CASE STUDIES ON PRODUCTIVITY IMPROVEMENT AND SUPPLIER SELECTION

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By

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Certificate of Approval

This is to certify that the thesis entitled **CASE STUDIES ON PRODUCTIVITY IMPROVEMENT AND SUPPLIER SELECTION** submitted by ***Sri Harekrushna Dalai*** has been carried out under my supervision in partial fulfillment of the requirements for the Degree of ***Bachelor of Technology (B. Tech.)*** in ***Mechanical Engineering*** at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma. *However, experimental part reported here has been jointly conducted by Sri Harekrushna Dalai and Sri Durga Madhaba Padhy.*

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Abstract

Two case studies have been reported (i) improvement of productivity in Electrical Discharge Machining (EDM) and (ii) Multi-Criteria Decision Making (MCDM) approach for supplier selection.

Case study (i) highlights EDM of stainless steel in which best process environment (optimal) has been determined to satisfy productivity and quality requirements simultaneously. Material Removal Rate (MRR) during the process has been considered as productivity estimate with the aim to maximize it. Where as surface roughness i.e. (R_a value) of the machined surface has been chosen as surface quality estimate with the requirement to minimize it. These two contradicting requirements have been simultaneously satisfied by selecting an optimal process environment (optimal parameter setting). Desirability Function (DF) approach coupled with Taguchi method has been used to solve the problem.

In case study (ii), usefulness of grey based MCDM approach method has been highlighted to solve multi-criteria decision making problem of supplier selection. The method has been found efficient to aggregate multiple attribute values into an equivalent single quality index (overall grey relation grade) which facilitates ranking/benchmarking as well as selection of the appropriate alternative supplier.

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1. A CASE STUDY ON PRODUCTIVITY IMPROVEMENT

Quality and productivity are two important aspects have become great concerns in today's competitive global market. Every manufacturing/ production unit mainly focuses on these areas in relation to the process as well as product developed. Achieving high quality necessarily requires higher degree of skill, sophisticated machine/ tools, advanced technology, precise control, immense attention-inspection and considerable time. Improvement of quality results reduction in productivity and vice versa. Thus, optimality must be maintained between quality as well as productivity.

Product quality is described by some attributes; called quality indices. These can be treated as process response(s). Process response(s) can be represented as a function of process control parameters. Now, in the machine/ setup, a number of discrete points are available in the parameter domain in which the said factor(s)/ parameter(s) can be adjusted. A particular combination of factors setting is called a process environment. Depending on the availability of factors setting in the equipment, various factorial combinations are possible. Maximum number of factorial combination can be estimated by full factorial design of experiment depending on the total number of factors and their levels of variation. It is obvious that if number of factors and their levels increase, the total experimental run number in full factorial design also increases exponentially. As process responses (here, product quality indices) are likely to be influenced by the process control parameters; different parametric combination would likely to produce product quality different from each other. Moreover, there may be some parameter settings at which the product quality may become very unsatisfactory; the product may not be developed as well. The situation invites trial and error experimentation to select an appropriate parametric combination (process environment) in order to yield satisfactory quality product.

Quality of a process/ product is basically a cumulative performance index. The product quality can be described by multiple quality characteristics. These characteristics may be conflicting in nature from one another, depending on the requirement. There exist three types of quality requirements: Lower-the-Better (LB), Higher-the-Better (HB) and Nominal-the-Best (NB). A product is said to be conforming high quality, when all quality parameters are at desired level of satisfaction simultaneously.

In this context, it is indeed necessary to define an equivalent single quality index (representative of multi-quality features); based on which overall product quality can be assessed and the best one can be selected. The corresponding process environment is then said to be the most favorable process environment (optimal setting). For a mass production, this setting may be employed to avoid quality loss.

The entire study has been based on a case study in EDM. The goal is to search the best process environment (optimal parameters setting) to produce desired productivity as well as surface quality of the EDM product. The entire work has been based on the assumptions highlighted below.

1. Result of optimization/ prediction is valid only in the selected experimental domain.
2. There is no interaction effect of process control parameters.
3. Productivity has been interpreted in terms of MRR (Material Removal Rate) of the process and product quality has been described by the surface texture of the EDM machined surface.

1.1 Basics of Electric Discharge Machining (EDM)

Electric Discharge Machining (EDM) provides an effective manufacturing technique that enables the production of parts made of special materials with complicated geometry which is difficult to produce by conventional machining processes. Controlling the process parameters to achieve the required dimensional accuracy and finish placed this machining operation in a prominent position. From that reason, electric discharge machining has found broad applications in industry. The absorbing interest for electric discharge machines has resulted great improvements in EDM technology. Nowadays, sophisticated electric discharge machines are available for most of machine shop applications.

Basically Electric Discharge Machining (EDM) is a process for eroding and removing material by transient action of electric sparks on electrically conductive materials. This process is achieved by applying consecutive spark discharges between charged work piece and electrode immersed in a dielectric liquid and separated by a small gap. Usually, localized breakdown of the dielectric liquid occurs where the local electrical field is highest. Each spark melts and even evaporates a small amount of material from both electrode and work piece. Part of this material is removed by the dielectric fluid and the remaining part resolidifies rapidly on the surfaces of the electrodes. The net result is that each discharge leaves a small crater on both work piece and electrode. Application of consecutive pulses with high frequencies together with the forward movement of the tool electrode towards the work piece, results with a form of a complementary shape of the electrode on the work piece.

The material removal rate, electrode wear, surface finish, dimensional accuracy, surface hardness and texture and cracking depend on the size and morphology of the craters formed. The applied current, voltage and pulse duration, thermal conductivity, electrical resistivity, specific heat, melting temperature of the electrode and work piece, size and composition of the debris in dielectric liquid can be considered as the main physical parameters effecting to the process. Among them, applied current, voltage and pulse duration are the parameters which can be controlled easily.

Every EDM machine has the following basic elements as shown in Figure 1.

(i) Spark generator

(ii) Servo system

(iii) Dielectric liquid

(iv) Mechanical structure

1.1.1 Spark Generator

The required energy is in the form of pulses usually in rectangular form. Recent studies have been shown that application of pulses in the form of trapezoids resulted with a marked improvement in cutting efficiency. The optimum pulse form is not exactly a trapezoid, but similar.

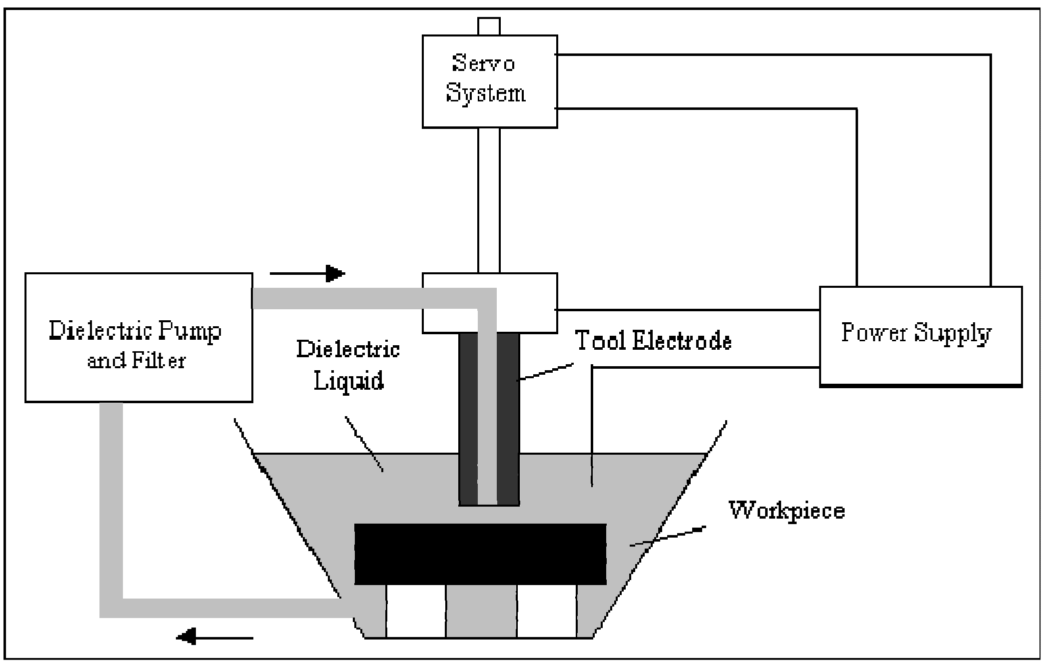

Figure 1: Basic Elements of an EDM system

Electrical energy in the form of shot duration impulses with a desired shape should be supplied to the machining gap. For this purpose, spark generators are used as the source of electrical pulses in EDM. The generators can be distinguished according to the way in which the voltage is transformed and the pulse is controlled. The discharge may be produced in a controlled manner by natural ignition and relaxation, or by means of a controllable semiconductor switching elements. Nowadays, sophisticated computer aided spark generators are in use as a result of fast development in electronics industry. These types of generators give us a better manner in controlling physical parameters.

1.1.2 Servo System

Both electrode and work piece are eroded during the process, after a certain time dimensions of the electrodes will be changed considerably. The result is increase in inter-electrode gap. This will increase the voltage required for sparking. This problem can be solved by increasing the pulse voltage or decreasing the gap distance. The former is not feasible since most of the electrical energy is used for overcoming breaking strength and producing plasma in dielectric liquid rather than machining, in addition to that, the required voltage can increase to the levels that spark generator can not supply, therefore; the inter-electrode gap should be maintained constant during the process. This can be achieved by a servo system which maintains a movement of the electrode towards the work piece at such a speed that the working gap, and hence, the sparking voltage remains unaltered.

1.1.3 Dielectric Circuit

High cooling rates during resolidification process changes the chemical composition of the both electrodes and dielectric liquid machining particles called debris are formed. Formation of such particles effects on machining performance, therefore, dielectric liquid should be circulated to prevent contamination in working gap. This circulation is done by a dielectric circuit which is composed of a pump, filter, tank and gages.

1.1.4 Mechanical Structure

EDM machines have similar construction with conventional drilling and milling machine frames with vertical tool feeding and horizontal worktable movements. Since there is not a real contact between electrodes, that is why, it is considered that, the frame elements not taking much force as in conventional machining so simpler design is possible. This consideration needs a little bit attention, because gas bubbles collapses at the end of discharge and cause high frontal shock waves, therefore; the frame should be strong enough to keep its dimensional stability.

1.2 Operation Types of Electric Discharge Machines

Electric discharge machining enables the machining operation in several ways. Some of these operations are similar to conventional operations such as milling and die sinking others have its own characteristic. Different classifications are possible and also it should be keep in mind that, current developments in its technology adds different types of operations. But a simple and general classification can done by considering famous applications such as ,

i. Die Sinking EDM
ii. Wire EDM
iii. EDM Milling

iv. Wire Electric Discharge Grinding

1.2.1 Die Sinking EDM

The tool electrode has the complementary form of finished work piece and literally sinks into the rough material. Complex shapes are possible, but needs more machining time but dimensional accuracy is high when compared with wire EDM.

1.2.2 Wire EDM

The electrode is a wire that cuts through the work piece and renewed constantly to avoid rapture. The wire is cheaper than the complex electrodes used in die sinking electric discharge machining. Less material should be removed, which leads short machining time and electrode wear. But, the operation is possible only for ruled surfaces and the wire may bend during machining, cause substantial shape errors.

1.2.3 EDM Milling

Usually a rotating cylindrical electrode follows a path through the work piece, yielding the desired final geometry. It is advantageous when large holes or complex geometries are required.

1.2.4 Wire Electric Discharge Grinding

In the case where small holes are needed, a relatively large electrode may be reversibly eroded against a sacrificial work piece. In this case the polarity between the electrode and the work piece is reversed, so that the material removal predominantly takes place on the electrode.

1.3 Material Removal Mechanism

A perfect general theory for EDM can not constructed since each machining condition has its own particular aspects and involves numerous phenomena, i.e., heat conduction and radiation, phase changes, electrical forces, bubble formation and collapse, rapid solidification. In addition, theories of how sparks eroded the work piece and electrode have never been completely supported by the experimental evidence since its very difficult to observe the process scientifically. Thus, most of the published studies are mostly concerned with simplified models of different events of EDM. Development of high-speed computers and comprehensive numerical techniques enabled scientist to involve more parameters in their models than before, but still many aspects of the process can not be explained in detail.

Melting, vaporization and even ionization of the electrode materials occurs at the point where the discharge takes place. Flushing action of the dielectric liquid pulls away whole vaporized and some of melted material. The result is formation of a crater on both electrode surfaces. Theoretical models based on one spark can be extended to the machining with same side effects.[49]Generally the physics of the sparks can be investigated in three phases.

(i) Breakdown (Ignition) phase

(ii) Discharge phase

(iii) Erosion(Crater Formation) phase

Breakdown phase takes a relatively small percent of the total spark time. It varies from few microseconds to several hundreds depending on discharge conditions. Erosion is only observed only in later stages of spark, partly after the discharge has eased.

1.3.1 Breakdown (Ignition) Phase

Breakdown in liquids is the initial condition for plasma formation. There are several proposed theories which try to explain the breakdown phase, but consistent results with experiments can not be obtained. A simplified expression can be given as below.

The charge induced on the two electrodes by the power supply creates a strong electric field. This field is strongest where the electrodes are closest to each other. This is the point where discharge takes place. Molecules and ions of the dielectric fluid are polarized and oriented between these two peaks and forming a narrow, low-resistance channel. When the dielectric strength of the liquid in the gap exceeded due to the electric field, breakdown occurs. Electrons emitted from both electrodes and the stray electrons and ions in the dielectric liquid are accelerated. When accelerated electrons and ions reached to the electrons a current flow starts which is the beginning of the discharge phase.

1.3.2 Discharge Phase

Discharge phase of the process is similar to many gas discharges in that a constant current is passed through the plasma. But, shorter pulse duration and use of dense dielectric liquid, changes macroscopic plasma features. These changes result with higher erosion on electrodes when compared with gas discharges.

Charged particles collide with the atoms in the dielectric liquid and then hits to the surfaces of the electrodes. This collision process transforms their kinetic energies in the form of heat and rapidly increases the pressure in the plasma channel due to evaporation of the dielectric liquid. The amount of energy transformed in the form of heat is very high. Heat fluxes up to can be attained. Thus, local temperature of the electrodes can be raised around which is much more than boiling points of most metals. Pressure increase in the plasma channel force to expand its boundaries and decrease the current density across inter-electrode gap. Most of the time, the pressure increase is as high as to prevent evaporation of the superheated material on the surfaces of the electrodes. High-speed photographs from various sources show the spark to be barrel shape with its radius near the cathode to be much smaller than that near the anode. Thus, the spark is neither a sphere nor a cylinder.

1.3.3 Erosion (Crater Formation) Phase

Removal of pulse voltage results with a rapid decrease in plasma pressure. Superheated electrode material is in a meta-stable equilibrium for a short while.

This condition may also start just before at the end of the applied pulse. Experimental observations show formation of a bubble or bubbles around this heated section. After formation, the bubble or bubbles grow very fast and explode violently. Then, some of evaporated metal cools down very rapidly and flush away by the dielectric liquid and leaving a small crater on the surface. The remaining part of the evaporated metal, which do not find time to cool down; splashes to the surface of the crater.

Applying consecutive spark discharges and driving one electrode towards the other will erode the work piece gradually in a form complementary to that of the tool electrode

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1.4 Characteristic of Electrical Discharge Machined Surfaces

The general appearance of the crater formed after sparking is almost the sane for the different materials except for their sizes and depth. Sparking leaves a well de fined ridge which could have come only through the deposition of the molten material from the crater. This is due to machined surface which projects out from the original surface indicating redeposition of the material after erosion. Thus with the formation of the crater, material is splashed to the sides forming the ridge. Thermal properties of machined material and dielectric fluid and energy condition of the spark can be considered as the main parameters which determine the size of the crater.

A spark eroded surface is matt surface with random distribution of overlapping craters. The violent nature of the process leads a unique structure on the surfaces of the machined parts. This nature compelled interest from several researchers.

1.4.1 Thermally Influenced Layers

Experimental observations revealed mainly two thermally effected, distinct layers of materials known as the white layer and the heat effected zone.

The white layer includes some particles resolidified during the process and can not be flushed away by dielectric fluid. The layer is densely infiltrated with carbon that has a totally different structure from that of the original work piece. Carbon enrichment occurs when the hydrocarbon dielectric breaks down and penetrates in to the hot work piece surface.

Heat effected zone lies below the white layer structure. It is partly affected by carbon drawn by the dielectric. It retains some structural properties of the original material. Unaffected material is lies just below to this layer.

1.4.2 Stress Distribution

The violent nature of the process leads a unique structure on the surfaces of the machined parts. High cooling rates can be attained on superheated material due to quenching effect of the dielectric. The high thermal contraction rates produce high stresses and cause severe slip, twining and cleavage on or near the crater. Another source of stresses can be considered as the shock waves produced by the explosion of bubble at the end of the discharge. Thus, the resolidified layer is highly stressed. These stresses change the material properties drastically and produce a network of micro cracks around the crater even in ductile materials.

1.5 Literature Review

Marafona and Wykes (2000) reported an investigation into the optimization of the process which used the effect of carbon which was migrated from the dielectric to tungsten–copper electrodes. This work led to the development of a two-stage EDM machining process where different EDM settings were used for the two stages of the process giving a significantly improved material removal rate for a given tool wear ratio.

Tzeng and Chen (2007) described the application of the fuzzy logic analysis coupled with Taguchi methods to optimize the precision and accuracy of the high-speed electrical discharge machining (EDM) process. A fuzzy logic system was used to investigate relationships between the machining precision and accuracy for determining the efficiency of each parameter design of the Taguchi dynamic experiments. From the fuzzy inference process, the optimal process condition for the high-speed EDM process was determined. In addition, the analysis of variance (ANOVA) was also employed to identify factor B (pulse time), C (duty cycle), and D (peak value of discharge current) as the most important parameters, which account for about 81.5% of the variance. The factors E (powder concentration) and H (powder size) were found to have relatively weaker impacts on the process design of the high-speed EDM. Furthermore, a confirmation experiment of the optimal process showed that the targeted multiple performance characteristics were significantly improved to achieve more desirable levels.

Kumar and Singh (2007) compared the performance of copper -chromium alloy with copper and brass as EDM electrode materials for machining OHNS die steel using kerosene and distilled water as dielectric media. Keeping all other machining parameters same, the hardened work material was machined with the three electrodes at different values of discharge current. It was found that copper -chromium alloy shows better results than copper and brass in terms of material removal rate, dimensional accuracy (lateral overcut) and surface finish in both the dielectric media. Tool wear rate of this alloy was lower which results in better accuracy and trueness of the machined profiles because the mirror image of the tool electrode was reproduced in the work piece. Regarding the use of distilled water as a dielectric medium, though material removal rate was low and tool wear rate was high, but hardness and finish of the machined surface showed a marked improvement.

Saha (2008) reported parametric analysis of the dry EDM process on experimental results. Experiments based on the Central Composite Design (CCD) were conducted to develop empirical models of the process behavior.

Process optimization was performed using Genetic Algorithms (GA). Surface roughness and MRR were optimized.

Rao et al. (2008) optimized the metal removal rate of die sinking electric discharge machining (EDM) by considering the simultaneous affect of various input parameters. The experiments were carried out on Ti6Al4V, HE15, 15CDV6 and M-250. Experiments were conducted by varying the peak current and voltage and the corresponding values of metal removal rate (MRR) were measured. Multi-perceptron neural network models were developed using Neuro solutions package. Genetic algorithm concept was used to optimize the weighting factors of the network. It was observed that the developed model was within the limits of the agreeable error when experimental and network model results were compared for all performance measures considered. It was further observed that the maximum error when the network was optimized by genetic algorithm reduced considerably. Sensitivity analysis was carried out to find the relative influence of factors on the performance measures. It was observed that type of material is having more influence on the performance measures.

Pradhan and Biswas (2008) investigated the relationships and parametric interactions between the three controllable variables on the material removal rate (MRR) using RSM method. Experiments were conducted on AISI D2 tool steel with copper electrode and three process variables (factors) as discharge current, pulse duration, and pulse off time. To study the proposed second-order polynomial mode for MRR, the authors used the central composite experimental design to estimation the model coefficients of the three factors, which are believed to influence the MRR in EDM process. The response was modeled using a response surface model based on experimental results. The significant coefficients were obtained by performing analysis of variance (ANOVA) at 5% level of significance. It was found that discharge current, pulse duration, and pulse off time significant effect on the MRR.

Tebni et al. (2009) proposed a simple and easily understandable model for predicting the relative importance of different factors (composition of the steel and Electro Discharge Machining processing conditions) in order to obtain efficient pieces. A detailed application on the tool steel machined by EDM was given in the study. This model was based on thermal, metallurgical, mechanical, and *in situ* test conditions. It gave detailed information on the effects of electrochemical parameters on the surface integrity and sub-surface damage of the material (Heat Affected Zone, HAZ), the level of residual stresses, and the surface texture. This approach was an efficient way to separate the responsibilities of the steel maker and machining process designer for increasing the reliability of the machined structures.

Popa et al. (2009) reported the importance of the EDM technology in the industry of machine building. It is mostly used in the machining of stamps and special processes in which the conventional technologies are inefficiently. It's known that only condition of machining with this method is that the material should be electro conductive. The main parameters that are followed during the process are the precision and the roughness of the surface. The collective tried to emphasize the importance variation of the roughness concerning some machining parameters. Some of the measurements were conducted at ETH Zurich using an electronic microscope.

Singh and Garg (2009) investigated the effects of various process parameters of WEDM like pulse on time (TON), pulse off time (TOFF), gap voltage (SV), peak current (IP), wire feed (WF) and wire tension (WT) to reveal their impact on material removal rate of hot die steel (H-11) using one variable at a time approach. The optimal set of process parameters was predicted to maximize the material removal rate.

Pradhan and Biswas (2009) used Response Surface Methodology (RSM) to investigate the effect of four controllable input variables namely: discharge current, pulse duration, pulse off time and applied voltage Surface Roughness (SR) of on Electrical Discharge Machined surface. To study the proposed second-order polynomial model for SR, a Central Composite Design (CCD) was used to estimation the model coefficients of the four input factors, which were alleged to influence the SR in Electrical Discharge Machining (EDM) process. Experiments were conducted on AISI D2 tool steel with copper electrode. The response was modeled using RSM on experimental data. The significant coefficients were obtained by performing Analysis of Variance (ANOVA) at 5% level of significance. It was found that discharge current, pulse duration, and pulse off time and few of their interactions had significant effect on the SR.

Iqbal and Khan (2010) established empirical relations regarding machining parameters and the responses in analyzing the machinability of the stainless steel. The machining factors used were voltage, rotational speed of electrode and feed rate over the responses MRR, EWR and Ra. Response surface methodology was used to investigate the relationships and parametric interactions between the three controllable variables on the MRR, EWR and Ra. Central composite experimental design was used to estimate the model coefficients of the three factors. The responses were modeled using a response surface model based on experimental results. The significant coefficients were obtained by performing Analysis Of Variance (ANOVA) at 95% level of significance. The variation in percentage errors for developed models was found within 5%. The developed models showed that voltage and rotary motion of electrode was the most significant machining parameters influencing MRR, EWR and Ra. These models could be used to get the desired responses within the experimental range.

1.6 Experimentation

The selected work piece material for this research work is UTS 304 grade stainless steel (density 8030 Kg/m^3). Experiments have been conducted on Electronica Electraplus PS 50ZNC die sinking machine. An electrolytic pure copper with a diameter of 30 mm has been used as a tool electrode (positive polarity) and work piece materials used were stainless steel rectangular plates of dimensions $100 \times 50\, mm$ and of thickness $4\, mm$. Commercial grade EDM oil (specific gravity 0.763 and freezing point 94^{0}C) has been used as dielectric fluid. Lateral flushing with a pressure of 0.3 Kgf/cm^2 has been used. Discharge current (I_P), pulse on time (T_{ON}), duty factor (τ) of the machine and discharge voltage (V) have been treated as controllable process factors. Table 1 reveals domain of experiments. Design of Experiment (DOE) has been selected as per Taguchi's L_9 orthogonal array (Table 2), in which interactive effect of process parameters have been neglected. Experimental data have been furnished in Table 3.

Table 1: Domain of Experiments

Factor(s)	Notation/ Units	Code	Levels of Factors		
			1	2	3
Discharge Current	I_P (A)	A	06	08	10
Pulse on Time	T_{ON} (µs)	B	300	400	500
Duty Factor	τ	C	8	10	12
Discharge Voltage	V (Volt)	D	40	45	50

Table 2: Design of Experiment (DOE)

Sl. No.	Design of Experiment (L_9 orthogonal array)			
	A	B	C	D
01	1	1	1	1
02	1	2	2	2
03	1	3	3	3
04	2	1	2	3
05	2	2	3	1
06	2	3	1	2
07	3	1	3	2
08	3	2	1	3
09	3	3	2	1

Table 3: Experimental Data

Sl. No.	Experimental Data	
	MRR (mm^3/min)	R_a (µm)
01	8.4682	8.66
02	8.7173	8.38
03	7.7210	8.42
04	13.4496	9.88
05	14.6949	10.72
06	11.7061	8.10
07	18.9290	11.22
08	15.4421	11.68
09	19.6762	9.02

1.7 Data Analysis

1.7.1 Desirability Function (DF) Approach

In this approach, individual responses are transformed to corresponding desirability values. Desirability value depends of acceptable tolerance range as well as target of the response. If the response reaches its target value, which is the most desired situation, its desirability is assigned as unity. If the value of the response falls beyond the prescribed tolerance rage, which is not desired, its desirability value is assumed as zero. Therefore, desirability value may vary with zero to unity.

In this section individual desirability values related to each bead geometry parameters have been calculated using the formula proposed by Derringer and Suich, (1980). For bead width, reinforcement, area of reinforcement and bead volume Lower-the-better (LB); and for depth of penetration, area of penetration and dilution percentage Higher-the-better (HB) criterion has been selected.

Individual desirability value using Lower-the-better (LB) criterion is shown in Figure 1. The value of $\hat{y}$ is expected to be the lower the better. When $\hat{y}$ is less than a particular criteria value, the desirability value d_i equals to 1; if $\hat{y}$ exceeds a particular criteria value, the desirability value equals to 0. So, d_i can vary within the range (0, 1). The desirability function of the Lower-the-better (LB) criterion can be written as below (equations 1 to 3). Here, $y_{\min}$ denotes the lower tolerance limit of $\hat{y}$, the $y_{\max}$ represents the upper tolerance limit of $\hat{y}$ and r represents the desirability function index, which is to be assigned previously according to the consideration of the optimization solver. If the corresponding response is expected to be closer to the target, the index can be set to the larger value, otherwise a smaller value.

If $\hat{y} \le y_{\min}$, $d_i = 1$ (1)

If $y_{\min} \le \hat{y} \le y_{\max}$, $d_i = \left(\dfrac{\hat{y} - y_{\max}}{y_{\min} - y_{\max}} \right)^r$ (2)

If $\hat{y} \ge y_{\max}$, $d_i = 0$ (3)

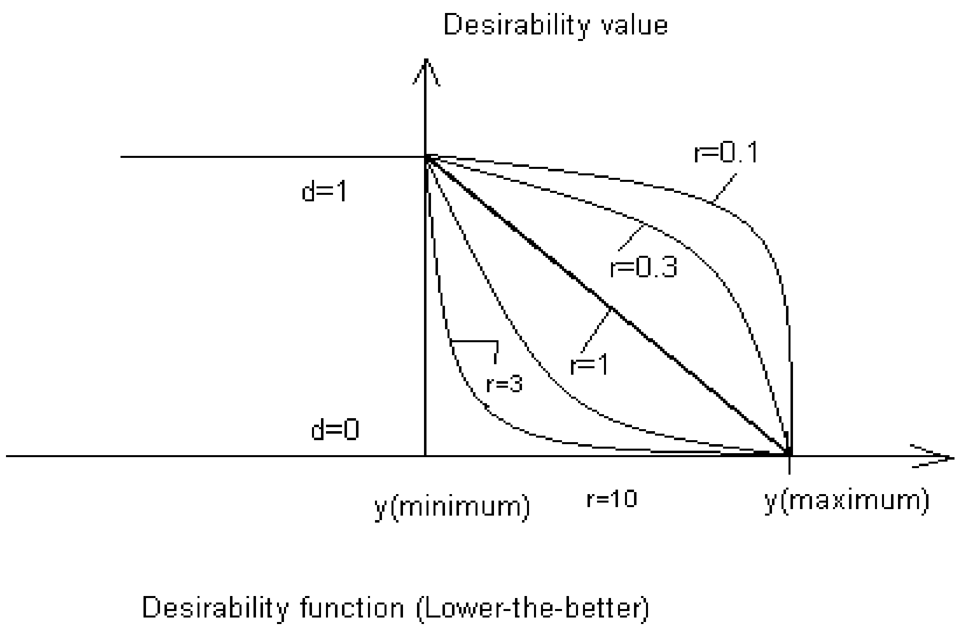

Figure 1: Desirability function (Lower-the-Better)

Individual desirability value using Higher-the-better (HB) criterion is shown in Figure 2. The value of $\hat{y}$ is expected to be the higher the better. When $\hat{y}$

exceeds a particular criteria value, according to the requirement, the desirability value d_i equals to 1; if $\hat{y}$ is less than a particular criteria value, i.e. less than the acceptable limit, the desirability value equals to 0. The desirability function of the Higher-the-better (HB) criterion can be written in the form as given in equations (4) to (6). Here, $y_{\min}$ denotes the lower tolerance limit of $\hat{y}$, the $y_{\max}$ represents the upper tolerance limit of $\hat{y}$ and r represents the desirability function index, which is to be assigned previously according to the consideration of the optimization solver. If the corresponding response is expected to be closer to the target, the index can be set to the larger value, otherwise a smaller value.

If $\hat{y} \le y_{\min}$, $d_i = 0$ (4)

If $y_{\min} \le \hat{y} \le y_{\max}$, $d_i = \left(\dfrac{\hat{y} - y_{\min}}{y_{\max} - y_{\min}} \right)^r$ (5)

If $\hat{y} \ge y_{\max}$, $d_i = 1$ (6)

The individual desirability values have been accumulated to calculate the overall desirability, using the following equation (7). Here D_O is the overall desirability value, d_i is the individual desirability value of ith quality characteristic and n is the total number of responses.

$$D_O = (d_1 d_2 ....d_n)^{\frac{1}{n}} \quad (7)$$

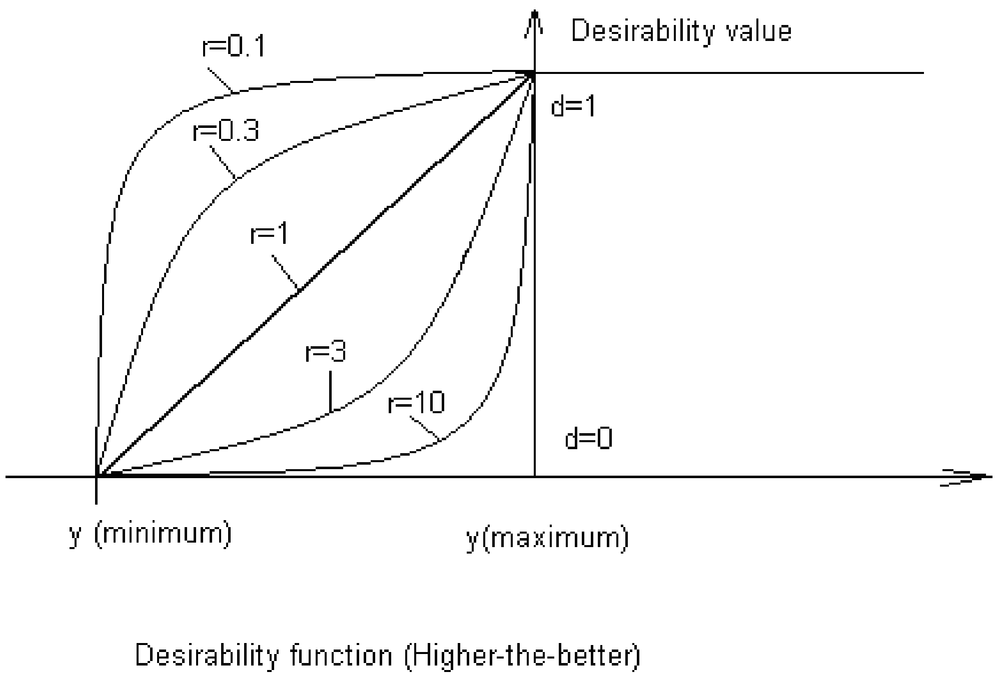

Figure 2: Desirability function (Higher-the-Better)

1.7.2Optimization Using DF Approach

Experimental data (Table 3) i.e. MRR and R_a (for each experiment) have been converted to corresponding desirability values. For MRR and R_a Higher-the-Better (HB) and Lower-the-Better (LB) criteria has been chosen respectively. For MRR, minimum limit has been selected- 7.72 mm^3/min and for R_a, maximum limit has been modified as 11.69 µm. This modification has been made to avoid difficulties in computing S/N ratio in Taguchi analysis. In this computation desirability function index has been assumed as unity. Individual desirability values have been aggregated to calculate overall desirability. Priority weight of each response has been assumed as 0.5. Table 4 represents individual desirability of responses, overall desirability value and corresponding S/N ratio. S/N ratio of overall desirability has been computed using HB criteria.

Table 4: Calculation of Desirability Values

Sl. No.	Individual Desirability Values of		Overall Desirability	Corresponding S/N Ratio
	MRR	R_a		
01	0.0626	0.8440	0.2298	-12.7730
02	0.0834	0.9220	0.2773	-11.1410
03	0.0001	0.9109	0.0087	-41.2096
04	0.4792	0.5042	0.4915	-6.1695
05	0.5834	0.2702	0.3970	-8.0242
06	0.3334	1.0000	0.5774	-4.7705
07	0.9375	0.1309	0.3503	-9.1112
08	0.6459	0.0028	0.0424	-27.4527
09	1.0000	0.7437	0.8624	-1.2858

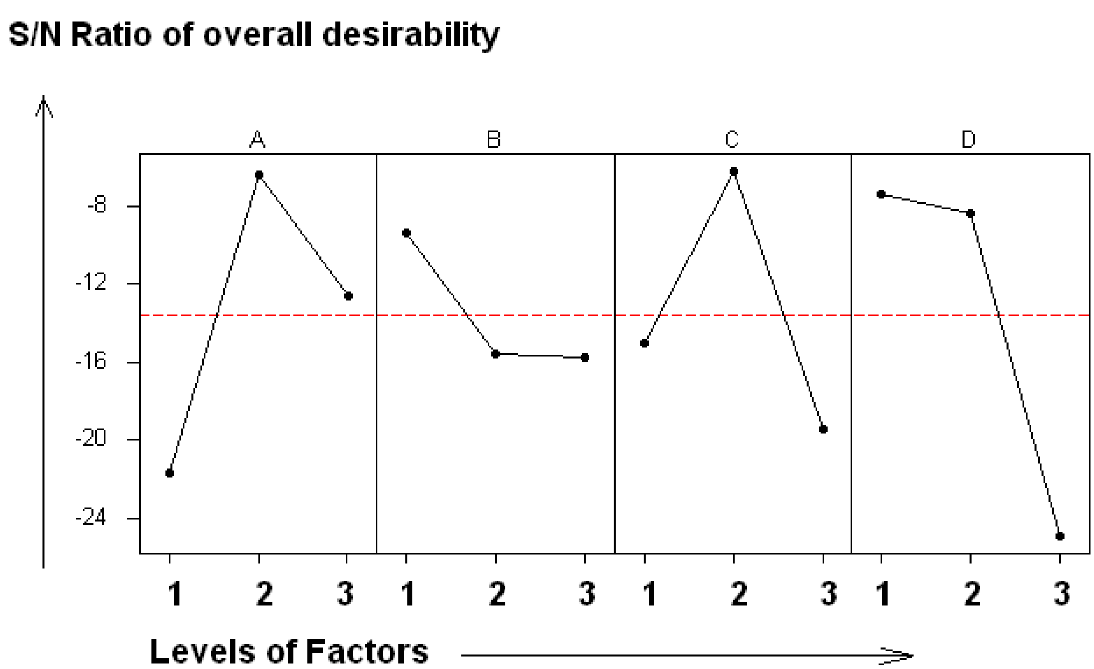

Figure 3: S/N Ratio plot of overall desirability (Prediction of Optimal Setting)

Table 5: Response Table for Signal to Noise Ratios

Level	A	B	C	D
1	-21.7079	-9.3512	-14.9987	-7.3610
2	-6.3214	-15.5393	-6.1988	-8.3409
3	-12.6166	-15.7553	-19.4483	-24.9439
Delta	15.3865	6.4041	13.2495	17.5829
Rank	2	4	3	1

Figure 3 represents S/N ratio plot of overall desirability; S/N ratio has been calculated using Higher-the-Better (HB) criteria. Optimal setting has been evaluated from this plot. Predicted optimal combination becomes: A2 B1 C2 D1. Optimal result has been verified through confirmatory test. According to Taguchi' prediction predicted value of S/N ratio for overall desirability becomes 11.4134 (higher than all entries in Table 4) whereas in confirmatory experiment it is obtained a value of 13.4792. So quality has improved using the optimal setting. Mean response table for S/N Ratio of overall desirability has been shown in Table 5; which indicates that discharge current and discharge voltage are most important factors influencing overall desirability. Next important process factor seems to be the duty factor which influences both pulse on and pulse off time.

1.8 Conclusion

- An efficient methodology has been proposed in the study for solving multi-objective optimization problem in order to estimate an optimal process environment (consisting of optimal parametric combination) to achieve desired productivity as well as product quality in EDM.

- Adaptation of Taguchi's Orthogonal Array design of experiment provides a limited number of well balanced experimental runs resulting saving in experimental cost as well as experimentation time.
- Desirability function approach has been found fruitful which can take care of the constraints imposed by the fixation of target/tolerance limit of the individual responses.
- Desirability function approach has been found efficient to convert a multi-objective optimization problem to a single objective optimization problem.
- The said approach can be recommended for multi-response optimization and off-line quality control.

2. A CASE STUDY ON SUPPLIER SELECTION

One of the critical challenges faced by purchasing managers is the selection of strategic partners that will furnish them with the necessary products, components, and materials in a timely and effective manner to help maintain a competitive advantage. Buyer-supplier relationships based solely on price are no longer acceptable for suppliers of critical materials or for organizations that wish to practice the latest innovations in supply chain management. Recent emphasis has also been on other important strategic and operational factors such as quality, delivery, and flexibility. Strategic relationships also play a vital role for the long-term well-being of a supply chain. Thus, to aid in the supplier selection process, a dynamic strategic decision model is introduced that allows inputs from a variety of managerial decision making levels (strategic to operational) while considering the dynamic competitive environment.

Strategic supplier selection processes require consideration of a number of factors beyond those used in operational decisions. With increased emphasis on manufacturing and organizational philosophies such as JIT and total quality management (TQM), and the growing importance of supply chain management concepts, the need for considering supplier relationships from a strategic perspective has become even more apparent.

While supplier selection is one of the most fundamental and important decisions that a buyer makes, it may also be one of the most difficult and critical. This is mainly due to the increased levels of complexity involved in considering various supplier performance and relationship factors. In order to perform a comprehensive evaluation of suppliers, a number of criteria can be utilized. For instance, a supplier could be evaluated and screened technically based on a number of factors that include:

- Emphasis on quality at the source
- Design competency
- Process capability
- Declining nonconformities
- Declining work-in-process (WIP), lead time, space, flow distance
- Operators cross-training, doing preventive maintenance
- Operators' ability to present statistical process control (SPC) and quick setup
- Operators able to chart problems and process issues
- Hours of operator training in total quality control (TQC)/JIT
- Concurrent design
- Equipment/labor flexibility
- Dedicated capacity
- Production and process innovation

2.1 Prior State of Art

In the competitive global business environment of the 21st century, enterprises must respond effectively to customer demands. The selection of suppliers and the evaluation of their service performance are becoming major challenges that face manufacturing managers. Assessing a group of suppliers and selecting one or more of them is a very complex task because various criteria must be considered in this decision making process. Supplier selection problem in a supply chain system is a group decision according to multiple criteria [Chen et al. (2006)].

Literature depicts several supplier selection methods available. Some authors proposed linear weighting models in which suppliers were rated on several criteria and in which these ratings are combined into a single score such as the categorical model. The categorical model was a simple method, but it was also the quickest, easiest, and least costly to implement [Petrone (2000)]. The weighted point model was also easy to implement, flexible, and fairly efficient in the optimization of supplier selection decisions. It was more costly than the categorical method, but tends to be more objective, even though it relied on the buyer's assessment of the supplier performance. Total cost approaches attempted to quantify all costs related to the selection of a vendor in monetary units. This approach includes cost ratio [Timmernam (1986)] and Total Cost of Ownership (TCO) [Ellram (1990)]. According to Chen-Tung *et al.* (2006), the fuzzy logic approach measured for supplier performance evaluation. This approach could help Decision Making (DM) to find out the appropriate ordering from each supplier.

The Multiple Attribute Utility Theory (MAUT) method had the advantage that it enabled purchasing professionals to formulate viable sourcing strategies and was capable of handling multiple conflicting attributes. However, this method was only used for international supplier selection, where the environment was more complicated and risky [Bross and Zhao (2004)]. Another useful method is the Analytical Hierarchical Process (AHP), a decision-making method developed for prioritizing alternatives when multiple criteria must be considered and allows the decision maker to structure complex problems in the form of a hierarchy, or a set of integrated levels [Saaty (1980)]. It allows decision makers to rank suppliers based on the relative importance of the criteria and the suitability of the suppliers. Chan (2003) indicated the calculation of preference between attributes was still based on the subjective judgment from senior management level and use of AHP was quite cumbersome and clearly not straightforward for most users. Many supplier evaluation methods in the literature often involved the simultaneous consideration of various important supplier performance attributes and give weight to each attribute. Lamberson et al. (1976), Monczka and Trecha (1976) adopted the linear weighting techniques. Timmerman et al. (1976) and Gregory (1986) linked the linear weighting technique to the matrix representation of data. Other methods include linear programming models [Pan (1989), Turner (1988)], clustering methods [Hinkle et al. (1969)] and dimensional analysis method [Wills (1993)]. Although each of these approaches has its own advantages in particular circumstances, some aspects of these techniques and models require more effort to be spent in deriving the attributes of the suppliers and the weights of these attributes. Almeida (2007) gave a multi-criteria decision model for outsourcing contracts selection based on a utility function. The utility function includes the impacts on cost, delivery time, and dependability.

In the present paper a Multi-Criteria Decision Making (MCDM) approach has been applied for quality evaluation and performance appraisal in vendor selection. Vendor selection is a Multi-Criteria Decision Making (MCDM) problem influenced by multiple performance attributes. These criteria attributes are both qualitative as well as quantitative. Quantitative criteria values are easy to handle where as qualitative criteria are based on expert opinion converted based on a suitable conversion scale. When both qualitative and quantitative simultaneously come into consideration; a common trend is to convert quantitative criteria values into qualitative performance indices. This conversion is based on human judgment; such result of vendor selection may not be accurate always because the method doesn't explore real data. To avoid this limitation, present study highlights application of grey relation theory for utilizing quantitative real performance estimates. Detail methodology of aforesaid MCDM technique has been illustrated in this paper through a case study.

2.2 Grey Relation Theory

The grey relational analysis consists of the following steps, [Wu (2007)].

(*a) Generation of reference data series* x_0 *.*

$$x_0 = \left(d_{01}, d_{02}, \ldots\ldots\ldots\ldots, d_{0m}\right)$$

Here m is the number of respondents. In general, the x_0 reference data series consists of m values representing the most favoured responses.

(b) Generation of comparison data series x_i *.*

$$x_i = \left(d_{i1}, d_{i2}, \ldots\ldots\ldots\ldots, d_{im}\right)$$

Here $i = 1, \ldots\ldots\ldots\ldots, k$. k is the number of scale items. So, there will be k comparison data series and each comparison data series contains m values.

(c) Compute the difference data series Δ_i *.*

$$\Delta_i = \left(\left|d_{01} - d_{i1}\right|, \left|d_{02} - d_{i2}\right|, \ldots\ldots\ldots\ldots\ldots\ldots, \left|d_{0m} - d_{im}\right|\right)$$

(d) Find the global maximum value $\Delta_{\max}$ *and minimum value* $\Delta_{\min}$ *in the difference data series.*

$\Delta_{\max} = \overset{\max}{\forall i}\left(\max \Delta_i\right)$ and $\Delta_{\min} = \overset{\min}{\forall i}\left(\min \Delta_i\right)$

(e) Transformation of individual data point in each difference data series to grey relational coefficient.

Let $\gamma_i(j)$ represents the grey relational coefficient of the j_{th} data point in the i_{th} difference data series, then

$$\gamma_i(j) = \frac{\Delta_{\min} + \varsigma.\Delta_{\max}}{\Delta_i(j) + \varsigma.\Delta_{\max}}$$

Here $\gamma_i(j)$ is the j_{th} value in Δ_i difference data series. ς is called distinguishing coefficient (= 0.5).

(f) Computation of grey relational grade for each difference data series.

Let Γ_i represent the grey relational grade for the i_{th} scale item and it is assumed that data points in the series are of the same weights, then

$$\Gamma_i = \frac{1}{m}\sum_{n=1}^{m} \gamma_i(n)$$

The magnitude of Γ_i reflects the overall degree of standardized deviance of the i_{th} original data series from the reference data series. In general, a scale item with a high value of Γ indicates that the respondents, as a whole, have a high degree of favoured consensus on the particular item.

(g) Sorting of Γ values into either descending or ascending order to facilitate the managerial interpretation of the results.

2.3 Example

As a case study, the supplier selection problem in procuring silencer of vehicle in an automotive industry in eastern part of India has been explored. Table 6 represents multiple attributes to be taken under consideration while selecting an appropriate supplier. The industry has its own requirements which have been assumed as target. The targeted values of each criterion correspond to the elements of reference data series for comparison. The target is to minimize cost, achieve high insertion loss and less volume, less weight, less number of components associated with the silencer. These data have been normalized. The normalized and reference data series have been furnished in Table 7. Table 8 exhibits loss estimates; the difference between reference data series as well as normalized data series. Based on loss estimates grey relational coefficients for all the attributes have been computed for each of the alternative suppliers (Table 9). Finally overall grey relational grade has been obtained by putting equal priority weight to all the attributes. Thus supplier ranking and selection of the best supplier (to whom order is to be given) have been made.

2.4 CONCLUSION

In the present study, application feasibility of grey based MCDM approach method has been highlighted to solve multi-criteria decision making problems through a case study of supplier selection. The study demonstrates the effectiveness of the said MCDM techniques in solving such a supplier selection problem. The method has been found efficient to aggregate multiple attributes into an equivalent single quality index which facilitates ranking/benchmarking as well as selection of the appropriate alternative.

Table 6: Attributes for Silencer of a Vehicle: Supplier Selection Criteria

Sl. No.	Attributes C_i	Alternative Vendors				
		A	B	C	D	E
1	Cost (Rs.)	1800	400	1000	1200	1400
2	Insertion Loss (dB)	12	7	9	8	10
3	Volume (CC)	44000	9000	30000	37000	40000
4	Weight (Kg)	20	5	10	12	16
5	No. of Components	10	6	7	8	9

Table 7: Grey Relational Generation (Normalized, Reference Data Series)

Suppliers	Normalized Data Series				
	Attributes				
	C1	C2	C3	C4	C5
A	0.2222	1.0000	0.2045	0.2500	0.6000
B	1.0000	0.5833	1.0000	1.0000	1.0000
C	0.4000	0.7500	0.3000	0.5000	0.8571
D	0.3333	0.6667	0.2432	0.4167	0.7500
E	0.2857	0.8333	0.2250	0.3125	0.6667
Reference Data Series					
X_0	400	12	9000	5	6

Table 8: Loss Estimates

Suppliers	Attributes				
	C1	C2	C3	C4	C5
A	0.7778	0.0000	0.7955	0.7500	0.4000
B	0.0000	0.4167	0.0000	0.0000	0.0000
C	0.6000	0.2500	0.7000	0.5000	0.1429
D	0.6667	0.3333	0.7568	0.5833	0.2500
E	0.7143	0.1667	0.7750	0.6875	0.3333
X_0	0.0000	0.0000	0.0000	0.0000	0.0000

Table 9: Grey Relational Coefficients and Overall Grey Relational Grade

Suppliers	Attributes					Grey Relation grade	Ranking
	C1	C2	C3	C4	C5		
A	0.3333	1.0000	0.3333	0.3333	0.3333	0.4667	2
B#	1.0000	0.3334	1.0000	1.0000	1.0000	0.8667	1
C	0.3933	0.4546	0.3623	0.4286	0.5833	0.4444	3
D	0.3684	0.3846	0.3445	0.3913	0.4444	0.3867	5
E	0.3525	0.5556	0.3392	0.3529	0.3750	0.3950	4

#Supplier B is selected

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