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Applications of AHP, FAHP, BWM, Entropy, and CRITIC Methods in Electrohydraulic Forming Process Parametric Evaluation for Automotive Panels Using the 1100 Aluminum Alloy Sheets

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ABSTRACT

Although multicriteria selection methods are flexible and extensively used in machining, less attention has been paid to their comprehensive test performance in the electrohydraulic forming process. In this study, five new applications of multicriteria selection methods are proposed to analyze available parameters in the electrohydraulic forming process and select parameters best suited for further analysis and improvement of the process. The analyzed parameters are the stand-off distance, electrode gap, voltage, and medium, while the multicriteria methods are the AHP, FAHP, BMW, entropy, and CRITIC. The proposed methods were demonstrated on experimental data from the literature utilizing an impulse magnetizer system (walker type). For each method, the prioritized parametric results were obtained. All the methods assign the first position to the medium as a parameter with consensus on the voltage parameter has the worst (lowest) value of weights in all the methods. The weights of the medium parameter for the best results are 0.5030 (AHP method), 0.5600 (FAHP method), 0.5230 (best-worst method), 0.4090 (entropy method), and 0.5000 (CRITIC method). The worst parameter for all the methods is the voltage of 0.0320 (FAHP method). The results obtained from the proposed applications were compared with one another and found to be effective for multicriteria selection decisions. This article offers new methods to establish the parametric values of the electrohydraulic forming process for machining composites made of AA1100 sheets.

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1. INTRODUCTION

Industries are nowadays faced with an increasingly sophisticated product demand requiring multiple product features, low weight, and timely delivery (Bao et al., 2020; Wu et al., 2021, Frank et al., 2021). This, therefore, places manufacturing processes such as joining, machining, casting, and forming as solutions to these product demands from customers (Wang and Bos, 2018; Ringen et al., 2022). However, forming has emerged as a significant manufacturing process due to multiple products undergoing this process. The electrohydraulic forming (EHF) process has recently been established as a key transformation agent in achieving modern and sophisticated products for industrial and other uses (Shrivastava et al., 2019; Stöbener et al., 2020; Li et al., 2022). For instance, Li et al. (2022) reported a 20% enhancement in the forming height limit. Zheng and Yu (2020) concluded that the electrohydraulic forming sample had higher even dislocation spread and dislocation density. Zia et al. (2017) found a 23.6% increase in breakpoint elongation compared to electro-hydraulic forming. Stöbener et al. (2020) described an in-situ measurement approach for recording the 2D deformation field of the micro-sample surface during the electro-hydraulic forming process.

Furthermore, the science of the EHF involves the use of shockwaves to deform metals in water in the process of pulse power generation, magnetic pulse tool application, and the development of electrohydraulic tools (Zia et al., 2017; Woo et al., 2017a,c; 2019a,b; 2020; Zheng and Yu, 2020). The pulse power generator includes the source, load, store, and release, while the magnetic pulse and electrohydraulic tools form the EHF process's forming aspects. The EHF system produces discharge current in a subsystem comprising a capacitor bank, an alternative current main supply to the power rectifier unit, and a charging resistor and switch (Zheng and Yu, 2020). This generates an electric arc in water where two electrodes are situated (Zheng and Yu, 2020). The function of the electric arc is to vaporize the neighboring water, transforming the created electrical energy into powerful mechanical energy in the form of shockwaves (Woo et al., 2017b; Zohoor and Mousavi, 2018). Then the mechanical energy acts on the metal work materials, changing it into a situation of visco-plastic. This is accelerated to a die where complicated shapes are produced in a cold state but at high speeds.

Next, the traditional cold-forming process has its foundation laid on product/system-based criteria and geometrical attributes of components (Lazzarotto et al., 1998; Long et al., 2002; Long et al., 2004). For instance, Lazzarotto et al. (1998) proposed three criteria for selecting lubricating oils for forming processes. These are the presence of two kinds of surface defects, the consequential roughness of the sample and the frictional coefficient. In the case of Long et al. (2002), a generative computer-oriented process planning scheme was deployed to the metal forming arena for selection purposes. Yet, in another study, Long et al. (2004) deployed a knowledge-oriented process selection scheme for the cold form of components. The scheme's principal pillar is the obtainable cold forming process, forming hints associated with the material types, formable geometric shapes, and formability miles.

Based on these mentioned articles, it is shown that the product/system-based criteria and the geometrical attributes of components have been the dominant selection criteria used in forming processes. Process engineers constantly adopt these criteria as their attention is centered on product performance. However, the scanting literature review presented to support the dominant selection criteria in the literature, the absence of multicriteria decision-making methods makes the available method incompetent to address the emerging and modern engineering system of the electrohydraulic forming process. Therefore, appeals have been made in practice for less costly and effective methods, which employ limited experimental data to achieve the selection process for the electrohydraulic forming process. To the present authors' knowledge, available studies in the forming literature have fallen short of tackling the multicriteria selection problem where limited experimental data exists. While conducting the selection process, the judgment of experts is an important component. Notwithstanding, the option of objective assessment using objective multicriteria methods is still an important aspiration in the forming process. Thus, the novelty of this article is the use of five multicriteria methods to solve a new problem of parametric optimization in the electrohydraulic forming process for automotive panel applications. Hence, it contributes five multicriteria approaches for the first time in automotive panel applications.

This article presents five novel multicriteria selection methods used to solve the electrohydraulic forming process parametric problem. This problem is prevalent in automotive panel products such as using the 1100 aluminum alloy sheets. However, as a research strategy, the analytic hierarchy process and the fuzzy analytic hierarchy process are two subjective methods covered in the research, while the entropy method, best-worst method, and the CRITIC method are chosen to represent objective methods used in this work (Saaty, 1990; Kheybari and Ishizak, 2022; Zhao et al., 2022). Thus, it is understood that research activities in engineering and the mechanical industry, in particular, are largely conducted using subjective and objective multicriteria methods. Each is studied because of its unique advantage. As observed in most manufacturing processes, subjective multicriteria methods such as the AHP and FAHP are deployed to solve engineering problems as they evaluate the expert's opinion and how the experts understand the engineering problem and ideas (Saaty, 1990). Furthermore, as each expert tackles the same question differently, it provides an opportunity for the decision maker/researcher to choose the best analysis method. For the objective multicriteria methods such as entropy, best-worst, and CRITIC methods, the application of the methods provides an opportunity for the decision maker/researcher to deeply probe and obtain reliable and rich data concerning the phenomenon being studied (Zhao et al., 2022).

Furthermore, this paper is sectioned into these parts: section 1 introduces the studied problem and reviews the literature, while section 2 describes the methods of the AHP, FAHP, BW, entropy, and CRITIC. Section 3 presents the application of the five methods to the electrohydraulic forming process problem discussed in Shrivastava et al. (2019). This section also contains the results from the application of the work. Section 4 concludes the study.

2. MATERIALS AND METHODS

2.1. The proposed AHP method

The applicable steps to establish the analytical hierarchy process method in the electrohydraulic process are as follows (Rao, 2004; Saaty, 1990; Okponyia and Oke, 2021):

Step 1: The scale of relative importance is used as a guideline to establish a pair-wise comparison matrix.

Step 2: An addition is made for each column within the pair-wise comparison matrix.

Step 3: The user divides the pair-wise comparison matrix segments by the sum taking note of the corresponding rows.

Step 4: Equation (1) is deployed to evaluate the weights of the criteria

Criterion weight (CW) = Values on rows/Total number of factors (1)

Step 5: Then the weighted sum (WS) idea is implemented to determine if the calculations are consistent. Notice that WS is obtained through the product of each criterion and the associated criterion weight, and then each row is added.

Step 6: Evaluate the proportion of WS to CW for each factor.

Step 7: Deploy Equation (2) for the consistency index (CI) evaluation.

$$CI = (\lambda_{\max} - n)/(n-1) \quad (2)$$

where $\lambda_{\max}$ represents the greatest eigenvalue of the n-order matrix. It also represents the average proportion of WS to CW, while *n* is the number of factors.

Step 8: Evaluate the proportion of consistency given in Equation (3),

$$CR = CI/\text{Random Index} \quad (3)$$

where the random metric represents the consistency metric of a randomly produced pair-wise matrix.

2.2. The fuzzy analytic hierarchy (FAHP) process method

The fuzzy analytic hierarchy (FAHP) process allows the process engineer to express the weights of parameters in fuzzy terms for additional evaluation (Saaty, 1990). Alternatively, the fuzzy numbers could be defuzzified to obtain crisp numerical values. It is important to have background knowledge of the analytic hierarchy process as it will assist in understanding the working mechanism of the FAHP. In the AHP, whose knowledge is utilized here, creating a pairwise comparison matrix is the most important stage of the computation: To create the pairwise comparison matrix, the scale of comparative importance is created. Within this scale, diversities of values are available. They are majorly referred to as crisp numerical values, such as 5, 7, and 9. However, viewing from the fuzzy perspective, these crisp numerical values are converted into fuzzy numbers. In this article, the details of fuzzy systems are ignored, but extracts of important aspects that form the basis of the computation sued in the present article are made. In using the fuzzy system, there are several terms that the researcher should be used, including fuzzification, which converts linguistic terms into membership functions.

In Figure 1, the triangular shape is referred to as the membership function. The membership function based on a triangular shape is called the triangular membership function. Notwithstanding, other alternative membership functions are available such as trapezoid membership function, bell-shaped membership function, etc. Of importance to the researcher is the fuzzy value, represented by which is equal to A and the same as (1,2,3). The latter part, "(1,2,3)," is the fuzzy number and has associated membership functions of 1, 2, and 3. Members 1, 2, and 3 are the triangular's lower, middle and upper ends on the x-axis. For the scale of relative importance, the crisp members like 1, 3, 5, 7, and 9 are replaced with fuzzy members. It is understood that assigning a single number to any term may not be justified. For instance, in the AHP scale of importance, moderate is assigned a value of 3. However, what could be said about a value of 2.5 or 3.5? Can we call 3.5 moderate or strong using the AHP scale of importance? To overcome this concern, the idea of fuzzy numbers was introduced. While viewing from the perspective of fuzzy numbers, moderate could be assigned a fuzzy number of (2, 3, 4). Then the triangle representing moderate in Figure 2 could be shown to have the lower, middle, and upper points of the fuzzy numbers as 2, 3, and 4, respectively.

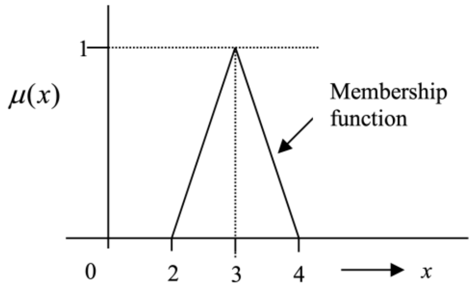

Figure 2. Triangular membership function (Okponyia and Oke, 2021)

Thus, 2, 3, and 4 are called the membership function for moderate. However, the intermediate membership function is also shown. In solving the problem using the pairwise comparison matrix coupled with the crisp numerical values and fuzzy members, there is a need to convert the crisp numerical values and replace them with the fuzzy members. Once the crisp members, the other numbers that exist as reciprocals are involved in using the converter expressed in Equation (4) (Okponyia and Oke, 2020):

$$\overline{A}^{-1} = (l, m.u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right) \quad (4)$$

Then, the fuzzified pairwise comparison matrix is obtained, which will be worked upon using the geometric mean method to calculate the weights, as discussed in Buckley (1985). Furthermore, the fuzzy geometric mean values are calculated using Equation (5) (Okponyia and Oke, 2020):

$$\widetilde{A}_1 \otimes \widetilde{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \quad (5)$$

Next, the fuzzy geometric mean value is obtained by multiplying all the lower points and taking the nth root of the number, where n represents the number of criteria under consideration. Likewise, all the middle values are multiplied, and the nth root is taken. Then, the fuzzy weights, wi2, is computed as expressed in Equation (6) (Okponyia and Oke, 2020):

$$\widetilde{w}_i = \widetilde{r}_i \otimes (\widetilde{r}_1 \oplus \widetilde{r}_2 \oplus \ldots \oplus \widetilde{r}_n)^{-1} \quad (6)$$

Then, the center of the area (COA) is computed as (Okponyia and Oke, 2020), Equation (7):

$$w_i = 1/3\,(l + m + u) \quad (7)$$

2.3. The best-worst method

This is another technique that decision-makers deploy to evaluate the weights of criteria. The best-worst method works on a decision matrix containing attributes, criteria, and alternatives (Kheybari and Ishizak, 2022). In this work, the decision matrix is based on the electrohydraulic forming data. The first step in implementing the best-worst method is establishing the set of decision criteria. The second step is for the decision maker to establish the best and worst criteria (Kheybari and Ishizak, 2022). The third step is to establish the preference for the best criterion over all the other criteria using a number between 1 and 9. Now, an optimization model will be formed and solved (Kheybari and Ishizak, 2022). Here, the objective function is

$$\text{Min } \xi_L \tag{8}$$

Subject to:

$$| w_b - a_{Bj} w_j | \leq \xi_L, \text{ for all } j \tag{9}$$

$$| w_j - a_{jw} w_w | \leq \xi_L, \text{ for all } j \tag{10}$$

$$\sum w_j = 1 \tag{11}$$

$w_j \geq 0$, for all j

2.4. Entropy method

The entropy strategy is a technique utilized for surveying the weight in a given issue because, with this technique, the chosen pattern for a lot of individual materials contains a specific measure of data. The steps taken in this method are listed below (Zhao et al., 2022):

Step 1: The decision matrix (extracted data) is normalized using Equation (12):

$$r_{ij} = \frac{X_{ij}}{\sum_{j=1}^{m} X_{ij}} \tag{12}$$

Where r_{ij} is the normalized matrix

X_{ij} represents the individual value in each segment

Step 2: The entropy is evaluated by deploying Equation (13):

$$e_j = -h \sum_{i=1}^{m} r_{ij} \ln r_{ij} \tag{13}$$

where $h = \frac{1}{\ln m}$ (14)

and *m* represents the number of options

Step 3: The level of diversification d_j is evaluated by deploying Equation (15):

$$d_j = 1 - e_j \tag{15}$$

Step 4: The weight of each criterion is then evaluated.

2.5. The CRITIC method

The CRITIC (Criteria Importance Through Intercriteria Correlation) method is a competing method with the entropy method, which process engineers adopt to evaluate the objective weights of criteria proposed by Diakoulaki et al. in the year 1995 (Zhao et al., 2022). The CRITIC method is a solution to the problem whereby the process engineer in an electrohydraulic forming (EHF) process finds it challenging due to conflicts of criteria to evaluate the differences between criteria. The foremost step for the CRITIC method is to normalize the decision matrix, provided by Equation (16) (Zhao et al., 2022):

$$\bar{X}_{ij} = \frac{X_{ij} - X_j^{worst}}{X_j^{best} - X_j^{worst}} \tag{16}$$

The essential requirement in Equation (16) is to evaluate the best and the worst values, represented as X_j^{best} and X_j^{worst}, respectively. Evaluating the best and worst values should be tailored to each criterion. In this situation, the process engineer determines whether the criterion considered is beneficial to the forming process in which its increase is desired as it helps to achieve the performance efficiency goal of the system. On the other side, if the opposite of being beneficial, i.e., non-beneficial status, is agreed upon for the forming process criterion, it is regarded as a non-beneficial criterion. In the choice of the beneficial criterion, the utmost value is the attractive best value for the forming process. Then the minimum value is chosen as the worst value. The second stage of evaluating the CRITIC method is to assess the standard deviation, j, for every criterion in the forming process Equation (16) (Zhao et al., 2022):

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \mu)^2}{N}} \tag{16}$$

where σ_j is the population standard deviation, N is the size of the population, x_i represents each value from the population, and μ is the population mean.

The third step entails establishing the symmetric matrix of the m x n structure having elements r_{jk}, which is the linear correlation coefficient between the vectors X_j and X_k, Equation (17) (Zhao et al., 2022):

$$r_{xy} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \tag{17}$$

where r_{xy} is the correlation between x and y, x_i represents the values of x within the experimental data, y_i represents the values of y within the experimental data, $\bar{x}$ is the average of the values of x within the experimental data, and $\bar{y}$ is the average of the values of x within the experimental data. The fourth step entails the evaluation of the degree of conflict created by criterion j concerning the decision situation, established by the rest of the criteria, Equation (18) (Zhao et al., 2022).

$$c_j = \sigma_j \times \sum_{k=1}^{n} (1 - r_{jk}) \tag{18}$$

where c_j is the degree of conflict, σ_j is the standard deviation, and r_{xy} is the correlation coefficient.

The following step establishes the objective weights, Equation (19) (Zhao et al., 2022).

$$w_j = \frac{c_j}{\sum_{k=1} c_j} \tag{19}$$

where c_j is the degree of conflict for individual criterion.

Table 1. Control factors and their levels (Shrivastava et al., 2019)

Control factor	**The symbol for coded value**	**Number of Levels**		
		1	2	3
Stand-off distance	A	10mm	20mm	30mm
Electrode gap	B	20mm	30mm	40mm
Voltage	C	220V	260V	300V
Medium	D	Water (0.89cP*)	Oil (1.53cP **)	Air (0.01837***)

Key: *,** and *** are modified values according to the present authors

3. RESULTS AND DISCUSSION

Table 1 shows the data that serves as the foundation for the present study. In this data, the ‘medium’ factor consists of levels that are not numerical values and, as such, cannot be used for computation and will need to be changed. In doing this, the dynamic viscosities of water and air and also the absolute viscosity of oil (mercury) are substituted and then used for computation. For water, the dynamic viscosity is taken as 0.89cP at 25°C. For air, the dynamic viscosity is taken as 0.01837cP at 25°C, and the absolute viscosity of oil (mercury) is taken as 1.53cP at 300K. The modified aspect of the table is the numerical aspect that describes the medium as a factor, Table 1

3.1. Application of analytic hierarchy process

In this section, the methodology details regarding the widely used multicriteria approach named analytic hierarchy process (AHP) are given (Saaty, 1990). The literature on the engineering process has reported the success of using the AHP method to evaluate the weights of parameters or even outcomes of the process. Due to such success, the AHP has been applied in this article to evaluate the criteria weights. The starting point is to formulate the problem by developing a decision matrix from the data given in Table 1. In Table 1, four parameters are mentioned: standoff distance, electrode gap, voltage, and medium. Then, to apply the AHP method, the hierarchical structure needs to be developed (Saaty, 1990). This often contains levels of items, such as goals, which are assigned to the first level of the structure. The criteria are then positioned at the second level. Each criterion has related values. The development of a hierarchical structure for the electro-hydraulic forming process parametric evaluation and placement is the first step in this section. The second step is the development of a pairwise comparison matrix for the electrohydraulic forming process.

The information from the pairwise matrix is the comparative importance of one criterion to the other while keeping the process goal in mind in the specific case of the forming, a process considered. The researchers asked the question of how important the standoff distance is relative to the goal of forming quality components from the electrohydraulic process. A question could also be asked what the importance of electrode gap during the electrohydraulic forming process when the quality of the formed component is considered. To answer these questions, Thomas developed ranges of n-range and associated attributes to evaluate the importance of the parameters being considered. Based on Saaty’s conception, the crisp values of 1, 3, 5, 7, and 9 represent equal importance, moderate importance, strong importance, and very strong importance extreme importance, respectively. However, for intermediate values between 1 and 3, 2 is given. Likewise, the intermediate values between 3 and 5, 5 and 7, and 7 and 9 are, respectively, 4, 6, and 8. Furthermore, Saaty's scale comprises reciprocals, of the earlier defined attributes of equal importance to extreme importance, for instance, the reciprocals of 1,3,5,7 and 9 are 1/1, 1/3, 1/5, 1/7, and 1/9, respectively.

For the pairwise matrix developed on the electrohydraulic forming process, the length of the pairwise matrix is the same as the number of criteria used in the decision-making procedure. To be specific, the electrohydraulic forming process problem solved is a 4x4 matrix since there are four parameters involved, namely, standoff distance, electrode gap, voltage, and medium. Then, the values in the pairwise matrix are determined by evaluating the present authors. Let us consider the row containing standoff distance in the matrix and concurrently the column containing electrode gap. There should be value at this intersection. In this instance, the researchers asked themselves questions placing themselves in the position of the process engineer. The researchers should answer the question of how important is the standoff distance regarding the electrode gap. The consensus of the present authors is that the electrode gap is of stronger importance in the ratio of 3;1 when compared with the standoff distance. This interprets that as we allocate a value to standoff distance, the electrode gap should be allocated with three multiples of the value given to the standoff distance according to containing along the standoff distance row. The present researcher allocated 5:1 and 1:2 to voltage and medium, respectively, noting that the intersection of a parameter against itself earns a value of 1. Now, the next row is considered where electrode gap is the indicated parameter against standoff distance, voltage, and medium, earning values of 1:3, 3:1, and 1:4, respectively. For the row on voltage against standoff distance, electrode gap, and medium, the value of 1:5, 1:3, and 1:7 are assigned by the considering medium in the row against standoff distance, electrode gap, and voltage, the values of 2:1, 4:1 and 7:1 are allocated to the respective cells by the present authors.

Besides, looking closely at the electrode gap on the row, there is also an electrode gap column. Here, the reciprocal values obtained for the column analysis are placed in the cell for the row analysis. For instance, when the standoff distance is along the row and voltage is along the column, a value of 5:1 is given. Now the cell concerning voltage along the column will be considered, and a value of 1:5 will be placed therein. This procedure is followed, and the matrix is obtained for further processing. Having obtained the matrix, the researcher covered the fractional value into decimals. Then considering the columns, all the element along a particular column is added, which means that for the columns representing standoff distance, electrode gap, voltage, and medium, the sums are 3.5333, 8.3333, 16.0000, and 1.8929, respectively.

Furthermore, a new matrix is produced considering each column, and each cell is divided by the sum. For instance, under the standoff distance, the values obtained are 0.2830, 0.0943, 0.0566, and 0.5660, respectively, for standoff distance, electrode gap, voltage, and medium, respectively. By doing this for other columns of electrode gap, the voltage of 0.3600, 0.1200, 0.0400, and 0.4800 are obtained, for voltage, 0.3125, 0.1875, 0.0625 and 0.4375 are attained, and for medium, 0.2612, 0.1321, 0.0755 and 0.5283, respectively, for each of standoff distance, electrode gaps, voltage, and medium along the columns. Now, considering each row, starting with the standoff distance, all the cell values are added. Their average is found to be 0.3049, 0.1335, 0.0586, and 05030 for standoff distance, electrode gap, voltage, and medium rows, respectively. These criteria weights are then applied to produce the weighted sum on the AHP method. However, the next step is to evaluate the consistency to check that the values obtained are connected pairwise comparative matrix, which is not normalized. Each value in the column is multiplied by the criterion values. It could be observed that the criterion weight of 0.3049 for standoff distance has been multiplied with each element along the column of standoff distance as (0.3049 x 1), (0.3049 x 0.3333), (0.3049 x 0.2) and (0.3049 x 2), to yield 0.3049, 0.1016, 0.0609 and 0.6098, respectively.

For the column name electrode gap, the calculated values are 0.4005, 01335, 0.0445, and 0.534, respectively. For the column representing voltage, the values for standoff distance, electrode gaps, voltage, and medium are 0.2930, 0.1758, 0.0586, and 0.4102, respectively. For the column of the medium, the values due to standoff distance electrode gap, voltage, and medium are 0.2515, 0.1258, 0.0719, and 0.5030, respectively. Then the weighted sum value is calculated along each row as the sum of all entries along the row. Thus, for the standoff distance, electrode gap, voltage, and medium, the weighted sum value are 1.2499, 0.5367, 0.2360, and 2.0570, respectively. Next, the ratios of the weighted sum value and criterion weights are obtained as 4.0994, 4.0200, 4.0265, and 4.0895, respectively, for standoff distance, electrode gap, voltage, and medium. Then the $\lambda_{\max}$ is obtained by finding the average of these values of 4.0994, 4.0200, 4.0265, and 4.0895 to obtain 4.0588. Next, the consistency index CI is obtained as $(\lambda_{\max} - n)/(n-1)$, where n is 4 and $\lambda_{\max}$ is 4.0588. This gives (4.0588-4)/(4-1) = 0.0196. Then, the consistency ratio is obtained as the ratio of the consistency index to the random index. However, for n=4, the random index is 0.90. This gives a consistency ratio of 0.0218, less than 0.10, and the proportion of inconsistency is less than 10%, which is the accepted standard. The authors assumed that the developed matrix is reasonably consistent. This gives us the backing to convince decision-making using the AHP method. Then based on the evaluation, the criteria weight chosen are standoff distance, electrode gap, voltage, and medium as 0.3049, 0.1335, 0.0586, and 0.5030, respectively.

3.2. Application of fuzzy analytic hierarchy (FAHP) process method

Several steps are involved in applying the FAHP method to the electrohydraulic forming process problems, as discussed in this section (Saaty, 1990). The data of factors and levels provided by Shrivastava et al. (2019) is interpreted pairwisely, whereby the intersection of a criterion with itself is taken as 1. Other comparisons are made based on the judgments of the authors. Consider the first row where standoff distance is compared with itself, electrode gap, voltage, and medium. Here, comparing standoff distance and electrode gap, the intensity of importance is 3:1, i.e., 3. Similarly, all the other entries are computed. Based on the scale of relative importance, a matrix is defined where all the judgments are interpreted as crisp numerical values and their reciprocals. Here all the crisp numbers are written first. For instance, along the first column for factors, considering the standoff distance, the values at its intersections with standoff distance, electrode gap, voltage, and medium are 1, 3, 5, and ½. The rest of the values are so decided (Table 2).

The next step is transforming these crisp numeric values into corresponding fuzzy numbers. Continuing the illustration with the first row, the corresponding fuzzy numbers for 1, 3, and 5 are (1,1,1), (2,3,4), and (4,5,6), respectively (Table 3). These transformations are done for the crisp numbers in the matrix, but the values with fractions are considered separately. The fraction is now converted into a fuzzy number with the following guidelines for the first row containing the standoff distance considered earlier. Considering any value to be transformed from a crisp value to a fuzzy number is calculated as discussed by using the earlier stated equation. Thus, for ½, the transformed fuzzy number is (1/3, ½, 1/1). This is done for all fractions present in the matrix.

Now to obtain a fuzzified pairwise comparison matrix, the work of Buckley was published in 1985, which showcases the principle of the geometric mean adopted to evaluate weights in this work. To evaluate the fuzzy geometric mean value, which is the next phase of work, the equation used to multiply two fuzzy numbers is deployed, Equation (6). Here, the lower point is multiplied by, the lower point of the second number. The middle of one number is multiplied by the middle of the other. Then the upper number of one number is used to multiply the other, and the multiplied fuzzy number is obtained. Thus, the first fuzzy geometric mean number $\tilde{\boldsymbol{r}}_{\mathbf{1}}$ is calculated as follows:

$$\tilde{\boldsymbol{r}}_{\mathbf{1}} = \left((\mathbf{1} * \mathbf{2} * \mathbf{4} * \mathbf{1/3})^{\frac{1}{4}}, (\mathbf{1} * \mathbf{3} * \mathbf{5} * \mathbf{1/2})^{\frac{1}{4}}, (\mathbf{1} * \mathbf{4} * \mathbf{6} * \mathbf{1/1})^{\frac{1}{4}}\right)$$
$$= (\mathbf{1.3867}, \mathbf{1.9574}, \mathbf{2.8845})$$

Table 2. Pair-wise comparison matrix

Factors	Stand-off Distance	Electrode gap	Voltage	Medium
Stand-off distance	1	3	5	½
Electrode gap	1/3	1	3	¼
Voltage	1/5	1/3	1	1/7
Medium	2	4	7	1

Table 3. Transformation of pair-wise comparison matrix to fuzzy numbers and Geometric mean representation

Factors	Stand-off distance	Electrode Gap	Voltage	Medium	$\tilde{r}_i$
Stand-off Distance	(1,1,1)	(2,3,4)	(4,5,6)	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	(1.3867, 1.9574, 2.8845)
Electrode Gap	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	(1,1,1)	(2,3,4)	$\left(\frac{1}{5},\frac{1}{4},\frac{1}{3}\right)$	(0.4642, 0.63, 0.8736)
Voltage	$\left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right)$	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	(1,1,1)	$\left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right)$	(0.1733. 0.212, 0.2752)
Medium	(1,2,3)	(3,4,5)	(6,7,8)	(1,1,1)	(2.6207, 3.8259, 4.9324)

Table 4. Fuzzy weights $\tilde{w}_1$ and defuzzified weights w_i

Factors	$\tilde{w}_i$	w_i	Normalized weighs
Stand-off Distance	(0.1547, 0.2954, 0.621)	0.357	0.311
Electrode Gap	(0.0518, 0.0951, 0.188)	0.1116	0.097
Voltage	(0.0193, 0.032, 0.0592)	0.0368	0.032
Medium	(0.2923, 0.5775, 1.0619)	0.6493	0.560
	Total	1.1493	1.000

This is inserted into the last cell in the last row for the standoff distance (Table 3). Then all the $\tilde{r}_i$s for the four criteria are computed and used to fill Table 3. Next, the fuzzy weights $\tilde{w}_i$s are evaluated. This is evaluated using the equation previously stated in the section on methods. The direction of evaluation is to add all the fuzzy geometric mean values. The lower, middle, and upper values of each fuzzy number are obtained and added.

$$\begin{aligned}\tilde{\boldsymbol{r}}_{\mathbf{1}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{2}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{3}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{4}} = {} & (\mathbf{1.3867+0.4642+0.1733} \\ & \mathbf{+\,2.6207, 1.9574+0.63+0.212} \\ & \mathbf{+\,3.8259, 2.8845+0.8736} \\ & \mathbf{+\,0.2752+4.9324}) \\ = {} & (\mathbf{4.6449, 6.6253, 8.9657})\end{aligned}$$

This is the first part of the computation. But the reciprocal of this computation is desired, which is obtained as $\tilde{\boldsymbol{r}}_{\mathbf{1}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{2}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{3}}\oplus\tilde{\boldsymbol{r}}_{\mathbf{4}} = (\mathbf{1/8.9657, 1/6.6253, 1/7.6449})$

However, the aim is to obtain $\tilde{\boldsymbol{r}}_{\boldsymbol{i}}$ multiplied by the last computed values. For instance, for the standoff distance, the final computation is: (1.3867, 1.9574, 2.8845) ⊗ (1/8.9657,1/6.6253,1/7.6449). This yields (0.1547, 0.2954, 0.6210) as it is known that each component of the first bracket is multiplied by the corresponding component of the second bracket. To elaborate on this discussion, 1.3867 is multiplied by 1/8965 to yield 0.1547. Similar multiplications are done to obtain 0.2954 and 0.6210 as the second and third components of the last matrix. Then the procedure is followed for all other criteria (Table 4).

Now, if it is desired for the weights to be in fuzzy expression, then the four fuzzy numbers each for criterion can be used to compute for further computations. Alternatively, the four fuzzy numbers could be defuzzified to obtain crisp numerical values using the center of the area, COA, given as w_i= 1/3 (l + m +u). Here the lower, middle and upper values are added, and their average is obtained. Using this for standoff distance, 0.1547, 0.2954, and 0.621 are added and averaged to obtain 0.357. Accordingly, the weights for other criteria are evaluated. As each of the obtained weights is added, the result is 1.14993. This calls for normalization in which the sum of numbers will be 1. Thus, each of the weights is placed as numerators to 1.1493, and the normalized values are shown in Table 4.

3.3. The application of the best and worst method

By stating the first step taken to establish the best-worst method, which is to determine the decision criteria, the details of the literature data used here are presented (Kheybari and Ishizak, 2022). In the data, four decision criteria were extracted from the real-life data and used in the present study, which are standoff distance, electrode gap, voltage, and medium. Next, the process engineer (decision maker) is asked to specify the best and worst criterion. In this case, the best criterion was chosen as the medium, while the voltage was assigned as the worst criterion. Next, the process engineer established the preference of the best criterion over all other criteria using a number between 1 and 9 (Kheybari and Ishizak, 2022).

In this case, 1 represents equal importance, which is used for the intersection of the same parameter/criterion with itself. For instance, 1 is assigned to the common cell in comparing standoff distance to itself. As determined by the authors' assessment, the medium is of a particular value of which the standoff distance is twice that value. Then 2 units are allocated to the cell under the standoff distance. The same logic is used to allocate the other criteria of electrode gap and voltage, which have appreciated values of 5 and 6 multiplied by the value of the medium, and 5 and 6 are therefore allocated under the electrode gap and voltage, respectively. The preceding classification is the selection of medium as the best criterion. However, it is essential to also consider the worst criterion. In this case, each of the other criteria is compared with the voltage to observe the degree to which they are worse than the voltage. The standoff distance, electrode gap, and medium are weighed with voltage in this case. The resulting values of 4, 2, 1, and 6 are obtained for the standoff distance, electrode gap, voltage, and medium, respectively (Table 5).

Table 5. The most important and least important criteria weighed against others

Factor	Stand-off distance	Electrode gap	Voltage	Medium
The most important criterion (Medium, w_m)	2	5	6	1
The least important criterion (Voltage, w_v)	4	2	1	6

The next step is to find the optimal weights, and the linear program below helps to achieve this goal.

Min $\boldsymbol{\xi_L = f(w_s, w_E, w_V, w_m)}$ (20)

Subject to:

$$\boldsymbol{w_m - 2w_s \leq \xi_L} \quad (21)$$

$$\boldsymbol{w_m - 2w_E \leq \xi_L} \quad (22)$$

$$\boldsymbol{w_m - 2w_V \leq \xi_L} \quad (23)$$

$$\boldsymbol{w_s - 2w_V \leq \xi_L} \quad (24)$$

$$\boldsymbol{w_E - 2w_V \leq \xi_L} \quad (25)$$

$$\boldsymbol{w_s + w_E + w_V + w_m = 1} \quad (26)$$

$$\boldsymbol{w_s, w_E, w_V, w_m \geq 0} \quad (27)$$

Solving the linear program, $\boldsymbol{w_s, w_E, w_V, w_m}$ which are the weights of the standoff distance, electrode gap, voltage, and medium, respectively, yields the corresponding values of 0.284, 0.114, 0.080, and 0.523.

3.4. Entropy method

The entropy method has been useful in diverse evaluations where the desire to evaluate the weight of criteria is critical to the system's progress. It serves as input to further decision-making as it is observable in the several electrohydraulic goals for the electrohydraulic forming process formulated. However, it becomes challenging to satisfy these conflicting views in a computational procedure. Fortunately, the entropy method has been found as a useful approach to solving this multi-goal problem using the philosophy adopted from the transportation field. As opposed to the analytic hierarchy process, where the opinions of the decision maker are aggregated and may be redeemed as a subjective method, the entropy method distinguishes itself as an objective approach that does not rely on experts' judgments. The entropy weight is one parameter that reveals the degree to which the different options move towards one another in computations regarding a particular criterion. The idea of entropy, adopted from the transportation model, states that entropy is acted upon as an evaluation of the crisp between the origins of a movement and the destination to which the body moves. Now, the electrohydraulic forming problem in this article is prosecuted, where selecting the best alternative among the standoff distance, electrode gap, voltage, and medium parameters is desired. The first effort should be directed at evaluating the normalized decision matrix (Table 6).

This is given in Equation (12). The implementation of Equation (12) is made by first evaluating the sum value by adding the values in each column representing each criterion. Next, the sum of X_{ij}, which represents the denominator, is evaluated. This is divided into each column that represents each criterion used for analysis in the electrohydraulic forming process. By solving using the formula, the desired values in Table 6 are obtained. Next, the entropy value is evaluated using Equation (13). In the Equation representing entropy, Equation (13), h's value is assessed using Equation (14). This is started as the reciprocal of log m. But it is the number of options, which means four options in the present evaluation scheme. It simply means that the value in the cell is multiplied by the log value of that particular value. To illustrate further calculation, consider the value of h as -0.7213, which is multiplied by log (4). By sharing the same viewpoint, other calculations for the alternatives are made accordingly and are displayed in the cells. We progress by evaluating the values of the sum of each column, which means the summation of $r_{ij}\log r_{ij}$. By adding the values, a final value of entropy is evaluated by multiplying the sum values with the negative value of m. From this multiplication, the values of entropy are obtained. Furthermore, the weight factor is evaluated. Here, l - e_j is regarded as the degree of diversification. The e_j value (Table 7), which is the entropy value, is subtracted from 1 to obtain the degree of diversification. After calculating the values, they are added to obtain other values. This value is then divided by the degree of diversification value, which leads us to the final weight, w_j.

Table 6. Process of normalizing the decision matrix and the normalized decision matrix

Factor	**Stand-off Distance**	**Electrode gap**	**Voltage**	**Medium**
Level 1	10	20	220	0.89
Level 2	20	30	260	1.53
Level 3	30	40	300	0.01837
$\sum_{j=1}^{m} X_{ij}$	60	90	780	2.43837
		Normalized decision matrix		
Level 1	0.1667	0.2222	0.2821	0.3650
Level 2	0.3333	0.3333	0.3333	0.6275
Level 3	0.5000	0.4444	0.3846	0.0075

Table 7. Calculated entropy

Factor	**Stand-off Distance**	**Electrode Gap**	**Voltage**	**Medium**
Level 1	-0.2986	-0.3342	-0.3570	-0.3679
Level 2	-0.3662	-0.3662	-0.3662	-0.2924
Level 3	-0.3466	-0.3604	-0.3675	-0.0368
$\sum_{i=1}^{m} r_{ij} \ln r_{ij}$	-1.0114	-1.0609	-1.0907	-0.6971
e_j	0.7296	0.7652	0.7868	0.5029
$d_j = 1 - e_j$	0.2704	0.2348	0.2132	0.4971

By solving, further values are obtained. The values may be applied as the objective weights of criteria or parameters of the electrohydraulic forming process. Summing the row for d_j gives 0.2704 + 0.2348 + 0.2132 + 0.4971 as 1.2155. Therefore, to get the weight of each criterion, we have standoff distance as 0.2225, electrode gap as 0.1932, voltage as 0.1754, and medium as 0.4090. It could be explained that the standoff distance occurs as a weightage of 0.2225. Similarly, the weights of electrode gap, voltage, and medium are 0.1931, 0.1754, and 0.4090, accordingly.

3.5. Application of the CRITIC method

There are four steps that can be used to implement the CRITIC method effectively. These steps, mentioned in the section on methodology, will be explained with numerical data in this section (Zhao et al., 2022). Step one involves the normalization of the criteria (Zhao et al., 2022). Recall that the first step suggested in implementing the CRITIC method is to normalize the decision matrix, Table 8.

To implement the normalization process, Equation (16), displayed in the methods section, uses the difference between the best and worst criterion to evaluate the criterion. First, the information on levels is extended by two more rows named “best” and “worst”, respectively. Then, the difference is calculated. The stand-off distance, $\boldsymbol{X_j^{best}}$ and $\boldsymbol{X_j^{worst}}$ are 30 and 10mm, respectively. In this case, all the criteria are regarded as beneficial, and computations are made accordingly. Now, the worst value is subtracted from the particular value in the cell. The result is divided by the difference between the best and worst values. Consider the cell of the intersection of level 1 and standoff, where a replacement value is sought. The worst value, 10, is subtracted from 10, which yields 0. This result, 0, is divided by the difference between the best value, 30, and the worst value, 10. The difference is 20. However, when 0 is divided by 20, it yields 20. Then the value to insert in a table for the normalized matrix at the intersection of level 1 and standoff distance is 0. The results in other cells follow similar computations, and they are reported in Table 8. Next, the value of the standard deviation is computed for each criterion using Microsoft Excel software. The Microsoft Excels computational command of “stdeva” is used, which prompts for the range of values in each criterion. Based on this, the standard deviations were obtained as 0.50, 0.50, 0.50, and 0.50 for the stand-off distance, electrode gap, voltage, and medium, respectively.

Table 8. The process of normalization in the CRITIC method

	Pre-normalization data				**Post-normalization data**			
Description	**Stand-off distance**	**Electrode gap**	**Voltage**	**Medium**	**Stand-off distance**	**Electrode gap**	**Voltage**	**Medium**
Level 1	10	20	220	0.89	0.00	0.00	0.00	0.58
Level 2	20	30	260	1.53	0.50	0.50	0.50	1.00
Level 3	30	40	300	0.02	1.00	1.00	1.00	0.00
X_j^{best}	30	40	300	1.53	-	-	-	-
X_j^{worst}	10	20	220	0.02	-	-	-	-
Difference	20	20	80	1.51	-	-	-	-
				Standard deviation	0.50	0.50	0.50	0.50

Key: Difference is $\boldsymbol{X_j^{best}}$ and $\boldsymbol{X_j^{worst}}$, $\boldsymbol{\sigma_j}$ is the standard deviation of the j^{th} item.

Table 9. Symmetric matrix and Measure of conflict of CRITIC method

	Symmetric matrix				**Measure of conflict**				
Factor	**S**	**E**	**V**	**M**	**S**	**E**	**V**	**M**	$\boldsymbol{\sum_{k=1}^{m}(1-r_{jk})}$
S	1	1	1	-0.5744	0	0	0	1.5744	1.5744
E	1	1	1	-0.5744	0	0	0	1.5744	1.5744
V	1	1	1	-0.5744	0	0	0	1.5744	1.5744
M	-0.5744	-0.5744	-0.5744	1	1.5744	1.5744	1.5744	0	4.7231

Key: Stand-off distance - S, Electrode gap - E, Voltage - V, Medium – M

Table 10. Quantity of data about each criterion and criterion weight

Factor	σ_j	$\sum_{k=1}^{m}(1-r_{jk})$	$\boldsymbol{C_j}$	**Weight**
Stand-off distance	0.5	0.5783	0.2891	0.1667
Electrode gap	0.5	0.5783	0.2891	0.1667
Voltage	0.5	0.5783	0.2891	0.1667
Medium	0.5020	1.7348	0.8674	0.5000
$\sum_{k=1}^{m} C_j$			1.7348	

Table 11. Summary of weights of factors for all methods

	Methods				
Factors	**AHP**	**FAHP**	**Best-worst**	**Entropy**	**CRITIC**
Stand-off distance	0.3049	0.3110	0.2840	0.2225	0.1667
Electrode gap	0.1335	0.0970	0.1140	0.1931	0.1667
Voltage	0.0586	0.0320	0.0800	0.1754	0.1667
Medium	0.5030	0.5600	0.5230	0.4090	0.5000

4. CONCLUSION

Electrohydraulic forming, although with high potential in near-net shape automobile panels production, has experienced extremely limited usage due to extremely low volume production in production facilities. This problem persists as the present equipment set-up is incapable of producing high-volume discharge timely. This article presents a multicriteria analysis of the electrohydraulic forming parametric determination problem by using five distinct multicriteria methods to contribute to capacity enhancement. These methods are the analytic hierarchy process, fuzzy analytic hierarchy process, entropy, best-worst, and CRITIC. Literature data were obtained from Shrivastava et al. (2019), and the data was applied to verify the methods. The results were compared. From the analysis carried out, the following conclusions were raised:

1. By applying the AHP, FAHP, BW, CRITIC, and entropy methods, the parametric characteristics regarding the strengths (values) of each parameter of standoff distance, electrode gap, voltage, and medium were established.
2. Expert's decisions were used as inputs to the AHP, FAHP, which may be subjective, but the objective determination of weights of the parameters was achieved through three multicriteria methods of entropy, best worst method, and CRITIC method. From the final weights, the ranks of the parameters were established.
3. All the methods assign the first position to the medium as a parameter with consensus on the voltage parameter has the worst (lowest) value of weights in all the methods.
4. The findings reveal that both subjective and objective multicriteria methods are valid in an evaluation process to position the electrohydraulic process parameters. Overall, the multicriteria methods are promising instruments to associate electrohydraulic process parametric decision-making with a prioritization basis.

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