Cutting Fluid Selection for Sustainable Design for Manufacturing: an Integrated Theory

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Abstract

Cutting fluids and their selection are very essential in manufacturing systems. In order to get more sustainable yield, not only the economic and technical factors, but also the ecological factors for sustainable design for manufacturing. The aim of this research to select the optimum cutting fluid that minimizes the environmental impact (E), cost (C) and maximizing the quality (Q). In this model, criteria weights are computed using the AHP method that ranking of the alternatives computed using VIKOR method. In this research, comparison has been made by taking the three cutting sustainable fluid v.i.z Traditional Cutting fluid, Syntilo 9930c and Syntilo R Plus cutting oil. The result shows that Syntilo 9930c is optimal in comparison with other.

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Keywords: Analytical Hierarchy Process (AHP), VIKOR, Sustainable design for manufacturing, sustainable cutting fluid (SCF);

1. Introduction

In conventional technique, cutting fluids selection are based on functional requirements, quality and cost performance factors. Due to the upcoming of number of laws and directives governing industrial safety and environmental security, the use of cutting fluids is putting strong financial pressure on manufacturing companies because cutting fluid is an important contributor for source of health and environmental risks. This will impacts the strongly on the operator health, which in turns affect the entire manufacturing system. Angels. D.I, and Lee. C.Y., (1996), Wedley W.C.,and Choo E.U., Schoner B., (2001), health and environmental impacts of cutting fluids are discussed, similarly disposal of cutting fluids can also impact the entire environment of the manufacturing system due to hazardous metal carry-off, hazardous chemical constituents etc.

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Even in the machining process, Cutting fluids are generally used as a coolant to ensure a smooth machining operation. Apart from serving as a lubricant, these fluids also serve to ensure good surface finish and improved tool life. Friction during machining process results in the generation of heat which in turn reduces tool life. Cakir, O. A. et al., (2007) has discussed regarding the effect of heat generated during the operation increases surface roughness, decreases tool life and decreases the dimensional sensitiveness of work material, which will also directly impact the entire manufacturing system. Yue Y., (2000), proposed comprehensive model on cutting fluid mist information in machining, including mechanism of atomization, vaporization and liquefaction. Domkondwar V, et.al. (1998), distributed modules in environmental part planning for machined components. Choi. A.C.K. (1997) developed a manufacturing modelling for environmentally impact assessment. Sheng, P. et.al., (1998a), discussed regarding the environmental planning for machining operation and system. Mexico, Sheng., and P. srinivasan. M., (1998b), developed a hierarchical part planning strategies for environmentally conscious manufacturing. Sutherland, J.W., (1997), explained the overview of environmentally conscious machining.

Later many authors have been worked in this area and have proposed a decision making problem frame work model for sustainable manufacturing, Tan X.C, et al. (2002), developed the decision making frame work for green manufacturing using MT-AMRI Tool. All these mentioned factors will directly affect the entire manufacturing system. In order to satisfy these factors one has to select the optimal cutting fluid for the entire manufacturing system based on the sustainable design. Therefore, the selection of the right cutting fluid is an important criterion towards achieving sustainable design.

From the above survey reveals that a selection cutting fluid problem is found to be a multi criteria decision problem. So MCDM approaches need to be applied to achieve. Initially AHP is developed by Saaty, T.L., (2008), later many researchers have been worked in the area of material selection. Antonio. C, et al., (2013), used AHP based methodology for selecting the safety device of industrial machinery. Ray Amitava, et al., (2010a), used AHP for Strategic Decision on Energy Planning using Multi-Criteria Decision Analysis (MCDA). Ray Amitava, et al., (2010b), employed the AHP for the Solving Multiple Constraint Resources in TOC. Ray Amitava, et al., (2010c), in this paper is to develop and demonstrate an outsourcing decision model in which constraint resource prevents the throughput of the organization using AHP. Bhattacharyay A., et al., (2005), developed an integrated theory for selection of the industrial robot using AHP-QFD.

Similarly, Julia Meciarova. and Miroslav Stanovsky., (2011), cutting fluids evaluation based on occupational health and environmental hazards. Cakir, O. A. et al., (2007), Selection of cutting fluids in machining processes. Sokovic M. and Mijanovic K., (2001), characterised the ecological factors of cutting fluids and showed its impact on nature, and wild life. Ali, S.M., et al., (2011), showed significant reduction in tool wear, dimensional accuracy and surface roughness by using MQL technique over dry machining by reducing the temperature in the cutting zone. Wu. J.A., and Wu, N.D., (1991), used AHP for storage for strategic planning model by the complex strategic problems into a three level AHP model. Zoran D., et al., (2011), used AHP for the selection of an optimal transportation system in a main haul corridor. Dalalah Doraid., et al., (2010), Shahroodil, et al., (2012), Figuera, J., Greco. S. and Ehrgott, M. (Eds), (2005), Lee. C.W. and Kwak. N.K., (1999), Macharis, C., et al., (2004), Mathematica Aeterna.,(2012), Ishizaka Alessio and Lusti Markus.,(2003), Omkarprasad S. Vaidya, and Sushil Kumar.,(2006), discussed on different application of AHP in various decision making problems like selecting cranes for construction purpose, supply chain management etc. Similarly for VIKOR model Halil Caliskan., et al., (2013), AHP-VIKOR model used for the material selection for the tool holder working under hard milling conditions. Girubha R. Jeya, and Vinodh S., (2012), application of fuzzy VIKOR and environmental impact analysis for material selection of an automotive component.
Huajun Cao., et al., (2004), a decision-making framework model of machining process planning for green manufacturing and its application using AHP method. Tan X.C., et al., (2002), selection of cutting fluid for green manufacturing using MT-AMRI Tool.

The objective factors of cutting fluid form the sustainable design point of view are, environmental impact(E), cost(C) and quality(Q). In this research cutting fluid is selected based on the minimizing the both environmental impact and cost, in the same time maximizing the its quality. The Environmental factors are further sub divided into following sub criteria, Tan X.C., et al., (2002):

- **Ecological Impact**: The cutting fluids degrade the ecological system by contaminating land, water bodies and wild life.
- **Health and safety hazard**: Long term exposure to the cutting fluid environment gives rise to some lethal diseases.
- **Insecurities**: Refers to the accidents and other hazards caused by machining.

From the literature review, many production practices shows that building an optimal selection of cutting fluid is an effective make use of the capability of the cutting fluid, to reduce the cost, maximizing the quality and minimizing the environmental impacts that is generated by the use of cutting fluid in the manufacturing system. Therefore, the main objective of this paper is to developing the decisions making frame work model for the sustainable design.

In the present work, we proposed an integrated theory that serves the all the purpose of sustainable design. The proposed methodology helps towards the selection of optimal cutting fluid which reduces the cost, minimizing the environmental impact and maximizing the quality based on the sustainable design. In this paper, therefore, a systematic integrated theory is framed to help the designers in selecting the optimal cutting fluids among a different set of available alternatives.

The following sections are organized as follows: In the next two sections, brief introduction and its details steps of the both AHP and VIKOR has been explained. Section: 4 talks about the proposed integrated theory. Validation of the proposed theory has been discussed in section: 5, section: 6 discuss the results and discussion and final conclusion has been explained in the section: 7, references have been listed at last section.

### 2. AHP Method

The AHP is decision support tool developed by Saaty, T.L., (2008). In which comparison of alternatives are qualified based on subjective criteria to provide a numeric scale for prioritizing decision alternatives. The steps involved for an AHP model are as follows:

**Step-1:** Construct the decision matrix.

- Describing a complex decision-making problem as a hierarchy (Fig.1).
- Using pairwise comparison technique using saaty’s nine point scale (Table.1), decision matrix is framed.(Eq:1)
\[ X = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \]

Where, the criteria’s are denoted by, \( X_1, X_2, \ldots, X_n \).

\[
X_{ji} = 1, X_{ij} = \frac{1}{X_{ji}}, X_{ji} \neq 0
\]  

(1)

Table 1. Nine-Point scale of pairwise comparison

| Values | Description                     |
|--------|--------------------------------|
| 1      | Equal importance               |
| 3      | Moderate importance            |
| 5      | Essential difference in importance |
| 7      | Major difference in importance |
| 9      | Extreme difference in importance |
| 2, 4, 6, 8 | Intermediate values between |

Step-2: Develop a normalized matrix by dividing each number in a column of the pair-wise comparison matrix by its column sum and average each row of the normalized matrix to get the priority vector of each alternative with respect to the particular criteria.

Step-3: Compute the consistency ratio using following equation.

\[
CR = \frac{CI}{RI}
\]

(2)

Where, \( CI \) is Consistency index, is calculated using Eq :(3)

\[
CI = \frac{\lambda_{Max} - n}{n - 1}
\]

(3)

Where, \( n = \) No. of criteria and

\( RI = \) Random number index which depends on the no of criteria’s are used in the present problem and taken as per the Table.1.

Step-4: If the consistency ratio (CR) is \(< 10\% \) or \( 0.10 \) then the level of consistency is acceptable. if not, then the evaluation process should be re-evaluated and checked for inconsistencies again and again until the level of consistency reached.
3. VIKOR

It is an effective method used in multi criteria decision making problems to rank the alternatives based on their performance value. The main procedure of the VIKOR method is described below, Halil Caliskan., et al., (2013).

Step-1: First, determination of the best, i.e. \((X_{ij})_{\text{Max}}\) and the worst, i.e. \((X_{ij})_{\text{Min}}\) values for all the criteria from the decision matrix.

Step-2: Calculate the values of \(E_i\) and \(F_i\) using following equations.

\[
E_i = \sum_{j=1}^{n} \left( W_j \frac{(X_{ij})_{\text{Max}} - (X_{ij})}{(X_{ij})_{\text{Max}} - (X_{ij})_{\text{Min}}} \right) 
\]

\[
E_i = \sum_{j=1}^{n} \left( W_j \frac{(X_{ij})_{\text{Min}} - (X_{ij})}{(X_{ij})_{\text{Max}} - (X_{ij})_{\text{Min}}} \right) 
\]

\[
F_i = \text{Max} \sum_{j=1}^{n} \left( W_j \frac{(X_{ij})_{\text{Max}} - (X_{ij})}{(X_{ij})_{\text{Max}} - (X_{ij})_{\text{Min}}} \right) 
\]

Where, Eq. (4) is applicable to the, for non- beneficial criteria Eq. (5) is used.

Step-3: Calculate the \(P_i\) (Performance Index value) values for all the considered alternatives using following equation.

\[
P_i = \left\{ \frac{E_i - E_{i-Min}}{E_{i-Max} - E_{i-Min}} \right\} + \left(1 - \nu \right) \left\{ \frac{F_i - F_{i-Min}}{F_{i-Max} - F_{i-Min}} \right\} 
\]
Where, $E_{i_{\text{Max}}}$ is the maximum value of $E_i$, and $E_{i_{\text{Min}}}$ is the minimum value of $E_i$, and $F_{i_{\text{Max}}}$ is the maximum value of $F_i$, and $F_{i_{\text{Min}}}$ is the minimum value of $F_i$. $V$ is used as the weight strategy of the majority of criteria and its value taken as 0.5, while it’s generally in the range from 0 to 1.

Step-4: Arrange the alternatives in the ascending order according to the values $P_i$. The best alternative is determined as the one having the minimum value of $P_i$.

4. Proposed Methodology

The following proposed methodology has been developed:

Step-1: Identification of the overall objective, criteria, sub-criteria’s and its different alternatives. A quantitative or qualitative value is assigned to each identified criteria to construct the related decision matrix.

Step-2: Development Normalized decision matrix using Eq. (1).

Step-3: Weights $(W_j)$ for the considered criteria are estimated using AHP.

Step-4: Determination of the best, i.e. $(X_{j_{\text{Max}}})$ and the worst, i.e. $(X_{j_{\text{Min}}})$ values for all criteria.

Step-5: Calculate the values of $E_i$ and $F_i$ using Eq. (4, 5, and 6).

Step-6: Calculate the $P_i$ (Performance Index value) values using Eq. (7).

Step-7: Arrange the alternatives in the ascending order according to the values $P_i$. The best alternative is determined as the one having the minimum value of $P_i$.

5. Validation of the proposed methodology. A Case Study

Based on the above model, a case study is selected to discuss the working and significance of the proposed model. The three cutting fluids selected for this purpose were,

- SCF1: Traditional Cutting fluid
- SCF2: Syntilo 9930c and
- SCF3: Syntilo R Plus cutting oil.

Step-1: Identification of the overall objective, criteria, sub-criteria’s and its different alternatives. A quantitative or qualitative value is assigned to each identified criteria to construct the related decision matrix.

In this step, we identified the three main criteria’s of sustainable design for manufacturing are quality (Q), environmental impact (E) and cost(C)(Fig-1), ten sub-criteria’s are Lubricating ability, cooling ability, cleaning ability, corrosion resistance, toxicity, security, environmental pollution, enterprise cost, consumer cost, social cost(Table.3) and corresponding three alternatives are SCF1: Traditional Cutting fluid, SCF2: Syntilo 9930c and SCF3: Syntilo R Plus cutting oil have been identified (Table.4).
Step-2: Development Normalized decision matrix using Eq. (1).

In this step, a decision matrix (Table 5) is constructed to measure the relative degree of importance for each sub-criteria and alternatives selected, based on the proposed methodology.

| Alternative | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| SCF1        | 0.0923 | 0.1001 | 0.1095 | 0.0926 | 0.0891 | 0.0891 | 0.0787 | 0.6668 | 0.6480 | 0.1693 |
| SCF2        | 0.6155 | 0.300 | 0.5813 | 0.6150 | 0.3234 | 0.3234 | 0.6584 | 0.1110 | 0.1221 | 0.4433 |
| SCF3        | 0.2920 | 0.5997 | 0.309 | 0.2923 | 0.5874 | 0.5874 | 0.2627 | 0.2220 | 0.2297 | 0.3873 |

Step-3: Weights (Wj) for the considered criteria are estimated using AHP.

In this step, the weights (Wj) (Table 6) for all the criteria are computed using the AHP methodology.

| Criteria | W | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 |
|----------|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|          | W  | 0.3000 | 0.3000 | 0.3000 | 0.0999 | 0.1221 | 0.2297 | 0.6480 | 0.5813 | 0.1095 | 0.3090 |

Step-4: Determination of the best, i.e. (Xji)Max and the worst, i.e. (Xji)Min values for all criteria.

| Criteria | (Xji)Max | C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 |
|----------|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|          | 0.6155    | 0.5997 | 0.5813 | 0.615 | 0.5874 | 0.5874 | 0.6584 | 0.6668 | 0.6480 | 0.4433 |
| (Xji)Min | 0.0923    | 0.1001 | 0.1095 | 0.0926 | 0.0891 | 0.0891 | 0.0787 | 0.1110 | 0.1221 | 0.1693 |

Step-5-6-7: Calculate the values of Ei, Fi and Pi (Performance Index value) using Eq-4, 5 and 7

| Alternative | Ei   | Fi   | Pi   |
|-------------|------|------|------|
| SCF1        | 2.300 | 0.701 | 1.000 |
| SCF2        | 1.036 | 0.600 | 0.146 |
| SCF3        | 1.522 | 0.480 | 0.175 |

| Alternative | Pi    | Rank |
|-------------|-------|------|
| SCF2        | 0.146 | 1    |
| SCF3        | 0.175 | 2    |
| SCF1        | 1.000 | 3    |
6. Results and Discussion

Proper selection cutting fluid for sustainable design point of view helps in the entire manufacturing system to achieve the above mentioned objectives. This paper has proposed a decision making integrated theory to show the effectiveness of the proposed model. In this, AHP method is used for computing the criteria weights and development of decision matrix and ranking of the alternatives are performed by the VIKOR. The analysis result shows that Syntilo 9930c (SCF2) is optimal in comparison with other and their result is shown in the Fig.2.

![Performance Index Value($P_i$)](image)

Fig.2. Ranking of alternatives based $P_i$

7. Conclusion

Sustainable design is the approach to reduce the environmental impact in the product manufacturing system. Every cutting fluid has different environmental effect during the manufacturing system. The aim of this research to select the optimum cutting fluid that minimizes the environmental impact (E), cost(C) and maximizing the quality (Q), for sustainable design for manufacturing. To satisfy this, a decision making integrated theory is farmed, which integrated the three factors combined in to the cutting fluid for sustainable design.

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