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MULTI-OBJECTIVE OPTIMIZATION OF MRR, Ra AND Rz USING TOPSIS

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ABSTRACT

The multi-criteria decision making methods are very significant in solving the engineering problems which involves in critical decision making situations. In the present work the effect of cutting parameters on the responses was studied using most familiar multi-criteria methods like WSM, WPM and TOPSIS. The experiments were done on CNC lathe using Tungsten carbide tool under dry environment. Cutting parameters of speed, feed and depth of cut were taken as input parameters and Material Removal Rate (MRR), Arithmetic average Roughness (R_a), Average peak to valley height Roughness (R_z) were considered as the responses. The experiments were conducted as per the taguchi's standard L9 Orthogonal Array. From the results of WSM, WPM and TOPSIS it is found that the ninth alternative i.e. speed at 225 m/min, feed at 0.15 mm/rev and depth of cut at 0.4 mm, is the best among all the experiments.

KEYWORDS: Material Removal Rate (MRR), Arithmetic average Roughness (R_a), Average peak to valley height Roughness (R_z), Orthogonal Array (OA), Weighted Sum Method (WSM), Weighted Product Method (WPM) and TOPSIS method.

INTRODUCTION

Surface roughness is generally the variation in the height of the surface relative to a reference plane. Surface roughness is measured in several ways they are, Ra-CLA (Centre Line Average) or Arithmetic Average, Rq or Root Mean Square (RMS), Rz-Average Peak-to-Valley height, Rt-Extreme Value Height descriptor (Ry, Rmax, or maximum peak to valley height), Rp -Maximum Peak Height or Maximum peak to mean height, Rv- Maximum Valley Depth or Mean to lowest valley height, and Rpm- Average peak to mean height and Skewness (S_K) and Kurtosis (K), etc. Among all Ra, and Rz are surface topology parameters which are very significant from contact stiffness and surface wear point of view. Surface roughness affect the functional attributes of parts, like surface friction, wearing, light reflection, ability of distributing and holding a lubricant and resistant fatigue etc. The weighted sum method (WSM) is the earliest and most commonly used method of MCDM. Other widely used methods are WPM and TOPSIS. WSM used for solving single dimensional problems. The difficulty with this method emerges when it is applied to multi dimensional MCDM problems. To avoid this problem weighted product method (WPM) has been developed. It is very similar to the WSM but the main difference is that instead of adding in the model there are multiplication. The WPM can be used in single and multi-dimensional MCDM problems. An advantage of the method is that instead of the actual values it can use relative ones. TOPSIS is the technique for order preference by similarly to ideal solution. It was developed by Hwang and Yoon in 1980 as an alternative to the ELECTRE method and can be considered as one of its most widely accepted variants. The basic concept of this method is that the selected alternative should have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution in any geometrical sense. The TOPSIS method first converts the various criteria, dimensions into non-dimensional criteria. Generally in TOPSIS, A^+ indicates the most preferable alternative or the ideal solution. Similarly, alternative A^- indicates the least preferable alternative or the negative ideal solution.

In the present work, an experiment has been conducted to study the influence of speed, feed and depth of cut on Material Removal Rate and the Surface Roughness characteristics R_a and R_z. The experiments were done on a medium carbon steel EN19 using CNC lathe with Tungsten carbide tool as per the Taguchi's standard L9 Orthogonal Array. For the optimization of multiple responses the multi-criteria decision making (MCDM) methods of WSM, WPM and TOPSIS have been employed and the optimum conditions are found.

EXPERIMENTATION AND METHODOLOGY

The work piece of EN19 (each of 25 mm ϕ and 75 mm L) has been taken for the experiment. The experiments were performed on CNC lathe (Jobber XL, 7.5Kw, 50-4000 rpm) under dry conditions using Tungsten carbide tool. For the finished products surface roughness values were measured by using SJ-301 (Mututoyo) gauge. Experiments were done as per the standard Taguchi's L9 Orthogonal Array. The payoff matrix with the actual values of nine alternatives of speed, feed and depth of cut and their corresponding criteria values were given in the table 1.

Steps involved in multi criteria decision making methods

- Defining the problem and fixing the criteria's
- Establishment of feasible/efficient alternatives
- Formulation of the payoff matrix (alternative versus criteria array)
- Selection of appropriate method to solve the problem. (WSM, WPM and TOPSIS)
- Incorporation of a decision-makers preference structure
- Choosing the best/suitable alternative

Weighted sum method (WSM)

Weighted sum method is used in single dimensional problems. For m number of alternatives and n criteria's the best alternatives are the one that satisfying

$$B^*_{WSM} = \max \sum_{i}^{j} r_{ij} W_j$$

Where, r_{ij} is the normalized value, W_j is weight of the response and B^*_{WSM} is the weighted sum method score of the best alternatives.

Weighted product method (WPM)

The Weighted Product Method (WPM) is also similar to WSM. The main difference is that instead of addition in WPM multiplication has to be done. The overall performance score is computed as

$$R_i = \prod_{j=1}^{n} |r_{ij}|^{W_j}$$

Here, r_{ij} is the normalized values of decision matrix and W_j is the weight of the response. The best alternative is the one having the highest R_i value.

TOPSIS method

TOPSIS decision making method is a technique introduced by Yoon and Hwang. The basic principle in this method is that chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution.

TOPSIS calculation procedure

TOPSIS calculation involves in 6 steps they are

Step1. Determination of Normalized decision making matrix

$r_{ij} = \frac{Y_{ij}}{\sqrt{\sum_{i=1}^{n} {Y_{ij}}^2}}$; Where, r_{ij} represents the normalized performance of A_i with respect to characteristic Y_j.

Step2. Construction of a weighted normalized decision matrix

$V_{ij} = W_j r_{ij}$; Where, W_j represents the relative weight of the J^{th} criteria.

Step3. Determine the Positive ideal solution and Negative ideal solution

$A^+ = \{(\max_i V_{ij} | j \in J), (\min_i V_{ij} | j \in J') \; i = 1,2 \dots m)\}$

$= \{v_1^+, \; v_2^+, \dots v_j^+, \dots \dots v_n^+\}$

$A^- = \{(\min_i V_{ij} | j \in J), (\max_i V_{ij} | j \in J') i = 1,2, \dots \dots \dots m\}$

$= \{v_1^-, \; v_2^-, \dots \dots v_j^-, \dots \dots v_n^-\}$

J = 1, 2, 3........n, associated with the beneficial attributes.
J = 1, 2, 3...n, associated with non-beneficial adverse attributes.

Step4. Calculation of separation values from the PIS and NIS.

The separation of each alternative from PIS is given by $S_i^+ = \sqrt{\sum_{j=1}^{n}(v_i^+ - v_{ij})^2}$; Where, i = 1, 2 ...m.

The separation of each alternative from NIS is given by $S_i^- = \sqrt{\sum_{j=1}^{n}(v_j^- - v_{ij})^2}$; Where, i = 1, 2 ...m.

Step5. Calculation of relative closeness to the ideal solutions.

Relative closeness coefficient, $C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}$; Where i = 1, 2......m

The larger the C_i^+ value, the better the performance of the alternatives.

Step6. Rank the preference order.

Table 1. Payoff matrix

Experiments (Alternatives)	Speed (v)	Feed (f)	Depth of cut (d)	Criteria 1 (MRR)	Criteria 2 (R_a)	Criteria 2 (R_z)
A-1	75	0.05	0.2	0.75	2.6	12.6
A-2	75	0.1	0.4	3	3.1	14.2
A-3	75	0.15	0.6	6.75	3.7	15.3
A-4	150	0.05	0.4	3	1.8	6.4
A-5	150	0.1	0.6	9	2.3	9.8
A-6	150	0.15	0.2	4.5	2.8	12.8
A-7	225	0.05	0.6	6.75	0.9	4.1
A-8	225	0.1	0.2	4.5	1.6	7.6
A-9	225	0.15	0.4	13.5	2.1	9.7

RESULTS AND DISCUSSIONS

MCDM/MADM approaches of WSM, WPM and TOPSIS are most widely used methods in analyzing complex engineering problems. The results of MCDM methods were discussed below. The actual decision matrix of the responses was given in the table 2. From the decision matrix values the weights for the responses were calculated using entropy method. The output entropy and the corresponding weight values for the responses were given in the tables 4 and 5.

Table 2. Actual decision matrix of responses

Experiment No. (Alternatives)	Criteria 1 (MRR)	Criteria 2 R_a	Criteria 3 R_z
A-1	0.75	2.6	12.6
A-2	3	3.1	14.2
A-3	6.75	3.7	15.3
A-4	3	1.8	6.4
A-5	9	2.3	9.8
A-6	4.5	2.8	12.8
A-7	6.75	0.9	4.1
A-8	4.5	1.6	7.6
A-9	13.5	2.1	9.7

Table 3. Normalized decision matrix

Experimental No.	MRR	R_a	R_z
A-1	0.01449	0.12440	0.13622
A-2	0.05797	0.14833	0.15351
A-3	0.13043	0.17703	0.16541
A-4	0.05797	0.08612	0.06919
A-5	0.17391	0.11005	0.10595
A-6	0.08696	0.13397	0.13838
A-7	0.13043	0.04306	0.04432
A-8	0.08696	0.07656	0.08216
A-9	0.26087	0.10048	0.10486

Table 4. Output entropy values

Criteria	MRR	R_a	R_z
$\acute{\varepsilon}_j$	0.911336	0.971786	0.970811

Table 5. Weights of responses

Criteria	MRR	R_a	R_z
W_j	0.6070	0.1932	0.1998

The WSM values for each alternative have been calculated as the sum of product of the normalized value and the corresponding weight of the responses. The calculated values of WSM and the ranking were given in the table 6. A graph is plotted by taking Experiment number on X-axis and the WSM values on Y-axis shown in the figure 1 and it is observed that the ninth alternative has the highest score among all the alternatives.

Table 6. WSM values and ranking

Experiment No.	WSM	Rank
A-1	0.16779	9
A-2	0.25788	5
A-3	0.39232	2
A-4	0.17599	8
A-5	0.38905	3
A-6	0.28621	4
A-7	0.25024	6
A-8	0.22287	7
A-9	0.51753	1

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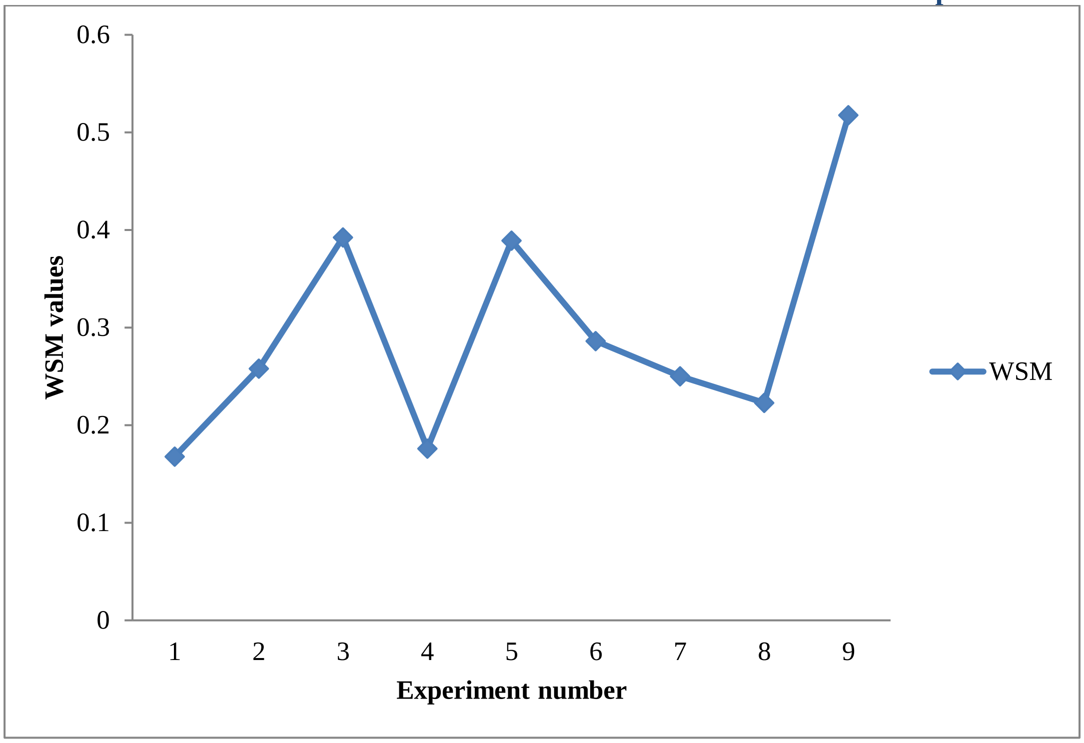

Figure 1. Experiment number Vs. WSM

The WPM values for each alternative have been calculated as the product of the normalized value to the power weight of the corresponding responses. The calculated values of WPM and the ranking were given in the table 7. A graph is plotted by taking Experiment number on X-axis and the WPM values on Y-axis shown in the figure 2 and it is observed that the ninth alternative has highest score among all the alternatives.

Table 7. R_i Values of WPM and ranking

Experiment No.	WPM	Rank
A-1	0.09125	9
A-2	0.22428	6
A-3	0.38537	2
A-4	0.17219	8
A-5	0.38298	3
A-6	0.27550	4
A-7	0.22542	5
A-8	0.22281	7
A-9	0.48033	1

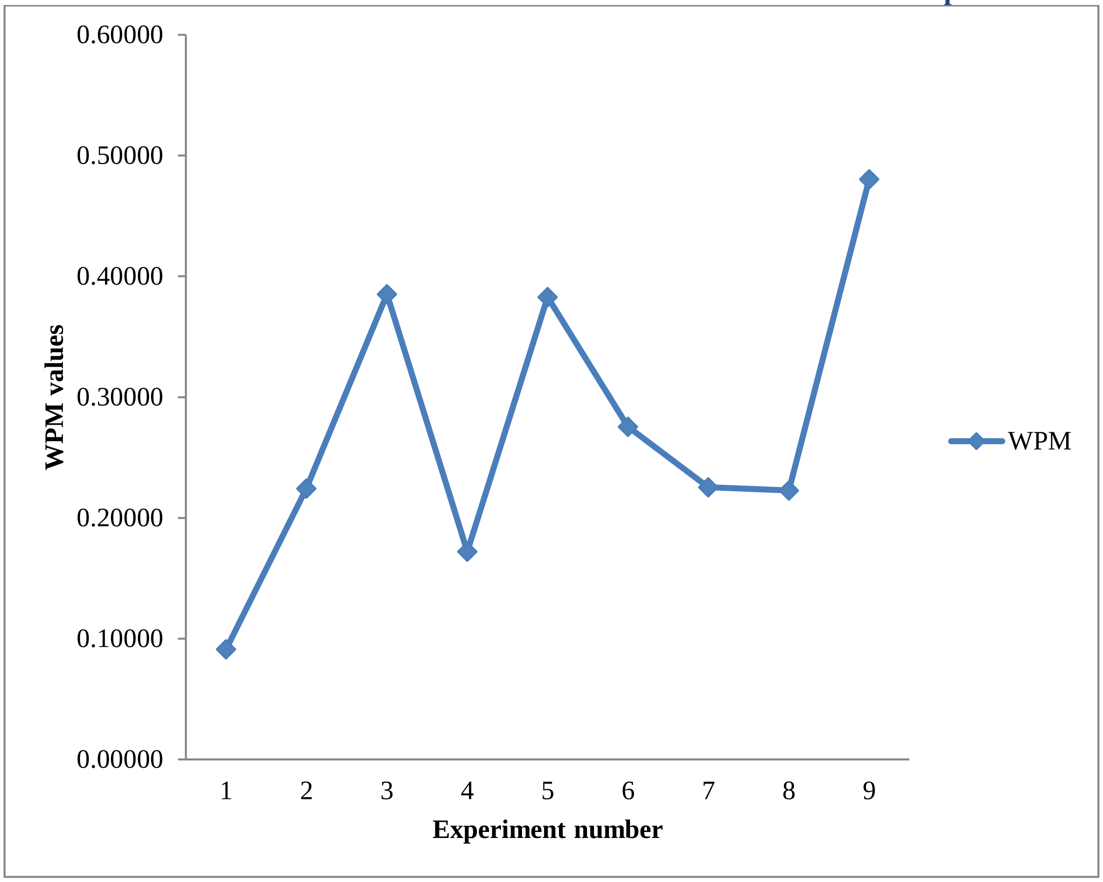

Figure 2. Experiment number Vs WPM

The TOPSIS calculation, the first step involves in normalization of the decision matrix. The normalized values of decision matrix were given in the table 8.

Table 8. Normalized decision matrix

Experiment No.	MRR	R_a	R_z
A-1	0.03689	0.35313	0.38628
A-2	0.14754	0.42104	0.43533
A-3	0.33197	0.50253	0.46905
A-4	0.14754	0.24447	0.19621
A-5	0.44263	0.31238	0.30044
A-6	0.22131	0.38029	0.39241
A-7	0.33197	0.12224	0.12569
A-8	0.22131	0.21731	0.23299
A-9	0.66394	0.28522	0.29737

The second step involves in the formation of the weighted normalized decision matrix by multiplying the each normalized value of the response with the corresponding weight. The weighted normalized decision matrix values were given in the table 9.

Table 9. Weighted normalized decision matrix

Experiment No.	MRR	R_a	R_z
A-1	0.02239	0.06822	0.07718
A-2	0.08956	0.08134	0.08698
A-3	0.20151	0.09709	0.09372
A-4	0.08956	0.04723	0.03920
A-5	0.26867	0.06035	0.06003
A-6	0.13434	0.07347	0.07840
A-7	0.20151	0.02362	0.02511
A-8	0.13434	0.04198	0.04655
A-9	0.40301	0.05510	0.05942

Third step in TOPSIS involves in identifying the Positive ideal solution and Negative ideal solutions for the responses. For higher-the-better characteristics, maximum value is the PIS and minimum value is the NIS among all the alternatives. Similarly, for the lower-the-better characteristics, maximum value is the NIS and minimum value is the PIS. The value of PIS and NIS of the responses were given in the table 10.

Table 10. PIS and NIS values

Criteria	MRR	R_a	R_z
PIS	0.40301	0.02362	0.02511
NIS	0.02239	0.09709	0.09372

Fourth step is to measure the distances of PIS and NIS from the ideal value. The Distance measures were given in the table 11.

Table 11. Distance measures

Experiment No.	S_i^+	S_i^-
A-1	0.38675	0.03317
A-2	0.32467	0.06937
A-3	0.22520	0.17912
A-4	0.31466	0.09986
A-5	0.14358	0.25129
A-6	0.27842	0.11542
A-7	0.20150	0.20541
A-8	0.27016	0.13339
A-9	0.04658	0.38446

After calculation of the distance measures, the next step is to calculate the relative closeness values and the values were given in the table 12. The ranking was given in descending order of the C_i^+ values for the alternatives. A graph is plotted by taking the experiment number on X-axis and the relative closeness coefficient (C_i^+) on Y-axis and shown in the figure 3. From the plot it is found that the C_i^+ value is high for the ninth alternative.

Table 12. Relative closeness values and ranking

Experiment No.	C_i^+	Rank
A-1	0.07898	9
A-2	0.17604	8
A-3	0.44301	4
A-4	0.24090	7
A-5	0.63638	2
A-6	0.29307	6
A-7	0.50480	3
A-8	0.33054	5
A-9	0.89193	1

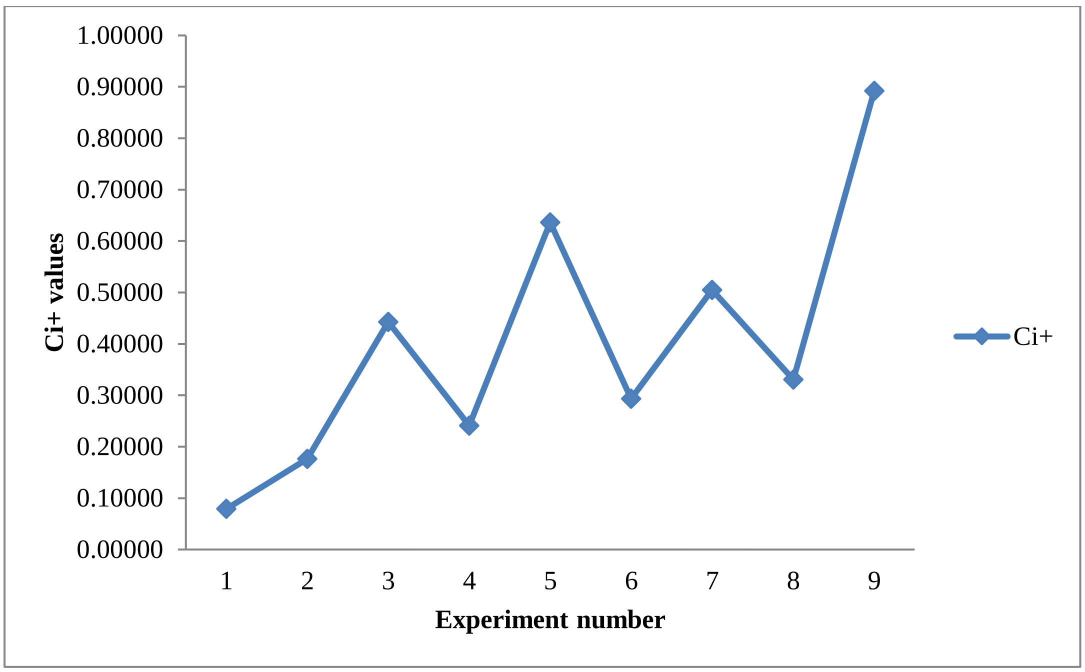

Figure 3. Experiment number Vs C_i^+

CONCLUSIONS

- From the Weighted Sum Method (WSM) results, the optimal combination of process parameters is found at the Speed: 225 m/min, Feed: 0.15 mm/rev and Depth of cut: 0.4 mm.
- From the Weighted Product Method (WPM) results, the optimal combination of process parameters is found at the Speed: 225 m/min, Feed: 0.15 mm/rev and Depth of cut: 0.4 mm.
- From the TOPSIS results, the optimal combination of process parameters is found at the Speed: 225 m/min, Feed: 0.15 mm/rev and Depth of cut: 0.4 mm.

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