A Fuzzy-TOPSIS Method for Optimizing of Forging Problems

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Abstract: Forging industry consists of simple procedural steps, but a lot of problems are associated with the forging industries. This paper describes the major problems in forging industries along with their cause and effect that reduce the extent of profits. An attempt has also been made to apply Fuzzy multi-criteria combined with TOPSIS method in ranking the problems on the basis of various parameters. This approach improves the quality of manufacturing for forging goods, material availability & its price, fuel supply, technology upgradation, material wastage etc. The proposed approach is very useful due to its capability of providing optimal results with incomplete significant information. The study is the first of its type in forging industries. A numerical model is considered to indicate the effectiveness of the present technique.

Keywords: Fuzzy Logic, TOPSIS, Optimization Technique, Forging Industry

I. INTRODUCTION

Forging is a metal working process at elevated temperature in which metal deformed plastically under controlled condition. It is used to get a preset shape or size by exerting compressive force with mean of different type of die, hammer and press or an upsetting machine. Most commonly used metals include aluminum, brass & copper, carbon, very hard tool steels, alloy & stainless steel, titanium, and high temperature alloys which contain molybdenum, nickel or cobalt. Forging finds largest application in agriculture, aerospace, automotive, material handling & several industrial equipment, national defense, construction, mining. With the help of forging process, parts can be created stronger as compared to other metal working process but a lot of problems are associated with the forging industries. These problems along with their causes and effects are listed in table 1. Fuzzy-TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is being adopted by many researchers for evaluating performance of different manufacturing processes like EDM (Electric discharge machining) [1, 2, 3], Laser drilling [4], Turning [5], Robust design [6], Milling [7], Welding [8], Product infant failure [9], Sustainable city logistic planning [10], Organizations performance [11], Supplier evaluation and management [12, 13], Group decision making [14], Vehicle technologies [15], Electronics industry [16], Design (Cost Management) [17], Rapid prototyping [24] etc. Dewangan et.al. [1] implemented Fuzzy-TOPSIS approach to analyze the effects of various process parameters of EDM. To find optimal parametric setting of AISI P20 tool steel, authors focused on the surface integrity and dimensional accuracy of workpiece. Sivapirakasam et.al. [2] utilized Taguchi method combined with Fuzzy-TOPSIS to explore and understanding the optimization problem of multi-response parameters in green EDM. Priyadarshini et.al. [4] used Fuzzy-TOPSIS method to analyze the heat affected zone (HAZ), HC (Hole Circularity), Material Removal Rate in pulsed Nd: YAG laser micro-drilling of High Carbon steel. It is also found that, optimization of process parameters depends upon the minimizing the HC & HAZ and maximizing the MRR. Gok [5] utilized Fuzzy-TOPSIS combined with GRA (Grey Relational Analysis) to analyze the turning of ductile iron to optimize the value of cutting parameters. Yang et.al. [6] adopted the Fuzzy-TOPSIS methodology to work on the remanufacturing product design. MS (Material Selection), MJM (Material Joining Method), SD (Structure Design) & SCM (Surface Coating Method) are the major design perspectives in remanufacturing. Hsieh et.al. [18] used HFACS (Human factors analysis and classification system), fuzzy TOPSIS, and AHP (analytic hierarchy process) to explore the important error factors of human being in Taiwan (Department of Emergency). (Surface Coating Method) are the major design perspectives in remanufacturing. Hsieh et.al. [18] used HFACS (Human factors analysis and classification system), fuzzy TOPSIS, and AHP (analytic hierarchy process)


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Table 1. Common problems in forging industries with their causes and effects

| S.N. | Problems                                      | Causes                                      | Effects                                                                | Overcome                          |
|------|-----------------------------------------------|---------------------------------------------|------------------------------------------------------------------------|-----------------------------------|
| 1    | Lack of Technology Upgradation                | Non-availability of new technology.         | Due to lack of technology upgradation, the forging process may lose the capability of satisfying the needs of new customers. | Low productivity, Low profitability |
| 2    | Lack of Automation                            | Initial investment is too high; Non-availability of automation system; Political pressure. | Lack of automation leads to increase workers fatigue and effort or labour intensive operation, increase product or material being damaged or destroyed, permit non-conforming product from shipping, decrease efficiency etc. | Low profit, Low productivity, Accident |
| 3    | High Material Cost                            | Less availability of source; High transportation cost; High labour cost. | Purchase of raw materials are costlier due to very less sources of material, high transportation and labour cost. | Low productivity, High price of finished product |
| 4    | Poor Maintenance Check                        | Irregular maintenance. Low of trained labour. | Poor maintenance check causes is too much pressure, too wide pressure fluctuation, system extra dirty, extra oil cellard work, shortened bearing life, extra repair shop work etc. and so many problems are created which leads to damages and accidents in industry. | Low productivity, Higher Cost, Increased lead time, Accident and Damage |
| 5    | Lack of Marketing in International Market     | Less production rate; High cost; Less support of government for international market. | Due to lack of marketing in international market opportunities for collaboration and mutual learning are missed. Also leads to face maximum direct competitive battles. | Low productivity, Lower brand value |
| 6    | Lack of Workers                               | Non-availability of trained workers. To cut cost, less workers requirement. | Due to low availability of workers, always extra work load comes on the available workers. | Low productivity, Accidents |
| 7    | Unskilled Workers                             | Lack of regular training. Low investment on training. | Due to limited training and education workers are mostly unskilled and inefficient. These workers have lack of basic skills, poor interpersonal communication skills. | Low productivity, Low turnover, Negative impact of customer service or inner-company communication |
| 8    | Product Defect                                | Low quality machine and equipment.          | Defects such as unfilled section, cold shut, scale pits, die shift, flakes, surface cracking, improper grain growth, incomplete forging penetration, residual stresses in forging etc. appear. | Lower productivity, Poorer quality, Less price of finished product |
| 9    | Low Fuel Supply                               | Lack of resource; High transportation cost; Shortage of labour at mines. | Generally in forging, Coal is used as fuel. Continuous production are interrupted due to shortage of fuel supply. | Low productivity |
| 10   | Low Material Availability                     | Lack of resource. Lack of exploration.      | Material availability is important in forging due to demand of forging parts especially in automobile. Continuous production are interrupted due to shortage of fuel material. | Low productivity, High price of finished product |
| 11   | Not follow the environmental policies completely | Negligence. Lack of awareness. Failure of implementing authority. | If we don’t follow the environmental policies, pollution increases which cause allergies, disease, damage to crops, air pollution imbalances slowly aid in the depletion of the ozone layer etc. | Low productivity, Health issue, Safety issue |
| 12   | Lack of Pollution Control Initiatives         | Negligence. Least priority is given by manufacturer. Lack of awareness. | Due to lack of pollution control initiatives, the source and implementing particles are increasing that increase the creation of pollutants which results pollution (air, water and soil pollution). | Low productivity, Health issue, Environmental issues (like air, water and soil pollution) |

To explore the important error factors of human being in Taiwan (Department of Emergency). (Surface Coating Method) are the major design perspectives in remanufacturing. Hsieh et.al. [18] used HFACS (Human factors analysis and classification system), fuzzy TOPSIS, and AHP (analytic hierarchy process) to explore the important error
factors of human being in Taiwan (Department of Emergency). Marbini & Kang [20] applied Fuzzy-TOPSIS for analyzing the stock exchange in Tehran. It is found that, by agreement between risk & return in stock, this profit should be maximized within designed portfolio. Sirisawat & Kitacharoenpol [21] utilized Fuzzy & AHP combined with TOPSIS to analyze the RL (Reverse Logistics Barriers) in industry for electronics applications. In this study, authors mainly aimed on the categorization of RL and ranking barriers & solution of RL implementation. Liu & Wei [22] investigated Fuzzy-TOPSIS to analyze the risk factors considering questionnaire survey and estimate the overall risk levels of EV (electric vehicle) charging infrastructure Public-Private Partnership (PPP) projects. Walczak & Rutkowska [23] adopted Fuzzy-TOPSIS for the personalized ranking of projects in a participatory budget (PB). But the researches on forging problems by Fuzzy-TOPSIS approach is negligible and need more studies. Fuzzy-TOPSIS approach is a powerful tool to find out optimal setting of process parameters in any manufacturing technique but still it is not applied to forging in literature.

In present paper, we select a Fuzzy-TOPSIS based approach for multi-criteria decision making. An attempt has been made to highlight the problems that are causing the most of the damage. In decision making, FST (Fuzzy Set Theory) is applied to find a pattern of vagueness & unpredictability. Linguistic terms are considered for representing the preferences of decision maker in FST. The decision makers give linguistic rankings for the forging problem to the concerned criteria and corresponding alternatives that are combined by using Fuzzy-TOPSIS, the main benefit is that it differentiate between the better (Benefit criteria) & less the better (Cost criteria). It also helps to select a solution that is near to positive ideal solution & away from negative ideal solution. Recommendation is made for procurement to the alternative with maximum score. Linguistic data are chosen to analyze forging criteria characteristics. Sensitivity analysis is also conducted to find out the best problem solver of forging problems. Various strategic recommendations were made to overcome the forging problems mentioned. Remaining part of the work is presented in following sequence as section 2, linguistic fuzzy set & Fuzzy-TOPSIS are discussed, section 3, a fuzzy multi-criteria method for forging problems is described, section 4, approach of numerical application, section 5, conclusions remarks of present work.

II. LINGUISTIC FUZZY SET AND FUZZY-TOPSIS

A. Linguistic fuzzy set

In FST, conversion scales are adopted to get fuzzy numbers from the linguistic term. In present work, we utilized the properties of two triangular Fuzzy numbers to estimate the criteria & alternatives. These properties are given below:

1. Property of addition

\[ \bar{B} (+) \bar{C} = (B_1 + E_1, B_2 + E_2, B_3 + E_3) \quad B_1 \geq 0, E_1 \geq 0 \]

2. Property of subtraction

\[ \bar{B} (-) \bar{C} = (B_1 - E_1, B_2 - E_2, B_3 - E_3) \quad B_1 \geq 0, E_1 \geq 0 \]

3. Property of multiplication

\[ \bar{B} (\cdot) \bar{C} = (B_1 \cdot E_1, B_2 \cdot E_2, B_3 \cdot E_3) \quad B_1 \geq 0, E_1 \geq 0 \]

4. Property of division

\[ \bar{B} (\cdot) \bar{C} = (B_1/E_1, B_2/E_2, B_3/E_3) \quad B_1 \geq 0, E_1 \geq 0 \]

5. Property of inverse

\[ \bar{B} = (\frac{1}{B_1}, \frac{1}{B_2}, \frac{1}{B_3}) \quad B_1 \geq 0 \]

6. Property of symmetric image

\[ -\bar{B} = (-B_1, -B_2, -B_3) \quad B_1 \geq 0 \]

7. Property of multiplication by a constant

\[ \bar{B} \cdot \kappa = (\kappa \cdot B_1^1, \kappa \cdot B_2^1, \kappa \cdot B_3^1) \quad B_1 \geq 0 \]

8. Property of division by a constant

\[ \bar{B} \cdot \kappa = (\kappa \cdot B_1^1, \kappa \cdot B_2^1, \kappa \cdot B_3^1) \quad B_1 \geq 0 \]

9. Property of a constant division by fuzzy number

\[ \bar{B} \cdot \kappa = (B_1^1 \cdot \kappa, B_2^1 \cdot \kappa, B_3^1 \cdot \kappa) \quad B_1 \geq 0 \]

Fuzzy ratings & linguistic variables are applied for the alternatives. The linguistic variables & fuzzy ratings applied for the criteria are presented in table 2 and table 3 respectively.

Table 2. Linguistic membership function for alternatives with rating

| Linguistic term | Membership function |
|-----------------|---------------------|
| Worse (WE)      | (0.2,0.2,0.4)       |
| Bad (BD)        | (0.2,0.4,0.6)       |
| Medium (ME)     | (0.4,0.6,0.8)       |
| Good (GD)       | (0.6,0.8,1.0)       |
| Better (BE)     | (0.8,1.0,1.0)       |

Table 3. Linguistic membership function for criteria with rating

| Linguistic term | Membership function |
|-----------------|---------------------|
| Very small (VS) | (0.2,0.2,0.4)       |
| Small (S)       | (0.2,0.4,0.6)       |
| Medium (ME)     | (0.4,0.6,0.8)       |
| Much (MU)       | (0.6,0.8,1.0)       |
| More (MO)       | (0.8,1.0,1.0)       |

B. Fuzzy-TOPSIS

Fuzzy-TOPSIS is one of the many approaches being used to determine the selected criteria against multiple alternatives. This approach, consist of nine steps is now explained below:

1. First, Criteria ratings and Alternatives ratings are assigned.
2. Then, Criteria and Alternatives aggregate fuzzy ratings are computed.

\[ a = \min_k (a_k), b = \frac{1}{3} \sum_k a_k, c = \max_k (c_k) \]

\[ a_{ij} = \min_k (a_{ik}), b_{ij} = \frac{1}{3} \sum_k a_{ij}, c_{ij} = \max_k (c_{ik}) \]

Now, criteria aggregate fuzzy weights, \( \bar{w}_j = (w_{j1}, w_{j2}, w_{j3}) \) where
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\( w_{ij} = \frac{\min(w_{ijk})}{k} \), \( w_{11} = \frac{1}{\sum_{k=1}^{K} w_{ijk}}, w_{21} = \min(w_{ijk}) \)

Now, we compute the decision matrix of Fuzzy.

\[
\bar{A} = \begin{bmatrix}
\bar{A}_1 & \bar{A}_2 & \ldots & \bar{A}_n \\
\bar{A}_1 & \bar{A}_2 & \ldots & \bar{A}_n \\
\vdots & \vdots & \ddots & \vdots \\
\bar{A}_1 & \bar{A}_2 & \ldots & \bar{A}_n \\
\end{bmatrix}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n
\]

4. Then, normalization of decision matrix of Fuzzy
\( \bar{R} = [\bar{r}_{ij}]_{m \times n}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \)

Where
\[
\bar{r}_{ij} = \left( \frac{a_{ij}^B}{\sum_{j=1}^{n} a_{ij}^B}, \frac{a_{ij}^C}{\sum_{j=1}^{n} a_{ij}^C}, \frac{a_{ij}^L}{\sum_{j=1}^{n} a_{ij}^L} \right) \quad \text{and} \quad \bar{c}_j = \max_i a_{ij} \quad \text{(Benefit Criteria)}
\]
\[
\bar{r}_{ij} = \left( \frac{a_{ij}^B}{\sum_{j=1}^{n} a_{ij}^B}, \frac{a_{ij}^C}{\sum_{j=1}^{n} a_{ij}^C}, \frac{a_{ij}^L}{\sum_{j=1}^{n} a_{ij}^L} \right) \quad \text{and} \quad \bar{c}_j = \min_i a_{ij} \quad \text{(Cost Criteria)}
\]

5. Now, we compute the matrix of weighted normalized.
\( \bar{P} = [\bar{p}_{ij}]_{m \times n}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \) where \( \bar{p}_{ij} = \bar{r}_{ij}(i,j)\bar{\bar{r}} \)

6. Then, we compute the FPIS & FNIS.
\( A^+ = (\bar{p}_{11}, \bar{p}_{21}, \ldots, \bar{p}_{m1}) \) where \( \bar{p}_{ij} = \max_i \{\bar{p}_{ij}\}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \)
\( A^- = (\bar{p}_{11}, \bar{p}_{21}, \ldots, \bar{p}_{m1}) \) where \( \bar{p}_{ij} = \min_i \{\bar{p}_{ij}\}, \quad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \)

7. Now, we compute the distances of each alternative from FPIS & distances of each alternative from FNIS.
\[
d_i^G = \sum_{j=1}^{n} d_G(\bar{p}_{ij}, \bar{p}_G^G), \quad i = 1, 2, \ldots, m
\]
\[
d_i^- = \sum_{j=1}^{n} d_G(\bar{p}_{ij}, \bar{p}_G^-), \quad i = 1, 2, \ldots, m
\]

8. Finally, we compute the each alternatives closeness coefficient \( CC_i \).

9. Alternatives are ranked ac to \( CC_i \).

Where, Alternatives, \( A_j \) (j=1, 2… m); Criteria, \( C_i \) (i=1, 2… n); Aggregate Fuzzy weight (\( \bar{w}_j \)), \( \bar{w}_j = (w_{1j}, w_{2j}, w_{3j}) \);
\( \bar{D} = \) Alternatives decision matrix of Fuzzy; \( \bar{V} = \) Weighted normalized matrix if Fuzzy; \( \bar{A}^+ = \) FPIS; \( \bar{A}^- = \) FNIS; \( d_i^G = \) Distances of each alternative from FPIS; \( d_i^- = \) Distances of each alternative from FNIS; \( CC_i = \) Closeness coefficient

III. FUZZY MULTI-CRITERIA METHOD FOR FORGING PROBLEMS: CRITERIA SELECTION

First of all, select the criteria for evaluating common problems of forging. After going through literature review on forging problems and from practical experience of working at Heavy Engineering Corporation Limited, Ranchi, India, the criteria are selected. The criteria used for selecting are chosen based on expert opinions to incorporate their possible working practices. They generally consider linguistic values to criteria rating & corresponding alternatives. Linguistics terms cannot be used to do mathematical operation, they are transformed into Fuzzy triangular number so that these can be used in Fuzzy-TOPSIS. Total 12 criteria are selected. These criteria are Technology Upgradation (C1), Need of Automation (C2), Material Cost (C3), Maintenance (C4), Need of Marketing in International Market (C5), Insufficient Workers (C6), Unskilled Workers (C7), Product Quality (C8), Fuel Supply (C9), Material Availability (C10), Adherence to environmental policies (C11), and Pollution Control Initiatives (C12). The different criteria are presented in table 4 in details.

| S.N. | Criteria | Id | Definition | Category |
|------|----------|----|------------|----------|
| 1    | Technology Upgradation | C1 | Technology upgradation refers to increase in new potential & skill to fulfill the customer need. | B |
| 2    | Need of Automation | C2 | Automation is an apparatus making technique, automatically operating leading to the capability and the ability to fulfill new customer needs. | B |
| 3    | Material Cost | C3 | Material cost is the amount of money invested in the purchase of raw material which is needed in production of product. | C |
| 4    | Maintenance | C4 | Maintenance is defined as functional checking, servicing, restoring or checking of necessary device, equipment, machinery, building infrastructure and supporting utilities in industry. | B |
| 5    | Need of Marketing in International Market | C5 | Need of marketing in international market refers to examine the step to opportunities maximization for collaborating & collective learning and at the same time minimizing the cause of direct cutthroat battles. | B |
| 6    | Insufficient Workers | C6 | Insufficient workers means that fewer workers than they need to be. | C |
| 7    | Unskilled Workers | C7 | Unskilled workers refers to the worker with limited training and less education. | C |
| 8    | Product Quality | C8 | Product quality is ability of product that contribute to meet the customer’s satisfaction. | B |
Material Availability refers to the material readily available and abundantly.

Adherence to environmental policies means the understanding and adherence to environmental policies to improve its products, services and processes to minimize waste and improving recycling activities.

Pollution control initiatives work on pollution source reduction and implementing particles that reduce or eliminate the creation of pollutants.

Criteria are calculated.

All alternatives for the three decision makers as:

While C1 is a benefit criteria, the normalized values for all 12 criteria are determined for every alternative. The values of \( a^-_i \) & \( c^+_i \) are chosen as 1 and 1 respectively. The weighted decision matrix of fuzzy for all four alternatives is determined using Eq. (9). The weighted decision matrix of fuzzy for all alternatives are calculated by using equation (3), (7) & (8), e.g. criteria fuzzy weight C1 and alternative A1 is shown by

Table 6. Linguistic analysis for the four alternatives (A1, A2, A3, and A4)

| Criteria | Decision makers | A1 | A2 | A3 | A4 |
|----------|-----------------|----|----|----|----|
| C1       | MU              | B  | B  | B  | B  |
| C2       | S               | M  | E  | D  | E  |
| C3       | MO              | M  | B  | B  | B  |
| C4       | MO              | MO | E  | E  | E  |
| C5       | MO              | ME | ME | ME | B  |
| C6       | ME              | ME | ME | ME | ME |
| C7       | ME              | ME | ME | ME | ME |
| C8       | MO              | MO | B  | B  | B  |
| C9       | ME              | MO | MO | MO | MO |
| C10      | MO              | MO | MO | MO | MO |
| C11      | VS              | VS | S  | S  | S  |

Next, normalization is carried out for the fuzzy decision matrix of all alternatives with the help of Eq. (6–8), e.g. the alternative normalized rating A1 for criteria C1 is calculated as

\[ c^+_i = \max_j (0.8, 1.0, 1.0, 1.0) = 1.0 \]

\[ a^-_i = \min_j (0.2, 0.2, 0.2, 0.6, 0.2) = 0.2 \]

Similarly, the normalized values for all 12 criteria are determined for every alternative. The values of \( a^-_i \) & \( c^+_i \) are chosen as 1 and 1 respectively. The weighted decision matrix of fuzzy for all four alternatives is determined using Eq. (9). The weighted decision matrix of fuzzy for all alternatives are calculated by using equation (3), (7) & (8), e.g. criteria fuzzy weight C1 and alternative A1 is shown by

Table 5. Linguistic analysis for the 12 criteria

| Criteria | Decision makers | D3 | D1 | D2 |
|----------|-----------------|----|----|----|
| C1       | MU              | MU | ME | ME |
| C2       | S               | MO | S  | S  |
| C3       | ME              | MO | MO | MO |
| C4       | MO              | MO | MO | MO |
| C5       | VS              | MO | ME | ME |
| C6       | MU              | ME | ME | ME |
| C7       | MU              | ME | ME | ME |
| C8       | MO              | MO | B  | B  |
| C9       | VS              | ME | MO | MO |
| C10      | ME              | MO | MO | MO |
| C11      | VS              | S  | S  | S  |
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\[ \bar{\mathbf{v}}_{ij} = (0.2, 0.466, 0.8) \cdot (0.4, 0.733, 1.0) = (0.08, 0.342, 0.8) \]

Similarly, for all 12 criteria and their four alternatives, fuzzy weight are figure out. Then, we have determined the FPIS \((A^+)^+\) and the FNIS \((A^-)^-\) based on using Eq. (10) and (11) for every alternatives, e.g., for criteria \(C_1\), \(A^+ = 0.08\) and \(A^- = 1.0\). In the same way, computations are completed for rest of the criteria. Then, the distance \(d_i(\ast)\) of each alternative is calculated with the help of the fuzzy positive ideal matrix \((A^+)\) and fuzzy negative ideal matrix \((A^-)\) using Eq. (12) and (13). For e.g., for alternative \(A_1\) & criteria \(C_1\), the distances \(d_v(A_1, A^+)\) & \(d_v(A_1, A^-)\) are determined given below:

\[
d_v(A_1, A^+) = \sqrt{\frac{1}{3} \left[ (0.08 - 0.08)^2 + (0.342 - 0.08)^2 + (0.8 - 0.08)^2 \right]} = 0.442 \\
d_v(A_1, A^-) = \sqrt{\frac{1}{3} \left[ (0.08 - 1.0)^2 + (0.342 - 1.0)^2 + (0.8 - 1.0)^2 \right]} = 0.663
\]

Likewise, the distances for rest of the criteria are computed for all the alternatives. Then, the distances \(d_i^+\) and \(d_i^-\) are determined respectively using Eq. (12) and (13). Closeness coefficient \((CC_i)\) for the twelve criteria and four alternatives are computed and plotted in Table 7 and 8 respectively.

### Table 7. Closeness coefficient \((CC_i)\) for the twelve criteria

| Criteria | \(d_i^-\) | \(d_i^+\) | \(CC_i\) | Rank |
|----------|---------|---------|---------|------|
| \(C_1\)  | 2.247   | 2.353   | 0.488   | 4    |
| \(C_2\)  | 2.384   | 2.566   | 0.481   | 5    |
| \(C_3\)  | 1.646   | 2.740   | 0.375   | 12   |
| \(C_4\)  | 1.873   | 2.225   | 0.457   | 8    |
| \(C_5\)  | 1.859   | 2.819   | 0.397   | 11   |
| \(C_6\)  | 1.925   | 2.669   | 0.419   | 10   |
| \(C_7\)  | 2.146   | 2.793   | 0.434   | 9    |
| \(C_8\)  | 2.441   | 2.509   | 0.493   | 2    |
| \(C_9\)  | 2.240   | 2.645   | 0.458   | 7    |
| \(C_{10}\)| 2.268   | 2.334   | 0.492   | 3    |
| \(C_{11}\)| 1.367   | 1.476   | 0.480   | 6    |
| \(C_{12}\)| 2.546   | 2.345   | 0.520   | 1    |

By comparing the \(CC_i\) values of the twelve criteria (Table 7), it has been found out that \(C_{12} > C_8 > C_{10} > C_1 > C_2 > C_{11} > C_9 > C_4 > C_7 > C_6 > C_5 > C_3\) which indicates the criteria weight for solving the forging problems and improves the industrialization revolution in forging industries. By comparing the \(CC_i\) values of the four alternatives (Table 8), it can be seen that \(A_2 > A_1 > A_3 > A_4\). Therefore, it can be said that supplier \(A_2\) has the best problems solver of common problem of forging as per the view of the decision making committee.

### Table 8. Closeness coefficient \((CC_i)\) for the four alternatives

| Criteria | \(d_i^-\) | \(d_i^+\) | \(CC_i\) | Rank |
|----------|---------|---------|---------|------|
| \(A_1\)  | 6.421   | 6.613   | 5.966   | 5.945|
| \(A_2\)  | 7.203   | 7.248   | 7.475   | 7.548|
| \(A_3\)  | 0.471   | 0.477   | 0.443   | 0.443|
| \(A_4\)  | 0.484   | 0.466   | 0.480   | 0.480|

A. Analysis of Sensitivity

To evaluate the criteria impact, weights represented by \(W_{Ci}\) for criteria \(C_i\) (where \(i = 1, 2, ..., n\)) are determined to find out the best problem solver of common problems of forging. The sensitivity analysis is also conducted. Total 17 experiments were performed & details are shown in Table 9.
It can be observed from Table 9, all criteria weights for first five experiments are set equal to (0.2,0.2,0.4), (0.2,0.4,0.6), (0.4,0.6,0.8), (0.6,0.8,1.0), and (0.8,1.0,1.0). The weight of each criteria for experiment 6–17 is set as highest (0.8,1.0,1.0) in successive experiment and lowest value (0.2,0.2,0.4) for the remaining criteria. The objective is to observe the criteria influencing highly the decision making process. As an illustration, the criteria C1 has the highest weight (0.8,1.0,1.0) for experiment 6, whereas the weight (0.2,0.2,0.4) for remaining criteria. The analysis of sensitivity is carried out and its result are presented in Fig. 1. It is observed from Fig. 1 & Table 9 that, alternative A2 score highest in 13 experiments (Expt. No. 1–6, 8–9, 11–13, 16–17) out of 17 experiments while alternative A1 score 4 votes for remaining experiments. Hence, we can conclude that alternative A2 emerging as the winner with a majority of votes (76.47%) and relatively insensitive to criteria weights for our decision making process.

B. Recommendations

There are following various strategic recommendations made to deal with the forging problem.

1) Procurement of raw material is the fundamental item and required serious attention. The dimension (length & diameter) of the raw material should be selected such that there is minimum wastage of material during further operation. This will result in increment of maximum raw material availability & ultimately decrease the raw material wastage.

2) Proper layout is always encourageable. The proper process layout helps in easy movement of material and the workforce required to movement of material. This will be not increasing production rate only but also save the wastage of time and money.

3) The management play a very significant role in development of any industries. Employee should always be motivated by their management. The employee can be motivated by either by developing personnel or by increasing their financial growth. The proper awareness regarding security & safety also enhance employee’s morale.

4) Some important control measures of pollutions are as follows:

(a) Control at Source: It helps in the choice of raw materials and treatment of exhaust gases before final discharge and stock height increase up to 38 meters for proper mixing of the discharged pollutants.
V. CONCLUSIONS

The degree of proper project selection has been highly affecting the rate of success for any project of industries particularly in forging industry. In this aspect, the Fuzzy-TOPSIS which is one of the hybrid approach to select the problem and also estimating all influencing parameter’s weightage to select the alternatives. A number of alternatives have been looked over by considering the various criteria, which are highly responsible for different types of problems. The Fuzzy-TOPSIS approach is being used to get order of priority among the alternatives.

The proposed approach has three steps. In step 1, the evaluating criteria of forging problems are noticed. These criteria are Technology Upgradation, Need of Automation, Material Cost, Maintenance, Need of Marketing in International Market, Insufficient Workers, Unskilled Workers, Product Quality, Fuel Supply, Material Availability, Adherence to environmental policies, and Pollution Control Initiatives. In step 2, Linguistic ratings to the alternatives & criteria provided by the experts as (a) Fuzzy-TOPSIS approach has been used to aggregate the ratings and generation of an overall closeness coefficient score for every alternatives to measure the forging problem solver.

(b) The forging problem solver having highest score is the best among alternatives.

In step 3, the influence of criteria on weights in decision making process is determined by performing sensitivity analysis.

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