USE AND APPLICATION OF QUALITY ENGINEERING IN INCREASING PRODUCTIVITY OF ETHIOPIAN PLASTIC SHARE COMPANY

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ABSTRACT

The purpose of this paper is to demonstrate uses and application of quality engineering in general and Taguchi methods in particular in Ethiopian Plastic Share Company (EPSC) main processes. As a methodology, secondary data from the company has been collected and used to identify process variation and their associated losses. In addition, this data has been an input to conduct the experiment. The result clearly shows that the uses of design of experiment to parameter design ensure about 90% reduction of the company's losses. Often the company's management associated these losses to the employee's technical capability. This conforms with Deming's teaching that 80-90% of an organization's problems are attributed to the parameter design than the employees.

***Key Words**: Quality Engineering, Taguchi's Method, Design of Experiment, Taguchi's Loss Function, Orthogonal Array.*

INTRODUCTION

At the end of 20th century, products quality was measured and known before production – in the design phase. The practice of controlling or managing quality at the design phase is now known as Quality Engineering (QE). It is classified into on-line QE and off-line QE. On-line QE is in contrast with traditional Statistical Process Control (SPC) used for the identification, measurement, analysis, and control of all causes of variation in any process and off-line QE is in contrast with classical design and analysis of experiment. It is applicable prior to production of the product. In the sequence of the two functions off-line precedes on-line quality engineering. Off-line quality control consists of two stages: (1) product design and (2) process design. The product design stage is concerned with the development of a new product or a variant of an existing product. The goals in product design are to properly identify customer needs and to design a product that meets those needs. The process design stage is what is usually considered to be a manufacturing engineering function. It is concerned with specifying the processes and equipment, setting work standards, documenting procedures, and developing clear and workable specifications for manufacturing [1, 2, 3, 4].

While much of quality control deals with monitoring a process or inspecting item during and after production, there are substantial literatures on means of designing quality into the product directly before production begins. The Taguchi method focuses on a three-step approach applicable to both of product and process design stages. These are: (1) system design (2) parameter design and (3) tolerance design [5, 6, 7].

System design applies scientific and engineering methods to translate customer needs into manufacturing requirements. This includes innovative ideas, and techniques and philosophies to the selection of materials, process and tentative parameter values.

Parameters should be chosen by analytic methods or carefully planned experiments. This is a key step in quality engineering to increase quality without increasing cost. Examples of parameters in product design include the dimensions of components in an assembly. Examples of parameters in process design include the speed and feed in a machine operation or the temperature in heating process.

Any deviation from target value will incur an economic loss. Therefore, setting tolerances on process to meet requirements at minimum cost is the last phase of quality engineering process to build quality in the product and manufacturing process design.

This study focuses on the use and applications of Taguchi Methods in increasing productivity of the EPSC.

BACKGROUND TO THE COMPANY

The Ethiopian Plastic Share Company (EPSC) is a government-owned company established in 1960's by few Italian entrepreneurs. It was the first of its kind in the country in the sector. Currently the company is under Metals and Engineering Corporation (METEC) and has a capital of Birr 30 million. It has about 361 permanent employees engaged in production and sales of electric wires and cables, PVC pipes, conduits, garden hoses, polyethylene packaging materials, and some household items.

The company constitutes five manufacturing sections: Polyethylene, Conduit and Hoses, Pipes, Household items, and Wires and Cables section. The main processing systems in EPSC are: film blowing, extrusion, injection and blow-molding.

The Quality Control Service Department is directly under the office of the General Manager and is responsible for the quality inputs, processes, and outputs of the factory. The department collects data on every aspect of the production process, and as a result, well-organized data is available within the organization.

Through on-site observations and discussions with the workers, the researchers recognized: weak machine performance, high scrap generation, high non-conformance cost and high customer complaint. According to the company's report, in the year 2008, the company lost over two million Birr due to defective products.

This study aims at using and applying quality engineering techniques to reduce losses of the case company due to scraps, non-conformance and rejects. In the plastic production process, inspection and testing alone do not ensure the quality of a product. Several variables affect the quality of the product, such as temperature, cooling time, post-mold shrinkage, etc. These variables could be regulated by the application of quality engineering so that products conforming to specification can be produced and overall productivity of the company would be improved.

RESEARCH METHODOLOGY

To achieve the objective of this study, a three stage approach has been devised: problem analysis, design of experiment and validation. In the problem analysis, primary, historical data from the company's quality control department was collected for analysis. Defect types under each product category were prioritized and process variables were studied for the selected few products. From the variation the quality losses were calculated based on Taguchi loss function.

In the experimental design, the aim is to search for optimal design parameters of the production process, selected in the problem analysis. Though there are different approaches to conduct design of experiment, Taguchi method is used in this study which basically includes setting process parameters, identifying input factors, selection of orthogonal arrays and assignment of factors, conducting experiment and finally result interpretation. The design of experiment is carried out using Minitab 15 commercial software. The outcome of this stage is standardized process parameters that reduce variation and losses to the company.

In the validation stage, the variations and associated losses are measured using the Taguchi loss function. Finally, losses of the cases company before and after the design of experiment is compared to validated the benefits of applying quality engineering in general and Taguchi methods in particular.

PROBLEM ANALYSIS

Defects can be identified based on quality characteristics of each product. Among the different products, highest frequency of defects occurs on conduits followed by polyethylene-products (Film Blowing) and wires and cables. As shown in Fig. 1, these three products constitute about 75% of the company's defects. Table 1 shows the different types of defects.

As shown in Table 1 centering problem, diameter and wall thickness variation are the major defects in the conduit products. In light of the essence of the definition of quality, variation causes defects that dissatisfy customers and cause grave lose of income to a company. Therefore, reducing variation must be given due emphases in the production process. To study the impact of variation, analyses have been attempted based on data available on conduits (F/C 16mm and R/C 19mm), poly (P/S 38cm/160μm) and wires and cables (S/I/W 2.5mm2).

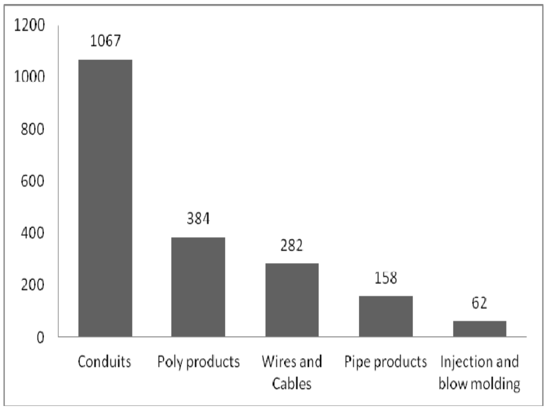


Figure 1 Frequency of defects in EPSC

Table 1: Frequently occurring defects

Product category	**Frequently occurring defects**
Conduit	Centering problems Diameter variation Wall thickness variation
Polyethylene products	Width variation Wall thickness variation
Wires and cables	Diameter variation Centering problems Mass variation

Variation Analysis

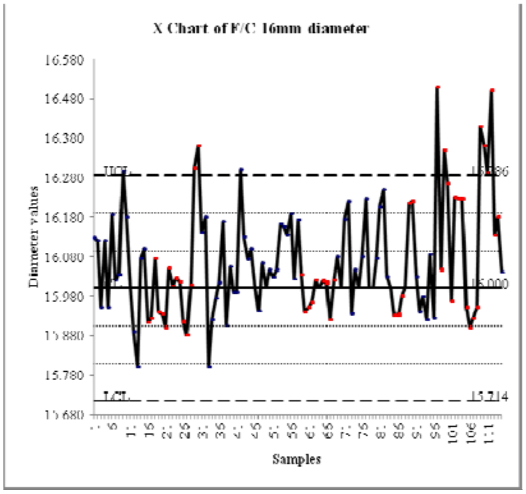
X-charts and R-charts are plotted to check the process variability based on data collected from the company. As summarized in Table 2, except R/C 19mm's Upper Specification Limit (USL) of the R-chart, all specification limits for all products are within the tolerance limits of the company. However, except Polyethylene (P/S 38cm/160µm) all products are out of process control. See Fig. 2 (a, b, c, d, e, f, g, h). Products have been manufactured within the tolerance limits but they have become defective. There are two basic reasons for this: it might be either due to random causes or due to assignable (system) problems. Random causes are power interruption, employee's error, machine failure, etc. Quality service supervisors in a discussion held with the researchers attributed the root problems for variations and defects to random causes. These were listed as follows.

- Setting operational parameters inappropriately,
- Not cleaning machineries before and after operation,
- Mixing wrong proportion of raw materials (as applied to some products),
- The existence of old machineries,
- Using poor quality of raw materials.

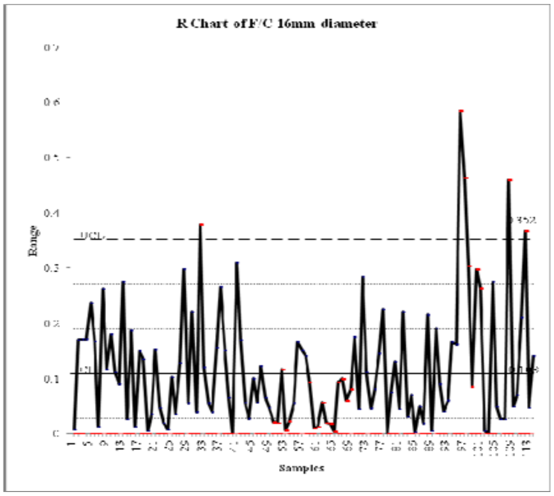
The supervisors push the blame to the operators for most of the quality failures. This has been confirmed by the company's report which attributes 78.5% of the problems to employees' technical capability. Before deciding on the causes of defects, first the losses due to defects are calculated by using Taguchi loss function and subsequently application of design of experiment is done.

Table 2: Upper and lower specification limits

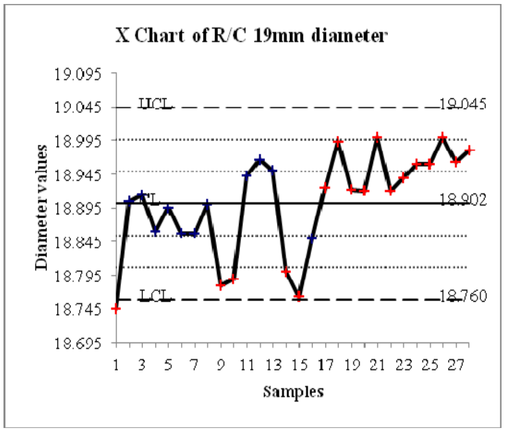
	EPSC's Tolerance	**X-chart**			**R-chart**		
		USL	**CL**	**LSL**	**USL**	**CL**	**LSL**
F/C Ø 16mm	16 ± 0.3	16.286	16.063	15.714	0.352	0.108	0
R/C Ø 19mm	19 ± 0.3	19.045	18.902	18.76	0.475	0.053	0
P/S 38cm/160µm	38±0.5	38.193	37.941	37.688	0.31	0.095	0
S/I/W 2.5mm^2	3.37 ± 0.11	3.392	3.37	3.348	0.026	0.008	0



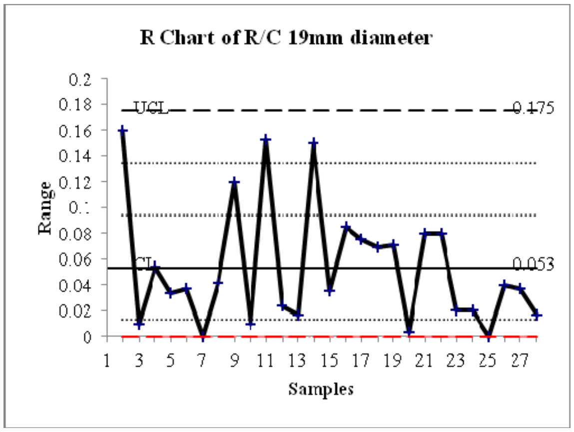
a. X – Chart of F/C Ø16mm



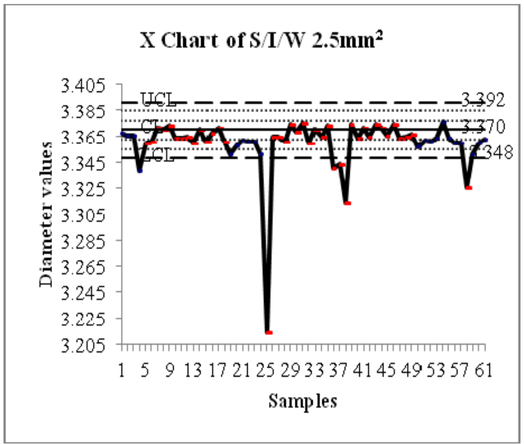
b. R – Chart for F/C Ø16mm



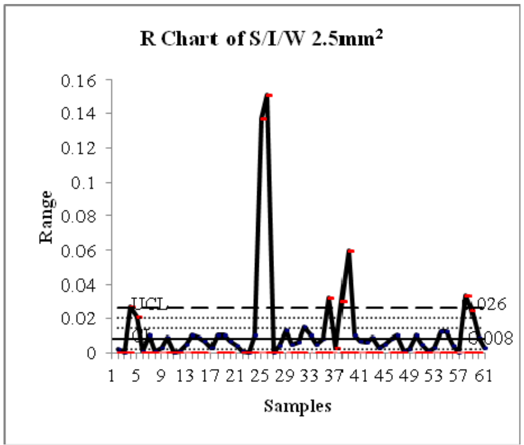
c. X – Chart of R/C Ø19mm product



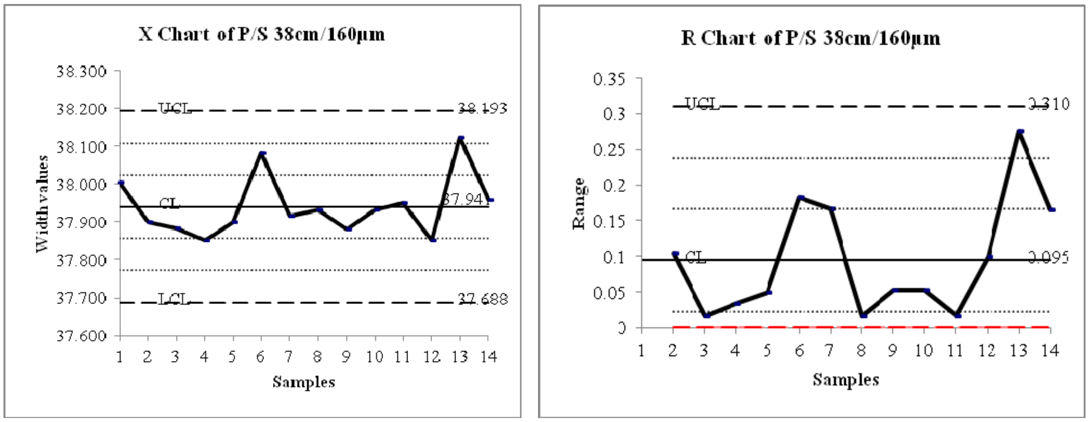
d. R – Chart of R/C Ø19mm product



e. X – Chart of S/I/W 2.5mm^2 products



f. R – Chart of S/I/W 2.5mm^2



g. X – Chart of P/S 38cm/160µm NC product

h. Chart of P/S 38cm/160µm NC product

Figure 2 X-chart and R-chart of EPSC's products

Taguchi's Loss Function Analysis

EPSC manufactures all products under the company's tolerance limit, but it is losing revenue due to defects and nonconformity. According to Taguchi's loss function, there is a loss even if the product is produced within the tolerance limit. Any value away from the target is a loss to the society. The Taguchi's quality loss function is:

$$L(y) = k\,(y - m)^2 \qquad (1)$$

Where

$L(y)$ = Failure cost of a product
y = Actual value of the performance
m = Target value
k = Constant

The average quality loss for a product of the company is calculated using a formula:

$$L = k(S^2 + (\mu - m)^2) \qquad (2)$$

Where

S = The mean square deviation of 'y' around its own mean and
μ = Is the average value of 'y'

In order to calculate the quality cost according to Taguchi's loss function, three basic assumptions are made. These are:

- Defective cost for a product is considered as production cost minus the cost of recyclable scraps. In a plastic production process, once a product is defective, there is no rework as it is common in metal machining process, either it would be recycled or scraped.
- Maximum loss is near to the tolerance limits (upper tolerance limit and lower tolerance limit)
- One performance parameter of a product is considered at a time to calculate losses associated to its variation. For example, diameter in the case of conduits, and Wires and Cables, and width variation in the case of Polyethylene.

Loss due to Variation

Loss per piece is calculated for the products mentioned and summarized in Table 3. To clarify the procedures used while calculating the loss, conduit type—F/CØ16mm is taken as an example.

Data collected by the Quality Department of EPSC are used to find out the mean and standard deviation. Target value and tolerance limits are obtained from the company's production standards. Defect costs are also calculated based on the production and raw material costs. See the Appendix.

$S = 0.138297$, $\mu = 16.0663$ mm, $m = 16$ mm,
TL = 16 ± 0.3 mm, and $L = 18.821$ birr

By substituting these values in the equations (1) and (2), first it is possible to find out the constant, k, and finally quality losses per piece.

$$L(y) = k\,(y - m)^2$$

$$1.821 = k\,(16.3 - 16)^2$$
$$k = 20.23$$

Therefore, the average quality loss for this product per piece become,

$$L = k\,[S^2 + (\mu - m)^2]$$
$$L = 20.23\,[0.138297^2 + (16.0663 - 16)^2]$$
$$L = 0.47\,\mathrm{Birr/Pc}$$

When summarized, EPSC is losing about three million Birr annually due to variation only by the four products taken in the sample study. Thus this research has tried to exemplify the application of quality engineering tool – design of experiment to reduce variations that caused losses to the company.

Due to these reasons, DoE is used and applied to improve the temperature variability in the EPSC manufacturing process. The experiment assumed that other process parameters are kept constant up to the required standards. The experiment is conducted on the four products discussed above. They have different temperature zones and settings. The operational parameters and their respective response values are, therefore, seen differently.

The following sections show input process parameters (control factors) and their respective levels assigned by the researcher for the selected products of the company. The levels for each factor were assigned based on the discussions made with the production manager and the company's past experience in setting the temperature values (simply the temperature values set by default).

Table 3: Summary of key parameters and losses due to variation

	TL	S	μ	m	Lm (Birr)	k	L (Birr)	Annual Production	Losses (Birr)
F/C Ø 16mm	16 ± 0.3	0.138	16.07	16	1.82	20.23	0.47	256,644Pcs	122162.5
R/C Ø 19mm	19 ± 0.3	0.073	18.9	19	9.86	109.5	1.63	198,584Pcs	324089.1
P/S 38cm/160μm	38±0.5	0.081	37.9	38	33.25	133	1.35	161302.9kg	218242.8
S/I/W 2.5mm^2	3.37 ± 0.11	0.022	3.36	3.37	3.91	324	0.189	11,832,602Pcs	2236361.8
Total losses due to variation									2,900,856.23

Note: TL = Tolerance Limit, S = Standard deviation, μ = Mean value of samples, m = Target Value, Lm= Maximum losses about the tolerance limit, k= constant, L = Unit failure cost of a product.

DESIGN OF EXPERIMENT

The main phases to conduct Design of Experiment (DoE) are: setting process parameters, identifying input factors, designing the experiment, conducting the experiment, analyzing, and finally interpreting the experiment

Processes Parameters

Temperature zones, feeding speed of machine, pressure and cooling time in the plastic manufacturing processes are critical parameters. In EPSC, most of these parameters are constant. However, comparatively, temperature zone setting is often disturbed mainly due to:

- Operators interchange
- Power interruption
- Operators decision—to reduce production process variability (for example softness and hardness of the die leaving product)

Assumptions have been made here in assigning level number for each control factor. Number of the levels is assigned depending on the appearances in the setting of the company (the factor value that is used many times in the factory's setting). See Table 4.

Design an Experiment Using Orthogonal Array

When designing an experiment, the factors, relevant interactions, and the factor levels need to be determined. In the Taguchi method, two to five levels are usually recommended. While using the Taguchi method, the experiment is designed by following the column assignments specified by an orthogonal array (OA). The orthogonal design employed is based on the number of factors, their levels and the number of selected interactions. In this research, two, three and four levels orthogonal arrays were used. The most common OAs for two level factors are the $\mathbf{L_4}(2^3)$, $\mathbf{L_8(2^7)}$, $\mathbf{L_{16}\ (2^{15})}$, and $\mathbf{L_{32}}(2^{31})$. For three level factors, the most common orthogonal arrays used are $\mathbf{L_9}$ (3^4) and $\mathbf{L_{27}}$ (3^7) and for four level factors, the most common orthogonal array is $\mathbf{L_{16}}$ (4^5). In an orthogonal array designated as $\mathbf{L_a}(b^c)$, the letters a, b, and c represent the number of runs, the number of levels for each factor, and the number of columns in the array (factors) respectively. After an orthogonal array is selected, designing an experiment becomes a "column assignment" task.

The response variables (dependent variables) were internal diameter, overall diameter and width for the category of products considered in this study. Emphasis was given for internal diameter of F/C Ø16mm and R/CØ19mm, overall diameter of S/I/W 2.5mm2 and width of P/S 38cm/160µm.

Four temperature zones (control factors) can affect the internal diameter of F/C Ø 16mm conduit products. Four levels were selected for each control factor. Three temperature zones (control factors) can affect the internal diameter of R/C Ø 19mm rigid conduit products and four levels were selected for each control factors. Seven temperature zones (control factors) affect the overall diameter of wire products (S/I/W 2.5mm2). Three levels are selected for each control factors for both products. Seven temperature zones (control factors) can affect the width of the polyethylene product (P/S 38cm/160µm) and two levels were selected for the product. See Table 4.

Table 4: Variables for the experiment

1. F/C Ø 16mm				
Control factors (Temperature zones)	Levels			
	1	2	3	4
Temperature 1	150	160	165	170
Temperature 2	150	155	160	170
Temperature 3	130	140	145	150
Temperature 4	130	135	140	145
Response variable: **Internal diameter**				
2. R/C Ø19mm				
Control factors (Temperature zones)	Levels			
	1	2	3	4
Temperature 1	225	235	240	245
Temperature 2	230	235	240	245
Temperature 3	160	180	200	210
Response variable: **Internal diameter**				
3. S/I/W 2.5mm²				
Control factors (Temperature zones)	Levels			
	1	2	3	
Temperature 1	159	160	165	
Temperature 2	158	159	160	
Temperature 3	156	157	160	
Temperature 4	154	156	157	
Temperature 5	153	154	155	
Temperature 6	151	152	153	
Temperature 7	150	151	152	
Response variable: **Overall diameter**				
4. P/S 38cm/160µm				
Control factors (Temperature zones)	Levels			
	1	2		
Temperature 1	140	150		
Temperature 2	145	150		
Temperature 3	145	150		
Temperature 4	145	150		
Temperature 5	155	160		
Temperature 6	160	165		
Temperature 7	160	165		
Response variable: **Width**				

A linear model was assumed and interactions were considered to be negligible. The specific factor levels were selected based on discussions with the production personnel of the company and most repeatedly occurring settings in the company's production process.

Selection of Orthogonal Arrays and Assignment of Factors

The selection of OA depends on the number of factors and interactions of interest, and the number of levels for each factor of interest. These two items determine the total degrees of freedom required for the entire experiment. The degrees of freedom for each factor are the number of levels minus one. The degrees of freedom for the factors under investigation, D, assuming no interactions exist, is given as:

$$D = F(l - 1) \qquad (3)$$

Where

D = Degree of freedom,
F = Number of factors, and
l = number of level for each factor

For example, for F/C Ø 16mm having four factors with four levels each is: $D = 4(4-1) = 12$. Thus, an OA is required that will accommodate D, the total number of degrees of freedom. The total degree of freedom available in an OA, D_o, is equal to the number of trial N minus one: $D_o = N - 1$. In order to select the particular orthogonal array for an experiment, the following inequality must be satisfied: $D_o \geq D$.

As can be seen from table below, for all categories of products, degree of freedom D is less than degree of freedom available in OA selected for each product. Therefore, the selection of orthogonal arrays (OA) is justified.

Table 5: Degrees of freedom for each product

No.	**Category of product**	**Degree of freedom (D)**	**OA selected**	**Degrees of freedom available in OA selected (D_o)**
1	F/C Ø 16mm	12	L_{16}	15
3	R/C Ø 19mm	9	L_{16}	15
5	S/I/W 2.5mm^2	14	L_{27}	26
7	P/S 38cm/160µm	7	L_8	7

Conducting the Experiment

To conduct experimental investigation (depending on the recorded data) for different types of products Minitab 15 statistical software was used. Different orthogonal arrays were used for each type of products depending on their number of factors affecting the production process. From the recorded data of the company, the researchers found that different response values were registered for the similar factor settings of process parameters, in which case it was filled in the two column of response place (example, Diameter 1, Diameter 2). As it was stated previously, L_8, L_{16} and L_{27} orthogonal arrays were used and in total 16, 32 and 54 recorded data were used respectively.

Experimental Analysis and Results

Mean response and Signal-to-Noise ratio (S/N) responses are analyzed. The mean response analysis shows the factors that have the greatest impact on the mean. The S/N analysis also shows the factors that have the greatest impact on the variance and mean. Flexible conduit **(F/CØ16mm)**

From the mean response and S/N response tables, the mean and S/N of product F/C Ø16mm internal diameter is highly influenced by Temperature 1 and Temperature 4. The ANOVA also shows that these two temperatures have greatest influence on the products quality.

Table 6: Response table of F/C Ø16mm

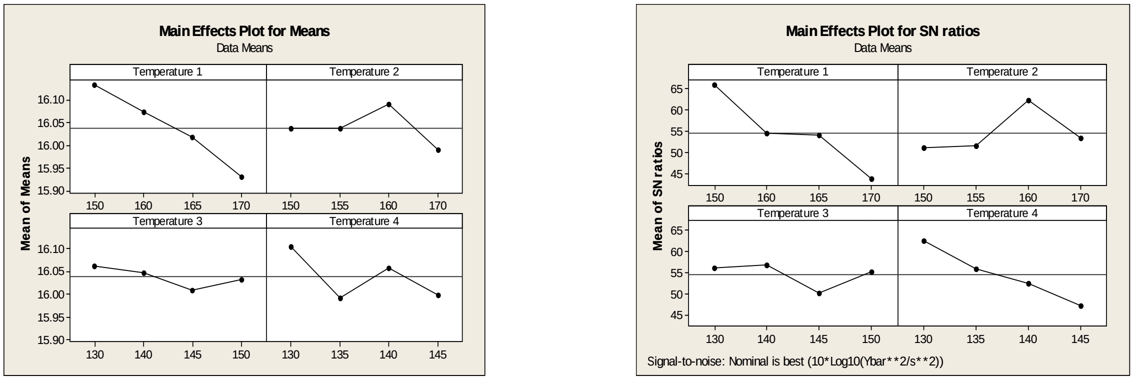
No.	**Average diameter (mm)**	**S/N**
1	16.2225	73.2333
2	16.1240	69.0980
3	16.1585	70.2764
4	16.0235	50.8472
5	16.0845	44.1541
6	16.0400	49.0526
7	16.2175	73.2306
8	15.9500	51.5025
9	15.9775	41.2798
10	16.0325	50.8521
11	16.0315	57.8618
12	16.0275	66.2798
13	15.8600	45.4327
14	15.9500	37.5231
15	15.9525	47.5124
16	15.9575	44.4629

Table 7: Response table for mean of F/C Ø16mm

Levels	**Temperature 1**	**Temperature 2**	**Temperature 3**	**Temperature 4**
1	16.13	16.04	16.06	16.10
2	16.07	16.04	16.05	15.99
3	16.02	16.09	16.01	16.06
4	15.93	15.99	16.03	16.00
Delta	0.20	0.10	0.05	0.11
Rank	1	3	4	2

Table 8: Response table for S/N of F/C Ø16mm

Levels	Temperature 1	Temperature 2	Temperature 3	Temperature 4
1	65.86	51.02	56.15	62.57
2	54.48	51.63	56.76	55.97
3	54.07	62.22	50.15	52.44
4	43.73	53.27	55.09	47.17
Delta	22.13	11.20	6.62	15.39
Rank	1	3	4	2



a. Mean response graph

b. S/N response graph

Figure 3 Mean and S/N response graph of F/C Ø16mm

The target value required to be produced is 16mm, and the mean response graph above shows that on the temperature 1 setting 165, temperature 2 setting 155, temperature 3 setting 145 and temperature 4 setting 145 produce the product with the value close to the target. But to select settings, its effect on the S/N ratio should be considered. The response S/N ratio is required to be large or should not be significantly minimized for any type of design of experiment analysis; and from the response S/N ratio temperature 1 setting-150, temperature 2 setting 160, temperature 3 setting-140 and temperature 4 setting-130 makes the response S/N ratio large.

To select optimum setting of temperature values, the setting that results in a mean response value closing to the target and that has a large or not significantly reduced S/N ratio is considered. But all temperature settings selected above for mean response and S/N ratio are not similar (for example, for mean response at temperature 1, setting 165 or level 3 is chosen, whereas for S/N ratio setting 150 or level 1 is chosen). Therefore, to compromise the trade-offs, it is better to choose the settings that bring a mean value close to the target and S/N ratio not significantly reduced simultaneously. In this case, temperature 1 setting 165 (level 3), temperature 2 setting 155 (level 2), temperature 3 setting 150 (level 4) and temperature 4 setting 135 (level 2) are chosen. Using these temperature settings, the response value can be achieved with improved variation from target value. See table 9. Factor setting for the remaining three products are also conducted by using the same methodology.

The predicted values for the four products under study are shown in Table 10 These values are compared with the target values and the actual production mean as presented in Table 11.

Table 9: Summary of factor settings selected using the design of experiment

1. F/C Ø 16mm			
Controllable factors	Level selected	Value of the level	Rank of affecting the mean response
a. Temperature 1	3	165	1
b. Temperature 2	2	155	3
c. Temperature 3	4	150	4
d. Temperature 4	2	135	2
2. P/S 38cm/160µm			
Controllable factors	Level selected	Value of the level	Rank of affecting the response
a. Temperature 1	1	140	3
b. Temperature 2	1	145	4
c. Temperature 3	1	145	6
d. Temperature 4	1	145	2
e. Temperature 5	1	155	5
f. Temperature 6	1	160	1
g. Temperature 7	1	160	7
3. R/C Ø 19mm			
Controllable factors	Level selected	Value of the level	Rank of affecting the response
a. Temperature 1	3	240	2
b. Temperature 2	2	235	3
c. Temperature 3	2	180	1
4. S/I/W 2.5mm²			
Controllable factors	Level selected	Value of the level	Rank of affecting the response
a. Temperature 1	2	160	4
b. Temperature 2	2	159	6
c. Temperature 3	3	160	7
d. Temperature 4	1	154	3
e. Temperature 5	1	153	1
f. Temperature 6	3	153	5
g. Temperature 7	1	150	2

Table 10: Predicted values of the products response factors

Product type	**Predicted values**					
	Mean		**S/N ratio**		**Standard deviation**	
	Diam./Width	**Wall thickness**	**Diam./Width**	**Wall thickness**	**Diam./Width**	**Wall thickness**
F/C Ø16mm	15.9643	1.48181	53.1518	47.2264	0.0414099	0.0084853
R/C Ø19mm	18.9901	1.50913	66.1580	36.0620	0.0026517	0.0470226
P/S 38cm/160µm	37.9045	161.25	67.3496	39.2015	0.0162635	1.76777
S/I/W 2.5mm²	3.37411	-	64.8202	-	0.0014142	-

Table 11: Predicted and actual mean values of the products

Type of product	**Target value**	**Actual mean value**	**Predicted mean value**
F/C Ø 16mm	16mm	16.0663mm	15.9643mm
P/S 38cm/160µm	38cm	37.9405cm	37.9045cm
R/C Ø 19mm	19mm	18.9024mm	18.9901mm
S/I/W 2.5mm²	3.37mm	3.3645mm	3.37411mm

VALIDATION

The analysis clearly shows the losses due to variations. DoE is used to identify the optimal parameters that can results with minimum variations. In order to justify the improvements made, the losses associated with the new parameters are calculated as follows and summarized in Table 12.

Let us take F/C Ø16mm as an example. The only changing variable as shown in the following calculation is the sample mean, μ.

$$S = 0.0414099, \mu = 15.9643mm, m = 16mm,$$
$$TL = 16 \pm 0.3mm, L = 1.821birr, k = 20.23$$

The average loss for a piece of product is given as;

$$L = k\,[S^2 + (\mu - m)^2]$$
$$= 20.23\,x\,[(0.0414099)^2 + (15.9643 - 16^2)]$$

$$= 0.0605 Birr / Pc$$

The summary of the result of the quality loss function calculated above and its comparison with the one calculated before design of experiment application is shown in the table below with the percentage of improvement.

Based on the experiment result above, EPSC can reduce losses dramatically. The table below shows that EPSC losses could be reduced by about 90%.

As already observed, there was a quality loss in the manufacturing process of EPSC. Applying design of experiment properly would reduce non-conformance of the products, decreases rework and scrap rates, reduce rework, increases customers' satisfaction, and sales volume.

CONCLUSION

In spite of EPSC's effort to manufacture its products within the tolerance limit, paradoxically, it has defective products and non-conforming to the customers' requirements. It was noted that according to the company the causes for the defects were the operators of the machines. However, the result of this research indicates that about 90% of the problem is attributed to the process parameter design. This conforms to the teaching of Deming's theory which says that 80-90% of quality problem is related to the organization's process parameter design than machine operators' failure.

As regards to EPSC's process improvement, reducing defects and non-conformity can be attained through the uses and application of quality engineering. Proper identification and definition of causes for quality problem is the first step to be taken to introduce improvement before making decision and/or action on the employees.

Table 12: Comparison of quality loss before and after experimental analysis

Type of product	**Loss before (Birr)**	**Loss after (Birr)**	**% improvement**	**Annual Production**	**Losses (Birr) Before**	**Losses (Birr) After**
F/C Ø 16mm	0.476	0.0605	87.29	256,644.0 Pcs	122,162.5	15,527.0
R/C Ø 19mm	1.632	0.012	99.26	198,584.0 Pcs	324,089.1	3,889.1
P/S 38cm/160μm	1.353	1.248	7.76	161,302.9 kg	218,242.8	201,306.0
S/I/W 2.5mm^2	0.189	0.0061	96.77	11,832,602.0 Pcs	2,236,361.8	72,178.9
Total losses before and after experiment					**2,900,856.2**	**292,901.0**

BIBLIOGRAPHY

[1] Hassn, Adnan., "Issues in quality engineering research", *International Journal of Quality and Reliability management*, Vol.17, No.8, 2000, pp 858-875.

[2] Vlachogiannis, G. John and Vlchonis, V.George., "An experimental design for the determination of Cu and Pb in marine sediments using Taguchi methods", *International Journal of Environmental Analytical Chemistry*, Vol.83, No.12, 2003, pp1021-1034.

[3] Tay, Kaing-Meng. and Butler, Clive., "Methodologies for experimental design: a survey, comparison, and future predictions", *Quality Engineering*, Vol.1, No.3, 1999, pp 343-356.

[4] Groover, P. Mikell., "*Automation, production systems, and computer integrated manufacturing*", Pearson education Asia, 2001.

[5] Taguchi G., Elsayed E. and Hsiang T., "*Quality engineering in production systems*", New York: Megraw-Hill Book company, 1989.

[6] Li, William. and Wu,C.F.J., "An integrated method of parameter design and tolerance design", *Quality Engineering*, Vol. 11, No.3, 1999, pp417-425.

[7] Lin, Yu-Hsin., Deng, Wei-Jaw., Huang, Cheng-Hung., and Yang, Yung-Kuang, "Optimization of Injection Modeling Process for Tensile and Wear Properties of Polypropylene Components via Taguchi and Design of Experiment Method", *Polymer-Plastic Technology and Engineering*, Vol.47, No.1, 2007, pp 96-105.

[8] Perumallu., K.P., "Process development for Achieving Uniform Plating Thickness", *Quality Engineering*, Vol.10, No.2, 1997, pp231-238.

[9] Mackay, R. Jock. and Steiner, H.Stefan., "Strategies for Variability Reduction", *Quality Engineering*, vol.10,No.1, 1997, pp125-136.

[10] John F. Kros and Christina, M. Mastrangelo., "Impact of non-quadratic loss in the Taguchi design methodology", *Quality Engineering*, Vol. 10, No. 3, 1998, pp 509-519

[11] Escalante, J. Edgrado., "Quality and productivity improvement: a study of variation and defects in manufacturing", *Quality Engineering*,Vol.11, No.3, 1999, pp 427-442.

[12] Blomquist, J.Howard., "Setting on target and reducing variation (or vice versa?)", *Quality Engineering*, Vol.11, No.3, 1999, pp 449-455.

APPENDIX

EPSC product, production and defect cost

Annual production and production costs of selected products

Types of products	Annual Production (Kg)	Mass of a product per piece (Kg)	Cost of raw material (birr/Kg)	Production cost (birr)
F/C Ø16mm	58,874.20	0.229	6.88	2.866
R/C Ø19mm	85,157.56	0.429	12.9	12.244
S/I/W 2.5mm^2	369,177.18	0.0312	47.05	4.44
P/S 38cm/160µm	161,302.9	1	22.6	44

NB: 1Pc of conduit product is cut into 3m.
1Pc of a wire is taken as 1m.

Failure costs of the selected products, taking into consideration recyclable scraps

The general formula used to calculate the failure cost for all selected products is;

$$Cf = Cp - Mp * R * Cr$$

where

Cf is the Failure Cost,
Cp the Production Cost (Birr/pc),
Mp the Mass of Product (Kg/pc),
R Recyclable Percentage, and
Cr the Cost of Raw Material (Birr/Kg)

Using this formula, one compute the failure cost for the selected products as follows:

F/C Ø16mm

$$\begin{aligned} Fialure\ cost &= 2.866\ birr/pc - (0.229 Kg/Pc * 66.34\% * 6.88 birr/Kg) \\ &= 1.821\, birr/Pc \end{aligned}$$

R/C Ø19mm

$$\begin{aligned} Failure\ cost &- 12.244\ birr/Pc - (0.429 Kg/Pc * 43.16\% * 12.9 birr/Kg) \\ &= 9.855 birr/Pc \end{aligned}$$

S/I/W 2.5mm^2

$$\begin{aligned} Failure\ cost &= 4.44 birr/Pc - (0.0312 Kg/Pc * 35.78\% * 47.05 birr/Kg) \\ &= 3.915 birr/Pc \end{aligned}$$

P/S 38cm/160µm

$$\begin{aligned} Failure\ cost &= 44 birr/Kg - (1 * 47.53\% * 22.6 birr/Kg) \\ &= 33.258 birr/Kg \end{aligned}$$