Clutch Plate Rust Inhibition Process Optimization Study

(CsEx-05)

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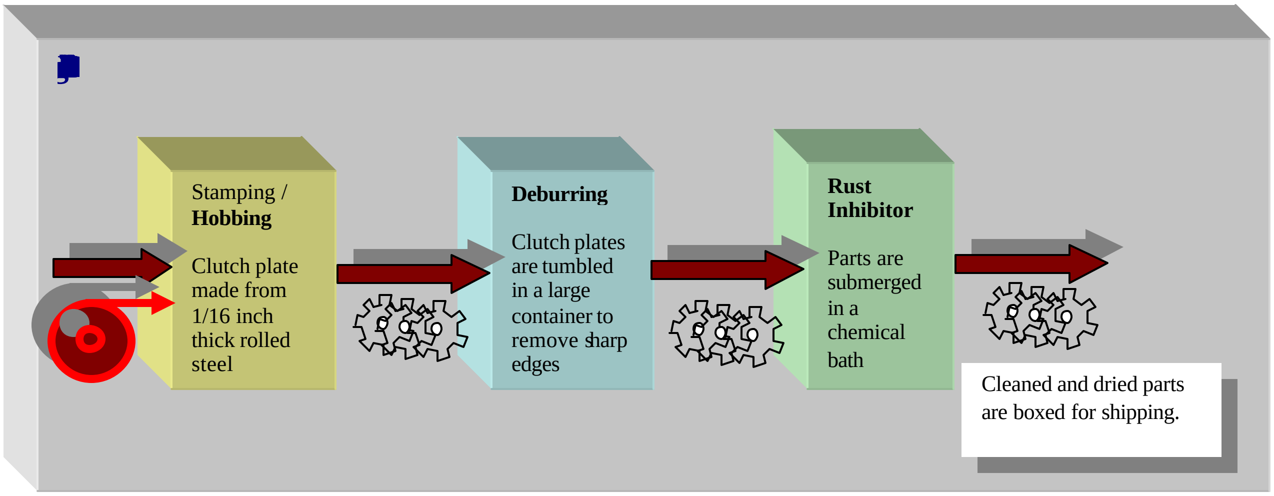
The Clutch plate is one of the many precision components used in the automotive transmission assembly. The part is about 12 inches in diameter and is made from 1/8-inch thick mild steel. Parts manufactured in one of the supplier's newer plants recently experienced excessive returned batches of parts and customer complaint. The reasons for customer complaints were two:

(a) Sticky Parts – During the assembly process, parts were found to be stuck together with one or more parts. This required manual intervention in the mechanical robot-arm operated assembly and affected production rate.

(b) Rust Spots – Operators involved in the assembly reported unusually higher rust spots on the clutch during certain period in the year. Although, rusty parts do not immediately affect the assembly or functionality of the assembled part, customers expressed concern for its effect on the long term durability life.

To address the defects reported by the customer, the process engineers in the suppliers manufacturing plant launched an experimental study to correct the problem. As a preparatory step for the study, the part fabrication steps were carefully reviewed. Among the tree main steps involved shown in Figure 1, the process of rust inhibition was considered the primary location for improvement. The project team was convinced that if the rust inhibition process were improved, both the sticky and rust spots could be eliminated.



[illegible]

A brainstorming session dedicated for planning the experiment, determined the procedure for evaluation of test samples and identified factors for the study. The project team agreed that evaluation be done based on the performance in both areas of the customer complaint and that the result be reduced for analysis of results by combining the evaluations. The description of the two criteria, their ranges of evaluations and their relative weight (consensus decision) are as shown in Table 1. The sticky property was evaluated by the amount of force necessary to separate two parts stuck together. The rust spots varied in sizes and distributions. The magnitude of rust was subjectively judged in a scale of 0 – 10 (by comparing with reference rust distribution scale prepared before the experiment).

[illegible]

[illegible] (Method of Evaluations)

#	**Criteria Descriptions**	**Worst Reading**	**Best Reading**	**QC**	**Rel. Weight** (WT_1)
1	Sticky (Y_1)	2 pound force	0 force	S	70%
2	Rust Spots (Y_2)	10	0	S	30%

For the experimental study, five factors shown in Table 2 were identified. From past experience, the factor E:Chemical Concentration was considered most influential. As its influence was expected to be nonlinear on the result, it was studied at four levels. All other factors were studied at their two extreme levels.

[illegible]

Factor	**Level 1**	**Level 2**	**Level 3**	**Level 4**
A: Cure Time in Furnace	Short	Delayed		
B: Time - Deburr to Furnace	Shorter	Standard		
C: Rust Inhibitor Load Rate	Slow	Fast		
D: Rust Inhibitor Load Method	Spindle	Hand		
E: Chemical Conc. (lb/cubic ft)	½ Strength	¾ Strength	Standard	1 ¼ Strength

The reported problems were more severe during three summer month of the year than the rest of the year. This fact along with the shipping schedule of the finished part, help identify three noise factors shown in Table 3. But because of the time constraint and cost involved, it was not possible to control the noise factors (outer array was not used in the experiment). Instead, the planned experiments were exposed to the noise condition at random. All experiments were performed during the summer months, randomly at mid-day and cool evenings.

Noise Factor	**Level 1**	**Level 2**	**Level 3**	**Level4**
X: Temperature	Cold	Hot		
Y: Humidity	Below 60%	Above 85%		
Z: Time Store (Raw material)	Regular	More Frequent		

To accommodate one 4-level factor and four 2-level factors included in this study, a modified L-8 array was used to design the experiment. The factor descriptions and the modified array are shown in Figures 2a & 2b.

Figure 2a. Factor Descriptions and their Column Assignments

Array Type: L-8

Use <ctrl> + <arrows> to move cursor.

	Factors	Level 1	Level 2	Level 3	Level 4
1	E: Chemical Conc.	½ Standar	¾ Strength	Standard	1 ¼ Strength
2	USED FOR UPGRADE	*UPGRADE*	------------	------------	------------
3	USED FOR UPGRADE	*UPGRADE*	------------	------------	------------
4	A: Cure Time in F	Short	Delayed	------------	------------
5	B: Time - Deburr	Shorter	Standard	------------	------------
6	C: Load Rate	Slow	Fast	------------	------------
7	D:Loading Method	Spindle	Hand	------------	------------

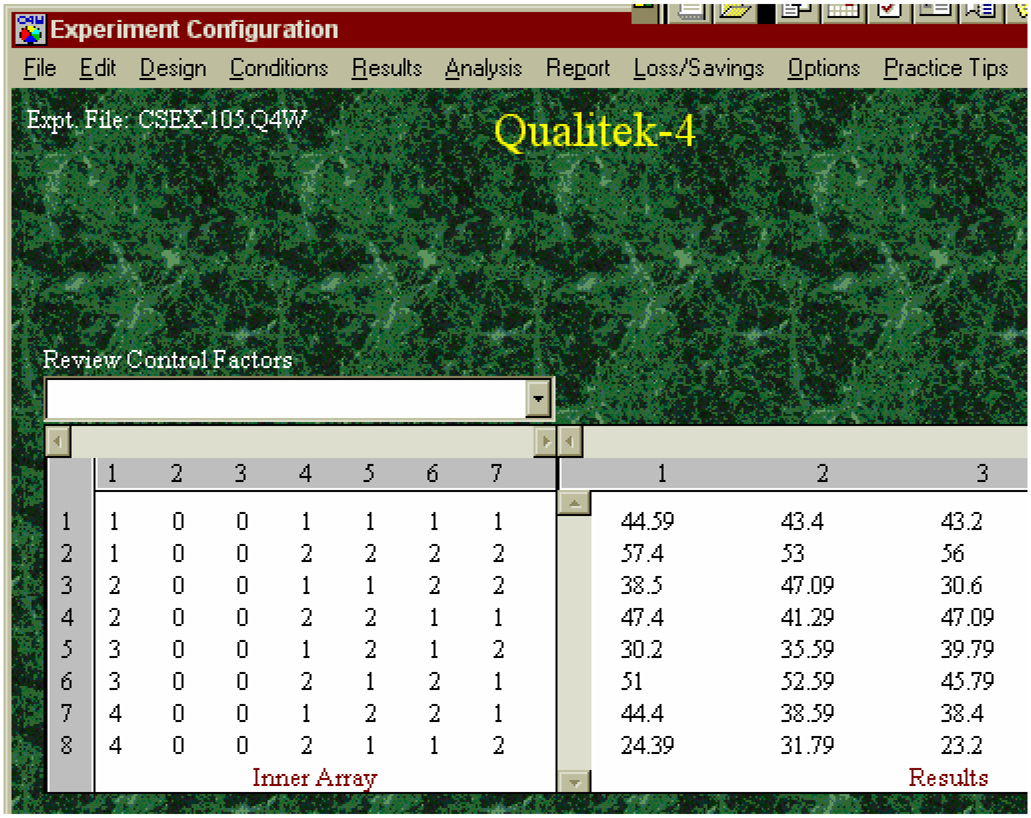
Figure 2b. Orthogonal array (modified L-8) used for the experiment

Array Type: L - 8

	1	2	3	4	5	6	7
1	1	0	0	1	1	1	1
2	1	0	0	2	2	2	2
3	2	0	0	1	1	2	2
4	2	0	0	2	2	1	1
5	3	0	0	1	2	1	2
6	3	0	0	2	1	2	1
7	4	0	0	1	2	2	1
8	4	0	0	2	1	1	2

The experiments as planned were carried out by running three samples in each trial condition. A sample comprised of a batch of plates fabricated and made ready for shipment. Before shipment, in some cases intentionally delayed to simulated shipment and storage time, ten parts were randomly selected from the batch and their sticky and rust properties evaluated. The evrage of the ten samples formed a representative evaluation (rounded off) for a single sample. Three such batches were evaluated in each of the eight expermental conditions. The two criteria of evaluations (Sticky and Rust) in each sample were combined using the Overall Evaluation Criterion (OEC) formulation. The OEC , which is the result for each test sample, are shown in the experiment configuration in Figure 3.

Figure 3. Experiment Configuration and the Results (OEC)



	1	2	3	4	5	6	7	1	2	3
1	1	0	0	1	1	1	1	44.59	43.4	43.2
2	1	0	0	2	2	2	2	57.4	53	56
3	2	0	0	1	1	2	2	38.5	47.09	30.6
4	2	0	0	2	2	1	1	47.4	41.29	47.09
5	3	0	0	1	2	1	2	30.2	35.59	39.79
6	3	0	0	2	1	2	1	51	52.59	45.79
7	4	0	0	1	2	2	1	44.4	38.59	38.4
8	4	0	0	2	1	1	2	24.39	31.79	23.2

The result for the first sample of trail condition 1 (Figure 3), 44.59, is the OEC value obtained by combining the sticky and rust properties (evaluations 190 and 6) for the sample. The original evaluations under each criteria of evaluations for all test samples are shown in Table 4.

Table 4 Evaluation of Experimental Samples

Trial	Sample 1		Sample 2		Sample 3			
	Sticky	Rust	Sticky	Rust	Sticky	Rust		
1	190	6	160	7	180	6		
2	260	7	250	6	250	7		
3	125	7	165	8	90	6		
4	210	6	145	7	165	8		
5	130	4	190	3	220	3		
6	300	3	290	4	220	5		
7	210	5	190	4	210	3		
8	110	3	120	5	80	4		

The OEC for the test samples are formulated by Qualitek-4 software from the original evaluations. It follows a formulation that recognizes the individual quality characteristic of the criteria and its relative weight. The calculation for the first trial result (44.59 from Sticky = 190 and rust = 6) is shown below. The criteria descriptions along with a few OEC values calculated by QT4 are shown in Figure 4.

OEC General formula (Notations described in Table 1)

$$\text{OEC} = [Y_1/Y_{1\text{ref}}] \times WT_1 + [Y_2/Y_{2\text{ref}}] \times WT_2$$

For the first sample evaluations of trial condition 1,

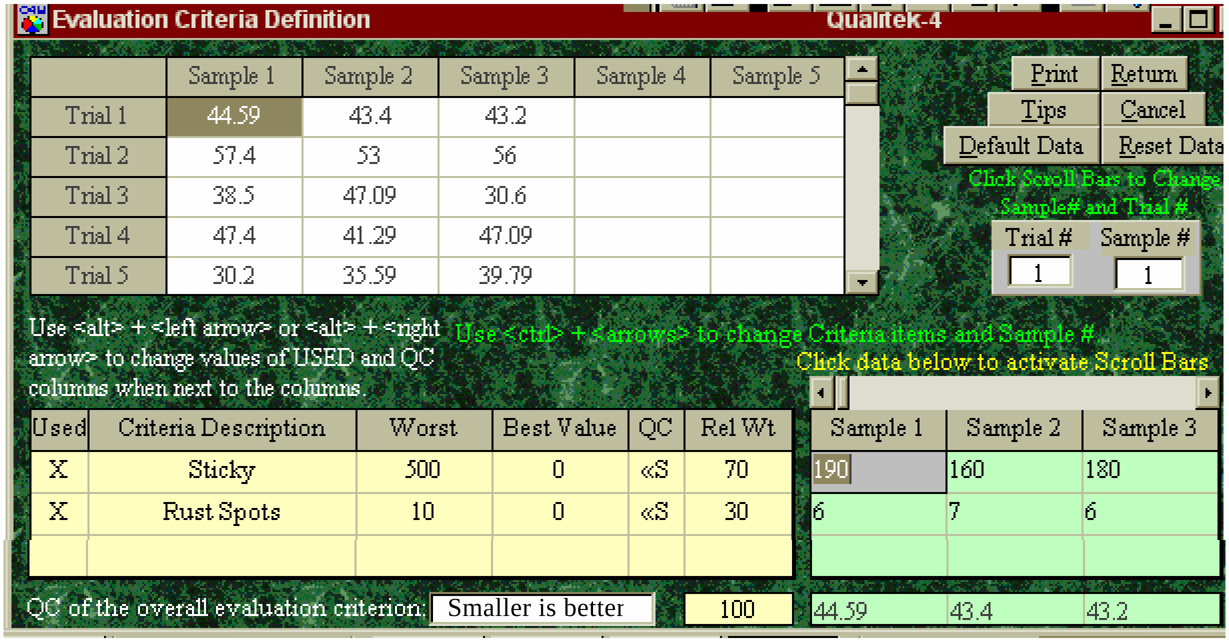
$$\text{OEC} = [\,190/500\,] \times 70 + [\,6/10\,] \times 30, \quad \text{with} \quad Y_{1\text{ref}} = 500 \text{ and } Y_{2\text{ref}} = 10$$

$$= 26.60 + 18.00$$

$$= 44.60$$ (compares with 44.59 in QT4 results in Figure 4)

Depending on quality characteristic of the individual criterion and their relative weight, the quality characteristic of the OEC (which is the result now) is determined. In this case, since both criteria have *smaller is better* characteristic; the OEC will have the same. For analysis of results and subsequent determination of the optimum condition, *smaller is better* quality characteristic is applicable.

Figure 4. Evaluation Criteria Descriptions and OEC from the Evaluations



	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Trial 1	44.59	43.4	43.2		
Trial 2	57.4	53	56		
Trial 3	38.5	47.09	30.6		
Trial 4	47.4	41.29	47.09		
Trial 5	30.2	35.59	39.79		

Trial # 1

Sample # 1

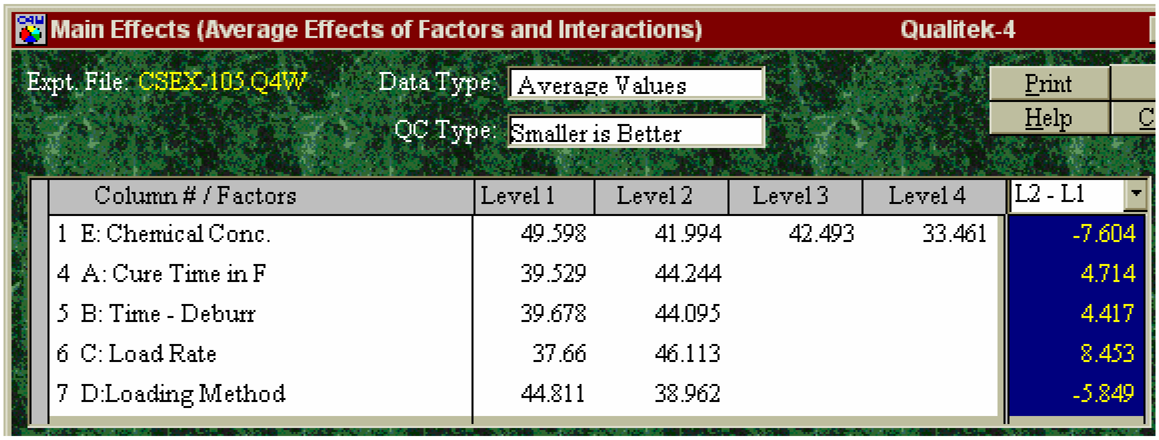
Use <alt> + <left arrow> or <alt> + <right arrow> to change values of USED and QC columns when next to the columns.

Used	Criteria Description	Worst	Best Value	QC	Rel Wt	Sample 1	Sample 2	Sample 3
X	Sticky	500	0	«S	70	190	160	180
X	Rust Spots	10	0	«S	30	6	7	6

QC of the overall evaluation criterion: Smaller is better 100 44.59 43.4 43.2

The experimental results reduced from the original sample evaluations were analyzed for *smaller is better* quality characteristic. The average factor effects calculated for all factors are shown in Figure 5.

Figure 5. Factor Average Effects (main effects)



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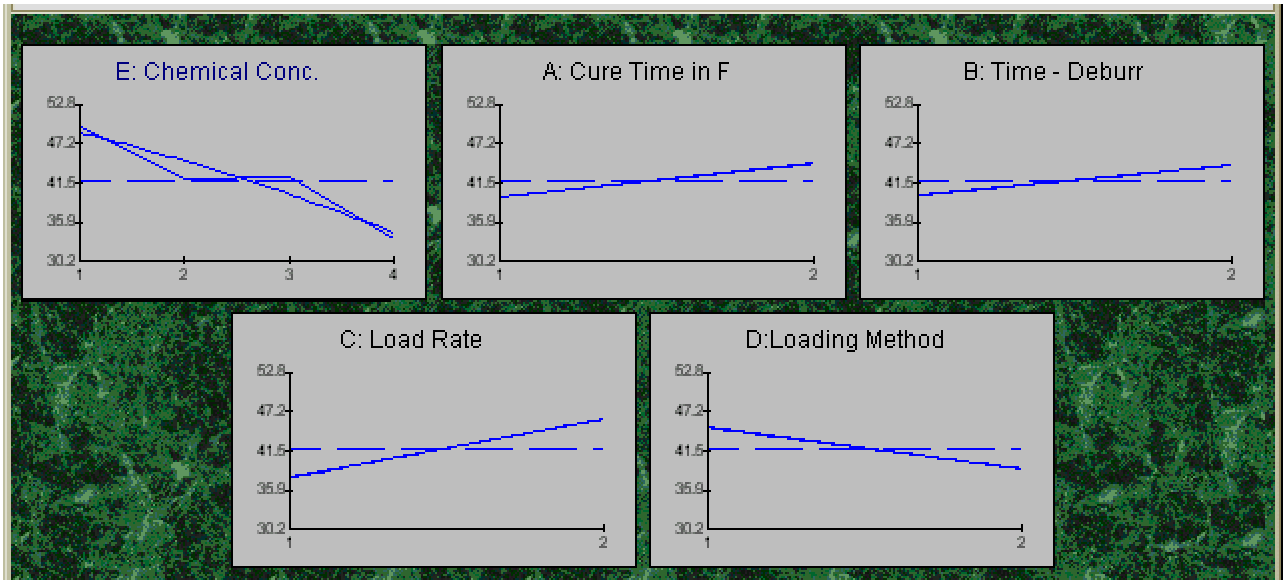
Data Type: Average Values

QC Type: Smaller is Better

Column # / Factors	Level 1	Level 2	Level 3	Level 4	L2 - L1
1 E: Chemical Conc.	49.598	41.994	42.493	33.461	-7.604
4 A: Cure Time in F	39.529	44.244			4.714
5 B: Time - Deburr	39.678	44.095			4.417
6 C: Load Rate	37.66	46.113			8.453
7 D:Loading Method	44.811	38.962			-5.849

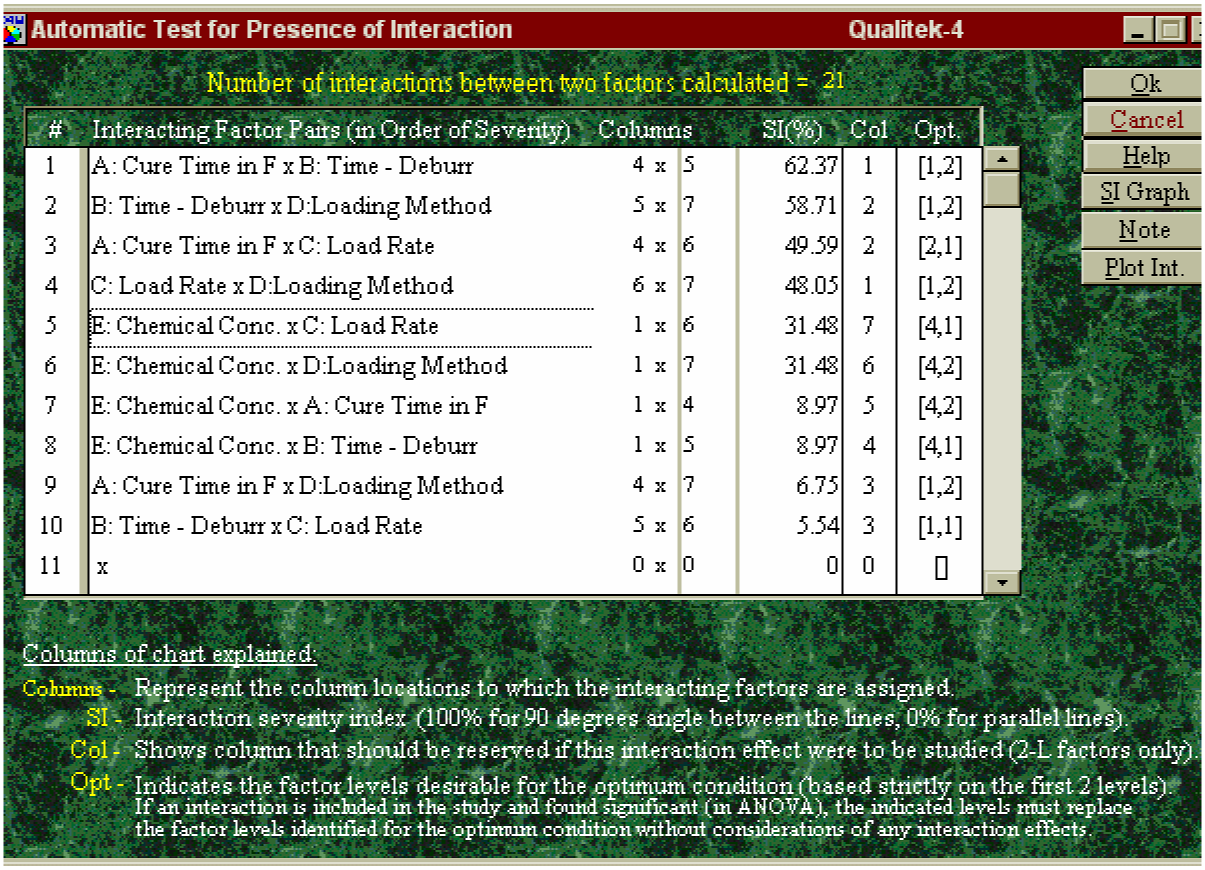
The plot of the factor average effects (main effects) is shown in Figure 6. Notice that factor E: Chemical Concentration assigned to column 1 of the array has four levels. Its average effects are joined by straight line in the plot of the main effect. The second curved line in this plot represents the more realistic behavior as a least-square fit of the average effect plot.

Figure 6. Plot of Factor Average Effects



Although, interaction was not considered as part of this study, the information about the presence of interaction (not the significance) is available and may be used in future studies. Among the five factors included in the study, there are 10 separate interactions between a pair of two factors. The strength of presence of interaction, which is quantified in terms of severity index, of all pairs are calculated and listed in order, from most to the least severe, in Figure 7. This interaction information could be valuable for setting up the repeat experiments, particularly when the predicted optimum performance from the first planned experiment does not confirm.

Figure 7. Severity Index from Test of Presence of Interaction



Number of interactions between two factors calculated = 21

#	Interacting Factor Pairs (in Order of Severity)	Columns	SI(%)	Col	Opt.
1	A: Cure Time in F x B: Time - Deburr	4 x 5	62.37	1	[1,2]
2	B: Time - Deburr x D:Loading Method	5 x 7	58.71	2	[1,2]
3	A: Cure Time in F x C: Load Rate	4 x 6	49.59	2	[2,1]
4	C: Load Rate x D:Loading Method	6 x 7	48.05	1	[1,2]
5	E: Chemical Conc. x C: Load Rate	1 x 6	31.48	7	[4,1]
6	E: Chemical Conc. x D:Loading Method	1 x 7	31.48	6	[4,2]
7	E: Chemical Conc. x A: Cure Time in F	1 x 4	8.97	5	[4,2]
8	E: Chemical Conc. x B: Time - Deburr	1 x 5	8.97	4	[4,1]
9	A: Cure Time in F x D:Loading Method	4 x 7	6.75	3	[1,2]
10	B: Time - Deburr x C: Load Rate	5 x 6	5.54	3	[1,1]
11	x	0 x 0	0	0	▯

Columns of chart explained:

Columns - Represent the column locations to which the interacting factors are assigned.
SI - Interaction severity index (100% for 90 degrees angle between the lines, 0% for parallel lines).
Col - Shows column that should be reserved if this interaction effect were to be studied (2-L factors only).
Opt - Indicates the factor levels desirable for the optimum condition (based strictly on the first 2 levels). If an interaction is included in the study and found significant (in ANOVA), the indicated levels must replace the factor levels identified for the optimum condition without considerations of any interaction effects.

The angle between the interaction plot is a measure of the strength (severity 100% for 90 degrees angle between the lines) of presence of interaction. The strongest interacting factors are shown in Figure 8. Interaction between a 4-level factor and a 2-level factor is shown in Figure 9. Generally, information about these interacting factor pairs is saved for future use.

Figure 8. Most Sever Interaction - between Two 2-level Factors

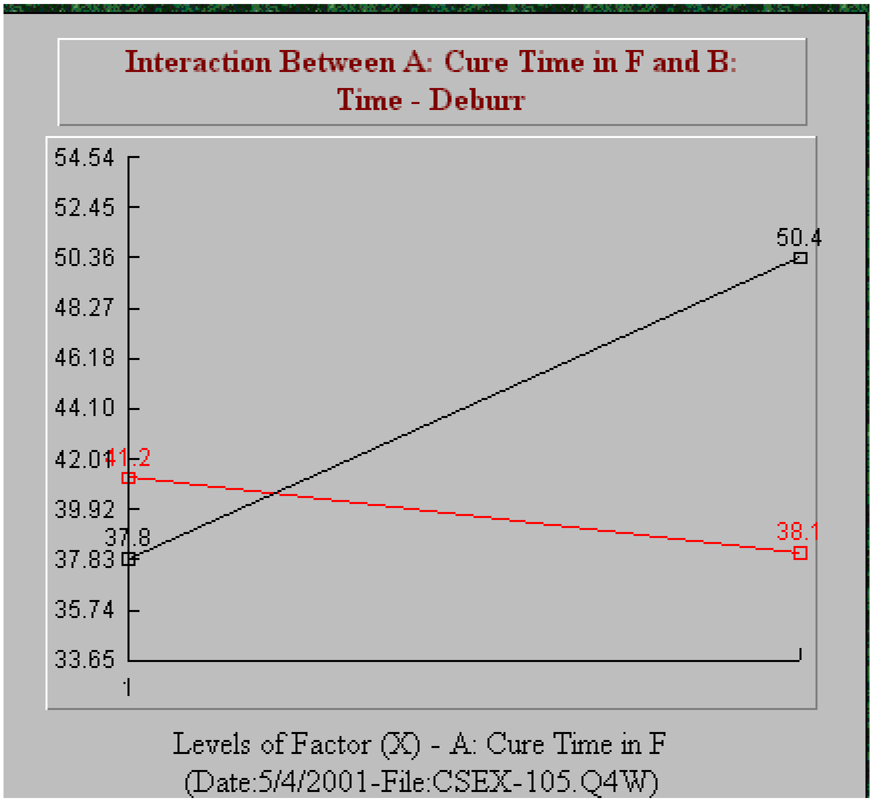
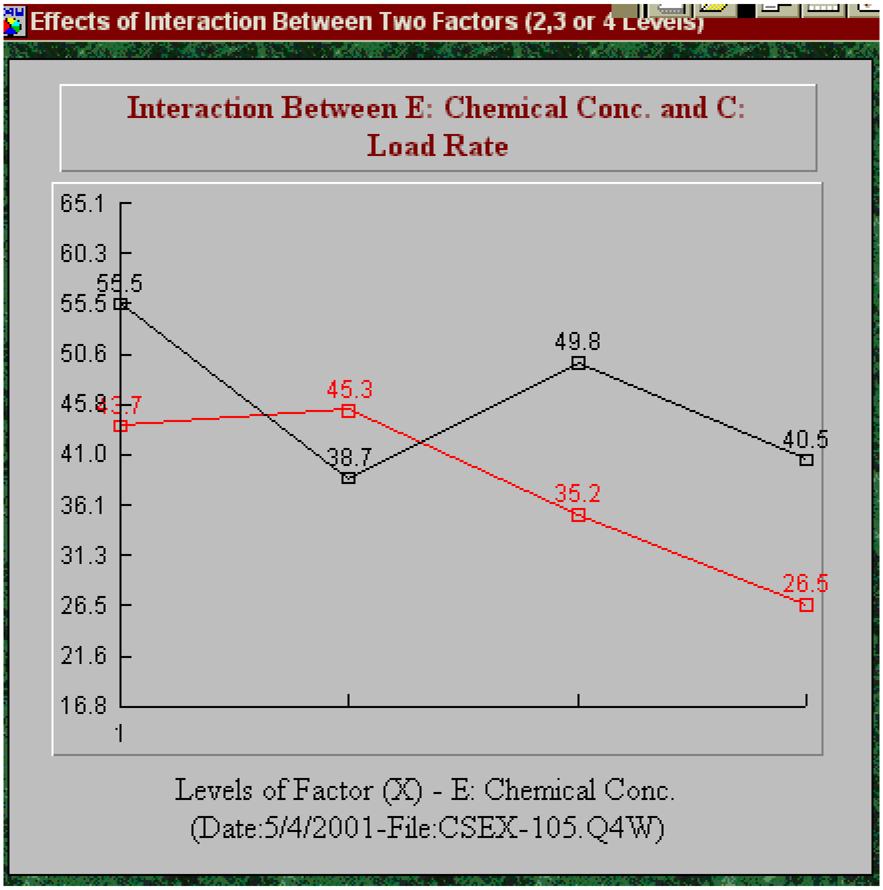
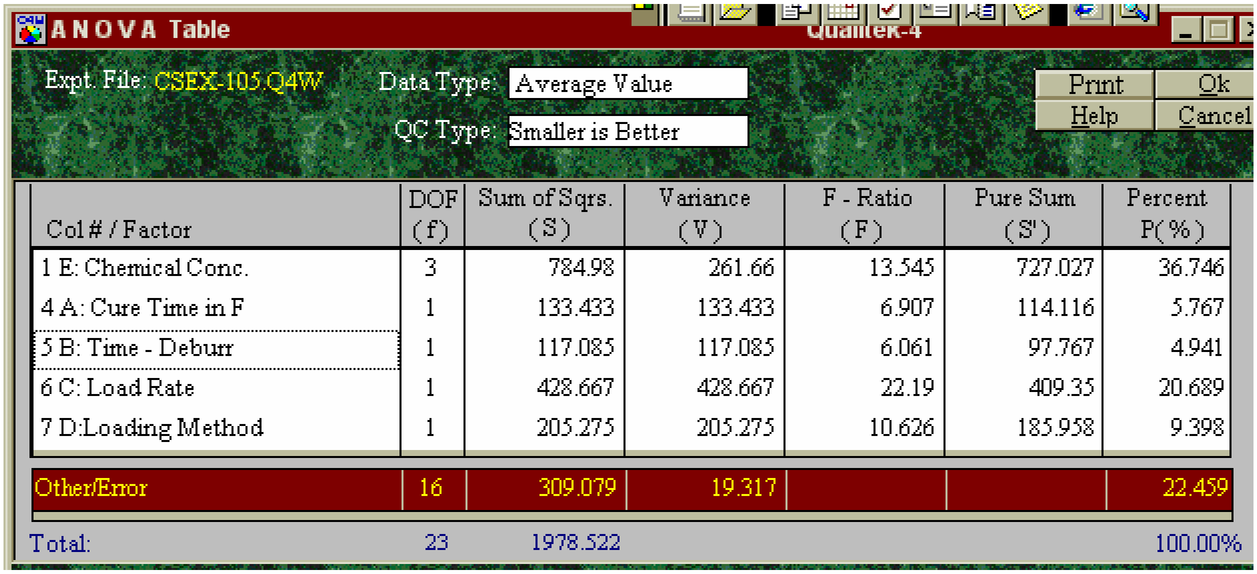


Figure 9. Interaction Between a 4-level and a 2-level factors



The right column of the analysis of variance (ANOVA) in Figure 10 shows the relative influence of the factors to the variation of results. This information is useful for tolerance specification and statistical process control projects. Since all factors are found to be significant over 95% (see Figure 11) confidence level, none is pooled (ignored). ANOVA shows that factors Chemical Concentration, Load Rate, and Loading Method are most significant and that about 22% of the influence to the variability in results come from sources other than those that are included in the study.

Figure 10. Analysis of Variance and Relative Influences of Factors



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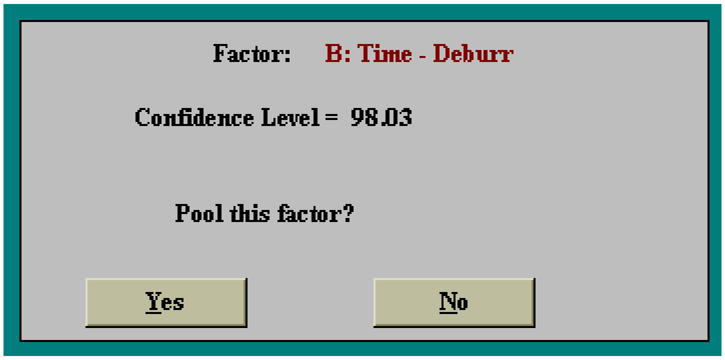
Data Type: Average Value

QC Type: Smaller is Better

Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 E: Chemical Conc.	3	784.98	261.66	13.545	727.027	36.746
4 A: Cure Time in F	1	133.433	133.433	6.907	114.116	5.767
5 B: Time - Deburr	1	117.085	117.085	6.061	97.767	4.941
6 C: Load Rate	1	428.667	428.667	22.19	409.35	20.689
7 D:Loading Method	1	205.275	205.275	10.626	185.958	9.398
Other/Error	16	309.079	19.317			22.459
Total:	23	1978.522				100.00%

Figure 11 Confidence Level on the Least Influential Factor



Factor: B: Time - Deburr

Confidence Level = 98.03

Pool this factor?

The plot of the relative influence of the factors shown in ANOVA (Figure 10) can be conveniently plotted in a bar graph and as a pie diagram as shown in Figures 12 and 13.

Figure 12. Bar Graph of Relative Influence of Factors

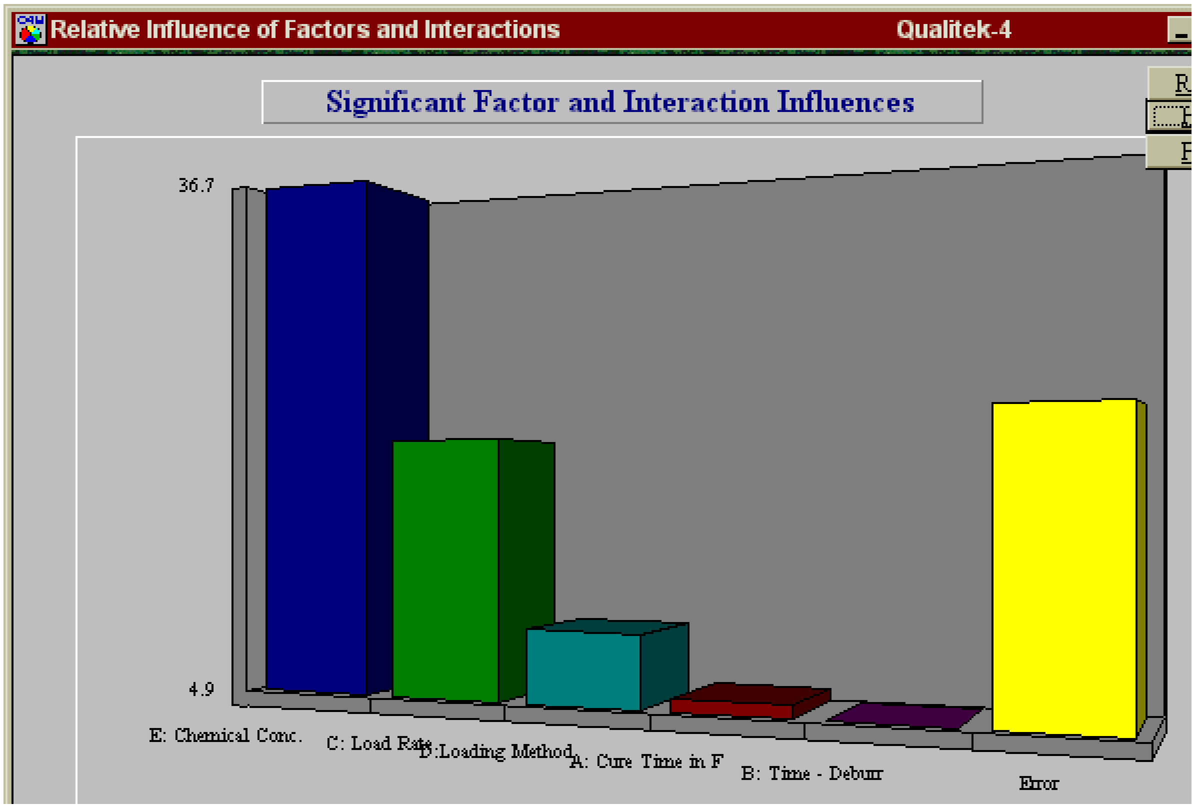
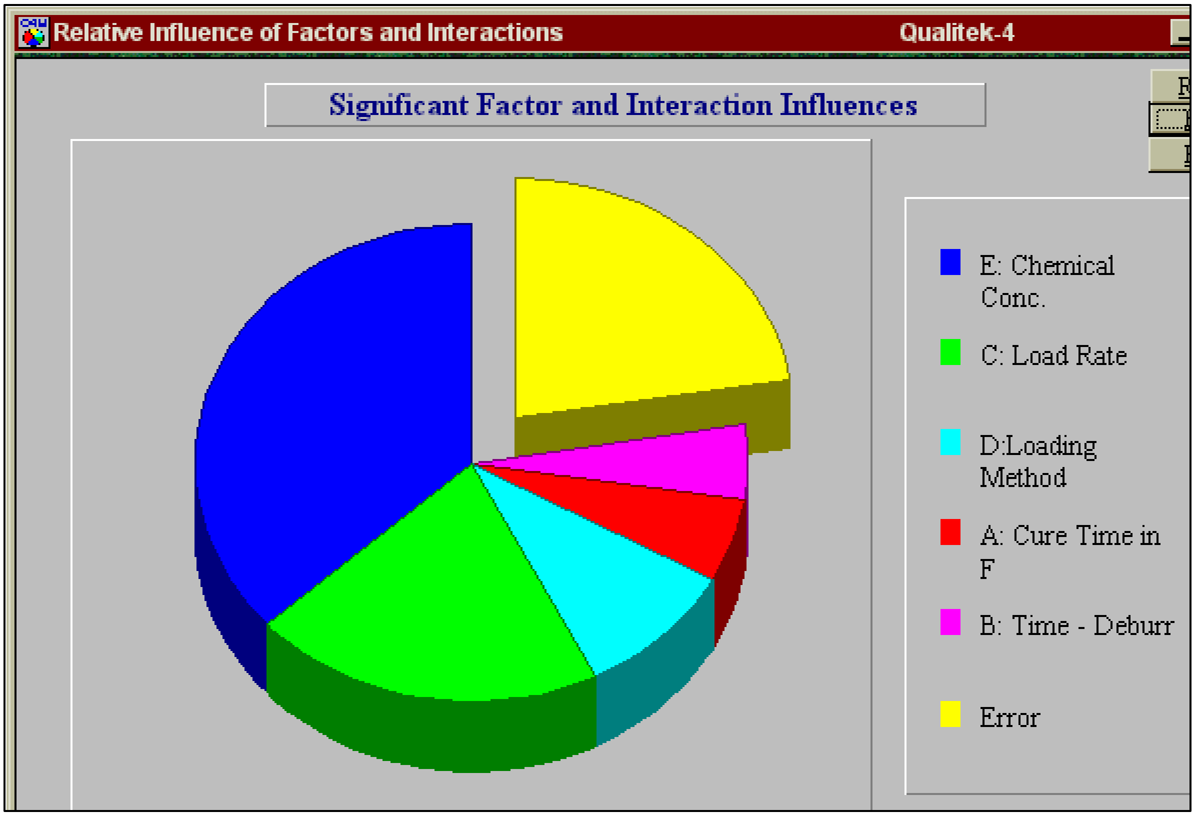


Figure Factor Descriptions and their Column Assignments

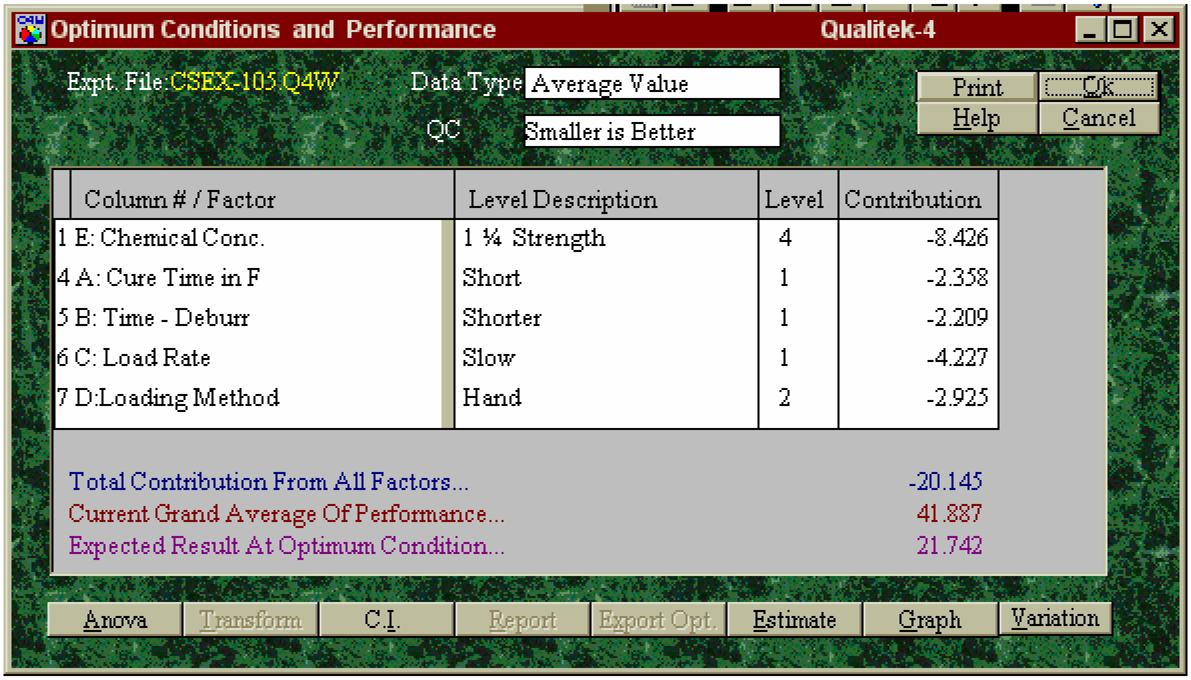
Figure 13. Pie Digram of Relative Influence of Factors



From the factor average effects (see Figures 5 and 6), the optimum condition and the performance at the optimum condition are as determined in Figure 14. Generally, the most desirable or optimum condition and the expected performance are calculated by selecting the desirable levels of significant factors only. Since, all factors included in the study, in this case, are found significant; no factor has been pooled (discarded/ignored in ANOVA). The optimum condition shown is the recommended design combination for best performance. This design condition is expected to lower the overall evaluation of the two criteria of evaluations (OEC number) of parts from 41.887 to 21.742.

Understand that the performance expected at the optimum condition is expressed in the OEC values as it was used for analysis. To get an estimate of performance under individual criterion of evaluation, *sticky or rust*, either perform separate analysis with the criteria results or accept the observed performance from a set of samples tested at the confirmation test (at the optimum condition).

Figure 14. Optimum Condition and Expected Performance



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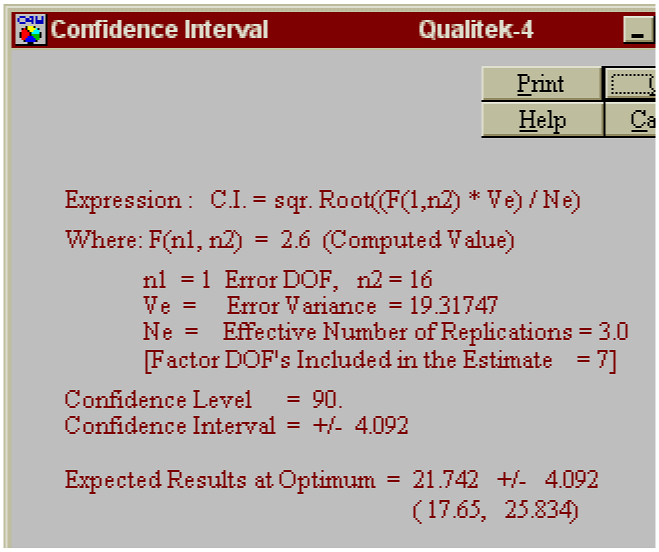
Data Type: Average Value
QC: Smaller is Better

Column # / Factor	Level Description	Level	Contribution
1 E: Chemical Conc.	1 ¼ Strength	4	-8.426
4 A: Cure Time in F	Short	1	-2.358
5 B: Time - Deburr	Shorter	1	-2.209
6 C: Load Rate	Slow	1	-4.227
7 D:Loading Method	Hand	2	-2.925

Total Contribution From All Factors...	-20.145
Current Grand Average Of Performance...	41.887
Expected Result At Optimum Condition...	21.742

ANOVA calculation shown earlier also provides boundaries of expected performance. The confidence interval (C. I.) on the expected performance at the optimum condition at 90% confidence interval is found to be between 17.65 and 25.834. This means that if 10 sets of samples were tested at the optimum condition, 9 out of 10 such sets are expected to produce the mean results between 17.65 and 25.834.

Figure 15. Confidence Interval on the Expected Performance



Expression : C.I. = sqr. Root((F(1,n2) * Ve) / Ne)

Where: F(n1, n2) = 2.6 (Computed Value)

n1 = 1 Error DOF, n2 = 16
Ve = Error Variance = 19.31747
Ne = Effective Number of Replications = 3.0
[Factor DOF's Included in the Estimate = 7]

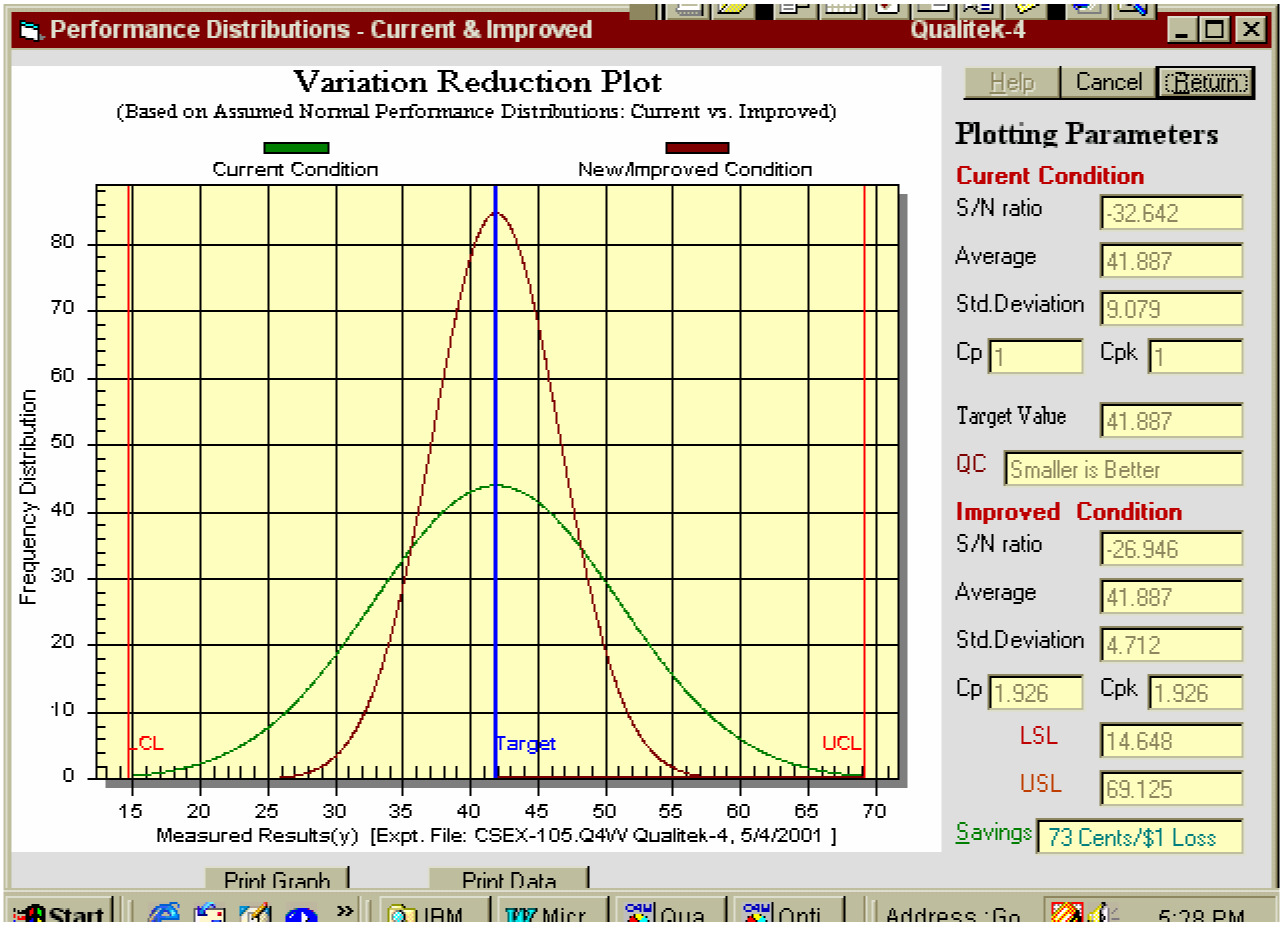
Confidence Level = 90.
Confidence Interval = +/- 4.092

Expected Results at Optimum = 21.742 +/- 4.092
(17.65, 25.834)

At the end of analyses, a single plot of performance distributions of current and new designs can be presented as shown in Figure 16. From the expected performance improvement data, and some standard assumptions, the estimate of other performance indices like, Cp, Cpk, Loss, etc. can be produced. Estimate of savings (66.6 cents for each dollar) and variation reduction is confirmed by analyzing the signal-to-noise (S/N) ratios of the results as shown in Figure 17.

- Factors E: Chemical Concentration, C: Load Rate, and D: Loading Method are the three most significant factors.
- The new design condition determined from the experimental results is expected to reduce OEC by 50% (from 41 to 21).
- When the optimum design condition is incorporated in the production process, it is expected to save over 65 cents out of every dollar loss due to returns and customer complaints.

Figure 16 Variation Plot from Standard Analysis



Plotting Parameters

Curent Condition

S/N ratio -32.642

Average 41.887

Std.Deviation 9.079

Cp 1 Cpk 1

Target Value 41.887

QC Smaller is Better

Improved Condition

S/N ratio -26.946

Average 41.887

Std.Deviation 4.712

Cp 1.926 Cpk 1.926

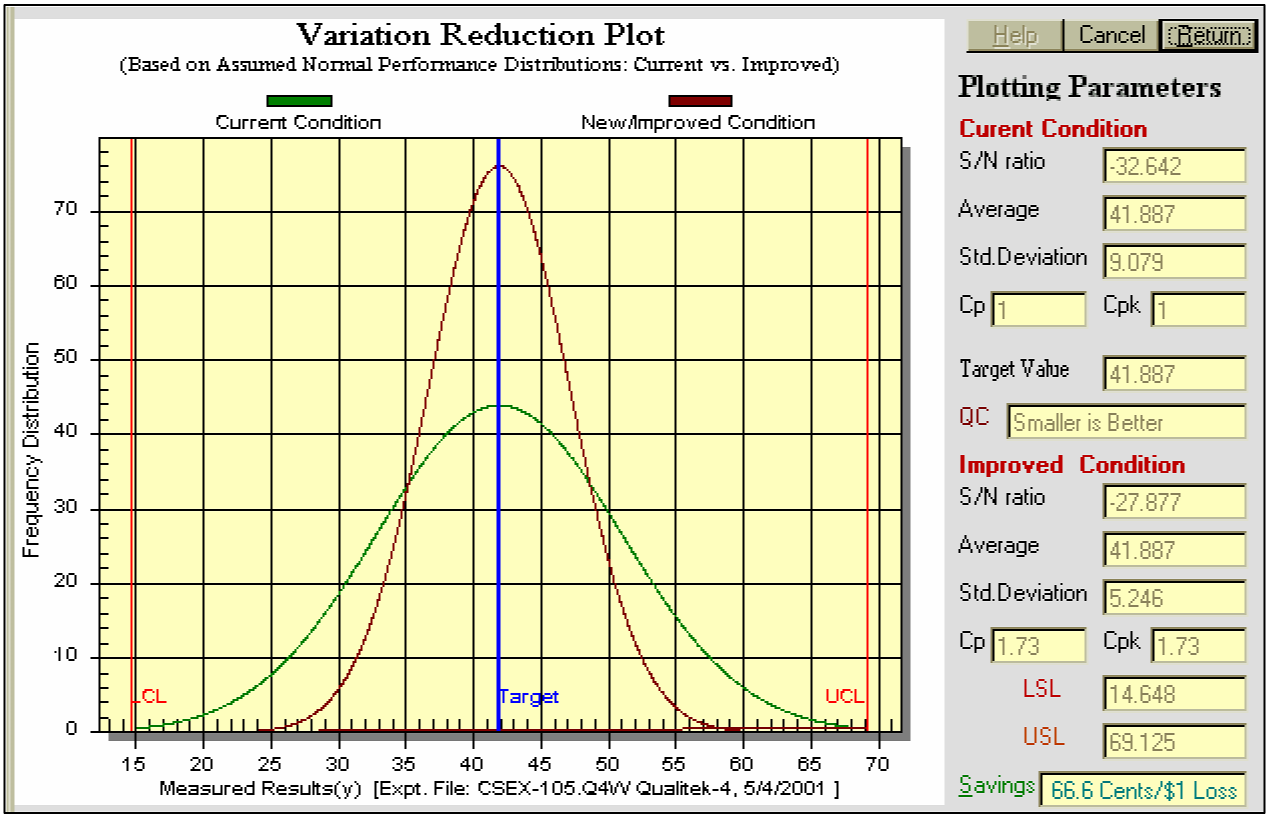
LSL 14.648

USL 69.125

Savings 73 Cents/$1 Loss

Analysis performed using the S/N of OEC results produced performance distribution and the common performance indices as shown in Figure 17.

Figure 17. Variation Plot from S/N Analysis



Plotting Parameters

Curent Condition

S/N ratio: -32.642

Average: 41.887

Std.Deviation: 9.079

Cp: 1 Cpk: 1

Target Value: 41.887

QC: Smaller is Better

Improved Condition

S/N ratio: -27.877

Average: 41.887

Std.Deviation: 5.246

Cp: 1.73 Cpk: 1.73

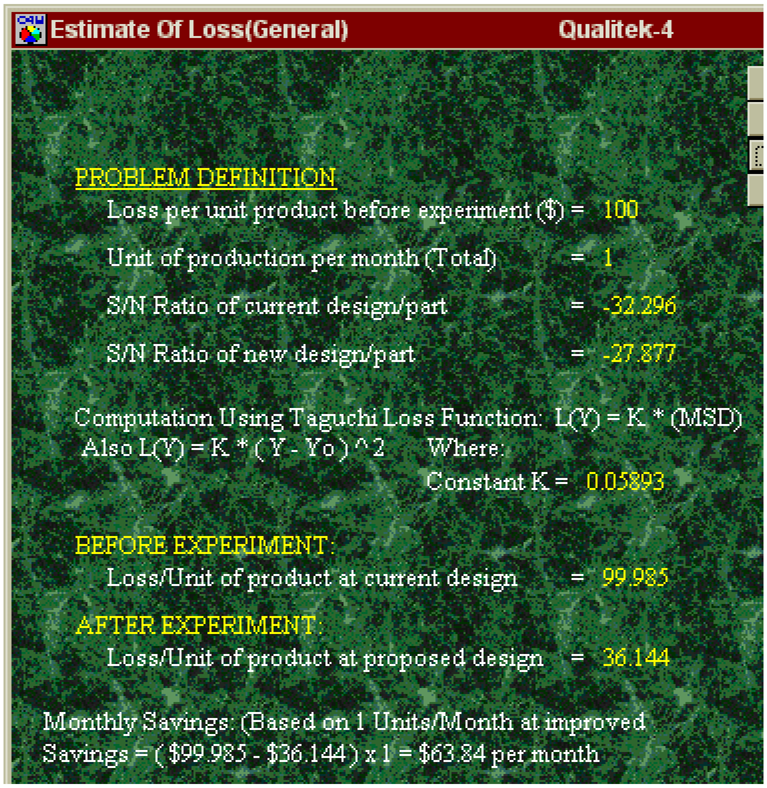
LSL: 14.648

USL: 69.125

Savings: 66.6 Cents/$1 Loss

Based on the current and future status expressed in terms of S/N, the expected loss and the savings produced from the reduced loss are shown in Figures 18 and 19.

Figure 18. Computation of Dollar Loss at Current and Improved Condition



PROBLEM DEFINITION

Loss per unit product before experiment ($) = 100
Unit of production per month (Total) = 1
S/N Ratio of current design/part = -32.296
S/N Ratio of new design/part = -27.877

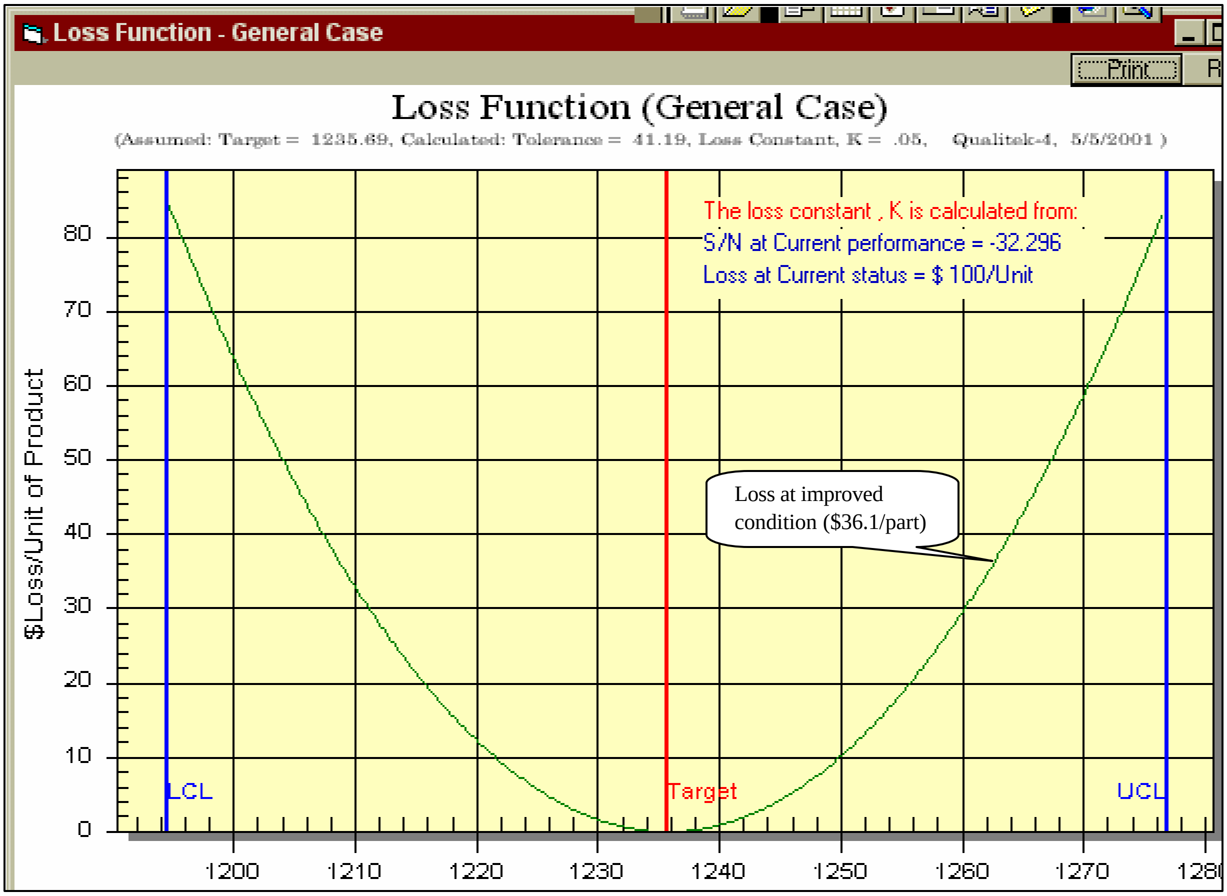
Computation Using Taguchi Loss Function: L(Y) = K * (MSD)
Also L(Y) = K * (Y - Yo) ^2 Where:
Constant K = 0.05893

BEFORE EXPERIMENT:
Loss/Unit of product at current design = 99.985

AFTER EXPERIMENT:
Loss/Unit of product at proposed design = 36.144

Monthly Savings: (Based on 1 Units/Month at improved
Savings = ($99.985 - $36.144) x 1 = $63.84 per month

Figure 19. Plot of the Loss Function


Loss Function - General Case

Loss Function (General Case)

(Assumed: Target = 1235.69, Calculated: Tolerance = 41.19, Loss Constant, K = .05, Qualitek-4, 5/5/2001)

The loss constant , K is calculated from:
S/N at Current performance = -32.296
Loss at Current status = $ 100/Unit

Loss at improved condition ($36.1/part)

References

1. **Genichi Taguchi**. 1987. System of Experimental Design, UNIPUB, Kraus International Publications, New York.
2. **Ranjit K. Roy**. 2001. Design of Experiments Using the Taguchi Approach : 16 Steps to Product and Process Improvement, Hardcover (January 2001) John Wiley & Sons; ISBN: 0471361011 (Available from WWW.AMAZON.COM)
3. **Ranjit K. Roy**. 1990. A Primer on the Taguchi method, Society of Manufacturing Engineers, Dearborn, Michigan, USA. ISBN: 0-87263-468-X Fax: 1-313-240-8252 or 1-313-271-2861 (Also available from WWW.AMAZON.COM)
4. **Ranjit K. Roy, 1996, QUALITEK-4** (for Windows): Software for Automatic Design of Experiment Using Taguchi Approach, IBM or Compatible computer, Nutek, Inc. 3829 Quarton Road, Bloomfield Hills, MI 48302 USA. Tel & Fax: 1-248-540-3212 . Free DEMO from http://www.rkroy.com.