International Journal of Advanced Research in IT and Engineering

ISSN: 2278-6244
Impact Factor: 5.418

MULTI OPTIMIZATION OF PROCESS PARAMETERS BY USING GREY RELATION ANALYSIS- A REVIEW

Mihir Thakorbhai Patel*

Abstract: *In this paper, a comprehensive and in-depth review on multi optimization of different process parameters were carried out using Grey relation analysis. Quality and productivity are two of the most important criteria in any machining operation. But it can be seen that there is tradeoff between them. So, it is essential to optimize quality and productivity simultaneously. The grey relation analysis is the effective methodology to optimize multiple performance parameters. The selection of the process parameters is also important for any optimization of required quality characteristics. The grey relation analysis is not used to optimize machining parameters only. It also used to software evaluation, site selection, bank selection etc. The grey relation analysis shows the optimal sequence which gives better results than theoretical predicated or conventionally selected sequence.*

Keywords: *ANOVA, Grey relation analysis, Multi optimization, Process parameters, Taguchi.*

*Lecturer, Department of Mechanical Engineering, BBIT, V.Vnagar, Gujarat

INTRODUCTION

The quality of a product is the important factor for showing growth of a company. Quality and productivity are two of the most important criteria in any machining operation. But it can be seen that there is tradeoff between them i.e. as the quality increases then productivity tends to decrease. It is therefore essential to optimize quality and productivity simultaneously. Optimization technique plays a vital role to improve the quality of the product. The product being machined has to have the minimum surface roughness and in order to obtain high quality. On other side the processing time has to be compromised which directly affects the productivity. It is very important to optimize both the factors simultaneously. In such a case multi objectives optimization are necessary to solve the above problem. There are various methods are used for multi optimization like grey relation analysis, utility concept etc.

GREY RELATION ANALYSIS

The grey relational analysis, which is useful for dealing with poor, incomplete and uncertain information, can be used to solve complicated inter-relationships among multiple performance characteristics satisfactorily. Following are the steps needed for converting the multi-response characteristics to single response characteristics [4].

1. Normalize the experimental results of metal removal rate and surface roughness (data preprocessing)
2. Calculate the Grey relational co-efficient.
3. Calculate the Grey relational grade by averaging the Grey relational co-efficient.

In the grey relational analysis, the experimental results are first normalized in the range between zero and unity. This process of normalization is known as the grey relational generation. After then the grey relational coefficient is calculated from the normalized experimental data to express therelationship between the desired and actual experimental data. Then, the overall grey relational grade is calculated by averaging the grey relational coefficient corresponding to each selected process response. The overall evaluation of the multiple process responses are based on the grey relational grade. This method converts a multiple response process optimization problem with the objective function of overall grey relational grade. The corresponding level of parametric combination with highest grey relational grade is considered as the optimum process parameter.

If the target value of the original sequence is "the-larger-the-better", then the original sequence is normalized using below mentioned equation.

$$X_j(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

If the target value of required purpose is "the-smaller-the-better", then the original sequence is normalized using below mentioned equation.

$$X_j(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

where, $x_i(k)$ and $x_j(k)$ are the value after Grey Relational Generation for Larger the better and Smaller the better criteria. $\max y_i(k)$ is the largest value of $y_i(k)$ for k^{th} response and min $y_i(k)$ is the minimum value of $y_i(k)$ for the k^{th} response. The Grey relational coefficient ξ (k) can be calculated as below mentioned equation.

$$\xi_i(k) = \frac{\Delta_{min} + \psi\Delta_{max}}{\Delta_{0i}(k) + \psi\Delta_{max}}$$

and

$$\Delta o_i = \left\| x_0(k) - x_i(k) \right\|$$

Where Δo_i is the difference between absolute value $x_0(k)$ and $x_i(k)$ and ψ the distinguishing or identification coefficient defined in the range 0= ξ =1 (the value may be adjusted based on the practical needs of the system). The value of ψ is the smaller, and the distinguished ability is the larger. ψ =0.5 is generally used. After the grey relational coefficient is derived, it is usual totake the average value of the grey relational coefficients as the grey relational grade. The grey relational grade is defined as follows:

$$\alpha_k = \frac{1}{n}\sum_{i=1}^{n} \xi_i(k)$$

Where nis the number of process responses. The higher value of grey relational grade is considered as the stronger relational degree between the ideal sequence $x_0(k)$ and the given sequence $x_i(k)$. The higher grey relational grade implies that the corresponding parameter combination is closer to the optimal.

Sometimes grey relation performed with Taguchi, it is also known as Taguchi Grey relation analysis. In that analysis following steps to be performed [8]:

1. Normalizing the experimental results of require response characteristics.

2. Performing the Grey relational generating and to calculate the Grey relational coefficient.
3. Calculating the Grey relational grade by averaging the Grey relational coefficient.
4. Performing statistical analysis of variance (ANOVA) for the input parameters with the Grey relational grade and to find which parameter significantly affects the process.
5. Selecting the optimal levels of process parameters.
6. Conducting confirmation experiment and verify the optimal process parameters setting.

LITERATURE REVIEW

AbhijitSaha et al. [1] were investigated multi response optimization of turning process for an optimal parametric combination to yield the minimum power consumption, surface roughness and frequency of tool vibration using a combination of Grey relational analysis (GRA). Confirmation test was also conducted for the optimal machining parameters to validate the test result. They have taken turning parameters, such as spindle speed, feed and depth of cut. Experiments were designed and conducted based on full factorial design of experiment.

Abhishek Dubey et al. [2] were worked on multiple response optimization of end milling parameter using grey based Taguchi method. Experiments were designed and conducted based on L_{27} orthogonal array design. The milling parameter were spindle speed, depth of cut, feed rate and pressurized coolant jet and the response was surface roughness. They concluded that the spindle speed was the most influential control factor among the all process parameters for minimization of surface roughness.

Arun Kumar Parida et al. [3] had optimized the machining parameters in turning of glass fiber reinforced polymer (GFRP) composites on all geared lathe machine. They had taken spindle speed, feed rate and depth of cut as machining parameters, surface roughness and material removal rate as a response parameters. Taguchi's L_9 orthogonal array has been used for perform experiments. Analysis of variance has been carried out to check the significant process parameter in a single objective performance characteristic. They concluded that performance characteristic of the machining process such as MRR and surface roughness are improved together by using this approach.

B. Shivapragash et al. [4] had studied effect of different process parameters on material removal rate and surface roughness on Al-TiBr material on radial drilling machining with dry conditions. 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.

Chao-Lieh Yang [5] has carried out the multi optimization in the cutting of glass fiber. They found optimal process parameters for given performance characteristics at highest cutting speed and the smallest cutting volume, and the medium cutting load. They used L_9 Taguchi orthogonal array for performing the experiments. The optimal setting for multiple performance characteristics was found at highest cutting speed and the smallest cutting volume, and the medium cutting load. They also found from analysis of variance that cutting speed was the most contributing parameters and cutting load was least contributing parameter for multiple response parameters. They also performed confirmation experiments for validate the optimal results. They also concluded that Grey-based Taguchi methods is a good way to improve the multiple performance parameters.

Chih-Hung Tsai et al. [6] had applied grey relation analysis for proper vendor selection. They have taken defect, quotation, delay rate, shortage rate and score as input parameters. They found that grey relation methodology significantly reduced the purchasing cost and increase the production efficiency and overall competitiveness.

D. Chakradharet al. [7] were performed multi optimization for Electrochemical machining on EN31 steel by Grey Relational Analysis. The process parameters considered are electrolyte concentration, feed rate and applied voltage and are optimized with considerations of multiple performance characteristics including material removal rate, overcut, cylindricity error and surface roughness.

Funda OZCELIK et al. [8] had evaluated banks sustainability performance in Turkey by using Grey relational analysis. Banks performances have been analyzed based on 3 financial, 2 social and 4 environmental ratios and banks have been listed based on their sustainability performance. According to the sustainability performance of banks, TSKB ranks first and is followed by Garanti Bank and Akbank respectively.

Geeta Nagpalet al. [9] had used grey relation analysis and fuzzy logic techniques for software estimation. Two alternative approaches using analogy for estimation have been proposed in this study. Firstly, a precise and comprehensible predictive model based on the integration of Grey Relational Analysis (GRA) and regression has been discussed. Second approach deals with the uncertainty in the software projects, and how fuzzy set theory in fusion with grey relational analysis can minimize this uncertainty.

Hossein Hasaniet al. [10] had performed grey relational analysis for optimizing the process parameters for open-end spun yarns. The raw materials used in this investigation were cotton fibers (35%) and cotton waste (65%) collected from ginning machines. They concluded that grey relational analysis and the Taguchi Method can be applicable for the optimization of process parameters and help to improve process efficiency.

J.T. Huang et al. [11] had applied to determine the suitable selection of machining parameters for Wire Electrical Discharge Machining (Wire-EDM) process using grey relation analysis. They found that the table-feed rate has a significant influence on the machining speed, whilst the gap width and the surface roughness are mainly influenced by pulse-on time. Moreover, the optimal machining parameters setting for maximum machining speed and minimum surface roughness can be obtained.

Kamal Jangraet al. [12] had optimized material removal rate and surface roughness simultaneously; grey relational analysis was employed along with Taguchi method. Analysis of variance (ANOVA) had shown that the taper angle and pulse-on time are the most significant parameters affecting the multiple machining characteristics. Confirmatory results, proves the potential of GRA to optimize process parameters successfully for multi-machining characteristics.

M. S. Reza et al. [13] were optimized multi-performance optimization characteristics on Electrical Discharge Machining injection flushing type control parameters by using Grey Relational Analysis. The machining parameters selected were polarity, pulse on duration, discharge current, discharge voltage, machining depth, machining diameter and dielectric liquid pressure. Results shown that machining performance was improved effectively using this approach.

Meenu Gupta et al. [14] had performed different experiments (using mixed L_{18} orthogonal array) to optimize process parameters on unidirectional glass fiber reinforced plastic material using NH–22 HMT lathe. They have analyzed the results data using Taguchi method and Grey relational analysis. They found that depth of cut was the factor, which has great influence on surface roughness and material removal rate, followed by feed rate. The percentage contribution of depth of cut was 54.399% and feed rate was 5.355%.

MehulA.Ravalet al. [15] had performed experiments on abrasive water jet machine on AISI 52100 steel material and analyzed the results using grey relation analysis. They have selected abrasive grain, pressure, tip distance and pole distance as the process parameters and material removal rate and surface roughness as quality parameters. They selected Taguchi L_9 orthogonal array to conduct experiments. They concluded that the optimum condition for multi response parameters was meeting at abrasive grain size (A1), pressure (B2), tip distance (C3) and pole to work piece distance (D1).

P. Narender Singh et al. [16] had used grey relation analysis to optimize multi performance characteristics like MRR, TWR, Taper, Radial over cut, and surface roughness for current, pulse on time, flushing pressure process parameters. They found that current at level 3, pulse on-time at level 3 and the flushing pressure at level 1 for maximizing MRR and for minimizing TWR, T, ROC and SF given an optimum machining conditions for the required output. The experimental result for the optimal setting shows that there was considerable improvement in the process.

Pankaj Sharma et al. [17] have tried to investigate the effect of various process parameters (Cutting Speed, Feed & Depth of cut) on material removal rate and surface roughness on CNC TC. Taguchi's L_{18} orthogonal array used for performs experiments. Analysis of variance (ANOVA) used to determine the significance of process parameters for individual quality parameter. The multi optimization was done by Grey relational analysis approach. They concluded that the performance characteristics for the turning operations, such as the material removal rate and the surface roughness are greatly enhanced by using this method. They found the optimal setting for multi objective quality parameters was V5-F2-D3.

Raghuraman S. et al. [18] have tried to investigate effect of different process parameters (Discharge current, Pulse ON time & Pulse OFF time) on different performance parameters (MRR, TWR, SR) in EDM. They performed experiments using L_9 orthogonal array, analysis has been carried out using Grey Relational Analysis and Taguchi method. The confirmation experiments were carried out to confirm the optimal results. Their results show that the Taguchi Grey relational Analysis is being effective technique to optimize the machining parameters for EDM process.

Reddy Sreenivasuluet al. [19] had studied, the effects of drilling parameters on surface roughness and roundness error were investigated in drilling of AI6061 alloy with HSS twist drills. The obtained experimental results were analyzed by Taguchi Grey relation analysis. They had taken Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio as control factors. They found that minimum surface roughness and roundness error were obtained with treated drills at 25.13 m/min cutting speed and 0.3 mm/rev feed rate,10mm drill diameter, 110 degrees point angle and 12% cutting fluid mixture ratio.

S V Subrahmanyamet al. [20] had tried to demonstrate the optimization of Wire Electrical Discharge Machining process parameters for the machining of H13 Hot Die Steel, with multiple responses material removal rate, surface roughness based on the Grey–Taguchi Method. They used Taguchi L_{27} (2^1x3^8) orthogonal to conduct experiments. They had taken eight process parameters TON, TOFF, IP, SV WF, WT, SF, WP each to be varied in three different levels. They used grey relation analysis to obtained optimal sequence for multi quality parameters. They found that the material removal rate was increased from 304.46 mm^3/min to 322.66 mm^3/min and the Surface Roughness was reduced from 2.11μm to 2.01μm respectively. They have also presented the mathematical model for individual quality parameter.

Semra BIRGUN et al. [21] have applied grey relation analysis approach for call center site selection. They have taken into consideration both qualitative and quantitative factors and also is one of the most important strategic decisions affecting organizations in terms of business success. They exemplified problem by applying on a part of a project for a call center site selection by using one of the multi-criteria decision-making methods, namely hierarchy grey relational analysis, based on application of analytic hierarchy process and grey relational analysis methods. The first part they applied conventional analytic hierarchy process to determine the relative weights of the criteria. And the second part they applied grey relational analysis to rank the alternatives and then selects the optimum site for call center.

Shunmugesh K. et al. [22] had performed 27 experiments (using Taguchi L_{27} orthogonal array) to identify the effect of speed, point angle and feed on surface roughness and delamination factor on drilling machine. They had taken glass fiber reinforced polymer as work material. They have used grey relational analysis to analyze the results data. They found the optimal setting for minimizing surface roughness and delamination factor was spindle speed 1000 rpm, point angle 135º and feed rate 0.5 m/min.

T Muthuramalingamet al. [23] have used Taguchi grey relation analysis approach for multi response optimization: maximize the material removal rate and minimize the surface roughness in electrical discharging machine. They have taken gap voltage, peak current, and duty factor as input process parameters. They found that peak current was the most significant parameters in electrical discharging machine. They also performed conformation experiments for validate the experimental results. During the confirmation runs, value of material removal rate and surface roughness were 15.78 and 6.42 respectively. The grey relation grade value during the confirmation experiments was improved by 1.7% from the predicated mean value.

T V K Gupta et al. [24] had tried to demonstrate the optimization of abrasive water jet machining process parameters for the machining of SS 304 material, with multiple responses surface roughness, taper, impact force, vibration & depth and width of cut based on the Grey–Taguchi Method. They have taken reverse speed, abrasive flow rate, abrasive size and standoff distance as process parameters. Based on the grey coefficients and grades of the experimental data, a traverse speed of 3000 mm/min, a diameter of 0.125 mm of abrasive particle at 0.49 kg/min abrasive flow rate and a standoff distance of 4 mm given an optimum machining conditions for the required output.

V. Chittaranjan Das et al. [25] have conducted experiments based on Taguchi L_9 orthogonal array to investigate the effect of process parameters current, open voltage, pulse duration, duty factor on multi response characteristics like material removal rate, tool wear rate and surface roughness in EDM. The validation experiments results had shown the machining performance of the material removal rate increases from 2.92 to 3.69 mg/min, the electrode wear ratio decrease from 0.13 to 0.10mg/min and the surface roughness decreases from 2.21 to 1.93µm, respectively.

Table 1 Summary of different review papers

Sr. No.	Year	Author	Material	Machine	Input Parameters	Responding Parameters
1	2013	AbhijitSaha and N.K.Mandal	IS: 2062, Gr. B. Mild steel	HSS MIRANDA S400 (AISI T – 42)	Spindle speed, Feed & DOC	Power consumption, Ra & Frequency of tool vibration
2	2014	AbhishekDubey, Devendra Pathak, Nilesh Chandra, AjendraNath Mishra and Rahul Davis	EN31 steel	Milling machine	DOC, Feed, Spindle Speed and Pressurized coolant jet	Surface roughness
3	2014	Arun Kumar Parida, Rajesh Kumar Bhuyan and Bharat Chandra Routara	GFRP composites	All geared lathe	spindle speed, feed rate and depth of cut	Material removal rate and Surface roughness
4	2013	B.Shivapragash, K.Chandrasekaran, C.Parthasarathy and M.Samuel	Al-TiBr2	Drilling machine	spindle speed, feed rate and depth of cut	Material removal rate and Surface roughness
5	2011	Chao-Lieh Yang	Glass fiber materials	Cutting machine	Cutting Speed, Cutting volume & Cutting load	Wear and Weibull modulus
6	2003	Chih-Hung Tsai, Ching-Liang Chang and Lieh Chen	-	Quality, Price, Delivery date, Quantity and Services	Defect, Quotation, Delay rate, Shortage rate and Score	Vendor Selection
7	2011	D. Chakradhar, A. VenuGopal	EN31 steel	ECM	Electrolyte conc., Feed rate & Voltage	MRR, Overcut, Cylidricity Error, Ra
8	2014	Funda OZCELIK &Burcu AVCI OZTURK	-	Bank	Economic Criteria, Environmental Criteria & Social Criteria	Evaluation of Bank
9	2014	GeetaNagpal, Moin Uddin and Arvinder Kaur	-	-	-	Software estimation
10	2012	HosseinHasani, SomayehAkhavanTabatabaei, GhafourAmiri	Cotton fibers	Open-end spun yarns	Yarn count, Rotor Speed, Opened Speed, Navel Speed	CV %, hair number per meter, and tenacity of yarn
11	-	J.T. Huang and Y.S. Liao	SKD11 alloy steel	EDM	Pulse-on time, Pulse-off time, Table-feed rate, Wire tension, Wire velocity and Flushing pressure	Material removal rate, Gap width & Surface roughness
12	2011	Kamal Jangra, Sandeep Grover and Aman Aggarwal	WC-Co Composite material	EDM	Taper angle, Peak Current, Pulse-on time, Pulse-off time, Wire Tension & Dielectric flow rate	Material removal rate and Surface roughness
13	2010	M. S. Reza, M. Hamdi and M.	AISI 304 Stainless	EDM	Polarity, Pulse on duration, Discharge Current,	Material removal rate, Electrode

Sr. No.	Year	Author	Material	Machine	Input Parameters	Responding Parameters
		A. Azmir	Steel		Discharge Voltage, Machining Depth, Machining Diameter & Dielectric pressure	wear ratio and Surface roughness
14	2013	Meenu Gupta and Surinder Kumar	Fiber reinforced plastic composite rods	NH–22 HMT lathe	Tool nose Radius, Tool Rake angle, Feed rate, Cutting speed, Cutting environment & DOC	Material removal rate and Surface roughness
15	2013	Mehul.A.Raval and Chirag. P. Patel	AISI 52100 Steel	water jet machine	Abrasive grain size, Pressure, Tip distance, Pole distance	Material removal rate and Surface roughness
16	2004	P. Narender Singh, K. Raghukandan& B.C. Pai	Al–10%SiCP composites	EDM	Current, Pulse on time, Flushing pressure	MRR, TWR, Taper, Radial over cut, and SR
17	2012	Pankaj Sharma, KamaljeetBhambri	AISI H13	HMT Stallion-100 HS CNC	Cutting Speed, Feed & Depth of cut	Material removal rate and Surface roughness
18	2013	Raghuraman S, Thiruppathi K, Panneerselvam T & Santosh S	Mild Steel IS 2026	EDM	Discharge current, Pulse ON time & Pulse OFF time	Material removal rate, Tool wear rate and Surface roughness
19	2012	Reddy Sreenivasulu and Dr.Ch.SrinivasaRao	Al6061 alloy	Drilling Machine	Cutting speed, feed rate, drill diameter, point angle and cutting fluid mixture ratio	Surface roughness and Roundness error
20	2013	S V Subrahmanyam and M. M. M. Sarcar	H13 HOT DIE STEEL	EDM	Pulse On time, Pulse Off time, Peak Current, Spark gap Voltage Setting, Wire tension setting, Wire Feed rate setting , Servo Feed Setting, Flushing pressure of dielectric fluid	Material removal rate and Surface roughness
21	2014	Semra BIRGUN, Cengiz GUNGOR	-	-	HRM, Economic, Regional condition	Call Center Site Selection
22	2014	Shunmugesh K, Panneerselvam. K and Jospaul Thomas	Glass Fibre Reinforced Polymer	Drilling machine	Speed, Point Angle and Feed	Surface roughness Delamination Factor
23	2013	T Muthuramalingam and B. Mohan	AISI 202 Stainless Steel	EDM	Gap voltage, Peak current, Duty factor	Material removal rate and Surface roughness
24	2013	T V K Gupta, J Ramkumar, PuneetTandon& N S Vyas	SS 304 material	Abrasive water jet machining	Reverse speed, abrasive flow rate, abrasive size and standoff distance	Surface roughness, Taper, Impact force, Vibration & Depth and Width of cut
25	2014	V.Chittaranjan Das, N.V.V.S.Sudheer	Metal matrix composites (Al/5%TiCp)	EDM	Current , Open voltage, Pulse duration, Duty factor	Material removal rate, Tool wear rate and Surface roughness

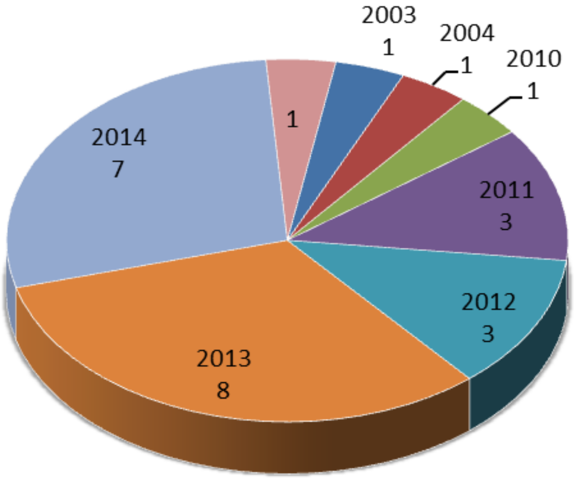

Figure 1.Pie chart of publication year with number of papers

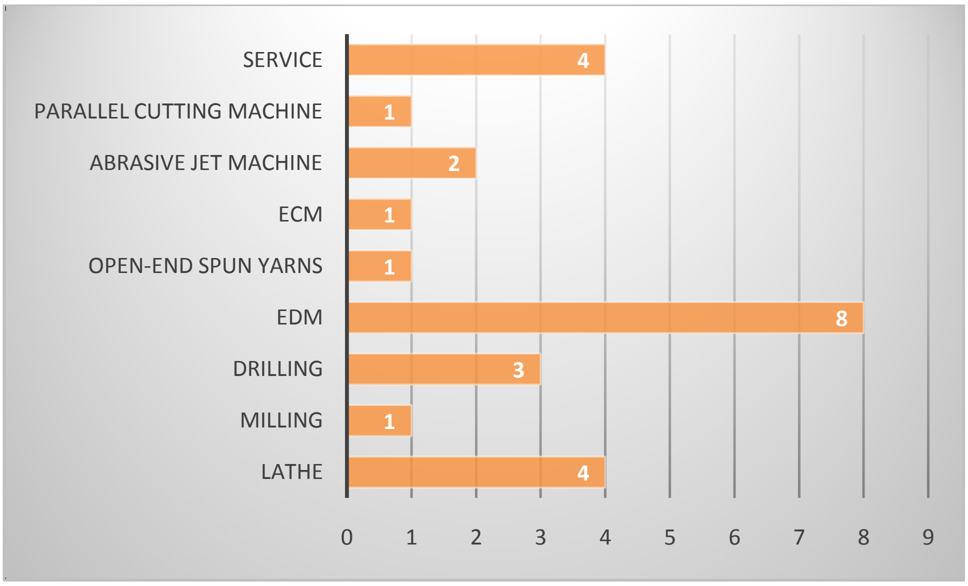

Figure 2. Bar chart of machines tools used in different research papers

CONCLUSION

From reviewed different research paper it has been concluded that

- Taguchi grey relation analysis is mostly used by different researchers.
- Grey relation analysis widely used for optimization problem has multi objectives. The grey relation analysis is not used for optimization of machining process parameters but also used for call center site selection, bank selection, vendor selection etc.
- Grey Relation analysis gives the significant improvement from convention results.
- Analysis of variance is also help to determine which parameter shows the significant effect on required performance characteristics.

- Grey relation analysis is the one of the simplest method and result gives significant improvement from existing solutions.

REFERENCES

1. Abhijit Saha and N. K. Mandal, "Optimization of machining parameters of turning operations based on multi performance criteria", International Journal of Industrial Engineering Computations 4, pp. 51–60, 2013.
2. Abhishek Dubey, Devendra Pathak, Nilesh Chandra, AjendraNath Mishra and Rahul Davis, "A Parametric Design Study of End Milling Operation using Grey Based Taguchi Method" , International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 4, pp. 1140-1146, April 2014.
3. Arun Kumar Parida, Rajesh Kumar Bhuyan and Bharat Chandra Routara, "Multiple characteristics optimization in machining of GFRP composites using Grey relational analysis", International Journal of Industrial Engineering Computations 5, pp. 511–520, 2014.
4. B. Shivapragash, K. Chandrasekaran, C. Parthasarathy and M. Samuel, "Multi Response Optimizations in Drilling Using Taguchi and Grey Relational Analysis", International Journal of Modern Engineering Research, Vol.3, Issue.2, pp-765-768, March-April. 2013.
5. Chao-Lieh Yang, "Optimizing the Glass Fiber Cutting Process Using the Taguchi Methods and Grey Relational Analysis", New Journal of Glass and Ceramics, 1, pp. 13-19, 2011.
6. Chih-Hung Tsai, Ching-Liang Chang and Lieh Chen, "Applying Grey Relational Analysis to the Vendor Evaluation Model", International Journal of The Computer, The Internet and Management, Vol. 11, No.3, pp. 45 – 53, 2003.
7. D. Chakradhar and A. Venu Gopal, "Multi-Objective Optimization of Electrochemical machining of EN31 steel by Grey Relational Analysis", International Journal of Modeling and Optimization, Vol. 1, No. 2, pp. 113-117, June 2011.
8. Funda OZCELIK & Burcu AVCI OZTURK, "Evaluation of Banks' Sustainability Performance in Turkey with Grey Relational Analysis", The Journal of Accounting and Finance, pp. 189-210, July 2014.

9. Geeta Nagpal, Moin Uddin and Arvinder Kaur, "Grey Relational Effort Analysis Technique Using Regression Methods for Software Estimation", The International Arab Journal of Information Technology, Vol. 11, No. 5, pp. 437-445, September 2014.
10. Hossein Hasani, Somayeh Akhavan Tabatabaei, Ghafour Amiri, "Grey Relational Analysis to Determine the Optimum Process Parameters for Open-End Spinning Yarns", Journal of Engineered Fibers and Fabrics, Volume 7, Issue 2, pp. 81-86, 2012.
11. J. T. Huang and Y. S. Liao, "Application of Grey Relational Analysis to Machining Parameters Determination of Wire Electrical Discharge Machining", pp. 1-15.
12. Kamal Jangra, Sandeep Grover and Aman Aggarwal, "Simultaneous optimization of material removal rate and surface roughness for WEDM of WCCo composite using grey relational analysis along with Taguchi method", International Journal of Industrial Engineering Computations 2, pp. 479–490, 2011.
13. M. S. Reza, M. Hamdi and M. A. Azmir, "Optimization of EDM Injection Flushing Type Control Parameters Using Grey Relational Analysis On AISI 304 Stainless Steel Work piece" National Conference in Mechanical Engineering Research and Postgraduate Student, 26-27, pp. 564-571, May 2010.
14. Meenu Gupta and Surinder Kumar, "Multi-objective optimization of cutting parameters in turning using grey relational analysis", International Journal of Industrial Engineering Computations 4, pp. 547–558, 2013.
15. Mehul A. Raval and Chirag P. Patel, "Parametric Optimization of Magnetic Abrasive Water Jet Machining Of AISI 52100 Steel using Grey Relational Analysis", International Journal of Engineering Research and Applications, Vol. 3, Issue 4 , pp. 527-530, May-Jun 2013,.
16. P. Narender Singh, K. Raghukandan & B.C. Pai, "Optimization by Grey relational analysis of EDM parameters on machining Al–10%SiC composites", Journal of Materials Processing Technology 155–156, pp. 1658–1661, 2004.
17. Pankaj Sharma, Kamaljeet Bhambri, "Multi-Response Optimization By Experimental Investigation of Machining Parameters In CNC Turning By Taguchi Based Grey Relational Analysis", International Journal of Engineering Research and Applications, Vol. 2, Issue 5, pp.1594-1602, September- October 2012,.

18. Raghuraman S, Thiruppathi K, Panneerselvam T & Santosh S, "Optimization Of EDM Parameters Using Taguchi Method and Grey Relational Analysis for Mild Steel IS 2026", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 7, pp. 3095-3104, July 2013.
19. Reddy Sreenivasulu and Dr. Ch. Srinivasa Rao, "Application of Gray Relational Analysis for Surface Roughness and Roundness Error in Drilling of Al 6061 Alloy", International Journal of Lean Thinking Volume 3, Issue 2, pp. 67-78, December 2012.
20. S V Subrahmanyam and M. M. M. Sarcar, "Evaluation of Optimal Parameters for machining with wire cut EDM Using Grey-Taguchi Method", International Journal of Scientific and Research Publications, Volume 3, Issue 3, pp. 1-9, March 2013.
21. Semra BIRGUN, Cengiz GUNGOR, "A Multi-Criteria Call Center Site Selection by Hierarchy Grey Relational Analysis", Journal of Aeronautics and Space Technologies, Volume 7 Number 1, pp.45-52, January 2014.
22. Shunmugesh K, Panneerselvam. K and Jospaul Thomas, "Optimising Drilling Parameters Of GFRP By Using Grey Relational Analysis", International Journal of Research in Engineering and Technology, Volume: 03 Issue: 06, pp. 302- 305, Jun-2014.
23. T Muthuramalingam and B. Mohan, "Taguchi – grey relation based multi response optimization of electrical process parameters in electrical discharge machine", Indian Journal of Engineering & Material Science, Vol. 20, pp. 471-475, December 2013.
24. T V K Gupta, J Ramkumar, Puneet Tandon and N S Vyas, "Application Of Grey Relational Analysis for Geometrical Characteristics in Abrasive Water Jet Milled Channels", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12, IIT Guwahati, Assam, India, pp. 393 1-6, 2014.
25. V. Chittaranjan Das, N. V. V. S. Sudheer, "Optimization of Multiple Performance Characteristics of the Electrical Discharge Machining Process on Metal Matrix Composite (Al/5%Ticp) using Grey Relational Analysis", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12, IIT, pp. 531 1-6, 2014.