Solution of Multi-response Optimization: Case Study in turning of AISI D2 Steel using Fuzzy TOPSIS Integrated Taguchi Approach

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Abstract: The present work aims to access the consequence of turning parameter e.g., spindle speed (N), depth of cut (D) and feed rate (f) on several execution indices viz. surface roughness and material removal rate in the machining of AISI D2 steel by means of PVD coated carbide tool. Experimentation trials were carried in accordance to the L9 orthogonal array. In addition, attempts were made to turn the multiple responses got into single responses utilizing TOPSIS. In this study, Decision-Makers’ (DMs’) subjective opinion (in regards of response weight) which were expressed in language-based terminologies has been transformed into fuzzy numbers. Fuzzy representation of multiple-judgments have been aggregated and finally defuzzified to obtain crisp weight. Response data thus obtained from machining experiments along with crisp weight of the responses have been utilized in TOPSIS. At last, for determining the combination of optimal parameters, Taguchi has been implemented.

KEYWORDS: AISI D2 steel; TOPSIS; Taguchi approach; Decision Maker and Fuzzy.

1. Introduction
Nowadays, for producing high hardness and high precision components the technology of hard turning has been evolved as tremendous development in manufacturing industries. AISI D2 steel have been generally applied in long-lasting application of tooling in which wear resistance e.g., blanking, thread rolling dies or other forming dies are important. Hence, it has turned as an essential mean for understanding the machinability performance of these types of materials. But, the machinability of each material is usually different in nature and does not reflect similar features. The composition, microstructure, processing routes and/or methods of processing of material affect the machining parameters at a great extent.
In turning, material of specimen AISI D2 steel Narutak et al. [1] utilize PCBN tool to observe the effect of variables e.g. speed of spindle , depth of cut and feed rate. They determined that cutting speed larger than 350m/min, the quality of surface decreases, thus this was credited side flow of material at the time of machining. Aouici et al. [2] used RSM and desirability function approach for AISI D3 steel and assessing the parameters of optimal process.
Konig et al. [3] found that for machining of hard steel, PCBN tools has larger tool life than ceramic tools.
Ferreira et al. [4] perform the experimental analysis suing ceramic tools i.e. wiper and conventional on the turning process of AISI H13 steel and found that the wiper tool reduces tool flank wear. In this
paper, TOPSIS coupled with Taguchi philosophy has been proposed for optimizing multiple characteristics to measure the performance for example MRR and the surface roughness. Asilturk et.al. [5] examined multi response CNC turning optimization variable using Taguchi method on the basis of RSA (Response Surface Analysis). Lalwani et. al. [6] observed the influence of various cutting variables on cutting forces and the surface roughness while turning. Experiments were carried out according to RSM. The relation between the parameters has been formed by using Linear and quadratic models. Simultaneously, Abouelatta et al. [7] studied the surface roughness and predicted it based on tool vibrations and cutting parameters for turning operations. Neseli et al. [8] recognized and optimized the variables of tool geometry in turning. Response surface methodology was used for this. Yang et. al. [9] studied the cutting variables for turning operations with the result basic parameters for cutting that affect the cutting performance can be defined. Kurt et al. [10] observed the optimization of cutting parameters so that high finished surface and accurate hole diameter during drilling can be obtained. Researcher have shown very interest in optimizing the cutting parameters in the recent time and are trying to diminish the cost of machining and enhance the surface quality. Although most methods to get optimal variables do not calculate every parameter. Aim is to keep the values of surface roughness and cutting force at some minimum value and undesirable results of machining are controlled. On the same time, to find both surface roughness and cutting force are significant for controlling the production at appropriate level of tolerances and for controlling the production cost also. The optimized parameters for cutting force and surface roughness are introduced through Grey relational analysis and Fuzzy TOPSIS. All this is done by analyzing Response Surface.

Dogra et. al. [11] studied latest research growth utilizing CBN tool for surface roughness, chip formation and wear rate while doing hard turning operation. FEM, various mathematical approach and soft computing are also explained and they concluded that tool chip formation is necessary in hard turning. Sahoo et. al. [12] observed using experiment the tool life, flank wear and the cost analysis. An analytical model was also developed. Coated carbide inserts were used for work piece material. Hessainia et. al. [13] studied turning of hardened steel 42CrMo4 using the method of Taguchi Design of Experiment and the RSM and found that surface quality decrease with increase in feed rate. Davim et. al. [14] investigated machinability of D2 steel utilizing ceramic turning tool. Statistical techniques approach was used. Li Bin [15] done an extensive review and estimated the tool wear by both numerical simulation and theoretical analysis. He found that FEM is a powerful tool with the help of which the cutting process variables can be predicted. Markov models also introduced the estimation of tool wear for turning operation. Asilturk et.al. [16] studied how machining parameters can be optimized to minimize the surface roughness while dry turning of hardened AISI 4140 (51HRC). Al2O3 + TiC coated carbide tool was used for machining and the result shows that in most instances feed affects surface roughness. Gaitonde et. al. [17] observed the influence of depth of cut on machining time and cutting force due to this parameter. Power consumed and tool wear rate were also recognized. The work piece machined were AISI D2 steel with GC, CC and CC650WG ceramic inserts. It was found that CC650WG shows better performance for machined surface roughness and tool wear and CC650 insert reduce the machining force and power consumed.

Kumari et. al. [18][19] studied and examined the characteristics of turning performance by conducting an experiment according to L9 orthogonal array. The work was made for the conversion of multi response to a single response. In this work an analytical model for entire grey relation grade in terms of various machining variables was also developed. Harmony search (HS) is a latest evolutionary algorithm of improved version was implemented to evaluate the most favorable condition for machining. The result obtained were also compared with genetic algorithm for validation of this mentioned approach. Kumar Verma et. al. [20] studied the Taguchi based application called Technique of order preferences by similarity to the ideal solution (TOPSIS) for multi criteria optimization of productivity and quality characteristics in tufted carpet that is machine made. A concurrent optimization for the performance characteristics was suggested through Taguchi method that is based on TOPSIS.
2. Material Experimentation

The experiment examined the effect of several variables e.g., depth of cut, spindle speed and feed rate in turning process of work specimen AISI D2 steel in figure 1, the machining variables are varied into three levels shown in Table 1. To obtain the experimental results, 9 experiments were carried out on lathe operated manually. So, for experimentation, proper design of the experiments is necessary.

![Sample Work-Piece](image)

**Figure 1: Sample Work-Piece**

| S. No. | Turning parameters | N   | f  | D   |
|--------|--------------------|-----|----|-----|
| 1      | Level 1            | 257.0 | 1.5 | 0.5 |
| 2      | Level 2            | 386.0 | 2.0 | 1.0 |
| 3      | Level 3            | 566.0 | 2.5 | 1.5 |

To find out the set of trials, Taguchi was then implemented. The orthogonal array (L9) in Table 2 was taken for experimental conduct. In turning process, Cemented carbide tool was used. The MRR and surface roughness were calculated as the qualities of the evaluation of machining. The equation used for calculating the MRR is given below. Here Surface roughness tester e.g., Talysurf is used for evaluation of the surface roughness and outcomes are shown in Table 2.

**Table 1: Experimental Domains**

| S. No. | Turning parameters | N   | f  | D   |
|--------|--------------------|-----|----|-----|
| 1      | Level 1            | 257.0 | 1.5 | 0.5 |
| 2      | Level 2            | 386.0 | 2.0 | 1.0 |
| 3      | Level 3            | 566.0 | 2.5 | 1.5 |

**Table 2: Experimental result obtained through L9 OA**

| N  | f  | D  | Ra [µm] | MRR (mm³/min) |
|----|----|----|---------|---------------|
| 257.0 | 1.5 | 0.5 | 3.870 | 1087.3860 |
| 257.0 | 2.0 | 1.0 | 2.920 | 803.3234 |
| 257.0 | 2.5 | 1.5 | 2.460 | 637.500 |
| 386.0 | 1.5 | 1.0 | 4.350 | 1256.970 |
| 386.0 | 2.0 | 1.5 | 3.810 | 923.7890 |
| 386.0 | 2.5 | 0.5 | 2.160 | 708.4340 |
| 566.0 | 1.5 | 1.5 | 3.030 | 789.6700 |
| 566.0 | 2.0 | 0.5 | 2.660 | 762.7177 |
| 566.0 | 2.5 | 1.0 | 3.930 | 1270.5280 |
3. Data Analysis

For data analysis, data preprocessing i.e., normalization has been carried out (TOPSIS method). The normalized data are shown in Table 3.

**Table 3: Calculated normalized values**

| Trial | Runs | Normalized-MRR | Normalized-Ra |
|-------|------|----------------|---------------|
| 1     |      | 0.384715       | 0.388243      |
| 2     |      | 0.284214       | 0.292938      |
| 3     |      | 0.225546       | 0.24679       |
| 4     |      | 0.444714       | 0.436398      |
| 5     |      | 0.326835       | 0.382224      |
| 6     |      | 0.250643       | 0.216694      |
| 7     |      | 0.279384       | 0.303974      |
| 8     |      | 0.269848       | 0.266855      |
| 9     |      | 0.44951        | 0.394263      |

To identify the most appropriate weight of specific responses, this experiment has taken seven linguistic terms to gathering skilled opinion. Linguistic weight is converted into fuzzy data as shown in Table 5. Subjective skilled decisions in relation to response weights have been shown in Table 5.

**Table 4: Linguistic Terms for assigning position weight of respective responses**

| Terms  | Extremely Small | Small | Moderate Small | Average | Moderately Large | Large | Extremely Large |
|--------|-----------------|-------|----------------|---------|------------------|-------|-----------------|
| Abbreviation | ES | S | MS | A | ML | L | EL |
| Fuzzy Sets | (0, 0, 0.1) | (0, 0.1, 0.3) | (0.1, 0.3, 0.5) | (0.3, 0.5, 0.7) | (0.5, 0.7, 0.9) | (0.7, 0.9, 1) | (0.9, 1, 1) |

Linguistic data translated into fuzzy sets have been aggregated first in Table 5. The best non-fuzzy performance value (crisp) equivalent to each response is utilized as crisp weight. The decision matrix has been normalized then and the normalized decision matrix is displayed in Table 3.

**Table 5: By Decision-Makers (DMs), the significance of Output Parameters is specified**
In the subsequent level, the resulting weighted decision matrix has been constructed in Table 7 by the using Table 6.

**Table 6: Fuzzy weights and corresponding crisp conversion**

| Output responses | MRR       | Ra        |
|------------------|-----------|-----------|
| Fuzzy weight     | (0.55, 0.75, 0.925) | (0.75, 0.925, 1) |

Best Non fuzzy Performance value (BNP) Crisp- weight 0.725 0.891667

**Table 7: Weighted normalized fuzzy decision matrix**

| S. No. | Wt.-MRR  | Wt.-Ra    |
|--------|----------|-----------|
| 1      | 0.278918 | 0.346184  |
| 2      | 0.206055 | 0.261203  |
| 3      | 0.163521 | 0.220055  |
| 4      | 0.322417 | 0.389121  |
| 5      | 0.236955 | 0.340817  |
| 6      | 0.181716 | 0.193219  |
| 7      | 0.202553 | 0.271043  |
| 8      | 0.19564  | 0.237945  |
| 9      | 0.325895 | 0.351551  |

Then, the positive-ideal solution (FPIS) and the negative-ideal solution (FNIS) i.e., $A^+$ and $A^-$, respectively, have been determined as shown in Table 8.

**Table 8: Best (Ideal) & worst (Negative ideal) solutions**

| Responses | best (Ideal) $A^+$ | worst (Negative ideal) $A^-$ |
|-----------|--------------------|-----------------------------|
| MRR       | 0.325895           | 0.163521                    |
| Ra        | 0.193218875        | 0.389121345                |
The distance for each alternative with respect to negative and positive ideal solution have been computed and shown in Table 9.

**Table 9: Calculated distance measures**

| S. No. | \(D^+_i\) | \(D^-_i\) |
|--------|-----------|-----------|
| 1      | 0.160016  | 0.123127  |
| 2      | 0.13778   | 0.134804  |
| 3      | 0.164577  | 0.169066  |
| 4      | 0.195933  | 0.158896  |
| 5      | 0.172323  | 0.087897  |
| 6      | 0.144179  | 0.196745  |
| 7      | 0.145842  | 0.124362  |
| 8      | 0.13772   | 0.15455   |
| 9      | 0.158332  | 0.166664  |

To recognize the furthermost significant variables, the average output values for Spindle speed (S), Depth of cut (DOC) and feed rate (f) have been evaluated and represent in Table 10.

**Table 10: SN Ratios (Larger is better)**

| Level | Spindle speed (N) | Feed Rate (f) | Depth of Cut (DOC) |
|-------|-------------------|---------------|--------------------|
| 1     | -6.418            | -6.984        | -5.847             |
| 2     | -7.060            | -7.026        | -6.298             |
| 3     | -6.025            | -5.493        | -7.357             |
| Delta | 1.035             | 1.532         | 1.510              |
| Rank  | 3                 | 1             | 2                  |

After calculating the distance measures, the closeness coefficient has been calculated, and shown in Table 11. An alternate having largest relative closeness has been treated as the best choice. The best preference has been determined for the trial no. 12 by Taguchi method. The analysis has been carried out by Minitab software package using Higher-the-Better (HB) criterion. The predicted S/N ratio for the optimal parametric combination (S3 f3 d1) (shown in fig. 1) is -4.36392 which is greatest among all the S/N ratios. Table 11 that authenticates the applicability of the proposed TOPSIS based Taguchi method.
Table 11: Closeness coefficients

| S. No. | CC_i | SNRA  | P-SNRA   |
|-------|------|-------|----------|
| 1     | 0.434858 | -7.23306 | -4.36392 |
| 2     | 0.494541 | -6.11596 |          |
| 3     | 0.506728 | -5.90450 |          |
| 4     | 0.447810 | -6.97812 |          |
| 5     | 0.337779 | -9.42734 |          |
| 6     | 0.577094 | -4.77508 |          |
| 7     | 0.460253 | -6.74007 |          |
| 8     | 0.528791 | -5.53432 |          |
| 9     | 0.512818 | -5.80073 |          |

Figure 2: Evaluation of optimal setting

4. CONCLUSION

In this research, the analysis shows that the quadratic loss function of Taguchi with Fuzzy TOPSIS to find out the various response surface roughness characteristics. The Taguchi method and Fuzzy TOPSIS deals with one dimensional problem and with multi-dimensional problem respectively and a performance measurement is required for the various responses at each experimental trial. Due to relation between the parameters parametric optimization is difficult to solve but in this paper the
analysis has done by us using orthogonal array, Fuzzy TOPSIS and sound perceptiveness to demonstrate an optimization approach.

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