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# Improving quality through statistical process control in Bayeh Mekonnen polypropylene bag factory

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***Abstract*** *— This article aims to allow Bayeh Mekonnen polypropylene (PP) bag factory in Bahir Dar, Ethiopia to achieve in producing qualified product and customer requirement based product through which the company reduces defects, variations, and quality costs by implementing statistical quality control to overcome all quality problems in the company. It is mainly concentrated in the tape plant and cutter sections of the company. Because most of the quality problems are incurred in these sections, to address such cases, this article mainly focuses on improving quality by using statistical quality control and control chart analysis to show the variation and stability of the process. According to the analysis conducted, the process control chart is out of control, then replacement analysis is utilized for existing and new cutter machines. Moreover, the experiment's design is analyzed because of the control chart for the tape plant section. The company can save 143,640 ETB per two months by applying the proposed parameter settings (annealing temperature, Pressure, speed of Feed, and melting Temperature).*

**Keywords —** *Control charts, DOE, Quality control, SPC*

## I. INTRODUCTION

Quality is about making organizations perform for their stakeholders by improving products, services, systems, and processes to ensure that the whole organization is fit and effective[1]. Control charts are used to identify random causes (common causes) of variation and assignable causes (special causes). Common causes of variation are natural causes of variation which inherent to the process. Whereas, Assignable causes of variation are special causes of variation which are acquired during the process. The control limits process is called in control or stable and is caused by the most common variation causes. The process that contains points beyond control limits is called out of control or unstable process, and the variation is mainly caused by an assignable or special cause of variation [1]. Noted that the consequences of non-conforming shipping products can be a significant loss, which can be measured in terms of customer dissatisfaction [2]. Garvin provides an excellent discussion of seven components or dimensions of quality, and the case company also tries to consider all these product dimensions when it produces the bag products [3], [8]. A. Yohannis, M. Haile, and S. Tsegaye studied the quantity related problems in the Amhara pipe industry. The case study was done on HDPE pipe product number defect size. Each process of the pipe thickness and making them were observed from three production lines and data were obtained, and the data was analyzed manually. The analyzed data were compared using Excel, and the root problems and errors were identified [4]. But the researchers used only SPC tools for improvement. A. Mebrate E. Kebede, and H. Semachew, analysis shows that the process is unstable, out of control, and also the process is incapable. Finally, important remarks and recommendations on quality improvement are forwarded for the company [5]. Mohamed Knairul Abdu does the other study. Halim in Chaudhary textiles (Malaysia) using SPC tools, especially the x-bar and R-bar chart and process capability study, variation due to assignable causes in the process identified where 4M causes become the main source of variation. After he takes prevention, action and countermeasures are proposed to get the process back on its target based on the assignable causes [6].

Higher product quality is required for a company to become more competitive, both locally and internationally trend. Improved quality increases productivity. According to its international standards, the factory especially manufacturing and distributes a product used in a factory related to agricultural sector development, flour factories, and exporters. However, Nowadays, the company produces a product at a lower quality, and products have not been producing as per the customer's conformance. Product measurement takes place for the inspection purpose in the Bayih mekonnen PP bag factory. During the inspection process, all products are measured depending on its parameter that needs to be measured. The measurement is performed at the end-product level. In the case company, quality-related activities are mainly inspection-oriented: inspection of finished production lots and comparing product measurements with product specifications. Companies tried to ensure product quality.

### *A. Design and Analysis of Experiment*

The design of experiments is a series of techniques which involves the identification and control of parameters which have a potential effect on the performance and reliability of a product design and/or the output of a process, intending to optimize product design, process design, and process operation, and limiting the effect of noise (uncontrollable) factors. The objective is to optimize the value of design parameters to make the system's performance immune to variation. Taguchi primarily uses orthogonal arrays to develop experimental designs to reduce the variation of performance characteristics affecting a product's target values [9].

### *B. Measurement of Performance Variation*

Taguchi defines the performance statistic signal to noise ratio for nominal as the best performance characteristics [7].

Signal to noise ratio detects the causes of variation. To measure this variation, Taguchi has suggested the use of loss function. He has also introduced the loss function concept to measure the variation of a performance characteristic affecting a product's quality from its target value in monetary terms.

## II. STATEMENT OF THE PROBLEM

The polypropylene (pp.) bag manufacturing companies today are facing ever-increasing competition. At the same time, raw material costs continue to increase. These are factors that companies, for the most part, cannot control. Therefore it should be concentrate on what they can control on their processes. It also needs to strive for continuous improvement in quality, efficiency, and cost reduction. The existing case company still rely only on inspection after production to detect quality issues. The company consists of plastic film or tape production, weaving, cutting, Swinging, printing, and packaging. Hence this article concentrates on tape plant and cutting sections. Because most quality defects have occurred in these two sections, some major defects in cutter areas are hook cuts, rope cuts, undersize cut, oversize cut, and bias-cut, and in the tape plant section, major defects are weak denier strength, over elongation, use of defective raw materials, power interruption, and low operator skill. Therefore to control these defects accurate and effective process control method (SPC) is required. Generally, whenever we see the two months production (March and April in 2018): In the tape plant section from the total production of 78,085 kg, 1330 kg of waste occurs. And in cutter section from total production of 1,175,212 bags (97,895.2 kg), 657kg wastes and 6531(544 kg) B grades (downgrades) are occurred .This shows that there are high scrape rates in these two sections. Hence the company needs great improvement by using SPC to overcome those defects.

**Figure 1:** Wastes in the tape plant section, defects (downgrades) in the Cutter Section, respectively.

## III. OBJECTIVES OF THE STUDY

**General Objective**

The general objective of this article is to improve quality through statistical process control.

**Specific objective**

The specific objectives are:

- To reduce variation around a target value of PP bag manufacturing company by determining the key source of variation in the production
- To identify and remove assignable causes
- To experiment to optimize the process by selecting the appropriate design of elements
- To analyze the results found from the experiment
- To propose the optimal method to improve the selected manufacturing process on the case study

## IV. METHODOLOGY OF THE STUDY

SPC data is collected in measurements of a product dimension/feature or process instrumentation readings. The data is then recorded and tracked on various control charts based on the type of data collected. The correct type of chart must be used to gain value and obtain useful information. The data can be in the form of continuous variable data or attribute data. The data can also be collected and recorded as individual values or an average group of readings. To study this article, we use the following data collection methods. Statistical process control tools are used to analyze the data. Depending on the data gained from the company, the statistical process control tools are used. In the SPC application, it is important to understand and identify key product characteristics critical to customers or key process variation.

## V. RESULTS AND DISCUSSIONS

As stated under the topic methodology, all the necessary data used to complete this article are gathered using different data gathering techniques. If a product is to meet or exceed customer expectations, it should generally be produced by a stable or repeatable process. More precisely, the process must be capable of operating with little variability around the target or nominal dimensions of the product's quality characteristics [1].

The analysis of the production process using those tools are as follows:

***A. Project Selection Area:***

**Table 1:** Amount of Defects in each Section

| NO | Sections | Product Type | Measurement | Products in March | Products in April |
|---|---|---|---|---|---|
| 1 | Tape plant | Quality product | Kg | 22,652 | 55,433 |
| | | Waste | Kg | 610 | 720 |
| 2 | Loom | Quality product | Meter | 407,784 | 667,791 |
| 3 | Cutter | Quality product | In No | 436,348 | 738,864 |
| | | Waste | In kg | 317 | 340 |
| | | B grade | In No | 3,218 | 3,313 |
| 4 | Singer | Quality product | In No | 445,518 | 728,628 |
| | | B grade | In No | 2,918 | 3,816 |

Based on the above table of the two months production can show that: tape plant section has 1330 kg wastes have occurred, in loom section, there are 526 kg wastes, in singer section, there are 6,734 B grades (561 kg) and in cutter section, there are 663kg wastes and 6,531 B grades. One piece of B grade=83.3 grams weighted hence 6,531 piece=6,531*83.3/1000=544 kg, totally in cutter section there are =1,201 kg wastes recorded .therefor we can calculate the other sections by the same fashion.

**Table 2:** Total Amount of Wastes in each Section

| NO. | Section | The total amount of Wastes (kg) |
|---|---|---|
| 1 | Tape plant | 1,330 |
| 2 | Loom | 526 |
| 3 | Cutter | 1,201 |
| 4 | Singer | 561 |

The above table shows that Tape Plant and cutter sections have higher wastes from out of four sections, so that this article focuses on the two areas of the company.

***B. Causes of scrap in the factory's production process: The analysis helps expose the root causes of the scrap problem and generate*** improvement ideas. Based on the information get from collected data cause and effect diagram depicted below as follows:

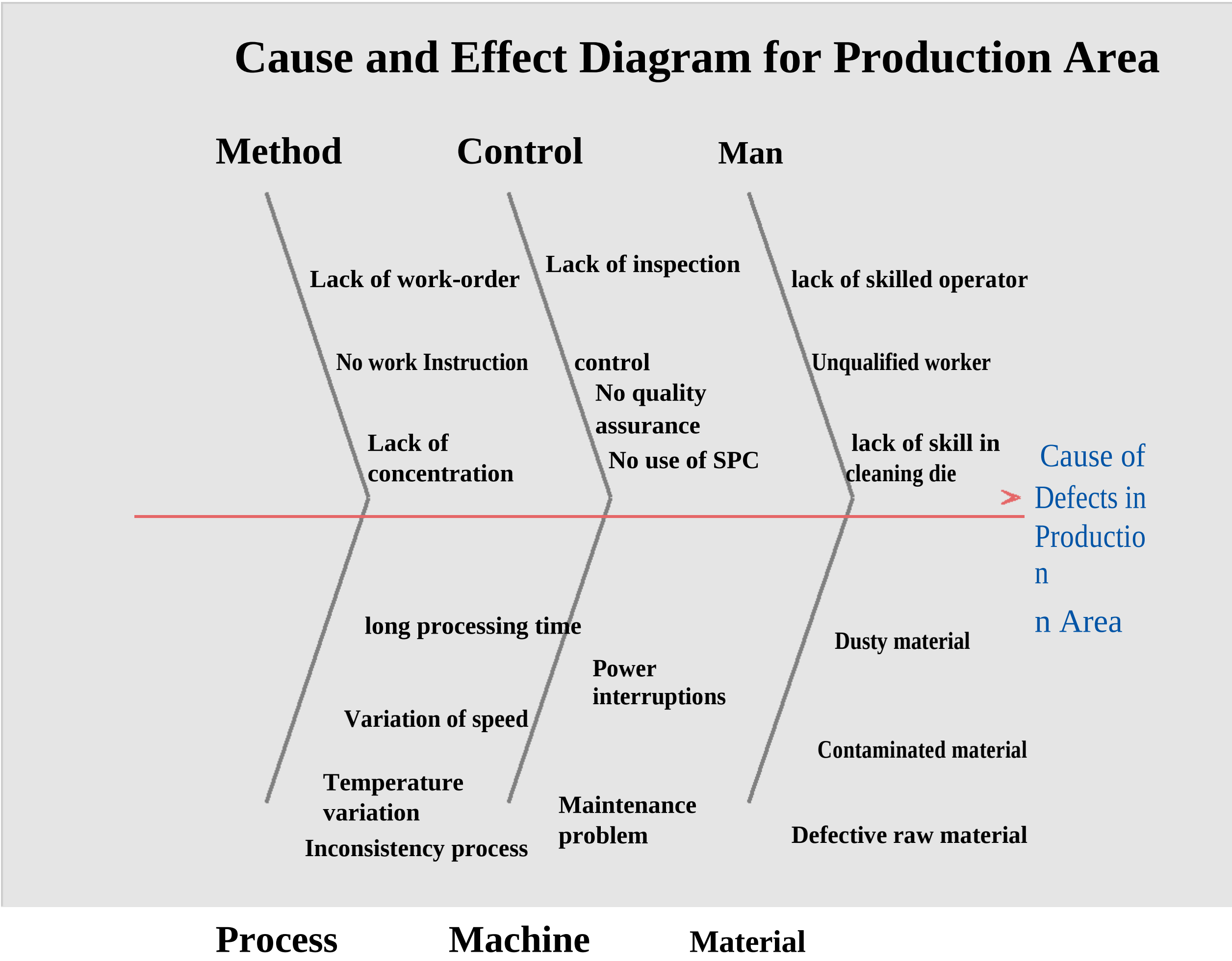



**Figure 3:** Cause and effect diagram

***a) Pareto Chart Analysis***

A study shows that about 80% of the problem comes from 20% of the potential causes.

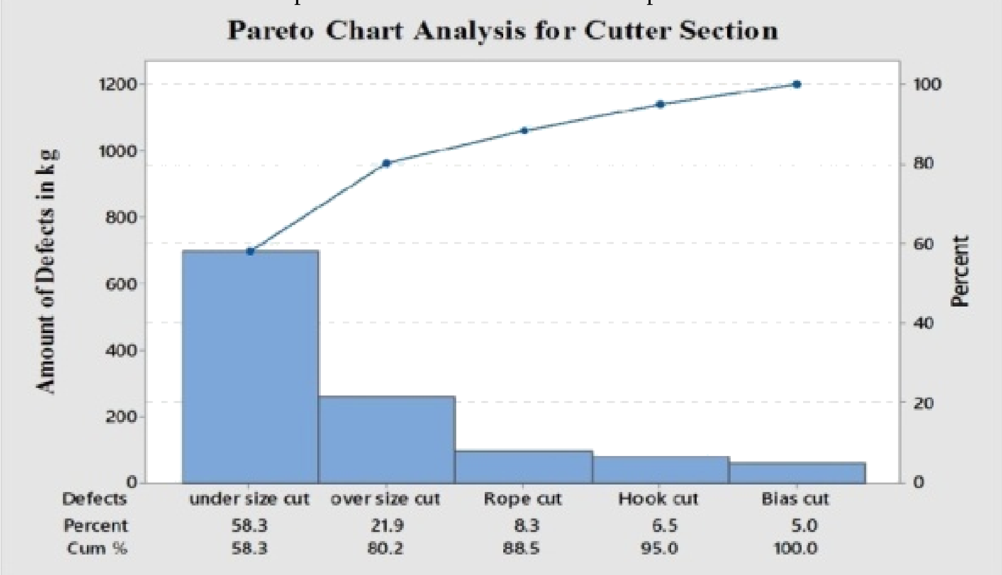



**Figure 3:** Pareto Analysis Chart for Cutter Section

The above chart shows that about 80% of the problems undersize cut and oversize cuts, and the remaining 20% is the potential cause. Hence according to Pareto's expression, 80% of the problem comes from 20% of the potential causes.

### *C. Recorded Data for Pareto Analysis*

**Amount of Defect Data Observed in Tape Plant and Cutting Sections**

Two months from (March to May) recorded defected data of the PP bag products in Tape Plant and cutting sections are shown below:

**I. Observed Defect Data In cutting Section:**

**Table 4:** Cumulative percentage of the number of defects recorded in the cutter section

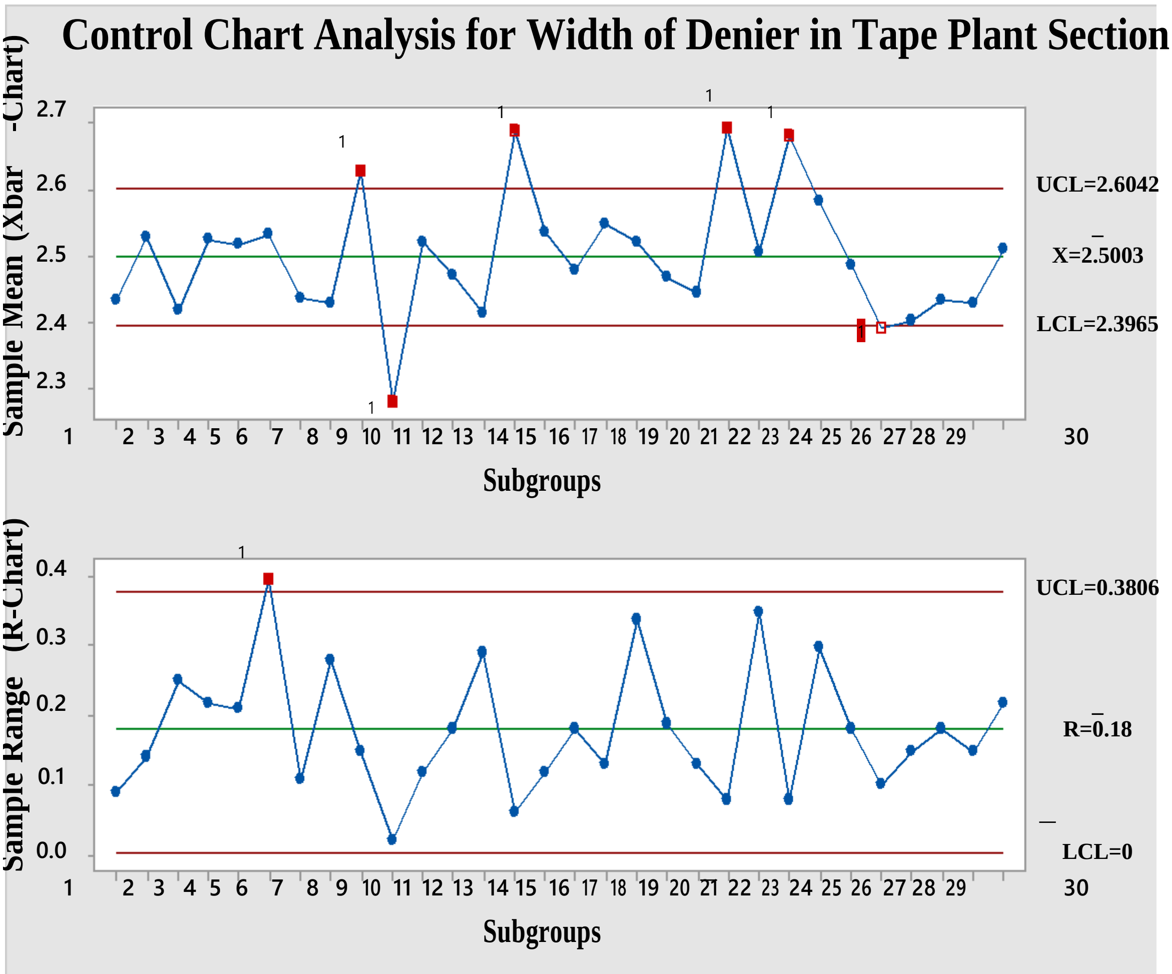
| Types of Defect | Amount of Defect (kg) | Cumulative Total | Percentage (%) | Cumulative % |
|---|---|---|---|---|
| Undersize cut | 700 | 700 | 58.3 | 58.3 |
| Oversize cut | 263 | 963 | 21.9 | 80.2 |
| Rope cut | 100 | 1063 | 8.3 | 88.5 |
| Hook cut | 78 | 1141 | 6.5 | 95 |
| Bias cut | 60 | 1201 | 5 | 100 |
| TOTAL | **1201** | | | |

**II. Observed Defect Data In Tape Plant Section:**

**Table 5:** Cumulative percentage of the number of defects recorded in the cutter section.

| Types of Defect | Amount of Defect (kg) | Cumulative Total | Percentage (%) | Cumulative % |
|---|---|---|---|---|
| Power interruption | 740 | 740 | 55.6 | 55.6 |
| Defective raw material | 327 | 1067 | 24.6 | 80.2 |
| Low operator skill | 104 | 1171 | 7.8 | 88.0 |
| Over Elongation | 104 | 1171 | 7.8 | 88.0 |
| Denier shrinkage | 67 | 1330 | 5.1 | 100 |
| TOTAL | **1330** | | | |

***D. Control Chart Analysis for Tape Plant Section*:** A control chart is utilized to eliminate abnormal variations by distinguishing variations due to assignable causes from these due to chance causes. It is also used to display control results and evaluate whether a measurement procedure is in control or out of control. I have analyzed the production process by using X and R bar charts for control chart analysis in Tape Plant Section: according to directly observed and collected 30 days real data (in March) 2017/2018, to check the variation of the width of the denier in this Section the company tests 5 samples per each shift of production.




The above chart shows that the process in the tape plant section is out of control. When we see the $\bar{X}$ -chart, the points 2.63, 2.68, and 2.69 are more than the upper control limit (UCL $\bar{X}$ =2.60), .and point 2.28 is lower than the lower control limits (LCL $\bar{X}$ =2.40). And the R-Chart, the point 0.40, is more than the upper control limit (UCLR=0.389). The process standard deviation is calculated as the coefficient of the subgroup's average value ranges to the value of constant d2 for the subgroup size five is 2.326. Hence the standard deviation:

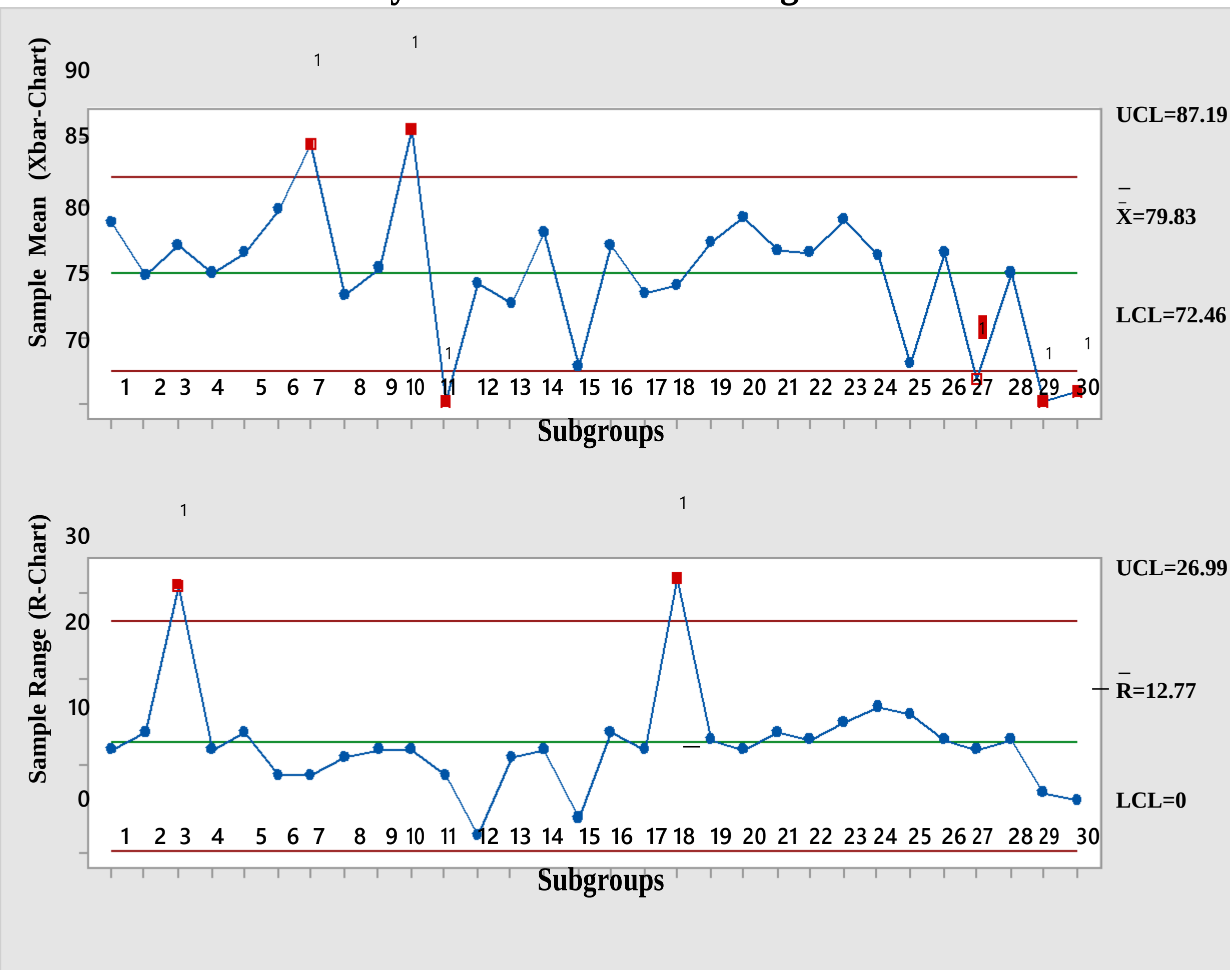
$$\sigma = \frac{\bar{R}}{d_2} = \frac{0.18}{2.326} = 0.0774 \qquad (1)$$

Then the process standard deviation shows that there is variation in the process output. The average value of the subgroup range (R-bar) is 0.18. and the value of $d_2$ for subgroup size is taken from the constant table.

***E. Control Chart Analysis for Cutter Section:***

We try to collect the width of 750 type diner bag at the cutter machine for doing the control chart analysis, and all data have been collected for 30 days (in March). In the cutter section, the company takes 5 samples per single shift during the inspection times.

**Control Chart Analysis for the Width of Bags at the Cutter Machine**




The above chart shows that the process in the cutter section is out of control. When we see the Bar-chart, the points 89.8 and 91are more than the upper control limit (UCL $X$ =87.19), .and point 70 is below the lower control limit (LCL $X$ =72.46). In the R-Chart, points 31 and 32 are more than the upper control limit (UCLR=27).as we see this cutter machine, many defects occur in case of undersize, oversize, and other types of cutting defects. The process standard deviation is calculated as the coefficient of the subgroup's average value ranges to the value of constant d2 for the subgroup size five is 2.326. Hence the standard deviation:

$$\sigma = \frac{\bar{R}}{d_2} = \frac{12.77}{2.326} = 5.49 \qquad (2)$$

Then the process standard deviation shows that there is a high variation in the process output. Hence as the solution, we have conducted a replacement analysis. Because the existing (Defender) cutter machine has the following disadvantages: Highly labor-intensive, low cutting capacity, high cost, high defects occurred in case of the machine and operators, not safe and due to the existing cutter machine there are about 1201 kg wastes occurred in two-month production, then 1201 kg*6 ETB/ (0.085kg) =84,776 ETB (Ethiopian birr) are lost per two months, since 85-gram bags sold by six ETB, therefore we have to change the existing cutter machine by the new fully automated cutter machine and it will have the following advantages. The new (challenger) has the following advantages: Reduce labor (fully automatic), no permanent operators, greater productivity, enhance safety, better instrumentation, and cutting consistency.

### *F. Replacement Analysis for Cutter Machine*

In an establishment, replacing equipment or asset is needed sooner or later. When an existing equipment or asset's economic service is not better than that of new equipment or asset, replacement is needed. There are three reasons for replacing equipment or asset: Physical impairment (deterioration), Altered requirements, the availability of new and improved technology.

**Important terminologies in Replacement Analysis:**

**Defender:** it is a piece of existing equipment (asset) owned by the company.

**Challenger:** new equipment (asset) it may replace the defender

**Sunk cost:** costs that are not affected by the future decision. For example, repair costs and depreciation costs

**Market value (current market value):** the selling price of defender

Economic Service Life (n): it is the service life (year) that yields the minimum equivalent annual cost (EAC) of owning (capital cost) and operating an asset or equipment (O& M cost) to minimize EAC. Replacement analysis decision approaches are conducted by utilizing cash flow approaches.

**I.Cash Flow Approaches** proceeds by treating a defender's seals as a down payment for purchasing new equipment (challenger).

**Defender (Existing machine):**

**Figure 4:** Existing cutting machine.

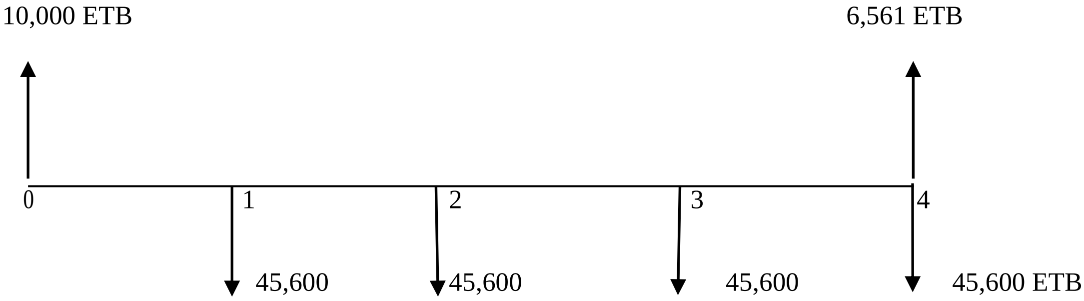
**Specification of the machine**:
Cutting capacity=3 pcs/min, CM=10,000 Birr (from the company document).
Operating cost in three shifts=1 operators *2000 birr=1,500 birr per month and 1 assistant operator*1500=1,500 birr Hence total operating cost per month=3,500 birr
Total operating cost per year=42,000 birr
Maintenance cost per month=300 birr and 3,600 birr per year. Therefore total operating and maintenance cost (total O&M cost) =45,600 birr,
Salvage value =4,500 birr,
Remaining service life (n) =4 years and
i=10

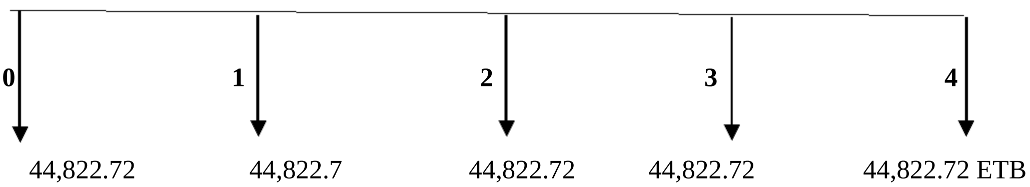
**Challenger (new machine):**

**Figure 5:** New cutting machine
Specification of the machine: we can see it on (www.machine.en.alibaba.com) website.
Cutting capacity=50-120 pcs/ min, Diameter of winder=1200 mm, Cutting width=750 mm
Price=216,000 birr,
Operating cost in three shifts =1 operator = 4500 birr and 1 assistant operator=2500 birr.
Hence total operating Cost per month=7000 birr per month but per year=7000*12=84,000 birr.
And maintenance cost per moth=8,333 birr but total in a year will be Maintenance cost=100,000 birr.
Therefore total operating and maintenance (O&M) cost is 184,000 birr,
Salvage value=90,000 birr and
The service life of the new machine (n) =4 years, i=10

**Cash Flow for Defender:**

Salvage value=CMV*(1-i) $^4$=10,000*(1-0.1)$^4$=6,561 ETB

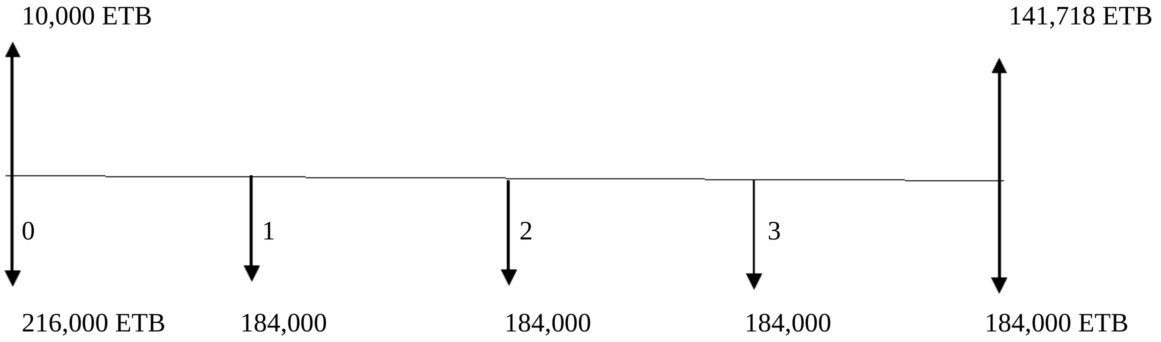


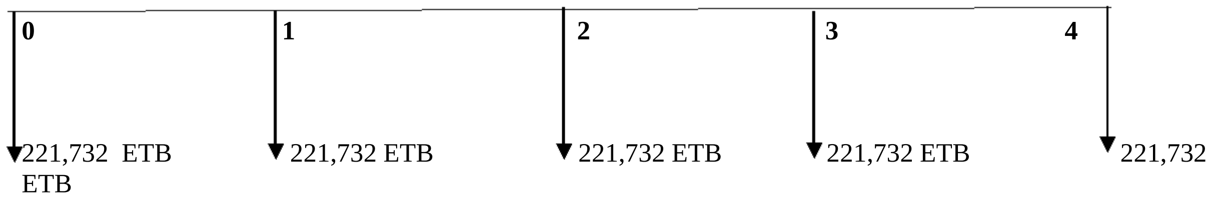




But there are nine (9) the same type manual cutter machines and 54(operators and assistant operators) in three shifts. Therefore total annual economic cost for nine machines (EACD)=44,822.72*9=403,405 birr/year. Hence the existing manual cutter machines are completely labor-intensive.

**Cash Flow for Challenger:**

Salvage value=CMV*(1-i) $^4$=216,000 birr*(1-0.1)$^4$=141,718 ETB




**Decision**

Hence the (EACD) is greater than (EACC), therefore replace the defender over the challenger.

***G. Design of experiment analysis in Bayih Mekonnen pp. and bag factory***

Orthogonal Arrays (often referred to as Taguchi Methods) are often employed in industrial experiments to study the effect of several control factors. An orthogonal array is a type of experiment where the independent variables' columns are "orthogonal" to one another. Orthogonal arrays are highly fractionated factorial designs. It involves reducing the variation in a process through the robust design of experiments. Taguchi's experimental design involves the use of orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of testing all possible combinations like the factorial design, the taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with minimum amount of experimentation, thus saving time and resources. This experiment's goal is to meet the target value of the product by organizing and controlling the parameters affecting the process and the levels at which they should be varied. Thus the measure of performance characteristics is "nominal is the best." The factors that affect the tape plant machine are Temperature, Pressure, speed of Feed, and winder speed. The operating conditions for each parameter and level are listed below.

**Table 6:** Operating conditions for each parameter and level

| AT: Annealing temperature | FR: Speed of Feed |
|---|---|
| Am1 = 125$^o$c<br>Am2 = 135 $^o$C (Actual)<br>Am3 = 145 $^0$C | S1=15 RPM<br>S2 =27 RPM (Actual)<br>S3 = 35 RPM |
| P: Pressure | AT: Melting Temperature |
| P1 =36 Pa | T1 = 271 $^o$C |
| P2 =52 Pa(Actual) | T2 =273 (Actual) |
| P3 = 90 Pa | T3 = 275 $^o$C |

**Table 7:** Selected factors and their levels

| Factors | Levels | | |
|---|---|---|---|
| | Low | Actual | High |
| Annealing temperature | 125 | 135 | 145 |
| Pressure | 36 | 52 | 90 |
| Speed of Feed | 15 | 27 | 35 |
| Melting temperature | 265 | 273 | 280 |

The orthogonal array selection is based on the number of parameters and the labels of variation for each parameter.

**Table 8:** Conforming feasibility of selected orthogonal array design:

| Conditions | Stage |
|---|---|
| OA selected | L9 |
| DOF | 8 |
| DM(DOF for the stage under investigation) | 7 |

The total DOF available in a selected OA must be greater than or equal to DOE for the stage. Therefore the selected OA is feasible, so it is possible to experiment. The array was created using an Algorithm developed by taguchi, allowing each variable and set to be tested equally.

**Table 9:** The proper orthogonal array is depicted below.

| Experiment | AT | P | SF | MT |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

**Table 10:** The completed orthogonal array with filled value is shown below:

| Experiment No | Annealing Temperature | Pressure | Feed Rate | Melting Temperature | Tri 1 | Tri 2 | Tri 3 | Mean ($Y$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 125 | 36 | 15 | 265 | 2.31 | 2.36 | 2.39 | 2.35 |
| 2 | 125 | 52 | 27 | 273 | 2.65 | 2.33 | 2.55 | 2.51 |
| 3 | 125 | 65 | 35 | 280 | 2.61 | 2.67 | 2.71 | 2.66 |
| 4 | 135 | 36 | 27 | 280 | 2.45 | 2.52 | 2. 37 | 2.45 |
| 5 | 135 | 52 | 35 | 265 | 2.61 | 2.47 | 2.69 | 2.59 |
| 6 | 135 | 65 | 15 | 273 | 2.70 | 2.27 | 2.47 | 2.48 |
| 7 | 145 | 36 | 35 | 273 | 2.29 | 2.25 | 2.27 | 2.27 |
| 8 | 145 | 52 | 15 | 280 | 2.46 | 2.54 | 2.50 | 2.50 |
| 9 | 145 | 65 | 27 | 265 | 2.45 | 2.65 | 2.73 | 2.61 |

The signal to noise ratio for nominal value is given as follows:

**Table 11:** Analogously, all the other variance, mean squared, and SN ratio for each experiment are calculated and shown below:

| Experiment No | AT | P | SF | MT | variance | Mean Squared | SN |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 0.0017 | 5.95 | 35.11 |
| 2 | 1 | 2 | 2 | 2 | 0.027 | 6.30 | 23.68 |
| 3 | 1 | 3 | 3 | 3 | 0.0026 | 7.08 | 34.35 |
| 4 | 2 | 1 | 2 | 3 | 6.00 | 0.0057 | 30.11 |
| 5 | 2 | 2 | 3 | 1 | 0.023 | 6.71 | 24.65 |
| 6 | 2 | 3 | 1 | 2 | 0.0463 | 6.15 | 21.23 |
| 7 | 3 | 1 | 3 | 2 | 0.0004 | 5.15 | 41.09 |
| 8 | 3 | 2 | 1 | 3 | 0.0016 | 6.25 | 35.92 |
| 9 | 3 | 3 | 2 | 1 | 0.0208 | 6.81 | 25.15 |

An average sample calculation of SN are shown as follows:

$$\frac{SN_1 + SN_2 + SN_3}{3} \qquad (3)$$

$$SN\,AT\,1 = \frac{35.11 + 23.68 + 34.35}{3} = 31.05$$

$$SN\,AT\,2 = \frac{30.11 + 24.65 + 21.23}{3} = 25.33$$

$$SN\,AT\,3 = \frac{41.09 + 35.92 + 25.15}{3} = 34.05$$

*Delta* = *Max* – *Min* = AT =34.05-25.33=8.72

**Table 12:** Analogously, the average SN calculation and associated range for other parameters are calculated and shown below:

| Levels | AT | P | SF | MT |
|---|---|---|---|---|
| 1 | 31.05 | 35.44 | 30.79 | 28.30 |
| 2 | 25.33 | 28.08 | 26.31 | 28.67 |
| 3 | 34.05 | 26.94 | 33.36 | 33.46 |
| Delta | 8.72 | 8.50 | 7.05 | 5.16 |
| Rank | **1** | **2** | **3** | **4** |

From this table, it can be seen that Annealing temperature has the largest effect on the productivity of the tape plant machine, and Melting Temperature is the smallest effect.

**The computing of average quality losses of response factors at the stage:**

The target value is 2.5m, Customer tolerance (Delta) is +/- 0.02, Production loss (Lc) is 0.18 ETB per meter.

$$L = k*(y-m)^2 \quad (4)$$

When y=m loses is zero, and it is the slope of loses function. This is appropriate because m is the best value for the loss L(y) increases slowly when we are near m, but as we go farther from m, the loss increases more rapidly.

$$K = \frac{Lc}{\Delta^2} = \frac{0.18}{0.02^2} = 9 \text{ birr (constant)} \quad (5)$$

$$MSD = \frac{1}{n}\sum_{i=1}^{n}(y_i - m)^2 \quad (6)$$

$$\text{Average quality loss } L(y) = k[S^2 + (Y - m)^2] \quad (7)$$

$$S_1^2 = \frac{(2.31 - 2.35)2 + (2.36 - 2.35)2 + ((2.39 - 2.35)2\,) = 0.00165}{3-1}$$

$L_1 = 9[0.00165 + (2.35 - 2.5)^2] = 1.268$ ETB $= 0.22$

**Normalization of quality loss in order to reduce variability**

$$NL_i = \frac{L_i}{L_{iMax}} = \quad NL_1 = \frac{0.22}{0.84} = 0.26\text{ETB}$$

**Table 13:** Analogously, the average loss and the respectively reduced variability is calculated and tabulated below:

| No experiment | Variance($S^2$) | Quality loss(ETB/m) | Reduced Variability Quality loss |
|---|---|---|---|
| 1 | 0.00165 | 0.22 | 0.26 |
| 2 | 0.027 | 0.24 | 0.29 |
| 3 | 0.0026 | 0.25 | 0.30 |
| 4 | 0.0057 | 0.07 | 0.09 |
| 5 | 0.022 | 0.27 | 0.32 |
| 6 | 0.066 | 0.61 | 0.71 |
| 7 | 0.0029 | 0.84 | 1 |
| 8 | 0.0016 | 0.01 | 0.02 |
| 9 | 0.0208 | 0.004 | 0.35 |

Based on the above table, it is possible to calculate the average quality loss and total quality loss on tape plant machines per two months period.

$$\text{Average quality loss} = \frac{0.22 + 0.24 + ... + 0.004}{9} = 2.514 \text{ ETB/denier} = 0.28\text{ETB/denier}$$

= 0.03 ETB/meter (m), since 1 denier = 9 m

For 500 dinner type tape, 9 m tape = 0.0025 Kg

How much = 1,330 Kg

9m*1,330 Kg/0.0025Kg = 4,788,000 meter are wastes during two months. During two months, 1,330 Kg wastes have occurred in the tape plant machine.

since 1m = 0.03 ETB

4,788,000 m = How much Then,

$$\frac{0.03\text{ETB} * 4{,}788{,}000\text{m}}{1\text{m}} = 143{,}460 \text{ ETB per two months}$$

This shows that the company lost 143,640 ETB per two months due to the inappropriate manufacturing width of tape on the tape plant machine.

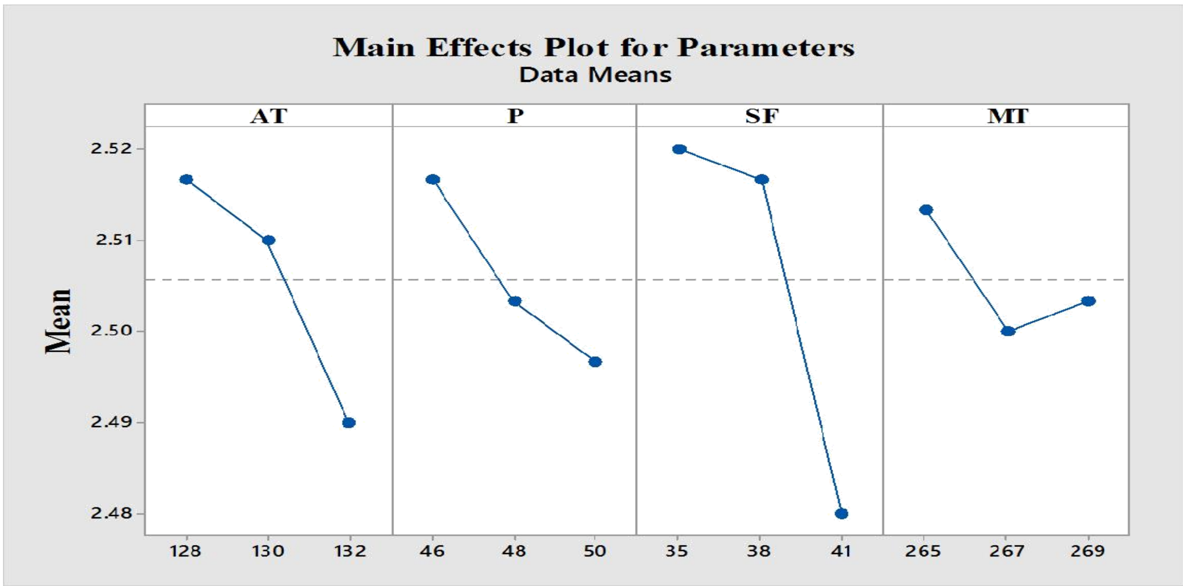
***a) Proposed method for optimizing response process problem***

**Optimizing the stage**

The above graph at the stage shows that most of the responses are out of specification. Still, from the main effect analysis on the above graph, the point near to the target point get between (130-132) degree centigrade, Pressure of (46-50), and Feed rate (35-41), and Melting Temperature of (265-269). Using these parameters, we draw the next main effect plot, and it shows the appropriate parameters that can give responses that are close to the target value. The following table below shows that the responses result from the next optimal parameters. It indicates that the responses are near the target point, which is better than the stage on this parameter value.

**Table 14:** Responses results from the next optimal parameters

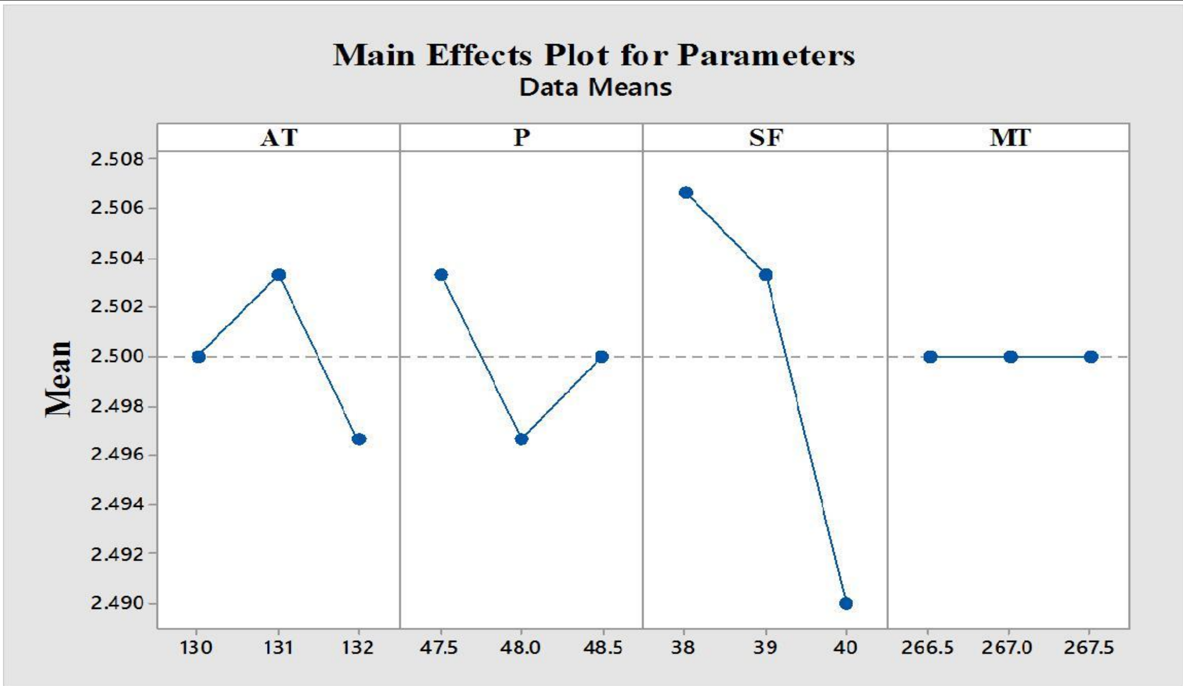
| Experiment No. | Annealing Temperature | Pressure | Speed of Feed | Melting Temperature | Tri 1 | Tri 2 | Tri 3 | Mean ($Y$) |
|---|---|---|---|---|---|---|---|---|
| 1 | 128 | 46 | 35 | 265 | 2.52 | 2.58 | 2.54 | 2.55 |
| 2 | 128 | 48 | 38 | 267 | 2.55 | 2.48 | 2.52 | 2.52 |
| 3 | 128 | 50 | 41 | 269 | 2.51 | 2.49 | 2.45 | 2.48 |
| 4 | 130 | 46 | 38 | 269 | 2.59 | 2.52 | 2. 48 | 2.53 |
| 5 | 130 | 48 | 41 | 265 | 2.51 | 2.48 | 2.49 | 2.49 |
| 6 | 130 | 50 | 35 | 267 | 2.50 | 2.49 | 2.55 | 2.51 |
| 7 | 132 | 46 | 41 | 267 | 2.45 | 2.49 | 2.48 | 2.47 |
| 8 | 132 | 48 | 35 | 269 | 2.46 | 2.54 | 2.50 | 2.50 |
| 9 | 132 | 50 | 38 | 265 | 2.50 | 2.49 | 2.50 | 2.50 |




The following table and figure below show that the appropriate and best optimal parameters result from the above one gives the best responses for the tape plant machine's process.

**Table 15:** The appropriate and best optimal parameters result

| Experiment No | Annealing Temperature | Pressure | Speed of Feed | Melting Temperature | Tri 1 | Tri 2 | Tri 3 | Mean (*Y*) |
|---|---|---|---|---|---|---|---|---|
| 1 | 130 | 47.5 | 38 | 266.5 | 2.49 | 2.51 | 2.52 | 2.51 |
| 2 | 130 | 48.0 | 39 | 267.0 | 2.51 | 2.49 | 2.50 | 2.50 |
| 3 | 130 | 48.5 | 40 | 267.5 | 2.51 | 2.49 | 2.48 | 2.49 |
| 4 | 131 | 47.5 | 39 | 267.5 | 2.51 | 2.52 | 2. 49 | 2.51 |
| 5 | 131 | 48.0 | 40 | 266.5 | 2.51 | 2.48 | 2.49 | 2.49 |
| 6 | 131 | 48.5 | 38 | 267.0 | 2.51 | 2.49 | 2.52 | 2.51 |
| 7 | 131 | 47.5 | 40 | 267.0 | 2.49 | 2.51 | 2.48 | 2.49 |
| 8 | 132 | 48.0 | 38 | 267.5 | 2.49 | 2.51 | 2.50 | 2.50 |
| 9 | 132 | 48.5 | 39 | 266.5 | 2.51 | 2.49 | 2.50 | 2.50 |



**Developed Optimal solution**

As indicated in the above figure and table, the final developed optimal parameter condition for manufacturing tapes with appropriate width is Annealing temperature of 130 degrees centigrade, Pressure of 48.5 Pascal, Speed of Feed 39 RPM, and Melting Temperature of 265-degree centigrade. Therefore, the company should operate the process with these developed optimal parameters to optimize the value of the process parameters to make the system's performance immune.

## VI. Conclusions

Defects, scraps, and variations are things that do not separate in any manufacturing company. The presence of such things forces the company to incur a high amount of quality costs. Bayih mekonnen PP bag factory is an example from different companies that face such quality problems. In the tape plant and cutter sections, the company incurred a large amount of waste, shown from the company document of the two-month data record (March and April 2018). There are 1,330 kg wastes in the tape plant section, and in the cutter section, there are also 1,201 kg wastes. Therefore, this waste causes labor loss, material loss, electric power loss, and different types of quality-related manufacturing overhead costs. The production processes (in tape plant and cutter sections) are analyzed using statistical process control tools (cause and effect chart, Pareto chart, and control charts). The control chart's data analysis shows that the production process is not stable (out of control) in both sections. To overcome such quality problems, this article sets possible directions for the solution. To reduce defects incurred in the cutter section due to the cutter machine, the company should replace the existing manual cutter machine by the proposed new fully automated cutter machine and reduce the tape plant section's problems. The company should use the proposed parameter settings. The company can save 143,640 ETB by applying the proposed parameter settings in the tape plant section. Moreover, to reduce all quality problems facing the case company, they should fully implement statistical process control as the main solution.

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