Session 3248

A Single Session, Laboratory Primer On Taguchi Methods

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Abstract

Over the past decade, Taguchi Methods have become an extremely popular approach to improving the quality of products. These techniques provide a systematic approach for the application of experiments to improve the product design and production process. However, outside of quality engineering courses, there is a lack of instruction on these methods in many technical programs. All technical professionals should have an understanding of Taguchi Methods. The reason for the absence is commonly attributed to a lack of room in the curriculum. This paper describes an experiment that introduces and employs Taguchi Methods in a single laboratory session. The experiment serves as a valuable primer on Taguchi Methods.

Introduction

In the current competitive marketplace, the high quality of a product and the associated customer satisfaction are key for the survival of an enterprise. Pre-production experiments can contribute significantly towards quality improvements of a product. A traditional method of improving the quality of a product is full factorial testing. This method adjusts one factor at a time during pre-production experimentation. After changing only one parameter, or factor, the result is observed. Of course, this method has the major disadvantages of being very costly and unreliable.

Taguchi Methods advocate the changing of many factors simultaneously in a systematic way, ensuring an independent study of the product factors. The results are statistically analyzed, to determine the influence of the factors on the desired product performance. Once these factors have been adequately characterized, steps are taken to control the production process so that causes of poor quality in a product are minimized [3].

Taguchi's main objectives are to improve process and product design through the identification of controllable factors and their settings, which minimize the variation of a product around a target response [15]. By setting factors to their optimal levels, a product can be manufactured more robust to changes in operation and environmental conditions. Taguchi removes the bad effect of the cause rather than the cause of a bad effect, thus obtaining a higher quality product.

Understanding Taguchi Methods

As mentioned, Taguchi methods are aimed at experimentally determining an optimal combination of design or process parameters. The initial phase in this process is the formulation of an objective statement, and definition of the possible design parameters. The objective statement identifies the performance criteria to be optimized, such as maximize the life of the electrical switch. The design parameters are the factors that can be controlled to create the optimized product. This phase also includes the identification of appropriate levels for the factors. For instance, if a design factor included molding pressure, suitable levels

Optimization using Taguchi Methods involves investigating the possible conditions of the many parameters in a design. Orthogonal arrays are used to plan the investigation of the design factors. These orthogonal arrays eliminate the need to investigate all possible combinations of the various factors.

Figure 1 illustrates an example orthogonal array that can be used when there are 7 identified design parameters, and two levels (minimum and maximum feasible values) of each parameter. This array is designated L_8 (2^7). Investigating all possible combinations of this situation would require 2^7, or 128 investigation trials, but would not provide appreciably more information.

Investigation Trial	Factors A	B	C	D	E	F	G
1.	1	1	1	1	1	1	1
2.	1	1	1	2	2	2	2
3.	1	2	2	1	1	2	2
4.	1	2	2	2	2	1	1
5.	2	1	2	1	2	1	2
6.	2	1	2	2	1	2	1
7.	2	2	1	1	2	2	1
8.	2	2	1	2	1	1	2

Figure 1

Each row in the orthogonal array represents an investigation trial with the parameter levels indicated by the numbers in the row. The vertical columns correspond to the design parameters identified in the study.

In Figure 1, each column contains the same number of level 1 and level 2 conditions for the design factors. In addition, when two columns of an array form a combination, that is (1,1), (1,2), etc., the same number of times, the columns are said to be balanced or orthogonal. Note that any two columns of the array in figure 1 form the same number of combinations. Thus, all columns are orthogonal to each other.

The orthogonal array facilitates the investigation process. To design an investigation is to select the most suitable orthogonal array, and assign the design parameters to the appropriate columns. The array defines the trials that need to be completed and the levels that the design parameters must be assigned for each trial. Figure 2 lists the most common orthogonal arrays.

Orthogonal array	*Number of design factors*	*Number of levels per parameter*	*No of trials required by array*	*No. of trials for all possible combination*
L_4 (2^3)	3	2	4	8
L_8 (2^7)	7	2	8	128
L_9 (3^4)	4	3	9	81
L_{12} (2^{11})	11	2	12	2048
L_{16} (2^{15})	15	2	16	32768
L_{16} (4^5)	5	4	16	1024
L_{18} (2^1 x 3^7)	1	2	18	4374
	7	3		

Figure 2

Once the investigation trials have been conducted, the results of the trials are analyzed using a technique termed the Response Table Method. The Response Table Method is a statistical procedure to determine the values for each design parameter to achieve the optimum condition for the design and the contribution of the individual design parameters. The steps to complete the response table are as follows [13]:

1. Calculate the average result for all experiments where factor A was set at level 1. Then calculate the average result for all experiments where factor A was set at level 2. Next, calculate the average result for all experiments where factor B was set at level 1. This process is continued until an average is calculated for all factors and all levels.

2. Use the average values obtained in the previous step to prepare a response table. A response table organizes the contribution of each factor level to the experiment result. An example response table is shown in figure 3 and is used for a three factor, two level experiment.

	Level 1	Level 2	Delta
Factor A			
Factor B			
Factor C			

Figure 3

3. Determine the combination of levels that yield the optimal solution. The ideal level for each factor is the one that obtains the better result. In other words, if

it is desired to maximize the result, the ideal level is the level that generates the greatest experiment result. This combination is the levels that have the desired average effect on the objective function.

4. Compute the average result for all experiments conducted, y_{avg}.

5. Estimate the value of the optimal result. This value is computed through equation 1.

$$y_{opt} = y_{avg} + (\text{factor A, optimal level} - y_{avg}) + (\text{factor A, optimal level} - y_{avg}) + \qquad \text{(Equation 1)}$$

Since the optimal combination may not be a configuration actually tested, it is recommended that a confirmation experiment be conducted.

The real benefit of the Taguchi Response Table is that the analysis involves minor arithmetic manipulation of the numerical results. Taguchi approach can be utilized to arrive at the best parameters for optimum design configuration with the least number of investigations.

Laboratory Experiment

The purpose of the laboratory experiment is to determine the conditions that will maximize the tensile strength of a bonded piece of wood. Therefore for this experimental design problem, the objective statement is written as:

Maximize the tensile strength of a glued wood bond.

Seven main design parameters have been identified. For each parameter, two feasible values were specified. These factors, and the corresponding levels, are listed in Figure 4.

		Levels	
Factor		**1**	**2**
A.	Shape*	Thick	Thin
B.	Glue type	Elmer's Carpenters	Liquid Nails
C.	Amount of Glue	1 drop	2 drops
D.	Type of Cut	Cross-cut	Angled
E.	Edge Preparation	Sanded	Notched
F.	Cure time	<30 min	>60 min
G.	Pressure during cure	Yes	No

* both shapes have identical cross-sectional areas.

Figure 4

A sketch of the wood sample is shown in Figure 5.

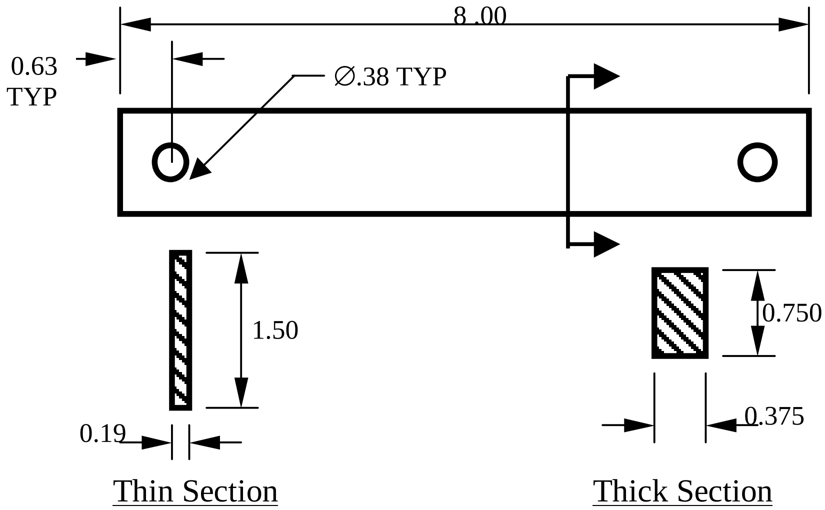

Figure 5

An L_8 (2^7) orthogonal matrix, as the one illustrated in Figure 1, is used to organize this experiment. Each person in the lab is to prepare at least one sample. It is preferred that each student prepares multiple samples. The preparation of samples must be organized to insure that the orthogonal array is entirely completed. It is preferred that each test be conducted a few times to identify errors in the sample preparation or test method.

A modest load frame was constructed to apply a tensile load to the samples. A picture of the fixture is shown as Figure 6.

Figure 6

As the samples are loaded, the orthogonal array is completed. The results from a lab session are shown in figure 7.

Factor	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Strength**
Test No.	Shape	Glue	Amount	Cut	Edge	Cure time	Pressure	(lbs)
1.	Thick	Elmer's	1 drop	Cross	Sanded	<30	Pressure	70
2.	Thick	Elmer's	1 drop	Angled	Notched	>60	No press	122
3.	Thick	L. Nails	2 drops	Cross	Sanded	>60	No press	95
4.	Thick	L. Nails	2 drops	Angled	Notched	<30	Pressure	35
5.	Thin	Elmer's	2 drops	Cross	Notched	<30	No press	38
6.	Thin	Elmer's	2 drops	Angled	Sanded	>60	Pressure	138
7.	Thin	L. Nails	1 drop	Cross	Notched	>60	Pressure	21
8.	Thin	L. Nails	1 drop	Angled	Sanded	<30	No press	52
								y_{avg} = 71

Figure 7

Once the experiments have been completed, a response table is constructed as shown in figure 3. For an L_8 (2^7) orthogonal array, factor A is at level 1 during trials 1, 2, 3 and 4. Therefore, the result of these four investigations can be averaged to determine the contribution of factor A, setting 1. Likewise, factor B is at level 1 during trials 1, 2, 5 and 6. Therefore, the result of these four investigations can be averaged to determine the contribution of factor B, setting 1. This procedure is repeated for all parameters and levels. The result is given in figure 8.

Factor		**Option 1**	**Option 2**	**Delta**
A.	Shape*	***80.5*** (Thick)	62.3 (Thin)	18.2
B.	Glue type	***92.0*** (Elmer's)	50.8 (L. N.)	41.2
C.	Amount of Glue	66.3 (1 drop)	***76.6*** (2 drops)	10.3
D.	Type of Cut	56.0 (Cross-cut)	***86.8*** (Angled)	30.8
E.	Edge Preparation	***88.9*** (Sanded)	53.9 (Notched)	35.0
F.	Cure time	48.9 (<30 min)	***93.8*** (>60 min)	44.9
G.	Pressure during cure	65.9 (Yes)	***76.9*** (No)	11.0

Figure 8

The optimum levels for each parameter is the level that produces the desired result. In this case, the desired result is maximizing the tensile strength. These optimal levels for each factor are bold-italic in figure 8. Summarizing, the glued wood bond will be strongest when a thick piece of wood is cut at an angle, the cut surface is sanded smoothly, two drops of Elmer's Carpenter's glue is used and the glue is allowed to dry over 60 minutes without using pressure to set the bond. Notice that this simulation was never performed, yet the analysis identified this as the optimal condition for the bond

The final column in figure 8 lists the difference between the minimum and maximum result for each parameter. This is a measure of the importance of each parameter on the desired outcome. For this example, the glue type is clearly identified as the design parameter that most significantly influences compressor efficiency.

Finally, an estimate of the optimal value can be readily computed. It accounts for the effect of setting each parameter at its optimal value. Mathematically, the optimal result is estimated by adding the total average and the difference from the optimal result from each setting and the total average.

$$\text{Optimal Strength} \cong 71.0 + (80.5-71.0) + (92.0-71.0) + (76.6-71.0) + (86.8-71.0) + (88.9-71.0) + (93.8-71.0) + (76.9-71.0) = 169.5 \text{ lbs}$$

Therefore, it is expected that a glue bond, prepared under these optimal conditions, will support approximately 169.5 lbs.

The Taguchi Methods can include more sophisticated phases of analysis. A more detailed examination of the results can include a full analysis of variance. However many situations can be solved using the simple techniques that are illustrated in this experiment.

Conclusions

This design situation is common. Design engineers work with commercial analysis tools, or custom simulation routines provided by consultants. Often, the design solution is attained with a trial and error process. In these circumstances, optimization occurs by merely reviewing the trials, and selecting the best configuration.

Taguchi Methods of optimization does not promise to outperform more traditional methods of optimization. However, applying these procedures is extremely straightforward, and a true optimal solution is obtained. Numerous experiences have demonstrated that Taguchi Methods are the most underutilized design tool.

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