RUHUNA JOURNAL OF SCIENCE
Vol. 1, September 2006, pp. 67–81
http://www.ruh.ac.lk/rjs/
ISSN 1800-279X

Validation of Taguchi design using a quality parameter of cosmetic soap manufactured in a local industry

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The objective of this study is to investigate the applicability of Taguchi method to the production process of a local industry. Harishchandra Mills (Pvt.) Ltd, Matara, which is engaged in soap manufacturing process has been selected as the local industry. This process is entangled with different kinds of variables. Four critical variables - two types of oil, coconut oil (a^1) and palm oil (a^0), on the basis of high and low saponification values, two levels of caustic soda (b^0, b^1), and two different saponification temperatures, 70°C(c^0) and 80°C(c^1), with and without stirring process for saponification (d^1, d^0) were adopted. The results obtained for Total Fatty Matter (TFM) was used to calculate optimum value (Y_{opt}) for each treatment with and without replicates. The results for Y_{opt} for TFM with and without replicates were 75.98%, and 76.66%, respectively. The best treatment combination under this method was $a^1b^1c^1d^1$ for the same sequence of quality parameters given above. The same best treatment combinations were also obtained for the validation test, four-factor experiment design and block design with and without replicates.

Key words: Soap manufacture, Statistical quality control, Taguchi method, Factorial experiment design, and Block design.

1. Introduction

Sri Lanka is a developing country, which enjoys a wide spectrum of production processes using abundant natural resources. With the emergence of global village concept and free market economy a substantial amount of business establishments have mushroomed throughout the country. Though there are many kinds of business establishments' function in the country, most of these do not posses an adequate advanced technical know how to cope with the issues encountered by them during their day today activities.

Aftermath of this development has resulted in releasing different kinds of sub-standard products, produced under manufacturer's own standard to the dynamic market. Hence in order to cope with this situation, the technical term "standardization" has come into light along with regulatory requirement with the view to protect the consumer.

Since modern market is also dynamic and competitive the entrepreneurs strive hard to maintain competitive edge on their products while minimizing wastages occurring in the production process and boosting the productivity.

On the other hand, Sri Lankan business establishments can be categorized into 3 key groups as traditional, semi modern and modern. The majority of them are coming under traditional and semi modern groups. However they do not posses adequate resources to face the challenges exerted by the conditions in the dynamic marketing environment.

Therefore switching on to advanced statistical designs is one of the options for any type of producer to improve the over all productivity of his business along with the quality while minimizing wastages.

Professor Genichi Taguchi, an engineer and an eminent scientist from Japan who encountered with a similar problem was able to introduce a new statistical design, after deeply studying the "off line quality control" activities of production lines. The new statistical design called "Taguchi design" is applicable to the modern industrial environment, in order to resolve most issues emerging from wilful errors and inadvertent errors in a production line. The other advantage of using this statistical design is the maximum utilization of tangible and intangible scarce natural resources in a production process.

Hence objective of the study was to use Taguchi design in a production process of a local industry, where production process is carried out amid considerable number of variables. Outcome of which is to be validated by two other designs to gauge the accuracy of Taguchi design.

1.1. Objectives

- Identification of error variables of Cosmetic Soap manufacturing process using control charts.
- Comparative study of Factorial experiment, confounded blocks design and Taguchi design.
- Manufacturing of cosmetic soap with respect to the 2^4 designs.
- Manufacturing of high quality soap for consumer market by identifying desirable limits for important variables of soap manufacturing process with respect to the advance Taguchi design.

2. Materials and Methods

2.1. Terminology

We shall use the following terminology throughout the paper. Total fatty matter (TFM), low saponification oil (a^0), high saponification oil (a^1), NaOH low concentration (b^0), NaOH high concentration (b^1), low temperature (c^0), high temperature (c^1), no stirring (d^0), with stirring (d^1), Oil (A), NaOH (B), Temperature (C), Stirring (D), number of replicate (n) and number of variable (f).

Table 1 Algebraic signs for the Taguchi design

Variable / Test	Treatment combination	A	B	C	D
(1)	$a^0b^0c^0d^0$	-	-	-	-
ad	$a^1b^0c^0d^1$	+	-	-	+
bd	$a^0b^1c^0d^1$	-	+	-	+
ab	$a^1b^1c^0d^0$	+	+	-	-
cd	$a^0b^0c^1d^1$	-	-	+	+
ac	$a^1b^0c^1d^0$	+	-	+	-
bc	$a^0b^1c^1d^0$	-	+	+	-
$abcd$	$a^1b^1c^1d^1$	+	+	+	+

2.2. Parameters

Four key variables responsible for major quality characteristics of soap were identified after scrutinizing the soap manufacturing process. They are,

- Saponification value of oils,
- Concentration of sodium hydroxide (NaOH),
- Saponification Temperature, and
- Period of stirring.

Quality parameter of the samples,

- Total Fatty Matter (TFM)

2.3. Taguchi Method

Taguchi constructed a special set of general designs for factorial experiments that cover many applications. The special set of designs consists of orthogonal arrays (OA). The use of these arrays helps to determine the least number of experiments needed for a given set factors. (Dayananda 1992)

The latest statistical model for design of an experiment, "Taguchi's advance design", was adapted for this study, which has the advantage of less treatment combinations in compared with other statistical designs. (See Table 1)

Above design was used to analyze the data obtained for TFM of soap samples in order to determine optimum values for critical variables.

2.3.1. Statistical Analysis of Data:

The data obtained for TFM of soap samples of different treatment combinations were statistically analyzed in order to determine Y_{opt} using following formula.

$$Y_{opt} = \frac{T}{N} + \sum_{i=1}^{4}(\bar{k_i} - \frac{T}{N}) \quad . \tag{1}$$

Where,

$$T = (\bar{a^0} + \bar{a^1}) + (\bar{b^0} + \bar{b^1}) + (\bar{c^0} + \bar{c^1}) + (\bar{d^0} + \bar{d^1}),$$

$\bar{k_i} =$ Mean value of optimum level of each variable, and
$N =$ Number of observations. (Nawarathne 2003)

Table 2 Algebraic signs for the 2^4 Experiment Design

	Fact effect \ run	I	A	B	AB	C	AC	BC	ABC	D	AD	BD	ABD	CD	ACD	BCD	$ABCD$
(I)	$a^0b^0c^0d^0$	+	-	-	+	-	+	+	-	-	+	+	-	+	-	-	+
a	$a^1b^0c^0d^0$	+	+	-	-	-	-	+	+	-	-	+	+	+	+	-	-
b	$a^0b^1c^0d^0$	+	-	+	-	-	+	-	+	-	+	-	+	+	-	+	-
ab	$a^1b^1c^0d^0$	+	+	+	+	-	-	-	-	-	-	-	-	+	+	+	+
c	$a^0b^0c^1d^0$	+	-	-	+	+	-	-	+	-	+	+	-	-	+	+	-
ac	$a^1b^0c^1d^0$	+	+	-	-	+	+	-	-	-	-	+	+	-	-	+	+
bc	$a^0b^1c^1d^0$	+	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
abc	$a^1b^1c^1d^0$	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	-
d	$a^0b^0c^0d^1$	+	-	-	+	-	+	+	-	+	-	-	+	-	+	+	-
ad	$a^1b^0c^0d^1$	+	+	-	-	-	-	+	+	+	+	-	-	-	-	+	+
bd	$a^0b^1c^0d^1$	+	-	+	-	-	+	-	+	+	-	+	-	-	+	-	+
abd	$a^1b^1c^0d^1$	+	+	+	+	-	-	-	-	+	+	+	+	-	-	-	-
cd	$a^0b^0c^1d^1$	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-	+
acd	$a^1b^0c^1d^1$	+	+	-	-	+	+	-	-	+	+	-	-	+	+	-	-
bcd	$a^0b^1c^1d^1$	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
$abcd$	$a^1b^1c^1d^1$	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
divisor		16	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

2.4. Validation Test - Four-Factor Experiment Design

The treatment combination in this design is given in Table 2 (George, William, Hunter 1978).

2.4.1. Statistical Analysis of Data of 2^4 Design:

The data obtained from the four-factor experiment design were analyzed using Table 2, and the contrast and the effect with respect to each variable were calculated. The effect for each variable was calculated using the following formula (Thomas 1998).

$$\text{Effect} = \frac{\text{Contrast}}{2^{f-1}n} \quad . \tag{2}$$

The sum of square for any effect of each variables were calculated using,

$$\text{SS} = \frac{(\text{Contrast})^2}{2^f n}. \tag{3}$$

The high percent contribution values were selected from ANOVA table of which significant levels of each variable were calculated. A basic model was developed using significantly different values from the ANOVA table. The function for the basic model is,

$$\begin{aligned} Y = & \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \beta_{14} X_1 X_4 \\ & + \beta_{24} X_2 X_4 + \beta_{34} X_3 X_4 + \beta_{123} X_1 X_2 X_3 + \beta_{134} X_1 X_3 X_4 + \beta_{234} X_2 X_3 X_4 \\ & + \beta_{124} X_1 X_2 X_4 + \beta_{234} X_2 X_3 X_4 + \beta_{124} X_1 X_2 X_4 + \beta_{1234} X_1 X_2 X_3 X_4 + \epsilon \end{aligned} \tag{4}$$

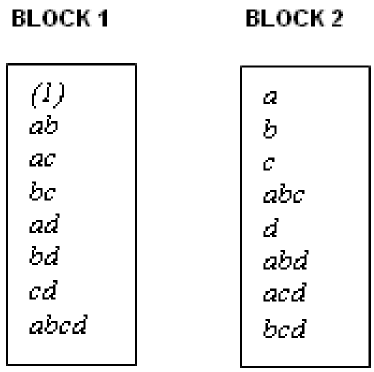

Figure 1 Assignment of the 16 runs to two blocks -without replicate (ABCD confounded).

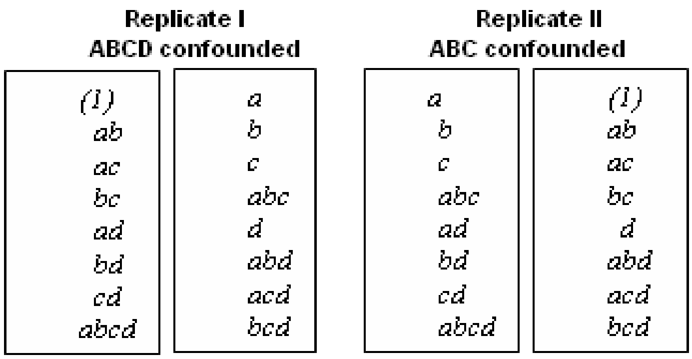

Figure 2 Partial confounding in the 2^4 design - with replicates.

The developed model for quality parameter TFM can be used to detect relationship between significantly different variables. This relationship can be depicted by either response surface or contour plot. (Douglas 2000)

2.5. Validation Test - Confounded Block Design

Same data obtained for four-factor experiment designs were used for block design in order to validate Taguchi design again. (Douglas 2000) (See Figure 1, 2)

2.5.1. Statistical Analysis of Confounded Block Design. The effect and sum of square for ABCD (block) was calculate using,

$$\text{Block effect } = \bar{y}_{block1} - \bar{y}_{block1} \quad . \tag{5}$$

$$SS_{Blocks} = \frac{(y_1)^2}{8} + \frac{(y_2)^2}{8} - \frac{(y_1+y_2)^2}{16} \quad . \tag{6}$$

where, $\bar{y}_{blocki}$ = average value of each block i and y_i = sum of block i.

Table 3 Comparison of factorial design and Taguchi Design

Factors	Level	Total number of experiments (factorial Design)	Taguchi Design Total number of experiments
2	2	4	4
3	2	8	4
4	2	16	8
7	2	128	8
15	2	32,768	16
4	3	81	9

However, the values of SS_{ABC} and SS_{ABCD} should be calculated using only the data in replicate I and replicate II, respectively. The effect and sum of square for the replicate were calculated using,

$$SS_{Rep} = \sum_{i=1}^{n} \frac{R_i^2}{2^k} - \frac{y_{\dots}^2}{2^k n} \tag{7}$$

where R_i is the total observation in the i^{th} replicate. n is the number of replicates, and k is the number of variable. $y_{\dots}$ is the sum of total observations.(Richard 1996)

2.6. Comparison of Factorial Design and Taguchi Design

The total number of experiments possible for different number of factors at 2 or 3 levels and the corresponding suggested Taguchi number of experiments is shown in Table 3. (www.stasoft.com 2004, Pathirana 2005)

Taguchi has established OAs that describes a large number of experimental situations.

3. Results and Discussion

Results pertaining to the TFM of wet soap manufactured with respect to Taguchi design were validated by two statistical designs, four- factor experiment design and block design.

3.1. TFM Value for Samples Prepared from each Design

TFM value was obtained for soap samples prepared with respect to each design, Taguchi design, four-factor experiment design and block design.

3.1.1. TFM value for Taguchi Design - Without and with Replicate: The data obtained for TFM value of soap with respect to Taguchi design without and with replicates (three replicates) are given in Table 4 and Table 5 respectively.

TFM values obtained for Taguchi design with respect to each variable are given in linear graphs in Figure 3 and Figure 4. These graphs clearly indicate that there is a positive relationship for TFM value with the increase of magnitude of each variable. Hence, the best treatment combination in order to enhance TFM value of soap manufacture is $a^1b^1c^1d^1$. Furthermore, the value of TFM is increased simultaneously with the increase of each variable. Calculation from the model (using equation 1) for optimum value of TFM (Y_{opt}) is equal to 75.98% and 76.66% with and without replicates, respectively. (See Figure 3, 4)

Table 4 TFM value for Taguchi design - without replicate

Variable Test	A	B	C	D	Treatment combination	Value
(1)	-	-	-	-	$a^0b^0c^0d^0$	63.00
ad	+	-	-	+	$a^1b^0c^0d^1$	68.25
bd	-	+	-	+	$a^0b^1c^0d^1$	60.42
ab	+	+	-	-	$a^1b^1c^0d^0$	66.30
cd	-	-	+	+	$a^0b^0c^1d^1$	73.90
ac	+	-	+	-	$a^1b^0c^1d^0$	65.32
bc	-	+	+	-	$a^0b^1c^1d^0$	72.10
$abcd$	+	+	+	+	$a^1b^1c^1d^1$	79.20

Table 5 TFM value for Taguchi Design - with replicates

Variable / Test	Treatment combination	Replicate I	Replicate II	Replicate III	Total Value
(1)	$a^0b^0c^0d^0$	62.50	63.00	62.50	188.00
ad	$a^1b^0c^0d^1$	68.20	67.30	68.00	204.00
bd	$a^0b^1c^0d^1$	60.52	60.88	60.86	182.26
ab	$a^1b^1c^0d^0$	66.50	66.20	66.30	199.00
cd	$a^0b^0c^1d^1$	72.70	73.30	74.00	220.00
ac	$a^1b^0c^1d^0$	64.30	64.50	64.20	193.00
bc	$a^0b^1c^1d^0$	70.90	71.40	71.70	214.00
$abcd$	$a^1b^1c^1d^1$	77.80	78.90	78.30	235.00

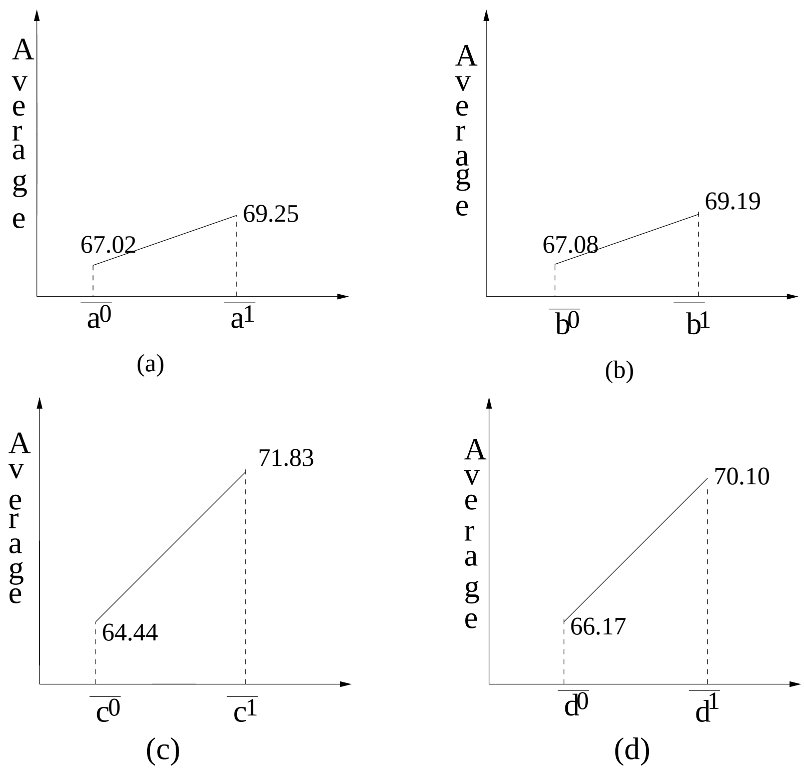

Figure 3 Relationship of TFM with respect to each variable- with replicates

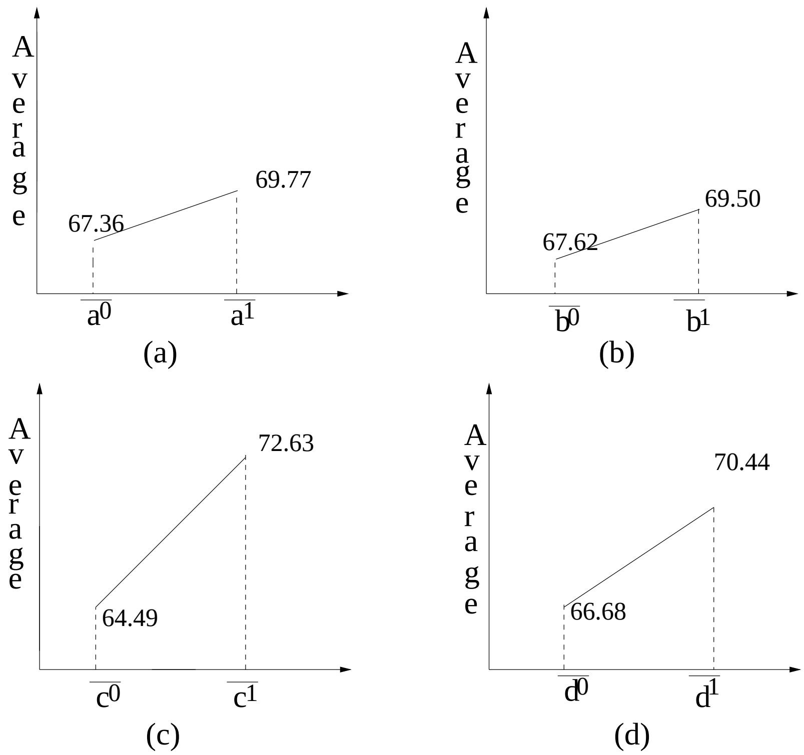

Figure 4 Relationship of TFM value with respect to each variable - without replicates

3.1.2. Four Factor Experiment Design With and Without Replicate for TFM. The data obtained for TFM value for without replicate design are given in Table 6. A normal probability graph of cumulative value of probability vs effect is drawn in Figure 5. The data obtained for TFM value for with replicates design are given in Table 7 Soap samples were prepared with respect to the 2^4 design and each treatment combination was replicated 3 times. A normal probability graph of cumulative value of probability Vs effect is drawn in Figure 6. These graphs (Figure 5 and Figure 6) clearly indicate that the variables C and D are more significant in compared with A and B. An ANOVA table was developed for further studies of the significance of variables C and D and the results are given in Table 8 and Table 9. The ANOVA table clearly indicates that calculated values for variables C (temperature) and D (stirring) are higher than the F distribution table values ($F_{1,5}(0.10) = 4.06$ and $F_{1,32}(0.01) = 7.56$).

From Table.8,

$$C = 4.16 > 4.06$$
$$D = 5.26 > 4.06$$

and from Table.9,

$$C = 24.68 > 7.56$$
$$D = 70.25 > 7.56.$$

Table 6 TFM value for 2^4 Factorial Design (without replicate)

Run number	Run label	Treatment Combination	Values
1	(I)	$a^0b^0c^0d^0$	66.20
2	a	$a^1b^0c^0d^0$	66.00
3	b	$a^0b^1c^0d^0$	57.00
4	ab	$a^1b^1c^0d^0$	58.00
5	c	$a^0b^0c^1d^0$	55.67
6	ac	$a^1b^0c^1d^0$	65.32
7	bc	$a^0b^1c^1d^0$	71.90
8	abc	$a^1b^1c^1d^0$	57.69
9	d	$a^0b^0c^0d^1$	69.31
10	ad	$a^1b^0c^0d^1$	68.25
11	bd	$a^0b^1c^0d^1$	57.42
12	abd	$a^1b^1c^0d^1$	56.90
13	cd	$a^0b^0c^1d^1$	73.50
14	acd	$a^1b^0c^1d^1$	48.20
15	bcd	$a^0b^1c^1d^1$	69.39
16	$abcd$	$a^1b^1c^1d^1$	78.20

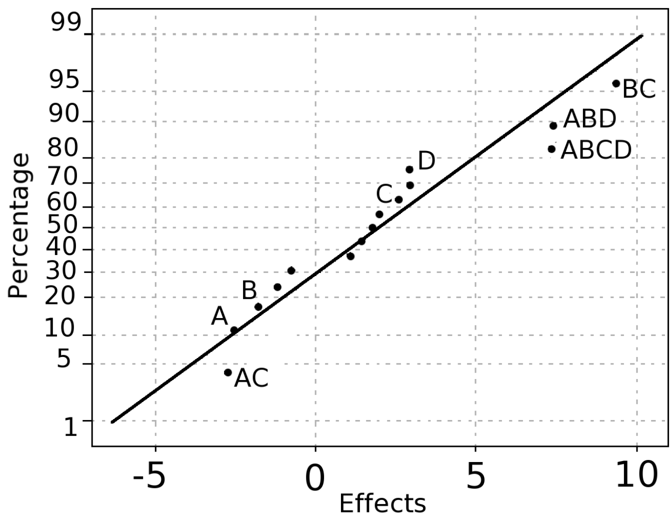

Figure 5 Normal probability plots for the effects for TFM (without replicate)

Therefore, relatively high temperature and stirring time have a big effect on TFM of soap manufactured. Since four-factor experiment design also shows that most important variables for TFM of soap manufacture are C and D and least effect variables are A and B, Taguchi method can be validated by four-factor factorial design as Taguchi method was also indicated that C and D variables at higher levels are critical for soap manufacturing process, in addition to A and B variables.

Table 7 TFM value for 2^4 experiment design- with replicates

Run Label	Treatment 1 Combination	Replicate I	Replicate II	Replicate III	Total
(1)	$a^0b^0c^0d^0$	69.63	66.50	65.33	201.46
a	$a^1b^0c^0d^0$	67.16	65.55	65.23	197.94
b	$a^0b^1c^0d^0$	58.69	56.72	55.63	171.04
ab	$a^1b^1c^0d^0$	56.72	56.80	57.40	170.92
c	$a^0b^0c^1d^0$	45.56	45.60	45.82	136.98
ac	$a^1b^0c^1d^0$	64.82	64.50	64.43	193.75
bc	$a^0b^1c^1d^0$	70.61	71.50	72.22	214.33
abc	$a^1b^1c^1d^0$	62.33	65.43	66.55	194.31
d	$a^0b^0c^0d^1$	70.20	69.22	68.50	207.92
ad	$a^1b^0c^0d^1$	68.11	67.45	68.22	203.78
bd	$a^0b^1c^0d^1$	58.20	58.40	57.70	174.30
abd	$a^1b^1c^0d^1$	54.42	57.27	58.98	170.67
cd	$a^0b^0c^1d^1$	72.98	73.30	74.40	220.68
acd	$a^1b^0c^1d^1$	45.39	50.34	48.87	144.60
bcd	$a^0b^1c^1d^1$	70.42	69.50	68.24	208.16
$abcd$	$a^1b^1c^1d^1$	78.30	78.42	78.85	235.57

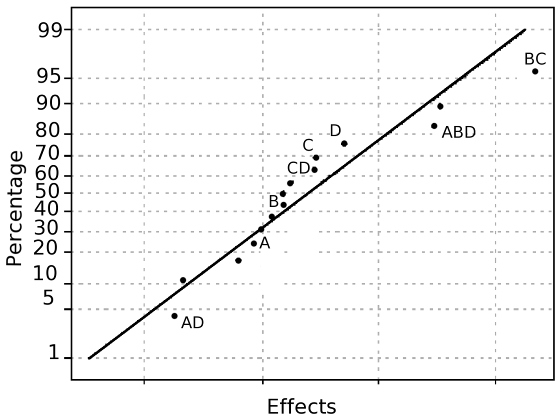

Figure 6 Normal probability plots for the effect for TFM - with replicates

Similarly out come of the ANOVA tables with and without replicate do not show any significant difference. Therefore, four-factor experiment design can also be used to validate Taguchi method.

A regression model can be developed using calculated F values, which should be more than the F table value. With replicates, the model is as follows.

$$Y = 63.47 + 0.46X_3 + 1.77X_4 + 0.64X_1X_2 - 1.86X_1X_4 + 5.84X_2X_3 + 1.13X_3X_4 + 3.70X_1X_2X_4 + 1.69X_1X_3X_4 + 3.82X_1X_2X_3X_4. \quad (8)$$

Table 8 TFM (without replicate)-Analysis of the variance

Source of Variation	Sum of Square	Degree of Freedom	Mean Squares	F_0 Value
C	27.01	1	27.01	**4.16**
D	34.19	1	34.19	**5.26**
AB	15.98	1	15.98	2.46
BC	350.91	1	350.91	**53.99**
CD	12.31	1	12.31	1.89
AC	25.68	1	25.68	3.95
AD	12.80	1	12.80	1.97
ABD	215.89	1	219.85	**33.82**
BCD	34.02	1	34.02	**5.23**
$ABCD$	214.84	1	214.84	**33.05**
Error	32.52	5	6.50	
Total	976.15	15		

Table 9 TFM (with replicates)-Analysis of the variance

Source of Variation	Sum of Square	Degree of Freedom	Mean Squares	F_0 Value
A	11.63	1	11.63	5.43
B	10.26	1	10.26	4.79
C	52.82	1	52.82	**24.68**
D	150.34	1	150.34	**70.25**
AB	19.52	1	19.52	**9.12**
AC	< 0.01	1	< 0.01	< 0.01
AD	167.07	1	167.07	**78.07**
BC	1639.50	1	1639.50	**766.12**
BD	1.60	1	1.60	0.75
CD	61.49	1	61.49	**28.73**
ABC	10.82	1	10.82	5.06
ABD	655.57	1	655.57	**306.34**
ACD	137.66	1	137.66	**64.33**
BCD	2.01	1	2.01	0.94
$ABCD$	698.98	1	698.98	**326.63**
Error	68.45	32	2.14	
Total	2390.96	47		

Significant F values are highlighted.

3.1.3. Confounded Block Design with and without replicate for TFM. The data obtained for TFM value of soap base, prepared in accordance with the block design are given in Figure 7. (ABCD confounded - without replicate).

Thus, each replicate of 2^4 designs must be run in two blocks. Two replicates are run, with ABCD confounded in replicate I and ABC confounded in replicate II. The data are given in Figure 8.

An ANOVA table was made with respect to the variables and interactions that are given in Table.10 and Table.11.

Block 1	Block 2
(1) = 46.20	*a* = 66.00
ab = 38.00	*b* = 57.00
ac = 45.32	*c* = 55.67
bc =51.90	*abc* = 57.69
ad = 48.25	*d* = 69.31
bd = 37.42	*abd* = 56.90
cd = 53.50	*acd* = 48.20
abcd=58.20	*bcd* =69.39

Figure 7 TFM value (without replicate) - 16 runs in two blocks

Replicate I ABCD confounded		Replicate II ABC confounded	
(1) = 69.63	*a* = 67.16	*a* = 65.55	(1) = 66.50
ab = 56.72	*b* = 58.69	*b* = 56.72	*ab* = 56.80
ac = 64.82	*c* = 45.56	*c* = 45.60	*ac* = 64.50
bc = 70.61	*abc* = 62.33	*abc* = 65.43	*bc* = 71.50
ad = 68.11	*d* = 70.20	*ad* = 67.45	*d* = 69.22
bd = 58.20	*abd* = 54.42	*bd* = 58.40	*abd* = 57.27
cd = 72.98	*acd* = 45.39	*cd* = 73.30	*acd* = 50.34
abcd= 78.30	*bcd* = 70.42	*abcd*= 78.42	*bcd* = 69.50

Figure 8 TFM - Partial Confounding in the 2^4 design

Table 10 TFM (without replicate) - Analysis of variance for block design

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	$F-$ Value
Block($ABCD$)	642.25	1	642.25	**98.81**
C	27.01	1	27.01	**4.16**
D	34.19	1	34.19	**5.26**
AB	15.98	1	15.98	2.46
AD	12.80	1	12.80	1.97
BC	350.91	1	350.91	**53.99**
CD	12.30	1	12.30	1.89
AC	25.68	1	25.68	3.95
ABD	215.89	1	213.89	**32.91**
BCD	34.02	1	34.02	**5.23**
Error	32.52	5	6.50	
Total	1403.55	15		

Significant F values are highlighted.

Since the ANOVA Table.10 and Table 11 revealed that calculated F values for C and D variables are higher than the table values, $F_{1,5}$ (0.01) = (4.06) and $F_{1,13}(0.01)$ = 9.07, these variables are more important than others.

Table 11 ANOVA for Block design - TFM (with replicates)

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	F_0 Value
Replicates	0.27	1	0.27	0.13
Block within Replicates	258.41	2	129.20	**61.82**
A	18.03	1	18.03	8.63
B	9.48	1	9.48	4.54
C	24.43	1	24.43	**11.68**
D	90.45	1	90.45	**43.28**
AB	7.33	1	7.33	3.51
AC	0.54	1	0.54	0.26
AD	116.36	1	116.36	**55.67**
BC	1135.50	1	1135.50	**543.30**
BD	0.07	1	0.07	0.03
CD	57.24	1	57.24	**27.39**
ABC (replicate I only)	5.20	1	5.20	2.49
ABD	439.83	1	429.83	**205.67**
ACD	91.46	1	91.46	**43.76**
BCD	4.52	1	4.52	2.16
ABC (replicate II only)	204.78	1	204.78	**97.98**
Error	27.18	13	2.09	
Total	2491.08	31		

Significant F values are highlighted.

Table 10:

$$C = 4.16 > 4.06$$

$$D = 5.26 > 4.06.$$

Table 11:

$$C = 11.68 > 9.07,$$

$$D = 43.28 > 9.07.$$

As block design indicates that C and D variables at higher levels are significantly contributed for the increase of TFM value, this can be used to validate Taguchi design, because Taguchi design is also showing similar results. Same results were obtained for variables with and without replicates.

4. Conclusion

Based on the results obtained under Taguchi method, we can conclude the following:

1. The optimal combination of four variables for highest TFM is high saponification value of oil (coconut oil), high concentration of NaOH (18%), high saponification temperatures (80℃) and with stirring. This was the case for both with and without replicates. The highest TFM obtained under this combination with and without replicates were 75.98% and 76.66% respectively. This is almost similar to the Sri Lanka standards value of 76.5% (Ceylon - Standard 27:1968).

2. When soap is manufactured with respect to advanced Taguchi design after the identification of critical variables, the quality parameters are easily falling in line with regulatory requirements (TFM).

3. Since the results for all quality parameters of soap have shown only a slightest difference with and without replicates, the experiment could be conducted even without replicates and achieve very precise results. Therefore, we can recommend that the advanced Taguchi Design could be applicable for some industrial environments at low cost with other high quality comparative designs as they need more treatment combinations to evaluate the effect of each variable or their combinations.

4. Taguchi method is an advance statistical design. It is most sensitive in terms of finding the effect of variation of variables. Taguchi method was able to find a little improvement when the variables A and B are increased from low level to high level (a^0 to a^1 and b^0 to b^1). However, the other two designs do not strong enough to find the variation of these two variables.

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Acknowledgments

C. P. S. Pathirana would like to thank Dr. L. A. L W. Jayasekara, Senior Lecturer, Department of Mathematics at University of Ruhuna for introducing me to the subject and providing the guidance for the success of this project.

C. P. S. Pathirana, also gratefully recalls the sincerity of Mr. Senaka Samarasesinghe, Managing Director of Harishchandra Mills (Pvt.) Ltd., for kindly permitting to carry out the research work in his establishment. Special words of gratitude go to Mrs. Sujeewa Rathnayake, Miss Devika Preshanthi, Miss Dammika Wijesekera and the other staff members of the research lab of Harishchandra Mills (Pvt.) Ltd., for their kind cooperation.

The authors, also, grateful to MSc course coordinator, Dr. S. K. Boralugoda, for his guidance, advice and the encouragement to proceed with this research project. Finally, we thank the Department of Mathematics, University of Ruhuna Matara, for the facilities provided for the success of this project.