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# Fuzzy Delphi and hybrid AH-MATEL integration for monitoring of paint utilization

**Kumar, A.[a,*], Mussada, E.K.[a], Ashif, M.[b], Tyagi, D.[b], Srivastava, A.K.[b]**

[a]BML Munjal University, Gurgaon, India
[b]MBA-Hero Lead Students, BML Munjal University, Gurgaon, India

**ABSTRACT**

This study investigates the unattended aspects of paint utilization selection criteria in industries. In today competitive business environment almost all companies focus towards sustainable manufacturing. The utilization evaluation and selection criteria for paint and its consumption reduction is the top priority for industry. Especially in automotive industries, paint shop stands as a centre for hazardous waste due to wastage of paint and thinner during the painting process. This research work focuses on optimizing consumption of paint by finding most important criteria affecting paint consumption and optimizing the same to achieve maximum paint yield. The study uses the routes of Delphi technique in a fuzzy environment to find out the most important criteria for paint utilization selection, so that maximize utilization and minimize consumption reduction of paint has been achieved. An integrated approach of AHP and DEMATEL methods has been implemented to prioritize the criteria and to familiarize the relationship within criteria. The outcomes of the study substantiate and prove that this study is the best way to select particular paint utilization selection criteria for the paint shop and also to anticipate the optimal level of paint utilization.



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**Corresponding author:*
anilror@gmail.com
(Kumar, A.)

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## 1. Introduction

In this modern era, intense competition and globalization are the main approaching criteria for many organizations. Every industry aims to provide best services to the customers by providing after sales service, warranty, repair services besides selling the product. The first and foremost characteristic which attracts the customer is the appearance of a vehicle. This appearance of vehicles comes from the design, finishing, paint, etc. Out of which, painting process plays a centre role in providing not only good appearance to vehicles but also prevents corrosion. That's why all the companies prioritize the painting process in assembly. As the painting process involves in investing more money, it is necessary to understand and investigate the suitability of paints on vehicles. Painting process also requires the use of costly and harmful chemicals and other resources and to enhance the profitability, the consumption of paint has to be reduced. Therefore, the selection of a particular paint supplier needs a lot of scrutinizes, and there are many factors which should be considered before selecting one. This study is an attempt to understand experts' views in the evaluation of paint utilization selection criteria so that they can use their supplier accordingly and how it can help in paint consumption reduction.

Many researchers across the globe explored various multi criteria decision making (MCDM) approaches in manufacturing [6], for supplier selection [11], supply chain [10], transportation and logistics [13]. However, no attempt has been found in selecting paint utilization criteria. After scrutinizing the available literature and identifying the gaps, objectives have been set. The primary objective of this study work is to investigate the main criteria points for paint utilization criteria consumption in a manufacturing plant, prioritizing criteria and establish an interrelationship in assembly and targeting paint suppliers accordingly. To achieve the objectives of the study, three MCDM techniques have been used. Out of these, the first one is Delphi in a fuzzy environment has been used to capture the ambiguity of the expert opinion during criteria selection; secondly, Analytical Hierarchy process (AHP) has been put into use to assist in quantifying relative priorities for the given set of evaluation criteria. Thirdly for confirmation and as a final check of interrelation among the criteria, DEMATEL method was later put into use.

The rest of the study has been organized in different parts. In the first part, introduction to the study has been given followed by the required basic preliminaries. The procedure for finalizing criteria for best paint utilization criteria has been given in the third part. Prioritizing of criteria and construction of a network relationship map has been discussed in the fourth part. Discussion and concluding remarks have been given in discussion and conclusion parts.

## 2. Preliminaries

### 2.1 Fuzzy sets

The some important definitions of fuzzy sets which we employed in this study are given below:

Def. 1. A fuzzy set $\tilde{A}$ is a subset of the universal set $X$, with mapping $\mu_{\tilde{A}} : X \rightarrow [0,1]$, where For the fuzzy set $\tilde{A}$ the function value of $\mu_{\tilde{A}}(x)$ is called the 'membership value' of x in $\tilde{A}$ representing the degree of truth that x is an element of the fuzzy set $\tilde{A}$.

Def. 2. the triangular fuzzy number (TFN) of fuzzy set defines as follows.

$$\mu_{\tilde{N}}(x) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \leq x \leq m, \\ (r-x)/(r-m) & m \leq x \leq r, \\ 0, & x > r, \end{cases}$$ which can be denoted as a triplet ($l$, $m$, $r$).

### 2.2 Fuzzy Delphi method

This section describes the procedure of fuzzy Delphi technique using triangular fuzzy number to capture experts' opinions by using Eq. 1.

$$\widetilde{W}_k = (l_k, m_{k,}, r_k\ ) \tag{1}$$

$\tilde{W}_k$ represents the fuzzy number for the criteria $k$. $l_k$, $m_k$, and $r_k$ can be represented as the minimum, average, and maximum number of experts opinions. The center-of-gravity method is used to calculate the value of $S_k$ by using Eq. 2.

$$S_k = (l_k + m_k + r_k)/3 \tag{2}$$

The principles for final selection of the criteria as follows: (1) If $S_k \geq \lambda$ accept criterion $k$; (2) If $S_k < \lambda$ omit criterion $k$.

Once the paint selection criteria is selected, the evaluation of each criteria against others criteria is done by experts for this AHP is employed and further to find the interrelationship, DEMETAL is utilized. In the earlier studies, AHP method has been used to find weight of criteria and all criteria are considered independent and is not considered to find cause-effect relationship within the criteria and DEMATEL method has been used for not only capturing the importance but also reveals the cause-effect relation within criteria [3, 7, 19]. A brief description of both the methods is described below.

## 2.3 Analytical hierarchy process (AHP) method

AHP is power full tool for handling multi-criteria factors in decision making, developed by Saaty [20]. If there are $n$ criteria through then $n\times(n-1)/2$ mutually comparisons can do with help of this method. 1-9 point scale is used to obtain expert's preferences about the selected criteria. A pairwise comparisons is formed as a matrix shows in Eq. 3.

$$\mathrm{A} = (a_{ij}) = \begin{bmatrix} a_{11} & a_{12} & . & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & . & a_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ a_{n1} & a_{21} & . & . & . & a_{nn} \end{bmatrix} = \begin{bmatrix} 1 & a_{12} & . & . & . & a_{1n} \\ 1/a_{12} & a_{22} & . & . & . & a_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & a_{n-1n} \\ 1/a_{1n} & 1/a_{2n} & . & . & 1/a_{n-1n} & 1 \end{bmatrix} \tag{3}$$

$a_{ij}$ is preference comparison the criterion *i* with criterion *j*.

Eigenvalues and eigenvectors with Eq. 4, are used to calculate the relative weights of the criteria.

$$Aw = \lambda_{max} w \tag{4}$$

Here eigenvector and largest eigenvalue of matrix A, are represented by $w$ and $\lambda_{max}$. With the help of Eq. 5 and Eq. 6, the reliability of the judgments of experts has been checked.

$$\text{Consistency Index } (CI) = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

$$\text{Consistency Ratio } (CR) = \frac{CI}{RI} \tag{6}$$

*RI* represents Random Index and *n* criteria. The value of *RI* against the number of criteria is given in Table 1.

If $CI \le 0.1$, it shows the consistency of the pairwise matrix and can proceed to calculate final weight of the criteria, otherwise, matrix has to be revised.

**Table 1** Random index

| *n* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| *RI* | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.45 |

## 2.4 Decision making trial and evaluation laboratory (DEMATEL) method

For better understanding and examining the dependent criteria for an INRM ((Influential Network Relationship Map), DEMATEL technique is generally put into use [8]. Cause computation and each constituent requires proper utilization of the matrix, the structural model and the related mathematical theories in the DEMATEL and thus complex problems are solved easily [18]. Complex and intertwined problem groups are easily solved by the DEMATEL [17]. DEMATEL is generally applied to get a better view of the specific problem and catalyse to the detection of feasible solutions by which we can find out the interdependence between the elements of a system with the help of a casual diagram. The casual diagram portrays the interdependence between the elements within a system. The causal diagrams show contextual relationships rather than graphs without direction and also the strengths of the influence between the elements. The different mathematical steps for DEMATEL as follows:

*Step 1:* Experts have been asked to rate the relationship among the criteria with the scale of 0-5, 0-no effect and 5-high effect. The average of experts' opinion has been calculated by Eq. 7.

$$A = [a_{ij}] = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^{k} \tag{7}$$

*Step 2:* The matrix normalization has been achieved by Eq. 8.

$$F = m \times A, \tag{8}$$

where,

$$m = \min\left[\frac{1}{max_i \sum_{i=1}^{n} a_{ij}}, \frac{1}{max_j \sum_{j=1}^{n} a_{ij}}\right], i, j \in \{1, 2, \dots, n\} \tag{9}$$

*Step 3:* Eqs. 10-11 have been utilized to estimate total relation matrix *T*.

$$T = \lim_{m \to \infty} (F^1 + F^2 + \dots + F^m) = \sum_{m=1}^{\infty} F^i \tag{10}$$

where,

$$\begin{aligned}\sum_{m=1}^{\infty} F^i &= F^1 + F^2 + \dots + F^m \\ &= F(I + F^1 + F^2 \dots + F^{m-1}) \\ &= F(I - F)^{-1}(I - F)(I + F^1 + F^2 \dots + F^{m-1}) \\ &= F(I - F)^{-1}(1 - F)^m \\ T &= F(I - F)^{-1}\end{aligned} \tag{11}$$

After identifying matrix *T*, *r* and *c* with help of Eq. 12 and Eq. 13 are calculated.

$$r = [r_i]_{n \times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1} \tag{12}$$

$$c = [c_i]_{1 \times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n} \tag{13}$$

*Step 4:* Eq. 14 had been used to calculate the threshold value ($\alpha$) and avoid minor effects.

$$\alpha = \sum_{i=1}^{n} \sum_{j=1}^{n} [t_{ij}] / N \tag{14}$$

where, *N* elements in the matrix *T*.

## 3. Paint utilization selection criteria

The fuzzy Delphi technique creates better criteria solutions [2, 5, 14] and used to finalize for paint utilization selection criteria. This concept has been implemented to measure the importance of the criteria by using linguistic scales in the form of TFN [9, 16] as mentioned in Table 2.

**Table 2** The linguistic scales

| Linguistic scales | Extremely important | | | Important | | | Normal | | | Unimportant | | | Extremely unimportant | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TFN | 0.7 | 0.9 | 0.9 | 0.5 | 0.7 | 0.9 | 0.3 | 0.5 | 0.7 | 0.1 | 0.3 | 0.5 | 0.1 | 0.1 | 0.3 |

**Table 3** Best paint utilization selection criteria

| Criteria | S |
|---|---|
| Transfer Efficiency ($C_1$) | 0.72201 |
| Solid Content of Paint ($C_2$) | 0.67320 |
| Conductivity of Paint ($C_3$) | 0.65402 |
| Hiding Power ($C_4$) | 0.72041 |
| Technical Support ($C_5$) | 0.62430 |
| Paint Workability ($C_6$) | 0.69831 |
| Thinner Intake ($C_7$) | 0.76343 |
| Supply Viscosity ($C_8$) | 0.65340 |

After using this method, the important criterion is generally shifted from the evaluation result and the shifting threshold value effects the number of criteria. This study adopts a threshold value of 0.6. 12 production managers from paint assembly automotive have been interview about paint utilization selection criteria and after using Eq. 1 and Eq. 2, and principles selection criteria are shown in Table 3.

Both qualitative and quantitative criteria are considered in evaluation and selection of the best paint utilization criteria and a brief description of each criterion as follows.

### 3.1 Transfer efficiency

Transfer efficiency of a painting process is the comparison of amount of paint deposited on component to the amount of total paint sprayed through the painting gun. This is commonly described as the % of weight of solids sprayed to the weight of solids increased by the component. As an illustration, 70 % transfer efficiency means that 50 % of the weight of the solids in the material that was sprayed actually touched the component and the remaining 30 % was lost during the spray finishing process. With help of formula below, we can calculate transfer efficiency easily.

$$\text{Transfer efficiency} = \frac{\text{Actual paint deposited on component}}{\text{Total paint sprayed on component}}$$

Transfer efficiency of a painting system plays major role to optimize paint consumption, as we can't achieve paint consumption beyond the transfer efficiency of the painting system by all means.

### 3.2 Solid content of paint

A conventional paint is a mixture of resins, solvents, pigments and additives. When a paint is applied over a surface of any solid portion, a dry or solid portion is left over when the paint is completely dried. The volume of the paint that is left over is represented in terms of volume solid. The volume solid of a coat is the ratio of the volume of non-volatile components to its total wet volume. The figure is generally articulated as percentage. Awareness of Volume Solids provides many benefits: 1) It helps to compare and understand the true cost of different paints, 2) It helps to determine and predict how much paint is actually required to be applied to obtain adequate coverage, and 3) It helps to control the actual quality of the painting.

### 3.3 Thinner intake of paint

Thinner intake of paint is the thinner volume essential to achieve desired viscosity from supplied viscosity. Paint is transported from manufacturing plants to automotive paint shop in with a viscosity ranging from 0.14-0.21 Pa·S but paint cannot be applied on parts with the supplied viscosity by any paint applicator whether it is manual painting or electrostatic spraying. For ease of paint application, viscosity is required in the range of 0.03-0.05 Pa·S depending on the paint and application technique and to reduce the viscosity of paint thinner is added.

$$\text{Thinner intake (\%)} = \frac{\text{Volume of thinner added (L)}}{\text{Volume of raw paint (L)}}$$

### 3.4 Paint conductivity

Paint Conductivity is the measure of charge carrying capacity of paint, it plays major role in electrostatic painting application where painting is achieved due to potential difference between paint and substrate. Electrostatic painting is based on Coulomb's Law i.e. oppositely charged particle attracts each other. In electrostatic painting, paint is given negative charge and substrate is earthed through conveyor. Paint conductivity is measured by resistivity of paint, which is opposite of paint conductivity. An optimum value of paint conductivity is required to achieve maximum transfer efficiency of an electrostatic painting system.

Paint conductivity = 1/Paint resistivity

### 3.5 Hiding power of paint

Hiding power of paint is actually the capability of a particular coating to hide the surface on which coating is used. The thumping power is directly linked to the method by which the film is actually applied and also the film thickness. The hiding power of the coating is influenced by the pigments in the binder media. A coating with strong hiding power develops the pigment particles scatter the light so strongly that they hardly reach the substrate. Thus, hiding power is selected as an important parameter for selecting a paint.

### 3.6 Supply viscosity

Viscosity is described as the internal resistance of a fluid to flow and may be considered as a measure of fluid friction. In paint manufacturing and application industry, the very first information available about paint is its viscosity. Paint supplier supplies paint in a relatively high viscous condition.

### 3.7 Technical support

In an automotive paint shop, the process of painting is carried out inside a spraying chamber. This spraying chamber is an effective pressurized enclosed environment, which is generally used to paint parts of a vehicle loaded in a well-designed hangers fixed on a moving conveyer. For maintaining efficient working conditions, the spray booths are equipped with air supply units, air exhaust blowers, LNG heating system and continuous waster scrubber. During the painting process a lot of these parameters are generally required to be optimized by the paint shop in charge or the engineer, on the other hand some parameters related to paint are optimized by the technical support staff of the concerned paint supplier during the painting process.

### 3.8 Paint workability

Paint workability is defined as the ability of paint to spread over the surface and provide uniform thin layer of paint after baking.

## 4. Prioritization and network relationship map (NRM)

To get the weight of criteria, AHP is used and data has been synthesized in excel and then analysed. Let $C = \{C_j | j = 1, 2, \ldots, n\}$ is the decision criteria set. The data of the available pair wise comparison of n criteria can actually be summarized into an ($n$ x $n$) evaluation matrix named A in which each element $a_{ij}$ ($i, j = 1, 2, \ldots, n$) is of weights of the criteria. We would have (n x n) matrixes for every expert, then the geometric mean of all the matrixes was taken to form a geometric mean matrix [4]. The geometric mean has been taken as more ratio properties are involved [1].

$$G_{ij} = \left[\prod_{i=1}^{n} x_{ij}\right]^{\frac{1}{n}} \quad \forall\, i, j \tag{15}$$

By using Eq. 15, matrix shown in Table 4 has been formed by averaging all the corresponding ranking of each pairwise comparison of all experts/respondents.

**Table 4** Average matrix

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ |
|---|---|---|---|---|---|---|---|---|
| $C_1$ | 1.00 | 0.33 | 3.00 | 5.00 | 5.00 | 3.00 | 3.00 | 5.00 |
| $C_2$ | 3.00 | 1.00 | 3.00 | 5.00 | 3.00 | 3.00 | 5.00 | 5.00 |
| $C_3$ | 0.33 | 0.33 | 1.00 | 3.00 | 3.00 | 3.00 | 5.00 | 7.00 |
| $C_4$ | 0.20 | 0.20 | 0.33 | 1.00 | 1.00 | 3.00 | 3.00 | 5.00 |
| $C_5$ | 0.20 | 0.33 | 0.33 | 1.00 | 1.00 | 0.33 | 1.00 | 3.00 |
| $C_6$ | 0.33 | 0.33 | 0.33 | 0.33 | 3.00 | 1.00 | 3.00 | 5.00 |
| $C_7$ | 0.33 | 0.20 | 0.20 | 0.33 | 1.00 | 0.33 | 1.00 | 1.00 |
| $C_8$ | 0.20 | 0.20 | 0.14 | 0.20 | 0.33 | 0.20 | 1.00 | 1.00 |

For normalization matrix shown in Table 5, is obtained by dividing column by the sum of the corresponding column. As a process of cross verification sum of each column is checked if it was 1 or not and the same has been confirmed.

**Table 5** Normalization matrix

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ |
|---|---|---|---|---|---|---|---|---|
| $C_1$ | 0.34 | 0.11 | 0.36 | 0.32 | 0.29 | 0.22 | 0.14 | 0.16 |
| $C_2$ | 0.54 | 0.18 | 0.36 | 0.32 | 0.17 | 0.22 | 0.23 | 0.16 |
| $C_3$ | 0.11 | 0.06 | 0.12 | 0.19 | 0.17 | 0.22 | 0.23 | 0.22 |
| $C_4$ | 0.07 | 0.04 | 0.04 | 0.06 | 0.06 | 0.22 | 0.14 | 0.16 |
| $C_5$ | 0.07 | 0.06 | 0.04 | 0.06 | 0.06 | 0.02 | 0.05 | 0.09 |
| $C_6$ | 0.11 | 0.06 | 0.04 | 0.02 | 0.17 | 0.07 | 0.14 | 0.16 |
| $C_7$ | 0.11 | 0.04 | 0.02 | 0.02 | 0.06 | 0.02 | 0.05 | 0.03 |
| $C_8$ | 0.07 | 0.04 | 0.02 | 0.01 | 0.02 | 0.01 | 0.05 | 0.03 |

The average of each row has been taken to find the weight, by doing this the individual weightage of each criteria and rank has been derived and is shown in Table 6. The degree of consistency (CI) and consistency ratio (CR) has been calculated by routes given by Saaty [20] with Eq. 5 and Eq. 6. The CR value obtained is less than 0.1 and it substantiates the acceptability of matrix *M*.

**Table 6** Weightage

| Criteria | Weightage | Percentage (%) | Rank |
|---|---|---|---|
| Transfer Efficiency ($C_1$) | 0.221 | 22.1 | 2 |
| Solid Content of Paint ($C_2$) | 0.291 | 29.1 | 1 |
| Conductivity of Paint ($C_3$) | 0.165 | 16.5 | 3 |
| Hiding Power ($C_4$) | 0.097 | 09.7 | 4 |
| Technical Support ($C_5$) | 0.059 | 05.9 | 6 |
| Paint Workability ($C_6$) | 0.096 | 09.6 | 5 |
| Thinner Intake ($C_7$) | 0.041 | 04.1 | 7 |
| Supply Viscosity ($C_8$) | 0.030 | 03.0 | 8 |

To check the interdependent among selected criteria, DEMATEL technique has been utilized. Firstly, the average matrix A is constructed by Eq. 7 as displayed in Table 7. The normalized influence matrix is calculated by Eq. 8 and Eq. 11 the total influence matrix *T*. In last the NRM is constructed by Eq. 12 and Eq. 13 as displayed in Fig.1.

According to step 2, by using Eq. 8 and Eq. 9, we got *m* is 0.053 and the nominalization matrix *F* as follows

**Table 7** Average matrix

$A$ =

| | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | $C_7$ | $C_8$ | Sum |
|---|---|---|---|---|---|---|---|---|---|
| $C_1$ | 0.000 | 3.000 | 3.833 | 2.000 | 1.000 | 1.000 | 2.083 | 0.083 | 13.000 |
| $C_2$ | 1.000 | 0.000 | 1.750 | 3.000 | 1.000 | 2.000 | 3.000 | 2.000 | 13.750 |
| $C_3$ | 1.917 | 2.000 | 0.000 | 2.000 | 1.000 | 2.667 | 2.917 | 2.000 | 14.500 |
| $C_4$ | 2.917 | 3.000 | 2.000 | 0.000 | 2.000 | 2.833 | 2.000 | 2.000 | 16.750 |
| $C_5$ | 1.000 | 1.000 | 1.000 | 2.000 | 0.000 | 2.000 | 1.000 | 2.000 | 10.000 |
| $C_6$ | 2.000 | 2.917 | 2.917 | 1.000 | 1.000 | 0.000 | 1.000 | 2.000 | 12.833 |
| $C_7$ | 2.000 | 3.000 | 2.083 | 2.000 | 2.917 | 3.000 | 0.000 | 3.833 | 18.833 |
| $C_8$ | 1.000 | 2.917 | 2.000 | 1.000 | 1.000 | 2.000 | 3.917 | 0.000 | 13.833 |
| **Sum** | 11.83 | 17.83 | 15.58 | 13.00 | 9.917 | 15.50 | 15.917 | 13.917 | -------- |

$$F = \begin{bmatrix} 0.000 & 0.159 & 0.204 & 0.106 & 0.053 & 0.053 & 0.111 & 0.004 \\ 0.053 & 0.000 & 0.093 & 0.159 & 0.053 & 0.106 & 0.159 & 0.106 \\ 0.102 & 0.106 & 0.000 & 0.106 & 0.053 & 0.142 & 0.155 & 0.106 \\ 0.155 & 0.159 & 0.106 & 0.000 & 0.106 & 0.150 & 0.106 & 0.106 \\ 0.053 & 0.053 & 0.053 & 0.106 & 0.000 & 0.106 & 0.053 & 0.106 \\ 0.106 & 0.155 & 0.155 & 0.053 & 0.053 & 0.000 & 0.053 & 0.106 \\ 0.106 & 0.159 & 0.111 & 0.106 & 0.155 & 0.159 & 0.000 & 0.204 \\ 0.053 & 0.155 & 0.106 & 0.053 & 0.053 & 0.106 & 0.208 & 0.000 \end{bmatrix}$$

According to step 3, by using Eq. 11 matrix $T$ is calculated and given as follows

$$T = \begin{bmatrix} 0.250 & \mathbf{0.499} & \mathbf{0.493} & 0.373 & 0.262 & 0.374 & \mathbf{0.431} & 0.306 \\ 0.319 & 0.389 & \mathbf{0.421} & \mathbf{0.427} & 0.280 & \mathbf{0.441} & \mathbf{0.492} & \mathbf{0.416} \\ 0.367 & \mathbf{0.498} & 0.352 & 0.393 & 0.284 & \mathbf{0.477} & \mathbf{0.499} & \mathbf{0.422} \\ \mathbf{0.437} & \mathbf{0.581} & \mathbf{0.486} & 0.332 & 0.349 & \mathbf{0.518} & \mathbf{0.497} & \mathbf{0.450} \\ 0.240 & 0.329 & 0.293 & 0.299 & 0.159 & 0.339 & 0.302 & 0.319 \\ 0.331 & \mathbf{0.483} & \mathbf{0.442} & 0.314 & 0.247 & 0.304 & 0.375 & 0.374 \\ \mathbf{0.424} & \mathbf{0.626} & \mathbf{0.524} & \mathbf{0.459} & \mathbf{0.417} & \mathbf{0.568} & \mathbf{0.448} & \mathbf{0.572} \\ 0.314 & \mathbf{0.524} & \mathbf{0.432} & 0.343 & 0.281 & \mathbf{0.441} & \mathbf{0.535} & 0.325 \end{bmatrix}$$

Bold component of matrix are > α.

Using Eq. 6 to Eq. 7, Table 8 is found out.

**Table 8** Cause and effect

| **Crietria** | $r_i$ | $c_j$ | $r_i + c_j$ | $r_i - c_j$ | **Impact** |
|---|---|---|---|---|---|
| Transfer Efficiency ($C_1$) | 2.989 | 2.681 | 5.671 | 0.308 | Cause |
| Solid Content of Paint ($C_2$) | 3.185 | 3.929 | 7.114 | -0.744 | Effect |
| Conductivity of Paint ($C_3$) | 3.292 | 3.442 | 6.735 | -0.149 | Effect |
| Hiding Power ($C_4$) | 3.651 | 2.942 | 6.593 | 0.709 | Cause |
| Technical Support ($C_5$) | 2.280 | 2.280 | 4.560 | -0.001 | Effect |
| Paint Workability ($C_6$) | 2.871 | 3.463 | 6.334 | -0.593 | Effect |
| Thinner Intake ($C_7$) | 4.038 | 3.580 | 7.618 | 0.457 | Cause |
| Supply Viscosity ($C_8$) | 3.196 | 3.185 | 6.380 | 0.011 | Cause |

A threshold value has been set up to obtain the Network Relation Map (Fig.1). The threshold value ($\alpha$) has been computed by Eq. 14 and that threshold value is also used to remove some minor effects elements in matrix T.

In matrix T the values of $t_{ij}$ have been calculated, if element of matrix T greater than threshold value α (0.398) that element shown in bold in matrix T e.g. the value of $t_{12}(0.499) > \alpha$ (0.398), the arrow in the digraph is drained from $C_1$ to $C_2$. The network relationship map for all the eight criteria is built as depicted in Fig. 1.

$$\alpha = \sum_{i=1}^{n} \sum_{j=1}^{n} [t_{ij}] / N \quad = 25.50/64 = 0.398$$

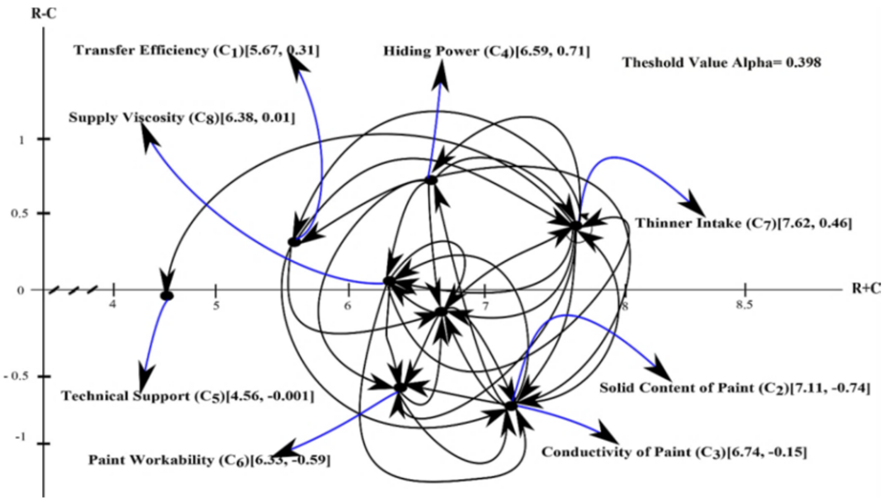


**Fig.1** Network relation map (NRM) within criteria

## 5. Discussion

It is well known acceptable fact that all the components of paints are required, but all of them don't have the same priority. In many cases, decisions are made upon giving crisp values, but all these crisp values are not such an accurate reflection of what is exactly happening in the real world. The need for fuzzy set theory arose from the fact that human judgments about preferences are always unclear and are hard to estimate from numerical values. To handle such situations which are complex and uncertain Delphi method was first applied in the fuzzy environment to finalize the selection criteria of paint selection. AHP was used to prioritize and from the results derived from AHP. DEMATEL technique has been employed to find out the interrelationship relationship between criteria and to identify the interrelationship within the criteria. AHP analysis shows that the criteria solid content of paint has the first rank with the weightage value of 29.1 followed by transfer efficiency, conductivity of paint with the weightage value of 22.1 and 16.5. Hiding power (9.7), paint workability (9.6), technical support (5.9), thinner intake (4.1), and supply viscosity (0.3) are contained the rank four to eight. The oval prioritization of criteria is as $C_2 > C_1 > C_3 > C_4 > C_6 > C_5 > C_7 > C_8$.

On the basis of (*r*-*c*) values all eight criteria have been divided into two group, i.e., (i) cause group and (ii) effect group.

(i) Those criteria has (*r*-*c*) has positive value, there are in net cause group and affect the rest criteria, high value shows major impact. The criteria: Transfer Efficiency ($C_1$), Hiding Power ($C_4$), Thinner Intake ($C_7$), and Supply Viscosity ($C_8$) are in this group and having 0.3088, 0.7098, 0.4573 and 0.0110 values. The analysis shows that Hiding Power ($C_4$) is the most critical criteria on the others followed by Thinner Intake ($C_7$), Transfer Efficiency ($C_1$), and Supply Viscosity ($C_8$). The analysis shows that mutual interaction between Transfer Efficiency ($C_1$) and Thinner Intake ($C_7$) has also the mutual interaction with $t_{17}$(0.4313) and $t_{71}$(2.2757), $t_{17}$(0.4242) values and all are greater than α (0.3985).

(ii) If (*r*-*c*) has negative value, say it is net receive and all net receive criteria. The current study, Solid Content of Paint ($C_2$), Conductivity of Paint ($C_3$), Technical Support ($C_5$), and Paint Workability ($C_6$) are categorized in the effect group, with the (*r*-*c*) values of -0.7442, -0.1499, -0.0001 and -0.5925. The criteria Thinner Intake ($C_7$) is impacting all other criteria followed by Hiding Power ($C_4$), Supply Viscosity ($C_8$), and Transfer Efficiency ($C_1$).

## 6. Conclusion

Paint suppliers optimization and choosing them is a major challenge for any automobile industry. It is important because they have to sustain themselves in the competitive environment and to do that they are always on a look out to upgrade their selection criteria of paint suppliers so that they can achieve their maximum utilization of paint that they usually consume. It has been observed that solid content of paint is the most important criteria and supply viscosity of Paint is the least important dimension for the paint supplier selection. The outcomes of DEMATEL results validates that the thinner intake is the most influential and has the strongest connection to other criteria. The criteria Transfer Efficiency is at rank two with weight 22.1 %, and comes in cause group, which has a direct effect on the criteria i.e. Solid Content of paint, Conductivity of Paint, and Thinner Intake, this the most suggested criteria according analysis of the study for paint supplier selection. The criteria Hiding Power ranks four with weightage 9.7 % and has a direct relationship with Transfer Efficiency, Solid Content of paint, Conductivity of Paint, Paint Workability, Thinner Intake, and Supply Viscosity. Thinner Intake is also in cause group and directly affected by all the other criteria Transfer Efficiency, Solid Content of paint, Conductivity of Paint, Hiding Power, Technical Support, Paint Workability, Thinner Intake, Supply Viscosity. The last criteria, which comes in cause group is Supply Viscosity and affected to Solid Content of paint, Conductivity of Paint, Hiding Power , Paint Workability, Thinner Intake.

The current work is having a great future scope and more detailed investigations of criteria's that effects the utilization of paint consumption and its selection criteria. Further artificial intelligence techniques could be employed to optimize the various paint utilization criteria.

## References

[1] Büyüközkan, G., Çifçi, G. (2012). A combined fuzzy AHP and fuzzy TOPSIS based strategic analysis of electronic service quality in healthcare industry, *Expert Systems with Applications*, Vol. 39, No. 3, 2341-2354, doi: 10.1016/j.eswa.2011.08.061.

[2] Chang, P.-T., Huang, L.-C., Lin, H.-J. (2000). The fuzzy Delphi method via fuzzy statistics and membership function fitting and an application to the human resources, *Fuzzy Sets and Systems*, Vol. 112, No. 3, 511-520, doi: 10.1016/S0165-0114(98)00067-0.

[3] Chen, H.H., Kang, H.Y., Xing, X., Lee, A.H.I., Tong, Y. (2008). Developing new products with knowledge management methods and process development management in a network, *Computers in Industry*, Vol. 59, No. 2-3, 242-253, doi: 10.1016/j.compind.2007.06.020.

[4] Dalalah, D., Hayajneh, M., Batieha, F. (2011). A fuzzy multi-criteria decision making model for supplier selection, *Expert Systems with Applications*, Vol. 38, No. 7, 8384-8391, doi: 10.1016/j.eswa.2011.01.031.

[5] Dalkey, N., Helmer, O. (1963). An experimental application of the Delphi method to the use of experts, *Management Science*, Vol. 9, No. 3, 458-467, doi: 10.1287/mnsc.9.3.458.

[6] Ghorabaee, M.K. (2016). Developing an MCDM method for robot selection with interval type-2 fuzzy sets, *Robotics and Computer-Integrated Manufacturing*, Vol. 37, 221-232, doi: 10.1016/j.rcim.2015.04.007.

[7] Ho, W.-R.J., Tsai, C.-L., Tzeng, G.-H., Fang, S.-K. (2011). Combined DEMATEL technique with a novel MCDM model for exploring portfolio selection based on CAPM, *Expert Systems with Applications*, Vol. 38, No .1, 16-25, doi: 10.1016/j.eswa.2010.05.058.

[8] Hung, Y.-H., Huang, T.-L., Hsieh, J.-C., Tsuei, H.-J., Cheng, C.-C., Tzeng, G.-H. (2012). Online reputation management for improving marketing by using a hybrid MCDM model, *Knowledge-Based Systems*, Vol. 35, 87-93, doi: 10.1016/j.knosys.2012.03.004.

[9] Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., Mieno, H. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration, *Fuzzy Sets and Systems*, Vol. 55, No. 3, 241-253, doi: 10.1016/0165-0114(93)90251-C.

[10] Lin, Y.-H., Tseng, M.-L. (2016). Assessing the competitive priorities within sustainable supply chain management under uncertainty, *Journal of Cleaner Production*, Vol. 112, Part 3, 2133-2144, doi: 10.1016/j.jclepro.2014.07.012.

[11] Malik, M.M., Abdallah, S., Hussain, M. (2016). Assessing supplier environmental performance: Applying analytical hierarchical process in the United Arab Emirates healthcare chain, *Renewable and Sustainable Energy Reviews*, Vol. 55, 1313-1321, doi: 10.1016/j.rser.2015.05.004.

[13] Tadić, S., Zečević, S., Krstić, M. (2014). A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection, *Expert Systems with Applications*, Vol. 41, No. 18, 8112-8128, doi: 10.1016/j.eswa.2014.07.021.

[14] van Zolingen, S.J., Klaassen, C.A. (2003). Selection processes in a Delphi study about key qualifications in senior secondary vocational education, *Technological Forecasting and Social Change,* Vol. 70, No. 4, 317-340, doi: 10.1016/S0040-1625(02)00202-0.

[15] Rao, R.V., Rai, D.P., Ramkumar, J., Balic, J. (2016). A new multi-objective Jaya algorithm for optimization of modern machining processes, *Advances in Production Engineering & Management*, Vol. 11, No. 4, 271-286, doi: 10.14743/apem2016.4.226.

[16] Kumar, A., Dash, M.K. (2016). Using DEMATEL to construct influential network relation map of consumer decision-making in e-marketplace, *International Journal of Business Information Systems,* Vol. 21, No. 1, 48-72, doi: 10.1504/IJBIS.2016.073380.

[17] Wu, W.-W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach, *Expert Systems with Applications*, Vol. 35, No. 3, 828-835, doi: 10.1016/j.eswa.2007.07.025.

[18] Wu, H.-H., Tsai, Y.-N. (2012). An integrated approach of AHP and DEMATEL methods in evaluating the criteria of auto spare parts industry, *International Journal of Systems Science*, Vol. 43, No. 11, 2114-2124, doi: 10.1080/00207721.2011.564674.

[19] Jafari-Moghadam, S., Zali, M., Sanaeepour, H. (2017). Tourism entrepreneurship policy: A hybrid MCDM model combining DEMATEL and ANP (DANP), *Decision Science Letters*, Vol. 6, No. 3, 233-250, doi: 10.5267/j.dsl.2016.12.006.

[20] Saaty, T.L. (2008). Decision making with the analytic hierarchy process*, International Journal of Services Sciences*, Vol. 1, No. 1, 83-98.

[21] Kumar, A., Dash, M.K. (2014). Criteria exploration and multi-criteria assessment method (AHP) of multi-generational consumer in electronic commerce, *International Journal of Business Excellence*, Vol. 7, No. 2, 213–236, doi: 10.1504/IJBEX.2014.059549.