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Taguchi Robust Design for Optimal Setting of Process Wastes Parameters in an Automotive Parts Manufacturing Company

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***Abstract*—**As a technique that reduces variation in a product by lessening the sensitivity of the design to sources of variation, rather than by controlling their sources, Taguchi Robust Design entails the designing of ideal goods, by developing a product that has minimal variance in its characteristics and also meets the desired exact performance. This paper examined the concept of the manufacturing approach and its application to brake pad product of an automotive parts manufacturing company. Although the firm claimed that only defects, excess inventory, and over-production were the few wastes that grossly affect their productivity and profitability, a careful study and analysis of their manufacturing processes with the application of Single Minute Exchange of Dies (SMED) tool showed that the waste of waiting is the fourth waste that bedevils the firm. The selection of the Taguchi L9 orthogonal array which is based on the four parameters and the three levels of variation for each parameter revealed that with a range of 2.17, that waiting is the major waste that the company must reduce in order to continue to be viable. Also, to enhance the company's throughput and profitability, the wastes of over-production, excess inventory, and defects with ranges of 2.01, 1.46, and 0.82, ranking second, third, and fourth respectively must also be reduced to the barest minimum. After proposing -33.84 as the highest optimum Signal-to-Noise ratio to be maintained for the waste of waiting, the paper advocated for the adoption of all the tools and techniques of Lean Production System (LPS), and Continuous Improvement (CI), and concluded by recommending SMED in order to drastically reduce set up time which leads to unnecessary waiting.

***Keywords*—**Taguchi Robust Design, signal to noise ratio, Single Minute Exchange of Dies, lean production system, waste.

I. Introduction

ALSO known as Taguchi Method, Robust Design Method of production enhances engineering productivity by increasing throughput and manufacturing of quality products that guarantee customer satisfaction. This is achieved by consciously considering the noise factors which are environmental variation during the product's usage, manufacturing variation, and component deterioration, as well as the cost of failure in the field [1]. However, [2], noted that Taguchi Robust design method of manufacturing makes products or processes insensitive to variation by reducing the variations without eliminating its causes.

Taguchi robust design is a "method of designing experiments to examine how different parameters affect the mean and variance of a process performance characteristic that defines how well a process is operating" [3]. It involves reducing the variation in a process through robust design of experiments, as its overall objective is to produce high quality product at a low cost to the manufacturer.

This distinctive method of achieving quality assurance and robustness during the design phase applies identification of the ideal function of a product or process, as opposed to traditional method which focuses on inspection as a basis for improvement, thereby leading to improved quality, reduced cost of manufacturing and lead time [4]. The Robust Design system simultaneously yields significantly improved quality, reliability, and durability, as well as the reduction of design cycle times, and manufacturing costs.

Reference [5] explained that the major aim of Taguchi robust design is to reduce and possibly eliminate loss to the society that arise due to variations and wastes in production processes are achieved. They concluded that for business of production to be competitive and profitable in the 21st century, steps to reduce and possibly eliminate all forms of wastes by implementing full Taguchi robust design approaches of LPS is imperative.

The objective of Taguchi's robust design method is to reduce the output variation from the target (the desired output), by making the performance insensitive to noise, such as imperfections in manufacturing, environmental variations as well as deterioration, as the objective has been recognized to be very effective in improving product and manufacturing process design [6].

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II. Company's Brief History

Established over two decades ago, Company C started as a manufacturer of filters and coolants which gave it the opportunity to concentrate on the ever-expanding automobile products and has been winning outstanding contracts from the local automotive parts dealers due to its exceptional ability to manufacture reliable products. The remarkable ability to provide high quality products at the right time to its teeming customers explains why the company remains viable and continues to increase its market share even when some of its competitors are folding up.

The establishment of automobile manufacturing and assembling companies like Innoson Vehicle Manufacturing Company and Anambra Motor Manufacturing Company in South East Nigeria has impacted positively on the company's fortune as it repositioned itself as a key manufacturer of light weight automotive parts, with the introduction of other products like brake pads, lubricating oil, power transmission belts, and engine sittings.

The firm adopted LPS as its method of manufacturing about five years ago and has ever since been benefiting from the numerous advantages it has over mass production which the company was implementing in the past. According to [7], improving efficiency and productivity cannot be achieved through the traditional system of manufacturing which involves mass production. He noted that this is because to remain competitive in the global market, manufacturers should embrace LPS which considerably reduces the cost of manufacturing, as it eliminates the wastes that are associated with mass production, thereby enabling organizations to save lots of money.

Low throughput and profitability, as well rise in lead time, defective products, customers' complaints, and high scrap rate were the main reasons that compelled the company's management to replace mass production with LPS - a manufacturing system that has been accepted as the best manufacturing approach. Although they were unable to record much improvement at the onset, but consistency with the various tools and techniques of Lean enabled them to identify and reduce some of the wastes that adversely affect their productivity and product quality.

With an initial 3-day LPS implementation training programme and a continuous on-the-job training for many of its employees, the company used Five S practice, SMED and CI as its training curricula to ensure that its workforce was adequately equipped. However, the various LPS tools and techniques will not achieve the desired results if they are not properly utilized; as LPS is not just the application of a bunch of tools but rather a completely different approach of manufacturing [8].

The major problem encountered at the trainings was the staff's attitude as they all believed that the manufacturing process was not part of their culture. But, with determination, motivation, CI, and the use of incentives, the employees' mind-sets were changed especially as they began to experience the LPS benefits.

III. Wastes Identification

As Company C had been implementing LPS for the past five years, it is expected that they must have drastically reduced all the wastes in their manufacturing processes, however, although LPS had helped them tremendously to minimize the wastes over the years, a careful study of their nine months brake pads production chart showed that the wastes of defects, inventory, and over-production has not been adequately tackled.

As could be observed from Table I, in the month of September 2016, the company had a total of seven defective cartons of brake pads, 425 excess inventory, zero over-processing, while the difference from the manufactured brake pads and the quantity sold revealed that nine cartons were over-produced.

TABLE I
Brake Pads' Nine Months Production Chart

Months	Available Inventory	Manuf. Brake pads	Sold Brake pads	Defects	Excess Inventory	Over Production	Over Processing
September 2016	17004	16569	16560	7	435	9	0
October 2016	24012	23800	23796	2	212	4	0
November 2016	15896	15896	15888	1	0	8	0
December 2016	31000	31000	30996	3	0	4	0
January 2017	16433	16430	16428	0	3	2	0
February 2017	29807	29643	29640	2	164	3	0
March 2017	25000	24713	24708	4	287	5	0
April 2017	12307	12093	12108	1	214	-15	0
May 2017	26008	26003	25992	2	5	11	0

Although the company's management pointed out that only defects, excess inventory, and over-production were the only wastes that they are contending with, the teams' knowledge of set-up time and the works of Shingeo Shingo on SMED made them to probe further on the efforts to reduce their set-up time. This is because SMED plays a prominent role in Lean Manufacturing, as achieving set-up time reduction is very important in transforming a company from mass production to Lean production. This is because the application of SMED results in remarkable set-up time reductions as well as increase in productivity even in its inception [9]. With quick changeover, SMED contributes immensely to increase in flexibility, production capacity and the maintenance of very low inventory in Optimum production, as one-piece flow and streamlining operations can easily be achieved.

A. Calculating the Waste of Waiting

The quantity of time expended per month for the waste of waiting can be evaluated with (1), with knowledge that 0.25 minute is spent to mount 12 brake pads on the machine.

$$\text{Monthly Waiting} = 0.25\ (\text{minute}) * \frac{\text{number of manufactured ladder tops}}{12} \quad (1)$$

Substituting in (1).

For September 2010: $Waiting = 0.25 * \frac{16569}{12} = 345.19$

The values obtained by performing similar calculations for the remaining months are summarised in Table II.

TABLE II
THE CALCULATED TIME IN MINUTES

Months	Available Inventory	Manuf. Brake pads	Sold Brake pads	Defects	Excess Inventory	Over Production	Waiting (Minutes)
Sept. 2016	17004	16569	16560	9	435	9	345.19
Oct. 2016	24012	23800	23796	2	212	4	495.83
Nov. 2016	15896	15896	15888	1	0	8	331.17
Dec. 2016	31000	31000	30996	3	0	4	645.83
Jan. 2017	16433	16430	16428	0	3	2	342.29
Feb. 2017	29807	29643	29640	2	164	3	617.56
March 2017	25000	24713	24708	4	287	5	514.54
April 2017	12307	12093	12108	1	214	-15	251.94
May 2017	26008	26003	25992	2	5	11	541.73

IV. TAGUCHI ROBUST DESIGN APPLICATION

From Table II, it could be deduced that the four wastes that are adversely affecting the company's LPS efforts are: defects, Excess inventory, Over-production, and waiting. The selection of the Taguchi L9 orthogonal array is based on the four parameters and the three levels of variation for each parameter. Table III shows the standard Taguchi L9 orthogonal array.

TABLE III
THE TAGUCHI L9 ORTHOGONAL ARRAY

Experiment Number	Parameter 1	Parameter 2	Parameter 3	Parameter 4
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

With the actual variables and states, the L9 orthogonal array becomes Table IV.

A. Objective Function, Experimentations, and Quality Characteristics

The main aim of LPS is to minimise or possibly eliminate all forms of wastes in production processes. The identified wastes are defects (A), excess inventory (B), over-production (C), and waiting (D).

C_A=Cost of Defects Production
C_B=Cost of Excess Inventory
C_C=Cost of Over-Production, and
C_D=Cost of Waiting

The total cost of wastes (C_T) is the objective function to be reduced and can be expressed as follows:

$$C_T = C_A + C_B + C_C + C_D$$

When trying to optimize a complex mechanism or a production process where no design model exists, the robust design is achieved by running physical tests in which a quality characteristic is measured to determine the effects of various settings of the control parameters and noise factors.

To successfully apply the Taguchi Robust design calculations, three different experimental trials which are the costs of the various wastes were obtained from the company as shown in Table V.

TABLE IV
THE L9 ORTHOGONAL ARRAY FOR THE WASTES IN BRAKE PADS PRODUCT

Experiment Number	Defects (A)	Excess Inventory (B)	Over-production (C)	Waiting (D) in Minutes
1	9	435	9	345.19
2	2	212	4	495.83
3	1	0	8	331.17
4	3	0	4	645.83
5	0	3	2	342.29
6	2	164	3	617.56
7	4	287	5	514.54
8	1	214	-15	251.94
9	2	5	11	541.73

Applying (2)-(4), the mean, variance, and the standard deviation of the measured quality characteristics were evaluated.

$$\grave{y} = \sum_{i=1}^{n} \frac{y_i}{n} \tag{2}$$

$$s^2 = \sum_{i=1}^{n} \frac{(y_i - \grave{y})^2}{n-1} \tag{3}$$

$$s = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \grave{y})^2}{n-1}} \tag{4}$$

B. The Mean, Variance, and Standard Deviation

To calculate the Mean ($\grave{y}$), Variance (S^2), and Standard deviation (S), the information on Table V is used in conjunction with (2)-(4) for the nine different experiments, and the results are summarised in Table VI.

The entire calculated values and the experimental trials are shown in Table VII.

C. Taguchi Robust Design Equations and Calculations

As the aim of LPS is the minimising or possible elimination of wastes, which in this scenario involve minimising the performance characteristics, the smaller the better definition of the Signal to Noise (SN) ratio is used for the calculations.

$$SN_i = -10 \log \left(\sum_{u=1}^{N_i} \frac{y_u^2}{N_i} \right) \tag{5}$$

Computing the nine different experiments using (5) and the values of the trials from Table VII yield Table VIII.

TABLE V
THE TRIALS FROM THE EXPERIMENTS

Experiment Number	Defects	Excess Inventory	Over-production	Waiting	Trial 1 (y_1)	Trial 2 (y_2)	Trial 3 (y_3)
1	9	435	9	345.19	38.0	43.4	38.2
2	2	212	4	495.83	56.3	48.9	52.0
3	1	0	8	331.17	33.6	37.0	39.0
4	3	0	4	645.83	48.1	49.7	52.4
5	0	3	2	342.29	32.8	37.0	35.8
6	2	164	3	617.56	50.9	46.5	48.0
7	4	287	5	514.54	46.6	46.6	45.8
8	1	214	-15	251.94	31.3	31.0	28.7
9	2	5	11	541.73	47.3	43.3	47.4

TABLE VI
STANDARD DEVIATION OF MANUFACTURED WASTES

y_1	y_2	y_3	ỳ	$\frac{(y_1-ỳ)^2}{n-1}$	$\frac{(y_2-ỳ)^2}{n-1}$	$\frac{(y_3-ỳ)^2}{n-1}$	S^2	S
38.0	43.4	38.2	39.86667	1.74223	6.24221	1.38889	9.37333	3.06159
56.3	48.9	52.0	52.4	7.605	6.125	0.08	13.81	3.71618
33.6	37.0	39.0	36.53333	4.30221	1.17555	6.24221	11.71997	3.42344
48.1	49.7	52.4	50.06667	1.9339	0.06722	2.72221	4.72333	2.17332
32.8	37.0	35.8	35.2	2.88	1.62	0.18	4.68	2.16333
50.9	46.5	48.0	48.46667	2.96055	1.93390	0.10889	4.90534	2.21480
46.6	46.6	45.8	46.33333	0.03556	0.03556	0.14222	0.21334	0.46189
31.3	31.0	28.7	30.33333	0.46723	0.22222	1.33388	2.02333	1.42244
47.3	43.3	47.4	46.0	0.845	3.645	0.98	5.47	2.33880

TABLE VII
CONTROL MATRIX AND THE EXPERIMENTAL TRIALS RESPONSE

Exp. No.	A	B	C	D	Trial 1 (y_1)	Trial 2 (y_2)	Trial 3 (y_3)	ỳ	S^2	S
1	9	435	9	345.19	38.0	43.4	38.2	39.86667	9.37333	3.06159
2	2	212	4	495.83	56.3	48.9	52.0	52.4	13.81	3.71618
3	1	0	8	331.17	33.6	37.0	39.0	36.53333	11.71997	3.42344
4	3	0	4	645.83	48.1	49.7	52.4	50.06667	4.72333	2.17332
5	0	3	2	342.29	32.8	37.0	35.8	35.2	4.68	2.16333
6	2	164	3	617.56	50.9	46.5	48.0	48.46667	4.90534	2.21480
7	4	287	5	514.54	46.6	46.6	45.8	46.33333	0.21334	0.46189
8	1	214	-15	251.94	31.3	31.0	28.7	30.33333	2.02333	1.42244
9	2	5	11	541.73	47.3	43.3	47.4	46.0	5.47	2.33880

TABLE VIII
THE COMPUTED SIGNAL TO NOISE RATIO VALUES WITH THE TRIALS

Experiment Number	Defects	Excess Inventory	Over-production	Waiting	Trial 1 (y_1)	Trial 2 (y_2)	Trial 3 (y_3)	S_N
1	1	1	1	1	38.0	43.4	38.2	−32.03
2	1	2	2	2	56.3	48.9	52.0	−34.40
3	1	3	3	3	33.6	37.0	39.0	−31.27
4	2	1	2	3	48.1	49.7	52.4	−34.0
5	2	2	3	1	32.8	37.0	35.8	−30.94
6	2	3	1	2	50.9	46.5	48.0	−33.72
7	3	1	3	2	46.6	46.6	45.8	−33.32
8	3	2	1	3	31.3	31.0	28.7	−29.64
9	3	3	2	1	47.3	43.3	47.4	−33.26

To successfully compute the average Signal to Noise (SN) ratio of each waste in the nine experiments, Table IX which summarizes the nine experiments is required.

To create the response table, the first step is to calculate the average SN value for each factor and level, before calculating the range.

For the defects (A), the three formulae for the calculation of the average Signal to Noise value are:

$$S_{NA1} = \frac{S_{N1} + S_{N2} + S_{N3}}{3} = \frac{-32.03 - 34.40 - 31.27}{3} = -32.57$$

$$S_{NA2} = \frac{S_{N4} + S_{N5} + S_{N6}}{3} = \frac{-34.0 - 30.94 - 33.72}{3} = -32.89$$

$$S_{NA3} = \frac{S_{N7} + S_{N8} + S_{N9}}{3} = \frac{-33.32 - 29.64 - 33.26}{3} = -32.07$$

$$Range\Delta = Maximum - Minimum = -32.07 + 32.89 = 0.82$$

TABLE IX
SIGNAL TO NOISE RATIO AND CONTROL MATRIX

Experiment Number	A (Defects)	B (Excess Inventory)	C (Over-production)	D (Waiting)	S_N
1	1	1	1	1	−32.03
2	1	2	2	2	−34.40
3	1	3	3	3	−31.27
4	2	1	2	3	−34.0
5	2	2	3	1	−30.94
6	2	3	1	2	−33.72
7	3	1	3	2	−33.32
8	3	2	1	3	−29.64
9	3	3	2	1	−33.26

For B (Excess Inventory)

$$S_{NB1} = \frac{S_{N1} + S_{N4} + S_{N7}}{3} = \frac{-32.03 - 34 - 33.32}{3} = -33.12$$

$$S_{NB2} = \frac{S_{N2} + S_{N5} + S_{N8}}{3} = \frac{-34.4 - 30.94 - 29.64}{3} = -31.66$$

$$S_{NB3} = \frac{S_{N3} + S_{N6} + S_{N9}}{3} = \frac{-31.27 - 33.72 - 33.36}{3} = -32.70$$

$$Range\Delta = Maximum - Minimum = -31.66 + 33.12 = 1.46$$

For C (Over-production)

$$S_{NC1} = \frac{S_{N1} + S_{N6} + S_{N8}}{3} = \frac{-32.03 - 33.72 - 29.64}{3} = -31.80$$

$$S_{NC2} = \frac{S_{N2} + S_{N4} + S_{N9}}{3} = \frac{-34.4 - 34.0 - 33.26}{3} = -33.81$$

$$S_{NC3} = \frac{S_{N3} + S_{N5} + S_{N7}}{3} = \frac{-31.27 - 30.94 - 33.32}{3} = -31.84$$

$$Range\Delta = Maximum - Minimum = -31.8 + 33.81 = 2.01$$

For D (Waiting)

$$S_{ND1} = \frac{S_{N1} + S_{N5} + S_{N9}}{3} = \frac{-32.03 - 30.94 - 33.26}{3} = -32.08$$

$$S_{ND2} = \frac{S_{N2} + S_{N6} + S_{N7}}{3} = \frac{-34.4 - 33.72 - 33.32}{3} = -33.81$$

$$S_{ND3} = \frac{S_{N3} + S_{N4} + S_{N8}}{3} = \frac{-31.27 - 34 - 29.64}{3} = -31.64$$

$$Range\Delta = Maximum - Minimum = -31.64 + 33.81 = 2.17$$

TABLE X
THE RESPONSE TABLE

Level	A (Defects)	B (Excess Inventory)	C (Over-production)	D (Waiting)
1	-32.57	-33.12	-31.8	-32.08
2	-32.89	-31.66	-33.81	-33.81
3	-32.07	-32.7	-31.84	-31.64
Range Δ	0.82	1.46	2.01	2.17
Rank	**4**	**3**	**2**	**1**

Table X is the response table and is derived from the values of the calculated Signal to Noise ratios of the various wastes.

As could be observed from Table X, waiting (which the company initially did not see as a waste) has the largest effect on the quality characteristics of manufacturing of brake pads. While over-production, excess inventory, and defects ranked second, third, and fourth respectively.

From the above table, the optimum levels of the factors can be gotten by plotting the major effects plots as shown in Fig. 1, this is because the largest value of SN ratio is the preferred value.

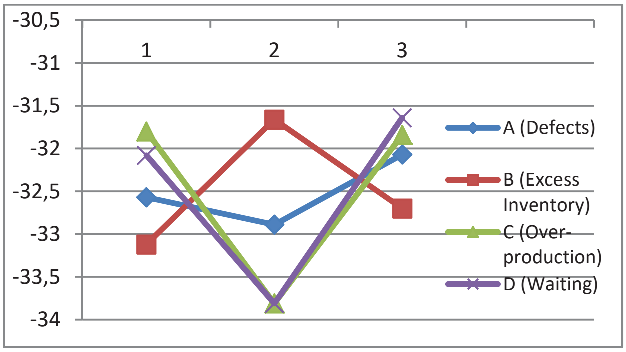

Fig. 1 Major effect plots of factors with Table X

V. CONCLUSION

Although the firm had made a lot of efforts in the past to be lean, the results from the analysis have however shown that to maintain their lead as a major manufacturer of Brake pads that a lot still had to be done to tackle all the wastes that act as clogs in their wheel of progress.

The highest optimum Signal-to-Noise ratio to be maintained for the most significant waste (Waiting) in the company is -33.84 to guard against all forms of wastes.

As CI in all manufacturing processes is the major aim of LPS, constant efforts geared towards reducing the wastes and possible elimination will not only increase the profitability of the company but will also ensure that they will continue to beat their numerous competitors. This is because the whole concept of LPS is aimed at using little resources to achieve more, as well as increasing the quality of manufactured products, lessen lead times, reduce costs and also increase manufacturing flexibility and profitability [10].

While the company should adopt all the principles, tool and technique of LPS which will enable it to work on their supply chain in order to reduce their rate of over-production and excess inventory, they should also source for suppliers with a high-quality track record in order to reduce the rate of defective products. However, they must adopt and implement the entire concept of Shingeo Shingo's SMED, to enable them to drastically reduce their set-up time which leads to unnecessary waiting at the shop floor.

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