OPTIMIZATION OF GREEN ELECTRO-DISCHARGE MACHINING USING VIKOR

BRIJESH PATEL [1] | NARENDRA JAISWAL [2]

[1] M.TECH. SCHOLAR, DEPARTMENT OF MECHANICAL ENGINEERING, VINDHYA INSTITUTE OF TECHNOLOGY AND SCIENCES, SATNA.

[2] ASSISTANT PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, VINDHYA INSTITUTE OF TECHNOLOGY AND SCIENCES, SATNA.

ABSTRACT:

In the present study an efficient Multi-Criteria Decision Making (MCDM) approach has been proposed for optimization of green electro-discharge machining, because it is a commonly used non-traditional machining process. Green electro-discharge machining is a Multi-Criteria Decision Making (MCDM) problem influenced by multiple performance criteria/attributes. These criteria attributes are of two types, qualitative and quantitative. Qualitative criteria estimates are generally based on previous experience and expert opinion on a suitable conversion scale. This conversion is based on human judgment; therefore, obtained result may not be accurate always. These are analyzed using AHP, QFD, Fuzzy techniques etc. reported in literature. So to find the solution of MCDM problems there should be converted quantitative criteria values into an equivalent single performance index called Multi-attribute Performance Index (MPI). Selection of the best alternative can be made in accordance with the MPI values of all the alternatives. In this text, present study highlights application of VIKOR method adapted from MCDM techniques for obtaining the accurate result. Detail methodology of VIKOR method has been illustrated in this report through a case study.

KEYWORDS:

DECISION- MAKING METHODS, VIKOR METHOD, ELECTRO-DISCHARGE MACHINING, OPTIMIZATION PROCEDURE.

INTRODUCTION

Introduction to decision making in the manufacturing environment

In any industrialized nation Manufacturing work as backbone. Its importance can be measured by the fact that, in an economic activity, it comprises approximately 20 to 35% of the value of all goods and services produced. Level of manufacturing activity of a country is directly related to its economic health. So we can say that the higher the level of manufacturing activity in a country, the standard of living will be higher of its people. Manufacturing can be defined as the application of physical, mechanical and chemical processes to modify the geometry, properties and/or appearance of a given starting material in the making of new form, finished parts or products. This effort includes all intermediate processes required for the production and integration of a product's components. The ability to produce this conversion efficiently determines the success of the company. The type of manufacturing performed by a company depends on the kinds of products it makes. Manufacturing is an important commercial activity carried out by companies that sell products to customers. In the modern sense, manufacturing involves interrelated activities that include product design and documentation, material selection, process planning, production, quality assurance, management, and marketing of products.

To meet the challenges, manufacturing industries have to select appropriate product designs, manufacturing strategies, manufacturing processes, work piece and tool materials, machinery and equipment, *etc*. The selection decisions are more complex, as decision making is challenging today. Necessary conditions for achieving effective decision making consist in understanding the current and upcoming events and factors influencing the whole manufacturing environment, in examine the nature of decision-making processes and the reach of different typologies of techniques and methods, and finally in structuring appropriately the decision-making approach based on a wide range of issues related to manufacturing systems design, planning, and management. Decision makers in the manufacturing sector frequently face the problem of assessing a wide range of alternatives, and selecting one of them based on a set of conflicting criteria.

In manufacturing sector there is wide range of alternative option for decision makers. Some of the important decision-making situations in the manufacturing environment are listed below:

- Material selection for a given engineering problem
- Evaluation of best product designs
- Evaluation of machinability for work materials
- Selection of cutting fluid for a given machining application

- Selection and evaluation of modern machining methods
- Selection and evaluation of flexible manufacturing systems
- Selection of machine's group in a flexible manufacturing cell
- Analysis of cause of failure of machine tools
- Selection of robot for a given industrial application
- Selection of automated inspection systems
- Selection of material handling equipments
- Selection of a rapid prototyping process in rapid product development
- Selection of software for design and manufacturing applications
- Selection of the most appropriate welding process for a given job
- Mould ability analysis of parts
- Evaluation of metal stamping layouts
- Selection of forging conditions for a given component
- Evaluation and examine of environmentally conscious manufacturing process
- Environmental impact estimation of manufacturing processes
- Evaluation of risk in green manufacturing

INTRODUCTION

In today's' competitive Manufacturing sector, EDM process has become a major concern for every industry. This technique also used for finishing parts for aerospace and automotive industry and surgical components **[43]**. This technique has been developed in the late 1940s **[44]** where the process is based on removing material from a part by means of a series of repeated electro discharges between tool called the electrode and the work piece in the presence of a dielectric fluid **[45]**. To ionize the dielectric we have to keep electrode toward the work piece until the gap is small enough so that the impressed voltage is great enough. Short duration discharges are generated in a liquid dielectric gap, which separates tool and work piece **[46]**. The material is removed due to the thermal energy generated in the discharge channel. Heat generated in the channel causes some of the work material to melt and even evaporate. As the spark collapses, the evaporated metal and part of the molten metal are carried away by the dielectric fluid which is flushed using pressure **[3]**. There is not direct contact between the electrode and the work piece where it can eliminate mechanical stresses chatter and vibration problems during machining in EDM process **[43]**. Materials of any hardness can be cut as long as the material can conduct electricity **[47]**. EDM process has developed in many fields. Trends on activities carried out by the researchers depend on the interest of the researchers and the availability of the technology. In a book published in 1994, Rajurkar **[48]** has indicated some future trends activities in EDM: machining advanced materials, mirror surface finish using powder additives, ultrasonic-assisted EDM and control and automation.

From literature review, it has been observed that, choosing a suitable and efficient methodology to solve a multi-criteria decision making problem and selecting the best alternative is a great challenge to the researchers as well as management practitioners due to the existence of conflicting and non-commensurable criteria associated with green manufacturing problem. To overcome this shortcoming, in the present reporting VIKOR based Multi attribute Decision Making approach has been proposed to utilize exact numeric values of quantitative parameters (quality and performance indices).

INPUT-PROCESS-OUTPUT DIAGRAM OF EDM PROCESS

Choi et al. [10] proposed a modified form of input-process output model as shown in F**igure 1** shows the relationship between the process parameters and output responses. The inputs of the process consists

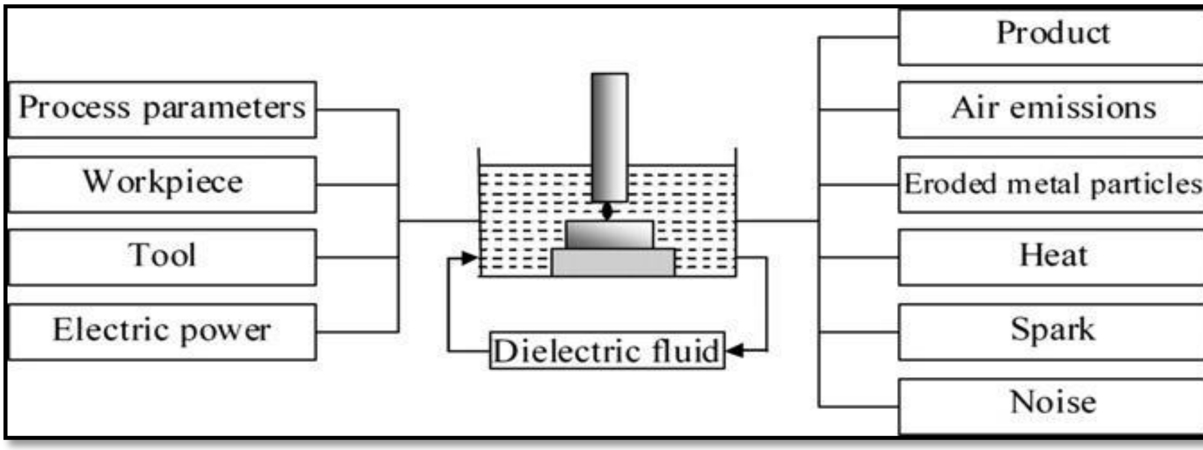
The following four process parameters are used in this case study:

- peak current
- voltage
- pulse duration
- flushing pressure

Input for process includes work piece, tool and dielectric fluid, and electrical energy

- Work
- Tool
- Dielectric
- Electric energy

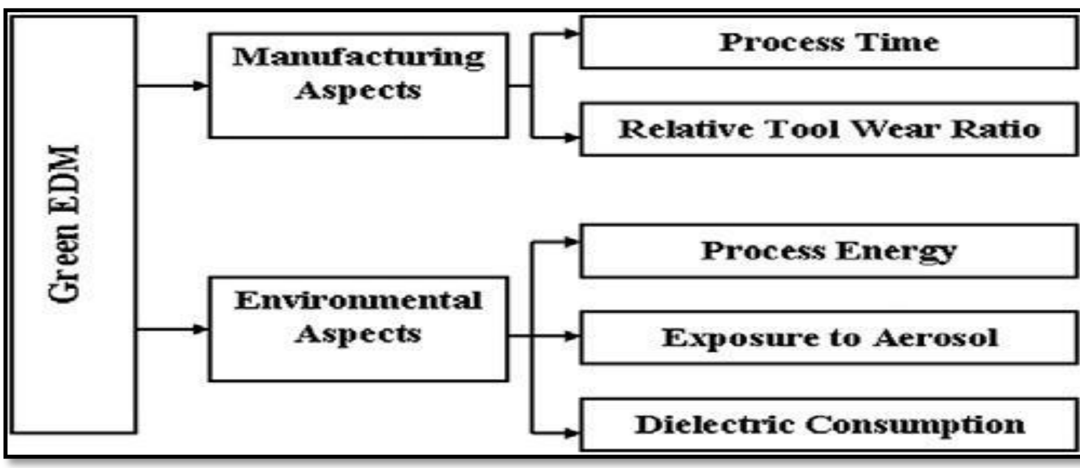
Outputs of this process includes material removal rate, tool wear rate, air emissions, dielectric wasted in the form of liquid, eroded work and tool materials, heat and noise



INPUT-PROCESS-OUTPUT DIAGRAM OF EDM PROCESS [49]

In EDM process, an electric arc struck between two electrodes produces the energy required for the material removal. The process is carried out in a dielectric medium. As thermal energy generated in discharge channel results high temperature reached by the surface of both the electrodes and this is the main cause of material removal. Some of the work material melt and even evaporate due to heat generated in channel. **Abbas et al. [3]** found that as the spark collapses, the evaporated metal and part of the molten metal are carried away by the dielectric fluid which is flushed using pressure.

DECISION MAKING MODEL FOR GREEN EDM



OPTIMIZATION USING VIKOR

There are four input parameters in this case study which we have to optimize to achieve the green EDM.

- Current
- Pulse duration
- Dielectric level
- Flushing pressure

These are independent variables.

For optimization of these parameters we have to analyze the output responses; process time, relative tool wear ratio, process energy, concentration of aerosol and dielectric consumption. Process time can be calculated by the **Eq. 15**, relative tool wear is calculated by calculated the ratio of tool wear ratio and material removal rate as shown in **Eq. 16**, process energy is calculated by **Eq. 17**, concentration of aerosol is calculated by **Eq. 12** and dielectric consumption is calculated using **Eq. 18**.

After calculated the output responses, L9 (3^4) orthogonal array is selected to conduct experimental runs. The process variables and their levels for the design used in this study are shown in **Table 1.** The design of experiment matrix and experimental results are presented in **Table 2.**

TABLE 1: INPUT PARAMETERS AND THEIR LEVELS [22]

Parameters	Unit	Level 1	Level2	Level 3
Current	A	2	4.5	7

Pulse duration	µs	2	261	520
Dielectric level	mm	40	60	80
Flushing pressure	Kg/cm^2	0.3	0.5	0.7

TABLE 2: EXPERIMENTAL RESULTS [22]

SI.		Input parameters					Output parameters		
No.	Peak current	Pulse duration	Dielectric level	Flushing pressure	Process time (s)	REWR	Process energy (W)	Conc. of aerosol	Dielectric consumption
	(A)	(µs)	(mm)	(kg/m^3)				(mg/m^3)	(cm^3)
1	2	2	40	0.3	0.7258	0.3899	54.433	0.82	0.0665
2	2	261	60	0.5	1.5357	0.0055	115.178	0.77	0.0981
3	2	520	80	0.7	1.6393	0.0051	122.951	0.64	0.0865
4	4.5	2	60	0.7	0.4705	0.3496	79.389	1.22	0.0510
5	4.5	4.5	80	0.3	0.3415	0.0041	57.620	2.13	0.0332
6	4.5	520	40	0.5	0.3942	0.0049	66.516	1.98	0.0394
7	7	2	80	0.5	0.4062	0.3452	106.632	2.4	0.0497
8	7	261	40	0.7	0.2381	0.0065	62.4884	4.12	0.0351
9	7	520	60	0.3	0.2646	0.0076	69.469	5.05	0.0434

OPTIMIZATION PROCEDURE

First we calculate the normalize matrix, as shown by the **Eq. 19.**

0.2878	0.6214	0.2126	0.1059	0.369	
0.609	0.00876	0.45	0.0995	0.545	
0.650	0.00812	0.4804	0.0827	0.48	
0.1866	0.5572	0.3102	0.1577	0.283	
0.1354	0.006535	0.225	0.275	0.184	(19)
0.1563	0.00781	0.2599	0.255	0.219	
0.1611	0.5502	0.4166	0.31	0.276	
0.0944	0.01036	0.2441	0.532	0.195	
0.1049	0.0121	0.2714	0.652	0.241	

After normalize matrix we will calculate the positive and negative ideal solution for each output response. And in this case study for all output responses positive ideal solution will be minimum value and negative ideal solution will be maximum value from their correspondent column.

For process time

Positive ideal solution = 0.0944

Negative ideal solution = 0.650

For relative tool wear ratio

Positive ideal solution = 0.006535

Negative ideal solution = 0.6214

For process energy

Positive ideal solution = 0.2126

Negative ideal solution = 0.480

For concentration of aerosol

Positive ideal solution = 0.0827

Negative ideal solution = 0.652

For dielectric consumption

Positive ideal solution = 0.184

Negative ideal solution = 0.545

Then we will calculate utility measure (S_i) and regret measure (R_i); Utility measure matrix (S_{ij}), shown by the **Eq. 20.**

0.0696	0.2	0	0.0082	0.1025	
0.1852	0.0007	0.1773	0.0059	0.2	
0.2	0.0005	0.2	0	0.1639	
0.0332	0.1791	0.0733	0.0263	0.0548	
0.0147	0	0.0093	0.0676	0	(20)
0.0223	0.0004	0.0353	0.0605	0.0194	
0.0240	0.1768	0.1524	0.0799	0.0509	

0 0.0012 0.0235 0.1578 0.0061
0.0038 0.0018 0.04390. 0.20. 0.0316

Now Regret Measure will be the maximum value of each row in utility measure matrix.

Both values of Utility measure and Regret measure are shown in the **Table**

TABLE 3: VALUES OF UTILITY MEASURE AND REGRET MEASURE

SI. NO.	utility measure (S_i)	regret measure (R_i)
1	0.3803	0.2
2	0.5692	0.2
3	0.5645	0.2
4	0.3668	0.1791
5	0.0916	0.0676
6	0.1379	0.0605
7	0.4840	0.1768
8	0.1887	0.1578
9	0.2811	0.2

After calculating the values of Utility measure and Regret measure, we will find the VIKOR index for Determination of optimal parametric combination. The multi-attribute quality scores for each alternative can be determined from the VIKOR index. The best one is finally determined, in view of the fact that a smaller VIKOR value indicates a better quality. Values of VIKOR index as shown in **Table 4,** for each experimental run.

TABLE 4: VIKOR INDEX

SI. NO.	Current (A)	Pulse Duration)	Dielectric Level (mm)	Flushing Pressure (kg/cm^2)	VIKOR INDEX
1	2	2	40	0.3	0.8022
2	2	261	60	0.5	1.0000
3	2	520	80	0.7	0.9951
4	4.5	2	60	0.7	0.7132
5	4.5	261	80	0.3	0.0254
6	4.5	520	40	0.5	0.0484

7	7	2	80	0.5	0.8276
8	7	261	40	0.7	0.4503
9	7	520	60	0.3	0.6984

RESULTS AND DISCUSSIONS

The VIKOR Index for each experiment of the L9 orthogonal array were calculated as discussed in the previous section **Table 4.** According to the performed experiment design, it could be clearly observed from **Table 4**, that the EDM parameters setting of experiment No. 5 yielded the lowest VIKOR index. Therefore, experiment No. 5 had the optimal machining parameters setting for the desirable output responses simultaneously (i.e. the best multi-performance characteristics) among the nine experiments. The response table for the Taguchi method was used to calculate the VIKOR index for each level of the input parameters. The procedure is: (i) group the VIKOR index by factor level for each column in the orthogonal array and (ii) take the average of them.

The VIKOR index values for each level of process parameters are shown in **Table 5.** Regardless of the category of performance characteristics, a lower VIKOR index value corresponds to better performance. Therefore, the optimal level of the machining parameters was the level with the lowest VIKOR index value. Based on the VIKOR index values given in **Table 5**, the optimal machining performance for the green EDM is obtained for 4.5A peak current (level 2), 261 pulse duration (level 2), 40 mm dielectric level (level 1) and 0.3 kg/cm² flushing pressure (level 1). As listed in **Table 5**, the difference between the maximum and the minimum value of the VIKOR index of the EDM parameters are as follow: 0.6701 for peak current, 0.2891 for pulse duration, 0.3702 for dielectric level and 0.2109 for flushing pressure. The most effective factor affecting performance characteristics was determined by comparing these values. This comparison demonstrated the level of significance of the input parameters over the multi-performance characteristics. The most effective controllable factor will be the maximum of these values. Here, the maximum value is 0.6701. This value indicated that the **peak current** had the strongest effect on the multi-performance characteristics among the input parameters. The order of importance of the controllable factors to the multi-performance characteristics in the EDM process, in sequence can be listed. as follows: peak current, dielectric level, pulse duration and flushing pressure, as shown in response **Table 5** for VIKOR index.

TABLE 5: COMPUTED MEANS OF VIKOR INDEX

Input parameter	Average VIKOR INDEX			Max–min	Rank
	Level 1	Level 2	Level 3		
Peak current	0.9324	0.2623	0.6588	0.6701	1
Pulse duration	0.7810	0.4919	0.5806	0.2891	3
Dielectric level	0.4336	0.8039	0.6160	0.3702	2
Flushing pressure	0.5087	0.6253	0.7195	0.2109	4

Taguchi method is used to plot means for VIKOR index for each level of input parameters. It can be clearly observed from the **Figure 3,** that for optimal machining parameter for green EDM a 4.5 A peak current, 261 pulse duration, 40 mm dielectric level and 0.3 kg/cm² flushing pressure.

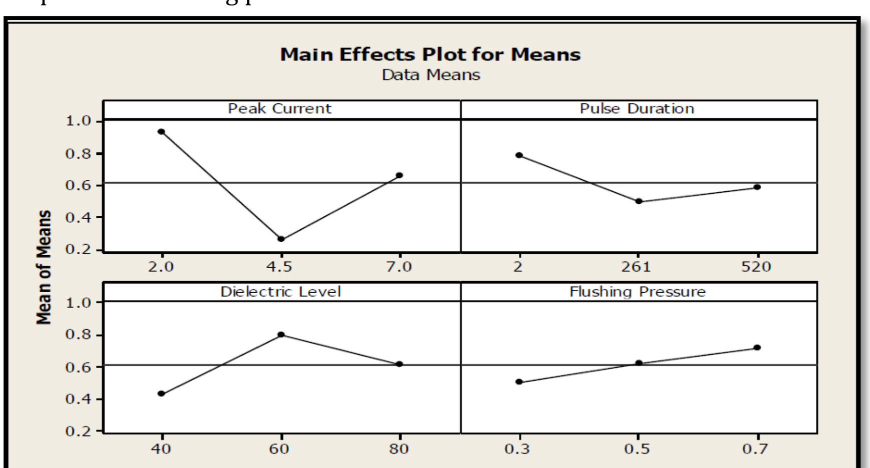
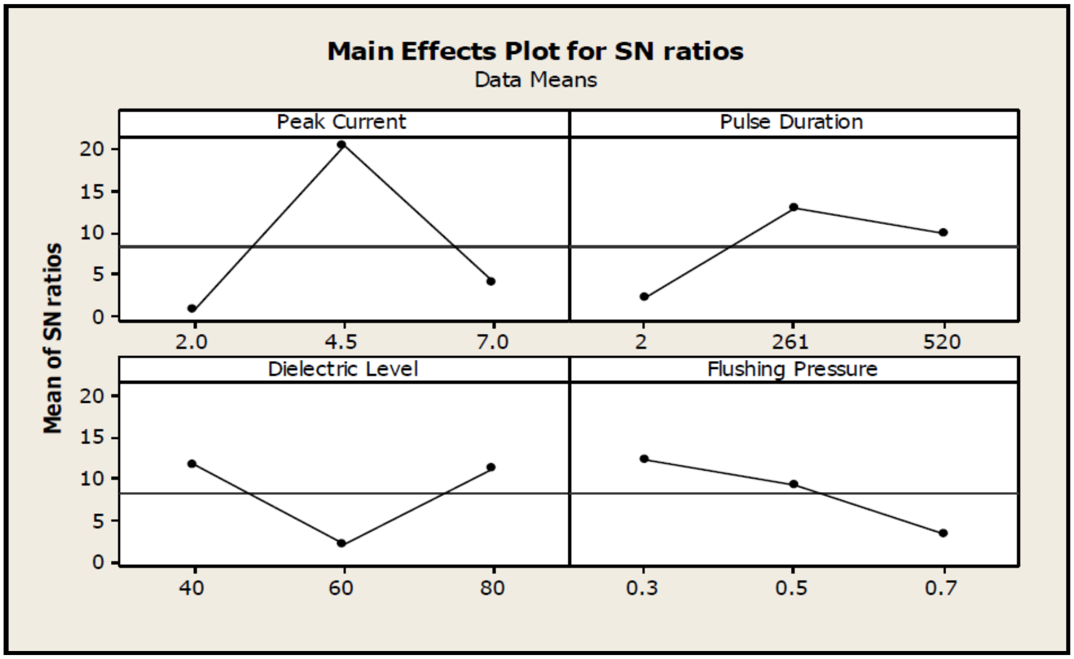


FIGURE 3: MEANS PLOT FOR VIKOR INDEX

Taguchi method is also used to compute the S/N (signal to noise) ratio of VIKOR index for each level of input parameters as shown in **Table 6,** and S/N ratio plot for VIKOR index as shown in **Figure 4.**

TABLE 6: COMPUTED S/N RATIO OF VIKOR INDEX

Input parameter	Level 1	Level 2	Level 3	Max–min	Rank
Peak current	0.6523	20.3807	3.8972	19.7284	1
Pulse duration	2.1646	12.9444	9.8212	10.7799	2
Dielectric level	11.7158	2.0179	11.1965	9.6976	3
Flushing pressure	12.3119	9.3156	3.3028	9.0091	4



If this problem (multi-response parameter optimization problem in green electro-discharge machining) evaluated by combination of Taguchi method and TOPSIS then, the optimum factor level combinations were identified based on the closeness coefficient values. The optimal machining performance for the green EDM was obtained for 4.5 A peak current

(level 2), 261 pulse duration (level 2), 40 mm dielectric level (level 1) and 0.5 kg/cm^2 flushing pressure (level 2). From analysis of the closeness coefficients, it was identified that the peak current was the most influential parameter in multi-performance characteristics. And by solving the same problem using combination of Taguchi

and VIKOR method the results are different, as using TOPSIS the optimal value of flushing pressure was 0.5 kg/cm^2, while in VIKOR the optimal value of flushing pressure is 0.3 cm^2, while other optimal values are same for both methods. And by solving the same problem from both methods peak current had the strongest effect on the multi-performance characteristics among the input parameters.

REFERENCES

1. Samantra, C. (2012), Decision-making In fuzzy environment, M. Tech thesis, NIT Rourkela.

2. Rao, R. (2006), Decision making in the manufacturing environment using graph theory and fuzzy multiple attribute decision making methods, Springer, New Mexico.

3. Abbas, N. M., Solomon, D. G., and Bahari, M. F. (2007), A review on current research trends in electrical discharge machining (EDM), International journal of machine tools & manufacture, Vol. 47, pp. 1214–1228.

4. Tong, L. I., Chen, C. C. and Wang, C. H. (2007), Optimization of multi-response processes using the VIKOR method, International journal of advanced manufacturing technology, Vol. 31, pp. 1049-1057.

5. Derringer, G. C. and Suich, R. (1980), Simultaneous optimization of several response variables, Journal of quality technology, Vol. 12, pp. 214-219.

6. Khuri, A. I. and Conlon, M. (1981), Simultaneous

optimization of multiple responses represented by polynomial regression functions, American statistical association and american society for quality, Vol. 23, pp. 367-35.

7. Logothetis, N. and Haigh, A. (1988), Characterizing and optimizing multi-response processes by the taguchi method, Quality and reliability engineering international, Vol. 4, pp. 159-169.

8. Phadke, M. S. (1989), Quality engineering using robust design. Prentice-Hall.

9. Bortolan, G. and Degani, R. (1985), A review of some methods for ranking fuzzy subsets, Fuzzy sets and systems, Vol. 15, pp. 1–19.