

(Development incomplete ....)

## Qualitek-4 and Taguchi DOE Application Knowledge Base

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### About Qualitek-4

Qualitek-4 (QT4) Version 6.6 is a Windows software for Automatic Design and Analysis of Taguchi Experiments. The software was originally introduced in 1987 as Qualitek-3, and later enhanced and released in 1991 as Qualitek-4 for DOS and in 1996 as Qualitek-4 for Windows (3.1). The version for Microsoft Windows is based on the DOS version, but, represents completely redesigned screens, user interfaces, and several technical capabilities and is compatible with Windows 95, 98, ME, 2000, and XP.

The program comes with over 50 example experiments. These example experiments include all exercises in the text: A Primer on The Taguchi Method, all problems and exercises in the Nutek seminar handout, and solutions to many other example experimental projects.

### WHO WOULD BENEFIT FROM Qualitek-4 SOFTWARE

If you are a design engineer, manufacturing engineer, quality assurance specialist or research scientist involved in product or process optimization studies, you will greatly benefit from the use of the Taguchi technique and Qualitek-4 software.

## **What does the program do?**

With little or no decision on the part of the user, QT4 can :

- Design most common Taguchi Experiments
- Carry out Analysis (main effect, ANOVA, Optimum, etc.)
- Plot graphs of factor influence, contributions etc
- Prepare presentation quality reports in matter of minutes
- Let you calculate Loss/Savings based of the expected improvement

## **Program Capabilities:**

L-4, L-8, L-9, L-12, L-16, L-18 ... L-32 and L-64 arrays, 2, 3 and 4 level factors, 2 to 63 factors, Std. and S/N analysis using BIGGER, SMALLER or NOMINAL, and dynamic quality characteristics.

**Program Size:** About 12 MEG. You will need an IBM/Compatible 486 or better computer.

## **How much does it cost and how to order ?**

The current price regular copy of QUALITEK-4, for single installation, casts \$1,195 (US) + Shipping & Handling (\$20 within USA, \$60 international). To order, call or fax us your purchase order or ask your software dealers to contact us.

**References** (Visit <http://www.rkroy.com/wp-txt.html> )

## **Frequently Asked Questions**

### *How do I Downloading Qualitek-4 Before and After Purchasing It?*

You can download the demo version of the software (demo can be unlocked to offer full capabilities with a valid registration number) from our web site ([www.rkroy.com/wp-q4w.html](http://www.rkroy.com/wp-q4w.html) ). We prefer that you download the software and try it before making purchase decision.

### *Where can I find other reference files fo Qualitek-4?*

While at our download site ([www.rkroy.com/wp-q4w.html](http://www.rkroy.com/wp-q4w.html) ), find other downloadable files with instruction for installation and reference manual. When you purchase the software from us (except electronic version at reduced price), you will receive a hard copy reference manual with the program CD.

### *Downloading and Installing the Demo Version of Qualitek-4*

After you download our demo program file (q4wxpdemo.zip), you will need to unzip the file and install the setup.exe file in to your computer. While installing the Qualitek-4, you will use "demo" as the default registration number. This installs our complete software in your computer (default directory will be C:\Program Files\Q4W32 or Q4W. The program you install as demo allows you to use all the program capability for experiment you designed using only the L-8 array (restricted from use of all other arrays). However, you can review over 50 example experiment files of all sizes included with the program file.

### *How can I contacting for Installation support after purchasing software?*

If you have problem installing the software or need help placing the purchase order, please visit our site and follow purchase instruction ([www.rkroy.com/wp-q4w.html](http://www.rkroy.com/wp-q4w.html) ) or write ([rkroy@rkroy.com](mailto:rkroy@rkroy.com)) or call us at 1-248-540-4827.

*What Happens to the Demo Version After Purchasing Qualitek-4?*

When you purchase the software you will receive a license letter with special registration number along with the program CD and the reference manual (unless you opt for the electronic version). You can then use the registration number to re-install the demo version you downloaded before or discard the demo version and install the software from the program CD you received. In either case, you can re-install the software in the same directory without fear of losing any of the experiment files ( in sub-directpory C:\Program Files\Q4W32\Ustrfiles ).Gnereally, the demo version you download (q4wxpdemo.zip) will contain the same program version as the one in that in the CD. However, the software CD you receive always contain the up-to-date version of the software, and also contain many additional helpful and product information files.

*Why does my installed Qualitek-4 says Demo Version?*

The registration screen of Qualitek-4 shows the status of your program along with a few other license information. If it indicates the status as “Demo Version”, this could be because you have not installed the software using the registration number you received, or that you do not have a valid registration number. The the registration number is a 15 digit number (all numeric). In rare occasion, the number you received may be erroneous. If you suspect the number is faulty, please write to us ([rkroy@rkroy.com](mailto:rkroy@rkroy.com) ) or call with your registration number.

*What should I do if Qualitek-4 Crashes when I create or open an experiment file?*

If the program fail to run after installation, the problem could be with your system. Check the program requirements (Windows 95, 98, 200, ME, XP, disk space 20 Meg, etc ) and contact your system administrator

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[Unedited class lecture topic notes from early 1990's]

**Subject Index =====**  
**(Descriptions need to be written ....)**

Attractive Features of QT4  
Option Highlights  
System Requirements

Installing Program On Hard Disk  
Using Program On Hard Disk  
Using Program In Drive A Or Drive B  
Registration  
De-Installation Of Program  
General Tips For Operation And Printed Output  
Printing Screen Data  
Printing Graphics Screens Using Printers  
What To Do When In Doubt

Invoke On-Line Task Sensitive Help(Shift+F1)

Review Overviews Of Taguchi Methods  
Review Brainstorming Procedure  
Examine Triangular Tables  
Design Your Own Experiment  
Let Qt4 Design (Automatically)  
Your Experiment  
Define Your Own Array  
Use Your Own Array To Design Experiment  
Modify Standard Array For Your Experiment  
Save Your Experiment Data File  
Retrieve An Experiment Data File  
Prepare A Backup Copy Of Experiment File  
Delete An Experiment File  
Define Factors And Levels  
Edit Factors And Level Descriptions  
Modify Orthogonal Array  
Used.In The Experiment  
Define Outer Array And Dynamic Characteristics  
Describe And Edit Noise Factors And Levels  
Edit Outer Array  
Eliminate Outer Array  
Review Experiment Configuration  
Display Trial Conditions  
Print Trial Conditions  
Display Noise Conditions  
Print Noise Conditions  
Exit Program Temporarily For Dos Tasks  
Quit Program And Exit To Dos  
Reset Printer And Color Code

Invoke On-Line Task Sensitive Help (Shift+F1)  
Enter Results For Standard And S/N Analysis  
Import Results From Lotus Files  
Edit Results

Perform Standard Analysis Using Averages  
Perform Analysis Using S/N Ratios  
Check Compatibility Of Experiment Design  
Select Quality Characteristics For Analysis

Select Alternative Definition Of S/N

Examine Main Effect  
Examine Average Effects Of Noise Factors  
Plot Main Effects Of Factors One At A Time  
Plot Main Effects Of Multiple Factors  
Plot Main Effects Of A Selected Group Of Factors  
Plot Interaction Between Two 2-Level Factors  
Plot Average Effects Of Noise Factors

Examine Anova Table  
Test For Significance Of A Factor Influence  
Pool Factors By Test Of Significance  
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Examine Optimum Condition And Performance  
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Plot Stacked Graph Of Optimum Performance  
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Calculate Loss For General Quality Characteristics  
Calculate Loss For "Nominal Is Best" Quality Characteristic  
Calculate Manufacturer And Supplier Tolerances  
Calculate Parameters And Normal Distributions  
Compare Cost And Plot Two Normal Distributions  
Calculate Msd, S/N, Cpk, Etc. From Given Parameters  
Review Relationships Among Msd, S/N, Cpk. Etc.  
Preparation Of Results From Multiple Evaluation Criteria  
Review Methodology  
Review Oec Screen  
Review Criteria Definition  
Enter And Review Evaluations  
Review Oec Equation  
Accumulation Analysis  
Enter Results  
Perform Analysis  
Report And Y Of Results

## **APPENDIX A**

Design factors and their levels  
Individual Trial Condition  
Results and factor effects (Main effects)  
ANOVA and optimum performance  
Plot of main column effect with C.I.  
Plot of interaction between factors  
Bar Chart of Significant Factor Influence  
Pie Chart of Significant Factor Influence  
Bar Graph of Optimum Condition

## **APPENDIX B**

Tips on Common Applications (How To's)  
Troubleshooting  
References

## **How to get Support**

For Installation or Product Defects:

Please note any screen message or steps where problem occurred and describe nature of the problem.  
Be on or near the system when calling. (Response time: 0 - 24 hours)

For Application Assistance:

Call us if you have difficulty performing elements of experiment design and analysis tasks. Most of your questions may be resolved by reading screen HELP or pulldown HELP.  
(Response time: 0 - 24 hours)

For Technical or Theory questions:

Call for quick questions. Email to attention: R.Roy rkroy@wwnet.com.

Consult DOE experts in our web site: <http://www.wwnet.com/~rkroy>  
(Response time: 0 to 7 days)

Phone: 810-642-4560, Fax: 810-642-4609, Email: [rkroy@wwnet.com](mailto:rkroy@wwnet.com)  
Home Page: <http://www.wwnet.com/~rkroy>

#### How to Give Feedback

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We always like to hear from you about any improvement you would like to suggest or any difficulty you experienced. Please call, fax, write, or email us.

Phone: 810-642-4560, Fax: 810-642-4609, Email: [rkroy@wwnet.com](mailto:rkroy@wwnet.com)  
Home Page: <http://www.wwnet.com/~rkroy>

#### Release Notes:

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The target for release of Qualitek-4, Version 4.70 (Windows) is expected to be released in November 1996.

#### Upgrade Information

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If you are a current user of Qualitek-4 (DOS), you may upgrade to the Windows version any time before December 20, 1997 for only \$665 (USD). If you purchased our DOS version after April 15, 1996, you can upgrade to the Windows version for a special price of only \$298.75 ( 25% of the list price of \$1,195). This special upgrade price is valid till Jun 1, 1997.

Shipping and Handling: \$ 20 within the USA, \$ 30 Canada, \$45 - \$85 all other countries.

#### Frequently Asked Questions

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What are your other software packages?

We have two other software, Qualitek-1 and Qualitek-2. Subject and content wise these two packages bear no relations to Qualitek-4 or the Taguchi technique.

Qualitek-1 is for Component Durability Test Planning. It does all the statistical calculations necessary to determine the statistically valid test parameters. It is generally used by the professionals involved in the durability or reliability test setups.

Qualitek-2 is for Weibull Analysis. Weibull analysis is statistical technique to determine reliability status of failure test data and predict the behavior of the population performance. It is a popular technique used by the test and validation activities of major manufacturing organizations.

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#### Dear Qualitek-4 Demo Users:

Subject: **Qualitek-4 Demo Software Evaluation & Quick Guide** (Print for reference)

Thank you for downloading the working version of our **Qualitek-4** software from our web site (<http://www.rkroy.com>). If you are about to use our software for the first time, we strongly recommend that you print this mail and keep it for your reference.

The software you downloaded contains over 50 example experiments of all sizes, which you can review to explore most capabilities of the software. Should you need to unlock the full range of its capabilities for unrestricted immediate use, obtain your *personal Registration number* by placing an order with us. If you are a student, continue to use the limited capability of Demo without any obligation. To purchase Qualitek-4, please visit [www.rkroy.com/wp-q4w.html](http://www.rkroy.com/wp-q4w.html) and follow the purchase instruction.

Visit our DOE information sites at your convenience:

|   |  |
|---|--|
| <a href="http://www.rkroy.com/wp-s4d.html">http://www.rkroy.com/wp-s4d.html</a> | => DOE Public Seminars in Detroit Area |
| <a href="http://www.rkroy.com/wp-doe.html">http://www.rkroy.com/wp-doe.html</a> | = >DOE/Taguchi Overview.               |
| <a href="http://www.rkroy.com/wp-tip.html">http://www.rkroy.com/wp-tip.html</a> | = >Experiment Design <b>Tips</b>       |
| <a href="http://www.rkroy.com/wp-txt.html">http://www.rkroy.com/wp-txt.html</a> | = > <b>Textbooks</b>                   |
| <a href="http://www.rkroy.com/wp-ine.html">http://www.rkroy.com/wp-ine.html</a> | = >Application <b>Case Studies</b>     |
| <a href="http://www.rkroy.com/wp-q4w.html">http://www.rkroy.com/wp-q4w.html</a> | => Qualitek-4 Software                 |
| <a href="http://www.rkroy.com/wp-sps.html">http://www.rkroy.com/wp-sps.html</a> | => DOE Application Assistance          |
| <a href="http://www.rkroy.com/wp-ons.html">http://www.rkroy.com/wp-ons.html</a> | => On-site Seminar/Workshop.           |
| <a href="http://www.rkroy.com/wp-sem.html">http://www.rkroy.com/wp-sem.html</a> | => Seminars All Topics                 |

**DOE Discussion Group** ([www.rkroy.com/wp-doedg.html](http://www.rkroy.com/wp-doedg.html) free membership).

Sincerely,

Paula

Customer & Sales Support

**Nutek, Inc.** (<http://www.rkroy.com>), Email:Customer Support<[rkroy@wwnet.net](mailto:rkroy@wwnet.net)>

Visit [www.rkroy.com/wp-txt.html](http://www.rkroy.com/wp-txt.html) to review **the text** *Design of Experiments Using the Taguchi Approach : 16 Steps to Product and Process Improvement*.

**"DOE Demystified"** <http://www.manufacturingcenter.com/tooling/archives/1202/1202qmdesign.asp>

### [Quick Evaluation Guide \(Print this and keep for your own use\)](#)

**Basic Capabilities** (review analysis capabilities first)

1. Run Qualitek-4 (QT4) program from your computer and click OK past the Registration Screen to the *experiment configuration screen*. Notice that experiment file PISTON.Q4W is already loaded in memory. If not, OPEN file PISTON.Q4W.

2. Proceed to Review and Analyze Results of PISTON and other example experiments. There are over 50 example experiments of all sizes included with the program.

3. Click Analysis menu and select Standard Analysis (either average or stand. deviation). Since PISTON has three samples/results per trial, QT4 will remind you to perform S/N. Click OK to proceed. In the next screen check Bigger is Better Quality Characteristic and click OK.

4. Review results and click on Graph if you wish to view it. Click OK when done.

5. While in the Main Effect screen, click Plot to view plots of Main Effect. Once you are in the graphics screen, click the "<<" or ">>" button at the bottom of the graph to display other factor plots. Click OK to return to Main Effect screen.

6. Click on Interaction button, to display interaction plots between any two factors. Select the Automatic option if you want QT4 to calculate interaction between all possible factors, even though you may not have thought about all the interactions or included them in your study. QT4 calculates  $N(N-1)/2$  possible pairs of interactions for N factors and ranks them by Severity of their presence (Severity Index, 0 - 100%). Review the list to note the important pairs of interaction for future reference. Click OK or Cancel to return to Main Effect screen and click OK to proceed to ANOVA screen.

7. In ANOVA screen, try POOLING the factor with least amount of influence (last column). To POOL factors, double click on the factor description. At prompt, review % Confidence Level and click OK. Notice how the ANOVA table gets updated. You can also try one or more of the following tasks.

- Pool another factor with the least influence
- Reset ANOVA
- Pool all factors with less than 98.6% confidence level.
- Plot bar graph , pie chart, and Re-start ANOVA
- Review Pie diagram

8. Click OK to move to the OPTIMUM screen

- At the Optimum screen:
- Read expected response
- Convert this result to a real number when S/N analysis is used.
- Plot graph of factor contribution
- Find response for all factors at level 2
- Go back to ANOVA and pool all factors below 10% influence
- Determine 90% confidence interval of the optimum response
- Return to optimum screen

9. Click OK to return to the *main screen*. From the file menu, click on Open and select any other experiment file from the list of over 50 files (Open POUND.Q4W if you are interested in reviewing OEC). Analyze results by following steps 3 -8.

### **Design your Own Experiment**

10. prepare a list of factors and levels for a practice experiment (say 5 factors at 2-level each). Click on the DESIGN menu and select *Manual Design*. Check L-8 for your design. When in design screen, describe factors and their levels by assigning to any rows (which are columns of the array). Since you will be using five of the seven available columns, click on the UNUSED button to designate the two columns as unused. Click OK to move to the Orthogonal Array screen. Click OK to experiment file screen. Supply only the first eight characters of your file . The file extension .Q4W is automatically added.

11. **Automatic Experiment Design** If you want Qualitek-4 to select the appropriate orthogonal arrays and design the experiment, select the *Automatic Design* option in the DESIGN menu. Qualitek-4 can design experiments for most common situations. Give this a try.

12. After design is completed, you may review the trial condition by clicking on REVIEW menu and selecting Trial Condition. Should you want to carry out these experiments, you may print some or all the trial conditions. You may also save the trial conditions in a file to email/export electronically to distant locations.

### **Experimental Results Entry**

13. Once the experiments are carried out, you will need to enter the results by clicking on RESULT menu and then, selecting Enter Result option. If your result includes multiple evaluation criteria, you will select Multiple Criteria (OEC) option. Enter results/evaluation criteria as applicable. When done entering results, perform analysis following steps 3 - 8 as described above.

For additional help with exploring program capabilities, download *TourQT4.zip PowerPoint presentation file (2.15 MEG Zipped File)*. This presentation shows you how to use **Qualitek-4** for **ANALYSIS** and **DESIGN** tasks. Unzip, then double click on the file to run using Microsoft PowerPoint program. (Recommended for users who are new to DOE/Taguchi). Click on the link below to download: <http://www.rkroy.com/tourqt4.zip>

===== **DEMO Capabilities Special Note to instructors** =====

Do you realize that you can design over **15 different types of experiments using the L-8 array** (in demo version)?  
Here are the type of experiments:

- (1) Four 2-Level factors, (2) Five 2-Level factors, (3) Six 2-Level factors, (4) Seven 2-Level factors,
- (5) Four 2-Level factors + Three interactions, (6) Five 2-Level factors + Two interactions
- (7) Six 2-Level factors + One interaction, (8) Four 2-Level factors + One 4-Level factor
- (9) Three 2-Level factors + One 4-Level factor, (10) Two 2-Level factors + One 4-Level factor
- (11) One 2-Level factors + One 4-Level factor, (12) Four 2-Level factors + One 3-Level factor
- (13) Three 2-Level factors + One 3-Level factor, (14) Two 2-Level factors + One 3-Level factor
- (15) One 2-Level factors + One 3-Level factor.

The textbooks ([www.rkroy.com/wp-txt.html](http://www.rkroy.com/wp-txt.html)) by R. Roy corresponds 100% with the software. Consider using one or both books for your class when you plan to use the software for the class (visit [www.rkroy.com/wp-q4w.html](http://www.rkroy.com/wp-q4w.html) for free license).

## Her is what our other users say about Qualitek-4.

*"Weve looked at several packages, but Qualitek-4 looks most userfriendly and does the job better for us."*

*"If your purpose is to design and analyze Taguchi DOE, nothing beats this package."*

*"We liked the option to design experiments with mixed level factors. Qualitek-4 seem to offer quite a selection of arrays."*

*"The automatic design option in Qualitek-4 is cute. Im glad I dont have to remember how to upgrade and downgrade columns and how to assign factors The software does it all."*

*"We found the software to be easy to use. I was able to design L-8 experiment and print trial conditions in matter of minutes."*

*"Some of the new features in the Windows XP version great. The option to save trial condition to a file help me send the information electronically to distant experimental locations."*

*"Im happy about the many ways of analyzing results and the fact that it instantly transform the S/N prediction in terms of real units of results."*

*"The severity index for all possible interactions that we do not included in the experiment, is a feature I have not found in any other package."*

*"The process diagram and analysis of DYNAMIC CHARACTERISTICS are streamlined advanced features that are incredibly easy to follow."*

[To test use example DC-AS400.Q4W]

*"We find that handling of multiple objective simultaneously is unique with Qualitek-4."*[To test use example POUND.Q4W]

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## About the Taguchi Methods

Design Of Experiments(DOE) is a statistical technique introduced by R. A. Fisher in England in the 1920's to simultaneously study the effect of multiple variables on the outcome. In his early applications, Fisher wanted to find out how much rain, water, fertilizer, sunshine, etc. are needed to produce the best crop. Since that time, much development of the technique has taken place in the academic environment, but not many applications in the manufacturing industries.

As a researcher in Electronic Control Laboratory in Japan, Dr. Taguchi carried out significant research with DOE techniques in the late 1940's. His effort has been to make this powerful experimental technique more user-friendly (easy to apply) and apply it to improve the quality of manufactured products. Dr. Taguchi's standardized version of DOE, popularly known as Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. Today it is one of the most attractive quality building tools used by all types of engineers in manufacturing industries.

The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects in the manufacturing industry. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations. DOE can be highly effective when we want to:

### Overall application goals:

- Optimize product and process designs
- Study the effects of multiple factors (i.e.- variables, parameters, ingredients, etc.) on the performance
- Solve production problems by objectively laying out the investigative experiments

### Specific Objectives:

- Influence of individual factors on the performance
- Which factor has more influence, which ones have less
- Which factor should have tighter tolerance, which tolerance should be relaxed
- Which factor influences are significant and which are not
- How to allocate quality assurance resources based on objective data
- Whether a supplier's part causes problems or not (ANOVA data)
- How to combine different factors in their proper settings to get the best results
- How you can substitute a less expensive part to get the same performance
- How much money you can save if you make the design improvement
- How you can determine which factor is causing most of your problems
- How you can set up your process such that it is insensitive to uncontrollable factors
- Which factors have more influence on the mean performance
- What you need to do to reduce performance variation around the target

- How you can adjust factors for a system whose response varies proportional to signal factor (Dynamic response)
- How to combine multiple criteria of evaluation into a single index
- How you can adjust factor for overall satisfaction of criteria of evaluations
- How the uncontrollable factors affect the performance
- etc.,

### **How is the Taguchi Approach different from DOE as introduced by R. A. Fisher?**

The application of DOE requires careful planning, prudent layout of the experiment, and expert analysis of results. Based on years of research and applications of the technique, Dr. Genichi Taguchi has standardized the method for application of the technique and analysis of experimental results. Thus, DOE using the Taguchi approach has become a much more attractive tool to the practicing engineers and scientists.

### **Experiment planning and problem formulation:**

- Experiment planning guidelines are consistent with modern work disciplines of working as teams. Consensus decisions about experiment objectives and factors make the projects more successful.

### **Experiment layout:**

- High emphasis is put on cost and size of experiments
- Size of experiment for a given number of factors and levels is standardized
- Approach and priority for column assignments are established
- Clear guidelines are available to deal with factors and interactions (interaction tables)
- Uncontrollable factors are formally treated to reduce variation
- Discrete prescriptions for setting up test conditions under uncontrollable factors are described
- Guidelines for carrying out the experiments and number of samples to be tested are defined

### **Data analysis:**

- Steps for analysis are standardized (main effect, NOVA and Optimum)
- Standard practice for determination of the optimum is recommended
- Guidelines for test of significance and pooling are defined

### **Interpretation of results:**

- Clear guidelines about meaning of error term
- Discrete indicator about confirmation of results (Confidence interval)
- Ability to quantify improvements in terms of dollars (Loss function)

### **Overall advantage of the Taguchi approach:**

DOE using the Taguchi approach attempts to improve quality which is defined as the consistency of performance. Consistency is achieved when variation is reduced. This can be done by moving the mean performance to the target as well as by reducing variations around the target. The prime motivation behind the Taguchi experiment design technique is to achieve reduced variation (also known as ROBUST DESIGN). This technique, therefore, is focused to attain the desired quality objectives in all steps. The classical DOE does not specifically address quality .

"The primary problem addressed in classical statistical experiment design is to model the response of a product or process as a function of many factors called model factors. Factors, called nuisance factors, which are not included in the model, can also influence the response... The primary problem addressed in Robust Design is how to reduce the variance of a product's function in the customer's environment."

-Madhav Phadke, Quality Engineering using Robust Design

To learn more about DOE using Taguchi approach, consider attending or sponsoring our 4-day Seminar with Application Workshops ([www.rkroy.com/wp-s4d.html](http://www.rkroy.com/wp-s4d.html) )

## #qt4-020 Frequently Asked Questions

- Downloading Qualitek-4 Before and After Purchasing It
- Downloading Qualitek-4 Reference Files
- Downloading and Installing the Demo Version of Qualitek-4
- Contacting for Installation Support after Purchasing Software
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- What To Do When You need More Capabilities
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- Qualitek-4 Crashes Upon Startup

## Topic Overviews

### TAGUCHI METHOD OF QUALITY ENGINEERING

Taguchi introduced several new concepts in improving quality :

#### 1. NEW PHILOSOPHY

- Building quality in the product design.
- Measuring quality by deviation from target (not by rejection).

#### 2. NEW DISCIPLINE

- Complete planning of experiments and evaluation criteria before conducting experiments.
- Determining a factor's influence by running the complete experiment.

#### 3. SIMPLER AND STANDARDIZED EXPERIMENT DESIGN FORMAT

- Orthogonal arrays for experimental design.
- Outer array design for robust product design.
- More clear and easier methods for analysis of results.

### QUALITY: DEFINITION and OBJECTIVE

- Reduced variation around the target with least cost.

### APPROACH: ROBUST DESIGN

- Reduce variation without actually removing the cause of variation. Achieve consistent performance by making product/process insensitive to the influence of uncontrollable factors.

## WHAT DOES IT DO?

- Optimize design, solve problems, build robust products, etc.

## WHY DO IT?

- Save cost (Reduce warranty, rejection and cost of development).

## AREAS OF APPLICATION:

- Analytical simulation (in early stages of design).
- Development testing (in design and development).
- Process development.
- Manufacturing.
- Problem solving in all areas of manufacturing and production.

## REFERENCES:

1. SYSTEM OF EXPERIMENTAL DESIGNS - By Genichi Taguchi, UNIPUB KRAUS INTERNATIONAL PUBLICATIONS, NEW YORK. 1987.
2. ORTHOGONAL ARRAYS AND LINEAR GRAPHS - By Yuin Wu. AMERICAN SUPPLIER INSTITUTE, Dearborn, Michigan. 1986.
3. TAGUCHI TECHNIQUES FOR QUALITY ENGINEERING - Philip J. Ross, McGraw Hill Book Company, New York. 1988.
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(F02) =====

## APPLICATION STEPS

The Taguchi method is used to improve the quality of products and processes. Improved quality results when a higher level of performance is consistently obtained. The highest possible performance is obtained by determining the optimum combination of design factors. The consistency of performance is obtained by making the product/process insensitive to the influence of the uncontrollable factor. In Taguchi's approach, optimum design is determined by using design of experiment principles, and consistency of performance is achieved by carrying out the trial conditions under the influence of the noise factors.

1. BRAINSTORMING: This is a necessary first step in any application. The session should include individuals with first hand knowledge of the project. All matters should be decided based on group consensus, (One person -- One vote).
  - Determine what you are after and how to evaluate it. When there is more than one criterion of evaluation, decide how each criterion is to be weighted and combined for the overall evaluation.
  - Identify all influencing factors and those to be included in the study.

- Determine the factor levels.
- Determine the noise factor and the condition of repetitions.

2. **DESIGNING EXPERIMENTS:** Using the factors and levels determined in the brainstorming session, the experiments now can be designed and the method carrying them out established. To design the experiment, implement the following:

- Select the appropriate orthogonal array.
- Assign factor and interaction to columns.
- Describe each trial condition.
- Decide order and repetitions of trial conditions.

3. **RUNNING EXPERIMENT:** Run experiments in random order when possible.

4. **ANALYZING RESULTS:** Before analysis, the raw experimental data might have to be combined into an overall evaluation criterion. This is particularly true when there are multiple criteria of evaluation.

Analysis is performed to determine the following:

- The optimum design.
- Influence of individual factors.
- Performance at the optimum condition.
- Relative influence of individual factors. etc.

5. **RUNNING CONFIRMATION EXPERIMENT(S):** Running the experiments at the optimum condition is the necessary final step.

(F03) =====  
**BRAINSTORMING (F3)**

**SUGGESTED TOPICS OF DISCUSSIONS:**

### 1. OBJECTIVES OF STUDY AND EVALUATION CRITERIA

- What are the criteria of evaluation?
- How are each of these criteria measured?
- How are these criteria combined into a single number?
- What is the common characteristic of these criteria?
- What is the relative influence these criteria exhibit?

### 2. FACTORS

- What are the factors that influence the performance criteria?
- Which factors are more important than others?

### 3. NOISE FACTORS

- Which factors can't be controlled in real life?
- Is the performance dependent on the application environment?

### 4. FACTOR LEVELS

- What are the ranges of values the factors can assume within practical limits?
- How many levels of each factor should be used for the study?
- What is the tradeoff for a higher level?

#### 5. INTERACTION BETWEEN FACTORS

- Which factors are most likely to interact?
- How many interactions can be studied?

#### 6. SCOPES OF STUDIES

- How many experiments can we run?
- When do we need the results?
- How much does each experiment cost?

#### 7. ADDITIONAL ITEMS

- What do we do with factors that are not included in the study?
  - In what order do we run these experiments?
  - Who will do these experiments?
- etc.

### (F04) ===== QUALITY CHARACTERISTICS (F4)

Quality Characteristic (QC) generally refers to the measured results of the experiment. The QC can be single criterion such as pressure, temperature, efficiency, hardness, surface finish, etc. or a combination of several criteria together into a single index. QC also refers to the nature of the performance objectives such as "bigger is better", "smaller is better" or "nominal is the best".

In most industrial applications, QC consists of multiple criteria. For example, an experiment to study a casting process might involve evaluating cast specimens in terms of (a) hardness, (b) visual inspection of surface and (c) number of cavities. To analyze results, readings of evaluation under each of these three criteria for each test sample can be used to determine the optimum. The optimum conditions determined by using the results of each criterion may or may not yield the same factor combination for the optimum. Therefore, a weighted combination of the results under different criteria into a single quantity may be highly desirable. While combining the results of different criteria, they must first be normalized and then made to be of type 'smaller is better' or 'bigger is better'.

When quality characteristic(QC) consists of, say, three criteria, an overall evaluation criteria(OEC) can be constructed as:

$$OEC = (X1/X1ref.)W1 + (X2/X2ref.)W2 + (X3/X3ref.)W3$$

where  $X$  = evaluation under a criterion  
 $X_{ref}$  = a reference(maximum) value of reading  
 $W$  = weighting factor of the criterion (in %)

Use of OEC as the result of an experimental sample instead of several readings from all criteria, offers an objective method of determining the optimum condition based on overall performance objectives.

When there are multiple criteria of evaluation, the experimenter can analyze the experiments based on readings under one category at a time as well as by using the OEC. If the individual outcomes differ from each other, the optimum obtained by using OEC as a result should be preferred.

(F05) =====  
FACTORS AND LEVELS (F5)

FACTORS ARE:

- \* design parameters that influence the performance.
- \* input that can be controlled.
- \* included in the study for the purpose of determining their influence and control upon the most desirable performance.

Example: In a cake baking process the factors are:  
Sugar, Flour, Butter, Egg, etc.

LEVELS ARE:

- \* Values that a factor assumes when used in the experiment

Example: As in the above cake baking process the levels for sugar and flour could be:  
2 pounds, 5 pounds, etc. (Continuous level)  
type 1, type 2, etc. (Discrete level)

LIMITS: Maximum of 31 factors and 4 levels.

(F06) =====  
INTERACTION BETWEEN FACTORS (F6)

Two factors (A and B) are considered to have interaction between them when one has influence on the effect of the other factor respectively.

Consider the factors "temperature" and "humidity" and their influence on comfort level. If the temperature is increased by, say 20 degrees F, the

comfort level decreases by, say 30% when humidity is kept at 90%. On a different day, if the temperature is raised the same amount at a humidity level of 70%, the comfort level is reported to drop only by 10%. In this case, the factors "temperature" and "humidity" are interacting with each other.

Interaction:

- \* is an effect (output) and does not alter the trial condition.
- \* can be determined even if no column is reserved for it.
- \* can be fully analyzed by keeping appropriate columns empty.
- \* affects the optimum condition and the expected result.

QT4 supports computation of interactions between 2-level factors only.

>> For interaction column, refer to Triangular Table.

(F07) =====  
NOISE FACTORS AND OUTER ARRAYS (F7)

Noise factors are those factors:

- \* that are not controllable.
- \* whose influences are not known.
- \* which are intentionally not controlled.

To determine robust design, experiments are conducted under the influence of various noise factors.

An "Outer Array" is used to reduce the number of noise conditions obtained by the combination of various noise factors.

For example:

Three 2-level noise factors can be combined using an L-4 into four noise conditions(4 repetitions). Likewise seven 2-level noise factors can be combined into eight conditions(8 repetitions) using an L8 as an outer array.

When trial conditions are repeated without the formal "Outer Array" design, the noise conditions are considered random.→

(F08) =====  
SCOPE AND SIZE OF EXPERIMENT (F8)

The scope of the study, i.e., cost and time availability, are factors that help determine the size of the experiment. The number of experiments that can be accomplished in a given period of time, and the associated costs are strictly dependent on the type of project under study.

The total number of samples available divided by the number of repetitions

yields the size of the array for design. The array size dictates the number of factors and their appropriate levels included in the study.

Example: A number of factors are identified for an optimization study.

- \* Time available is two weeks during which only 25 tests can be run.
- \* Three repetitions for each trial condition is desired.

> Array size  $25/3 \rightarrow 8$  L-8 array.

- Seven from available 2-level factors can be studied.

(F09) =====  
ORDER OF RUNNING EXPERIMENTS (F9)

There are two common ways of running experiments. Suppose an experiment uses an L-8 array and each trial is repeated 3 times. How are the  $3 \times 8 = 24$  experiments carried out?

REPLICATION - The most desirable way is to run these 24 in random order.

REPETITION - The most practical way may be to select the trial condition in random order then complete all repetitions in that trial.

NOTE: In developing conclusions from the results of designed experiments and assigning statistical significance, it is assumed that the experiments were unbiased in any way, thus randomness is desired and should be maintained when possible.

MINIMUM REQUIREMENT - A minimum of one experiment per trial condition is required. Avoid running an experiment in an upward or downward sequence of trial numbers.→

(F10) =====  
REPETITIONS AND REPLICATIONS (F10)

REPETITION: Repeat a trial condition of the experiment with/without a noise factor (outer array).

Example: L-8 inner array and L-4 outer array.  $8 \times 4 = 32$  samples.  
Select a trial condition randomly and complete all 4 samples.  
Take the next trial at random and continue.

REPLICATION: Conduct all the trials and repetitions in a completely randomized order.

In the above example, select one sample at time in random order from among the 24 (8x4).

NOTE: Results from replication contain more information than those from repetition. Since replication requires resetting the the same trial condition, it captures variation in results due to experimental set up.→

(F11) =====  
AVAILABLE ORTHOGONAL ARRAYS (^F1)

The following Standard Orthogonal Arrays are available for designing experiments using control factors (INNER ARRAY)

L-4 L-8 L-12 L-16 L-32      ALL AT 2 LEVELS  
L-9 L-18 L-27              AT 3 & 2 LEVELS

In addition, users may create their own array (up to 32 trials). Such an array must first be defined by entering in option F10 from MAIN MENU before starting to design experiment. The user defined array will be named as DATA-LUD automatically.

Six arrays from the above list are also available for combining the noise factors included in the study (OUTER ARRAY).

L-4 L-8 L-12 L-16 L-9 and L-18

(F12) =====  
TRIANGULAR TABLE/LINEAR GRAPHS (^F2)

TRIANGULAR TABLE OF INTERACTIONS (2-LEVEL COLUMNS)

---

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

---

(1) 3 2 5 4 7 6 9 8 11 10 13 12 15 14  
(2) 1 6 7 4 5 10 11 8 9 14 15 12 13

(3) 7 6 5 4 11 10 9 8 15 14 13 12  
 (4) 1 2 3 12 13 14 15 8 9 10 11  
 (5) 3 2 13 12 15 14 9 8 11 10  
 (6) 1 14 15 12 13 10 11 8 9  
 (7) 15 14 13 12 11 10 9 8  
 (8) 1 2 3 4 5 6 7  
 (9) 3 2 5 4 7 6  
 (10) 1 6 7 4 5  
 (11) 7 6 5 4  
 (12) 1 2 3  
 (13) 3 2  
 (14) 1  
 1234567890123456789012345678901234567890123456789012345678901234567890

TRIANGULAR TABLE OF INTERACTIONS (3-LEVEL COLUMNS)

---

|      | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9 | 10 | 11 | 12 | 13 |
|------|----|----|----|----|----|----|----|----|---|----|----|----|----|
| (1)  | 3  | 2  | 2  | 6  | 5  | 5  | 9  | 8  | 8 | 12 | 11 | 11 |    |
|      | 4  | 4  | 3  | 7  | 7  | 6  | 10 | 10 | 9 | 13 | 13 | 12 |    |
| (2)  | 1  | 1  | 8  | 9  | 10 | 5  | 6  | 7  | 5 | 6  | 7  |    |    |
|      | 4  | 3  | 11 | 12 | 13 | 11 | 12 | 13 | 8 | 9  | 10 |    |    |
| (3)  | 1  | 9  | 10 | 8  | 7  | 5  | 6  | 6  | 7 | 5  |    |    |    |
|      | 2  | 13 | 11 | 12 | 12 | 13 | 11 | 10 | 8 | 9  |    |    |    |
| (4)  | 10 | 8  | 9  | 6  | 7  | 5  | 7  | 5  | 6 |    |    |    |    |
|      | 12 | 13 | 11 | 13 | 11 | 12 | 9  | 10 | 8 |    |    |    |    |
| (5)  | 1  | 1  | 2  | 3  | 4  | 2  | 4  | 3  |   |    |    |    |    |
|      | 7  | 6  | 11 | 13 | 12 | 8  | 10 | 9  |   |    |    |    |    |
| (6)  | 1  | 4  | 2  | 3  | 3  | 2  | 4  |    |   |    |    |    |    |
|      | 5  | 13 | 12 | 11 | 10 | 9  | 8  |    |   |    |    |    |    |
| (7)  | 3  | 4  | 2  | 4  | 3  | 2  |    |    |   |    |    |    |    |
| (8)  | 1  | 1  | 2  | 3  | 4  |    |    |    |   |    |    |    |    |
|      | 10 | 9  | 5  | 7  | 6  |    |    |    |   |    |    |    |    |
| (9)  | 1  | 4  | 2  | 3  |    |    |    |    |   |    |    |    |    |
|      | 8  | 7  | 6  | 5  |    |    |    |    |   |    |    |    |    |
| (10) | 3  | 4  | 2  |    |    |    |    |    |   |    |    |    |    |
|      | 6  | 5  | 7  |    |    |    |    |    |   |    |    |    |    |
| (11) | 1  | 1  |    |    |    |    |    |    |   |    |    |    |    |
|      | 13 | 12 |    |    |    |    |    |    |   |    |    |    |    |
| (12) | 1  |    |    |    |    |    |    |    |   |    |    |    |    |
|      | 11 |    |    |    |    |    |    |    |   |    |    |    |    |

NOTE: Interaction between two 3-level factors is not included in the current version of QUALITEK-4. The information

is for reference only.

(F13) =====  
UPGRADING A COLUMN (^F3)

#### COLUMN MODIFICATIONS:

PREPARING A 4-LEVEL COLUMN - Select 3 2-level columns that are naturally interacting. Pick two and discard the third. Use the two columns to generate a new column.

Follow these rules:

| Old Columns | New Column |
|-------------|------------|
|-------------|------------|

---

|     |          |
|-----|----------|
| 1 1 | -----> 1 |
| 1 2 | -----> 2 |
| 2 1 | -----> 3 |
| 2 2 | -----> 4 |

Example: Suppose factor A is a 4-level factor. Using columns 1 2 3 of L-16 a new 4-level column can be prepared and factor A assigned.

#### PREPARING AN 8-LEVEL COLUMN

An 8-level column can be prepared from three of the seven interacting columns of an L-16. (Use columns 1 2 & 4, discard 3 5 6 & 7.)

Follow these rules:

| Old Columns | New Column |
|-------------|------------|
|-------------|------------|

---

|       |          |
|-------|----------|
| 1 1 1 | -----> 1 |
| 1 1 2 | -----> 2 |
| 1 2 1 | -----> 3 |
| 1 2 2 | -----> 4 |
| 2 1 1 | -----> 5 |
| 2 1 2 | -----> 6 |
| 2 2 1 | -----> 7 |
| 2 2 2 | -----> 8 |

An eight level factor/column is not supported by this version of QUALITEK-4 software. The above information is for user reference only.

(F14) =====  
DUMMY TREATMENT (^F4)

DUMMY TREATMENT  
-----

This method allows a 3-level column to be made into a 2-level column or a 4-level column into a 3-level column (e.g. levels 1 2 3 to 1 2 1'). The notation 1' is used to keep track of the changed status only. For level assignment 1'=1. The selection of the level to be treated is arbitrary.

Example:

Three 3-level factors and one 2-level factor.  
--> Use an L-9. Dummy treat any column and assign the 2-level factor.

(F15) =====  
RESULTS OF MULTIPLE CRITERIA (^F5)

Frequently your experiment may involve evaluating results in terms of more than one criteria of evaluations. For example, in a cake baking experiment, the cakes baked under different recipes (trial conditions) may be evaluated by taste, looks and moistness. These criteria may be subjective and objective in nature. The best recipes can be determined by analyzing results of each criterion separately. The recipes for optimum conditions determined this way may or may not be the same. Thus, it may be desirable to combine the evaluations under different criteria into one single overall criteria and use them for analysis.

To combine readings under different evaluation criteria, they must first be normalized (unitless), then combined with proper weighting. Furthermore, all evaluations must be of the same quality characteristic, i.e., either bigger or smaller is a better type. When an evaluation is of the opposite it can be subtracted from a larger constant to conform to the desired characteristic [(X2ref. - X2) instead of X2].

For the purpose of combining all evaluations into a single criterion,

Assume:

- X1 = Numeric evaluation under criterion 1
- X1ref = Highest numerical value X1 can assume
- Wt1 = Relative weighting of criterion 1

Then an Overall Evaluation Criterion (OEC) can be defined as:



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### WHAT IS DYNAMIC CHARACTERISTIC?

A system is considered to exhibit dynamic characteristics when the strength of a particular factor has a direct effect on the response. Such a factor with a direct influence on the result is called a SIGNAL factor.

SIGNAL FACTOR - is an input to the system. Its value/level may change.

CONTROL FACTOR - is also an input to the system. Values/level is fixed at the optimum level for the best performance.

NOISE FACTOR - is an uncontrollable factor. Its level is random during actual performance.

STATIC SYSTEM GOAL - is to determine combination of control factor levels which produces the best performance when exposed to the influence of the varying levels of noise factors.

### DYNAMIC SYSTEM GOAL-

is to find the combination of control factor levels which produces different levels of performances in direct proportion to the signal factor, but produces minimum variation due to the noise factors at each level of the signal.

Example: Fabric dyeing process (Ref: QUALITEK-4, ASI-400.QT4)

Control factor: Types of dyes, Temperature, PH number, etc

Signal factor: Quantity of dye

Noise factor: Amount of starch

### CONDUCTING EXPERIMENTS WITH DYNAMIC CHARACTERISTICS

When carrying out experiments, proper order and sequence of samples tested under each trial condition must be maintained. The number of samples required for each trial condition, will depend on the number of levels of signal factor, noise conditions and repetitions for each cell (a fixed condition of noise and signal factor).

Step 1. Design experiment with control factors using option F1 from main menu ( manual or automatic design).

Step 2. Print description of trial conditions using option F5.

Step 3. Select option F8, then F5 to describe(\*) DYNAMIC CHARACTERISTICS and print description of test conditions (noise and signal).

\* You will need to describe signal and noise factors and their levels.

You will also have to decide on the number of levels of signal and noise factors. BUT MOST IMPORTANTLY, you will have to choose the nature of the ideal function (Straight line representing the behavior Response vs. Signal) applicable to your system.

Step 4. Strictly follow the prescribe test conditions.  
 Step 4. Enter results in the order and locations (run#) prescribed  
 in step 4 using option F1 from analysis menu.

**SIGNAL-TO-NOISE RATIO EQUATIONS** (alternate dynamic characteristic equations)

Signal factor may not always be clearly defined or known. For common industrial experiments, one or more attributes may be applicable:

- \* TRUE VALUE KNOWN
- \* INTERVAL BETWEEN FACTOR LEVELS KNOWN
- \* FACTOR LEVEL RATIOS KNOWN
- \* FACTOR LEVEL VALUES VAGUE

Depending on the circumstances of the input signal values and the resulting response data, different signal-to-noise (S/N) ratio equations are available.

**ZERO POINT PROPORTIONAL** - Select this I response \*  
 type of equation when response line I \*  
 passes through the origin. The signal I \*  
 may be known, unknown or vague. I \*

$$I = \frac{I^*}{\text{Signal}}$$

**REFERENCE POINT PROPORTIONAL** - this I response \*  
 type of equation should be the choice I \*  
 when response line does not go through I \* |  
 the origin but through a known value I \* |  
 of the signal or when signal values I\* |  
 are wide apart or far away from origin. I |Known

$$I = \frac{I^*}{\text{Signal} + \text{Known}}$$

When the signal values are known, zero pint or reference point proportional should be considered first. If neither is appropriate, the linear equation should be used.

**LINEAR EQUATION** - is based on the least I response \*  
 squares fit equation and should be I \*  
 used where neither zero and reference I \*  
 point proportional equation are I \*  
 appropriate. Use it when signal values I\*  
 are close together and response does I  
 not pass through the origin. I

$$I = \text{Signal}$$

WHEN IN DOUBT - plot the response as a function of the signal factor values on a linear graph and examine if the y-intercept. If it passes through origin, use ZERO POINT. If the intercept is not through origin but the line passes through a fixed point, use REF.POINT. In all other situation use LINEAR EQUATION.

S/N Ratio Equation and Calculation Steps

$$y = m + \text{Beta} (M - \text{Mavg}) + e \quad \text{Linear Eqn. (L)}$$

$$y = \text{Beta} M \quad \text{Zero Point (Z)}$$

$$y = \text{Beta} (M - \text{Mstd.}) + \text{ystd} \quad \text{Ref. Point (R)}$$

Where y = system response (QC), M = Signal factor  
 Beta = slope of the ideal Eqn. Mavg = Average of signals  
 ystd. = avg. response under reference/standard signal  
 Mstd = reference/standard value of the signal strength

Notations

\* = multiplication, ^ = raised to the power  
 / = division by

Response Components for Each Trial Condition  
 (Layout shown only for trial#1 below)

SIGNAL FACTOR

|       | Signal lev 1         | Signal lev 2         | Signal lev 3        |    |
|-------|----------------------|----------------------|---------------------|----|
|       | N1                   | N2                   | N1                  | N2 |
| Trl#1 | y11, y12, y13, y14.. | y21, y22, y23, y24.. | y31, y32, y33, y34. |    |

Step 1: Determine r (Start with trial# 1)

ro = Number of samples tested under each SIGNAL LEVEL  
 (Number of NOISE LEVELSxSAMPLES per CELL)  
 M1, M2, M3,.. Mk. Signal levels (strengths)  
 N1 & N2 are two levels of the noise factor  
 k = number of signal levels  
 Mavg = (M1 + M2 + .... Mk)/k

$$r = ro [ (M1-\text{Mavg})^2 + (M2-\text{Mavg})^2 + \dots + (Mk-\text{Mavg})^2 ] \dots \text{(L)}$$

$$r = ro [ (M1-\text{Mstd})^2 + (M2-\text{Mstd})^2 + \dots + (Mk-\text{Mstd})^2 ] \dots \text{(R)}$$

$$r = ro ( M1^2 + M2^2 + M3^2 \dots + Mk^2 ) \dots \text{(Z)}$$

Step 2: Calculate of Slope Beta

$$\text{Beta} = (1/r) [y_1*(M_1 - \text{Mavg}) + y_2*(M_2 - \text{Mavg}) + \dots + y_k*(M_k - \text{Mavg})] \dots (\text{L})$$

$$\text{Beta} = (1/r) [y_1*(M_1 - \text{Mstd}) + y_2*(M_2 - \text{Mstd}) + \dots + y_k*(M_k - \text{Mstd})] \dots (\text{R})$$

$$\text{Beta} = (1/r) (y_1*M_1 + y_2*M_2 + \dots + y_k*M_k) \dots (\text{Z})$$

Step 3: Determine Total Sum of Squares

$$\text{St} = \text{Sum}[\text{Sum}(y_{ij} - y_{\text{avg}})] \quad i=1,2 \dots k. \quad j=1,2,\dots r \quad \dots (\text{L})$$

$y_{\text{avg}} = \text{ystd for (R), } y_{\text{avg}} = 0 \text{ for (Z)}$

Step 4: Calculate Variation Caused by the Linear Effect

$$\text{Sbeta} = r \text{Beta}^2 \dots \text{ for all equations}$$

$$\text{Sbeta} = (1/r) [y_1*(M_1 - \text{Mavg}) + y_2*(M_2 - \text{Mavg}) + \dots + y_k*(M_k - \text{Mavg})]^2 \dots (\text{L})$$

$$\text{Sbeta} = (1/r) [y_1*(M_1 - \text{Mstd}) + y_2*(M_2 - \text{Mstd}) + \dots + y_k*(M_k - \text{Mstd})]^2 \dots (\text{R})$$

$$\text{Sbeta} = (1/r) (y_1*M_1 + y_2*M_2 + \dots + y_k*M_k)^2 \dots (\text{Z})$$

Step 5: Calculate the Variations Associated with Error and Nonlinearity

$$\text{Se} = \text{St} - \text{Sbeta} \dots \text{ for all equations}$$

Step 5: Calculate Error Variance

$$\text{Ve} = \text{Se} / [k*r - 2] \dots (\text{L})$$

$$\text{Ve} = \text{Se} / [k*r - 1] \dots (\text{R and Z})$$

Step 6: Calculate S/N Ratio

$$\text{Eta} = 10 \text{Log} (\text{Sbeta} - \text{Ve}) / (r*\text{Ve}) \dots \text{ for all Eqns.}$$

Step 7: Repeat calculations for all other trials in the same manner.

12345678901234567890123456789012345678901234567890123456789012345678901234567890

Example calculations: Case of LINEAR EQUATION (Expt. file: DC-AS400.QT4)

The results of samples tested for trial#1 of an experiment with dynamic characteristic. There are three signal levels, two noise levels, and two repetitions per cell.

|       | M1      |         | M2      |         | M3      |         |      |      |      |      |      |      |
|-------|---------|---------|---------|---------|---------|---------|------|------|------|------|------|------|
|       | Noise 1 | Noise 2 | Noise 1 | Noise 2 | Noise 1 | Noise 2 |      |      |      |      |      |      |
| Trl#1 | 5.2     | 5.6     | 5.9     | 5.8     | 12.3    | 12.1    | 12.4 | 12.5 | 22.4 | 22.6 | 22.5 | 22.2 |

Signal strengths:  $M1 = 1/3$ ,  $M2 = 1$ ,  $M3 = 3$

CALCULATIONS FOR S/N:

$$M_{avg} = (1/3 + 1 + 3) / 3 = 1.444$$

$r_o = 4$  (2 smple/cell \* 2 noise levels)

$$\begin{aligned} r &= 4[(1/3 - 1.444)^2 + (1 - 1.444)^2 + (3 - 1.444)^2] \dots (L) \\ &= 4( 1.2343 + 0.1971 + 2.421 ) \\ &= 15.41 \end{aligned}$$

$$y1 = 5.2 + 5.6 + 5.9 + 5.8 = 22.5$$

$$y2 = 12.3 + 12.1 + 12.4 + 12.5 = 49.3$$

$$y3 = 22.4 + 22.6 + 22.5 + 22.2 = 89.7$$

$$\begin{aligned} \text{Beta} &= (1/r)[22.5*(1/3-1.444) + 49.3*(1-1.444) + 89.7*(3-1.444)] \\ &= (1/15.41) [ -24.9975 - 21.692 + 139.5732 ] \\ &= 92.8842/15.4101 \\ &= 6.01 \end{aligned}$$

$$S_{beta} = r * \text{Beta}^2 = 15.4101 * 6.0274^2 = 556.82$$

$$y_{avg} = [5.2 + 5.6 + \dots + 22.2]/12 = 161.5/12 = 13.46$$

$$\begin{aligned} S_t &= (5.2 - y_{avg})^2 + (5.6 - y_{avg})^2 + \dots + (22.2 - y_{avg})^2 \\ &= 68.23 + 61.78 + 57.15 + 58.67 + 1.346 + 1.85 + 1.123 + .921 \\ &\quad + 79.92 + 83.54 + 81.72 + 76.387 \\ &= 572.65 \end{aligned}$$

$$S_e = S_t - S_b = 572.65 - 556.82 = 15.83$$

$$V_e = S_e / (12 - 2) = 15.83 / 10 = 1.583$$

$\text{Eta} = 10 \text{ Log } (S_{beta} - V_e) / (r * V_e) \dots$  for all Eqns.

$$= 10 \text{ Log } [(556.82 - 1.583)/(15.41 * 1.583)]$$

$$= 10 \text{ Log}(22.76)$$

$$= 13.572 \quad (\text{S/N for the trial\# 1 results})$$

Similarly, S/N ratios for all other trial conditions are calculated and analysis performed using NOMINAL IS THE BEST quality characteristic as normally done for the static systems.

(F17) =====  
TAGUCHI VS. CLASSICAL DOE (^F7)

Taguchi approach and classical design of experiments(DOE) were developed to achieve separate objectives and are different in many ways. Some of differences are:

| TAGUCHI  | CLASSICAL DOE  |
|--|--|
| <b>OBJECTIVES:</b>                                     |  |
| Obtain reproducible results and robust products.       | Gather scientific knowledge about factor effects and their interactions. |
| <b>GENERAL ATTRIBUTES:</b>                             |  |
| * Standard or "cook book" approach.                    | * Methods are not standardized.  |
| * Smaller number of experiments.                       | * Larger number of experiments.  |
| * Standard method of noise factor treatment.           | * No standardized method of noise factor treatment.                      |
| * Seeks to find stable condition in the face of error. | * Develops models by separating weak main effects for random error.      |
| * Used to solve engineering probs.                     | * Used to solve scientific experiments.                                  |

(F18) =====  
LOSS FUNCTION (^F8)

The Loss Function offers a way to quantify the improvement from the optimum design determined from an experimental design study.

Definitions:

$$L = K (Y - Y_0)^2 \dots \text{for a single sample.}$$

$$L = K (\text{MSD}) \dots \text{for the whole population.}$$

where  $L$  = Loss in dollar.

$K$  = Proportionality constant.

$Y_0$  = Target value of the quality characteristic.

$Y$  = Measured value of the quality characteristic.

>>> THE COST SAVINGS WHEN THE MEAN VALUE IS HELD AT A TARGET VALUE CAN BE CALCULATED WHEN THE FOLLOWING INFORMATION IS AVAILABLE :

- TARGET VALUE OF QUALITY CHARACTERISTIC.
- TOLERANCE OF QUALITY CHARACTERISTIC.
- COST OF REJECTION AT PRODUCTION(PER UNIT).
- UNITS OF PRODUCTION PER MONTH (TOTAL).
- S/N RATIO OF THE OLD DESIGN.
- S/N RATIO OF THE IMPROVED DESIGN.

: Since the S/N ratio is a direct product of ANOVA, it is conveniently used for calculation of loss. However, the loss function requires MSD and must be calculated from the S/N ratio.

(F19) =====

GENERAL NOTES AND COMMENTS (^F9): HELPFUL TIPS ON APPLICATIONS

COMBINATION DESIGN

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This is a method to fit two "2-level" factors in a "3-level" column. Suppose you have factors A and B at two levels and factors C, D, and E at three levels. An L-9 has four "3-level" columns. Factors C,D & E can occupy three columns leaving one column for A and B. A and B form A1B1 A2B1 A1B2 & A2B2. Select any three of these four and assign them to the three levels of the respective columns reserved for A and B.

DESIGNS TO INCLUDE NOISE FACTORS (OUTER ARRAY)

-----

This version (version 4.0) of the program simultaneously handles inner and outer arrays. The noise conditions for repetitions can be studied by describing the outer array following completion of experiment design (inner array). Whether an outer array is present or not, up to 35 repetitions of results (columns) can be entered and an analysis performed using this software.→

(F20) =====

HOW TO DESIGN AND ANALYZE EXPERIMENTS USING QUALITEK-4

If you are not familiar with the general design of experiment principles, Taguchi experiments, and/or require assistance with use of this software, you may find the following helpful.

(Notations: M-main menu, A-analysis menu)

## HOW TO:

### 1. DESIGN EXPERIMENTS

- For help with test planning/BRAINSTORMING steps, press [F7] FROM MAIN MENU. Use arrow keys to scroll up and down.
- Press [F1] to design your own experiment. Select [F1], manual experiment design option, then select the array of your choice. Type description of factors and levels. Use arrow keys to move factors and levels. Press function keys to set INTERACTION and UNUSED columns. Press F2 when done
- If you like QUALITEK-4 to select the array and assign factors, then select M-F1-F4 for automatic design option. Follow screen prompt to complete design.

In automatic design mode, the program asks for the number of factors at different levels. This critical information help the program choose the appropriate orthogonal array for the design. For your first exercise, you may enter 3 for the number of 2-level factors and then type in their descriptions as prompted. If you feel you mistyped something, don't worry, you will have a chance to edit the design after QT4 has created your design. QT4 is programmed to design experiments for a large number of experimental situations. If, for some reason it can't fit your situation with one of the programmed conditions, it will indicate so. Press [Esc] if you want to get out of any situation quickly. Follow screen prompts. Generally press [F2] to proceed to the next step.

- After your experiment is designed using option F1 from main menu, you would want to print the trial conditions using option F5. You print or review your design as you desire. Your program is set for HP LASERJET II compatible printers. To reset printer, use option F9 from main menu.

### 2. ENTER RESULTS OF YOUR EXPERIMENTS

- From the main menu press F6 to be in the analysis menu. Now press F1 and select F2 to enter results. Type results in the field of cursor. Use arrow keys to move to new locations. Note that the rows represent trials. Thus, if you have one sample per trial, you will only have one column of results. Press F2 when you are done entering results. In file save menu, select F1 to update file. If you want to make a duplicate file of your experiment, then select option F2.
- If, on the other hand, your results are made up of multiple criteria evaluations, you may want to prepare OVERALL EVALUATION CRITERIA by using F7 from analysis menu. When you return from this option,

your experiment file will be updated as per your choice. Note that the evaluation criteria dat will be save under file name with extension .OEC.

### 3. ANALYZE RESULTS (USE "PISTON.QT4" EXPERIMENT)

- You will be ready for analysis after you have entered the results. The results are analyzed using options F3/F4 from the analysis menu depending on the number of columns of results. If your results comprise of only one column, you must perform STANDARD analysis using option F3. To proceed with analysis, follow screen prompts.
- To see all the program capabilities, let's work with PISTON.QT4 file. Press [F2], then press [ENTER] a couple of times and select PISTON.QT4 file from the displayed list of files.
  - Press [F5] and then [F1] to display trial conditions. Press [F2] to continue to display trial conditions. Return to the main menu when done.
  - Press [F6] to move to the analysis menu. Press [F6] to review results for three samples per trial. Press [Esc] to return to the analysis menu.
  - Select option [F4] to carry out S/N analysis. Type [N] when prompted about design check. Select "Bigger is Better" quality characteristic for analysis. Press [F2] to proceed when screen displays results.
- At the MAIN EFFECT table, review factor averages. Press [F3] to display the graph of main effect. Try different ways of displaying the graph. Press [F2] at graph screen to move to the next graph. Return to main effect by pressing [Esc.]
- Press [F2] to proceed to the ANOVA screen. Try pooling less significant factors using [F4] or [F3]. Pool factors in columns 2 and column 5, one at a time by selecting [F3]. This will result in ERROR percentage as 19.49% Press [F5] to unpool ANOVA. Now try pooling the same factors by using automatic pooling by selecting [F4]. At prompt for confidence level, type 98.6 and press enter. Observe that factors in columns 2 and 5 are pooled and the ERROR becomes 19.49 again.

To review graphical representations of the relative percent influence of factors and interactions to the variation of the results, press [F7] for bar graph and [F8] for PIE CHART. Press [Esc.] to return to ANOVA.
- Press [F2] to proceed to OPTIMUM SCREEN. Press [ENTER] at notice for interaction. While in OPTIMUM screen, press [F3] to graph contributions. Press [Esc.] to return to optimum screen.

- Press [F4] to transform optimum performance shown in S/N ratio into results in measured units.
- Press [F2] to estimate results in any other combinations of factor levels. Notice the estimated performance instantaneously change as you change the levels. Press [Esc.] to return to optimum screen.

#### 4. PREPARE REPORTS

- Be in the OPTIMUM SCREEN to select options for report and summary observations.
- Press [F6] to prepare presentation quality report. Review summary report for management. Select complete report option. Follow screen print and proceed to print a sample report if printer is available. If you experience printer problem, return to main menu and reset printer file data.
- Return to analysis menu when done printing report.
- If you wish to print graphs, be in the graphical display screen. While the graph is displayed, press print options as indicated.
- Review more example experiments from over 40 experiment files included with the program.

#### 5. CALCULATE LOSS FUNCTION AND GENERATE DISTRIBUTION PLOTS

- While in the analysis menu, select [F8] for normal distribution and LOSS FUNCTION. To see normal distribution plots, select [F1] and [F1] again, then follow screen prompt to view a normal distribution plot for a sample data. While in this screen, enter 11 for Std. Dev. and .45 for average to see another distribution plot superimposed. You may input data for another plot if you wish. Press [Esc.] to return. Select other options and explore many capabilities relating S/N, MSD, Loss Function, Std. Dev. Cpk, etc.
- NOTE that computation of Loss requires that you enter "VALID" data. Try using the default values first.

For more detail information on the technique refer to A PRIMER ON THE TAGUCHI METHOD by R. Roy. To purchase, please call Van Nostran Reinhold at 1-800-544-0550 Dept. Z 3507 or Fax: 606-525-7778.

#### QUICK REFERENCE

(Notations: M-Main menu, A-Analysis menu, F1-Function key,etc.)

- \* Design experiment: M-F1-F1 for manual , M-F1-F4 for automatic design.
- \* Read experiment file: M-F2-[ENTER]-[ENTER]-..  
Print trial condition: M-F5-F3- etc.
- \* Enter results: A-F1-F2 Modify results: A-F6. Scale or transform

results: A-F6-F3 (OMEGA transform & back)

- \* Analyze results: A-F3 or A-F4. View graph of main effects: From main effect screen, press F3.
- \* Test for interaction between factors: From main effect screen, Press F4 and enter column#.
- \* Produce PIE CHART of factor influence: From ANOVA screen, press [F8].
- \* Print complete report with summary page: From OPTIMUM screen, select option [F6].
- \* Calculate LOSS: A-F8-F2 or F3. Prepare results from multiple evaluation criteria: Select F7 from analysis menu.

### **About Nutek, Inc. =====**

Nutek, Inc. was established in 1987 by its president Dr. Ranjit K. Roy as a consulting company specializing in training and implementation of quality improvement techniques for the manufacturing industries.

#### Areas of Specialization:

- Design of Experiment(DOE) Using Taguchi Approach( Seminar, Software & Consulting
- Reliability Test Planning and Evaluation (Workshop & Software)
- Structured Problem Solving (Consulting)
- Statistical Process Control

#### What we do best:

At NUTEK, we're quality engineering specialists. It's our business to solve quality-related production problems, and to teach clients how to do the same. Our main focus is on real-world applications, not theory. We've taken the methods developed by pioneers in the field and streamlined them to fit the practical needs of American manufacturers today.

#### Our Primary Training Specialization:

Nutek offers 3-day seminars (and 4-day on-site seminar/workshop) intended for practicing engineers & scientists, in the use of the Taguchi Experimental Design Technique. The first two days are dedicated to teaching application techniques through actual case studies. The focus is on the "method" rather than the "math". Practical application steps, including brainstorming, are discussed in detail. The third day is dedicated to the mathematical basis and the application steps. The methods for achieving experiment layout, calculations, main effect, interaction study, ANOVA and factor influences using the QUALITEK-4 software are also discussed. Attendees are able to apply the method immediately after attending the seminar.

Our training seminars on Design of Experiments(DOE) using the Taguchi approach, provide an immediate working knowledge of quality building techniques. Always application-oriented, our teaching is aimed at helping your engineering, manufacturing and production specialists implement quality improvement plans from day one.<P>

Our user-friendly QUALITEK-4 software automates Taguchi experiment layout and performs complex calculations in a matter of seconds. It also analyzes results, and makes recommendations for product and process design improvements

Our consulting services offer immediate solutions to difficult and persistent problems. We work with your project teams to plan experiments, analyze results, and make recommendations for improvements. Our comprehensive application consulting services support clients in the following three phases of the projects:

**Troubleshooting** =====

(to include as troubles are reported from the Betata Tests)