Journal of Innovations in Business and Industry

Vol. 02, No. 03 (2024) 147-160, doi: 10.61552/JIBI.2024.03.004 - http://jibi.aspur.rs

# DEFECTS MINIMIZATION USING DESIGN OF EXPERIMENT BASED DMAIC APPLICATION: A CASE OF ROYAL PVC

Muhammad Shihab Ud Din[1]
Muhammad Tahir

Received 14.11.2023.
Accepted 18.01.2024..

Keywords:

*PVC, DMAIC, Quality control, Design of Experiment (DOE), ANOVA.*

A B S T R A C T

*Currently there is 19% rejection in manufacturing occurring due to poor quality. The data was collected and Pareto analysis ranked the defects in descending order according to their counts. The major factors identified are materials composition, temperature of extruder machine, speed of the pull conveyer and feed rate of the motor. ANOVA for diameter is analyzed against the compositions and temperature of the extruder machine. Both samples were rejected based on software results and shown that the variation is uniform. Color failure analysis is based on verbal communication with dealers and SMEs at site work. In the improvement phase, two levels were selected for each factor (temperature, feed rate and conveyer speed) and the experiment is designed as three factors factorial design. Main effect and interaction effects were identified and consequently, the conveyer speed and the interaction of temperature and feed rate (2-way interaction) were found to be significant factors.*



## 1. INTRODUCTION

Efficient and potent statistical methods are employed in Six Sigma, a customer-centered quality engineering approach, to determine, quantify, analyze, improve, and control procedures used by organisations to guarantee superior performance. The goal of Motorola's Six Sigma approach, which has been embraced by many businesses, is to decrease variation in manufacturing as well as business procedures. Quality control is a process or set of actions envisioned to certify that a factory-made product or achieved service stick to to a demarcated customary of quality standards or sees the necessities of the consumer or buyer (Dale H. Besterfield, 2007). Effective businesses unavoidably place excessive weight on handling excellence control. Quality is critical to satisfying customers and retaining their loyalty (Khan, Dalu and Gadekar, 2014). Offering quality products to customers provide a competitive advantage over competitors which helps in winning business and gives manufacturers the chance to custody top prices for a higher product (Devor, Chang and Sutherland, 1992). A quality control structure aids to inferior levels of surplus and rework, lowering costs and enlightening output and production efficacy (Johan, 2011). The concept of six sigma is wide but can easily be expressed through a graph of a normal curve (Hakeem–Ur–Rehman, 2010). Pakistan is full associate of International Standards Organization (ISO) via PSQCA (PSQCA, 2023). Pakistan Standard set measures, rubrics and strictures in contradiction of products, amenities and progression are restrained or related. Unfortunately, due to current political situations for the last few years PSQCA don't completely follow up and the quality policies are variant from organization to organization (PSQCA, 2023). Experimentation is considering a vigorous fragment of the scientific or engineering system. Methods of experimental design have originated wide application in various disciplines. In wide-ranging, experiments are employed to explore the recital of procedures as well as systems (Devor, Chang and Satharland, 1992). Designed experiments

[1] Corresponding author: Muhammad Shihab Ud Din
Email: 03-398201-035@student.bahria.edu.pk

show a significant part in improvement of the quality (Douglas C., 1984). In the present study, a thorough Six Sigma DMAIC research was conducted within a firm functioning in PVC pipe manufacturing which are then shipped to different sectors like irrigation, sanitation and other government as well as private sectors and dealers. DMAIC methodology was applied in the firm for the lower diameter, wall thickness and color variations problem which create around 19% of the total product rejection found via primary examination. The objectives of the work were attained by applying several tools and methods like workflow, SIPOC, Pareto chart, Anderson Darling analyses, control charts and capability analysis(Magar et al., 2014).

**Design of Experiment**

Design of experiments (DOE) is an organized technique to control the connection amongst aspects up setting a process and the production of that course. In simple words, it is employed to determine cause-and-effect relations. This evidence is desirable to achieve process involvements in order to enhance the productivity(Correia et al., 2023). In DOE, controllable factors are varied in a controlled environment to determine their impact on the response variable. For analyzing a process, experiments are conducted to evaluate which input variables yield a desired response variable(Phadke, 1989). Design of experiment helps in preparation, steering, analyzing and understanding meticulous assessments to assess the aspects that rheostat the value of a parameter or set of parameters(Selvamuthu and Das, 2018). It also helps in reducing manufacturing costs by lessening dissimilarity and reduces redraft, scrap and need of inspection and significantly improves process yield.

A well–performed test may deliver answers to queries such as, what are the main issues in the process? at what situations would the process bring satisfactory presentation? what are the important, chief and interface effects in a process? what situations would fetch near fewer dissimilarity in the production? Expressive responses to these queries a well-organized process can be generated. DOE is employed when further than one contribution feature is supposed of persuading the production (Roy, R.K., 2001). For instance, it may be wanted to comprehend the consequence of temperature and compression on the forte of an adhesive bond. DOE can likewise be incorporated to settle supposed input/output relations and to grow a extrapolative equation appropriate for acting what-if investigation(Briand, Bunse and Daly, 2001).

**Factorial Design**

A factorial design is kind of intended experiment that rents study of the properties that numerous aspects can have on the response. When steering an experimentation, changing the levels of entire aspects at the identical time as an alternative of one at a time rents the scholars examine the connections among the factors(Gardeur et al., 2007).

Old-style research approaches usually used to study the outcome of single variable in a period, though, in several situations, two or more independent factors effect on a single dependent variable, so it is unreasonable or untrue to try to analyze them in the outmoded technique (Chen et al., 2011).

Factorial design helps in simplifying the process and makes the research easier. Factorial design is essential when connections between factors may be contemporary to evade deceptive conclusions (Ek, 2002). The disadvantage of factorial design is the extent of experiment will upsurge as the number of features rises. It is hard to interpret large size of factorial experiment, even a minor mistake can lead to wrong results (Heiderscheidt et al., 2015). For a 2x2 factorial design, having two factors say A and B at two levels, the formulas used are:

Average main effect of A = $1/2n\,[ab + a - b - (1)]$

Average main effect of B = $1/2n\,[ab + b - a - (1)]$

Interaction effect AB = $1/2n\,[ab + (1) - a - b]$

Where,

“a” signifies treatment grouping of factor A at tall level and factor B at short level.

“b” signifies treatment combination of factor B at high level and factor A at low level.

And,

$SSA = [ab + a - b - (1)]^2 / 4n$

$SSB = [ab + b - a - (1)]^2 / 4n$

$SSAB = [ab + (1) - a - b]^2 / 4n$

Where SS denotes sum of squares of the distinction coefficients for A, B and AB respectively(Meszaros et al., 2005).

Process description

The PVC pipe manufacturing process consists of the following steps. Fig. 1 maps the complete process.

**Mixing**

a. Heating of mix in crushed form to eliminate moisture at temp of 140-150˚C
b. Cooling it to 30-40˚C

**Feeding**

a. Strident raw material to the extruder through bolt inside revolving at 30 rpm

**Extrusion**

a. Material stream cross wise identical screw tub revolving at 180-200 rpm & temperature choice 140-170˚C with the support of heaters.
b. Material liquifiesowing to high temperature, trailed by compaction of raw material, solidity proportion is 1.5:1
c. Bonded material at temp. of 180- 230ºC is accepted through die &mandril to produce 110 mm

**Cooling**

a. Quenching of warm pipe to temperature range of 20-30ºC, through water as coolant, engaging 20 pipes
b. Water and air chilling

**Pulling of pipe**

a. To wrench the pipe from the die revolving at 15 rpm

**Stamping**

a. Engravingaccreditation on the pipe

**Cutting of pipe**

a. Cutting the pipe in 6-meterfragments

**Tilting pipe**

a. Pipe on holder

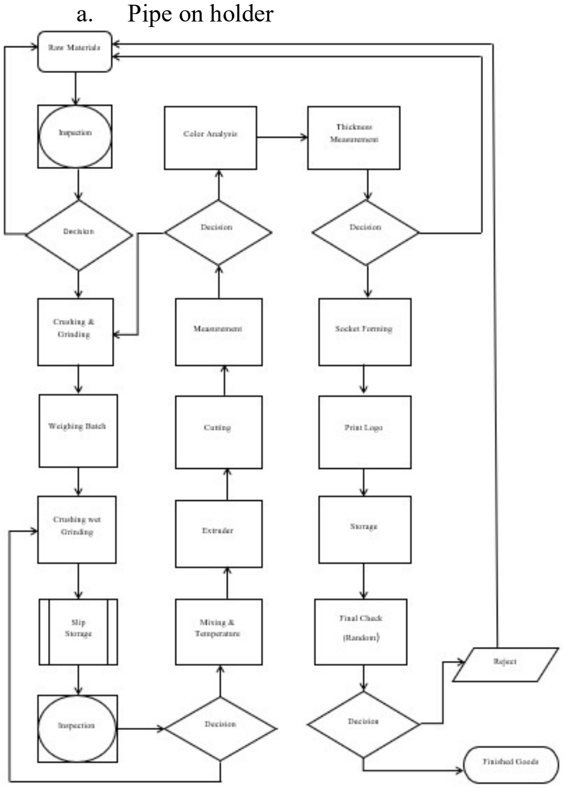


**Figure 1** Process flow for PVC pipe manufacturing

## 2. DEFINE PHASE

In the define phase of the DMAIC methodology, the problem statement and research objectives is the first step to kick off with.

**Problem statement**

Rolex PVC Industry is manufacturing PVC, UPVC and HDPE pipes. Currently there is 81% production free from defects and on the other hand 19% rejection in products occurring due to poor quality. Quality defects in Products are Variation in color of Pipes, variation in weight, Reduction in length and Variation in diameter caused by conveyer speed and Temperature of extrusion machine. The firm is in desperate need to minimize the rejection rate and improve the quality of pipes that meet customer satisfaction and more profitable for the organization as a whole.

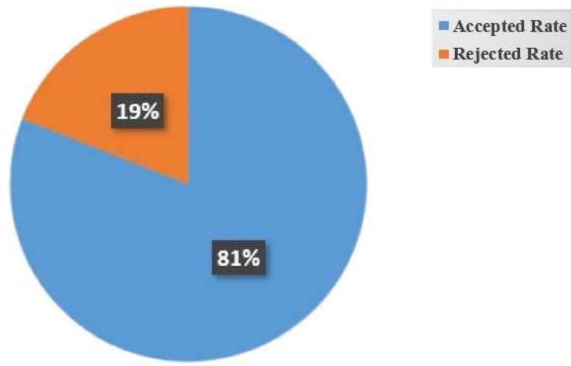


**Figure 2.** Production overview

**Objectives of the research**

The central objective of the researchis to reduce the rejection rate by minimizing the defects in diameter, thickness and color variation of the pipes by not exceeding the tolerance limits.

**SIPOC analysis**

To understand the process inputs, suppliers, outputs and customers of workstation in production line the SIPOC table is developed and also to understand the different processes on production line. It also provides important information and process dependencies on each other hence provide the whole picture of production line(Sabir et al., 2015). Table 1 summarize the SIPOC entities in details.

**Defects in Finished Product**

The main defects in finished goods observed at pulling of pipe and in final inspection, on basis of which the products rejected are thickness, variation in length, variation in diameter and change in color.

**Parameters and Effects**

There are diverse parameters in manufacturingsetting which effects the process ofmanufacturing and lead to defects in pipes.

- Temperature
- Pressure
- Environment
- Operators
- Operations

**Table 1** SIPOC analysis

| S | I | P | O | C |
|---|---|---|---|---|
| Phenolic | Resin | **Mixing**<br>Direct import<br>1. Central heating of mix in crushed form to eliminate moisture at temp of 140-150<br>2.cooling it to 30-40 C | Mixture in crushed form | Hopper |
| China made | | | | |
| Straight import | | | | |
| Gulshan Rajasthan | Calcium Carbonate | | | |
| Local Company | Pack | | | |
| Godrej | Steric Acid | | | |
| Imported | Crude wax | | Temperature 30-40 | |
| Yamuna | Calcium Steric | | | |
| Dupond | Titanium | | | |
| | Temperature range 20-30 | | | |
| | Churn RPM: 750 rpm | | | |
| Mixture | Mix in Powdered Formula at a temperature of 30-40 | **Feeding**<br>3. Pushing raw material to extruder with screw, inside rotating at 30 rpm | Semisolid state combination at 45-50 degree, Celsius | Die &mandril |
| | Motor speed 21 rpm | | | |
| **Hopper** | Tub zone temperatures:<br>Zone1: 199-210C<br>Zone2: 194-200C<br>Zone 3: 191-198C<br>Zone 4: 138-159C<br><br>Die zone temperatures:<br>zone1: 160-170C<br>Zone2: 168-174C<br>Zone 3: 180-181C<br>Zone 4: 185-193C | **Extrusion**<br>4. Material movementcrossways twin screw caskcircling at 180-200 rpm & temperature series 140-170 with the support of heaters.<br><br>5. Material dissolvesowing to high temperature, followed by compaction of raw material, solidityproportion is 1.5:1<br><br>6. Bonded material at temp. of 180-230c is approved through die & mandrel to yield 110 mm | Extruded Pipe<br><br>Temp. 45-50 C<br><br>Dia = 60 mm<br><br>Thickness 2.5 – 3mm | Cooling Tank |
| Extruder | Water flowing from 20 jets<br>7. Quenching of warm pipe to Cooling water temperature 20-40C | **Cooling**<br>7. Extinguishing of hot pipe to temperature of 20-30 c, with water as coolant, engaging 20 pipes<br>8. Water & air cooling | Quenched pipe next to a temperature of 20-30$^{o}$C | Haul Off |
| Cooling Unit | Holding Pressure: 1 Kgf<br>Haul off RPM: 15 RPM | **Pulling of pipe**<br>9. To wrench the pipe from die revolving at 15 rpm | Maintaining the pipe | Engraving |
| Haul-off | Stamp | **Stamping**<br>10. Stamping certification on pipe | Embossed Pipe | Cutting |
| Stamping | Programmed Gauges to measure dimension of 6m<br>Holding pressure=2kgf | **Cutting of pipe**<br>11. Cutting pipe in 6metre parts | Dimension of pipe = 6 M | Oriented Unit |
| Cutting | Scales | **Tilting pipe**<br>12. Pipe on stand | Collection of pipes on stand | Stock |

## 3. MEASURE PHASE

**Data collection Plan**

The company works round the clock and operating 3 shifts (Morning, Evening, and Night) with 8 hours per shift. Currently the product type is high density polyethylene (HDPE) pipes. The company measures production in term of weight (kg/shift). They use 3600kg of raw materials throughout all the three shifts. Weight of one pipe is 8kg and the running length is 8m.
Total production is 450 pipes per day.
Total Production per day = 450 pipes/day.
Weight per pipe = 8kg
Wall thickness = 2mm
Production per shift = 150 pipes/shift
Mean diameter = 6cm
Tolerance = ±0.2cm
Diameter = 6±0.2cm
The data collection is on daily base i.e. data is collected on daily bases (then count for specific defects) selecting a sample size of 130 i.e. 130 pipes are taken randomly and then count for the specific type of defects that how many pipes are defected (diameter, color, sink marks, thickness). Table 2 summarizes the defects observed.

**Table 2** Summary of observed defects

| **Defects** | **Diameter** | **Color failure** | **Sink Mark** | **Thickness** | **Length.** | **Scratches** |
|---|---|---|---|---|---|---|
| **Counts** | 119 | 73 | 81 | 83 | 68 | 63 |
| **Percentage** | 20.04% | 14.73% | 16.36% | 16.76% | 13.74% | 12.72% |
| **Avg. Rejection** | 17 | 10 | 12 | 12 | 10 | 9 |

**Identification of major defects**

Pareto chart will show those factors which are more contributing in mean rejection of products (diameter, color, thickness). The total number of defects occurring on the specific product was logged and this is analyzed by means of the Pareto chart to distinguish the most regularly taking place. The thorough analysis of this most important extrusion imperfection for a definite product is made very accurate. It is clearly seen from the Fig. 3 that the percentage of the diameter has the highest value i.e. 25.8, this shows that the diameter variation is the most occurring defects.

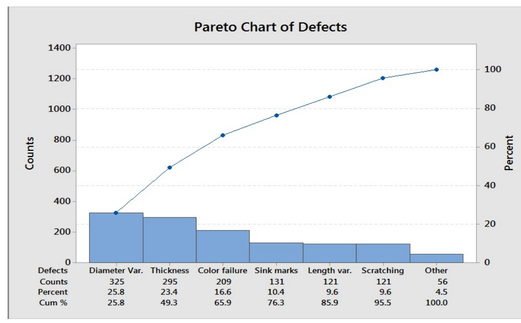


**Figure. 3** Pareto chart for types of defects

**Base line identification**

As the data was collected, get a start from checking the basic statistics for all the % pipes rejected. This is the very first step to check whether the claim of rejection (which is 19%) satisfied or not.

**Table 3.** Basic descriptive information

| **Variable** | **Total Count** | **N** | **N*** | **CumN** | **Percent** | **CumPct** | **Mean** | **SE Mean** | **TrMean** | **St Dev.** | **Variance** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total rejection | 20 | 20 | 0 | 20 | 100 | 100 | 25.00 | 0.750 | 24.944 | 3.356 | 11.263 |
| Variable | coefVar | sum | Sum of squares (SSQ) | | | Min | Q1 | Median | Q3 | Max | Range |
| Total rejection | 13.42 | 500.00 | 12714.000 | | | 20.000 | 22.00 | 24.500 | 27.000 | 31.00 | 11.000 |
| Variable | IQR | Mode | | N for Mode | | Skewness | | Kurtosis | | MSSD | |
| Total rejection | 5.000 | 22, 27 | | 3 | | 0.40 | | -0.83 | | 9.737 | |

As can be seen clearly from basic descriptive statistics in table 3 mean rejection is 25.00 and the standard deviation is 3.36. It does mean that there is a wide spread in data and more variation.
The mean rejection of 25 pipes in the sample size of 130 pipes satisfies the claim of 19% rejection[1]. N is the number of samples being taken. Standard errors of the mean show how quite the sample mean approximate the population mean. Minor SE Mean indicates more accurate estimate of the population means. Since here

[1]Mean of 25 in 130 sample size is 19%. i.e. 25/130*100= 19%

the standard deviation is larger and so is the SE Mean[2]. Standard deviation shows the common degree of diffusion that how much the data is spread from the mean(Sharma et al., 2019). Variance is the amount of spreading which is the degree to which a data is dispersedabout its mean value. It is a square of standard deviation. Greater the variance, greater is the chance of product being out of the specification(Sharma et al., 2018). Since the coefficient of variation has a large value, it shows large variability in data[3].

The Anderson-Darling Normality graph – Fig. 4 shows that mean rejection (mean is 25) lies between 23.429 and 26.571 which satisfies the claim of 19% (end note i) and Standard deviation lies between 2.552 and 4.902. In this test the A-Squared value is the Anderson-Darling indicators which shows how fine the data follows the specific distribution(Nelson, 1998). The well the distribution hysterics the data, the minor this measurement is. The hypothesis for this test is,

$H_o$; The data tail the quantified distribution

$H_1$; The data do not tail the quantified distribution

Decision is made on the bases of p-value in the test(Wasserstein and Lazar, 2016). If p-value is lower than significance level, concluded that the data do not tail a stated distribution. Here the p-value shows that the data follow a normal distribution as we specified this distribution while performing the test. The boxplot at the bottom shows the basic statistics. The left most edge shows the minimum value, the top shows Q1, mean and the right end shows Q3, the right most edge shows the maximum value. Also, the 95% confidence intervals for mean, median and standard deviation is shown.

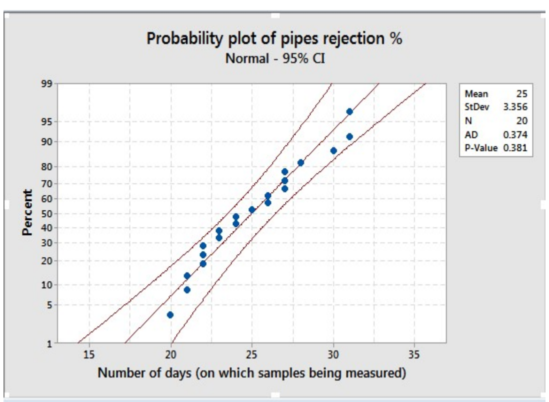


**Figure 4**. Anderson-Darling normality test

As clear from the Fig. 5 the normal distribution probability plot, mean of 25 and standard deviation 3.356 seems to appropriate the sample data impartiallyfine(Ives, Olson and Baroudi, 1983). The plot shows that,

- The strategized points form a rationally straight line.
- Plotted points tail the close-fitting line impartially closely.
- The p-value clears from Anderson-darling and probability plot is 0.381 which is well larger than 0.05. Subsequently the p-value is bigger than significance level (α = 0.05) the data is normal.

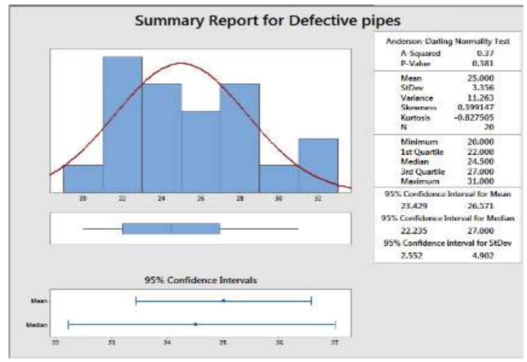


**Figure 5.** Probability plot of defects

**Process capability measurement**

Since the rejection of pipes is an attribute data so the Z-score method is used to find the average process capability(Wu et al., 2009). X denotes the rejection and P represent the probability of the rejection percentage. Referring to the table of standard normal distribution mean is nil and standard deviation is 1. Compare the values with table and calculate the Cpk value. The calculation summarizes as follows,

Inverse cumulative distribution function

Normal by mean = 0

Standard deviation = 1

Since mean is 19% so here it is 0.19

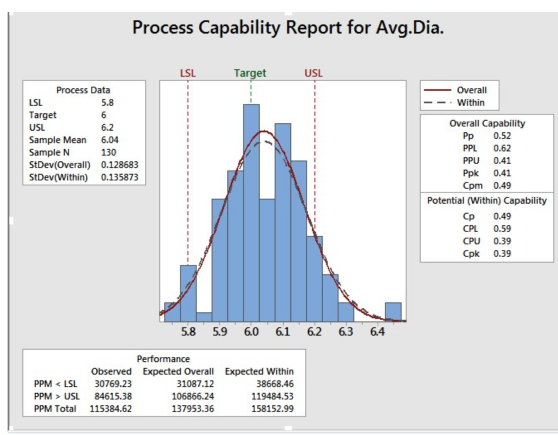


**Figure 6.** Capability analysis

**Capability Analysis**

The capability analysis shows how much the process meet the output(Jeang and Chung, 2009) as our data is normally distributed. Here we will do the analysis of the diameter values. Since target diameter is 6cm we'll give

[2]The SE Mean depicts sample standard deviation (s) divided by the square root of the sample size (n). Therefore:

· A higher standard deviation will form a higher SE Mean.

· A higher sample size will give a lower SE Mean

[3]A measure of relative variation, equal to the standard deviation divided by the mean

tolerance SL as CL for the process. Here the upper limit is 6.2 and lower limit is 5.8, the graph below shows the process capability analysis.

In Fig. 6, PPL dealings how near process mean successively close to inferior specification limit. PPU dealings how close process mean in succession close to higher specification limit. $Pp_k$ equals the lesser of PPL and PPU. Since in above graph the PPL>PPU, the process is not centered(Jeang and Chung, 2009). Process would be centered and more capable if both PPL=PPU. It is supplementary probable to yield malfunctioning units that disrupt the USL. $Pp_k$ value is compared with the benchmarked value which is 1.33 used by most of the industries. For interpreting the graphical results, data should roughly tail normal distribution which seems to have satisfied in our case as revealed by histogram in Fig. 6. As can be seen in Fig. 6 process mean 6.04 is slightly greater than the target and both tails fall outside of the specification limits. It means we'll sometimes see the pipes with diameter less or greater than the specification limits. $C_p$ is the capability index which compares the tolerance with the specification spread (Deleryd and Vännman, 1999). Here $Pp_k$ index is 0.41 indicating that the manufacturer must progress the process by falling the inconsistency and bring the process close to target value of 6.0. The PPM Total in graph is the number of parts per million (115384) whose diameter falls outside the limits. This means 115384 pipes out of 10, 00,000 pipes do not meet the specification.

**Key areas identification**

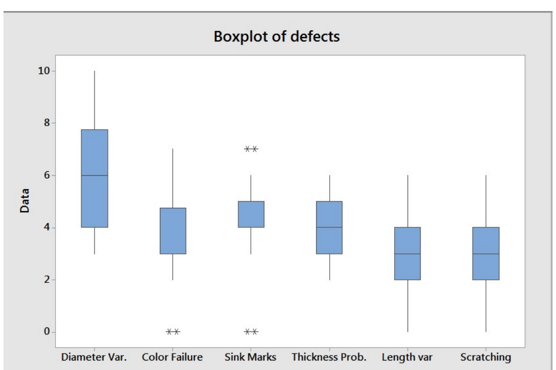


**Figure 7.** Box plot of defects

The box plot for each defect type is plotted against its rejection. In data table, we mentioned the rejection numbers of each defect type in a sample. The Data on y-axis shows the number of pipes being rejected and x-axis shows the specific defect type. The whiskers of the plot of diameter var. cover more area shows that most of rejection occurs due to the variation in diameter of the pipes. Similarly, color failure and thickness prob. (unusual wall thickness) also contribute in mean rejection.

Histogram summarizes the means and standard deviations in each defect type with normal distribution curve. The mean of diameter is 5.95 with standard deviation of 1.986 while means of sink marks and thickness is 4.1 with standard deviations of 1.832 and 1.182 respectively which has more contribution in rejection rate. As the team has also focus in color failure so will also take it in consideration. Here the mean is 3.4 and standard deviation is 1.729.

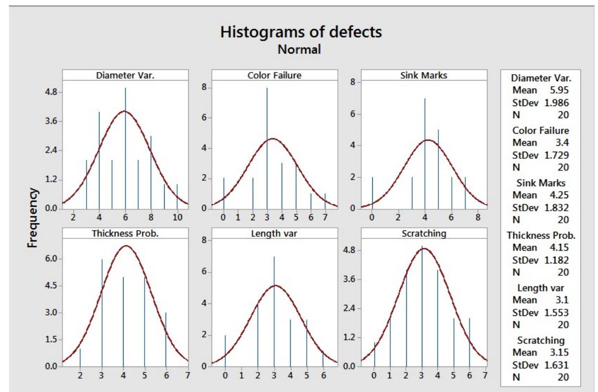


**Figure 8.** Histogram of defects

Now to check whether our data of the diameter measurement follow the normal distribution or not. For this check we'll use the probability chart. The plot points are the average of the 7 days measured data.

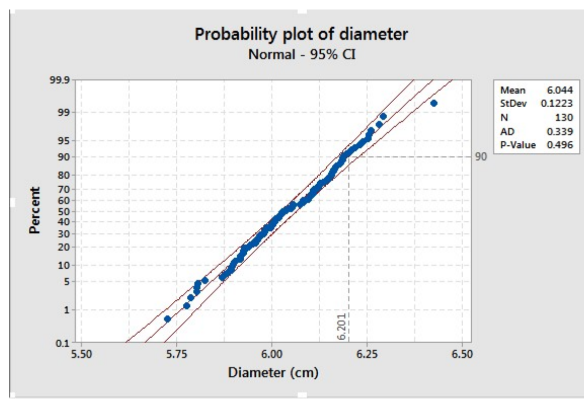


**Figure 10.** Probability plot of diameter (cm)

Data will follow a specified distribution (in our case normal distribution) if it meets the following requirements in probability plot(Wasserstein and Lazar, 2016).

1- The plotted points will closely form a straight line.
2- The plotted points will drop closed to the close-fitting distribution line[4].
3- The Anderson Darling statistic should be small (less than 1.0) and p-value should be greater than the chosen significance level.

[4]Fitted lines are used to know how well the sample data employ a specified distribution. This line generally overlaid the data points and decision is made on the bases of the parameters developed in graph.

Since all three requirements are meeting, the data is normal and follow a normal distribution.

Since we have taken the sample size of 130 units, then measured those for the diameter with digital vernier caliper. Each single day is being considered as a single subgroup. The observations continued for 7 subgroups. Then took the Average and plot those values on a control chart.

Since a tolerance of ±0.2cm from the mean value is allowed, it is clearly seen from the graph in Fig. 10 that some of the values for diameter either lies overhead the upper limit or beneath the lower limit which clearly shows that variation lies in the diameter.

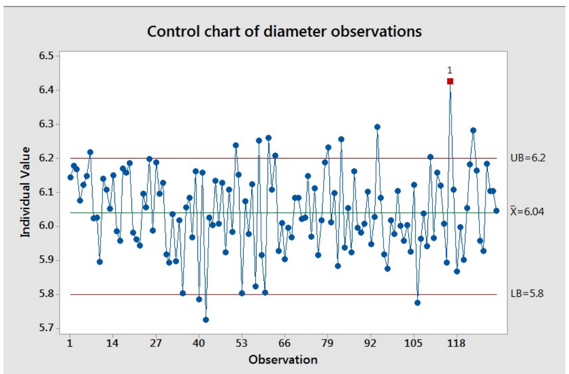


**Figure 10.** Control chart for diameter observations

The prospect plot in Fig. 11 meets the requirements for following the specified distribution by the data (points mentioned with Fig. 9).

## 4. ANALYZE PHASE

**One way ANOVA for composition versus Diameter**

To study the effect of composition against diameter, 15 compositions were tested at temperature T = 160˚C (Extruder temperature). A composition is composed of chalk, platinum, resin, chemicals, pant, clay, which are mixed in a fixed specific ratio by weight. A violation of the amount of ratio may cause variation. Each tested composition may give different result of diameter. Compositions are tested for 15 levels with different specimens at each time. The experiment runs for four replications. So as mentioned, one way ANOVA(Mohiuddin, Krishnaiah and Hussainy, 2015) for alpha (P value) of 0.05 is selected with 15 levels and four replications to study whether the mean diameter for composition is different or not. Each composition is to be analyzed carefully and then to select the best composition which gives appropriate results. Total of 60 runs (15 levels with 4 replications) are completely randomized. As diameter depends upon composition hence it is response variable and independent variable upon which response variable depends is composition.

a = 15 levels

n = 4 replications

Response = Diameter

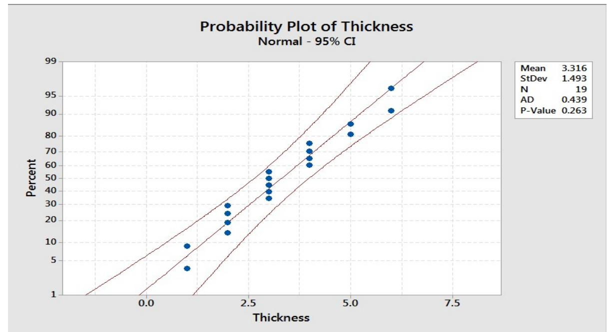


**Figure 11.** Probability plot of Wall thickness rejection

**Table 4** Experimental runs for compositions vs diameters

| Levels | Replications | | | |
|---|---|---|---|---|
| **Compositions** | **1** | **2** | **3** | **4** |
| 1 | 6.14 | 6.01 | 6.04 | 6.00 |
| 2 | 6.12 | 6.00 | 6.00 | 6.08 |
| 3 | 6.12 | 6.37 | 6.23 | 6.08 |
| 4 | 6.13 | 6.01 | 6.12 | 6.31 |
| 5 | 6.00 | 5.73 | 6.14 | 6.04 |
| 6 | 6.43 | 6.11 | 6.05 | 6.00 |
| 7 | 6.25 | 6.09 | 6.01 | 6.43 |
| 8 | 6.00 | 6.40 | 6.11 | 6.12 |
| 9 | 6.08 | 6.09 | 6.13 | 6.31 |
| 10 | 6.04 | 5.97 | 6.02 | 6.23 |
| 11 | 5.91 | 5.97 | 6.05 | 6.24 |
| 12 | 6.18 | 6.00 | 6.08 | 6.31 |
| 13 | 6.05 | 6.14 | 6.01 | 6.14 |
| 14 | 6.00 | 6.09 | 6.08 | 6.31 |
| 15 | 5.74 | 6.12 | 6.00 | 6.03 |

**Hypothesis test for composition versus Diameter**

As ANOVA is based on Alternative and null hypothesis, we have the following test hypotheses

$H_o$; Compositions produces equal means of length -- i

$\mu_1 = \mu_2 = \mu_3 = \ldots\ldots\ldots.. = \mu_{15}$

$H_1$ = At least one composition produces different mean of diameter --------- ii

The test is conducted with a confidence interval of 95% and the p value of 0.05. At these parameters Minitab gives the graphs shown in Fig. 12.

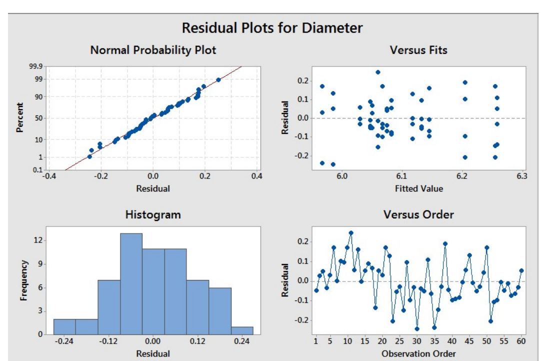


**Figure 12.** Residual plots for diameters

The normal probability graph in Fig. displays that the residuals are distributed normally about a straight path and follow it rationally. Keeping in view the centered zero of histogram and digits nearest to the straight line in normal probability graph, normality supposition of the residual is gratified.

**One-way ANOVA: Diameter versus Composition**

Null hypothesis All means are equivalent
Alternate hypothesis At least one mean is unlike
Significance level α = 0.05
Equal variances were presumed for the analysis.

| Factor Statistics | | | | | |
|---|---|---|---|---|---|
| **Factor** | **Level** | **Values** | | | |
| Composition | 15 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | | | |
| **Analysis of variance** | | | | | |
| **Source** | **DF** | **Adj SS** | **Adj MS** | **F value** | **P value** |
| Composition | 14 | 0.4309 | 0.03078 | 1.94 | 0.048 |
| Error | 45 | 0.7158 | 0.01591 | | |
| Total | 59 | 1.1468 | | | |
| **Model Summary** | | | | | |
| **S** | **R-sq** | **R-sq (adj)** | **R-sq(pred)** | | |
| 0.126124 | 37.58% | 18.16% | 0.00% | | |
| **Means** | | | | | |
| **Composition** | **N** | **Mean** | **StDev** | **95% CI** | |
| 1 | 4 | 6.0475 | 0.0640 | (5.9205, 6.1745) | |
| 2 | 4 | 6.0500 | 0.0600 | (5.9230, 6.1770) | |
| 3 | 4 | 6.2575 | 0.1081 | (6.1305, 6.3845) | |
| 4 | 4 | 6.0750 | 0.0592 | (5.9480, 6.2020) | |
| 5 | 4 | 5.9675 | 0.1715 | (5.8405, 6.0945) | |
| 6 | 4 | 6.255 | 0.204 | (6.1280, 6.3820) | |
| 7 | 4 | 6.1175 | 0.0998 | (5.9905, 6.2445) | |
| 8 | 4 | 6.2050 | 0.1827 | (6.0780, 6.3320) | |
| 9 | 4 | 6.1325 | 0.0685 | (6.0055, 6.2595) | |
| 10 | 4 | 6.0675 | 0.1187 | (5.9405, 6.1945) | |
| 11 | 4 | 6.0600 | 0.1763 | (5.9330, 6.1870) | |
| 12 | 4 | 6.0825 | 0.0911 | (5.9555, 6.2095) | |
| 13 | 4 | 6.1450 | 0.1162 | (6.0180, 6.2720) | |
| 14 | 4 | 6.0300 | 0.0424 | (5.9030, 6.1570) | |
| 15 | 4 | 5.9850 | 0.1676 | (5.8580, 6.1120) | |
| Pooled StDev = 0.126124 | | | | | |

The null hypothesis $H_o$ as stated earlier shows that the mean diameters of fifteen compositions are equal. But when the data is run through a software for composition vs diameter for ANOVA the results give the p value of 0.048 which is less than α = 0.05 hence indicates sufficient evidence that all the means are not equal. What it shows that at least one of the means is different at confidence interval of 95%. So, the null hypothesis is omitted and determined that composition has an impact on the diameter variation. Now to study the difference among the means of diameter and composition further analysis needs to be carrying out. Based on the analysis the best composition is to be selected which can satisfy the optimum requirements.

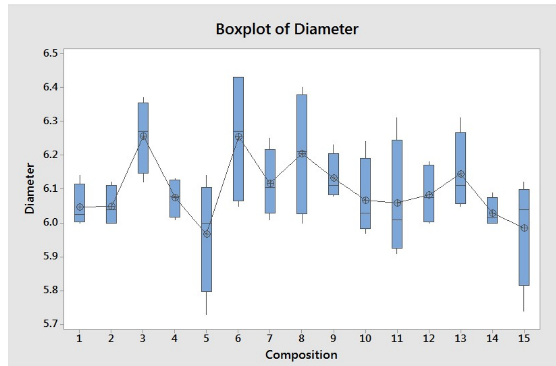


**Figure 13.** Box plot – composition vs. diameter

Since the mean diameter is 6cm but the acceptable lies in range between 5.8cm and 6.2cm and in the Box plot shown above this range is occupied by the compositions number 1, 2, 4, 9, 10, 12, 14 and the rest of the compositions do not have an acceptable range of diameter values and hence should not be consider in further analysis. From the accepted range of diameter values select two or three of most economical compositions. We will do the cost analysis for these compositions because they are different from each other having different ingredients mixed in a fixed specific ratio by weigh.

**Cost analysis**
In this section the cost analysis is conducted for the compositions that give the required results. Each composition is composed of some ingredients which are enlisted in table below. The cost of each ingredient is mentioned per 100kg in PKR. For each composition the amount of weight being using is shown in table 5.

**One –way ANOVA for Temperature vs Diameter**
To study the variance and effects of temperature on diameter we will repeat the same procedure as stated earlier for temperature vs diameter. 5 levels of temperatures were tested for four replications that gives different results and the runs are completely randomized. The experimental runs are summarized in the following table.

**Table 5** Cost analysis of composition

| Ingredients | Cost per 100kg | 1 | 2 | 4 | 9 | 10 | 12 | 14 |
|---|---|---|---|---|---|---|---|---|
| **Resin** | 36196 | 25 | 100 | 35 | 27 | 29 | 31 | 54 |
| **Titanium** | 51560 | 1.5 | 2.6 | 1.65 | 1.31 | 1.70 | 1.46 | 1.83 |
| **Grey** | 10430 | 60 | 60 | 60 | 60 | 43 | 45 | 54 |
| **Chemical** | 27000 | 1.5 | 2.8 | 1.45 | 1.87 | 1.46 | 1.59 | 1.47 |
| **Color** | 15000 | 0.4 | 0.0 | 0.45 | 0.87 | 0.46 | 0.23 | 0.46 |
| **DP Oil** | 28000 | 0.8 | 1.0 | 1.0 | 1.0 | 1.25 | 1.25 | 1.20 |
| **H×10** | 25000 | 0.8 | 1.0 | 0.8 | 0.5 | 0.4 | 0.5 | 0.5 |
| **Chalk** | 23000 | 10 | 10 | 15 | 10 | 20 | 15 | 10 |

**Table 6.** Experimental runs for temperature vs diameters

| **Levels** | **Replications** | | | | |
|---|---|---|---|---|---|
| **Temperature** | **Values** | **1** | **2** | **3** | **4** |
| $T_1$ | 151˚C | 6.08 | 6.12 | 6.14 | 6.12 |
| $T_2$ | 161 ˚C | 6.32 | 6.31 | 6.31 | 6.12 |
| $T_3$ | 171 ˚C | 6.04 | 6.14 | 6.03 | 6.13 |
| $T_4$ | 182 ˚C | 6.12 | 6.[illegible] | [illegible] | [illegible] |
| $T_5$ | 190 ˚C | 5.80 | 5.[illegible] | [illegible] | [illegible] |

**Hypothesis test for Temperature versus Diameter**

Since ANOVA is based on Alternative and null hypothesis, we have the following test hypothesis

$H_o$; Temperature produces equal means of diameter --- i

$\mu_1;\ \mu_2 = \mu_3 = \ldots\ldots\ldots. = \mu_5$

$H_1$; At least one temperature produces different mean of diameter --------- ii

The test is conducted with a confidence interval of 95% and the p value of 0.05. At these parameters Minitab gives the set of graphs.

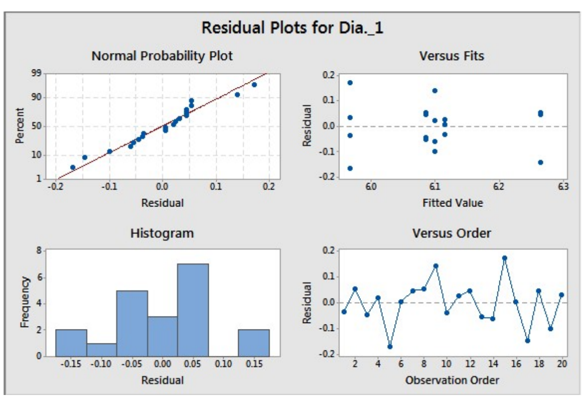


**Figure 14 Residual plots for diameters**

The normal probability graph in Fig. 14 depicts that the residuals are disseminated normally throughout a straight line and tail level headedly the straight line. Likewise, in the similar Fig. a histogram displays that the residual constructs a normal distribution positioned at zero. Keeping in sight the positioned zero of histogram and values nearer to the straight line in normal probability graph, normality supposition of the residual is contented.

**One-way ANOVA: Diameter versus Temperature**

Method

Null hypothesis All means are identical

Alternative hypothesis At least one mean is dissimilar

Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.

**Factor Information**

| **Factor** | **Levels** | **Values** |
|---|---|---|
| Temperature | 5 | T1, T2, T3, T4, T5 |

**Analysis of Variance**

| **Source** | **DF** | **Adj SS** | **Adj MS** | **F value** | **P value** |
|---|---|---|---|---|---|
| Temperature | 4 | 0.2508 | 0.06269 | 3.93 | 0.022 |
| Error | 15 | 0.2395 | 0.01596 | | |
| Total | 19 | 0.4903 | 0.07865 | | |

**Model Summary**

| **S** | **R-sq** | **R-sq (adj)** | **R-sq(pred)** |
|---|---|---|---|
| 0.126353 | 51.15% | 38.13% | 13.16% |

**Means**

| **Temperature** | **N** | **Mean** | **StDev** | **95% CI** |
|---|---|---|---|---|
| T1 | 4 | 6.1400 | 0.0589 | (6.0053, 6.2747) |
| T2 | 4 | 6.2650 | 0.0968 | (6.1303, 6.3997) |
| T3 | 4 | 6.1350 | 0.1439 | (6.0003, 6.2697) |
| T4 | 4 | 6.1000 | 0.1058 | (5.9653, 6.2347) |
| T5 | 4 | 5.9175 | 0.1873 | (5.7828, 6.0522) |

Pooled StDev = 0.126353

The null hypothesis $H_o$ as stated earlier shows that the mean diameters of five temperatures are equal. But when the data is run through a software for temperature vs diameter for ANOVA the fallouts give the p value of 0.022 which is less than $\alpha = 0.05$ hence indicates sufficient evidence that all the means are not equal. What it shows that at least one of the means is different at confidence interval of 95%. So, the null hypothesis is insignificant and determined that temperature has an impact over the diameter variation. Now to study the difference among the means of diameter and temperature further analysis needs to be carrying out. Based on the analysis the best exact or range of temperature is to be selected which can satisfy the optimum requirements.

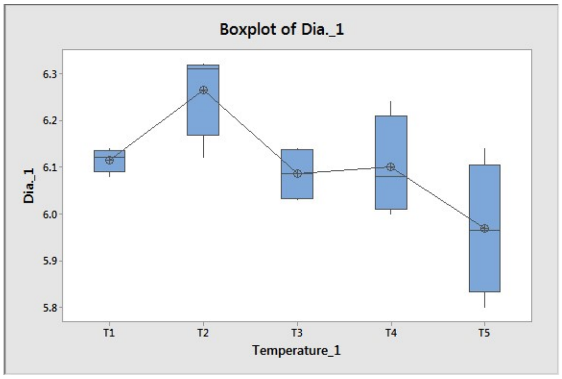


**Figure 15.** Boxplot of diameter vs temperature

Since the mean diameter is 6cm but the acceptable lies in range between 5.8cm and 6.2cm and in the Boxplot shown above this range is occupied by the temperatures $T_1$, $T_3$, $T_5$ and the rest of the temperatures do not have an acceptable range of diameter values and hence should not be consider in further analysis. From the accepted range of diameter values select these two temperatures. We will consider these temperatures in Improve Phase.

**Color failure Analysis**

The color failure analysis is based on the verbal communication with the dealers and Quality Engineer at Department of Irrigation Disstt. Nowshera (Oct – Dec 2023). The causes, types and occurrence of failure is summarized in the attached table. The team decided to go for the selection of specific ratio of coloring material in manufacturing process.

**Wall thickness Analysis**

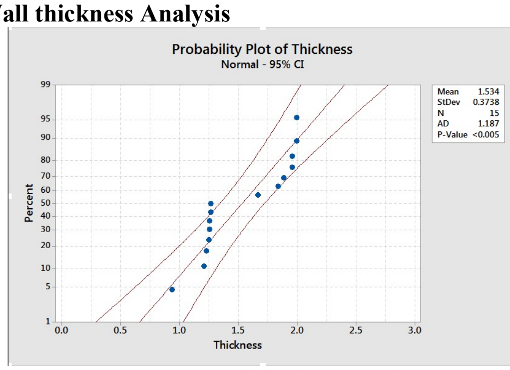


**Figure 16.** Wall thickness analysis

Since we are interested in a thickness value of 2mm with appropriate parameters. Here with the different speeds, a sample is completely deviating from the required specifications and limits. Mean thickness is 2mm but here the graph illustrates 1.5mm. Also, a p-Value is far lower than 0.05 so the sample is to be rejected. In short, speed is the matter of greater concern to control the process that maintains the thickness value in specified limits.

## 5. IMPROVE PHASE

**Design of experiment**

Afterward the derivation cause(s) has/have been found, the DMAIC's "Improve" stagegoals at recognizinganswers to decrease and block them. (Douglas C., 1984)proposes the implication of design of experiments (DOE). In this phase, an experiment is steered to find best values of Temperature and Conveyer Speed for improvement of variation in Thickness of PVC pipes. Therefore, the Full Design of Experiment method is used which consist of two or extraaspects, each with distinctconceivable values or "levels", and whose investigationalelements take on entirely possible groupings of these levels athwartentirely such aspects.

**Table 7** levels of factors

| S. No | Factors | Level (-1) | Level (1) |
|---|---|---|---|
| 1 | Temperature | 161 | 182 |
| 2 | Conveyer Speed | 8.6 | 9.1 |
| 3 | Feeder Speed | 9.1 | 9.4 |

**3 factors factorial design**

**Table 8** factorial design

| StdOrder | RunOrder | PtType | Blocks | Coveyer Speed | Temp | Feeder Speed | Response |
|---|---|---|---|---|---|---|---|
| 12 | 1 | 1 | 1 | 9.1 | 182 | 9.1 | 6.020 |
| 6 | 2 | 1 | 1 | 9.1 | 161 | 9.4 | 6.230 |
| 16 | 3 | 1 | 1 | 9.1 | 182 | 9.4 | 5.870 |
| 15 | 4 | 1 | 1 | 8.6 | 182 | 9.4 | 6.320 |
| 14 | 5 | 1 | 1 | 9.1 | 161 | 9.4 | 5.950 |
| 2 | 6 | 1 | 1 | 9.1 | 161 | 9.1 | 6.410 |
| 10 | 7 | 1 | 1 | 9.1 | 161 | 9.1 | 6.150 |
| 8 | 8 | 1 | 1 | 9.1 | 182 | 9.4 | 5.760 |
| 7 | 9 | 1 | 1 | 8.6 | 182 | 9.4 | 6.120 |
| 3 | 10 | 1 | 1 | 8.6 | 182 | 9.1 | 6.023 |
| 9 | 11 | 1 | 1 | 8.6 | 161 | 9.1 | 6.234 |
| 13 | 12 | 1 | 1 | 8.6 | 161 | 9.4 | 6.310 |
| 5 | 13 | 1 | 1 | 8.6 | 161 | 9.4 | 6.230 |
| 11 | 14 | 1 | 1 | 8.6 | 182 | 9.1 | 6.130 |
| 1 | 15 | 1 | 1 | 8.6 | 161 | 9.1 | 6.060 |
| 4 | 16 | 1 | 1 | 9.1 | 182 | 9.1 | 5.890 |

**Full factorial design**

Factors: 3 Base Design: 3, 8

Runs: 16 Replicates: 2

Lumps: 1 Focus pts (total): 0

Number of levels: 2, 2, 2

General Factorial Regression: Response versus Conveyer Speed, Feeder Speed, Temp

**Factor Information**

| Factor | Levels | Values |
|---|---|---|
| Conveyer Speed | 2 | 8.6, 9.1 |

Feeder Speed 2 9.1, 9.4
Temp 2 161, 18

The MiniTab provided the following resulted values when the design was run.

**Table 9** Result analysis

| Response | FITS1 | RESI1 |
|---|---|---|
| 6.020 | 5.9550 | 0.0650 |
| 6.230 | 6.0900 | 0.1400 |
| 5.870 | 5.8150 | 0.0550 |
| 6.320 | 6.2200 | 0.1000 |
| 5.950 | 6.0900 | -0.1400 |
| 6.410 | 6.2800 | 0.1300 |
| 6.150 | 6.2800 | -0.1300 |
| 5.760 | 5.8150 | -0.0550 |
| 6.120 | 6.2200 | -0.1000 |
| 6.023 | 6.0765 | -0.0535 |
| 6.234 | 6.1470 | 0.0870 |
| 6.310 | 6.2700 | 0.0400 |
| 6.230 | 6.2700 | -0.0400 |
| 6.130 | 6.0765 | 0.0535 |
| 6.060 | 6.1470 | -0.0870 |
| 5.890 | 5.9550 | -0.0650 |

**Regression Equation**

Response = -309 + 37 A + 0.91 B + 31 C - 0.109 A*B - 3.6 A*C - 0.077 B*C + 0.0094 A*B*C

This is the obligatory equation which will deliveroptimal value for Response Variable by entering the appropriate values to Temperature of extruder, conveyer speed and feed rate.

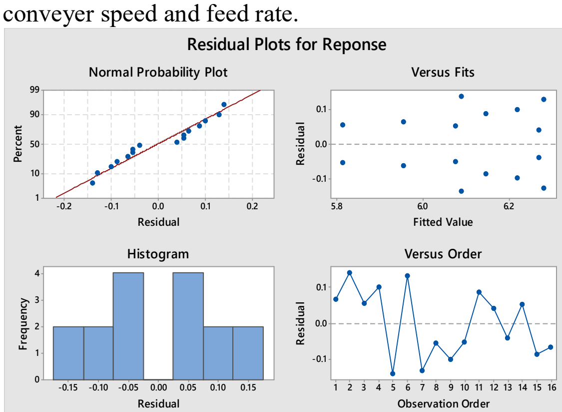


**Figure 17.** Residuals Plot for Response

The analysis of variance table gives a summary of main effects and interactions amongst these three aspects which are 'Temperature', 'Conveyer Speed' and 'Feeder Speed'. Subsequently, looking at the P-Values in table to regulate whether or not there is somewhat significant possessions at 95% confidence level i.e. Alpha 0.05. The outcome displays that main effects and interaction effects mutually are noteworthy as P-Value (0.023) of main effect factor which is Temperature is fewer than Alpha value (0.05) and while two-way interaction between Conveyer Speed and Feeder Speed have also their P-values (0.048) is lower than Alpha Value. and the three-way interaction have no substantial effects. The value of R squared 73.29% is fairlysufficient to fit the data and it depicts the proportion of variation covered by factors i.e. Temperature, Conveyer Speed and Feeder Speed.

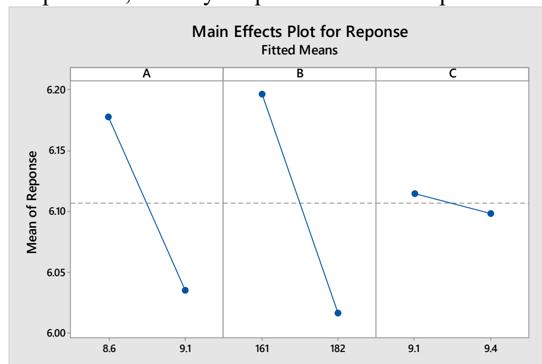


**Figure 18.** Main effect plot

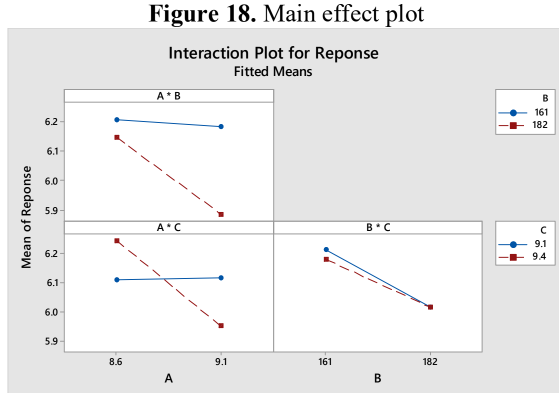


**Figure 19**. Interaction plot

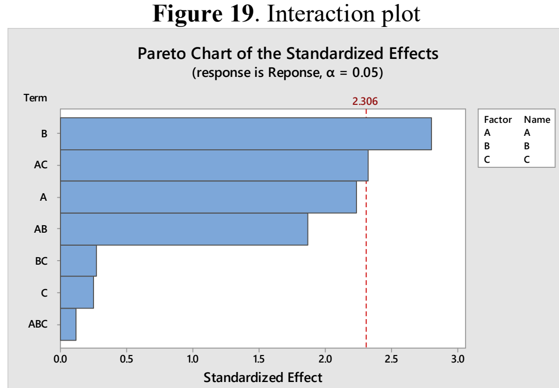


**Figure 20**. Final pareto chart of standardize effects

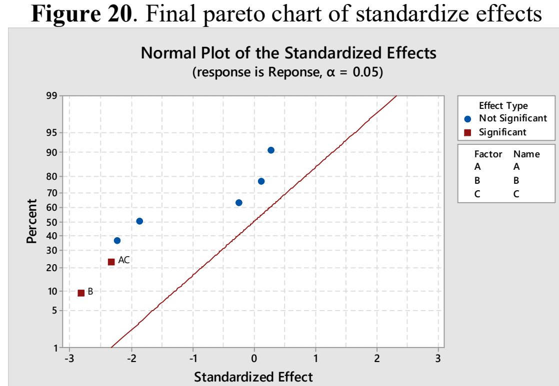


**Figure 21.** Final normal plot of standardize effects

**Prediction for Response**

Regression Equation in Uncoded Units

**Response** = -309 + 37 A + 0.91 B + 31 C - 0.109 A*B - 3.6 A*C - 0.077 B*C + 0.0094 A*B*C

**Variables Setting**

| | |
|---|---|
| A | 8.6 |
| B | 161 |
| C | 9.1 |

**Table 11.** Final response

| Fit | SE Fit | 95% CI | 95% PI |
|---|---|---|---|
| 6.147 | 0.0906789 | (5.937, 6.175) | (5.78482, 6.50918) |

The Session window output shows the model equation and the variable setup. The fit value (correspondingly called projected value) for these situations is 6.147 cm. Though, all approximations comprise uncertainty since they employ sample data. The 95% confidence interval is the assortment of probable values for the mean response value. By utilizing the Temperature value of 161, Conveyer Speed of 8.6 and Feeder Speed of 9.1, researcher is 95% assured that the mean response value which is Diameter, will be lying around 5.937 and 6.175 cm.

The constructive impression to the firm from the effective use of the DMAIC approach advocates that other organizations may advantage in the forthcoming by steering comparable process improvement studies. In accumulation, supplementary research can be steered to check whether the practice of the design of experiments grounded DMAIC procedure could produce comparable benefits particularly in the PVC products manufacturing industries.

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**Muhammad Shihab Ud Din**
UET Peshawar
Pakistan
03-398201-035@student.bahria.edu.pk
**ORCID** 0009-0002-3812-1150

**Muhammad Tahir**
UET Peshawar
Pakistan
16pwmec4132@uetpeshawar.edu.pk
**ORCID** 0009-0000-3409-1885