APPLICATION OF A COST-DRIVEN OPTIMIZATION METHOD IN BEER BREWING PROCESS

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Abstract   The final quality and cost of a manufactured product are determined to a large extent by the engineering design of the product and its production process through activities of off-line quality control methods, namely, System Design, Parameter Design and Tolerance Design. However, in the context of most non-industrialized countries, the off-line quality activities of product design and system design of production process design stages are negligible if not absent. Thus, whatever quality control activities there are in these countries should be confined only to conducting parameter (robust) design of manufacturing process design and on-line quality control activities. Out of these two activities, Robust Design is the most economical method as it increases quality and/or reduces costs without imposing any further investment in factors of production. It is in this context that robust design as an optimization method has been used to improve the product quality of cleaning sub-process of beer brewing process of Behnoosh Company in which 358% improvement over the current condition has been achieved.

Key Words   Robust Design, System Design, Parameter Design, Tolerance Design, Optimization

چکیده   کیفیت و هزینه های نهایی یک محصول تا حد بسیار زیادی توسط طراحی محصول و فرایند ساخت از طریق روش کنترل کیفیت یا بهینه سازی قبل از ساخت طی مراحل سه گانه طراحی سامانه، طراحی پارامتری و طراحی رواداری صورت می‌پذیرد. اما در اغلب کشورهای غیر صنعتی، فعالیت های واقعی طراحی محصول، طراحی سامانه و رواداری طراحی فرایند ساخت یا وجود ندارد و یا قابل صرفنظر است. بنابراین، فعالیت های کنترل کیفیت یا بهینه سازی در این کشور ها محدود به طراحی پارامتری در طراحی فرایند ساخت و روش های کنترل کیفیت حین ساخت می‌شود. از این دو نوع فعالیت، روش طرح استوار (طراحی پارامتری)، اقتصادی ترین این روش بدون تحمیل هزینه سرمایه گذاری اضافی در ارتباط با عوامل تولید، افزایش کیفیت و یا کاهش قیمت را باعث می‌شود. این روش از طریق بهره جویی اثرهای غیر خطی موجود بین پارامترهای طراحی (عوامل قابل کنترل)، عوامل اغتشاش در محیط ساخت یا حتی محیط بکارگیری و مشخصه های کیفی تعیین کننده سطح کیفیت محصول یا فرایند، بهینه سازی را سبب می‌گردد. به عبارت دیگر، برعکس روش های دیگر موجود در طراحی که بهینه سازی را از طریق حذف یا کنترل علت انجام می‌دهند، این روش دستیابی به هدف را از طریق غیر حساس نمودن سامانه ها نسبت به اغتشاشات تحقق می‌بخشد. در این تحقیق کاربرد روش طرح استوار برای بهینه سازی زیر فرایند بوجاری عملیات آبجو سازی شرکت بهنوش آزموده شده تا توانمندی روش در افزایش کیفیت محصول و کاهش هزینه کل محصولات تولیدی صنایع غذایی آشکار شود. نتایج بدست آمده بیانگر ۳۵۸ درصد بهبود نسبت به وضع موجود است.

1. INTRODUCTION

The traditional role of quality control is basically to eliminate from production lines those parts that do not conform to specifications, and to inspect and test finished products for defects. Given this definition, quality control is almost limited to inspecting and testing on a detailing or sampling basis. However, the increased emphasis on "high quality" products at lower cost, combined with the competition across domestic and international markets, has magnified the importance of quality control. Consequently, quality control activities have been redefined to ensure the quality of the product during every phase of its life cycle. This life cycle begins with product planning and continues through the phases of product design, production process design, on-line production control, market development, and packaging, as well as maintenance and product service [1,2].

According to one of these redefined quality control activities which is called Parameter (Robust) Design, the final quality and cost of a manufactured product are determined to a large extent by the engineering design of the product and its production process through activities of off-line quality control methods. However, in the context of most non-industrialized countries, the off-line quality control activities of product design and system design of production process design stages are negligible if not absent. So, whatever quality control activities there are in these countries are confined only to conducting parameter design of manufacturing process design and on-line quality control activities.

It is in this context that an attempt was made to improve the output of one of the sub-processes of beer production, namely, cleaning and grading process by using the method of Parameter Design. In this regard, it is worth mentioning that the wonderful obtained result was achieved under unimaginable vast conditions of the process without imposing any further cost in factors of production.

2. METHODOLOGY

Designing high-quality products and processes at low cost is an economic and technological challenge to an engineer. A systematic and efficient way to meet this challenge is a new method of design optimization for performance, quality, and cost. The optimization method, called Robust Design, consists of

1. making product performance insensitive to raw material variation, thus allowing the use of low grade material and components in most cases,
2. making designs robust against manufacturing variation, thus reducing labor and material cost for rework and scrap,
3. making the design least sensitive to the variation in operating environment, thus improving reliability and reducing operating cost and
4. using a new structured development process so that engineering time is used most productively.

The founder of the Robust Design methodology is Professor Genichi Taguchi. His approach includes both a philosophy and a methodology. The essence of philosophy is that any inquiry into improving the quality of products and processes should begin with an analysis of their respective designs. The methodology proposed to establish the optimal design parameters for the major design characteristics of products and processes is divided into three distinct steps or activities: system design, parameter design, and tolerance design.

System design requires the application of scientific and engineering knowledge to produce a prototype of the product or process that meets the basic objectives set for function and aesthetics. The specifications developed for the prototype define the starting point for improving its design characteristics [2]. Parameter design focuses on identifying the specific or parameter value for a design characteristic that will minimize its variability in performance or use. Since product and process performance variation and manufacturing and product lifetime costs may change with the changes in the settings of their design characteristics within their prescribed specification limits, there is a need to identify the optimal parameter settings for both products and processes designs. A study to determine the optimal design parameters for products and processes is referred to as parameter design. *Parameter Design*, which is also called Robust Design in production process design, determines the operating levels of the manufacturing so that variation in product parameters is minimized. Tolerance design refers to the methodology for determining the tolerances around the chosen nominal values that were determined by parameter design. Close tolerances tend to increase manufacturing costs while loose tolerances increase performance variability, which is in turn increase, the lifetime cost of ownership [1,2,3,4,5].

A complete parameter design experiments consist of two parts: a design parameter matrix and a noise factor matrix. *The design parameter matrix* specifies the test settings of design parameters. Its columns represent the design parameters and its rows represent different combinations of test settings. Apart from general noise factors, which are mostly unknown and uncontrollable, there may be specific known noise factors for which due to
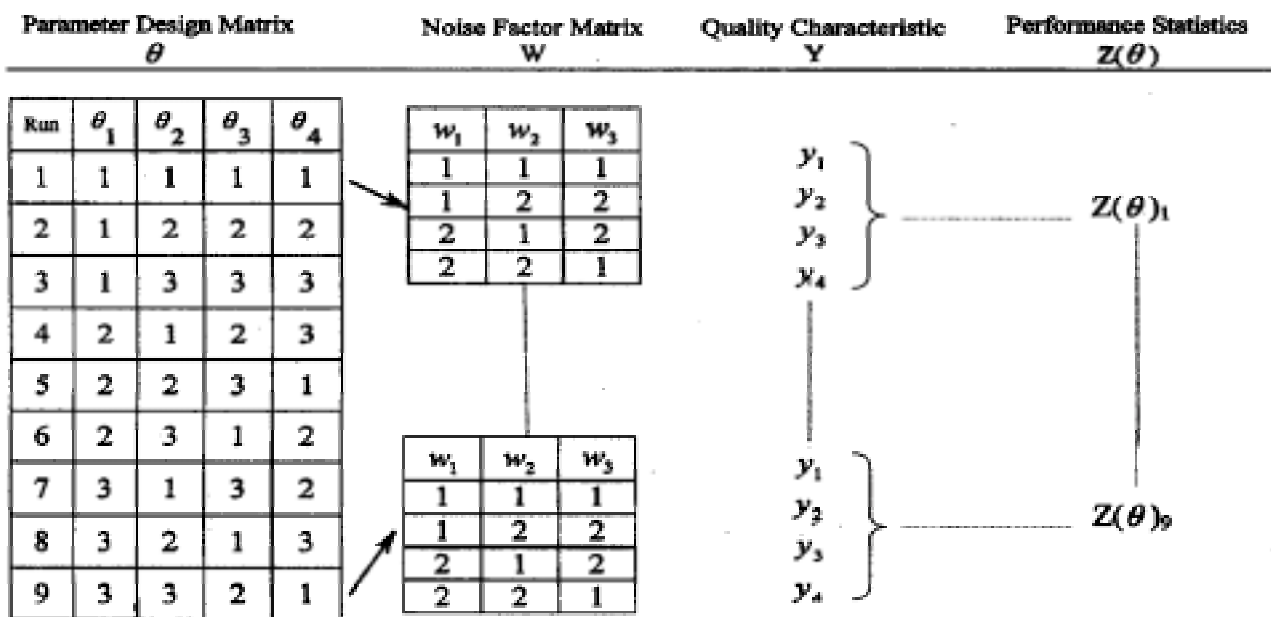
Figure 1. A Complete experiment consists of design parameter and noise factor matrices.

some reasons like manufacturing and / or operational costs, the system should be insensitive to them also. The *noise factor matrix* specifies the test levels of such noise factors. Its columns represent the noise factors and its rows represent different combinations of noise levels. Therefore, the complete experiment consists of a combination of the design parameter and the noise factor matrices (See Figure 1). Each test run of the design parameter matrix is crossed with all rows of the noise factor matrix. So that in the example in figure 1, there are four trials in each test run – one for each combination of noise levels in the noise factor matrix. The performance characteristic is evaluated for each of the four trials in each of the nine test runs. Thus, the variation in multiple values of the performance characteristic minimize the product (or process) performance variation at the given design parameter settings [1,2,3,4,5].

In the case of continuous performance characteristics (as shown in Figure 1), multiple observations from each test run of the design parameter matrix are used to compute a criterion called *Performance Statistic*. A performance statistic estimates the effect of noise factors. The computed values of a performance statistic are used to predict better settings of the design parameters. The prediction is subsequently verified by a confirmation experiment. The initial design parameter settings are not changed unless the veracity of the prediction has been verified. Several iterations of such parameter design experiments may be required to identify the design parameters settings at which the effect of noise factors is sufficiently small.

Parameter design experiments can be done in one of two ways: through physical experiments or through computer simulation trials. These experiments can be done with a computer when the function $Y= f (\theta, \omega)$-relating performance characteristic Y to design parameters θ, and noise factors ω-can be numerically evaluated [5, 6, 7].

Taguchi recommends the use of "orthogonal arrays" for constructing the design parameter and the noise factor matrices. All common factorial and fractional factorial plans of experiments are orthogonal arrays, but not all orthogonal arrays are common fractional factorial plans. Kackar, with discussions and response, and Hunter have discussed the use of orthogonal arrays from the statistical viewpoint.

TABLE 1. Average of Different Grades of Outgoing Barleycorns to Malting Process under Current Condition.

Grades of Incoming Barleycorns into Malting Process	Average Content (%)
First grade barleycorn (A)	13.55
Second grade barleycorn (B)	34.26
Third grade barleycorn (C)	35.05
Forth grade barleycorn (D)	17.14
Total	100.00

TABLE 2. Controllable Factors and Their Levels.

Factors and Levels / Process	Controllable factor or Design Parameter	Levels		
		I	II	III
Separator I	1. Air Suction 2. Speed 3. Feeding Rate	3 cm τ -3 cm τ' -0.5 cm	3.5 cm τ cm τ' cm	τ + 3 cm τ' + 0.5 cm
Separator II	4. Vibration 5. Air Suction	$6°$ $40°$	$7°$ $50°$	$8°$ $60°$
Grader	6. Upper Control Gradiometer 7. Lower Control Gradiometer 8. Speed	$0°$ $5°$ τ'' - 3 cm	$2°$ $8°$ τ'' cm	$4°$ $0°$ τ'' + 2 cm

3. BEER PRODUCTION PROCESS IN BEHNOOSH COMPANY

The present Behnoosh Company was established in 1967 in the name of SKOL. Essentially, it was an alcoholic beer producer. However, after Islamic Revolution in 1979, the production has been converted into non-alcoholic beer and different types of beverages. The process of beer production, which is commonly referred to as "Beer Brewing" and may use different types of cereals, consists of following sub-processes:
1.   Cleaning and Grading,
2.   Malting,
3.   Mashing,
4.   Boiling,
5.   Fermenting, and
5.   Filtering and Bottling.

In the first sub-process of non-alcoholic beer production in Behnoosh, which uses barleycorn, unwanted materials like dust, stones, straws, etc., are removed and grading is taken place to have specified barleycorns. In Malting process, the cleaned and graded barleycorns are soaked in water and treated in a way to germinate and then dried-germinated barleycorns, which are called malt, will be produced. In Mashing process the malt is crushed and treated with hot water (wort) to convert the malt-starch into sugar. Then, in boiling process, the wort is boiled vigorously with hopes to give the bitterness and desired

TABLE 3. Standard Orthogonal Array L_{18} of Experimental Design.

	Columns							
	1	2	3	4	5	6	7	8
Trial 1	1	1	1	1	1	1	1	1
Trial 2	1	1	2	2	2	2	2	2
Trial 3	1	1	3	3	3	3	3	3
Trial 4	1	2	1	1	2	2	3	3
Trial 5	1	2	2	2	3	3	1	1
Trial 6	1	2	3	3	1	1	2	2
Trial 7	1	3	1	2	1	3	2	3
Trial 8	1	3	2	3	2	1	3	1
Trial 9	1	3	3	1	3	2	1	2
Trial 10	2	1	1	3	3	2	2	1
Trial 11	2	1	2	1	1	3	3	2
Trial 12	2	1	3	2	2	1	1	3
Trial 13	2	2	1	2	3	1	3	2
Trial 14	2	2	2	3	1	2	1	3
Trial 15	2	2	3	1	2	3	2	1
Trial 16	2	3	1	3	2	3	1	2
Trial 17	2	3	2	1	3	1	2	3
Trial 18	2	3	3	2	1	2	3	1

color to beer. The Fermentation process, where sugar component splits into two equal parts of Alcohol and Carbon Dioxide, does not take place in Behnoosh. Finally, the product is filtered, carbonated further, bottled, and pasteurized.

4. CURRENT STATUS AND OBJECTIVES OF THIS STUDY

The process of cleaning and grading barleycorns in Behnoosh company is being done through three steps, namely

1. Separator I,
2. Separator II, and
3. Grader.

These steps are designed to remove dust, stones, fines, lights, and oversize debris, which are called the first type of waste at the process and are led to special waste bags. As it is mentioned before, the light and broken (so called fourth grade) barleycorns are not desired to be passed into malting process, as they do not germinate and therefore acting as a hindrance of productivity in malting and other next processes. It is in this concept that an attempt has been made to reduce passing these unwanted fourth grade barleycorns (second type of waste) into malting and other next processes of beer production. The current status of cleaning and grading process was very dramatic because of

1. using very old machines which were not maintained properly due to lack of availability of original spare parts,
2. increasing work time of machines which results in increasing the process costs,

TABLE 4. Results of Experiment.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Trial 1	10.32	8.02	7.12	8.119	9.2	8.56	8.87	8.21
Trial 2	9.08	5.95	8.69	11.05	8	8.58	9.47	8.58
Trial 3	7.65	8.87	7.19	8.2	5.26	5.28	5.77	7.22
Trial 4	9.36	8.72	9.09	9.02	7.84	8.039	7.86	8.82
Trial 5	9.4	9.16	8.06	9.82	7.72	9.17	9.51	9.09
Trial 6	5.85	7.18	5.5	6.54	6	7.99	4.86	4.19
Trial 7	4.46	5.38	4.46	7.15	6.61	6.95	5.37	4.15
Trial 8	4.2	4.99	4.28	6.15	7.27	5.74	6.15	6.37
Trial 9	4.52	4	7.48	7.47	2.54	5.25	3.03	2.52
Trial 10	7.25	6.9	7.18	8.27	7.2	8.17	7.26	7.56
Trial 11	4.91	7.87	7.84	6.38	6.41	7.87	7.82	4.51
Trial 12	7.72	9.55	6.56	8.09	8.13	7.39	6.62	6
Trial 13	7.76	3.97	1.18	1.64	3.01	3.58	5.44	5.08
Trial 14	7.9	6.61	6.94	7.54	12.84	11.16	12.97	9.52
Trial 15	7.62	7.25	9.1	8.63	8.26	9.89	9.68	7.43
Trial 16	4.019	4.9	6.68	4.4	4.7	4.58	4.43	4.43
Trial 17	5.39	4.7	5.29	4.79	4.31	4.71	4.67	4.96
Trial 18	7.67	7.37	2.88	4.03	6.56	3.29	4.25	3.07

TABLE 5. Analysis of Variance (ANOVA).

	Factors	DOF	Sums Of Squares	Variance	F-Ratio	Pure Sum	Percent
1	Air SucI	1	2.997	2.997	240.231	2.984	3.577
2	Speed	2	42.889	21.444	1,718.740	42.864	51.371
3	Feeding Rate	2	4.635	2.317	185.775	4.610	5.525
4	Vibration	2	0.498	0.249	19.959	0.473	0.566
5	Air Suc II	2	6.411	3.205	256.919	6.386	7.653
6	U.C.Grado.	2	7.455	3.727	298.764	7.430	8.905
7	L.C.Grado.	2	5.317	2.658	213.107	5.292	6.343
8	Speed G	2	13.210	6.605	529.384	13.185	15.802
	Other/Error	2	0.024	0.012			0.258
	Total:	17	83.440				100.000%

3. low productivity of next process due to improper separation of barleycorns in cleaning and grading process (Table 1).
4. outgoing some of the first, second, and third grade (wanted) barleycorns from the process and their leading to waste bags, and
5. lack of proper liquidity funds for changing the used technology.

Based on the findings in current status, the objective of this study in cleaning process has been set to reduce the average percentage of fourth grade barleycorns which goes into malting process under condition that no further investment should be taken place in any of the factors of production.

Table 6. Main Effects.

	Factors	Level 1	Level 2	Level 3
1	Air SucI	-16.915	-16.099	0
2	Speed	-17.714	-17.48	-14.329
3	Feeding Rate	-16.096	-17.222	-16.204
4	Vibration	-16.728	-16.327	-16.467
5	Air Suc II	-16.724	-17.106	-15.693
6	U.C.Grado.	-15.645	-17.19	-16.688
7	L.C.Grado.	-17.128	-16.591	-15.804
8	Speed G	-17.241	-15.306	-16.976

This means that

1. without upgrading incoming barleycorns into the cleaning process,
2. without reducing the current capacity of production,
3. without changing technology of the process,
4. without changing spare parts for the machines,
5. without changing the maintenance system, and finally
6. without increasing the cost of production.

The average percentage of forth grade (D) barleycorns which goes into the next process (malting) should be reduced.

5. DESIGN PARAMETERS AND DESIGN MATRIX OF EXPERIMENT

The analysis of important design parameters of cleaning process was being done after brainstorming sessions had taken place with manufacturing, engineering, and quality control persons. The outcome of the sessions gave rise to 8 controllable factors of 2 and 3 levels (Table 2).

Since 8 factors were identified and since due to some considerations like costs, time, and impractical conduction of many trials in real production, the decision about the tests of presence of interactions were left to comparing the slopes of the lines drawn for interaction between factors, and therefore specific interaction were not designed into the experiment, the standard orthogonal array L_{18} of experimental design was used (Table 3).

Conduction of Experiment and Collection of Data

The 18 tests of designed experiment were conducted in 9 working days, each in one shift. For each test, 7 random samples of 100 grams were taken and then it was processed through a pilot cleaning machine in laboratory to give the weight percentage of first (A), second (B), third (C), and fourth (D) grade barleycorn content in the sample (Table 4).

6. ANALYSIS OF EXPERIMENT

To study the possibility of reduction of outgoing forth (D) grade barleycorns into malting process, we use a performance statistic to estimate the effect of general noise or unspecific different sources of variation. Therefore, if we can find a specific performance statistic which reflects the effects of a particular class of noise factors and then transform their effects into a data point for each of the conducted tests in the experimental design, we will be able to find what factors and what levels has to overcome the effects of that particular class of noise factors upon the performance characteristic (outgoing forth (D)

TABLE 7. Optimum Condition and Performance.

	Factors	Level Desc.	Level	Contribution
1	Air SucI	3.5 cm	2	0.408
2	Speed	+3 cm Nominal	3	2.178
3	Feeding Rate	-0.5 cm N	1	0.411
4	Vibration	7	2	0.180
5	Air Suc II	60	3	0.814
6	U.C.Grado.	0	1	0.862
7	L.C.Grado.	10	3	0.703
8	Speed G	Nominal	2	1.201

Total Contribution From All Factors...   6.756

Current Grand Average Of Performance...   -16.507

Expected Result At Optimum Condition...   -9.750

grade barleycorn to malting process) in this study. One such performance statistic which can reflect the effects of categorized sources of variation (i.e., due to external, internal, and unit to unit variation) is the performance statistic $Z(\theta)$ given below. For this, the performance characteristic Y which takes non negative values with a target value equal to zero ($\tau = 0$), and a loss function L (Y) which increases as Y increases from zero, reflects the present study. In this case the expected loss, i.e. $l(y)=k. E[Y^2]$, is proportional to

Mean Squared Deviations from Target Value = MSD (θ) = E [(Y-0)^2] = E [Y^2]. Taguchi recommends using the performance measure

$$\xi(\theta) = -10 \log \text{MSD} (\theta).$$

Thus the larger the performance measure, the smaller is the mean squared deviation. Let y_1, y_2, …, y_n approximate a random sample from the distribution of Y for a given design parameters settings (θ). The above performance measure can then be estimated by the performance statistic

$$Z(\theta) = S/N = -10 \log \left[\sum y_i^2 / n \right]$$

where the performance statistic Z (θ) is the

method of moments estimator of $\xi(\theta)$. It is in this context that transformed data of each test in the experiment is calculated and analysis of variance (ANOVA) table is computed (Table 5). From the ANOVA table, it appears that 7 of the 8 considered design parameters with contribution percentage are significant at one percent level of significance ($F_{0.01,1,2} = 98.5$, $F_{0.01,2,2} = 99.0$) and therefore are able to counteract the effects of the mentioned noise factors on the performance characteristic. The validity of F-test confirmed through satisfactory results achieved from normal probability graph of data and Bartlett test for constant variances.

To optimize the settings, the main effects are calculated (Table 6) and then optimum condition and performance are computed (Table 7) through average level estimates of the design parameters. The optimum settings based upon the design parameters are to be A2 B3 C1 D2 E3 F1 G3 H2 and expected result at optimum condition is –9.75 decibel.

Therefore, base upon above findings, the theoretical estimate of expected results from S/N ratio at optimum condition (-9.75) can be calculated as below:

S/N = -10 Log (MSD) = -9.75   or

	Interaction Factor Pais	*Columns*	*SI (%)*	*Col.*	*Opt.*
1	Feeding Rate x Vibration	3 x 4	85.02	7	(1,2)
2	Air Suc II x L.C.Grado.	5 x 7	80.91	2	(3,3)
3	U.C. Grado.x L.C. Grado.	6 x 7	57.31	1	(1,3)
4	Feeding Rate x Speed G	3 x 8	56.7	11	(1,2)
5	Speed x U.C. Grado.	2 x 6	47.82	4	(3,2)
6	Feeding Rate x L.C.Grado.	3 x 7	42.92	4	(3,3)
7	L.C.Grado x Speed G	7 x 8	42.6	15	(1,2)
8	Speed x Speed G	2 x 8	38.75	10	(3,2)
9	Speed x Feeding Rate	2 x 3	37.17	1	(3,3)
10	Air Suc I x U.C. Grado.	1 x 6	37.05	7	(2,1)
11	Air Suc I x Vibration	1 x 4	36.05	5	(2,2)
12	Speed x Vibration	2 x 4	33.02	6	(3,1)
13	Vibration x Speed G	4 x 8	31.83	12	(3,2)
14	U.C. Grado x Speed G	6 x 8	31.2	14	(1,2)
15	Air Suc I x Feeding Rate	1 x 3	30.07	2	(2,1)
16	Vibration x Air SucII	4 x 5	26.14	1	(1,3)
17	Feeding Rate x U.C.Grado.	3 x 6	25.01	5	(3,2)
18	Air Suc I x Air Suc II	1 x 5	24.28	4	(2,3)
19	Air Suc II x U.C. Grado.	5 x 6	23.34	3	(3,1)
20	Speed x L.C.Grado.	2 x 7	20.33	5	(3,1)
21	Vibration x U.C.Grado.	4 x 6	18.61	2	(2,1)
22	Air SucI x Speed G	1 x 8	14.33	9	(2,2)
23	Vibration x L.C.Grado.	4 x 7	13.27	3	(2,3)
24	Feeding Rate x Air Suc II	3 x 5	8.09	6	(3,1)
25	Air Suc I x L.C.Grado	1 x 7	5.42	6	(2,3)
26	Speed x Air Suc II	2 x 5	3.74	7	(3,3)
27	Air Suc II x Speed G	5 x 8	3.12	13	(3,2)
28	Air Suc I x Speed	1 x 2	2.13	3	(2,3)

$$MSD = 10^{[-(S/N)/10]} = 9.440609$$

where MSD = $[(y_1)^2 + (y_2)^2 + \ldots + (y_n)^2]/n$ = Mean Squared Deviations from Target Value = Average $(y_i)^2 = [E(Y)]^2$ or

$$E(Y) = \sqrt{MSD}$$

Thus, expected performance in QC unit

(Percentage) which is based on S/N = -9.75 at optimum is:

E (Y) = 3.073%

As it is mentioned before, the decision about the presence of interactions can also be made by comparing the slopes of the lines drawn for interaction between factors. The strength of

TABLE 9. Confirmation Trail Data under Current and Proposed Conditions.

Sample	Under Current Condition		Under Proposed Condition	
1	A = 9.73 %	B = 30.46 %	A = 30.46 %	B = 42.76 %
	C = 38.20 %	D = 21.61 %	C = 22.58 %	D = 4.08 %
2	A = 11.80 %	B = 34.54 %	A = 27.73 %	B = 42.37 %
	C = 37.45 %	D = 16.21 %	C = 24.37 %	D = 5.53 %
3	A = 13.01 %	B = 33.05 %	A = 29.73 %	B = 40.11 %
	C = 36.51 %	D = 17.43 %	C = 24.24 %	D = 5.92 %
4	A = 19.76 %	B = 36.73 %	A = 32.00 %	B = 40.57 %
	C = 29.46 %	D = 14.05 %	C = 22.38 %	D = 5.05 %
5	A = 13.41 %	B = 35.12 %	A = 30.46 %	B = 41.52 %
	C = 33.10 %	D = 18.73 %	C = 22.74 %	D = 5.28 %
6	A = 14.91 %	B = 36.82 %	A = 31.29 %	B = 40.80 %
	C = 35.29 %	D = 12.98 %	C = 24.41 %	D = 3.50 %
7	A = 12.27 %	B = 33.20 %	A = 30.46 %	B = 42.76 %
	C = 35.51 %	D = 19.02 %	C = 22.58 %	D = 4.20 %

Average of Grades Under Current Condition	Average of Grades Under Proposed Condition
Grade A = 13.55 %	Grade A = 30.30 %
Grade B = 34.25 %	Grade B = 41.56 %
Grade C = 35.05 %	Grade C = 23.43 %
Grade D = 17.15 %	Grade D = 4.694 %

Descriptive Data of Grade D Under Current Condition	Descriptive Data of Grade D Under Improved Condition
Avg. value = 17.147	Avg. value = 4.794
Std. Dev. = 5.995	Std. Dev = 0.88
Range = 8.63	Range = 2.42
MSD = 301.719	MSD = 23.649
S/N Ratio = -24.796	S/N Ratio = -13.739

presence of interaction may be calculated by degrees magnitude at angles of the lines which range between zero, $0°$, and ninety, $90°$. The term *severity index* (SI) is defined such that SI = 100% when the angle between the lines is $90°$ and SI = 0 when the angle is zero [8]. As it can be observed from severity index (SI) of interacting factor pairs (Table 8), the optimum levels of considered factors are almost the same as optimum levels which are obtained through ANOVA of effective factors; and small-observed discrepancies,

which are due to ineffective factors, are negligible. Thus, there would be no need to change any level factors of optimum condition due to interaction effects.

7. CONCLUSION

The theoretical results of this study clearly indicate the reduction of outgoing fourth grade (unwanted)
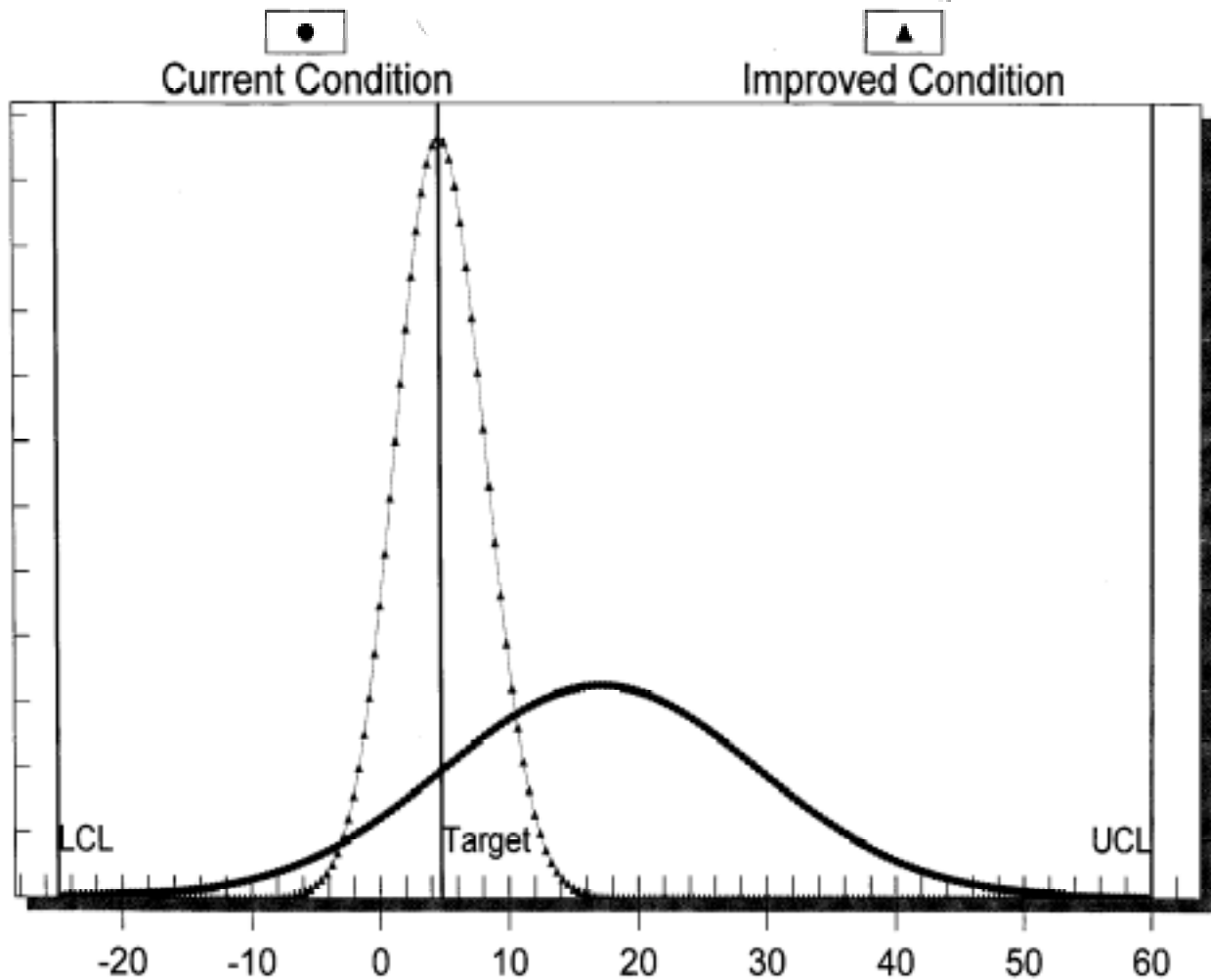
Figure 2. The comparison of normal plots at current and improved conditions.

barleycorns of cleaning sub-process into next (malting) sub-process. The results also indicated the mentioned reduction should be around 3.073 percent which is a wonderful outcome as this is to be achieve without imposing any further investment in factors of production. However, in order to support the theoretical achievements, a confirmation trial for proposed optimum condition was planned and its data was obtained (Table 9). The comparison of unwanted incoming fourth grade barleycorns into malting process under current and optimum conditions (Table 9) shows that the fourth grade barleycorns reduced from 17.147 % in current condition to 4.794% in proposed condition which in turn shows a 358%

improvement over the current situation. That is,

$$\left. \begin{array}{c} \text{Percentage advancement over} \\ \text{current condition in percent} \end{array} \right\} =$$

$$\left(\dfrac{\begin{array}{c} \text{Percentage of fourth grade barleycorn} \\ \text{under currant condition} \end{array}}{\begin{array}{c} \text{Percentage of fourth grade barleycorn} \\ \text{under proposed condition} \end{array}} - 1 \right) \times 100$$

$$= \left(\dfrac{17.147\%}{4.794\%} - 1 \right) = 358\%$$

Based on assumed normal performance distribution of quality characteristic and data obtained in confirmation trials, the comparison of normal plots at current and improved conditions may be as indicated in Figure 10.

Apart from major objective of the study, which was reduction of incoming fourth grade barleycorns into malting process, following subordinated results have been also achieved:

1. The average percentages of A and B grade barleycorns have been increased from 13.55 % and 34.25% to 30.30% and 41.56%, respectively. This shows that before conduction of this study, a noticeable percentages of A and B grade barleycorns were led to waste bags and instead the D grade barleycorns were going into malting process.

2. For every 9000 kilos daily processing, 1111.77 kilos of barleycorns can be saved (i.e., 17.147% - 4.794% = 12.353% $\Rightarrow$ 9000 * 12.353% = 1111.77) and therefore cost of processing is diminished and efficiency of cleaning sub-process is increased by 1111.77 kilos for the same two shift working hours.

The amount of A and B grade barleycorns, which was led to waste bags and sold as a waste, now can be led to malting sub-process and cause higher quality and efficiency in malting and next sub-processes.

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