

Optimization of Process Parameters by Utility Concept- A Review

Mihir Thakorbbhai Patel

Mechanical Engineering Department, B & B Institute of Technology, Vallabh Vidyanagar

Abstract — *In this paper, an extensive and in-depth review on multi optimization of different process parameters were carried out using Utility concepts. Today in a competitive environment, every company may try to supply the high quality product and services according to the needs of the customers. Every competitive industry tries to focus on general expense of the product. A single setting of process parameters may be optimal for only one quality parameter, but it may yield adverse results for other quality parameter. The utility concept shows the optimal sequence which gives better results than theoretical predicated or conventionally selected sequence.*

Keywords- *Multi Characteristics, Multi objective, Multi optimization, Taguchi, Utility Concept.*

I. INTRODUCTION

In today’s competitive environment, companies are prompted to constantly improve the quality of their products, because the market has raised the customer’s expectation. To stay in competitive environment, a company must supply the high quality product and services according to the needs of the customers. The overall cost of the product is determined with respect to a number of quality characteristics. These quality characteristics are often interrelated and need to be considered simultaneously. A single setting of process parameters may be optimal for only one quality parameter, but it may yield adverse results for other quality parameter. So, multi optimization strategy is required to provide an integrated criterion so as to represent the overall optimal setting of process parameters with respect to all the responding parameters.

II. UTILITY CONCEPT

A customer evaluates a product based on a number of different quality characteristics. The evaluations of different characteristics should then be combined to give a composite index. Such a composite index represents the utility of the product. The Utility of a product is the sum of individual utilities of various quality characteristics of a product or process. The estimated response of each quality characteristics is transformed into a common index by utility approach. If X is the measure of effectiveness of a quality characteristic i and there are n quality characteristics assessing the outcome space, then the Utility function can be articulated as:

$$U(X_1, X_2, X_3, \dots, X_n) = f[U_1(X_1), U_2(X_2), U_3(X_3), \dots, U_n(X_n)]$$

Where $U_i(X_i)$ is the utility of the i^{th} attribute. Assuming that the attributes are independent and have no interactions between themselves, and the overall utility function is a linear sum of individual utilities, the function becomes:

$$U(X_1, X_2, X_3, \dots, X_n) = \sum_{i=1}^n U_i(X_i)$$

The attributes may be given priorities as per customers’ requirements and corresponding weights for the individual utility index. The overall utility function can then be written as

$$U(X_1, X_2, X_3, \dots, X_n) = \sum_{i=1}^n W_i U_i(X_i)$$

Where W_i is the weight allocated to the quality i and the entirety of the weights for all ascribes is equivalent to 1. The utility function is of "higher the better" type. In the event that the composite measure (the overall utility) is maximized, the quality characteristics considered for the evaluation of utility will be optimized (maximized or minimized).

Determination of utility value:

To determine the utility value for a number of quality characteristics, a preference scale for each quality characteristic is constructed. Later these scales are weighted to obtain a composite number (overall utility). The weighting is done to satisfy the test of indifference on the various quality characteristics. The preference scale may be logarithmic or linear. The minimum acceptable value for each response is assigned at 0 and value 9 is assigned to the best value of the quality characteristics.

The preference number (Pi) can be expressed on a logarithmic scale as:

$$P_i = A \log \frac{X_i}{X_i'}$$

Where, X_i is the value of quality characteristic or attribute i, X_i' is the minimum acceptable value of the quality characteristic or attribute i and A is a constant.

Arbitrary, we may choose A such that $P_i = 9$ at $X_i = X^*$, where X^* is the optimal or best value

$$\text{So, } A = \frac{9}{\log \frac{X_i^*}{X_i}}$$

The next step is to assign the weights or relative importance to the performance characteristics considered for optimization. The task of weights is subjective and relies on upon the end utilization of the item or process according to client's preference. The weights are allocated in such a manner that following condition hold:

$$\sum_{i=1}^n W_i = 1$$

The overall utility can be computed as below:

$$U = \sum_{i=1}^n W_i P_i$$

Multi- Characteristic Optimization Algorithm

The stepwise algorithm for carrying out multi-response optimization with utility based Taguchi approach is given in following steps [6]:

1. Find the optimal values of each of the selected performance characteristic using Taguchi experimental design and analysis.
2. Construct a preference scale for each performance characteristic based on the optimal values and minimum acceptable levels.
3. Assign weights W_i , $i = 1, 2, \dots, n$, based on the experience and application of the components to various output characteristics.
4. Find the utility values for each experimental trial conditions for all the response characteristics involved in multi-response optimization.
5. Use the values obtained in step 4 as a response of the different trial conditions of the selected experimental matrix.
6. Analyze the results as per the procedure proposed by Taguchi method.
7. Find the optimal setting of the process parameters for mean and minimum deviation (optimum unity) based on analysis executed in step 6.
8. Predict the individual characteristic values that maximize the overall utility as determined in step 7.
9. Conduct confirmation experiments at the optimal settings to verify the optimal results.

III. LITERATURE REVIEW

Ajay Mishra et al. [1] were optimized process parameters of turning bar of AISI 1045 steel on engine lathe. They had investigated the multi-objective optimization of the turning process of AISI 1045 steel cylindrical bars to yield the minimum tool flank wear width, surface roughness and roundness through the combination of Taguchi method and Utility concept. They have performed nine experimental runs based on Taguchi's L_9 orthogonal array and data results were analyzed using signal to noise (S/N) ratios, analysis of variance (ANOVA) and utility values. They have used cutting speed, feed rate and depth of cut as turning process parameters and with tool flank wear width, surface roughness and roundness as response parameters. The optimal values obtained during the study using the multi-objective optimization with the help of Taguchi method and utility concept have been validated by confirmation experiments. The summary of results is as shown in below table.

Table 1 Summary of Result

Quality Parameter	Overall mean	Single objective optimization	% Improvement	Multi objective optimization	% Improvement
Tool flank wear width	114.073 μm	86.8519	23%	100.185 μm	12.17%
Surface Roughness	1.3262 μm	0.8422	36%	1.1088 μm	16.39%
Roundness	41.15 μm	33.5185	8%	37.5185	8.83 %

From the experiment they concluded that

- The tool flank wear width, surface roughness and roundness are improved by 12.17 %, 16.39 % and 8.83 % respectively.
- The optimum parameter values in the given operating condition are cutting speed = 110 m/min., feed rate = 0.15 mm/rev. and depth of cut = 0.20 mm.
- The results obtained in this study have been validated by confirmation experiments.

Ananthakumar et al. [2] had studied effect of different process parameters on Surface roughness, Material removal rate and Tool flank wear on medium carbon steel material on lathe machine. Investigations have been done using Taguchi's L_9 orthogonal array design with different combination of process parameters: (Cutting pace, Feed, Depth of cut). They analyzed the results using Grey relational analysis. They found for multi optimization that best combination of the cutting parameters was the set with spindle low speed, high feed rate and middle depth of cut.

B.Singarvel et al. [3] had done experimental analysis the optimum machining parameters were evaluated using Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools. This strategy has been utilized for simultaneous minimization of surface harshness, cutting power and maximization of material removal rate. They found that

- The results of ANOM shown that a combination of machining parameters for this investigation were cutting speed of 244 m/ min, feed rate of 0.10 mm/rev and depth of cut of 1.0 mm with CVD coated tool.
- The result of ANOVA shown that the coated tool was the most significant parameter followed by cutting speed.
- The prediction error (i.e) the difference between the predicted SN ratio and multi objective SN ratio was within the confidence level.

Bharat Chandra Routara et al. [4] had studied highlights a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass. Utility theory has been adopted to convert a multi-response optimization problem into a single response optimization problem; in which overall utility degree serves as the representative single objective function for optimization. They have been used combination of utility concept and Taguchi methodology for predicting optimal setting of process parameters. Finally the optimal setting has been verified by confirmation runs.

G. D. Kostina et al. [5] had worked on multi optimization problem. A variant of the linear weighted sum scalarization was described for the reduction of discrete multi criteria optimization problems to a single criterion task. This variant uses the utility concept to transform each of multiple criteria to a identical numeric form. The reduction was done by defining a generalized criterion as a linear sum of weighted utility values related with original individual criteria of given optimization problem. The use of utility values instead of actual values of criteria considerably simplifies the accumulation of multiple criteria that in general can be of different types and ranges of values. Created single generalized criterion can be used to determine the best alternative among the given set of alternatives by a single criterion optimization. The detailed algorithm was given that implements all operations to calculate such a criterion and to determine the optimal solution of the problem.

H. K. Kansal et al. [6] had worked to optimize of EDM process when silicon powder is suspended into the dielectric fluid of EDM. They have used powder concentration, peak current, pulse duration, duty cycle as process parameters and machine rate, surface roughness and tool wear rate were taken as the quality parameters. They found from the experiments that the peak current and concentration of the silicon powder suspended into dielectric fluid were the most significant process parameters and optimal setting values for machine rate, surface roughness and tool wear rate were 1.22 mm³/min, 0.51 μm and 0.005 mm³/min respectively. The optimal setting was verified by confirmation experiments. The percentage contribution for overall utility index for powder concentration, peak current, pulse duration, duty cycle were 84.01, 8.84, 4.2 and 2.95 respectively.

Hari Singh et al. [7] had tried to investigate the effect of cutting speed, feed and depth of cut process parameters on surface roughness, tool life, cutting force and power consumption. They optimized the process parameters as individual quality characteristics using Taguchi methodology and multiple optimizations (minimization of surface roughness, cutting force and power consumption and maximization of tool life) using Taguchi utility concept. The results shown below table:

Table 2 Summary of Result

Method	Characteristics	Optimal Condition	Optimal Value
Single characteristic optimization	Surface Roughness	A ₃ B ₁ C ₁	76.18 ru
	Tool life	A ₂ B ₁ C ₁	20.19 min
	Cutting force	A ₃ B ₁ C ₁	324.88 N
	Power Consumption	A ₁ B ₁ C ₁	1.028 kW

Method	Characteristics	Optimal Condition	Optimal Value
Multi-characteristic optimization	SR, TL, CF, PC	$A_2B_1C_1$	SR =81.38 ru TL=20.19 min CF=342.88 N PC=1.43 kW

Hari Vasudevan et al. [8] had studied a hybrid multiobjective optimization algorithm involving utility and fuzzy coupled with Taguchi methodology. Four process parameters, at three levels were selected for the study viz. tool nose radius, cutting speed, feed and depth of cut and surface roughness, cutting force and material removal rate were chosen as quality performance measures. They used Taguchi L_{27} orthogonal array to perform experiments. Woven fabric based GFRP/Epoxy tubes produced using hand layup process were finish turned using Poly Crystalline Diamond (PCD) tool. Utility values of the three performance measures were transformed into a single Multi Performance Characteristics Index (MPCI) using Mamdani type fuzzy inference system. Then, MPCI is then optimized using Taguchi analysis. The for multi characteristics the optimal sequence found: tool nose radius of 0.8 mm, cutting speed of 200 m/min, feed rate of 0.05 mm/rev and depth of cut of 1mm. The confirmatory experiment at these settings gives maximum value of MPCI validating the results.

Jaswinder Singh et al. [9] have optimized multi objective material handling task using utility concept. They have selected box size, body mass index, frequency of lift, load lifted, vertical distance, asymmetric angle as the parameters for multi response optimization (Oxygen consumption and Heart rate). They have chosen parameters based on subjective and practical knowledge. They found that Oxygen consumption and Heart rate were improved using utility concept.

Kishan Choudhuri et al. [10] had worked multi optimization. Multi characteristics response optimization model based on Taguchi and Utility concept which was used to optimize process parameters, such as speed, feed, and depth of cut on multiple performance characteristics, namely surface roughness and material removal rate during turning of Aluminium 6061 using a Carbide cutting tool on CNC TC. Taguchi's L_9 orthogonal array was selected for experimental planning. The experimental result showed that combination of higher levels of feed, depth of cut, and lower level of spindle speed was essential to achieve simultaneous maximization of MRR and minimization of surface roughness. They have performed ANOVA analysis for individual response characteristic. From ANOVA analysis they found that the depth of cut (65.57%) was most significantly influences the Ra followed by spindle speed (6.344%) and in case of material removal rate, feed (76.109%) was the most significant parameter followed by spindle speed (9.597%).

M. Kaladhar et al. [11] had optimized multi-characteristics response for turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool on CNC TC based on Taguchi and Utility concept. They have used this concept for optimize process parameters such as speed, feed, depth of cut, and nose radius and selected multiple performance characteristics, namely, surface roughness and material removal rate. Taguchi's L_8 orthogonal array was selected for experimental planning. The experimental result analysis showed that the combination of higher levels of cutting speed, depth of cut, and nose radius and lower level of feed is essential to achieve simultaneous maximization of MRR and minimization of Ra. They have performed ANOVA for individual quality parameters as well as for multi response case. Based on the ANOVA, the most statistical significant and percent contribution of the process parameters for multiple performances were depth of cut, cutting speed whereas feed and nose radius were less effective. They concluded that the proposed model based on Taguchi approach and Utility concept is simple, useful and provides an appropriate solution for multi-response optimization problems.

R. Jayadithya et al. [12] have been conducted experiments using 3 machine parameters such as pulse on time (TON), pulse off time, wire feed and one work piece parameter such as work piece thickness, each at three levels for obtaining the responses like cutting speed, surface roughness, and dimensional deviation. Taguchi's L_9 orthogonal array was selected to collect information regarding the process with lesser number of experimental runs. Conventional Taguchi approach is insufficient to solve a multi response optimization problem. In order to overcome this limitation, utility theory has been applied. ANOVA analysis was also carried out to find out the significant effect of the process parameters during WEDM process. Finally confirmation test has been carried out to verify the experimental result.

Ravinder Kataria et al. [13] had compared different multiple response optimization techniques for turning operation of AISI O1 tool steel. They selected nose radius, speed, feed and depth of cut as input process parameters and material removal rate, surface roughness as quality parameters. Taguchi method was employed for single response optimization. For multi-response optimization, weighted signal-to-noise ratio (WSN), grey relational analysis (GRA), utility concept and technique for order preference by similarity to ideal solution (TOPSIS) method have been utilized and their performance was evaluated. The optimal process parameter settings for WSN, GRA, Utility Concept and TOPSIS were $A_1B_3C_2D_3$, $A_2B_1C_1D_2$, $A_2B_3C_3D_2$ and $A_2B_2C_3D_3$ respectively. Hence, there has been considerable difference among the

optimal settings yielded by the methods investigated. Weighted signal-to-noise ratio method has been found to produce best results for multi-response optimization for this study.

Rina Chakravorty et al. [14] had studied the effect of process parameters such as work piece polarity, pulse-on-time, duty factor, open discharge voltage, discharge current, dielectric fluid on different quality parameters such as material removal rate and electrode wear rate in EDM process. The experimental results data of EDM processes were analyzed using the modified PCA-based UT approach and PCA-based PQLR method. The comparison of the optimization performances at the optimal conditions derived by the two methods indicates that the optimal condition derived by the modified PCA-based UT method leads to better optimization performance than PCA-based PQLR method. This suggests that the modified PCA-based UT approach can be a promising method for optimizing correlated responses of EDM process.

Tarun Goyal et al. [15] have used Utility theory and Taguchi quality loss function for simultaneous optimization of more than one response characteristics for low-pressure cold spray (LPCS) process to deposit copper coatings. They selected coating density and surface roughness as quality characteristics and feed type, substrate material, stagnation pressure, stagnation temperature, standoff distance taken as input process parameters. Utility values based upon these response parameters have been analyzed for optimization by using Taguchi approach. For the experiments they found that the selected quality parameters were significantly improved using Taguchi utility concept and analysis of variance also performed to analyzed the which parameters are significantly effect on multi responding parameters.

Yogendra Kumar et al. [16] had performed multi- response optimization in dry turning process using Taguchi and utility concept. They selected nose radius, cutting speed, feed rate and depth of cut as input process parameters and axial force, radial force, main cutting force, material removal rate as quality parameters. They have selected EN47 alloy steel as work material and experiments were performed based on mixed L_{18} Taguchi orthogonal array. They found that:

- All the four process parameters, namely, nose radius, cutting speed, feed and DOC had significant effect on utility function for multi optimization.
- The model can be used for optimization of multi-response characteristics that have realistic data.

Table 3 Summary of different reviewed papers

SR. No.	Year	Author	Material	Machine	Input Parameters	Responding parameters
1	2013	Ajay Mishra and Dr. Anshul Gangele	AISI 1045 Steel	Lathe Machine	Cutting speed, Feed, DOC	Tool Flank Wear width, Surface roughness and Roundness
2	2013	Ananthakumar. P, Dr.Ramesh.M and Parameshwari	AISI: 1040(ISO 683-1:C40)	Lathe Machine	Cutting speed, Feed, Depth of cut	Surface roughness, Material removal rate, Tool Flank wear
3	2014	B.Singarvel, T.Selvaraj and R.Jeyapaul	EN25 Steel	Lathe Machine	Coated tools, Cutting speed, Feed, DOC	Cutting Force, Surface Roughness, Material Removal rate
4	2010	Bharat Chandra Routara, Saumya Darsan Mohanty, Saurav Datta, Asish Bandyopadhyay And Siba Sankar Mahapatra	Brass UNS C34000	CNC end milling	Spindle speed, Feed and Depth of cut	Ra, Rq, Rku, Rsm
5	2014	G. D. Kostina, S. A. Kostina and I. O. Chudaykin	-	-	-	Multi criteria optimization problems to a Single criteria task
6	2006	H. K. Kansal, Sehijpal Singh and Pradeep Kumar	H-11 Die steel	Electrical discharge machining	Powder Concentration, Peak current, Pulse duration, Duty cycle,	Machine rate, Surface roughness and Tool wear rate

SR. No.	Year	Author	Material	Machine	Input Parameters	Responding parameters
7	2005	Hari Singh & Pradeep Kumar	EN24 steel	Lathe Machine	Cutting speed, Feed and DOC	Surface roughness, Tool life, Cutting force, Power Consumption
8	2014	Hari Vasudevan, Naresh Deshpande, Ramesh Rajguru and Sandip Mane	GFRP/Epoxy composites material	Lathe Machine	Nose radius, Cutting speed, Feed, DOC	Surface roughness parameter, cutting force and Material removal rate
9	2014	Jaswinder Singh, P. Kalra and R.S. Walia	-	Manual Material Handling	Box size, BMI, Frequency of lift, load lifted, Vertical distance, Asymmetric angle	Oxygen consumption and Heart rate
10	2014	Kishan Choudhuri, Sourabh Goyal, and Prasun Chakraborti	Aluminum 6061	Lathe Machine	Spindle speed, Feed and Depth of cut	Material removal rate, Surface roughness
11	2011	M. Kaladhar, K. V. Subbaiah, Ch. Srinivasa Rao and K. Narayana Rao	AISI 202 Austenitic Stainless Steel	Lathe Machine	Nose radius, Cutting speed, Feed, DOC	Material removal rate, Surface roughness
12	2014	R.Jayadithya, B.Deekshith, P.Lalith Chaithnya and G.Rajyalakshmi	Inconel825 alloy	Wire electrical discharge machining	Pulse on time, Pulse off time, wire feed and Work piece thickness	Cutting Speed, Surface roughness and Dimensional Deviation
13	2014	Ravinder Kataria and Jatinder Kumar	AISI O1 tool steel	Lathe Machine	Nose radius, Speed, Feed and Depth of cut	Material removal rate, Surface roughness
14	2012	Rina Chakravorty, Susanta Kumar Gauri and Shankar Chakraborty	composite materials, HSS	EDM	Work piece polarity, pulse-on-time, duty factor, open discharge voltage, discharge current, dielectric fluid	Material removal rate, Electrode wear rate
15	2011	Tarun Goyal, R.S. Walia, T.S. Sindhu	-	Low pressure cold spray	Feed type, Substrate material, Stagnation pressure, Stagnation temperature, Stand off distance	Coating Density, Surface roughness
16	2014	Yogendra Kumar and Hari Singh	EN 47 Steel	Lathe Machine	Nose radius, Cutting speed, Feed, DOC	Axial Force, Radial force, Main Cutting Force, Material removal rate

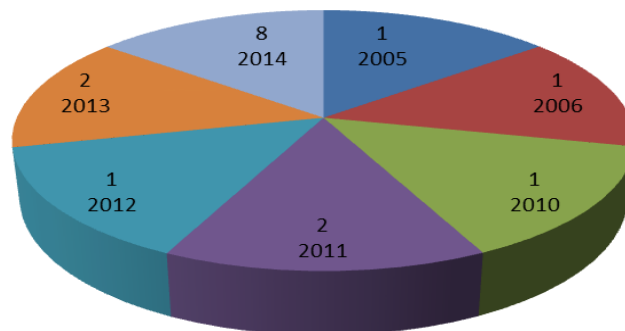


Figure 1. Pie chart of reviewed papers by year

IV. CONCLUSION

1. A traditional Taguchi method is used to optimize for single quality parameters only.
2. The Utility Concept is the one of the simplest method and result gives significant improvement from existing solutions.
3. The Utility Concept widely used for optimization problem has multi objectives. The Utility Concept has been applied in variety of problems that have realistic data.
4. Analysis of variance is also help to determine which parameter shows the significant effect on required performance characteristics.

V. FUTURE SCOPE

1. The Utility Concept used for multi optimizes quality parameters for any machine for selected process parameters.

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