scoring, is provided in Table 4. The AHP rankings are listed in Table 1.

The AHP calculations are addressed as steps follows:

Step_1: Decompose the entire problem into three levels: goal, judgment criteria, and alternatives, and construct a hierarchy accordingly.

Step_2: Establish scales for each criterion: and delineate the scale for each of the four criteria.

Step_3: Calculate a comparison matrix based on the defined scales in Table 1, Table 4 presents all requisite comparison matrices of all alternatives.

Step_4: Convert the comparison matrix into a normalized matrix, as shown in Table 5

**Table 5. The Normalized Matrix Obtained from the Comparison Matrix**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>System</th>
<th>ID</th>
<th>CI</th>
<th>MC</th>
<th>Impact of downtime (ID)</th>
<th>Customer’s inconvenience (CI)</th>
<th>Maintenance Cost (MC)</th>
<th>W_Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Axis_x</td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.148148148</td>
<td>0.10170831</td>
<td>7</td>
</tr>
<tr>
<td>E2</td>
<td>Axis_y</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.111111111</td>
<td>0.10096493</td>
<td>6</td>
</tr>
<tr>
<td>E3</td>
<td>Axis_z</td>
<td>2</td>
<td>8</td>
<td>5</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.185185185</td>
<td>0.21777871</td>
<td>5</td>
</tr>
<tr>
<td>E4</td>
<td>Fan Heat</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.1875</td>
<td>0.078431373</td>
<td>0.074074074</td>
<td>0.14661755</td>
<td>3</td>
</tr>
<tr>
<td>E5</td>
<td>Temp_Nose_Feeder</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>0.25</td>
<td>0.137254902</td>
<td>0.333333333</td>
<td>0.21777871</td>
<td>1</td>
</tr>
<tr>
<td>E6</td>
<td>Temp_Base</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>0.28125</td>
<td>0.137254902</td>
<td>0.074074074</td>
<td>0.20669554</td>
<td>2</td>
</tr>
<tr>
<td>E7</td>
<td>Feeder_Material</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>0.09375</td>
<td>0.176470588</td>
<td>0.074074074</td>
<td>0.11871183</td>
<td>4</td>
</tr>
</tbody>
</table>

Step_5 and Step_6: Calculate a pair-wise comparison matrix of all criteria and obtain their consistency:

We have our AHP process entails the following steps:

Step_a: Develop the comparison matrix of alternatives, as shown in Table 6.

**Table 6. The Comparison Matrix of Alternatives**

<table>
<thead>
<tr>
<th>j</th>
<th>ID</th>
<th>CI</th>
<th>MC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>ID</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>CI</td>
<td>1/4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MC</td>
<td>1/8</td>
<td>1/5</td>
</tr>
</tbody>
</table>

Step_b: Multiply the entries in each row of the matrix, and then calculate the $n_{th}$ root of the product, where $n$ represents the dimension of the matrix. The roots were then summed. The roots were then normalized using this sum to derive a value referred to as the eigenvector, as shown in Table 7.
Table 7. The Eigenvector analysis

<table>
<thead>
<tr>
<th></th>
<th>ID</th>
<th>CI</th>
<th>MC</th>
<th>3rd. Root</th>
<th>Eigenvector</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>1.000</td>
<td>4.000</td>
<td>8.000</td>
<td>3.556</td>
<td>0.549</td>
</tr>
<tr>
<td>CI</td>
<td>0.2500</td>
<td>1.000</td>
<td>5.000</td>
<td>1.967</td>
<td>0.303</td>
</tr>
<tr>
<td>MC</td>
<td>0.1250</td>
<td>0.2000</td>
<td>1.000</td>
<td>0.668</td>
<td>0.103</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>6.472</td>
<td></td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

Step_c: Each row of the comparison matrix is multiplied by the eigenvector column, following the principles of matrix multiplication. The calculations for all three rows yielded values of: 3.556, 1.967, and 0.668 respectively.

Step_d: The values obtained in Step_c is divided by each eigenvector to calculate the respective values of $\lambda$. The average of these three $\lambda$ values yields $\lambda_{\text{max}}$, which, in our case, is 3.194.

Step_e: The consistency ratio index (CI) was computed using the formula $(\lambda_{\text{max}}-n)/(n-1)$, which yielded a value of 0.0546 for $n=3$.

Step_f: The Consistency Index Ratio value of the (CIR) is calculated by dividing the value of the (CI) by the Random Index number of the (RI), denoted as 0.0418. AHP provides a Random Index value of the (RI) for different judgment orders. For $n=3$, the (RI) is 0.58, as shown in Table 2. The value of the (CIR) gets a value below 0.10, indicating that our judgment is consistent.

Step_7: Because the result of the CIR is less than 0.10, we can use the eigenvectors as the relative weights of all criteria for the calculation of all weighted values of the alternatives.

The total weighted score and final rank of the alternatives, as shown in Table 8, which presents the necessary ranking.
Table 8. The Final Rank of PM 3D ATOMIC IV Printer Machine by AHP Method

<table>
<thead>
<tr>
<th>Sensor</th>
<th>System</th>
<th>ID</th>
<th>CI</th>
<th>MC</th>
<th>Impact of downtime (ID)</th>
<th>Customer’s Inconvenience (CI)</th>
<th>Maintenance Cost (M_C)</th>
<th>W_Score</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 Axis_x</td>
<td></td>
<td>2</td>
<td>8</td>
<td>4</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.148146148</td>
<td>0.10170831</td>
<td>7</td>
</tr>
<tr>
<td>E2 Axis_y</td>
<td></td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.111111111</td>
<td>0.10095493</td>
<td>5</td>
</tr>
<tr>
<td>E3 Axis_z</td>
<td></td>
<td>2</td>
<td>8</td>
<td>5</td>
<td>0.0625</td>
<td>0.156862745</td>
<td>0.165185185</td>
<td>0.10552313</td>
<td>5</td>
</tr>
<tr>
<td>E4 Fan_Heat</td>
<td></td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>0.1875</td>
<td>0.078431573</td>
<td>0.074074074</td>
<td>0.14661755</td>
<td>3</td>
</tr>
<tr>
<td>E5 Temp_Nose_Feeder</td>
<td>8</td>
<td>7</td>
<td>9</td>
<td>0.25</td>
<td>0.137254902</td>
<td>0.353333333</td>
<td>0.21777871</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>E6 Temp_Base</td>
<td></td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>0.28125</td>
<td>0.137254902</td>
<td>0.074074074</td>
<td>0.20669554</td>
<td>2</td>
</tr>
<tr>
<td>E7 Feeder_Material</td>
<td>3</td>
<td>9</td>
<td>2</td>
<td>0.09375</td>
<td>0.176470588</td>
<td>0.074074074</td>
<td>0.11871183</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS

The findings of this study were intriguing. Temp_Nose_Feeder holds significant importance within the 3D Atomic IV machine printer system, which is corroborated by its top-ranking position with a weighted score of 0.2177, as indicated in Table 8.

Utilizing a multicriteria analysis, such as AHP, in conjunction with expert insights offers a valuable tool for identifying the most influential factors, thereby establishing a methodological approach that supports a robust maintenance strategy for 3D printer machines. Furthermore, the obtained scoring values, derived through AHP weight calculation methods, demonstrate correlation coefficient values exceeding 0.10 CRI, aligning well with predefined research objectives and inquiries.

Ultimately, the factors identified through the MCDM analysis, as presented in Table 8, encompass score values and rankings that harmonize with the advocated PM strategies illustrated in Figure 3. This model streamlines the identification of the requisite PM type and facilitates strategies tailored to the specific needs of enterprises.

CONCLUSIONS

A significant advantage of this type of analysis is its ability to provide a well-rounded perspective on the problem by incorporating all the pertinent criteria by the expert. Consequently, the analysis yielded superior results, marking a pioneering effort to conduct such analysis for 3D Atomic IV machine equipment using the AHP method pioneered by Saaty.
Moreover, Table 8 shows that Temp_TC emerged as the most crucial factor when scrutinizing all the individual factors under general classifications.

The primary contribution of this research from the standpoint of preventive maintenance strategy lies in furnishing a methodology that leverages the AHP method for Additive Manufacturing companies and researchers to identify the relevant factors for 3D Atomic IV machines. This enables the focused allocation of resources toward strategies that bolster competitiveness while averting high maintenance costs. The incorporation of expert judgment is pivotal because it facilitates the assignment of importance to the pertinent criteria in the AHP method.

Future endeavors entail (a) employing other MCDM approaches to compute weighting values via expert judgment and (b) integrating machine learning to analyze the principal factors of PM within 3D Atomic IV machines.

Future works are:

(a) Using another’s MCDM method to calculate the weighting values through expert judgment, and subsequently, a contrast analysis of the scoring and ranking values was obtained.

(b) Implementing machine learning to analyze the factors identified in our research.

Acknowledgements

I would like to acknowledge my thesis supervisor Dr. Arturo Woocay, who enabled this study. His guidance and advice helped me throughout all stages of writing this paper. I would also like to thank my school for giving me all the help in completing this research project.

Author information:

Funding: This study did not receive external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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