# Shainin and Taguchi Methods and Their Comparison on an Application

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ABSTRACT – A decrease in the variation of the output variable is done with new parameter values obtained by design of experiment (DOE) in the production. The purpose is to find the optimum values of factors / interactions which cause variation in the output level. However, because of both reduction in costs and the need to decide within a short time in competitive environment, companies avoid from long-lasting experiments. Another reason of not preferring DOE is that the computations are so complicated and hard to understand.

DOE done by Shainin Method can result in more than 70% reduction in the variation by removing negative reasons indicated above. The point of the method which has its own tools is to determine the important factors causing variations (Red X, Pink X, and Pale Pink X) are eliminating unimportant factors. Thus, net results can be reached by applying full factorial experiment.

Taguchi Method is an experimental design technique that reduces the number of experiments significantly by using the orthogonal arrays and also tries to minimize the effects of the uncontrollable factors.

In this study, on an industrial problem by applying Shainin and Taguchi Methods, differences in the results which emerged indicated.

*Key Words: Design of Experiment, Red X, Optimization, Shainin Method, Taguchi Method*

## 1. INTRODUCTION

With process improvement, cost reduction of the variability of output reduction, improvement of product quality and increase customer satisfaction is ensured. In this context, the process has been developed many methods to achieve improvement. Design of experiments (DOE) is also one of these methods.

DOE, for the first time in the 1920s had been proposed by R. Fisher. In later years, depending on the needs' increase and change, many innovations in DOE were made by different researchers.

According to the Taguchi and Shainin Methods, because all factors into account, Full Factorial Designs (FFD) will undoubtedly give the most accurate results. However, this method due to the absence of a practical use, FFD is not preferred. FFD's the most important problem is the need of too much experiments. For example, when 4 factors with 2-levels, the researcher has to manage 16 experiments ($2^n = 2^4$). But in practice, it is usually not to appear few factors as above. For example; 15 factors with 2-levels need $2^{15} = 32768$ experiment to do. Therefore, to reduce the number of experimental, fractional factorial design has been developed. Fisher's full factorial experiments were tried to accelerate by using fraction factorials.

### *1.1. Taguchi Method (TM)*

Genichi Taguchi simplified classical DOE by using orthogonal arrays (OA). However, the calculations in this experiment are more to be done and the parameters can not be revealed as the net result may affect negatively and may cause to be done to try different combinations. Taguchi created many new methods and ideas on the improvement of product and process. Some of them, "Taguchi Loss Function" and product/process design with three approaches to be used in the "System, Parameter and Tolerance Design" may be listed as. In addition to these, as an alternative test methodology, he used the OA [1]. Taguchi simplified the classical DOE by using OA. His using of the signal/noise (SN) ratio to reduce variance is a first in the experimental design.

After some simple adjustments are made to the system function, TM uses the SN ratio, which is used to predict the loss of quality, to maximize the robust design's objective function. SN ratio takes the test results' averages

and variances. According to the type of the specified target of quality loss function, Taguchi separates the practical problems into three groups, which has different definition of SN. (Table 1)

Table 1 – SN ratios

| Characteristics | SN | |
|---|---|---|
| The larger-The better | $-10.\log\left(\frac{1}{n}\sum_{i=1}^{r}\frac{1}{y_i^2}\right)$ OR $-10.\log\left(\frac{1}{n}\sum_{i=1}^{r}y_i^{-2}\right)$ | (1) |
| Nominal – The best | $-10.\log\left(\frac{\bar{y}^{-2}}{s^2}\right)$ OR $10.\log\left(\frac{s^2}{\bar{y}^{-2}}\right)$ | (2) |
| The smaller-The better | $-10.\log\left(\frac{1}{n}\sum_{i=1}^{r}y_i^2\right)$ | (3) |

Formulas, stated in Table 1, are described below.

$y_i$ = performance characteristic of the $i^{th}$ observed value
n = Trial number
$\bar{y}$ = Mean of observations
$s^2$ = Variance of observations

*1.2. Shainin Method (SM)*

After the classical DOE and TM, the third approach to the DOE is Shainin Methodology. Its strategy is based upon to detection of the one, two or three dominant causes of the process variations by focusing on a problem response. [2]

To reduce the process output variability, the methodology developed by Dorian Shainin, named Shainin Methods (SM), is simple, relatively easy to understand and implement, but formed by the combination of powerful statistical techniques, are more reliable and faster to achieve results compared to other techniques. At SM, the problem of the poor quality and causes of this problem are indicated by the colors of Green, Red and Pink. These parameters, named Red X, Pink X and Pale Pink X, are ranked according to the principles of Pareto Principle. Constitute a significant portion of the variation to take account of factors, with shades of red color, these factors are identified.

*Green Y:* is defined as special quality characteristics that are important to customers [3] or can be said as the selection and measurement of the views of the design team and corporate goals, depending on the response variable obtained. [2]

*Red X:* The dominant cause of the variation. Contains at least 50% of the causes of variation (Green Y)

*Pink X:* The secondary cause to the overall variation. It accounts 20-30% of the Green Y.

*Pale Pink X:* The tertiary important reason. It causes to 10-15 % of the Green Y [2]

With SM, the analysis can reduce the variation about 75% to 95% for the causes of the Green Y (Red X, Pink X and Pale Pink X). [4]

SM has mainly 12 techniques, of which 9 are for problem solving and 3 are for controlling and preventing any repetition of the solved problems.

**Problem Solving Techniques:**

1) Multi-Vari,
2) Components Search,
3) Paired Comparisons,
4) Product/Process Search
5) Variables Search,
6) Full Factorials,
7) B vs C Comparison,
8) Scatter Plots
9) Response Surface Methodology

**Preventing Techniques**

1) Positrol,
2) Process Certification,
3) Pre-Control

## 2. VARIABLES SEARCH

Variables search method (VSM) is an experimental design approach for reducing the causes of defects and for identifying the critical variables (Red X, Pink X and Pale Pink X) in any manufacturing processes. VSM finds these critical variables by decomposition of factors as "important" or "unimportant"

Thus, $C_p$ and $C_{pk}$ values of unimportant factors can be allowed to get 1.0 or less. In this case, factors that would provide an upgrade for the tolerance values, will also contribute to the reduction of production costs. [5]

The most important feature of the VSM is to ensure at least 2.0 for the process capability ($C_{pk}$=2.0), which has been got by important factors or interactions of the factors. Thus, the tolerance values of these factors become even more stringent. VSM follows these stages: [4]

1. *Finding predictive values (Ball Park):* To determine if the right variables and right levels for each variable have been selected for the experiment.
2. *Separation & Elimination (Swapping):* To separate the important variables from the unimportant variables. To eliminate the unimportant variables and their associated interaction effects.
3. *Verification (Capping Run):* To validate that the important variables are confirmed as important and the unimportant ones confirmed as unimportant.
4. *Factorial Analysis:* To quantify the magnitude and desired levels of the important variables and their associated interaction effects.

*2.1. Finding Predictive Values (Ball Park)*

It determines whether the right factors have been chosen. If the correct parameters (factors) have been successfully identified, a statistical confidence of 95% is caught. For this selection, the causes of the Green Y, mentioned by the people from production, quality, design departments and the operators, are ranked in order of importance by these people.

Then, two levels are assigned to each process variable, (+) for the best level and (–) for the worst level. According to the Green Y, two samples are taken from the production. The method begins with two experiments, one with all process variables at their best levels (+) and the other one with all process variables at their worst levels (–). The experiments are replicated twice to obtain a total of 6 experiments. All six experiments must be carried out in a random manner, to ensure that uncontrolled variables (or lurking variables) do not bias the response of interest. The response is the output or quality characteristic which is to be measured in an experiment.

To understand whether the critical values (Red X, Pink X and Pale Pink X) are in the determined list, it is looked to the relationships between the medians of the "Best" and "Worst" variables. In order to meet the critical values, the difference between medians ($D_M=M_B–M_W$) of the output response is estimated from experiments. $M_B$ and $M_W$ indicates the medians of the experiments at all best and worst level settings. After that, the output of the best and worst values of the variables are calculated separately for the intervals ($R_B$ and $R_C$) and their average ($\overline{R}$) is taken. For the statistical significance, median difference is divided by average of range intervals ($D_M / \overline{R}$). If this rate comes up at least 1.25, critical values (important factors) are in the specified list.

Control Limits (Decision Limits) are calculated for the medians. To find these limits, the formulas below are used:

$$CL_B = M_B \mp t_{(\alpha;n-2)} \cdot \left( \frac{\overline{R}}{d_2} \right) \quad (4)$$

$$CL_W = M_W \mp t_{(\alpha;n-2)} \cdot \left( \frac{\overline{R}}{d_2} \right) \quad (5)$$

$t_{(\alpha\ ;\ n-2)} = t_{(0,05\ ;\ 6-2)} = 2.776$

$d_2$ = Statistical constant (= 1.81)

### *2.2. Separation & Elimination (Swapping)*

The factors identified as unimportant and their interactions are eliminated. For this elimination, the bilateral comparisons of changed factors' levels are formed. First, the most important factors mentioned as "Best" (+) level is kept while all other factors are kept at their "Worst" (–) level (Experiment 7). Then, another experiment is done by changing the level of most important factor from its (+) level to (–) level while all other factors are kept at their "Worst" (+) level (Experiment 8). If the output response values from these experiments fall within the control limits ($CL_B$ and $CL_W$), then the influence of the swapped process variable can be eliminated. With this factor, its interactions are also eliminated. If the response is outside the limits the assessment is made as "this factor is influential in the formation of variation". These operations (swapping), continues in a similar way up to find the critical values. After obtaining 2,3 or 4 important variables from swapping, they enter to the next stage, the "Verification" (Capping Run).

### *2.3. Verification (Capping Run)*

In this stage, the factors which has been got from second stage and considered as important are verified whether they have been identified correctly. The Capping Run experiments are done with the important factors kept at their Worst (–) levels while the others are at (+) levels and vice versa. AS a result of these two experiments, if the output variables remain within control limits, some of the critical values are reached (Capping run is successful). If the response variables fall outside the limits, probably, the critical factors have not correctly identified in the first stage, so the new critical values to be determined.

### *2.4. Factorial Analysis*

According to the factors obtained at the end of the first three stages, FFD matrix was designed, to determine the direction of the main effects and interactions. This stage isn't a new experiment, but it is the phases of the experiments are to calculate. By the determined number of factors (n), the TFD matrix of $2^n$ is designed. Main and interaction effects are determined according to the results of experimentation.

## 3. APPLICATION

This study was performed in a workplace which produces bobbins (Figure 1). These bobbins are used for wrapping and carriage of the cords. After the cord has been wrapped, the bobbins get the load of 4 – 4.5 tons weight. To lift this loading, the longitudinal socket located within the bobbin must be robust. The square-shaped socket, named "box-profile", is controlled by mandrel after produced. Identified problems occur because of the mandrel can't enter the box-profile (box-profile is narrow), or the box-profile comes too loose to mandrel. Due from this narrow-loose state in the box-profiles, deformations consist.

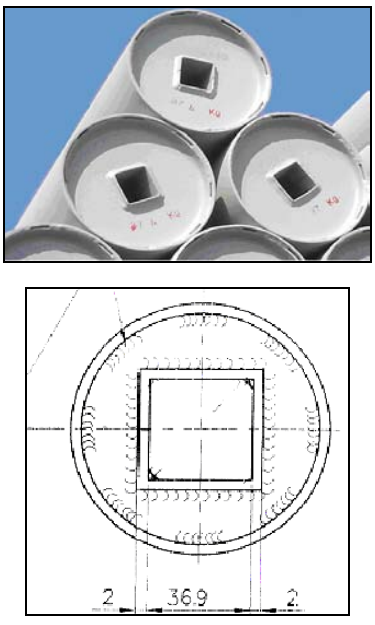



Figure 1 – Box-profile

*3.1. Solution by Shainin Method*

After the clue-generation method which helps to find the cause of problem, it is identified that the problem occurs by the length of the inside of the box-profiles. So, the inner edge of the box-profile length (mm) was taken as the output variable (Green Y). Specification limits are taken between 36.7 mm and 37.1 mm.

As a first, the factors affecting the inner length of box-profile and the levels of these factors were listed and ordered according to their importance by the research team. (Table 2)

Table 2 – List of factors according to their importance

| Process Variables | Labels | (–) Level | (+) Level |
|---|---|---|---|
| Carbon Ratio of Metal Sheet | A | High | Low |
| Cutting of Metal Sheet (Width) | B | 57 mm | 65 mm |
| Weld Type | C | Electrode | GMAW* |
| Bending Angle | D | 91° | 93° |
| Welding Length | E | 2 cm | 3 cm |
| Thickness of Metal Sheet | F | 2 mm | 3 mm |
| Alignment | G | 2 mm | 0 mm |
| Spot Position | H | Horizontal | Vertical |

* GMAW – Gas Metal Arc Welding

According to the determined rank of variables, at first, 3 random observations are taken from the all factors kept at their (+) levels. Similarly, another 3 observations are taken from the all factors kept at their (–) levels. All these 6 experiments must be done in a random manner. At Table 3, the measurements obtained from the six experiments are given.

Table 3 – Initial observations

| Exp. No | Process Variables | Length (mm) |
|---|---|---|
| 1 | $A_{(+)}\ B_{(+)}\ C_{(+)}\ D_{(+)}\ E_{(+)}\ F_{(+)}\ G_{(+)}\ H_{(+)}$ | 36,7 |
| 2 | $A_{(-)}\ B_{(-)}\ C_{(-)}\ D_{(-)}\ E_{(-)}\ F_{(-)}\ G_{(-)}\ H_{(-)}$ | 41,6 |
| 3 | $A_{(-)}\ B_{(-)}\ C_{(-)}\ D_{(-)}\ E_{(-)}\ F_{(-)}\ G_{(-)}\ H_{(-)}$ | 41,8 |
| 4 | $A_{(+)}\ B_{(+)}\ C_{(+)}\ D_{(+)}\ E_{(+)}\ F_{(+)}\ G_{(+)}\ H_{(+)}$ | 36,4 |
| 5 | $A_{(-)}\ B_{(-)}\ C_{(-)}\ D_{(-)}\ E_{(-)}\ F_{(-)}\ G_{(-)}\ H_{(-)}$ | 41,7 |
| 6 | $A_{(+)}\ B_{(+)}\ C_{(+)}\ D_{(+)}\ E_{(+)}\ F_{(+)}\ G_{(+)}\ H_{(+)}$ | 36,6 |

| | Experiments | (–) Level (mm) | (+) Level (mm) |
|---|---|---|---|
| **Initial** | 1. ve 2. | 41,8 | 36,7 |
| **1st Replication** | 3. ve 4. | 41,6 | 36,4 |
| **2nd Replication** | 5. ve 6. | 41,7 | 36,6 |

As a result of these observations, the “Best” (+) and “Worst” (–) groups belonging to the measurements was formed in the following way:

$$M_W = 41.7,\ M_B = 36.6,$$

$$R_W = 41.8–41.6 = 0.2\ ,\ R_B = 36.7–36.,4 = 0.3$$

$$D_M = 41.7–36.6 = 5.1\ ,\ \overline{R} = (0.2+0.3)/2 = 0.25$$

$D_M / \overline{R}$ ratio is checked whether the important factors are inside the determined list shown at Table 2. Since $D_M / \overline{R}$ = 20.4 ($\geq 1.25$), the factors have been identified correctly, and this list contains the critical factors inside. After this stage, the "Control Limits" for the median is calculated.

$$CL_B = 36{,}6 \pm 2{,}776.(0{,}25/1{,}81) = \mathbf{(36{,}22 – 36{,}98)}$$

$$CL_W = 41{,}7 \pm 2{,}776.(0{,}25/1{,}81) = \mathbf{(41{,}32 – 42{,}08)}$$

Factors, listed in order of importance, are taken individually (Table 4). An experiment is done while the first factor A is kept at (+) level while all other factors are kept at their (–) level (Experiment 7). Similarly, another experiment is carried out (Experiment 8) by changing the levels of these factors.

Because of the new values obtained from these experiments are outside the control limits, A is considered as an important factor. This explains the variation is caused by factor A or another factor which has an interaction with A.

To determine the next important factor, another experiment is conducted as similar to the one above. Since the factor B is located outside the control limits after the 9th and 10th experiments, B is considered as important. So, B or B’s interaction is affecting the variability.

**Table 4:** Swapping and Capping Runs

| Exp. No | Process Variables | Length (mm) | Control Limits | Result |
|---|---|---|---|---|
| 7 | $\mathbf{A_{(+)}}$. Others$_{(–)}$ | 40.5 | 41.3 – 42.1 | **A is important** |
| 8 | $\mathbf{A_{(–)}}$. Others$_{(+)}$ | 37.8 | 36.2 – 37.0 | |
| 9 | $\mathbf{B_{(+)}}$. Others$_{(–)}$ | 40.3 | 41.3 –42.1 | **B is important** |
| 10 | $\mathbf{B_{(–)}}$. Others$_{(+)}$ | 38.3 | 36.2 – 37.0 | |
| 11 | $\mathbf{A_{(+)}.B_{(+)}}$. Others$_{(–)}$ | 39.1 | 41.3 – 42.1 | *Capping run is unsuccessful* |
| 12 | $\mathbf{A_{(–)}.B_{(–)}}$.Others$_{(+)}$ | 37.1 | 36.2 – 37.0 | |
| 13 | $\mathbf{C_{(+)}}$. Others$_{(–)}$ | 41.9 | 41.3 – 42.1 | C is unimportant |
| 14 | $\mathbf{C_{(–)}}$. Others$_{(+)}$ | 36.4 | 36.2 – 37.0 | |
| 15 | $\mathbf{D_{(+)}}$. Others$_{(–)}$ | 40.8 | 41.3 – 42.1 | **D is important** |
| 16 | $\mathbf{D_{(–)}}$. Others$_{(+)}$ | 38.6 | 36.2 – 37.0 | |
| 17 | $\mathbf{A_{(+)}.B_{(+)}.D_{(+)}}$.Others$_{(–)}$ | 41.5 | 41.3 – 42.1 | *Capping run is successful* |
| 18 | $\mathbf{A_{(–)}.B_{(–)}.D_{(–)}}$.Others$_{(+)}$ | 36.9 | 36.2 – 37.0 | |
| 19 | $\mathbf{E_{(+)}}$. Others$_{(–)}$ | 41.9 | 41.3 – 42.1 | E is unimportant |
| 20 | $\mathbf{E_{(–)}}$. Others$_{(+)}$ | 36.6 | 36.2 – 37.0 | |
| 21 | $\mathbf{F_{(+)}}$. Others$_{(–)}$ | 41.8 | 41.3 – 42.1 | F is unimportant |
| 22 | $\mathbf{F_{(–)}}$. Others$_{(+)}$ | 36.7 | 36.2 – 37.0 | |
| 23 | $\mathbf{G_{(+)}}$. Others$_{(–)}$ | 41.5 | 41.3 – 42.1 | G is unimportant |
| 24 | $\mathbf{G_{(–)}}$. Others$_{(+)}$ | 36.4 | 36.2 – 37.0 | |
| 25 | $\mathbf{H_{(+)}}$. Others$_{(–)}$ | 42.0 | 41.3 – 42.1 | H is unimportant |
| 26 | $\mathbf{H_{(–)}}$. Others$_{(+)}$ | 36.5 | 36.2 – 37.0 | |

After A and B, indicated as important, this decision is confirmed with Capping Run. Two experiments are done for that. Since the outputs are in the CLs (Capping Run is unsuccessful), another important factor is required. (Experiments 11-12).

The experiments done for C shows that the factor C has no importance on the variability because of the outputs of C lay into the CLs. (Experiments 13-14)

Thus, the factor D leads to the next. Since D's test results appear to be an important factor (Experiments 15-16), this time, capping run is done for three important factors (A, B, and D).

At 17$^{th}$ experiment, A, B and D are kept at (+) levels while others are kept at their (–) levels. At the next trial, all levels turn to vice versa. According to the results, these three factors and/or interaction can be said to have an impact on the process (Capping Run is successful). Since the capping run has been successful, the remaining factors can be ignored in the next round of experimentation. Because, three important factors which have a large portion of the variation were found. However, special to this study, other factors also were taken into the experiment.

Therefore, further experiments for the next factor (E) were made. However, the factor E was within control limits, it has no effect on the output variability. F, G and H factors were made a similar investigation and they also showed up insignificance (Table 4). The results are also shown graphically in Figure 2.

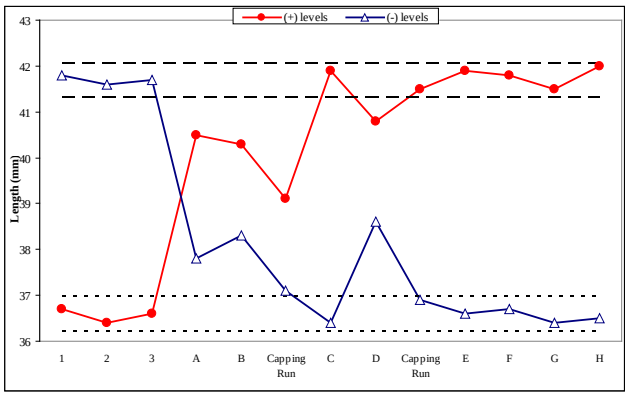



Figure 2 – All the results of the experiments revealed

When Figure-2 is examined, it can be seen that identified three main factors (A, B and D) takes better results than the others. These factors increase the length when they are set at (+) levels and decrease the length when kept at (–) levels. The main effects plot was constructed at Figure 3a. Factors' interaction with each other is shown at Figure 3b. In this graphic, if the lines show a parallel structure, it means that there is no interaction between them. Figure 3b reveals that factor A has an interaction with B and D. But these interactions appear to be weak.

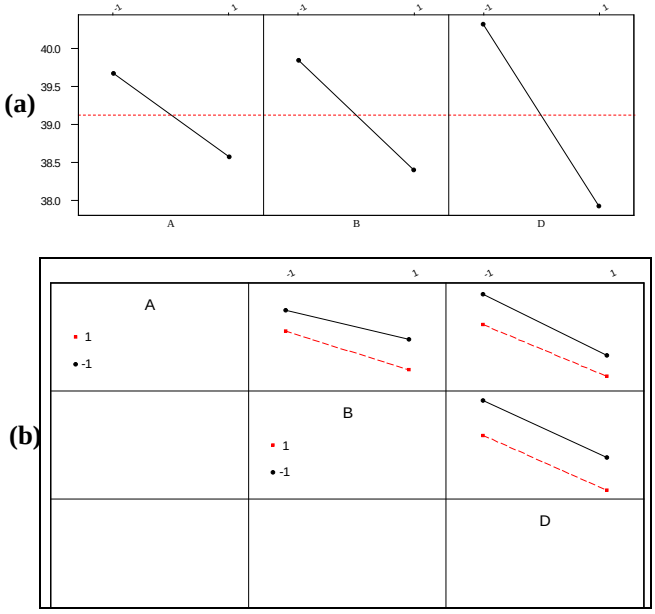



Figure 3 – Important factors: (a) and interactions (b)

After seeing that these factors haven't got significant interaction(s), FFD is constructed to determine the degree of impact of these three factors. For this, there is no need to do a new observation. Table 5 and Table 6 is created by using the results of important factors.

Table 5 – Important factors by their levels

| | | | A (+) | A (–) |
|---|---|---|---|---|
| B (+) | | D (+) | 36,7 36,4 36,4 41,5 Median = 36,65 | 37,8 Median = 37,80 |
| | | D (–) | 39,1 38,6 Median = 38,85 | 40,3 Median = 40,30 |
| B (–) | | D (+) | 38,3 Median = 38,30 | 37,1 40,8 Median = 38,95 |
| | | D (–) | 40,5 Median = 40,50 | 41,6 41,7 41,8 36,9 Median = 41,65 |

Table 6 – Important factors for the preparation of the Factorial Analysis.

| | Factors | | | Results | | | | Median |
|---|---|---|---|---|---|---|---|---|
| | A | B | D | | | | | |
| **1** | + | + | + | 36.7 | 36.4 | 36.6 | 41.5 | 36.65 |
| **2** | + | + | – | 39.1 | 38.6 | | | 38.85 |
| **3** | + | – | + | 38.3 | | | | 38.30 |
| **4** | + | – | – | 40.5 | | | | 40.50 |
| **5** | – | + | + | 37.8 | | | | 37.80 |
| **6** | – | + | – | 40.3 | | | | 40.30 |
| **7** | – | – | + | 37.1 | 40.8 | | | 38.95 |
| **8** | – | – | – | 41.6 | 41.8 | 41.7 | 36.9 | 41.65 |

When Table 7 is examined, it is observed that factor D (bending angle) has the biggest effect to the variation. So, this is the Red X. Factor of secondary importance, Pink X, is B (cutting of metal sheet). The third important reason for variations in the length of the resulting (Pale Pink X) is factor A (carbon ratio). These three important factors should be kept at (+) levels. Thus, the factors arranged in the form as $A_{(+)}.B_{(+)}.D_{(+)}.Others_{(-)}$ will produce the optimal results.

Table 7 – Main and interaction effects

| | Main Factors | | | Interactions | | | | Length |
|---|---|---|---|---|---|---|---|---|
| | A | B | D | A*B | A*D | B*D | A*B*D | |
| 1 | + | + | + | + | + | + | + | 36.65 |
| 2 | + | + | – | + | – | – | – | 38.85 |
| 3 | + | – | + | – | + | – | – | 38.3 |
| 4 | + | – | – | – | – | + | + | 40.5 |
| 5 | – | + | + | – | – | + | – | 37.8 |
| 6 | – | + | – | – | + | – | + | 40.3 |
| 7 | – | – | + | + | – | – | + | 38.95 |
| 8 | – | – | – | + | + | + | – | 41.65 |
| Mean(+) | 38.6 | 38.4 | 37.9 | 39.2 | 39.0 | 39.1 | 39.1 | |
| Mean(-) | 39.7 | 39.9 | 40.3 | 39.0 | 39.2 | 39.2 | 39.2 | |
| Effects | -1.1 | -1.5 | -2.4 | 0.2 | -0.2 | -0.1 | -0.1 | |
| | *Pale Pink X* | *Pink X* | *Red X* | | | | | |

When the other factors, known as C, E, F, G and H are kept at their (–) levels, the results hold up better. But they have no so much effect on the variations. Therefore, for these factors only determine the least costly of the level is adequate.

*3.2. Solution by Taguchi Method*

Same factors and same levels of these factors were used for the Taguchi experiments. For Taguchi experiment, the $L_{16}$ design (8 factors with 2 levels) was selected. to use the 1/16 fractional factorial arrangement, a statistical packet program –Minitab– was utilized. The bilateral interactions were given in the experimental design created by using aliases. According to the design of the system, the experiment was repeated three times at random.

The results of $L_{16}$ design are presented at Table 8. For the analyzing SN ratio, "nominal is the best" is used as Taguchi Loss Function. (Table-8)

Table 8 – Experiments of Taguchi and SN ratio

| Exp. No | Factors | | | | | | | | $\overline{Y}$ | SN |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | | |
| 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | **41.7** | 1.3 |
| 2 | 1 | -1 | -1 | -1 | -1 | 1 | 1 | 1 | **40.3** | 1.2 |
| 3 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | 1 | **41.2** | 1.2 |
| 4 | 1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | **38.2** | 1.1 |
| 5 | -1 | -1 | 1 | -1 | 1 | 1 | 1 | -1 | **41.1** | 1.2 |
| 6 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | 1 | **38.8** | 1.1 |
| 7 | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 1 | **40.4** | 1.2 |
| 8 | 1 | 1 | 1 | -1 | -1 | -1 | 1 | -1 | **38.4** | 1.1 |
| 9 | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 1 | **38.5** | 1.1 |
| 10 | 1 | -1 | -1 | 1 | 1 | -1 | 1 | -1 | **37.1** | 1.0 |
| 11 | -1 | 1 | -1 | 1 | -1 | 1 | 1 | -1 | **36.9** | 1.0 |
| 12 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | 1 | **36.8** | 1.0 |
| 13 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 | **37.3** | 1.0 |
| 14 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | -1 | **37.6** | 1.0 |
| 15 | -1 | 1 | 1 | 1 | 1 | -1 | -1 | -1 | **36.9** | 1.0 |
| 16 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **36.5** | 1.0 |

The experimental table prepared according to Minitab's design and shown the effects of the averages are given in Table 9.

Table 9 – Experimental design for means

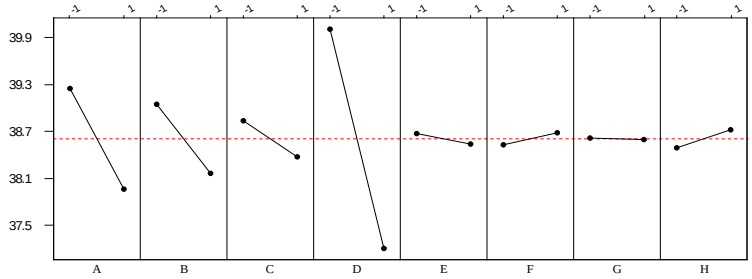
| Rnd. | Std. | $\overline{Y}$ | A | B | C | D | AB | AC | AD | AE | AF | AG | E | F | G | H | AH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 1 | **41.7** | -1 | -1 | -1 | -1 | 1 | 1 | 1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | 1 |
| 2 | 2 | **40.3** | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | 1 | 1 | 1 | 1 |
| 16 | 3 | **41.2** | -1 | 1 | -1 | -1 | -1 | 1 | 1 | -1 | 1 | 1 | 1 | -1 | 1 | 1 | -1 |
| 11 | 4 | **38.2** | 1 | 1 | -1 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | 1 | 1 | -1 | -1 | -1 |
| 4 | 5 | **41.1** | -1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 1 |
| 5 | 6 | **38.8** | 1 | -1 | 1 | -1 | -1 | 1 | -1 | 1 | -1 | 1 | 1 | -1 | -1 | 1 | 1 |
| 9 | 7 | **40.4** | -1 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | -1 | 1 | -1 |
| 12 | 8 | **38.4** | 1 | 1 | 1 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | -1 | -1 | 1 | -1 | -1 |
| 10 | 9 | **38.5** | -1 | -1 | -1 | 1 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | 1 | -1 | 1 | -1 |
| 6 | 10 | **37.1** | 1 | -1 | -1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 1 | -1 | -1 |
| 1 | 11 | **36.9** | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | -1 | 1 | 1 | -1 | 1 |
| 15 | 12 | **36.8** | 1 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | 1 |
| 8 | 13 | **37.3** | -1 | -1 | 1 | 1 | 1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | 1 | 1 | -1 |
| 3 | 14 | **37.6** | 1 | -1 | 1 | 1 | -1 | 1 | 1 | -1 | 1 | 1 | -1 | 1 | -1 | -1 | -1 |
| 7 | 15 | **36.9** | -1 | 1 | 1 | 1 | -1 | -1 | -1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 | 1 |
| 14 | 16 | **36.5** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | **Mean (-)** | | 39.25 | 39.05 | 38.84 | 40.01 | 38.65 | 38.51 | 38.16 | 38.85 | 38.50 | 38.51 | 38.68 | 38.53 | 38.61 | 38.49 | 38.59 |
| | **Mean(+)** | | 37.96 | 38.16 | 38.38 | 37.20 | 38.56 | 38.70 | 39.05 | 38.36 | 38.63 | 38.70 | 38.54 | 38.69 | 38.60 | 38.73 | 38.63 |
| | **Effects** | | **-1.288** | **-0.887** | -0.462 | **-2.813** | -0.087 | 0.188 | **0.887** | -0.488 | 0.125 | 0.188 | -0.137 | 0.163 | -0.012 | 0.238 | 0.038 |

According to Table 9, the factor most affected by variation is D (Effect value = -2.813). A second-ranked factor (Effect value = -1.288), while the factor B comes to the third row (Effect value = -0.887). Besides, the factor B has the same effect as the degree of interaction observed in AD. However, the second level in the value of this interaction is larger than the average level comes first.

According to the results of Table 9, the main factors and their interaction effects are shown graphically in Figure 4. Figure 4a graphs the effects of the main factors which were mentioned. As can be understood from the chart, factor D has the maximum effect to the variation. This factor is followed by A and B, respectively. Factor G belongs to the lowest effect. The second level of the greatest impact factors is shortening the length of the inside of the box profiles, and this is a desirable situation.

Bilateral interactions of the factors are shown at Figure 4b. From this graphic, AD, BH, CF, CH and EG are seen as interact factors (Not in parallel structure). This course, in AD interaction, 2nd levels of A and D determines the desired outcomes. In addition to this, in BH interaction, when B is kept at 2nd level and H is kept at 1st level, shortening in the box-profiles' inner length is observed. For CF interaction, C should be kept at 2nd level and F should be kept at 1st level.

**(a)**




**(b)**

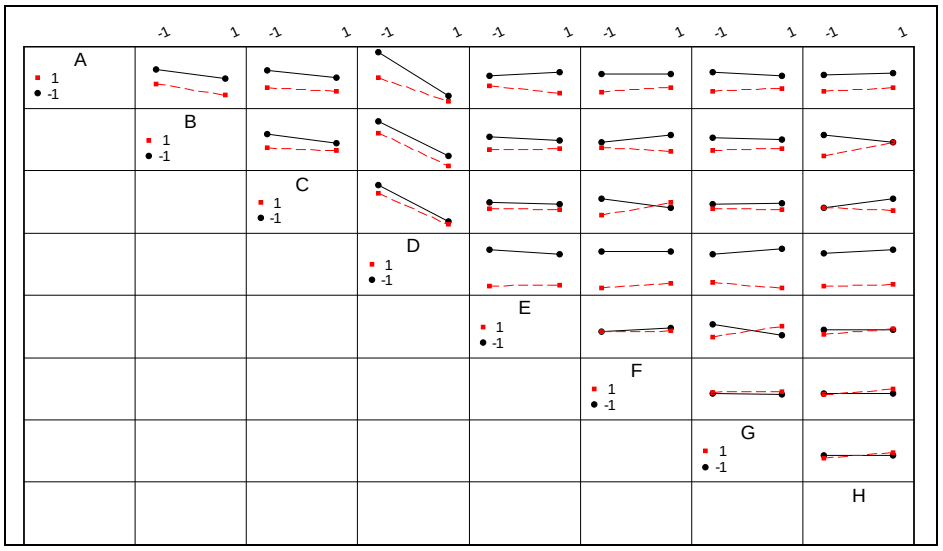



Figure 4 – Test results obtained at the main factors (a) and interactions (b)

In the experimental results, the greatest influence, D, A and B factors to be statistically significant or not can be exposed with normal plot of the effects (Figure 5). As evident from the chart, the factors or interactions which have the most influence to the length of the inner edge of the box profile, are respectively D, A, B and AD.

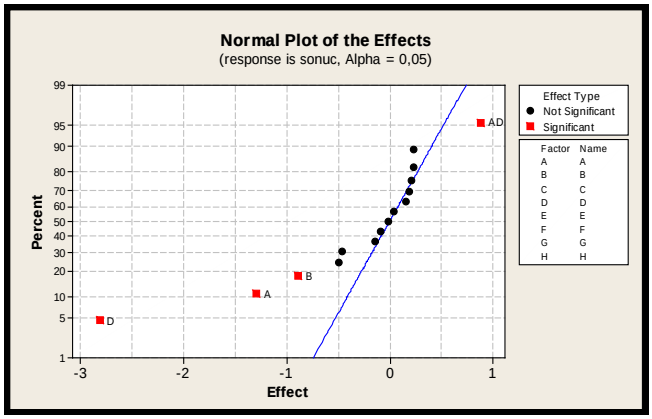



Figure 5 – Normal plot of the effects

For optimal results, levels of factors which must be kept are given in Table 10. In this table, according to the means, as well as the SN, the levels that the factors should be kept are exited the same. So, optimal result will be involved when the factors are kept at $A_2B_2C_2D_2E_2F_1G_2H_1$ levels.

Table 10 – Determining the levels by using means and SN

| | Mean | | | | SN | | | |
|---|---|---|---|---|---|---|---|---|
| | 1st level | 2nd level | Effect | Opt. level | 1st level | 2nd level | Effect | Opt. level |
| **A** | 39.25 | **37.96** | -1.29 | 2 | 31.86 | **31.58** | -0.28 | 2 |
| **B** | 39.05 | **38.16** | -0.89 | 2 | 31.82 | **31.62** | -0.20 | 2 |
| **C** | 38.84 | **38.38** | -0.46 | 2 | 31.77 | **31.67** | -0.10 | 2 |
| **D** | 40.01 | **37.20** | -2.81 | 2 | 32.04 | **31.41** | -0.63 | 2 |
| **AB** | 38.65 | 38.56 | -0.09 | | 31.73 | 31.71 | -0.02 | |
| **AC** | 38.51 | 38.70 | 0.19 | | 31.70 | 31.74 | 0.04 | |
| **AD** | 38.16 | 39.05 | 0.89 | | 31.63 | 31.82 | 0.19 | |
| **AE** | 38.85 | 38.36 | -0.49 | | 31.78 | 31.67 | -0.11 | |
| **AF** | 38.50 | 38.63 | 0.13 | | 31.70 | 32.48 | 0.77 | |
| **AG** | 38.51 | 38.70 | 0.19 | | 31.70 | 31.74 | 0.04 | |
| **E** | 38.68 | **38.54** | -0.14 | 2 | 31.74 | **31.71** | -0.02 | 2 |
| **F** | **38.53** | 38.69 | 0.16 | 1 | **31.70** | 31.74 | 0.04 | 1 |
| **G** | 38.61 | **38.60** | -0.01 | 2 | 31.73 | **31.72** | -0.01 | 2 |
| **H** | **38.49** | 38.73 | 0.24 | 1 | **31.70** | 31.75 | 0.05 | 1 |
| **AH** | 38.59 | 38.63 | 0.04 | | 31.72 | 31.73 | 0.00 | |

## *4. RESULTS*

The most important factors affecting to the variation were found as A, B, and D by Shainin Method. For optimization, the factors obtained by SM should be kept at $A_{(+)}.B_{(+)}.D_{(+)}$ (or $A_2B_2D_2$) levels. Accordingly, A (carbon ratio), B (cutting) and D (bending angle) is being held in the 2nd level while others' levels are chosen according to the cost reduction. The levels of other factors that reduce the cost are determined as $C_2$, $E_1$, $F_1$, $G_2$ and $H_1$. Accordingly, the SM says that optimum production will be provided with $A_2B_2C_2D_2E_1F_1G_2H_1$.

In this case, by keeping the bending angle at high level (93°) a significant portion of the variation of box-profile's inner length will be reduced. In addition, carbon ratio of metal sheet should be low and metal sheet should be cut at 65mm.

As a result of the implementation of the Taguchi Method, the most effective factors has respectively emerged as D (bending angle), A (carbon ratio) and B (cutting). Investigations to determine the levels of factors, the mean and SN ratio is calculated, in both cases the same results were obtained. Accordingly, factors should be kept in $A_2B_2C_2D_2E_2F_1G_2H_1$ level.

Besides being similar to the results of both methods, conducting experiments, data collection and processing stages and calculation reveals some differences. Table 11 indicates these differences.

Table 11 – Comparing of Shainin and Taguchi Methods after the experiments

| Parameter | Shainin | Taguchi |
|---|---|---|
| **Number of experiments** | 18 | 48 |
| **Time** | 7 hours | 19 hours |
| **Complexity** | Simple | Requires mathematical knowledge |
| **Cost** | Low | High |
| **Shut down the process** | Few | More |

TM has more calculations then SM. Moreover, the SM provides a system that is easier to understand. Furthermore, SM provides to continue the production with less disruption. Consequently, not to do more calculations and to launch the experimental results immediately, the technique presented by SM is more effective according to the TM.

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