Application of Taguchi's Method of Experimental Design in Optimization of Building Paint Procurement Process

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Abstract

The present competitive construction market is focusing on producing quality building products using quality material at lower cost. In procurement process of various building materials, purchase managers or project managers are responsible for taking decisions over the varied aspects and functions in different projects. Procurement process is one, where decision maker has to make choice considering qualitative & quantitative aspects. Procurement of building paints for big projects, involves varied sources of supply with varying cost, quality and many other parameters. Usually, suppliers are located in the environs of the site though their prices could vary amongst themselves as well as the index for the quality and customer satisfaction. In building painting work, performance and quality is required with minimum reprocess work at lower purchase cost. To help accomplish this objective, Taguchi method (DOE) is suggested for optimization of procurement process parameters in painting work. Taguchi method is most viable and efficient technique for the purpose of product and process quality optimization. It also reduces the time required for experimental investigations and also number of experiments. For the analysis, questionnaires are prepared to decide key impact factor and data is gathered from field survey. The experimental results are based on data collected from experienced building contractors and painting experts. The prime focus is to find the optimal set of parameters for paint procurement process. For this analytical assessment of the problem, Minitab software is used. Finally considering various experimental parameters, optimal level of procurement is decided for building paint work.

Keywords: **Optimization, Procurement process, Taguchi method, DoE**

1. INTRODUCTION

Now days the need for systematic procurement planning has gained more importance. The lack of planned procedures, for the selection of procurement system sometimes restrains the opportunity for clients to select a procurement option in a fully informed manner. The unsuitable procurement approach selection may lead to pay more for the poor quality & life. In a painting work there is a major capital investment whether project is new or old. In costly building projects, careful material selection, purchase and thoroughly investigating painting supplier can prevent interruptions. The type of paint used for a particular project is always dependant on the particular factors (e.g. paint cost, labour cost) and the client's specifications. Use of Taguchi method allows collecting data at combinations of factors involving in paint work and then use the findings to investigate the optimal set of parameters based on their typical characteristics, project requirement and external environment.

2. LITERATURE REVIEW

D. Bharathi and R. Baskaran [1] studied the Taguchi method of DOE, for improvement of painting process of steel structures. They studied the painting process of steel structures for the minimization of excess consumption of paint. Four main factors: viscosity, pressure, air compressor and gun distance was studied based on two levels. L8 orthogonal array was used for analysis. Results shows that if four main factors kept at level 2 as decided, there was considerable cost saving.

P. K. Chaulia and Reeta Das [2] presented the result of an experimental investigation carried out to optimize the mix proportions of the fly ash brick by Taguchi method of parameter design. L9 orthogonal array with four factors and three levels. The effects of water/binder ratio, fly ash, coarse sand, and stone dust on the performance characteristic are analyzed using S/N ratios and mean response data. Finally as water/binder ratio and stone dust play the significant role on the compressive strength of the brick.

Seyed Mojib Zahraee [3]et.al. used Taguchi method along with computer simulation to determine the optimum combination of resources for a real world case study involving a concrete pouring operation in order to optimize cycle time and process costs. Data was collected from construction site by stop watch method. In this research L8 orthogonal array was used which indicate assignment of seven factors in two levels. Hence only 8 experiments were required. Experiment results shows the optimum level of the all factors is located in the low level so that process cost and cycle time was improved.

H. Tanyildizi and Murat Sahin[4] discussed in his paper, the importance of experimental parameters on the compressive strength and ultrasonic pulse velocity of the concrete, strengthened with polymer after exposure to high temperature was investigated. L32 OA used where main parameters are polymerization type, the percentage of silica fume, and heating degree. The ANOVAs results showed that the silica fume percentage was the most significant effect on the compressive strength and ultrasonic pulse velocity.

S. kumari[5] et.al. employed to optimize the cement content in concrete using pozzolanic materials. M20 & M40 grades of concrete was studied considering W/B ratio,% of super plasticizers, cement content, fine aggregate and mineral content and content of GGBS, silica fume. A standard L16 orthogonal array selected. Applying Taguchi method established optimal mixes for strength and workability.In production engineering field, Ming and Shih [6] attempted to study the Chip on film (COF) technology. COF technology has several nonconforming items such as bonding misalignment, insufficient bonding strength and surface mount technology (SMT), solder joint defects, etc. The purpose of this study was to determine the optimum process parameters for COF technology improvement. An L18 OA was used; to study the effects on bonding misalignment and bonding strength. The results show that bonding misalignment was reduced and bonding strength increased.

In paper, published by Gopalsamy, Mondal and Ghosh [7], analysis of variance (ANOVA) and Taguchi method were applied to study the performance characteristics of machining process parameters for hard steel. An L18 orthogonal array was applied for analyzing the best process parameters for single performance characteristics. The optimum process parameters are calculated for rough machining and finish machining using grey theory and results are compared with ANOVA.

3. METHODOLOGY

3.1 Problem Definition:

In procurement process of building paints, purchase managers are responsible for taking decisions over the varied aspects and functions in different projects. They will face several problems involving decision making over the varied aspect and functions related with painting work. Procurement of building paints for big projects, involves varied sources of supply with varying cost, quality and many other parameters. Usually, painting contractors and suppliers are located in the vicinity of the site though their prices could vary amongst themselves as well as the index for the quality and customer satisfaction. While doing procurement of paint, we have to consider various factors such as painting cost per lit, paint coverage area, labour rate, durable life, quality etc. If we take all the parameters in our mind, no doubt, we will be able to save excess cost and also found the response factor in the paint procurement process for building projects.Fig.1 shows cause and effect diagram for identifying the possible influential parameters in this process.

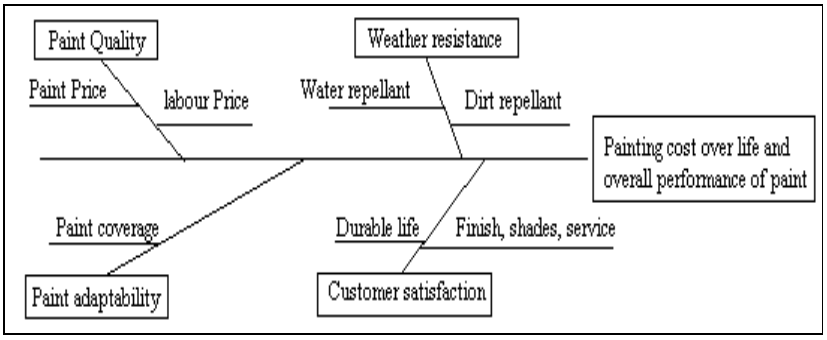

Figure 1.Cause and effect diagram for procurement process of paint

3.2 Need:

The purchase managers or project managers can make a sound decision only when the commercial data over the cost, quality and other relevant factors can be evaluated in a scientific manner to realize a solution. Since a huge investment is at stake during procurement, the impact of a right or a wrong decision could be phenomenal. Considering various factors and its effects on the procurement and performance index, the same needs to be evaluated using suitable mathematical or statistical method. The method should address the need for optimal values for the factors while being effective. The need of the hour is to utilize a reliable statistical tool to optimize the parameters to arrive at the desirable solution.

3.3 Flow chart depicting Taguchi methodology:

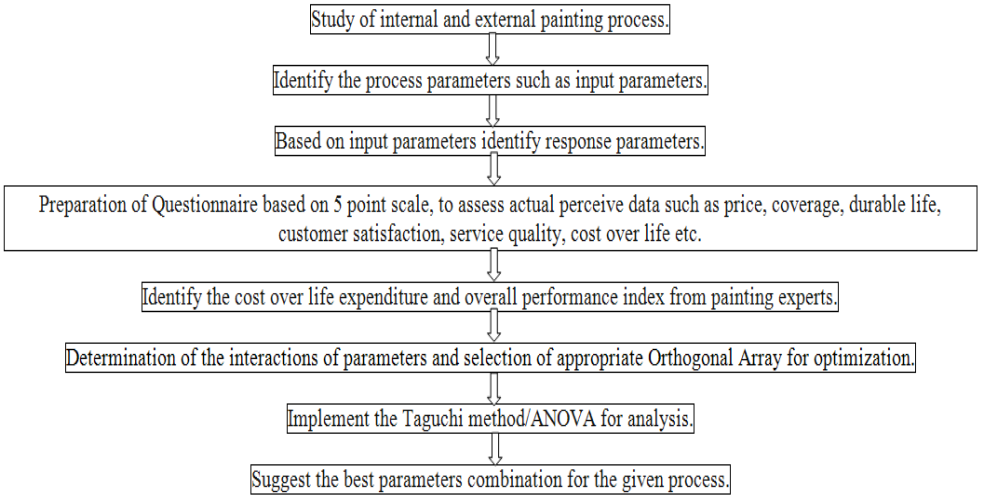

Figure 2. Flow chart depicting Taguchi methodology

4. DESIGN AND ANALYSIS

4.1 Taguchi Design of Experiments:

The objective of DOE is to find a set of parameters which gives optimal solution for the process and save the time. Taguchi gives a special design of orthogonal arrays (OA) to study the entire parameter set with a small number of experiments. He recommends the use of the loss function to measure the performance characteristics deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise ratio (η). Generally, three standard S/N equations are widely used to classify the objective function as: 'larger the better', 'smaller the better', or 'nominal the best'. An OA is a fractional factorial design with pair wise balancing property and the effects of multiple process variables on the performance characteristic can be find out with minimizing the number of test runs. Table 1 shows an L9 (3 x 4) standard orthogonal array.

Table 1. L_9 (34) Standard orthogonal array.

Experiment No	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

4.2 Data used for work:

In this work questionnaires were prepared to decide key impact factor and data is gathered from field survey. The experimental results were based on data collected from experienced building contractors and painting experts. After a detail analysis of collected data, the values of impact and response parameters of painting procurement process were decided. Table 2 shows the four painting parameters at three levels for external and internal paint separately.

Table 2. Control factors/parameters for paints

Para meters Levels	External paint parameters				Internal paint parameters			
	Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs	Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs
1	295	70	7.9	6	260	75	11.0	5.5
2	344	60	8.4	5	290	70	11.5	5.0
3	315	65	8.2	5.5	310	80	12.5	5.5

4.3 Analysis of data used:

Minitab software was used for the analytical assessment. Table 3 and 4 represents the layout of factors and S/N ratios and means for each level, which has been obtained by assigning the factors and their levels to appropriate columns of L9 orthogonal array. This array has 9 rows and 4 columns and each row represents a trial condition while each column represents specific process parameter. The numbers in each column indicate the levels of specific factors. In the present study, price, coverage, labour rate and durable life are input parameters to determine the cost over durable life which is a response parameter. Table shows response of '*Smaller the better*' type of quality characteristic since the goal is to minimize the cost over life. The standard S/N ratio computing formula for this type of response is

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right)$$

Where 'i' is the number of a trial; 'Yi' is the measured value of quality characteristic for the i^{th} trial and j^{th} experiment; 'n' is the number of repetitions for the experimental combination. Signal-to-noise ratios are calculated using Equation 1 for each of the nine conditions and are reported in Table 3 and 4. Since the experimental design is orthogonal, the factor effects can be separated out in terms of the S/N ratio and in terms of the mean response.

Table 3. Layout of factor and results of S/N ratios for external paint

Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs	Cost over life in Rs/yr	SNRA1	MEAN1
295	70	7.9	6.0	2.02	-6.10293	2.01905
295	60	8.4	5.0	2.66	-8.50851	2.66333
295	65	8.2	5.5	2.32	-7.29509	2.31608
344	70	8.4	5.5	2.42	-7.67910	2.42078
344	60	8.2	6.0	2.32	-7.31808	2.32222
344	65	7.9	5.0	2.64	-8.42702	2.63846
315	70	8.2	5.0	2.54	-8.09667	2.54000
315	60	7.9	5.5	2.39	-7.57126	2.39091
315	65	8.4	6.0	2.21	-6.87877	2.20769

Table 4. Layout of factor and results of S/N ratios for internal paint

Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs	Cost over life in Rs/yr	SNRA1	MEAN1
260	75	11.0	5.5	2.63	-8.4001	2.63030
260	70	11.5	5.0	3.04	-9.6656	3.04286
260	80	12.5	6.0	2.63	-8.3826	2.62500
290	75	11.5	6.0	2.56	-8.1686	2.56111
290	70	12.5	5.5	3.03	-9.6173	3.02597
290	80	11.0	5.0	2.92	-9.3225	2.92500
310	75	12.5	5.0	3.33	-10.4402	3.32667
310	70	11.0	6.0	2.57	-8.2035	2.57143
310	80	11.5	5.5	2.80	-8.9290	2.79545

5. RESULT AND DISCUSSIONS

5.1 Analysis of S/N ratio results:

In the Taguchi method, the term 'signal' represents the desirable value for the output characteristics and the term 'noise' represents the undesirable value for the output characteristics. Taguchi uses the SNR to measure the quality characteristic deviating from the desired value. There are several SNR available, depending on the type of characteristics Smaller is better S/N ratio was used in this study, because lower parameters of cost over life were desirable. Table 5 and 6 shows the Taguchi analysis response for S/N ratios of external and internal paints respectively. The analysis shows that parameter 'durable life' in years is most significant for external and internal painting as rank is first, and then followed by coverage, labour cost per sqft and price.

From obtained initial analysis of the data, the graphical analysis of SNR was done based on the graphs by Minitab for various parameters. Figures 3 and 4 show the plots of S/N ratios of various parameters for external & internal paint. The S/N ratios graph states the steep slope in durable life per year when compared to price, coverage and labour cost per sqft.

Table 5. Response table for s/n ratios of External paint

Level	Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs
1	-7.302	-7.799	-7.367	-8.344
2	-7.516	-7.534	-7.570	-7.515
3	-7.808	-7.293	-7.689	-6.767
Delta	0.506	0.506	0.322	1.577
Rank	**3**	**2**	**4**	**1**

Table 6. Response table for s/n ratios of Internal paint

Level	Price (Rs/lit)	Coverage (lit/sqft)	Labour rate (Rs/sqft)	Durable life in Yrs
1	-8.816	-9.162	-8.642	-9.809
2	-9.036	-9.003	-8.921	-8.982
3	-9.191	-8.878	-9.480	-8.252
Delta	0.375	0.284	0.838	1.558
Rank	**3**	**4**	**2**	**1**

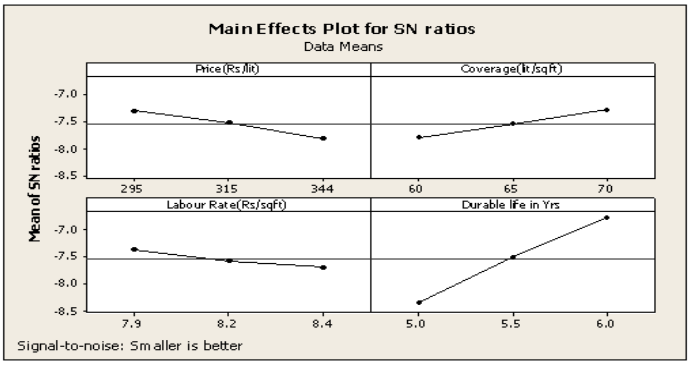

Figure 3. S/N ratio plots for various parameters of external paint

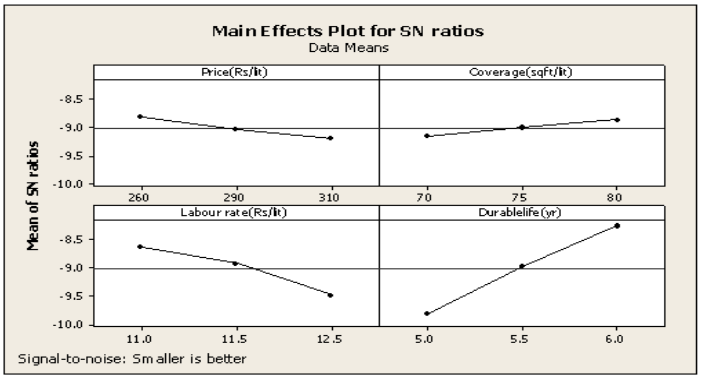

Figure 4. S/N ratio plots for various parameters of internal paint

5.2 Analysis of Variance (ANOVA)

ANOVA is a statistically based objective decision-making tool for detecting any differences in the average performance of groups of items tested. Table 7 and 8 shows ANOVA analysis. ANOVA helps in testing the significance of all main factors and their interactions by comparing the mean square against an estimate of the design errors at specific confidence levels. In the analysis, the F-ratio is a ratio of the mean square error to the residual error and is traditionally used to determine the significance of a factor. The P-value reports the significance level (suitable and unsuitable) or how likely the sample results are. It ranges from 0 to 1. A small p-value (< 0.05) indicates that the parameter has statistically significant effect on cost over life.

Table 7. Analysis of variance for cost over life, using adjusted SS for tests (external paint)

Source	Degrees of Freedom	Sum of Squares	Adj SS	Adj MS	F-ratio	P-value
Price(Rs/lit)	2	0.025034	0.025034	0.012517	2.53	0.283
Labour Rate(Rs/sqft)	2	0.00989	0.00989	0.00494	0.38	0.727
Coverage(lit/sqft)	2	0.026276	0.026276	0.013138	2.66	0.273
Durable life in Yrs	**2**	**0.279585**	**0.279585**	**0.139793**	**28.28**	**0.034**
Error	2	0.009888	0.009888	0.004944	-	-
Total	8	0.340784	-	-	-	-

Table 8. Analysis of variance for cost over life, using adjusted SS for tests (internal paint)

Source	Degrees of Freedom	Sum of Squares	Adj SS	Adj MS	F-ratio	P-value
Price(Rs/lit)	2	0.026114	0.026114	0.013057	1.79	0.359
Labour Rate(Rs/sqft)	2	0.01463	0.01463	0.00731	0.12	0.896
Coverage(lit/sqft)	2	0.125860	0.125860	0.062930	8.61	0.104
Durable life in Yrs	**2**	**0.394947**	**0.394947**	**0.197473**	**27.00**	**0.036**
Error	2	0.014626	0.014626	0.007313	-	-
Total	8	0.561548	-	-	-	-

6. CONCLUSION

In today's competitive market, high quality and low cost expectations have forced decision makers to pay more attention to enhancing construction material procurement performance parameters. In this work we use Taguchi method for determining the best set of parameter combination involved in a paint procurement process. The study shows that Taguchi analysis gives first rank to parameter 'paint durable life' in years based on smaller the better S/N ratio for both external and internal paint and the optimal level of other parameters. This means that the best set of parameter (price, coverage, labour cost) in procurement of external paint and internal paint should be 290, 70, 7.9 and 290, 75, 11.5 respectively. These obtained parameters value has considerable effect on paint cost over life and purchase manager will get the idea of, what should be the exact price, coverage and labour cost. Use of statistical treatment such as ANOVA and Taguchi methods, seem to be promising for deriving optimized results. ANOVA shows that the P-value for the parameter 'durable life' is less than 0.05 for both paints, which confirms that 'durable life' has significant effect on procurement response factor. The optimization can be pursued using Taguchi methods for determining optimal values for the significant parameters while the significant parameter can be identified using ANOVA. Therefore we proposed that the application of Taguchi method and ANOVA is a new approach in procurement process of paints in terms of cost over life. Future scope can be possible for same or different important construction materials using other statistical approaches such as Grey Relations analysis/Generic Algorithm/Regression Equation.

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