Automatic Design and Analysis of Taguchi Experiments

Qualitek-4

for Windows

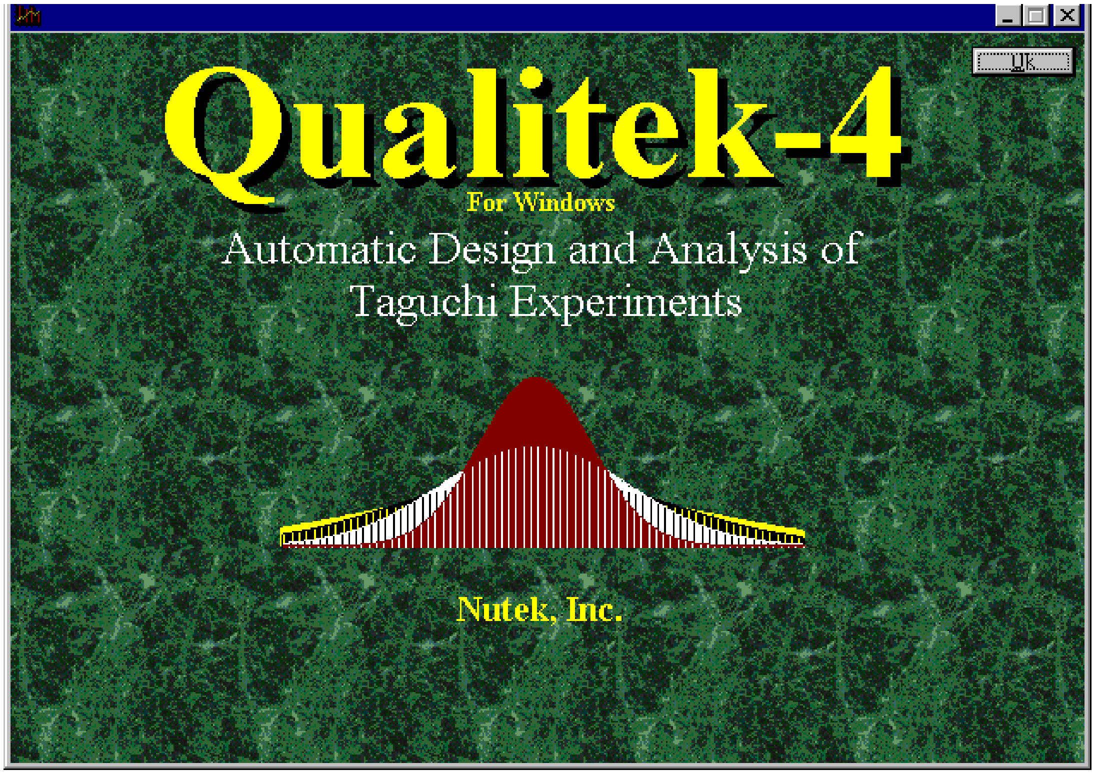
Automatic Design and Analysis of Taguchi Experiments

Reference Manual

Nutek, Inc.
Quality Engineering Seminar and Software
Bloomfield Hills, MI, USA. www.Nutek-us.com

Nutek

Reference Manual



IBM PC/Compatibles Software for
Automatic Design and Analysis of Taguchi Experiments

Nutek, Inc.

Bloomfield Hills, Michigan, USA.

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W A R R A N T Y

Nutek, Inc. warrants that the original QUALITEK-4 program diskettes are free from defects in material and workmanship, assuming normal use, for a period of ninety (90) days from the date of purchase.
If a defect occurs during this time, you may return the diskette along with proof of purchase, for a replacement copy free of charge.

NO LIABILITY FOR CONSEQUENTIAL

In no event shall Nutek be liable for any special, incidental, indirect, or consequential damages whatsoever (including damages for loss of business profits, business interruptions, loss of business information, or any other pecuniary loss) arising out of the use of or inability to use the software product, even if Nutek advised of the possibility of such damages.

Nutek Product Support

In case you have difficulty installing Qualitek-4(QT4) for Windows, call Nutek during weekdays. If we are unavailable when you call, be sure to leave a message with your name and telephone number. We will contact you within 24 hours.

Qualitek-4 for Windows is made for IBM/Compatibles 486 or later model computers.
You will be able to install QT4 if your computer has Windows 98 or later versions installed. **While preparing to install, you must close all other programs that you might be working on or otherwise may be open.**

If you are outside the United States, you may find it convenient to send us E-mail about your problem. We will respond to you within a week or earlier.

CUSTOMER SUPPORT PLAN

Nutek provides installation assistance to all registered users of the QUALITEK-4 (QT4) software. When calling for help, please identify the purchaser's name, company and the registration number of your QT4 software.
(The registration number is displayed in the registration screen of the QT4 program).

Most of your questions on the QT4 program can be answered by simply re-reading this manual and trying the procedure again. However, if you still have questions and need assistance with installation, please visit our web site (http://nutek-us.com/wp-q4w.html), call or write to us. The price of the software does not include support for use and project application of the software.

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Tel: 1-248-540-4827, For latest information visit: http://nutek-us.com

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Chapter 1

Welcome to Qualitek-4 for Windows

Welcome to Qualitek-4 (QT4) for Windows. QT4 is a user-friendly software for Automatic Design and Analysis of Taguchi Experiments. Like its predecessor, Qualitek-4 DOS version, it has many experiment design and analysis features that make you accomplish your projects in the least amount of time. Whether you are an expert or new to the Design of Experiment applications, QT4 will help you complete your projects more efficiently.

QT4 is easy to learn and use. Extensive on-line help can help you brush up your background on the subjects. There are over twenty topic overviews providing you with a comprehensive subject review. As a supplement to this manual, the on-line help can guide you every step of your application. Additionally, individual Screen Help provides you with clear interpretation of the items displayed on the screen.

About This Manual

Our experience tells us that a vast majority of users do not read the manual until necessary. We, therefore, organized the content of this manual in order of anticipated user needs rather than describing the menu items in sequence. Thus, we first talk about items you need to get started with. Then we discussed items that help you accomplish the experiment design, analysis etc. You will find that most of the materials are presented in a manner such that it addresses "how to" questions you may have.

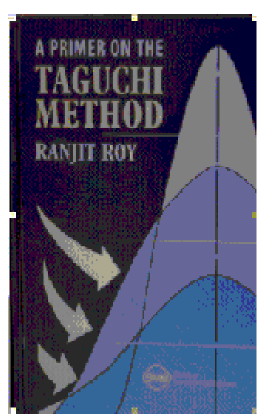
Short Tutorials and miscellaneous items and trouble shooting tips are included at the end. An adequate number of screen displays are included for ease of operation.

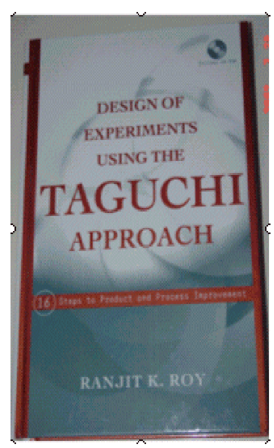
For latest changes, updates and brief operating guidelines, always visit our Web Site and download the applicable file and update the Qualitek-4 program directory as per the instruction.

This reference manual is not intended to provide the theories governing the application or purpose of the Taguchi approach and as such does not replace the need for training or a textbook on the subject. For theories and practices of the Taguchi methods, consult either of the following two books (Visit www.nutek-us.com/wp-txt.html for broader references):

1. *Design of Experiments Using the Taguchi Approach: 16 Steps to Product and Process Improvement* by Ranjit Roy, Hardcover (January 2001) John Wiley & Sons; ISBN: 0471361011.

2. *A Primer on the Taguchi Method by* Ranjit Roy ,Hardcover - 247 pages 1 edition





New Features in Qualitek-4 for Windows

QT4 for Windows has many new features over and above the features offered by the DOS version:

- Experiment design arrays have been extended to L-64 for both inner and outer array designs.
- Number of samples per trial condition has been extended to 120/trial.
- Dynamic characteristic includes 12 Signal and 10 Noise levels
- Test of presence of interaction can be carried out for mixed level factors
- Automatic experiment design capabilities extended to include more complex designs
- Savings due to improvement calculated automatically
- Reduced variation diagram generated from existing experiment data

Switching from Qualitek-4 for DOS

If you are familiar with earlier Qualitek-4 (DOS) version, you will immediately recognize the placement and content of the menu items. The design and analysis capabilities have been placed under the corresponding menu headings. You will be able to find the option necessary by determining the type of task, whether it falls under Design or Analysis, etc.

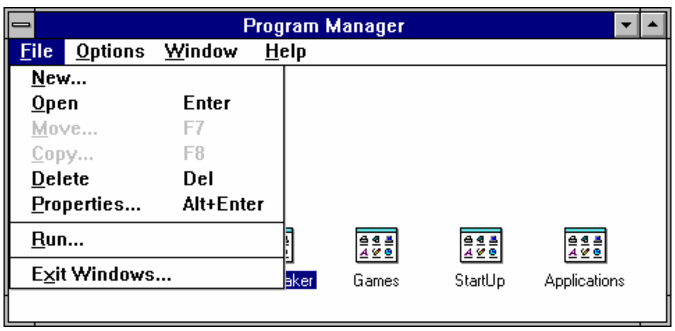
QT4 is compatible with your experiment files of the DOS version. All basic experiment files of DOS version have the extension .QT4. The Window version will have the extension .Q4W. To use your old experiment file, simply copy the file into your \USRFILES subdirectory. Then get into QUALTEK-4 and open your ___.QT4 file (make sure to display all files if you do not see your files the first time). You may work with your file as normal and be sure to save before you quit. When you save, the file will now be transformed automatically into the new format and saved with extension .Q4W. For your future applications you will work with your file with the new extension.

Chapter 2

Installing Qualitek-4 in Window 95 or Windows 3.x

To install Qualitek-4 program, you will need the program disks (Three 3-½ floppy disks or one CD-ROM) and your personal fifteen digit Registration number. If you do not have the correct registration number, the program will install as a DEMO version allowing you to use it for designing experiments with L-8 array only.

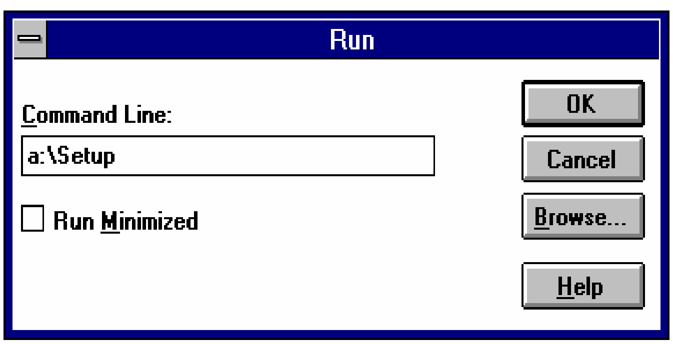
You will install the program the same way as all other Windows program - just insert the CD-ROM or disk 1 of 3 into the drive run X:\|SETUP (X = CD or floppy drive as applicable).



Windows 3.x installation

Close all open programs before starting installation. Insert program disk 1 into the floppy drive.

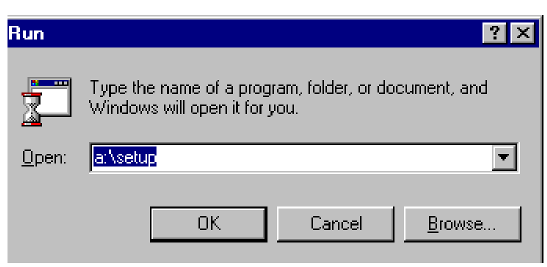
From the Program Manager screen, click on the File menu and click again on Run.



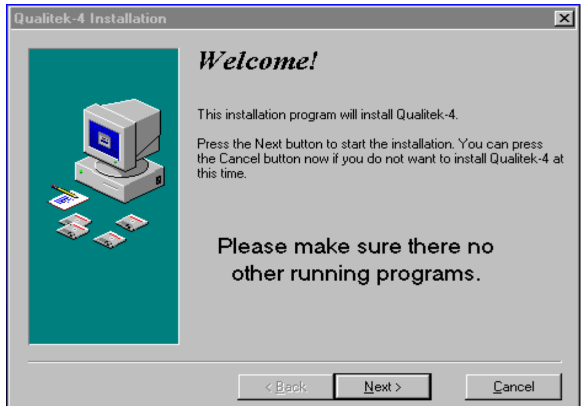
In the command lne box, type the letter of your 3 1/2" floppy drive (say A), a colon, a back slash and SETUP. For example if your drive is A, you would type A:\SETUP. Then click on the OK button and follow the screen instructions.

Window 95 installation

Close all open programs before starting installation. Insert program disk 1 into the floppy drive

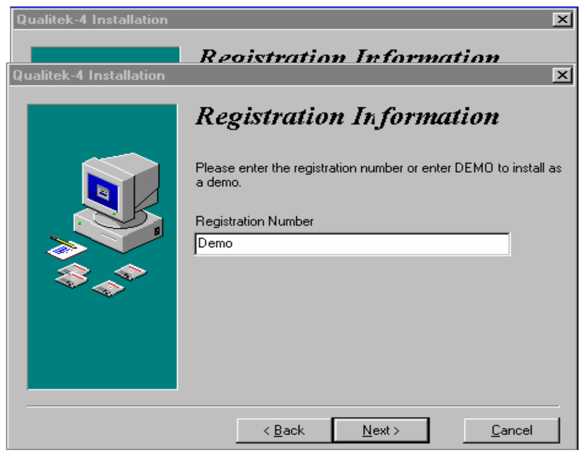


Click the **Start** button at lower left of your Window 95 screen and click Run from the menu. At the **RUN** command, open the X:\SETUP file and click OK. Follow the screen prompt to complete installation.



Qualitek-4 Installation in Progress

As you Run the SETUP file, you will see the screen on the right. Close all programs before you proceed to install Qualitek-4. If you have some program running, Click Cancel button, otherwis e Click Next button.



Enter the name of the registered user and
the
Cli

Qualitek-4 installation in progress

If you are installing from floppy disks, your computer will copy the initialization files from disk 1 and quickly prompt you for disk 2 and disk 3. Remove disk 1, insert disk 2, and click OK.

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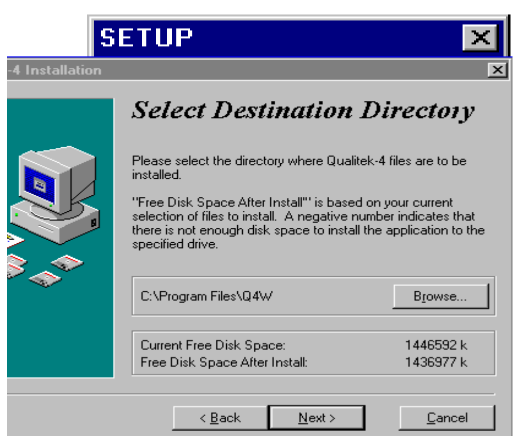
Your computer will begin to copy files and will quickly prompt you for disk 3. Remove disk 2 and place disk 3 in the floppy drive. Click OK to proceed with the program setup.



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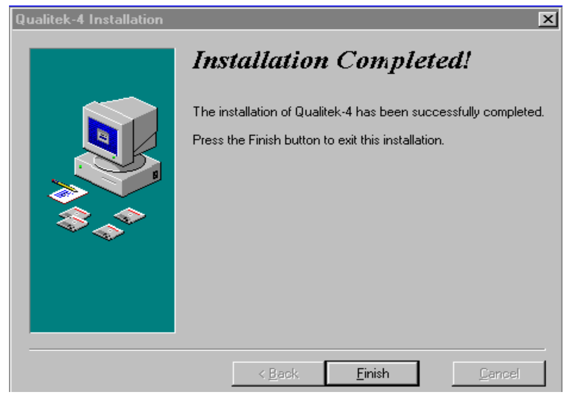
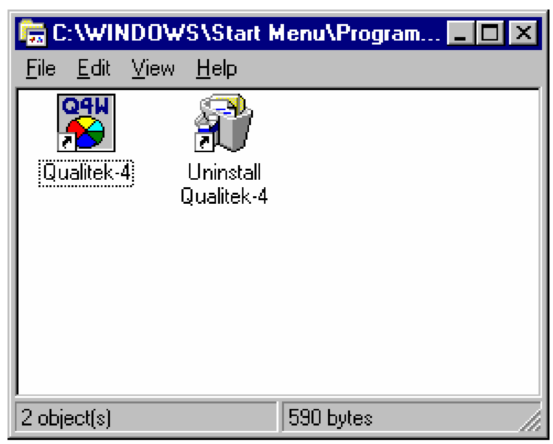




Installation Problems

First, check to see that your computer has the necessary requirements that Qualitek-4 needs. That is, check to see that you have enough hard disk space and enough memory (RAM). Also, you may want to check the integrity of the floppy disk(s) containing the program. If these solutions do not remedy your problem, feel free to contact us here at Nutek Inc. If you wish to return the program for a full refund, you must return it in the original package within two weeks of delivery.

Need Assistance With Application Procedures?

If you need help in the use of the program, or the logic behind the Taguchi Method, refer to the built in on-line help included with Qualitek-4. You may also find some more detailed and useful information on our web site:

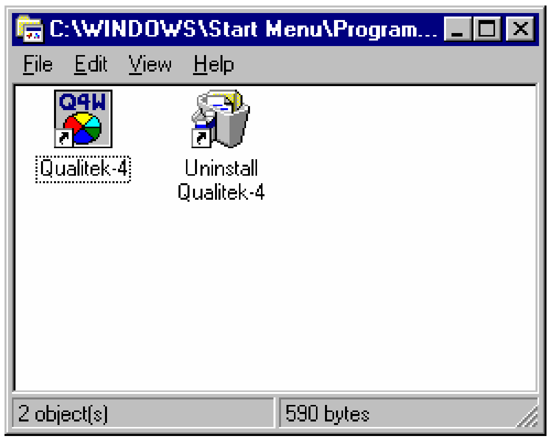
http://www.nutek-us.com

Chapter 3

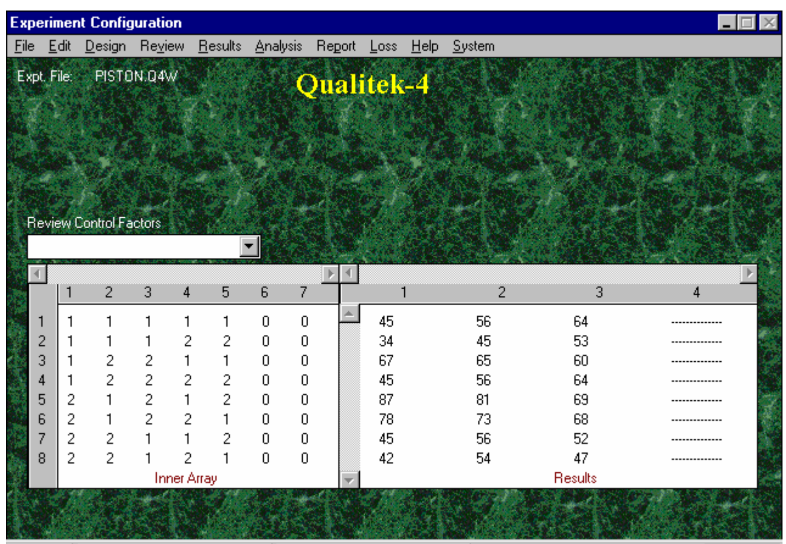
How to Start and Exit Program

You can use the Start button of Window 95 or later versions to start Qualitek-4 program. To start, click the Start button, and then point to Qualitek-4 program. If you are using Window 3.x, then double click the Qualitek-4 icon from the Window Program Manager screen.

Window 3.x
From the Qualitek-4 folder, double-click the Qualitek-4 icon.

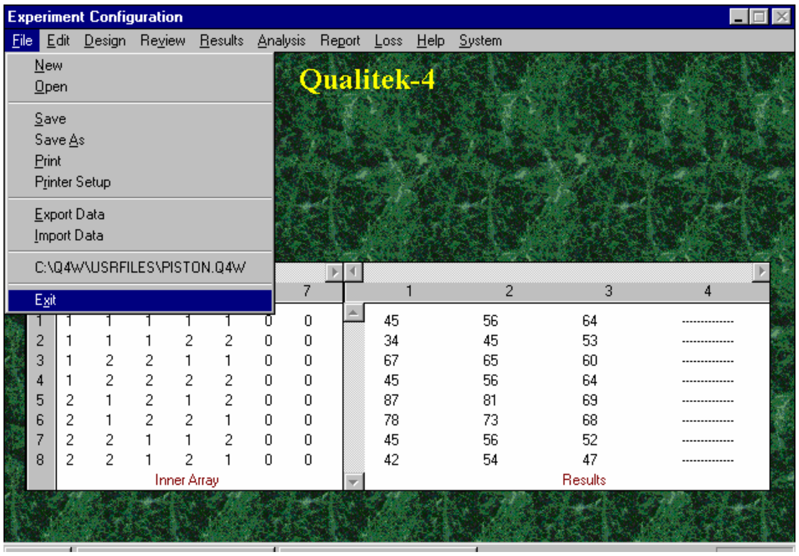


After a few introductory screens, you will arrive at the Qualitek-4 main screen. You can now begin to use the program for experiment designing.



For help with HOW TO GET STARTED and REVEW QUALITEK-4 Screens, visit:
http://nutek-us.com/wp-q4w-start.html & http://nutek-us.com/wp-q4w-screen.html

Qualitek-4 Main Screen



Quitting Qualitek-4

If at any time you wish to quit and exit Qualitek-4, choose the FILE option from the main screen's pull down menu and click on EXIT. You will then have exited Qualitek-4 and returned to the Windows Desktop.

When you exit the program, QT4 remembers the file you were working on. So that when you run QT4 again, it will start you with the file you were working on before. You need not CLOSE a file as when you open another experiment file from the FILE menu, QT4 automatically closes the previous file.

What to do next?

You have several options. If you are not ready to start a new design, you would most likely prefer to review one or more examples from the list of example experiments included with the QT4 program disk. To review an example experiment:

- From the FILE menu open file PISTON.Q4W or any other file of your choice.

- Click on the REVIEW menu and select Trials. This option allows you to review and print the trial conditions. Click on CANCEL button to return to main screen.

- Click on EDIT MENU and select Factors and Levels or any other item. Click OK when you are done and follow screen prompt to return to main screen.

- Click on ANALYSIS menu and select Standard or S/N analysis. Note that S/N is only allowed when there are more than one column of results. After you select the Quality Characteristic, follow the screen prompt or click on the OK buttons to proceed with the analysis. Note that there are three basic screens that display results of analysis. In the order of their sequence, they are; Main Effect, ANOVA, and Optimum screens. A number of options are available from each of these screens. The Optimum screens represent the conclusion of analysis at which point when you click the OK button, QT4 will bring you back to the main screen.

Chapter 4

On-line Application Support

The basic steps in the application process are as outlined below. Brief description and application guidelines are included on each of the application steps in the Qualitek-4 on-line help.

Select Project and plan Experiment

Look for simpler project to apply first. Arrange for the planning/brainstorming session. Determine:

* Evaluation criteria and define a method to combine them
* Control factors and their levels.
* Interaction (if any)
* Noise factors (if any)
* Number of samples to be tested.
* Experiment logistics.

Experiment Design

Design experiment & Describe trial conditions.
* Determine the order of running the experiment
* Describe noise conditions for testing samples if the design includes an outer array

Conduct Experiment

Carry out experiments
* Note readings, calculate and record averages if multiple readings of the same criteria are taken.
* Calculate OEC using the formula defined in the planning session.

Analyze Results

* Determine factor influence (Main Effect)
* Identify significant factors (ANOVA)
* Determine optimum condition and estimate performance
* Calculate confidence interval of optimum performance
* Adjust design tolerances based on ANOVA

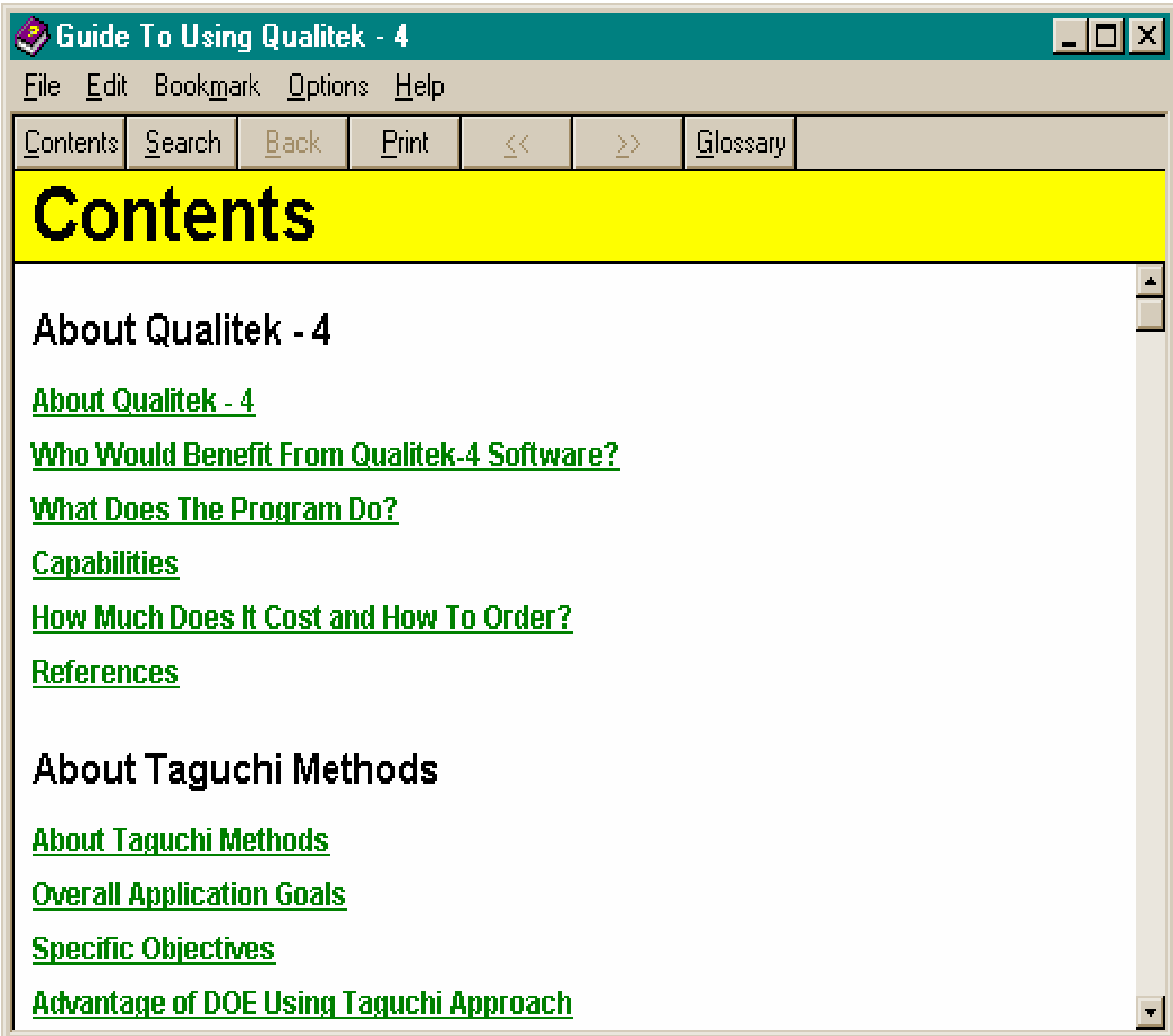
Confirm Predicted Improvement

Run confirmation tests with multiple samples at the optimum condition. Compare the average performance with the confidence interval determined from DOE.

Need Assistance With Application Procedures?

If you need further help in the use of the program, or the theory behind the Taguchi Approach, always refer to the built in on-line help included with Qualitek-4. You may also find some more detailed and useful information on our web site:
http://nutek-us.com

Although QT4 is designed mainly to help you accomplish your design and analysis tasks on command and not to teach you the method, we have placed a large volume of information about the method and its application strategies. Most of the theory related items and general topics have been placed under HELP menu in the main screen. Discussion topics and search items are described in hypertext so that when a click on an item it takes you directly into the subject matter. To get some tips on what the content of the screen mean or how to interpret the data, click on the HELP button for help on the specific screen.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About Taguchi Methods
Overall Application Goals
Specific Objectives
Advantage of DOE Using Taguchi Approach

Chapter 5

Experiment Planning

Experiment planning is a necessary and important first step in the application process. Of course planning/brainstorming for the project is done outside the program and before you come to use the program. But should you need some help with how to carry out the planning session or what to discuss in the planning session, a considerable amount of guidelines have been included in the main screen HELP in QT4. Remember it is the formal planning session, which supplies answers to the pertinent questions before an experiment is designed.

The main screen HELP in QT4 contains guidelines as follows:

PURPOSE OF BRAINSTORMING SESSION - Purposes of a brainstorming session are many:
* Identify factors, levels and derive other pertinent information about the experiment, collectively with all involved in the experiment.

* Develop team effort and achieve the maximum participation from the team members.

* Determine all experiment related items by consensus decisions.

WHO SHOULD CONDUCT?
The session should be facilitated by a person who has a good working knowledge of the Taguchi methodologies. Engineers or statisticians dedicated to helping others apply this tool will make better facilitators.

WHO SHOULD HOST THE SESSION?
The team/project leader should host the brainstorming session.

WHO SHOULD ATTEND?
The project team members consisting of all those who have first-hand knowledge and/or involvement in the subject under study should be included. For an engineering design or a manufacturing process, both the design and the manufacturing personnel should attend. If cost or supplier knowledge is likely factors, then persons from these disciplines should be encouraged to attend (group size permitting).

HOW MANY SHOULD ATTEND?
The more the better. The upper limit should be around 15. It can be as low as 2.

WHAT IS THE AGENDA FOR THE SESSION?
None. Some exposure will help. Application experience on the part of some participants will be a plus. A facilitator with application experience can help the participants with brief overviews when needed.

TOPICS OF DISCUSSIONS
The following topics should be included in the agenda for the brainstorming session.

1. OBJECTIVE OF THE STUDY (What are you after?)

A. What is the characteristic of quality? How do we evaluate the objective?
B. How do we measure the quality characteristic? What are the units of measurement?

C. What are the criteria (attributes) of evaluation for the quality characteristic?
D. When there is more than one criterion or there are several attributes of the quality characteristic, how do we combine them into an Overall Evaluation Criterion(OEC)?
E. How are the different quality criteria weighted?
F. What is the sense of the quality characteristic?
Lower is better, nominal is the best, etc.

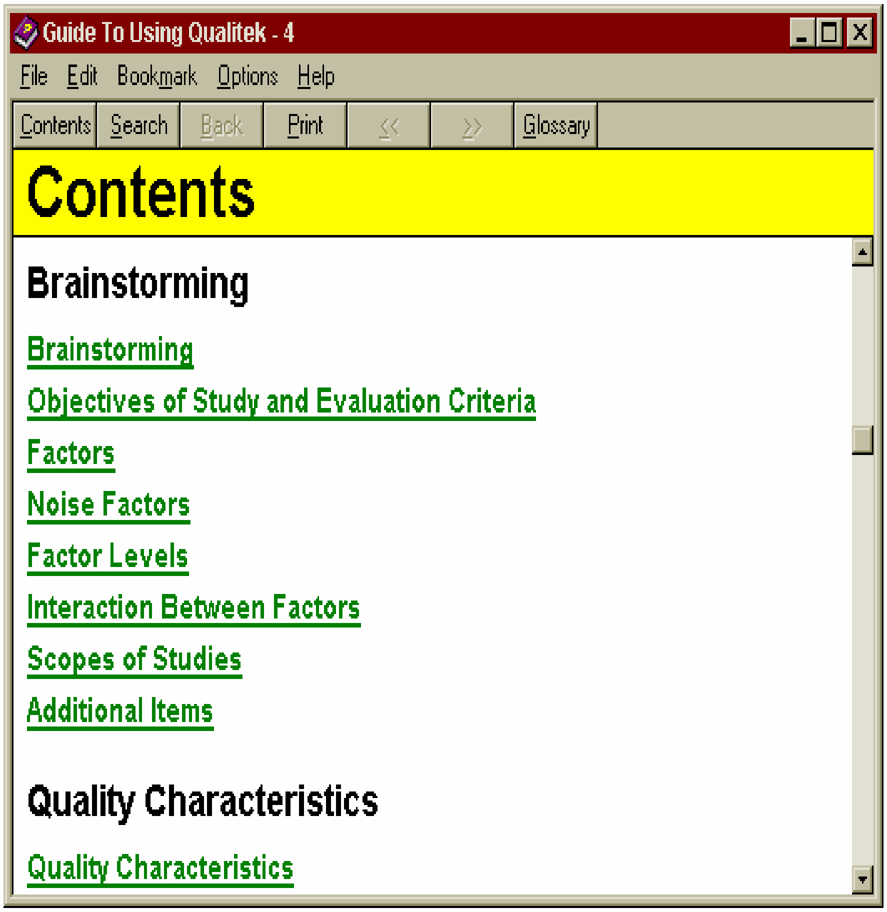
2. DESIGN FACTORS AND THEIR LEVELS

A. What are all the possible factors?
B. Which ones are more important than others (Pareto diagram)?
C. How many factors should be included in the study?
D. How to select levels for the factors? How many levels?
E. What is the trade off between levels and factors?

3. "NOISE" VARIABLES (How to make a robust design?)
A. What factors are likely to influence the objective function, but can not be controlled in real life.
B. How can the product under study be made insensitive to the noise factors?
C. How are these factors included in the study?

4. INTERACTION STUDIES (Which factors are likely to interact?)
A. Which are the factors most likely to interact?
B. How many interactions can be included?
C. Should we include an interaction or an additional factor?
D. Do we need to study the interaction at all?

5. TASK ASSIGNMENT AND DESCRIPTION (Who will do what, how and when?)
A. What steps are to be followed in combining all the quality criteria into an OEC?
B. What to do with the factors not included in the study?
C. How to simulate the experiments to represent the customer/field applications?
D. How many repetitions and in what order will the experiments be run?
E. Who will do what and when? Who will analyze the data?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Additional Items
Quality Characteristics
Quality Characteristics

Chapter 6

Experiment Design

Experiment design is the primary task you would want to accomplish by using QT4. The design task can only begin when you have completed the planning session and you have identified the factors and their levels and interactions. The size of your experiment will depend on the number of factors and levels you have. QT4 allows you to accomplish the experiment design two ways. The first option is for you to be in charge (Manual Design). Here you select the array for the experiment and also decide which factor goes to which column. The alternative way is to let QT4 prescribe the smallest design for your situation (Automatic Design).

Depending on your project your experiment design can have only and (a) Inner array, (b) Inner and Outer array, and (c) inner array and (c) Inner array and Dynamic characteristic. You can let QT4 design your experiments with Inner array only or experiments with outer array. But if you are studying Dynamic systems, you must add that to your inner array design manually.

If your design includes	Then select option		
	Manual Design		Automatic Design
(a) Simple experiment - Inner array only	Inner array	or	Inner array
(b) Experiment design with Outer array	Inner and Outer array	or	Inner and Outer
(c) Experiment design with Dynamic Characteristic	Inner array and DC	or	Inner array

(a) Simple Experiments

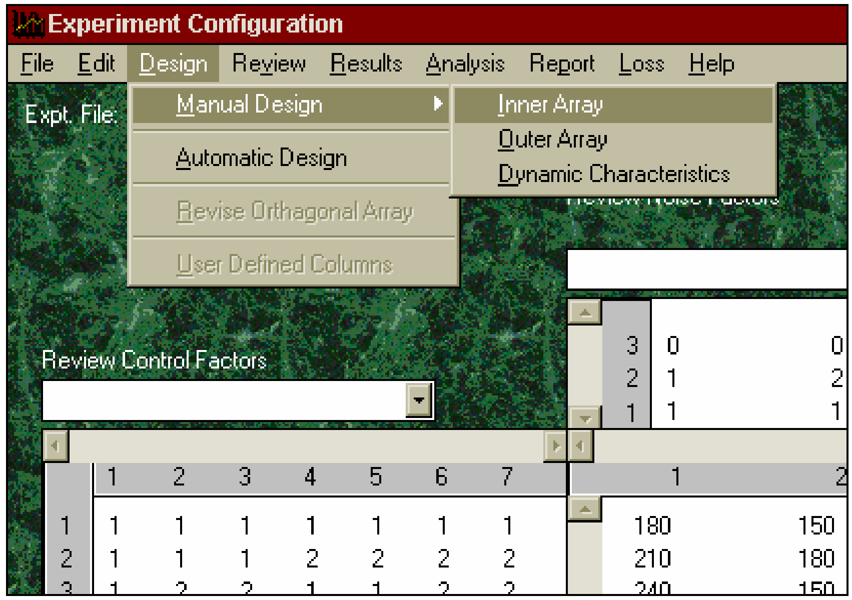
Simple experiments are those that are designed using only an inner array. Your experiment may indeed have noise factors; no formal outer array is utilized to define the noise conditions. You can design such experiments using the Manual or Automatic DESIGN options.

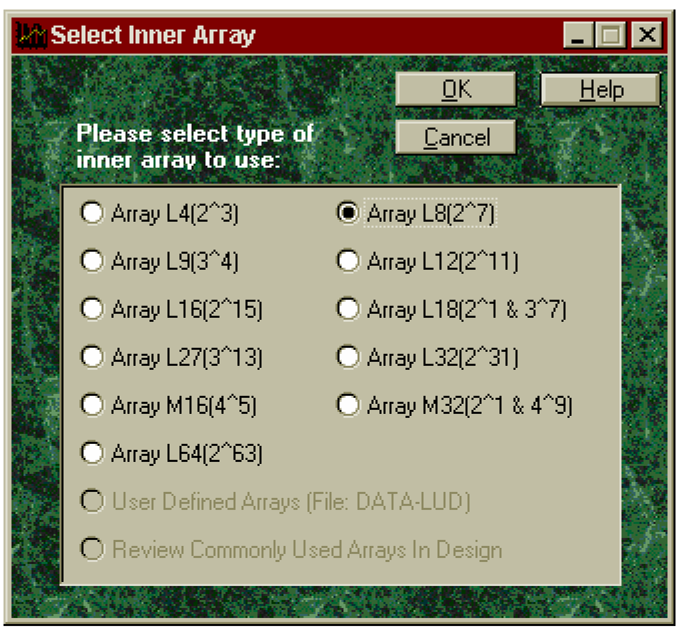
Manual design

1. Select Menu option

From the main screen, click on the DESIGN menu option and then select Manual and Inner array. You need not close the exiting experiment file on the screen. It will be closed automatically and data in memory will be erased.

Click the YES button when the message about the current data appears next.





2. Select Array

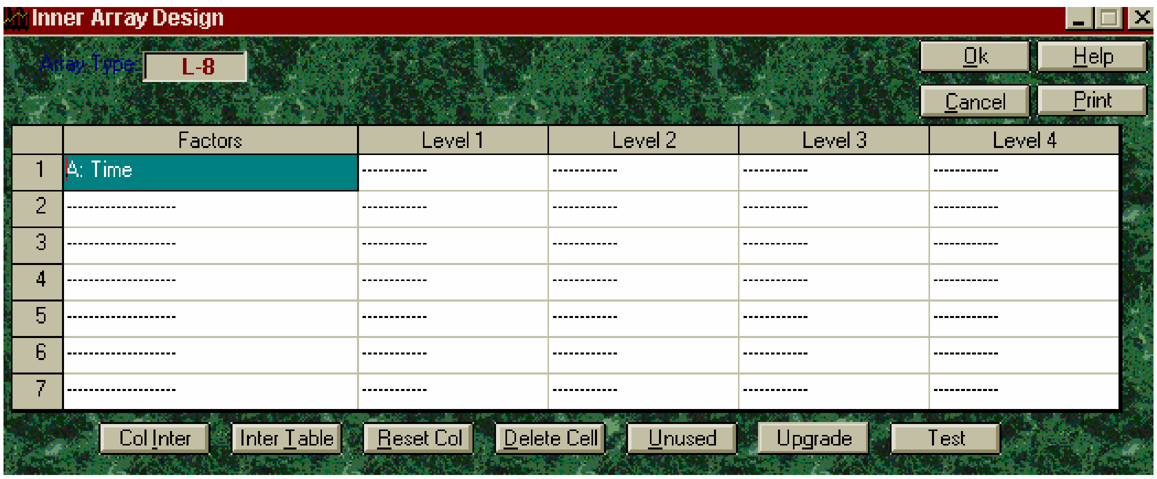
From the Inner array selection screen, check the array you want to use for your design. You have choice of selecting any array from the list of L-4 through L-64. Suppose that you select the L-8 array for your design.

3. Describe Factors and levels

Experiment design is accomplished in the Inner Array Design screen. Before start entering the description, you need to have a piece of paper where you have written the names of your factors and levels, and also identify which columns these factors are assigned.

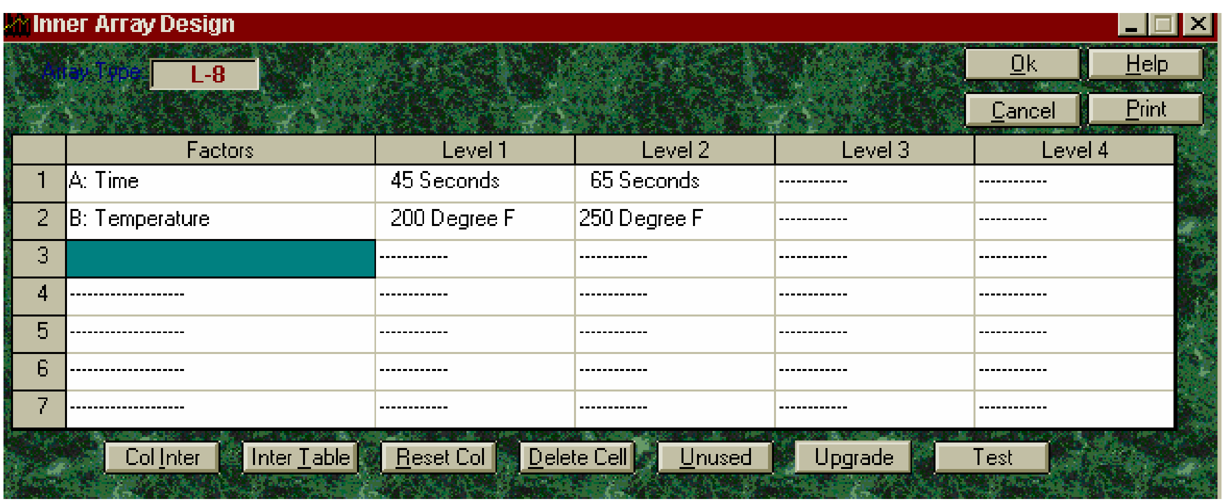
Suppose that the factor you want to assign in column 1 is TIME. Highlight the CELL under Factor and row number 1(rows in this table are columns of the Orthogonal array) by clicking with the right mouse button. Then type the description of the factor. For analysis reference purposes, it is a good idea to use a leader character designation like A, B, etc. So instead of typing TIME, type A: Time.

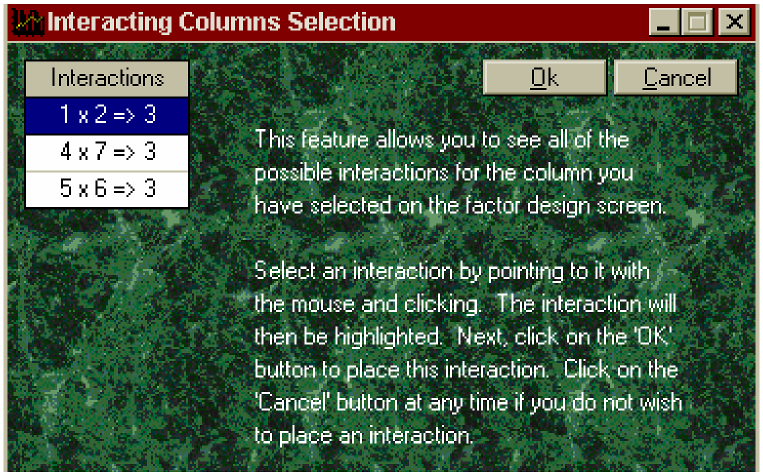
To describe the levels, click the CELL under Level 1 in the same row as the factor or press Shift+Right Arrow Key, then type the description of the level. Of course you have to have at least two levels for each factor. Also, while describing the level, if your level is 45 Seconds, type in 45 Seconds, not just 45. If you entered only 45, QT4 will not complain, but it is a good idea to include characters and numbers both for description.

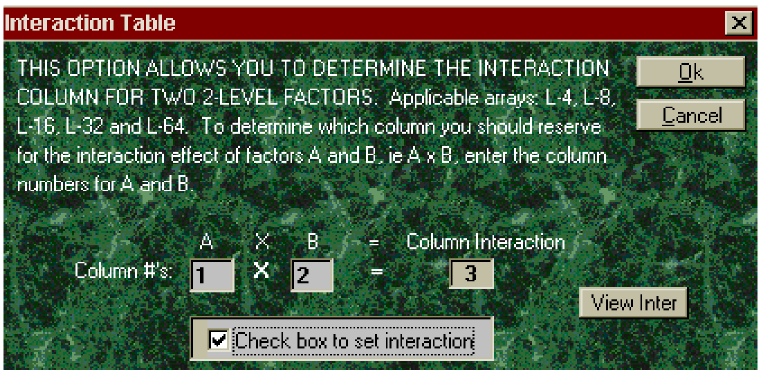


4. Reserve columns for Interaction studies

When your design includes interaction studies, you will need to reserve the appropriate columns for interaction. Suppose that you wish to reserve a column for interaction between factors (QT4 capabilities limited to interaction between 2-level factors only) A & B, you can do these two ways. If you already know the column for the interaction, from the Triangular Table, you can highlight the CELL under the Factor in the row number then click the COL.INT button at the bottom of the screen.







Interaction (Contd.)

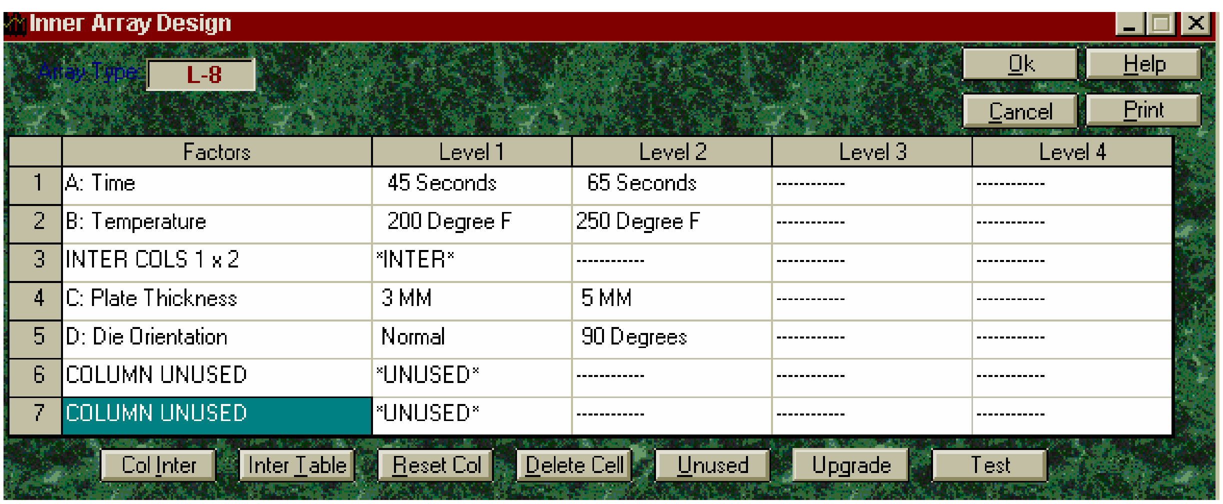
The screen will indicate a number of possible pairs of columns which will mix their interaction effect with the selected column (col. 3 in this case). To select the pair of interest, simply click on the column numbers, 1x2 in this case. Note that you can only select one pair of column at one time.

If on the other hand, you are not sure which column you should reserve to study the interaction between factors in columns 1 and 2, in other words you do not have the Triangular Table information, you need not highlight any column, simply click the INT.TABLE button from the bottom of the Inner array design screen. When in the Interaction Table screen, key in the number 1 under A and 2 under B, the click on Check box to set interaction. This will indicate the column which should be reserved for interaction. If you want QT4 to set this interaction automatically, click OK.

When interaction is set, QT4 will insert the appropriate description in the column, and indicate *INTER* in place of the first level in the same line. NEVER TYPE THIS DESCRIPTION YOURSELF.

5. Identify unused columns

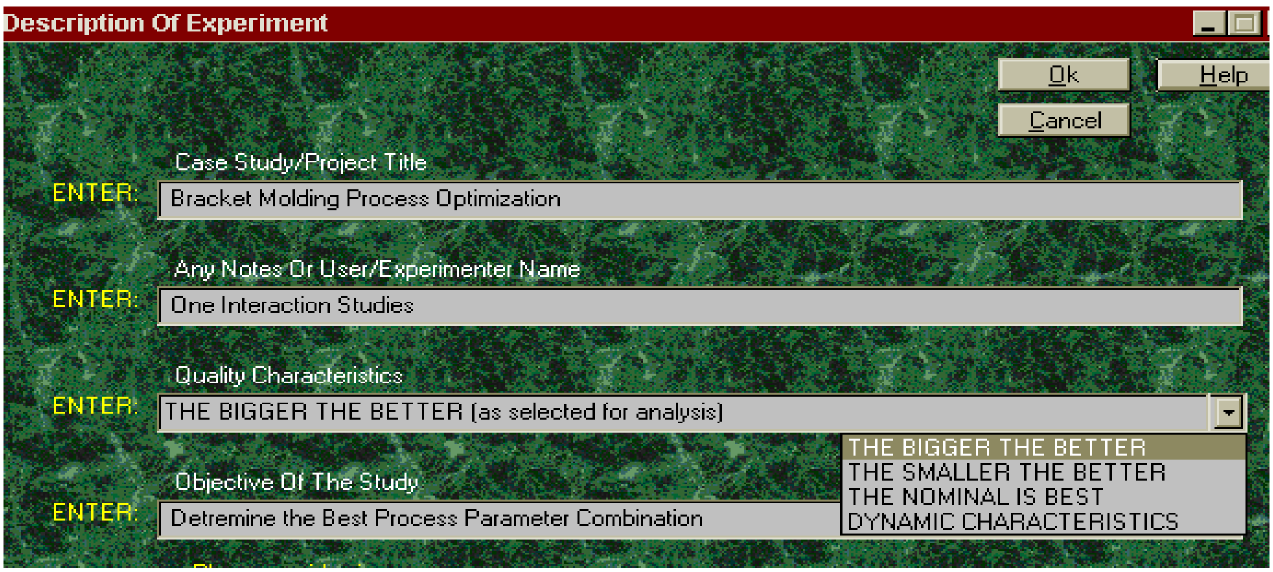
The columns that have no factors or interactions assigned are referred as unused columns. QT4 needs to know which columns, if any are determined by you as unused. To set a column as unused, highlight the CELL under Factor description in the line number corresponding the column by the mouse click, then click on the button UNUSED at the bottom of the Inner array design screen.



Your experiment design description is complete when you have addressed each and every column of the array, which are the rows identified by the number. For completeness, all columns must have a factor, an interaction, or be unused. In case of factors, there must be at least two levels described. QT4 will not allow you to proceed unless the description is complete. When ready, click OK to proceed.

6. Enter Project Descriptions

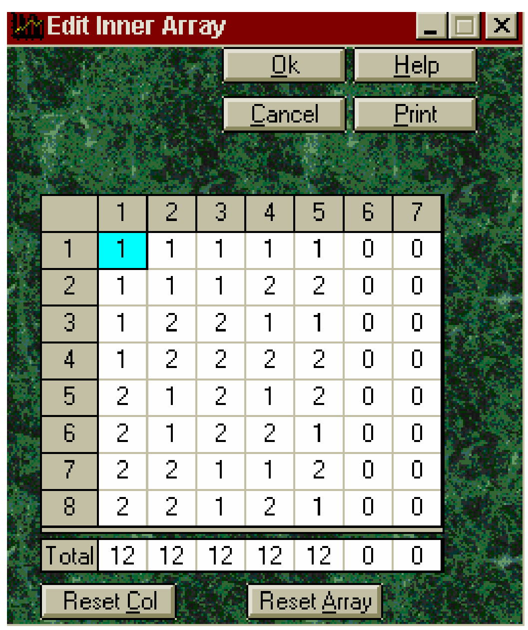
This screen allows you to attach four lines of description about your project. These items are optional and used only in printing reports when available. To set the Quality Characteristic appropriate for your experiment, click the pointer at the end of the line and make your selection. QT4 automatically puts the selected description.

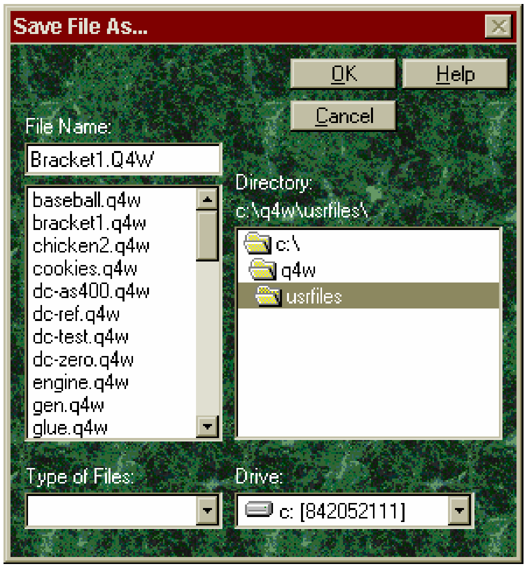


7. Review and Modify Array

The Edit Inner Array screen shows the array you have selected for your experiment. All columns except those are identified as unused, are shown in the original form. All unused columns are automatically turned into zero by QT4. If for some reason you want to use an unused column, you must reset the column to its original form. To reset the column, highlight the CELL in the first row of the column by the mouse click and then click on the RESET COL. button at the bottom of the screen. You would always need to do this step when you reassign a column from unused status to assigning a Factor or an Interaction.

If your design requires a column to be upgraded or modified, you can do so in this screen. Just click on the CELL to modify and key in the number.





8. Name and Save Files

The final screen in the experiment design process allows you to name your experiment file. QT4 attaches .Q4W to all experiment files. You need only to supply the first eight characters of the file name. It is a good idea to start your file name with an alphabetic character. You can have most any characters in the middle, except few delimiters like ",", ";", ":" etc. are not desirable.

The experiment file will always be saved in the directory called USRFILES. While installing you has a choice to place this directory in and drive and directory you want. By default, this is a sub-director under the Q4W director. If you do not see the USRFILE directory in the display box, click on C:\, search for the USRFILES directory and select it before you OK to save your file.

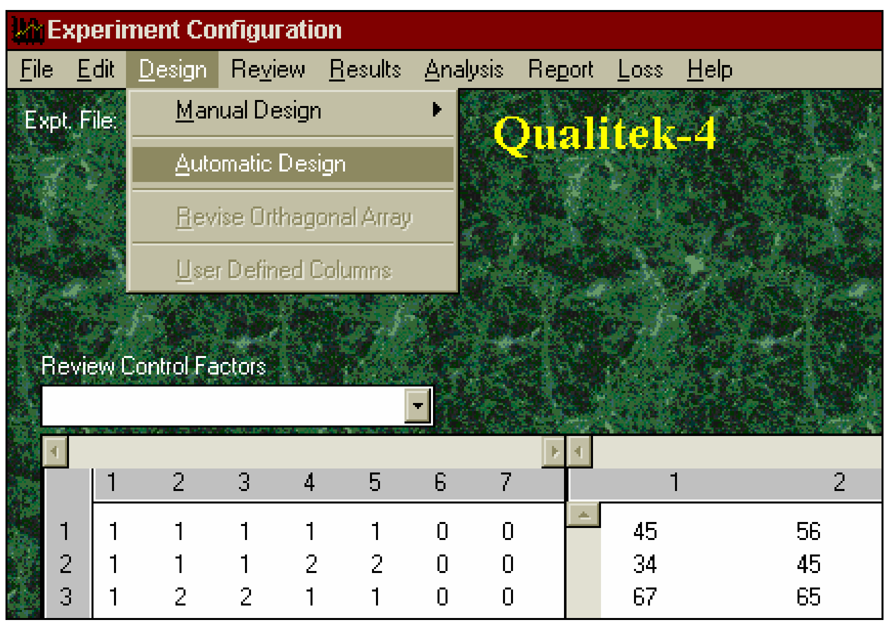
Automatic Design

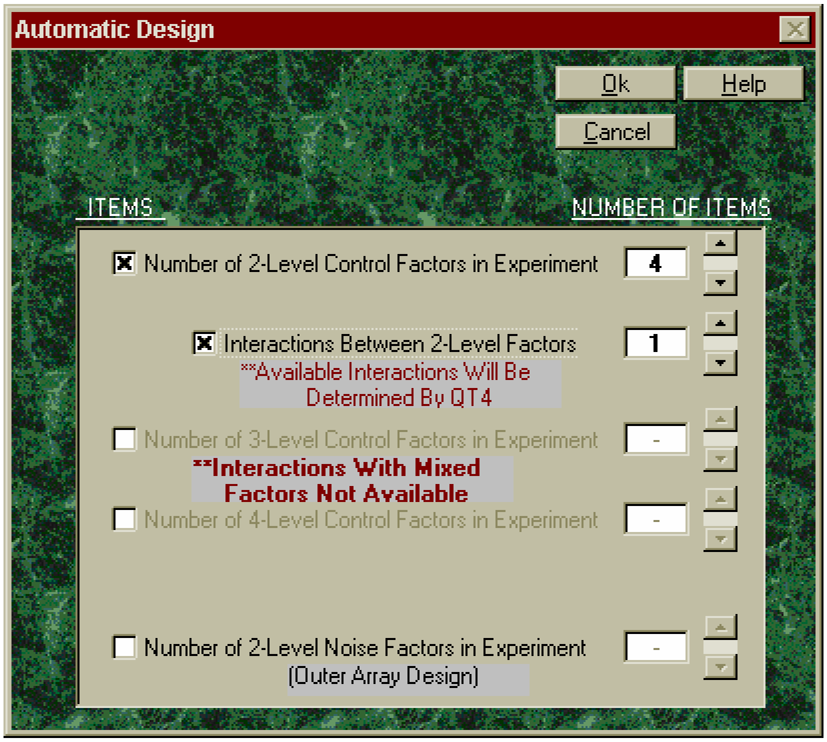
In automatic design, QT4 designs the experiment for you automatically. Given your experimental parameters such as number of factors at various levels and their descriptions, QT4 selects the most suitable array and assigns factors to the most desirable columns. Once the design is displayed, you can then modify the description, reassign the factors, and modify columns if necessary.

1. Selection Menu Option

To let QT4 design your experiment, click DESIGN option from the main screen (Experiment Configuration) and select Automatic Design.

In the next screen QT4 alerts you about the fact that all existing experiment data will be erased. Click OK to proceed.





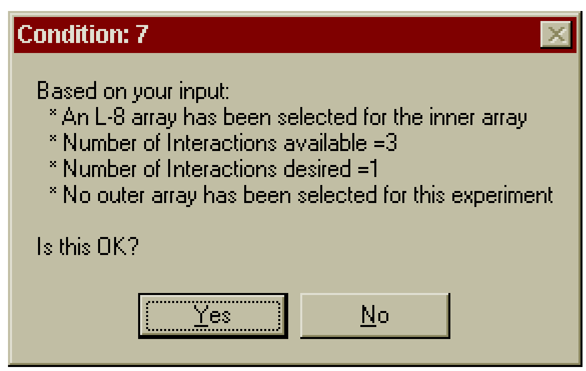
2. Set Requirements

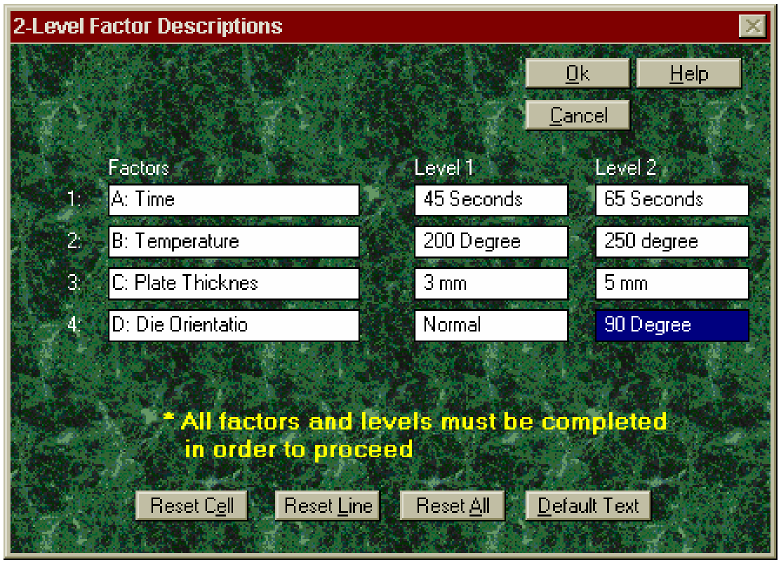
This screen allows you to set the experiment size by indicating the number of factors at two, three, and four levels, and also the interaction between two 2-level factors. Considering the same experiment designed earlier (four 2-level factors and one interaction), click the box left of Number of 2-level factors.., then set the counter to 4. Check the Interaction box next and set the counter number to 1. Since in this experiment there are no three or four level factors and no noise factors, nothing else needed to be checked.

Note: QT4 can design most common experimental situations requiring Inner and Outer arrays. If QT4 cannot design your experiment, it will prompt you so. Should you want QT4 to design your experiment anyway, modify your requirements slightly and try again. You will then have the opportunity to alter your design manually.

3. Review Proposed Experiment Design

Based on the requirements, QT4 selects the most economical array for the experiment. If the information displayed, which is what QT4 used to determine the design, is not correct, click No. This will allow you to redefine the requirements. Otherwise click OK to proceed.





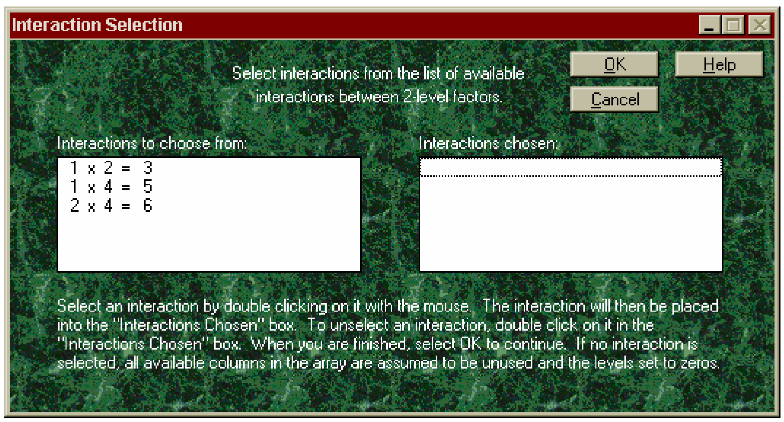
4. Describe Factors and Levels

Factors and levels are described using separate screens for 2-level, 3-level and 4-level factors. The 2-level factors are defined first. To describe factors and levels, click the appropriate box and type in the descriptions.

The numbers left of the factor description boxes indicate the sequence number of the factor and are not the column number

4. Select Interaction(s)

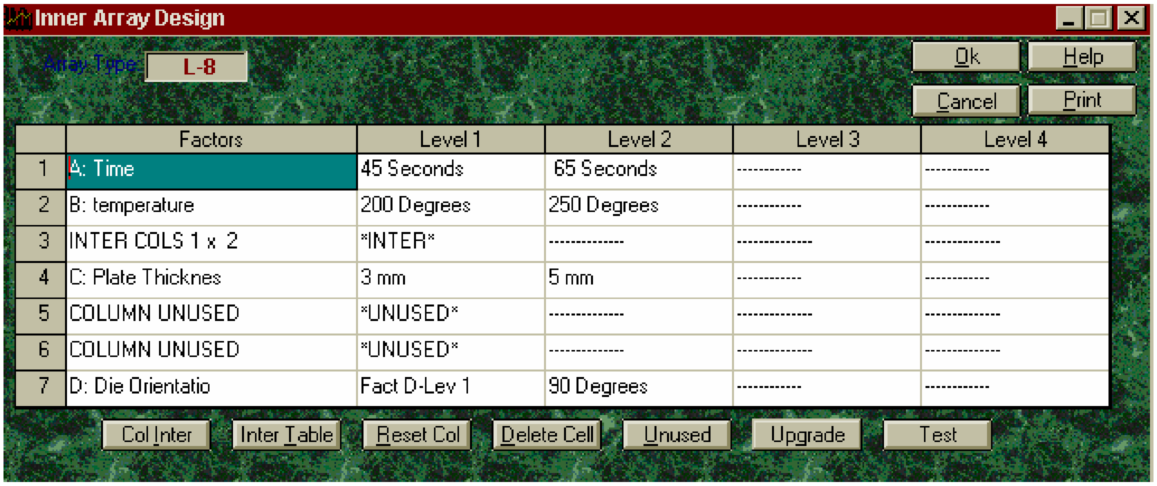
This screen allows you to select the interaction you desire from the list of available column interactions. QT4 always shows you the interaction applicable and available based on the number of factors and the array used for the design. In this example, since there are only four 2-level factors and the array has seven columns, there are three dependent(common column numbers) interactions are possible. You may select one or more interaction or none at all. In the example, interaction between factors in colums 1 and 2 (AxB) is desired. Follow the screen prompt to select the interaction you want.



5. Review Experiment Design

This screen is the same as in the manual design. You will notice that all factors, their level descriptions, and the interaction are placed in the appropriate column locations and the unused columns are identified. This design may or may not look like the one you would design using the manual option. QT4 has certain fixed rules it follows to assign the factors to the column. These rules follows design that minimizes mixing of unwanted interactions with the factor effects.

If you created an error in typing descriptions or you want to alter assignment of a column, you can highlight the CELL and retype the description. From this point onward, the screens are the same as in the Manual Design option. Click OK when you are ready to proceed.



	Factors	Level 1	Level 2	Level 3	Level 4
1	A: Time	45 Seconds	65 Seconds	-----------	-----------
2	B: temperature	200 Degrees	250 Degrees	-----------	-----------
3	INTER COLS 1 x 2	*INTER*	-------------	-------------	-------------
4	C: Plate Thicknes	3 mm	5 mm	-----------	-----------
5	COLUMN UNUSED	*UNUSED*	-------------	-------------	-------------
6	COLUMN UNUSED	*UNUSED*	-------------	-------------	-------------
7	D: Die Orientatio	Fact D-Lev 1	90 Degrees	-----------	-----------

6. Review Orthogonal Array

Examine the Orthogonal array and click OK to proceed.
(Same as the Manual Design option)

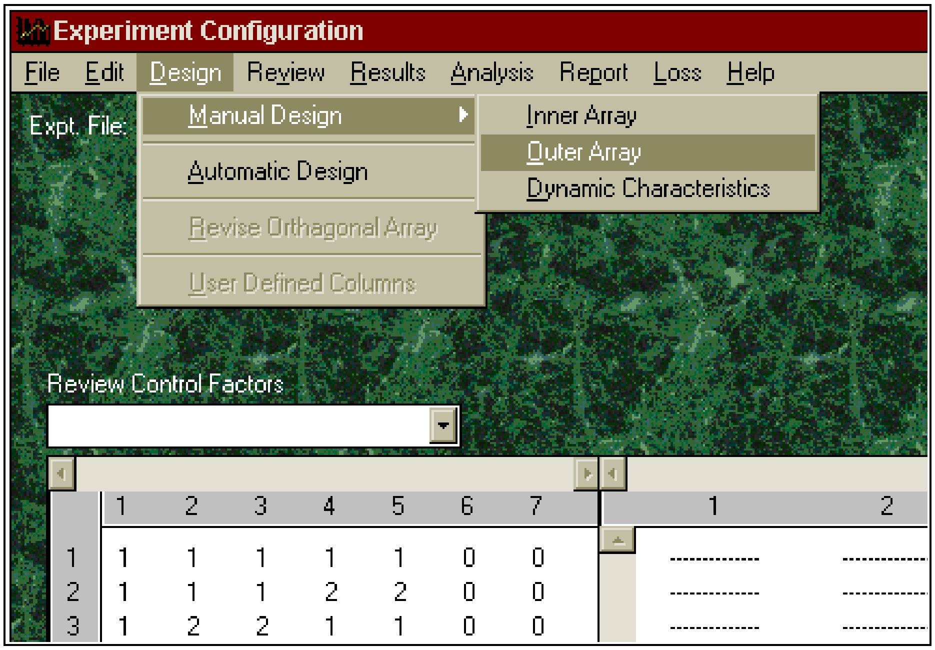
7. Save Experiment File

Find the USRFILES directory and name the experiment file with extension .Q4W (Bracket2.Q4W) and click OK when ready. Your file is now saved and you are ready to describe the Trial conditions and carry out the experiments.
(Same as the Manual Design option)

(b) Experiments with Outer Arrays

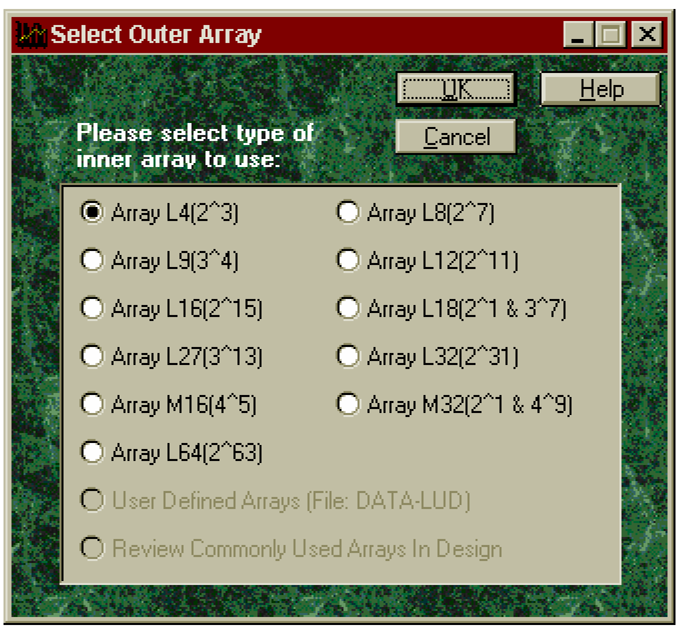
Outer arrays are used to formally incorporate the Noise factors into the experiment. Of course before an outer array is added to the experiment, the **inner array must be designed first**. Before proceeding to design the outer array, make sure that your Inner array is designed and that the desired experiment file is opened. If the file is not already opened, open the desired file by selecting the FILE menu from the main screen(Experiment Configuration).

Manual design



1. Select menu item

From the main screen DESIGN menu, select manual design then click on Outer Array.



2. Select Outer Array

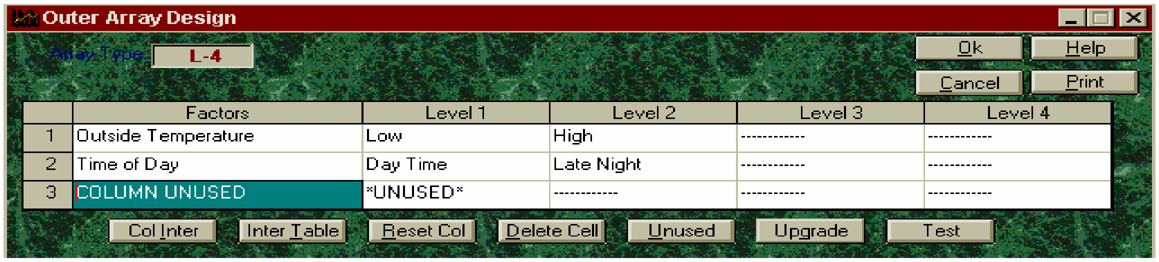
The same number of arrays as available for the Inner Array design is also available for the Outer Array design. Of course the Outer Array you need depends on the number of Noise factors you want to include in your experiment. The rules for selection of the array are, as for the control factors, dependent upon the number of Noise factors and their levels.

In the example experiment, two 2-level Noise factors are to be included and thus, an L-4 array is checked.

3. Describe Noise Factors and Levels

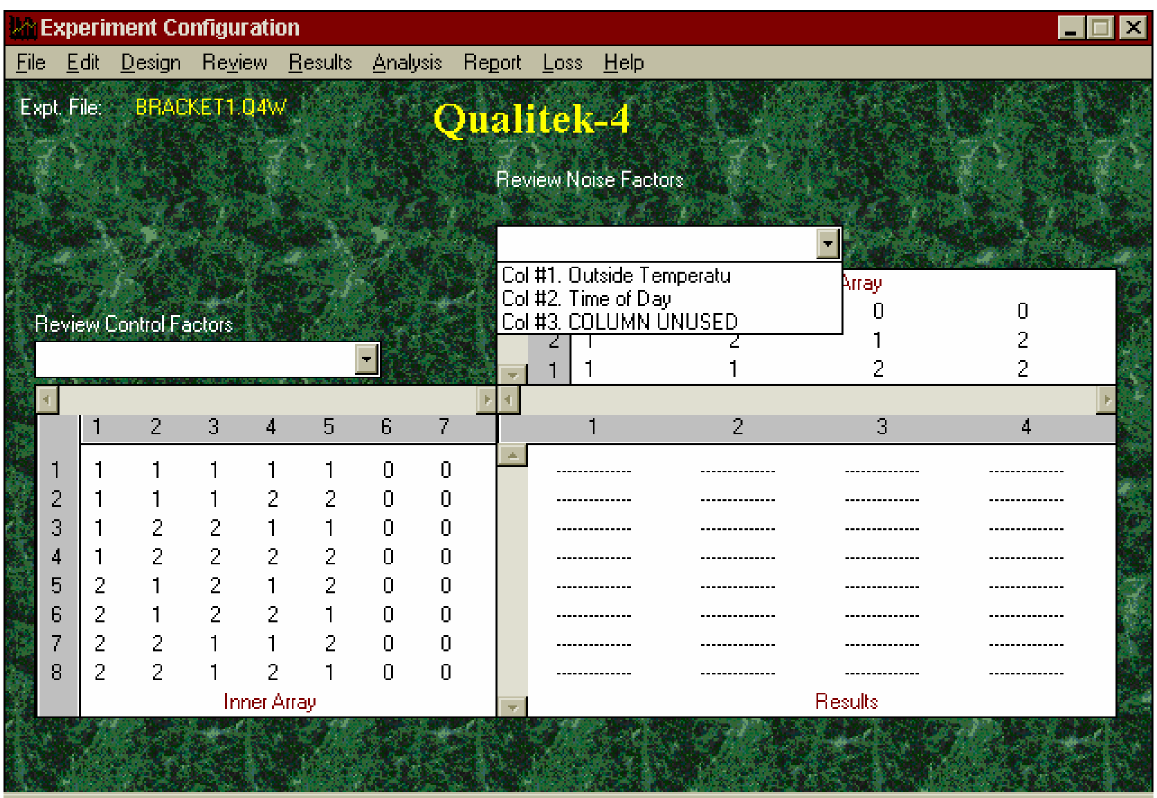
The descriptions of Noise Factors and their Levels are entered just the same way as the Control Factors and their Levels. This screen has all the same features as the Inner Array Design screen.

To enter a factor or level description, click the appropriate box and type the description. Be sure to use the command buttons to set the column for Interaction or to set it as Unused. When all rows (which are columns with respect to the orthogonal array) are described, click OK to proceed to the Outer array screen.



4. Complete Outer Array design

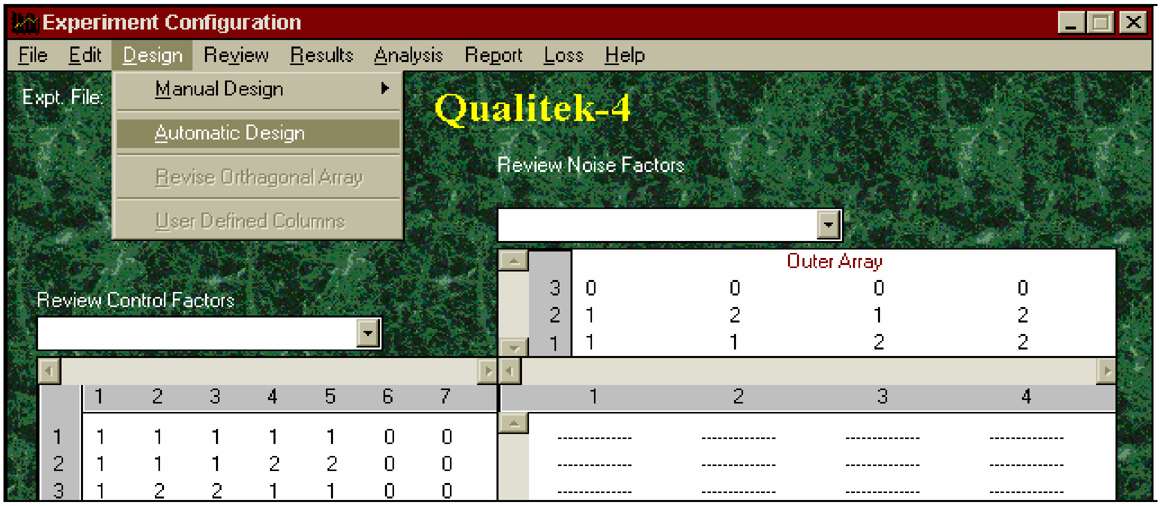
While at Outer Array screen, if any column modifications are needed, do so and click OK to proceed to the file update screen. Click OK for update and OK again to confirm that the file will be revised. QT4 will now return to the main screen displaying the experiment configuration with the Outer Array.



Automatic design

1. Select menu item

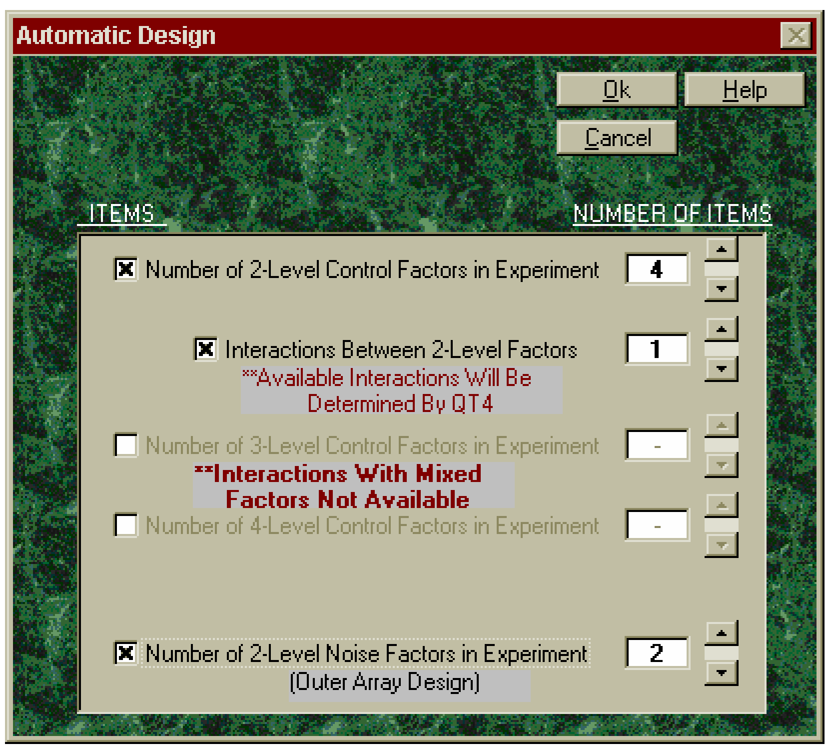
In the Automatic design option, both the Inner Array and the Outer Array design are accomplished at the same time. When you are ready to design your experiment, select the Automatic design option from the main screen DESIGN menu. You need not close the current design displayed as it will be closed as you proceed.



2. Select Design Options

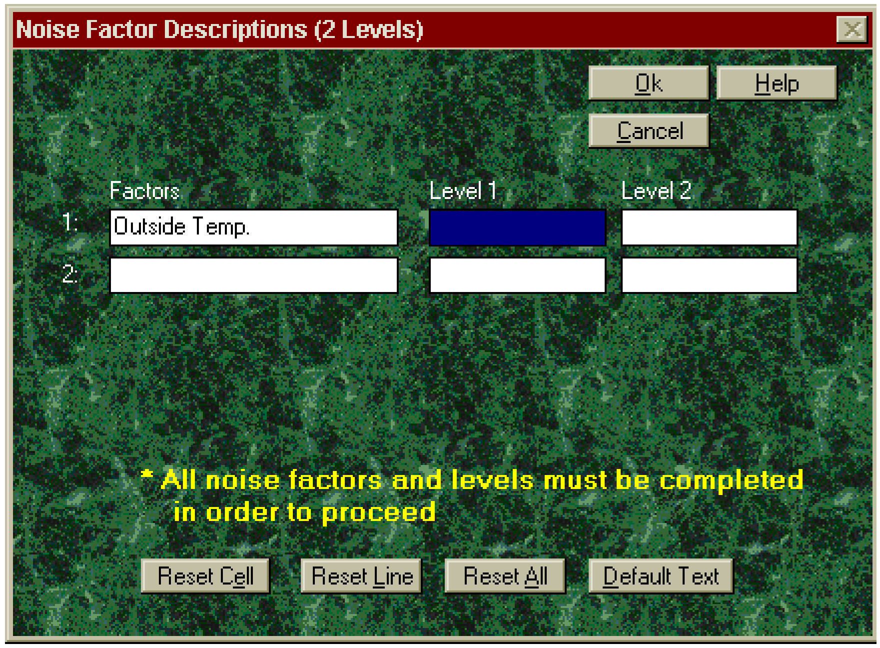
The parameters for experiment design are set in this screen. The example design (BRACKET1), used earlier, there are four 2-level factors, one Interaction, and two 2-level Noise factors. To set the numbers, first click on the box left of the description, then click on the up or down arrow to adjust the number.

Since in Automatic design the complete experiment, starting with the Inner array design, is accomplished, screens that are applicable for the Outer array portion are shown here. For Inner array design refer to the section described earlier.



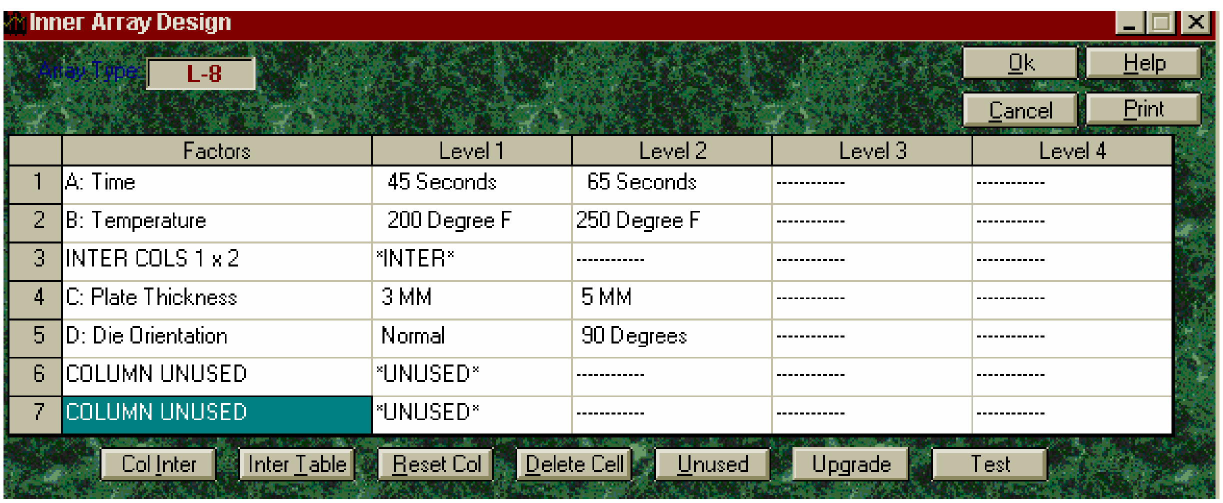
3. Describe Noise Factors and Levels

This screen will come after control factors are described. Click on the appropriate space and enter the description. Click OK when finished. QT4 automatically selects the smallest Outer array you need for the design and proceed to display the descriptions of both Inner and Outer Arrays. Follow the screen prompt and proceed.



4. Complete Automatic Design Process

Once the descriptions of factors and levels are entered, QT4 puts you back on the same set of screens that are used for the Manual design. Screens and action required to complete the design is the same as those shown under Manual Design earlier and should be referred when necessary.



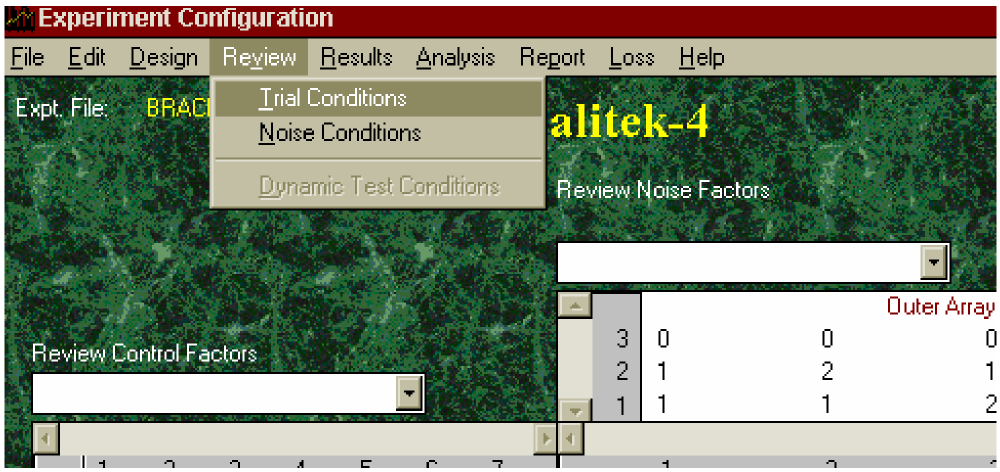
After the Inner array design screen, QT4 will display the Outer design screens for your review, and when finished, you will have option to save the data under a file of your choice. The subsequent screens are the same as those shown in the previous section.

Description of Trial and Noise Conditions

After the experiment is designed, the trial condition can be described using the Factors and the array. The term TRIAL CONDITION is used to the combinations of control factor levels which are the prescriptions for different test conditions necessary to accomplish the experiment (all trial conditions). The term NOISE CONDITION, on the other hand refers to the combinations of the Noise factor levels which created the condition to which the trial conditions are exposed to. In the example experiment an L-8 is used for the Inner array and an L-4 is used for the Outer array. Thus there will be eight Trial conditions and four Noise conditions. Experimenter should combine the Trial conditions and the Noise conditions as per the combinations required by the Outer array.

1. Select menu item

From the main screen REVIEW menu, select Trial Conditions or Noise Conditions as desired.

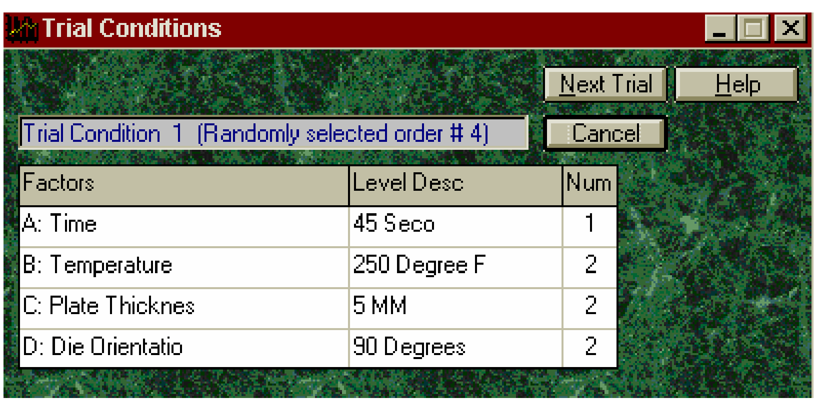


1. Review and Print Conditions

While in Trial Condition screen, click Next Trial to display the next condition. Click Print button if you want to print one or all the conditions.

The Randomly selected number indicates the order in which experimenter should conduct the experiment when possible. Click Cancel button when finished reviewing the conditions.

Repeat the same steps for Noise Conditions starting with the REVIEW menu option.



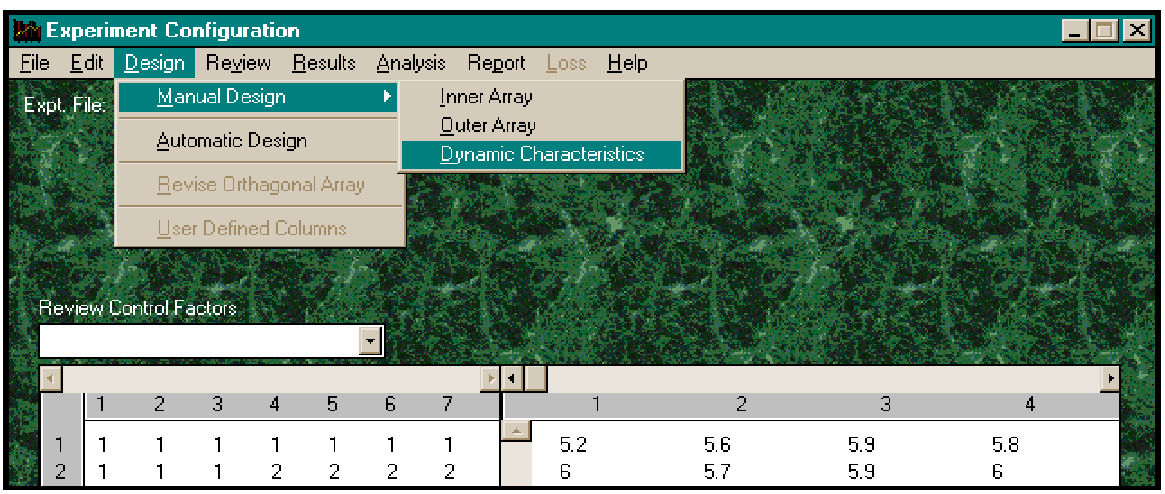
(c) Experiments with Dynamic Characteristics

Just as Outer arrays are used to formally incorporate the Noise factors, effect of Signal and Noise factors applicable to a Dynamic System is included in the experiment by this special design. There is no orthogonal array used for the outer array. Instead the levels of the Signal and the Noise factors are combined to form all the possible combinations are described. While conducting the experiment, each trial condition is exposed to these combinations of the Signal and the noise factors.

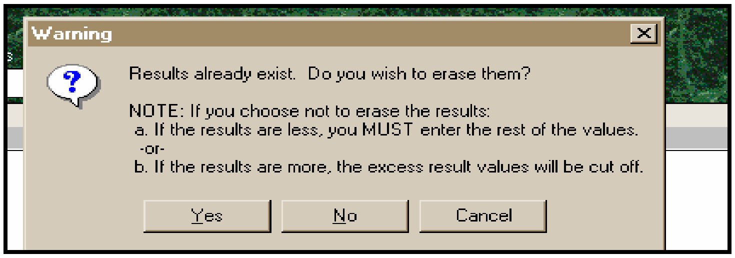
The Dynamic Characteristic can be added to the experiment only after the **inner array is designed first**. Before proceeding to design the outer array, make sure that your Inner array is designed and that the desired experiment file is opened. If the file is not already opened, open the desired file by selecting the FILE menu from the main screen (Experiment Configuration). To describe the Dynamic Characteristic (DC) design capabilities, the experiment DC-AS400.Q4W will be used. If you wish to redesign the DC for an existing experiment, you can work with a copy of the experiment file and proceed to redesign by first removing the existing DC design. To remove current DC, click on the EDIT menu item and select Remove Dynamic Characteristic option.

1. Select Menu Option

From the main screen DESIGN menu, select manual design then click on Dynamic Characteristic.



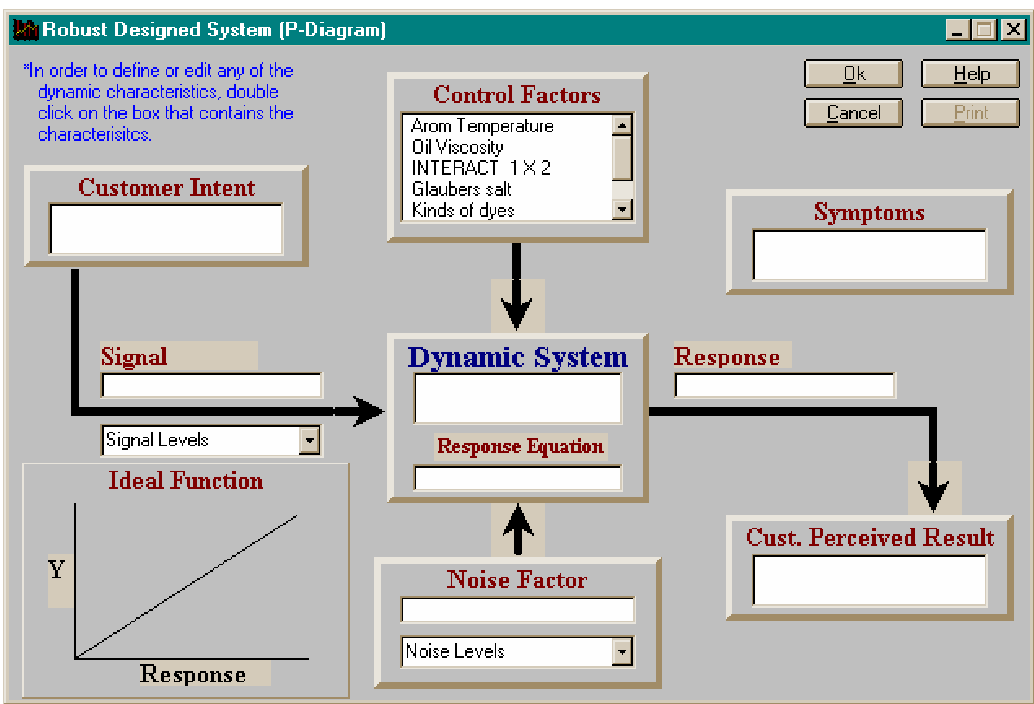
If you are working with an existing file which has results, QT4 will prompt you about the fact that the results will be erased. Click OK to proceed if you get this message. If you chose to keep the results, its size will be adjusted to suit the new DC design you are about to define.



2. Review P-diagram (before input)

The dynamic system function is schematically displayed in this screen. The control factors, which are already designed as part of the Inner Array, are only known parameters at this point. The factors which will be necessary are Signal factor (1 to 12 levels) and the Noise factor (2 to 10 levels). In addition, there are five system parameter descriptions such as Customer Intent, Symptoms, Perceived Results, etc. will have to be furnished in order to complete the system definition.

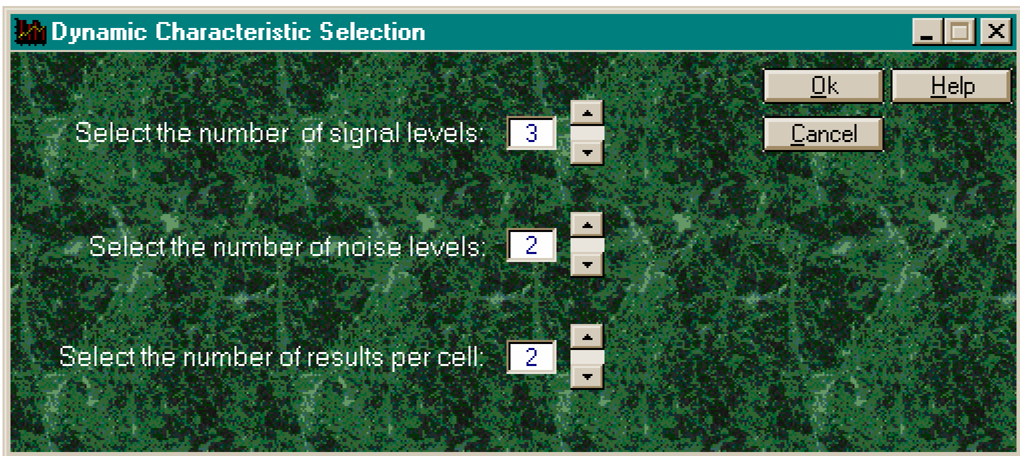
Double click on the box/text for Signal to describe the Signal and Noise factors and levels. Once you complete the description, you will return to this screen. Now proceed and describe the five system parameters by double clicking on the box for Dynamic System or any of the five locations.



3. Specify Number of Signal and Noise Factor Levels

QT4 allows you to incorporate one Signal factor which may have up to 12 levels (or 12 signals at one level each at 1 level) and one Noise factor with up to 10 levels (or 10 separate noise factors). The number of levels of the Signal and the Noise factors, along with the number of repetitions in each of the Signal & Noise factor combination(called a CELL), determines the size of the experiment.
QT4 requires that each trial condition will have equal number of Cells. The number of cell equals the number of Signal levels x number of Noise levels. The total number of samples/results, however, is number of Cell x number of samples in each Cell.

Click the up or down arrow for each box to adjust the levels you desire. Click OK to proceed to describe the factors.



Note:

How can you include multiple Signal factors?

Suppose you have 3 Signal factors at two levels. Treat them like 3 x 2 = 6 levels of Signal factor. While describing the levels of the Signal factor, keep note and describe the levels to reflect your description.

You can treat multiple Noise factors in the same manner.

Cell represents a unique condition defined by combining Signal and Noise levels. There must be at least one sample tested in each cell. Depending on the levels of the Signal and Noise, the number of samples per Cell could be very large. QT4 is limited to 120 samples per trial condition. Which means that?

Signal levels x # Noise levels x # samples/Cell = 120

Thus if # Signal levels = 3 and # Noise levels = 2, the number of samples per Cell could be as high as 120/(3x2) = 20.

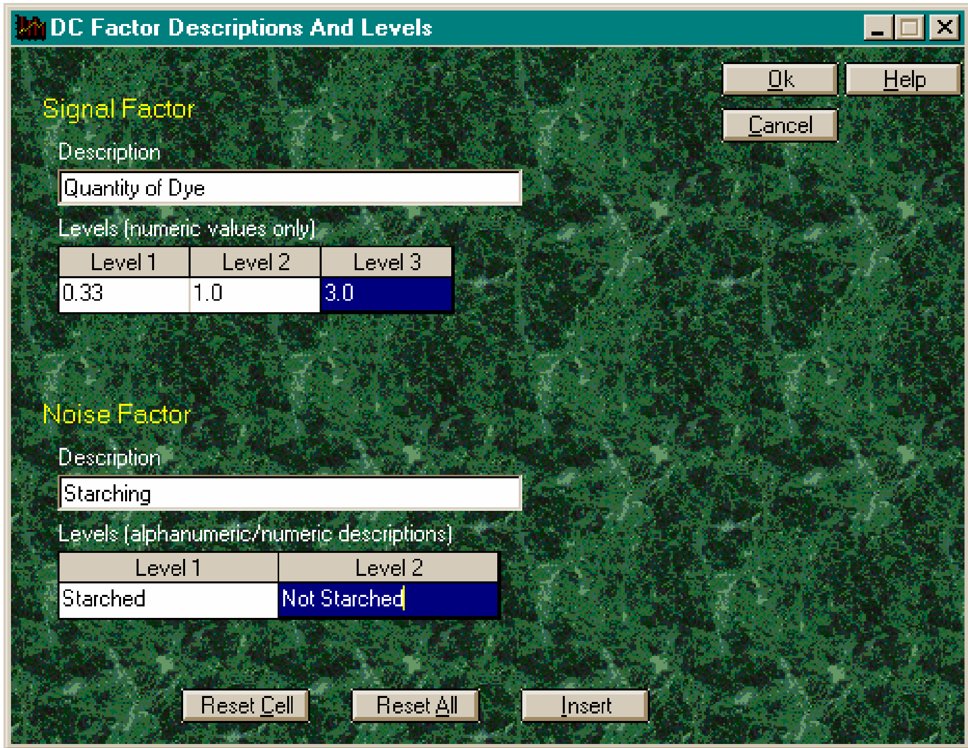
Size of Experiment Calculation

In the example considered, total number of samples required is 3 x 2 x 2 x 8 Trials = 96.

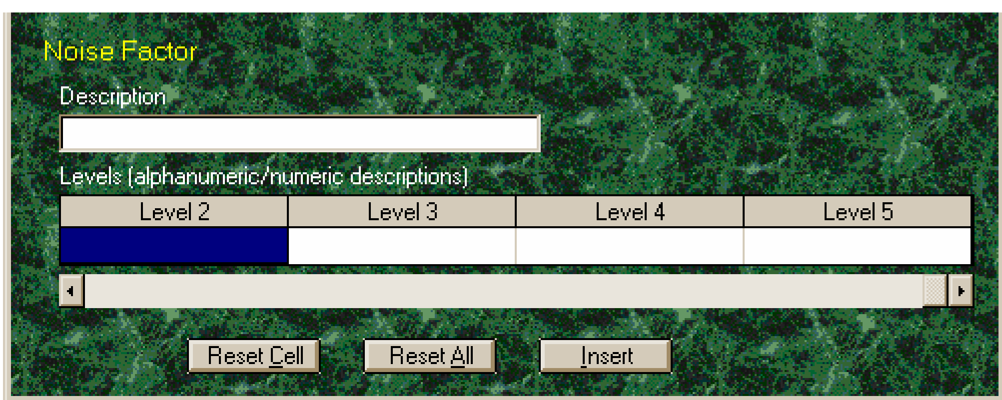
4. Describe Signal and Noise factors

Use the mouse to click on the box for description and type in the description of the Signal factor with alphabetic or numeric characters. Enter the numeric values of the Signal factor levels. The levels of the Signal factor MUST BE in terms of numeric quantities in the ascending order of magnitudes.

Similarly, key-in the description of the Noise factor. Unlike the Signal levels, the Noise levels may be described using alphabetic and numeric terms. They need not be numeric quantities.

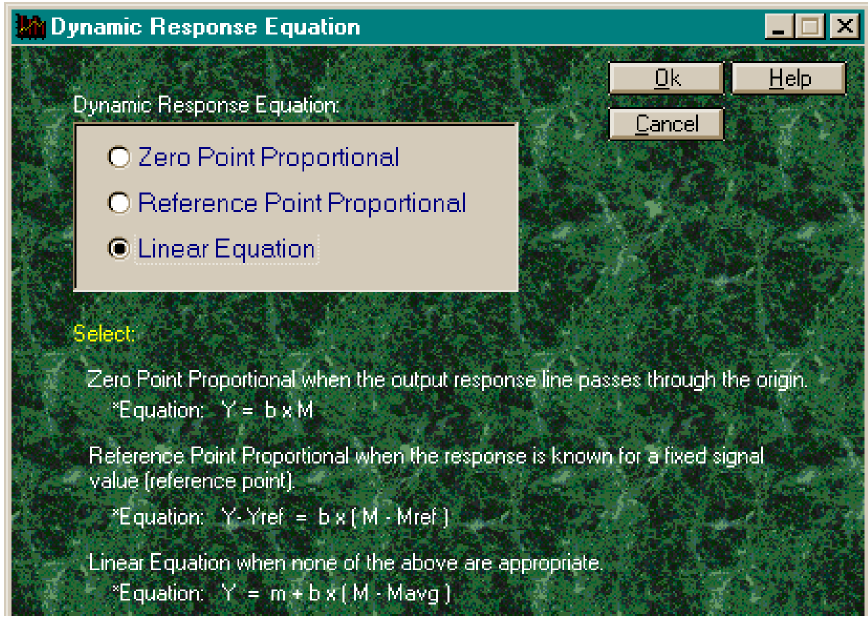


In case the number of levels of the Signal or Noise factors is larger than what the screen can accommodate, like other screens, a scroll bar will appear below the level description box. Scroll it to the right and complete descriptions of all levels before exiting the screen.

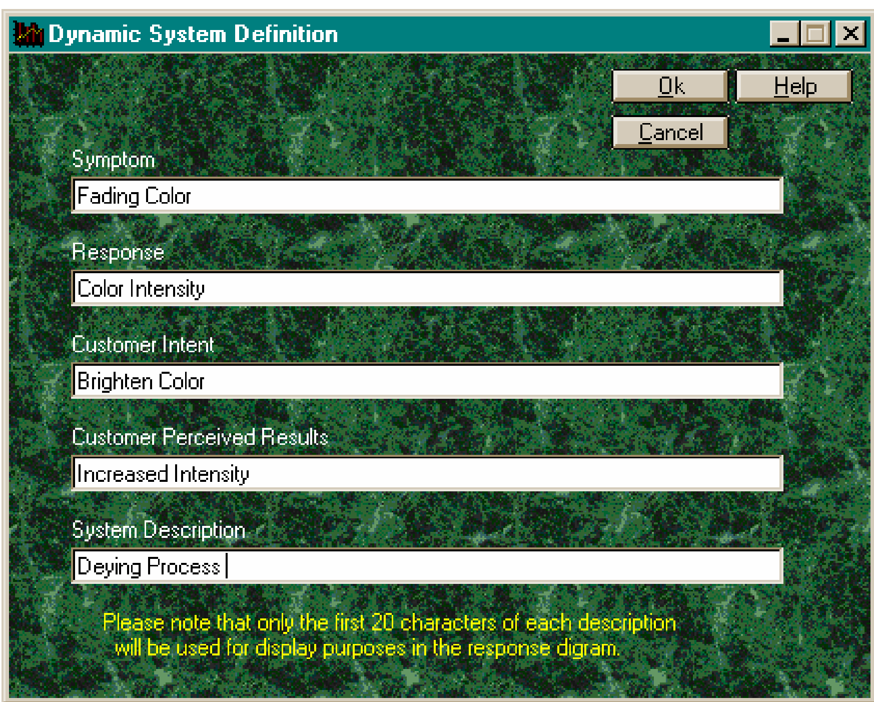


5. Indicate Response Equation Type

Depending of the nature of the dynamic behavior of the system, the response equation can be best described on of the three types of straight line equations. Prior knowledge or an assumption as to which one is most likely behavior is needed for the purposes of analysis of results. Click the item that best suits your system, then click OK to proceed.



When you are done with describing Signal and noise factors, QT4 will return you to the P-diagram. Double click on Dynamic System to enter descriptions of the system. When available, clearly describe Symptom, Response, etc. for the Dynamic System under investigation.



6. Define System Parameters

Symptom - It is the reason for the experimental study. Things that are causes for concern about the system performance.

Response - It is what the result/performance will be judged by.

Customer Intent - This is what customer does to obtain the desired results.

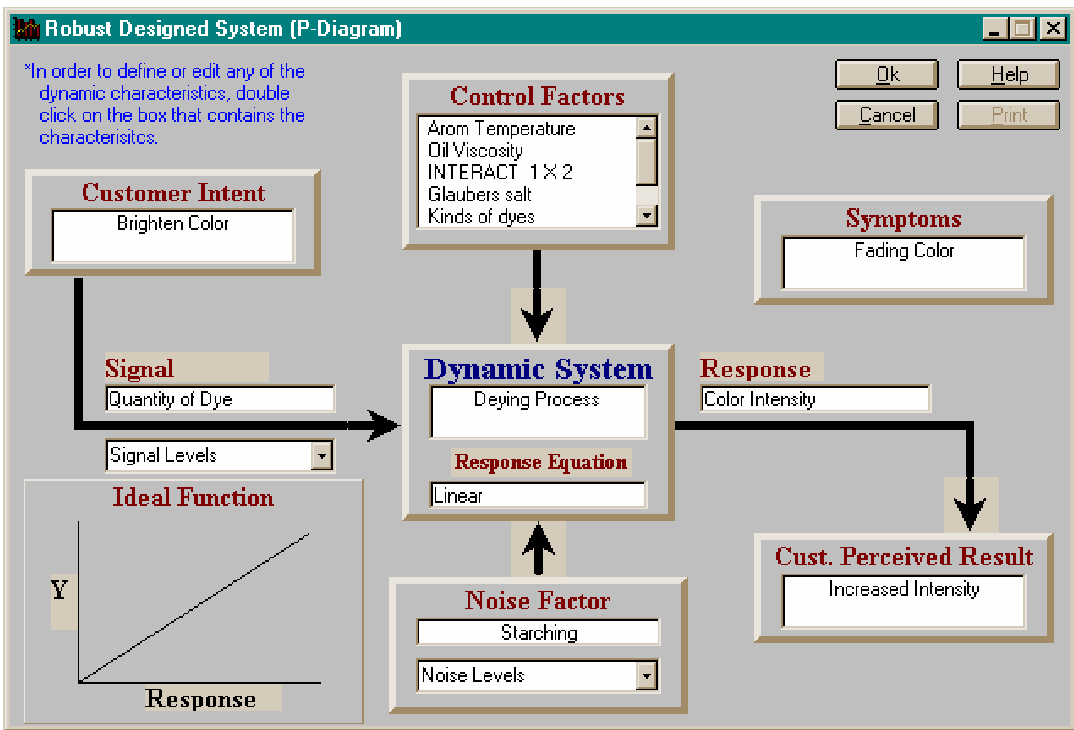
Customer Perceived Results - It is what the customer sees as the effect of improvement.

System Description - A word or two description of the system function.

Description of Signal and Noise Conditions

After experiment is designed, the combination of the Signal and the Noise levels to which the trial conditions are to be exposed can be described using REVIEW menu option from the main screen. These conditions are different from the description of the TRIAL CONDITIONS which are the combinations of control factor levels. The term NOISE CONDITION, on the other hand refers to the combinations of the Noise factor levels in case of OUTER ARRAY design, which represent the conditions under which the experiments are carried out. In the example experiment with Dynamic Characteristic, an L-8 is used for the Inner array and the three levels of Signal and the two levels of Noise creates six separate combinations(CELL). Since there are two samples tested in each cell, for each trial condition, two samples are exposed to each of the Signal and Noise combinations.

To review the Signal/Noise combination for experiment, click on the REVIEW menu item from the main screen and select Dynamic Characteristic. Review and Print descriptions using the screen buttons as desired. Note that the descriptions shown are applicable to all Trial conditions for the experiment.



Chapter 7

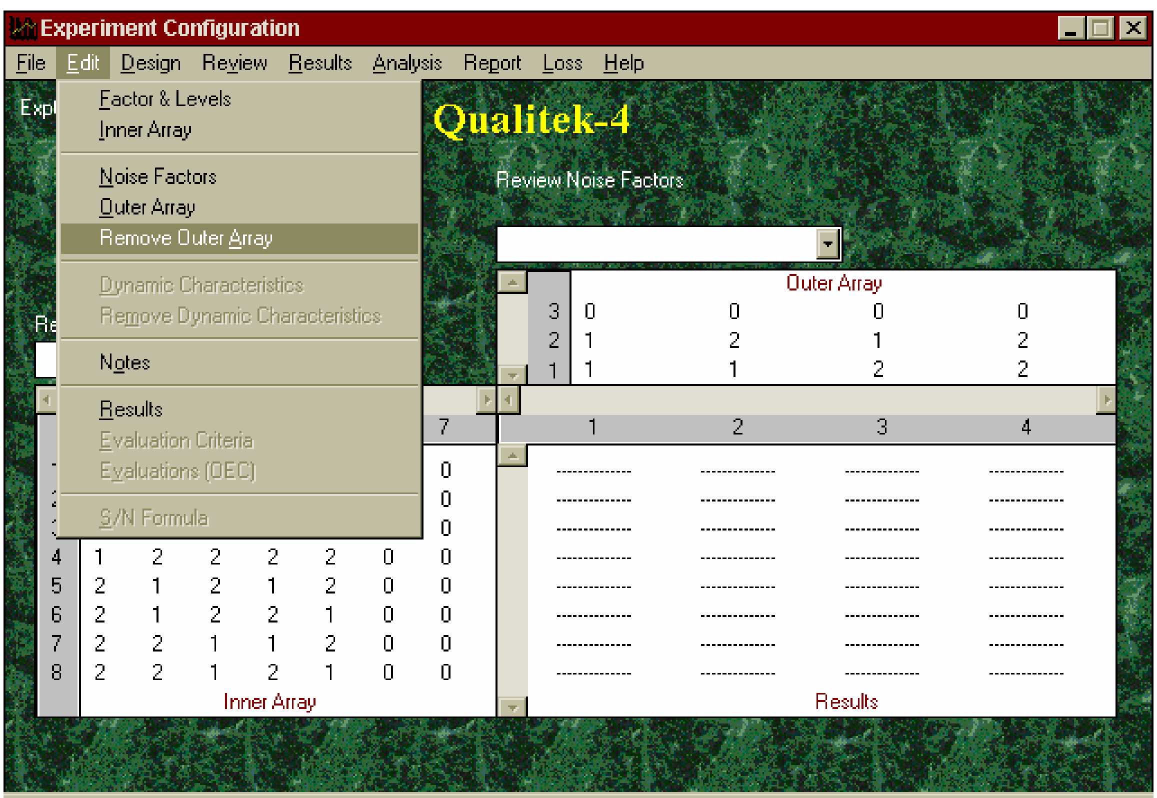
Editing Factors, Arrays and Results

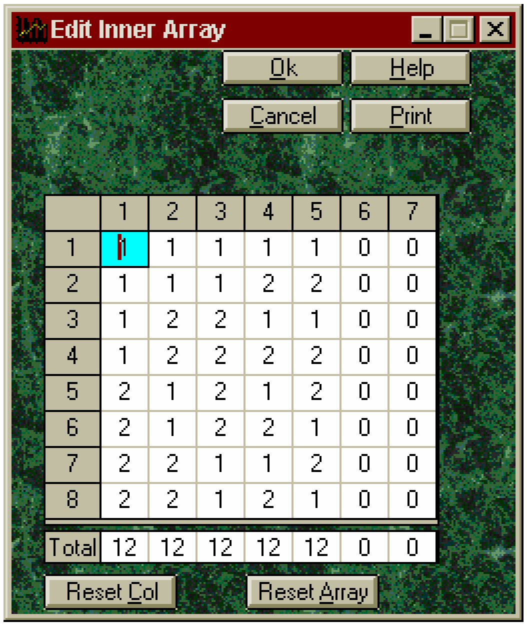
Corrections and modifications of experiment design parameters can be done online, that is while entering descriptions or results, and also after input is complete. The EDIT option from the main screen allows modifications of the Factors, Levels, Arrays, Results, etc. already entered earlier or belonging to an existing experiment. To edit information, OPEN the experiment file desired unless you are already working with the file and it is currently being displayed in the main screen.

In addition to editing factors and arrays, you will use this menu option also to REMOVE OUTER ARRAY from your experiment when you need to do so. To totally exclude the Noise factors from your experiment, simply select the option from the EDIT menu. This action removes the Outer Array and your experiment is displayed without it. BE SURE TO SAVE YOUR EXPERIMENT FILE IF YOU WISH TO RETAIN THIS EXPERIMENT DESIGN.

1. Select Menu Option

From the main screen, select the EDIT menu and click on the item desired for editing.





2. Modify Array

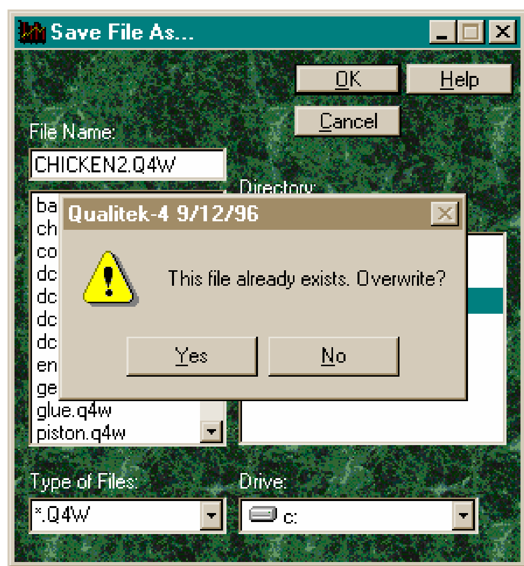
Once the item you want to modify is displayed, click on the item and retype the description. Click OK when finished. In the similar manner you can edit Control factors, Outer array, Noise factors, and Dynamic Characteristic involved in your experiment. Each item has to be selected, on e at a time from the EDIT menu, and modified.

2. Update File

Once you modify one or more data, QT4 allows you the option to save the file in the same name (update file) or save it under a different name. By default QT4 always displays the existing file name. Just click OK if you are simply updating the file.

The Save File screen always assumes that you will keep the same file name and update the existing file. If you want not to disturb the existing file and save changes under a new file name, then you type in the new file name (only the first 8 characters needed). If you keep the same file name and proceed to update, QT4 prompts to let you know that the file exits and that you are proceeding to overwrite. Click on YES button to proceed.

You can also direct the path for your file as you would in any Windows program. Click on the Directory and Drive to select the path and directory for the file you are saving.



Chapter 8

Direct Input and Preparation of Results

In Design of Experiments (DOE) the term RESULT has special meaning. For the first part, as usual, results are numerical data representing the performance of the product/process under investigation for a specific test sample. To be noted also that results are only intermediate input to the DOE application process and not to be confused with the results of analysis or the whole process. So what is obtained from analysis of the designed experiments? Of course these are CONCLUSIONS and PREDICTIONS made from the analysis.

For the second part, results could reflect combined evaluations of several objectives. In this case result is a single number without any units which is a single quantity obtained by combining several numbers representing evaluations from multiple objectives/criteria. If your experiment requires evaluation of the performance under more than one criteria of evaluation, you need to prepare the results by combining multiple evaluations into an Overall Evaluation Criteria(OEC). No matter the number of criteria of evaluation criteria, you will always have one OEC for one sample. Thus the OEC 's for the sample will constitute the results and should be used for analysis.

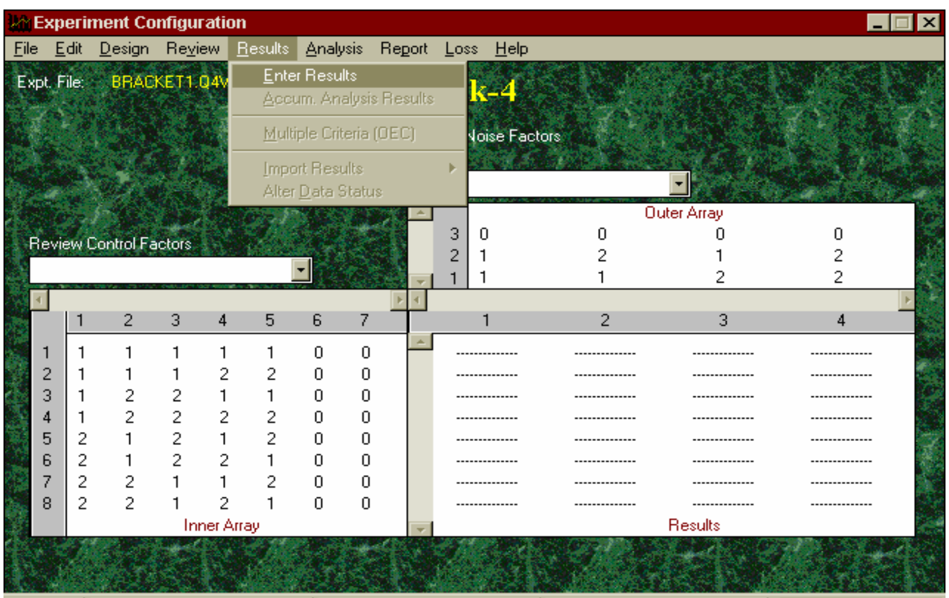
Direct Input of Results (Evaluation from Single Objective)

In case of single objective or when you wish to perform analysis using one evaluation at a time, you will enter the data directly in the result column. This is expected to be the case for most of your experiments. The number of columns of results, as always, will depend on the number of samples tested for each trial condition.

1. Select Menu Option

Open the file you want to work with and then select Enter Results from the RESULT menu from the main screen.

As you proceed QT4 erases all existing results, if any, in the file. Should you want to preserve the existing file, at end of result entry you will have a chance to save the file under a different name.

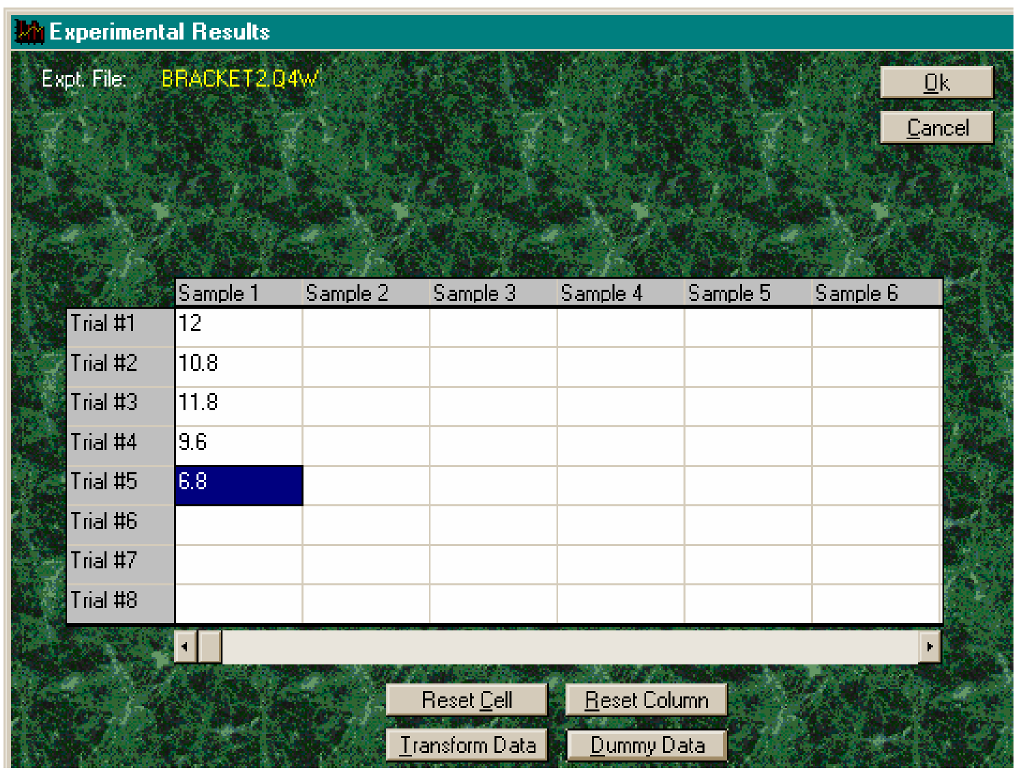


2. Enter Results and Update File

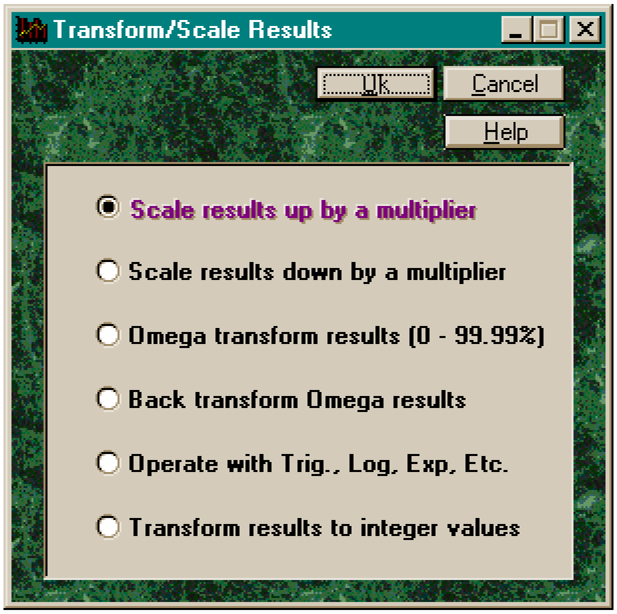
QT4 requires your experimental results to be equal in number for all trial condition. In other words you will always have full columns of results. It is a good idea, therefore, to key in results one column, starting with the first column, at a time. Your data range is between - 99,999 to 999,999. Zero is a valid entry and your results could be as small as .0001.

Reset Cell button clears a cell and Reset column will clear the entire column of data. Remember you can only see what the screen can fit. If your experiment is large, use the scroll bar to enter and view the rest of the results.

Use the Dummy Data button only when you wish a practice run. It can quickly fill the entire range of data (up to 120 columns) by some random numbers within the range you specify. When done entering results click OK to Save File option. Update the exiting file or under a new name and return to the main screen.



Transform Results



If your results are larger than 99,999 or smaller than .0001, then you should scale the results down or up as appropriate. To transform the results, after entering results, click on the Transform button and select the option you desire.

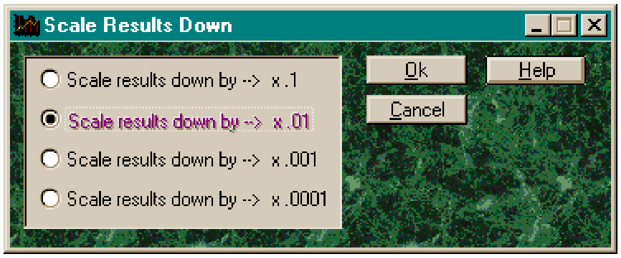
In addition to scaling results up or down, you may also convert the results in other coordinate systems.

Omega transformation - is recommended when your results are in percentages.

Back Omega transform - can be handy when you want to convert your results in percentages ranging between 0 and 99.999.

Trigonometric transform - will allow you to operate your results by Trigonometric functions.

Integer Values -will round off all your results leaving only the integer magnitudes.



Scaling Down Results

Results can be scaled down (or up) simply by clicking the option desired.

Preparation of Results (Combining Evaluation from multiple objectives)

Background
Preparation of results is a necessary consideration when your experimental results are evaluated using more than one criterion of evaluations. In this regard the word "Results" take a special meaning in DOE application process. Of course result is an intermediate input to the whole process. The basic data collected as the experimental results may be better called as READINGS. Readings represent quantitative data representing evaluation criteria. Each reading however, may be the average of many OBSERVATIONS of the same evaluation. Results can be a single READING or combination of multiple READINGS into a single index, as you as the experimenter wants it to be.

Practice of combining multiple criteria of evaluations into a single index is indeed common in academic, sporting and other competitive events. The grade point average we are so used to using, is nothing but a single quantity representing the average of all grades. The method of determining the best in the Olympic gymnastic events are determined in a scale of 0 - 6 by combining scores in several areas of performance like, jumping, style, balance, landing, etc. The scores in each of these criteria are averaged to calculate the final score.

If academic performance and sporting events can be determined by a single index, why can't scientific experiments and engineering projects be evaluated by a simplistic single index? There are good reasons. In the former cases, all evaluations have the same RANGE (low and high score) of evaluation. All evaluations also have the same units (mostly no units), same sense of desirability (Quality Characteristic/QC), same units of measurements, and same relative importance (weighting). This is not the case with scientific experiments. Thus attempts to meaningful combinations of evaluations from different criteria of evaluations, which most likely have different units of measurements and different importance, demands proper considerations of physics of the situation.

Why should you consider combining different evaluations into a single index?
When there are multiple objectives, each objective may be evaluated by different criteria of evaluations. Suppose that in the process of BAKING CAKE, the objectives are TASTE, MOISTNESS, and VOIDS. We can always analyze the results of the experiments by taking readings (single criteria reading as results) of each criteria separately and determine the best recipe for the cake. If the best recipe so determined by taking all criteria, one at a time, was the same, then there is no need to look at all the criteria collectively. But what if they are not? Which recipe then should we go for?

Just because two readings are expressed in numbers, they may not be added together to produce meaningful results. For instance, laws of physics will not allow us to combine one quantity expressed in terms of DEGREES FAHRENHEIT with another quantity expressed in terms of NEWTON METERS. The reason for this is obviously the units of measurement, which if unequal, addition is not allowed.

In addition to the units, the sense of desirability, that is the Quality Characteristic (QC) must also be of the same kind before two evaluation can be added together. Consider the case of two sportsmen who are both proficient in the game of Basketball and Golf. Their average scores are as shown.

	Sportsman 1	**Sportsman 2**	**QC**
Basketball	28	33	Bigger is better
Golf (9 holes)	42	37	Smaller is better
Totals	70	70	

Who is the better player? To answer this question, we will be grossly wrong if we simply compare their total scores. This is because, even though the two scores have the same unit of measurement, their sum does not produce meaningful numbers as they have different sense of desirability(or QC) since in the game of Basketball, the higher score is desirable, where as in the game of Golf, a lower score wins the match.

Measurements involved in engineering and science most often include evaluations which have different units of measurements and also different QC's. Combining them into a single index, called an Overall Evaluation Criteria (OEC), requires some adjustment to formula combining the individual criteria of evaluations. First the readings under individual evaluations must be NORMALIZED, that is freed from their units (dimensionless). Second, contribution from all reading must conform to the same QC, either Bigger or Smaller. Third, individual readings must be represented in proportion to the relative weightings (degree of importance) determined subjectively by the project team consensus. Consider the CAKE BAKING process and suppose that following were decided in the planning session convened for the experimental study.

Evaluation Criteria Table and OEC

Criteria Des. (X)	Worst Reading (X_w)	Best Reading (X_b)	QC	Rel. Weighting (W_t)	Sample Reading (X)
1. Taste (X_1)	0	12	Bigger	55%	9
2. Moistness(X_2), grams	25 - 50	40	Nominal	20%	34.9
3. Voids (X_3)	8	2	Smaller	25%	5

Overall Evaluation Criteria (OEC)

$$\textbf{OEC} = \left(\frac{|X_1 - X_{1w/b}|}{|X_{1b} - X_{1w}|} \right) \times W_{t1} + \left(1 - \frac{|X_2 - X_{2w/b}|}{|X_{2b} - X_{2w}|} \right) \times W_{t2} + \left(1 - \frac{|X_3 - X_{3w/b}|}{|X_{3b} - X_{3w}|} \right) \times W_{t3}$$

For the sample data: (example calculation with $X_1 = 9$ $X_2 = 34.9$ $X_3 = 5$

OEC = (9-0)/(12-0) x 55 + (1 - (34.19-40)/(40-25)) x 20 + (1 - (5-2)/(8-2)) x 25 = 41.25 + 12.25 + 12.5

= 66.0

Explanation of OEC equation

The Taste reading is a subjective evaluation and agreed to be a number between 0 to 12, with 12 being the best possible reading. The QC for this criteria is Bigger is better and since it carries a heavier relative weighting (55%), all other criteria will be made to conform to this QC.

The individual criteria reading(X) are first subtracted by lowest magnitude of the best or worst readings ($X_{w/b}$). This quantity is then divided by the range of the reading (best - worst) to convert the quantity into a dimensionless number. The resultant is now multiplied by the relative weighting expressed in percentage which reflects the appropriate importance carried by these particular criteria.

The second criteria, Moistness measured in grams is such that a fixed volume measures 40 grams in ideal condition, and the range is expected between 25 and 50 grams. This constitutes a *Nominal is the best* QC. A nominal reading is equivalent to *smaller is better* reading when the nominal value is subtracted from the reading. But in order to add a *Smaller is better* reading with one that is *Bigger is better*, its QC is theoretically changed to *bigger is better* by subtracting its effect from 1. Again the whole quantity is multiplied by the relative weighting for the criteria.

The third criteria, Voids, are a count of number of voids ranging between 2 and 8. Since least number of voids is desirable, this criteria is also handled the same way by converting its influence to *Bigger is better* QC.

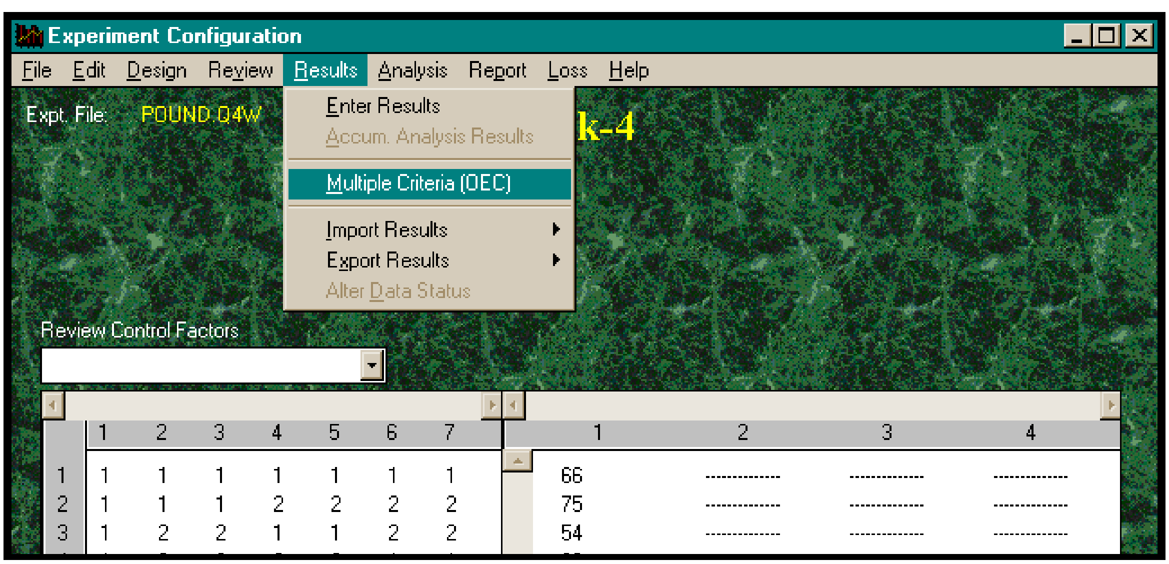
Qualitek-4 can prepare the OEC's which are considered as the RESULTS for the analysis when you describe the evaluation criteria table and enter the readings appropriately. To prepare the OEC from the reading under multiple criteria of evaluation follow these steps.

1. Describe Evaluation Criteria Table
2. Enter Evaluations for each sample under each Trial condition
3. Review OEC and accept (or reject) them as results.

1. Select Menu Option

Open the file you want to work with and then select Multiple Criteria(OEC) from the RESULT menu from the main screen.

The purpose of creating OEC's is to have an option to analyze the results using a single index for each of the sample by combining more than one evaluation criteria. Of course, when analysis is desired using readings under each individual criteria, the corresponding reading (one criteria readings at a time) can directly be entered as result using the Enter Result option.



2. Describe Evaluation Criteria (How to enter data)

Before entering any readings (sample evaluations), the criteria of evaluations must be described. To describe items, click the appropriate space first(use POUND.Q4W as a reference experiment)

a. Describe Criteria. Example: Taste (See Criteria Definition screen in next page)
b. Enter a numeric value under Worst Vlaue. Example: 0 (expected worst reading)
c. Enter a numeric value under Best Value. Example: 12 (expected best reading)
d. Click on QC until desired character appears. (must be consistent with best/worst value)
e. Enter a number between 1 and 99 in column for Rel Wt. The Rel. Wt. for all criteria must==100.
f. Click/Check the column Used to indicate the criteria is included.
g. Repeat steps a - f above to describe the other criteria.

Definitions

Criteria - can be any alphanumeric characters.

Worst Value - This is the worst reading expected/found among all samples tested. It must be numeric (in case of Nominal QC, it must be the worst deviant from the nominal value. For example, if range of expected readings is 25 - 50 and the nominal is 40, then worst reading will be 25)

Best Readi ng - It is the best possible numeric reading. In case of Nominal QC, it must be the target/Nominal value.

QC - It is the quality characteristic of the individual criteria of evaluation. Click this space to select the appropriate characteristic.

Rel. Weighting - It is the relative importance of the criteria in terms of a number between 0 - 100. It represents percent of importance, but % sign is not to be entered. All relative weighting must add to 100. And, of course, 0 will mean that the criteria are not included in calculating OEC.

Used - You must click this column and make sure X sign appears indicating that the criteria is included. This must be done before you can enter sample readings.

Once the criteria are described, you may enter readings under different criteria. Click on the appropriate space and key in data. Click on Trial# box to select the correct trial number.

3. Enter Evaluations (Original readings under each criteria of evaluation)

After the criteria are described, evaluations under each criterion are entered, for one test sample at a time. Each test sample tested is identified by a trial number and a run number. Each sample then, will have as many evaluations (one readings for each evaluation criteria) as the number of criteria described and checked (Used column). The numbers 11, 44 and 3 shown in the screen(next page) represent the Taste reading(11), Moistness reading(44), and Voids (3) reading for the first sample(Run#1) of Trial 1. As evaluations are entered, the OEC values are calculated and placed in the proper trial# and run# location.

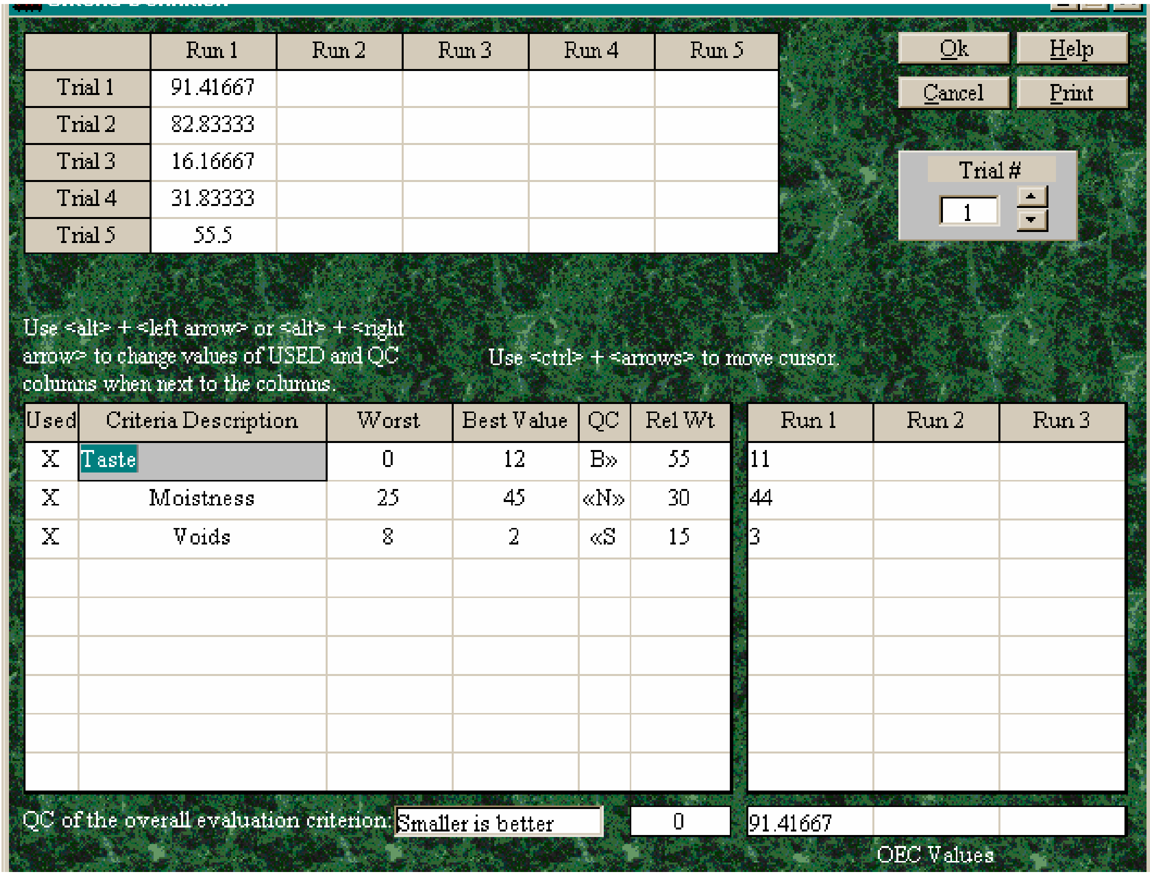
Qualitek-4 requires that all trial condition have the same number of runs. Therefore, evaluations for all trial and the same run numbers for all trials must be entered before clicking OK, which makes QT4 accept OEC as results. The QC for the result now becomes the Quality Characteristic shown for the OEC (as decided by Qualitek-4 based on the relative weightings of the criteria)

Be sure to **SAVE** experiment file by selecting Save or Save as from the File menu option.

4. Review OEC Values

Select OEC from the EDIT menu to modify any description or evaluations.
Be sure to SAVE experiment file by selecting Save or Save as from the File menu option.

[This capabilities were under development at the time of publication of this manual.]



OEC SUMMARY

When the product/process is to satisfy more than one objective, performances of samples tested for each trial condition are evaluated by multiple criteria of evaluations. Such evaluations can be combined into a single quantity, called Overall Evaluation Criteria (OEC), which is considered as the result for the sample. Each individual criterion may have different units of measurements, quality characteristic, and relative weighting. In order to combine these different criteria, they must first be normalized (no units), QC aligned (either Bigger or Smaller), and weighted accordingly.

When multiple objectives are present, as always, results of the experiments can be analyzed by taking evaluations (which is considered results for analysis) of each criteria, separately. This way a complete analysis can be performed based on each criteria of evaluation. If all such analyses produce the same optimum design and the same trend of factor influences, there would be no need for an additional analysis. Should they differ, however, an additional analysis using OEC may produce some vital statistics reflecting the relative merits (weightings) of the individual criteria of evaluation as determined by the project team during the planning session.

Evaluation Criteria Table

Criteria description	Worst reading	Best reading	Quality Characteristics	Relative Weighting	Sample 1 Readings
Taste	0	12	Bigger	55 %	11
Moistness	25	45	Nominal	30 %	44
Number of Voids	8	2	Smaller	15 %	3

Overall Evaluation Criteria(OEC)

Example: Test Sample for Trial 1, Run 1

Before combining readings of all criteria, each reading is made dimensionless by dividing by a reference number, which is the difference of the Worst and the Best reading. To avoid complication due to SIGN changes, absolute values are used. To make logical meaning out of adding two numbers, their QC's must also be of the same kind. Both Smaller and Nominal(which becomes Smaller when deviation from the nominal is used) QC's are transformed to act like Bigger QC by subtracting the fraction contribution from 1. Each criteria contribution are then multiplied by their respective relative weighting to for the OEC. Since all criteria have been made to behave like the Bigger QC, the QC for OEC is now Bigger is better. The decision about whether the OEC is made to have Bigger or Smaller QC depends on the cumulative percentages of all criteria with Bigger QC(over 50 or not).

$$(OEC)_{11} = \left(\frac{|11 - 0|}{|12 - 0|}\right) \times 55 + \left(1 - \frac{|44 - 45|}{|45 - 25|}\right) \times 30 + \left(1 - \frac{|3 - 2|}{|8 - 2|}\right) \times 15$$

$$= (11/12) \times 55 + (1 - 1/20) \times 30 + (1 - 1/6) \times 15$$

$$= 50.41 + 28.5 + 12.5$$

$$= 91.41$$

Likewise OEC for all runs in all trials are calculated. The Quality Characteristic(QC) for OEC is Bigger is better as all criteria have been switched to align their QC to match that of the Taste. This is done by (1 - fraction contribution), etc.

Note that there can be only one OEC (or RESULT) for a single sample and that the OEC calculated for each sample becomes the sample RESULT, which are then be used to carry out the analysis and to determine the optimum condition.

Exporting and Importing Results

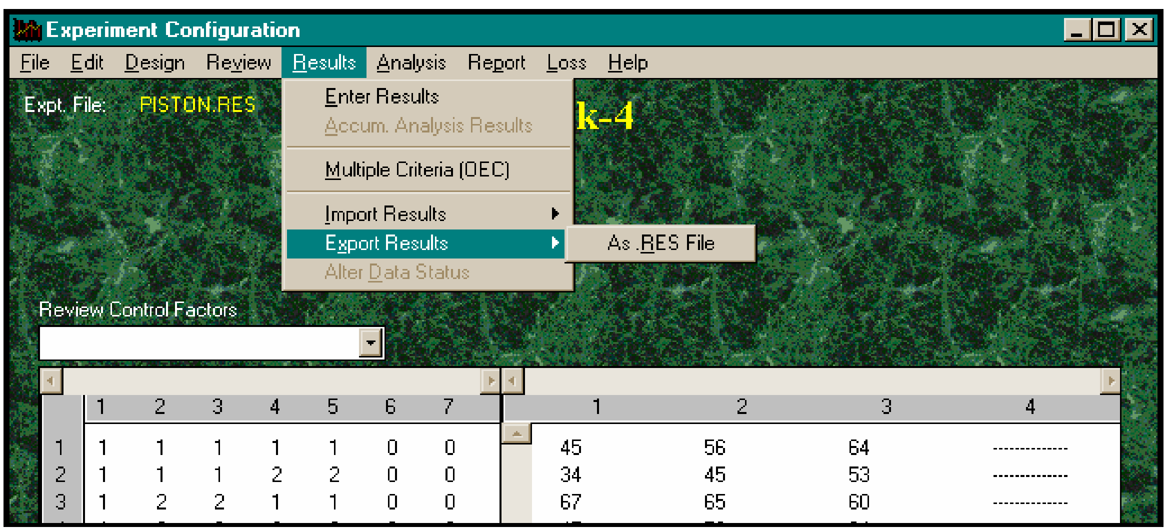
Results of your experiments can be exported for use by other analysis software. Results also can be imported saving manual entry. This would particularly be helpful when your array is large and the number of samples per trial is also large.

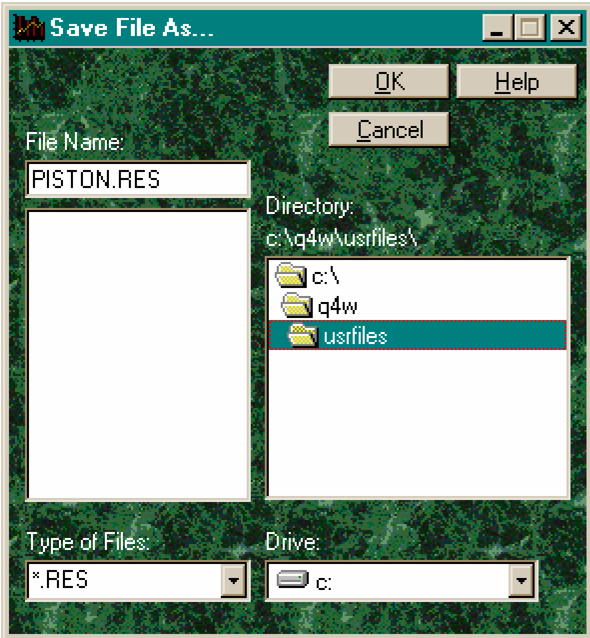
For exchanging results with another statistical analysis program or simulation model, the data format has been kept to basic text format. The result file can be created using DOS EDIT or made using and word processor program then saving them as text file. In either case, the file format must be strictly followed. The result file must be named with an extension .RES. In other words, for PISTON.Q4W file, the result file will be PISTON.RES. The exact format of the file can be seen by reviewing any .RES file in your directory or by exporting PISTON.Q4W file which will create a PISTON.RES file automatically.

1. Select Menu Option

Open the file you want to work with and then select Export Results from the RESULT menu from the main screen.

If you are importing results for the first time or you want to learn how to export results, you will find it beneficial to practice exporting results with PISTON. Experiment file. Open PISTON file and proceed.





2. Save Result File

The export file will be automatically named same as the experiment file of origin of the result with extension .RES. You will have the option to name differently if you want. You may also direct it to any directory and path of your choice.

The file saved will contain the results of the experiments with some instructions about the format which can be deleted or expanded as desired.

The **file format** shown below or how the export file appears must be maintained for the results file to be imported. The results from an experiment with L-8 array and three samples per trial will appear as the one shown below.

PISTON.RES (File format/content)

REM - This is a file of the results of PISTON.RES
REM - The number of results on each line is determined by NR
REM - but, the amount that can fit on a line in a text file
REM - is dependent on the text editor your using (usually 1022 characters)
REM - All files of this type must be in this format. There can be as many
REM - of these **REM lines as desired with no blank lines in between**. Then,
REM - there must be **one blank line after the REM lines**. The next line must
REM - be the **NE value**. The next line must be the **NR value**. Then each
REM - subsequent line must be each subsequent row of the result array with
REM - the values separated only by a comma.

8
3
45,56,64
34,45,53
67,65,60
45,56,64
87,81,69
78,73,68
45,56,52
42,54,47

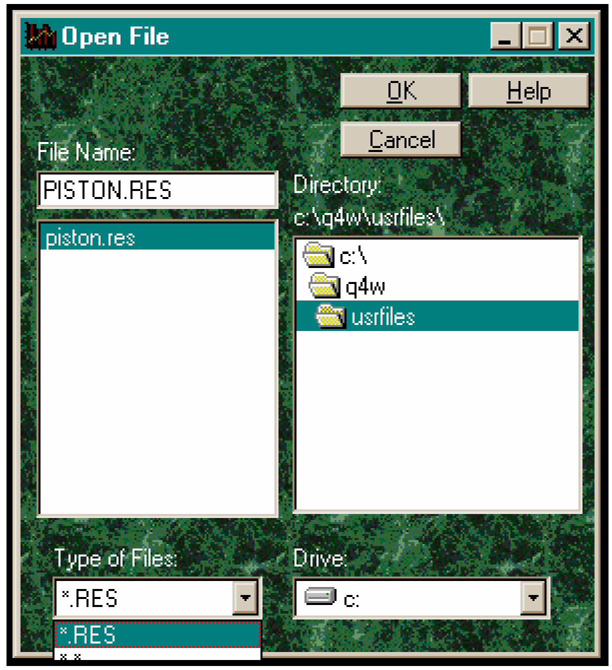
Importing Results File

Open the file you want to work with and then select Import Results from the RESULT menu from the main screen.

From the file selection screen, look for the .RES file you want to import. The file you want to imp ort need not be named same as the file name of your experiment. It can have any name as long as it has the extension .RES and contains results in the required format. If you do not see the file in the display window, be sure to adjust the Type of File and select the file. If your file is stored in another directory or drive, change the path accordingly.

If your experiment file happen to have results already, but you wish to overwrite or discard this results, you may do so by selecting Enter Results first and then CANCEL option. This will remove the old results and ready you for importing the result file.

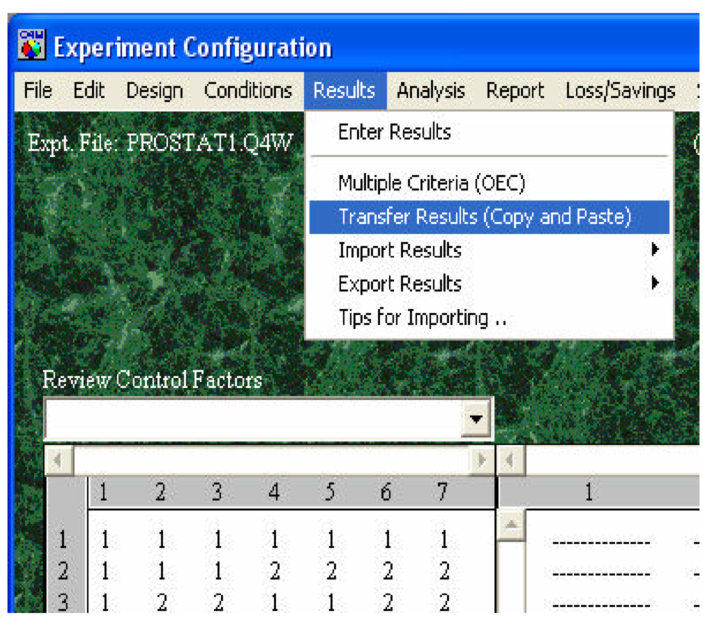
Before creating result file for import, review any existing ____.RES file or examine it by first creating a result file by exporting results from PISTON.Q4W file.



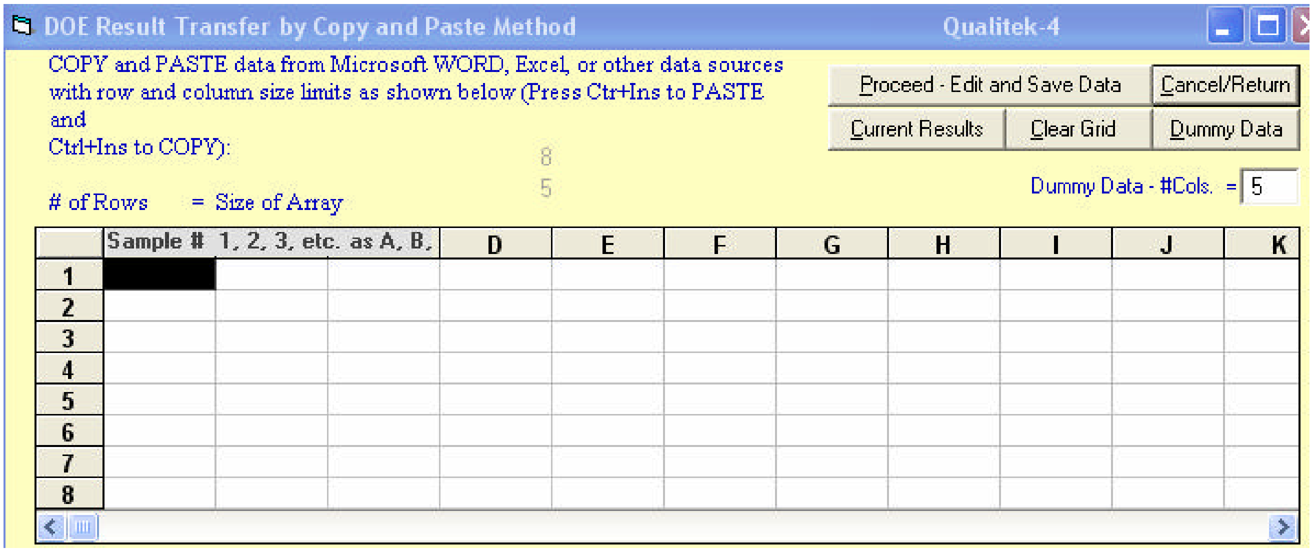
Transferring Results by Direct COPY and PASTE Method

To transfer results from spreadsheet or word processing, or text editor programs, follow the Transfer Results option from the Results menu in the Main Screen. You may find this option convenient when your experiment and/or the number of samples in each trial condition is large.

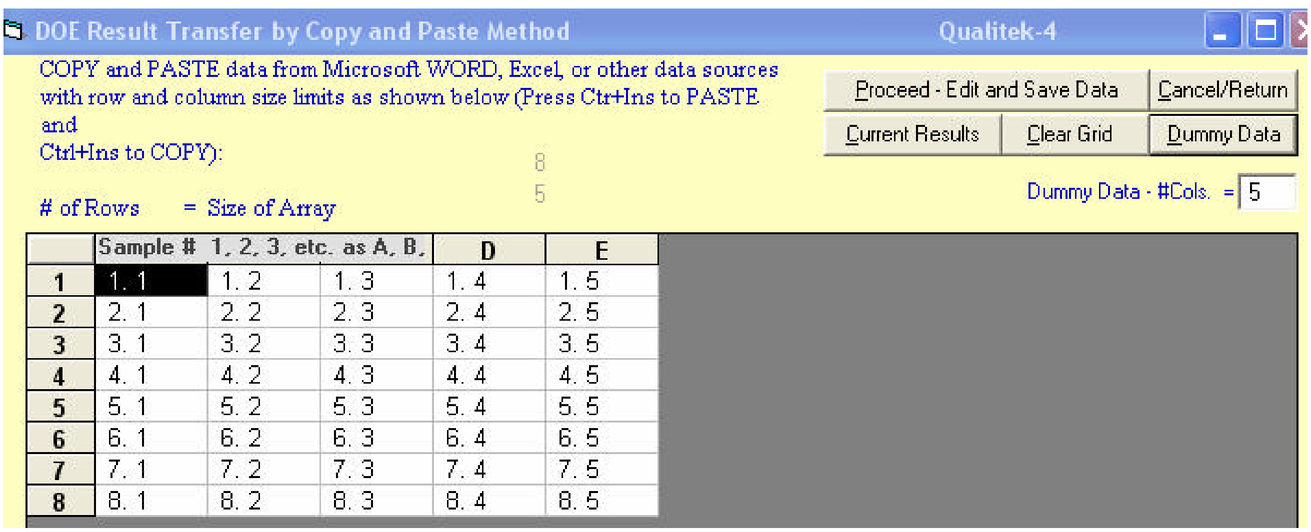
When you select this method of importing results, you will see the screen shown next.



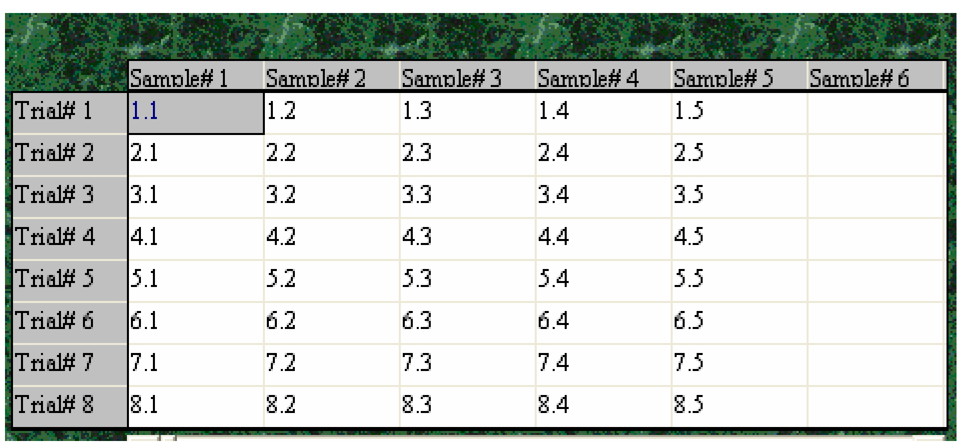
You can COPY and PASTE your results in a spreadsheet or word processing document. Make sure that the row and columns of your results matches the need for your experiments. That means that the number of rows of results must equal the number of trial conditions and the number of columns be within 120.



For practice, you may create DUMMY data with any number of columns (<120). A set of DUMMY DATA with 5 columns is shown below. When you are satisfied with the results in the grid, click Proceed –Edit and Save Data button.



The data you accepted will be shown in the next screen for your review. You will now be able to edit or modify these results using the options in this screen.



	Sample# 1	Sample# 2	Sample# 3	Sample# 4	Sample# 5	Sample# 6
Trial# 1	1.1	1.2	1.3	1.4	1.5	
Trial# 2	2.1	2.2	2.3	2.4	2.5	
Trial# 3	3.1	3.2	3.3	3.4	3.5	
Trial# 4	4.1	4.2	4.3	4.4	4.5	
Trial# 5	5.1	5.2	5.3	5.4	5.5	
Trial# 6	6.1	6.2	6.3	6.4	6.5	
Trial# 7	7.1	7.2	7.3	7.4	7.5	
Trial# 8	8.1	8.2	8.3	8.4	8.5	

Chapter 9

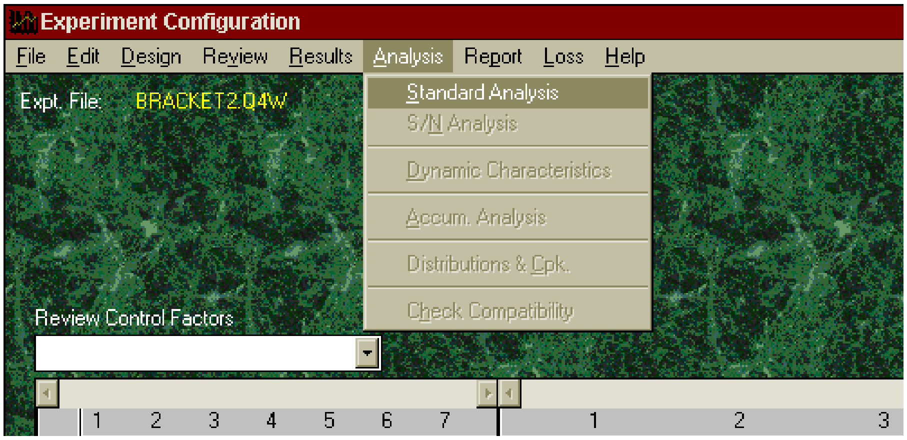
Analysis of Results

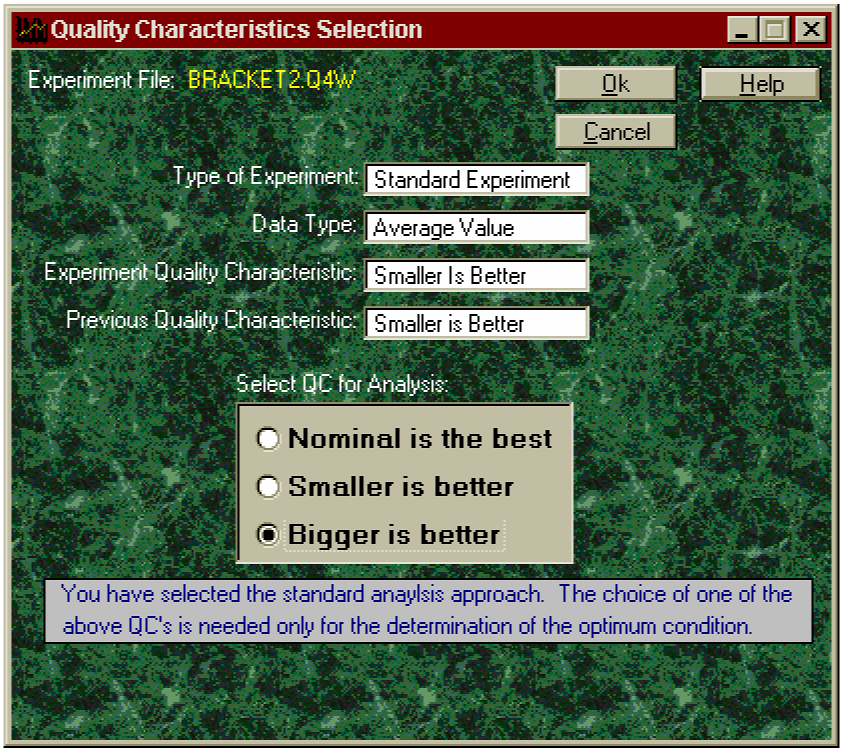
When all the trial conditions are tested and the results are entered into the experiment file, analysis of the results can now be performed. QT4 allows you to analyze the results in two ways: Standard Analysis is always performed when there is only one sample tested for each trial condition. In case of multiple samples per trial, Signal to Noise ratio (S/N) analysis is strongly recommended, but Standard analysis can be performed if desired. To demonstrate all major steps in analysis, the BRACKET example created earlier with one sample per trial will be considered.

Standard Analysis

1. Select Menu Option

Open the file you desire to work on. From the main screen, select Standard Analysis from the ANALYSIS menu option. If there were multiple columns of results, which will be the case when multiple samples for each trial were tested, you should analyze the results S/N ratios for each trial results.





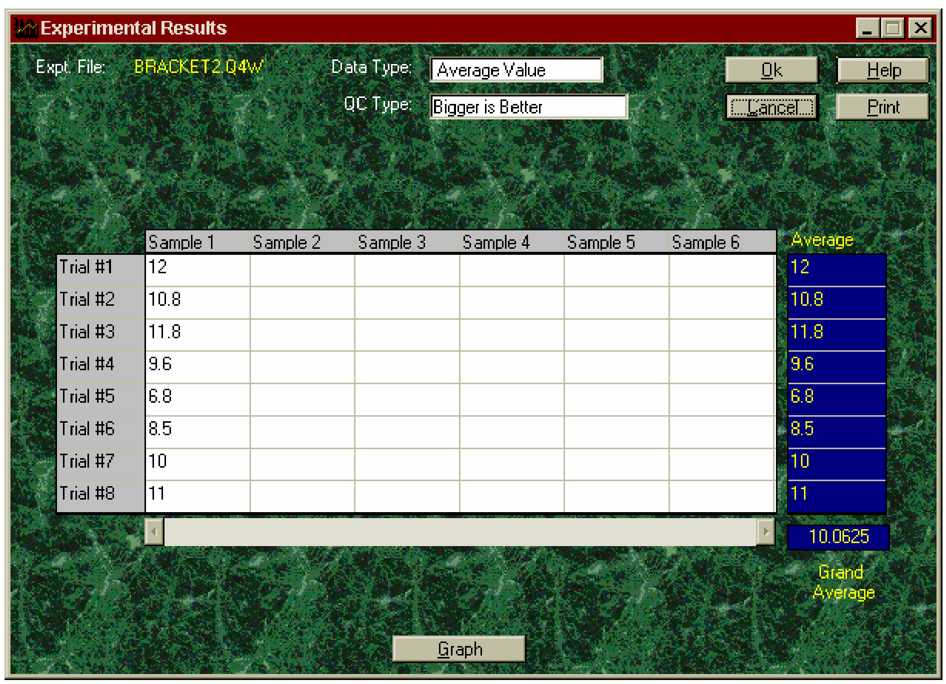
2. Select Quality Characteristic for Analysis

Whether you wish to perform Standard or S/N analysis, you have the option to pursue the same with one of the three Quality Characteristics (QC). Although your experiment most likely will have a fixed QC, you may select one QC at a time and perform analysis. The QC for your experiment and the one selected for the previous analysis are shown just above the QC selection box.

Check one of the three QC and click OK to proceed.

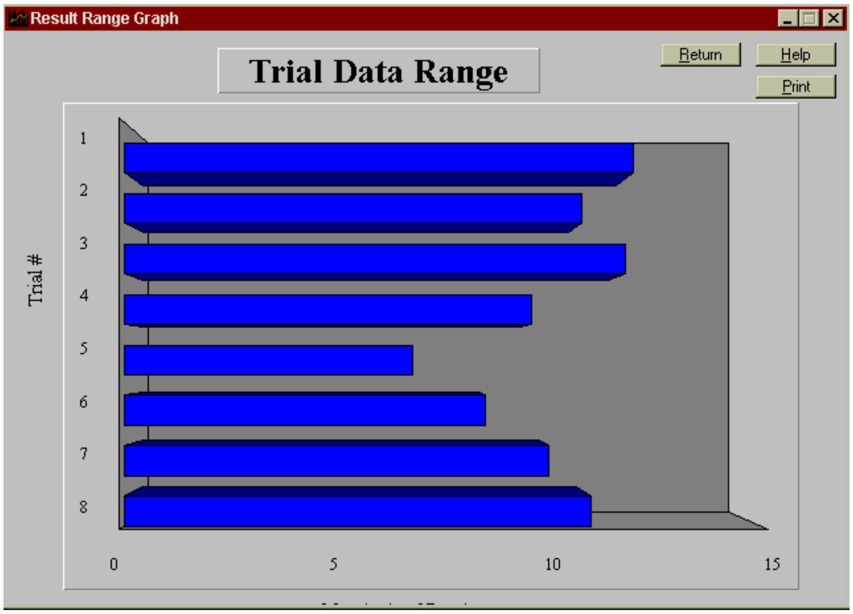
3. Review Results

This screen allows you to examine the results. If the size of the array is larger than the display area, be sure to click the scroll keys to review all rows and columns of results. The numbers under the BLUE shaded area lists the trial averages. In case of S/N analysis these numbers are the S/N ratios for each trial condition. Click on the GRAPH button to display graph of the results. Click OK when done.



4. View Results Graph

Bar graph of the trial results displays the variations of results within and between trial conditions. Click RETURN when done.



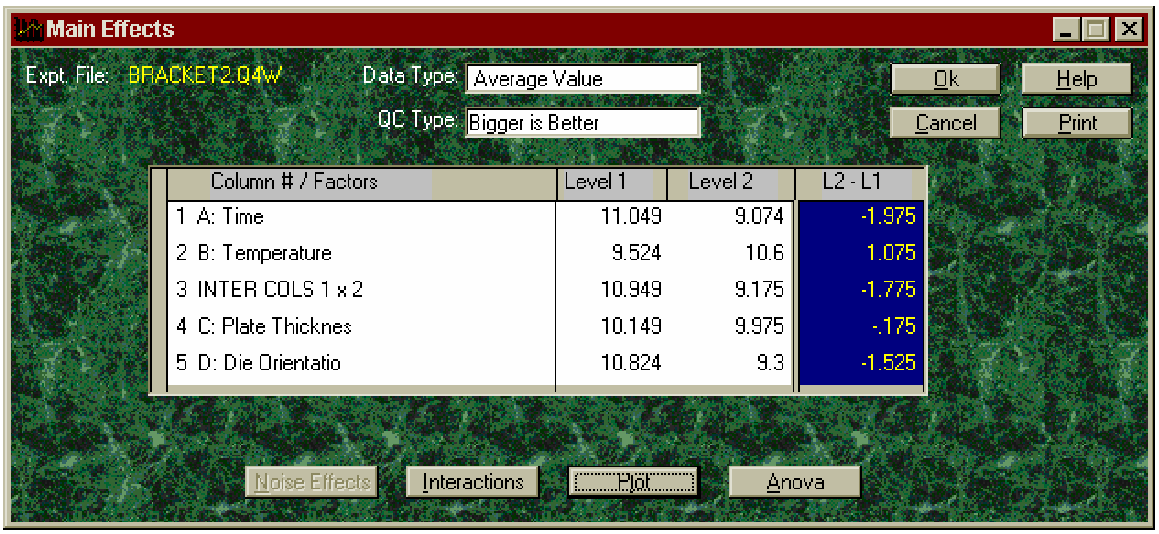
4.View Results Graph

Bar graphs of the results captures the variation of the same within and between trials. In the example case, since there is only one result for each trial, the bars graph as solid bars. In case of multiple sample results, the variations within the trials are shaded. Click RETURN when finished with review.

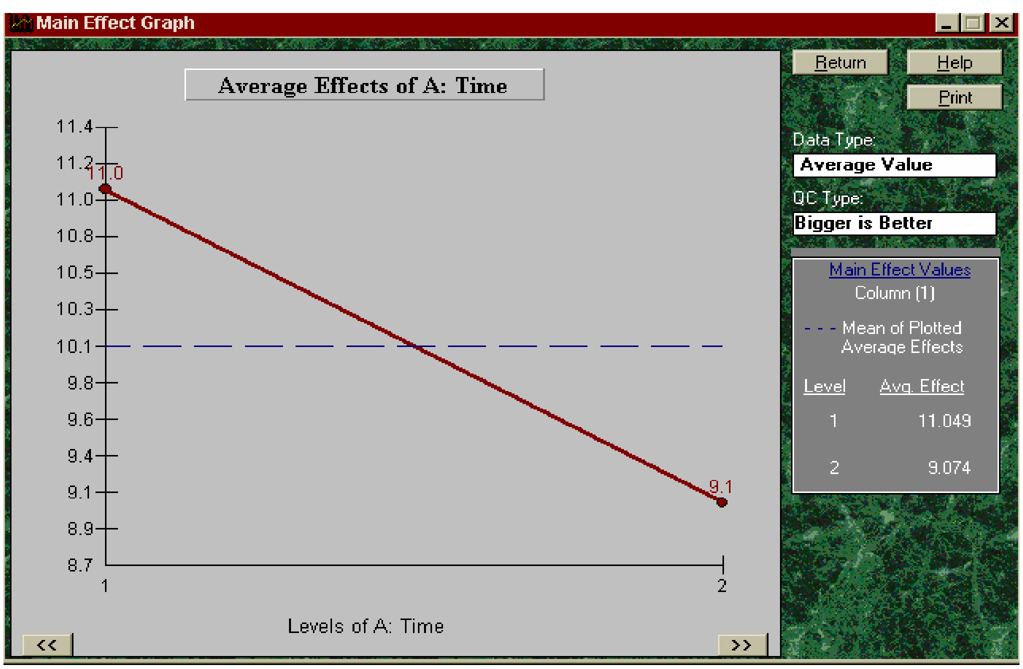
5. Study Factor Influences and Interactions

The averages of the trial results are used to calculate the average effects of factor at each of its levels. The difference between average effects and level 1 and level 2 are also shown as most common experiments involve 2-level factors.

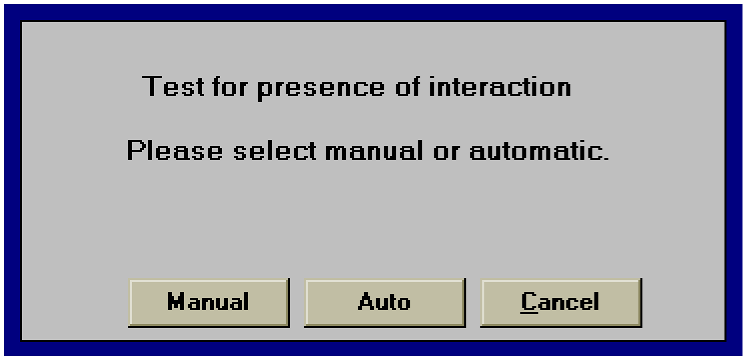
Click on the PLOT button to review graphs of individual factor influence. Click on the INTERACTION button to study interaction between any two factors.



You can view factor influence graph one factor at a time. Click the buttons at the bottom of that graph to view other factor graphs. The calculated values of the average effects used for the plot are shown on right. Click RETURN to go back to the Main Effect screen.



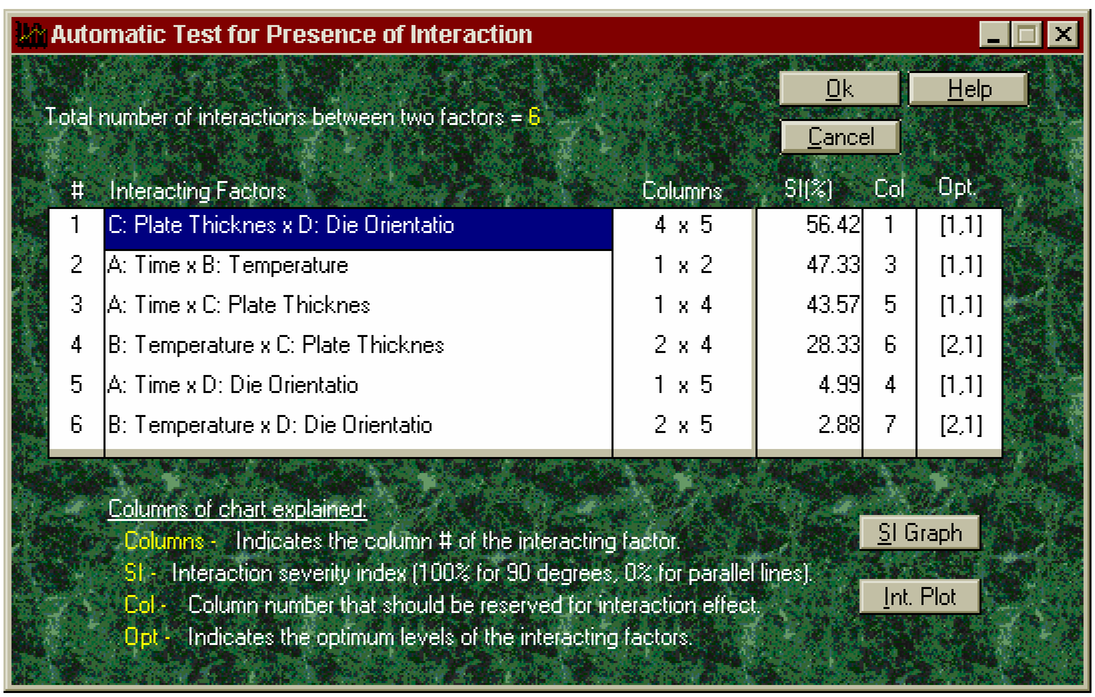
When you click th interaction button, QT4 allows the option to view interaction between selected pair of factors or let it calculate all possible interactions for your review. Click on MANUAL if you want to view interaction between any two factors, then double click on the factors. If you want QT4 to calculate all possible interactions, select AUTO.



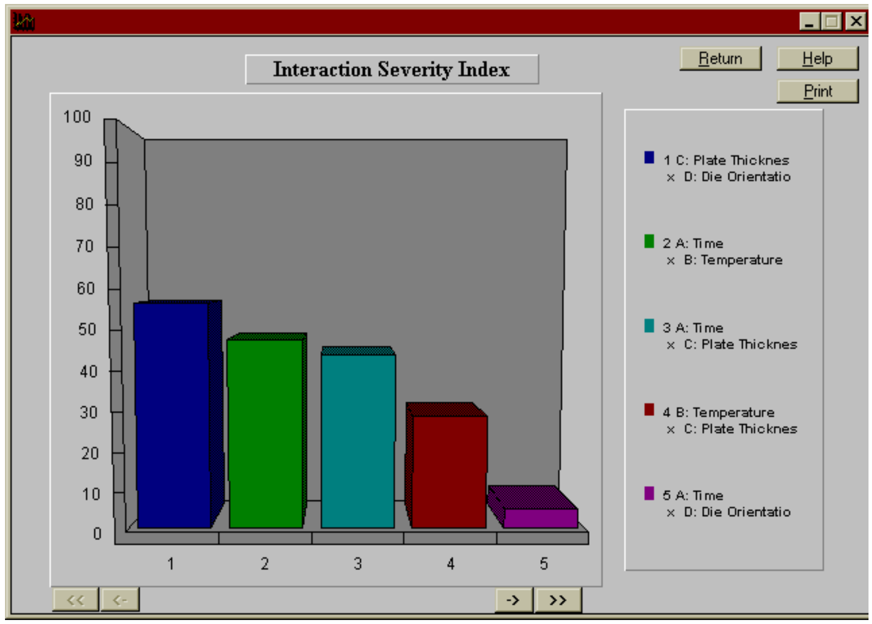
In AUTO option, QT4 calculates n(n-1)/2 interactions for n number of factors in the experiment. Thus if there were 15 factors, 15x(15-1)/2 = 105 interactions are calculated. In the current example there are only 4 factors which give rise to 6 interactions.

To rank the strength of these interactions in descending order, a quantity called SEVERITY INDEX (S.I) is calculated. The values of S.I. range between 0 - 100% corresponding to the angle between the interaction lines of 0 - 90 degrees.

To examine an interaction, double click the Interaction Factor descriptions. Click on the S.I. button if you want to examine the interaction pairs and their ranking.



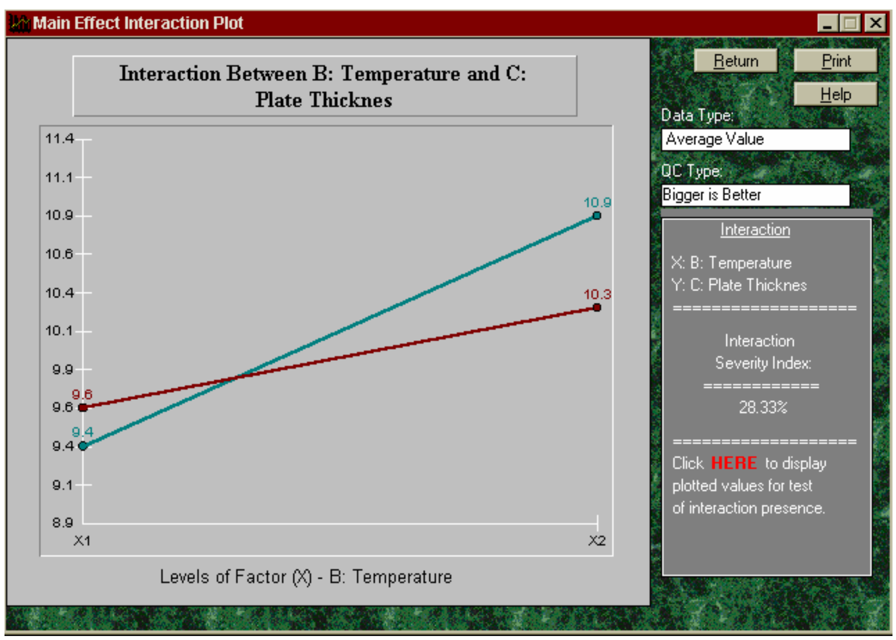
S.I graph shows the ranking of interactions based on their strength of presence.



How can you make use of the S.I. graph and its ranking?

For most part this information is useful in your subsequent experiments, if you decide to peruse any. The top ranking interactions are the ones to be included for your follow up experiment. Even if an interaction is strongly present, it is not an indication of whether it is significant or not, which can only be determined from ANOVA. But ANOVA allows test for significance only when a column is reserved for the interaction which is not the case for most interactions considered in the S.I. graph.

How would you decide whether you need to run follow up experiments? Use the confirmation test results and how close to estimated performance it is, as the indicator. If you do not confirm, there is a good possibility that the interaction studies will yield better results. Which interaction should you include in the future experiments? Use the S.I. information to develop your new experimental study.



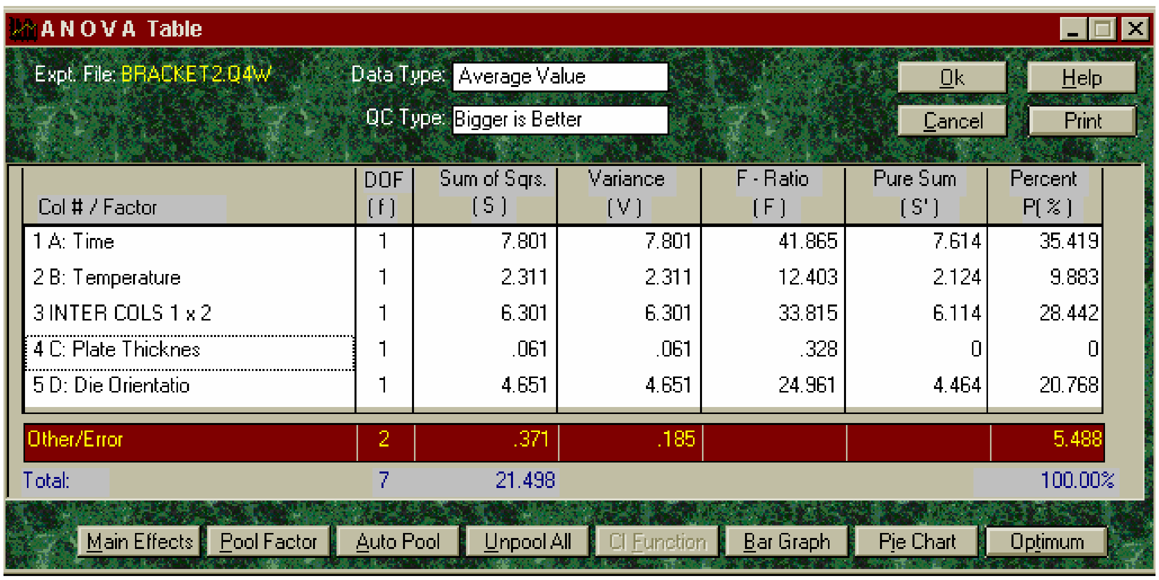
If you happen to find an interaction which is already included in your experiment, is significant (in ANOVA), then the review of the interaction plot is important. The factor levels most desirable to incorporate the interaction effect into the prediction of the Optimum condition and the performance, are determined from this graph. If QC is *Bigger is better*, the desirable level is obtained by the levels represented by the highest pint in the graph. The opposite is true if the QC were *Smaller is better*.

At the conclusion of interaction plot review, click return to get back to the Main effect screen, and click OK in that screen to proceed to ANOVA screen.

6. Study ANOVA and Pool Factors

The averages of the trial results are used to calculate the average effects of factor at each of its levels. The difference between average effects and level 1 and level 2 are also shown as most coomon experiments involve mostly 2-level factors.

Click on the PLOT button to review graphs of individual factor influence. Click on the INTERACTION button to study interaction between any two factors.



Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 A: Time	1	7.801	7.801	41.865	7.614	35.419
2 B: Temperature	1	2.311	2.311	12.403	2.124	9.883
3 INTER COLS 1 x 2	1	6.301	6.301	33.815	6.114	28.442
4 C: Plate Thicknes	1	.061	.061	.328	0	0
5 D: Die Orientatio	1	4.651	4.651	24.961	4.464	20.768
Other/Error	2	.371	.185			5.488
Total:	7	21.498				100.00%

What to do when you are in ANOVA?

Pool Factors

Discarding column effects that are insignificant is called POOLING. You can pool single column at a time by clicking on POOL button. Click on the Auto Pool factor button if you want to pool all effects below a desired Confidence Level.

View Bar Graph

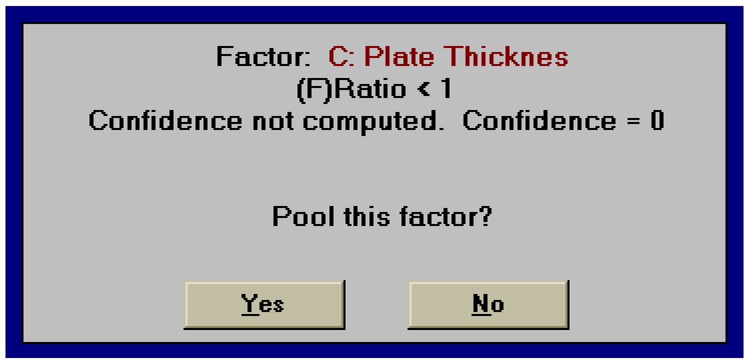
Generally after Pooling, you may want to examine the Bar Graph of the relative influence of the factor and interaction to the variation of results. Click on the Bar Graph button to view the graph. Click return when done.

Observe Pie Diagram

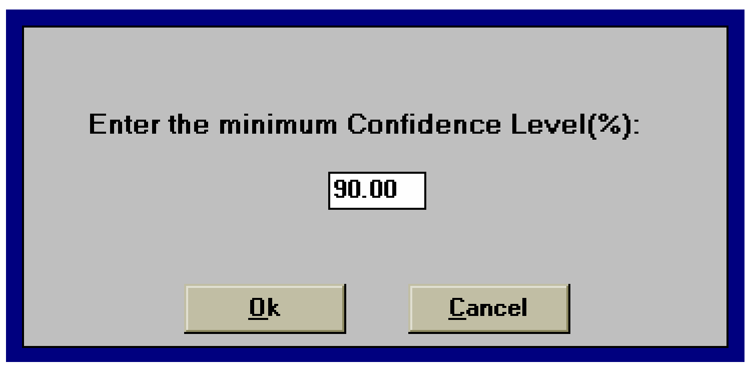
Pie diagram is an alternate display of the same effect shown in the bar graph.. Click on the Pie Diagram button to view the diagram. Click Retrun when done..

To Pool a column item, double click the description. The screen displays the confidence level the factor or column has. Click OK if you wish to Pool it. The decision of whether to pool should be based on the Confidence level desired. The level of confidence one wants can be arbitrary. It is recommended that you always work with a fixed Confidence level (C.L) for the experiment, say 80%, 90% or 95%. Whether a factor/Interaction is significant or not depends on whether it has the confidence level you desire. But the calculation of C.L a column has, or the test of significance can only be done when the Degrees of Freedom (DOF) of the error term(the last line in ANOVA table) is non-zero. So when the error DOF is zero or small, the C.L may not be calculated and you may decide to pool the factor arbitrarily. Obviously, you should start pooling with the weakest column when available. How long should you pool? Continue to pool factors/Interactions as long as they are insignificant and the error DOF is closer to half the total DOF of the experiment.

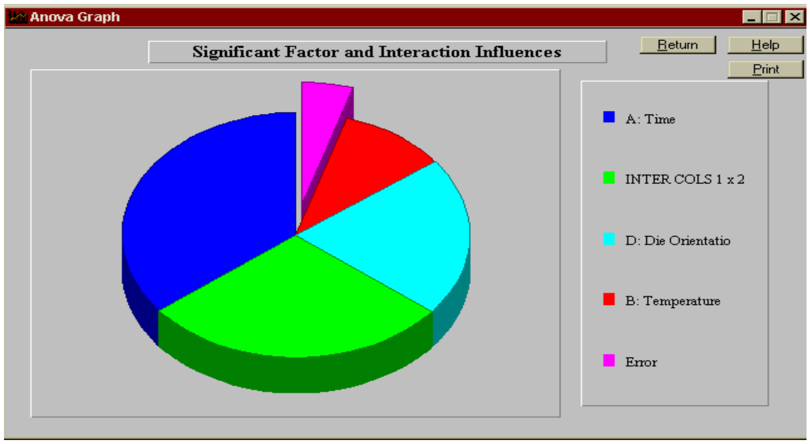
When it is not possible to calculate the C.L., QT4 prompts you and gives you option to pool or not pool.



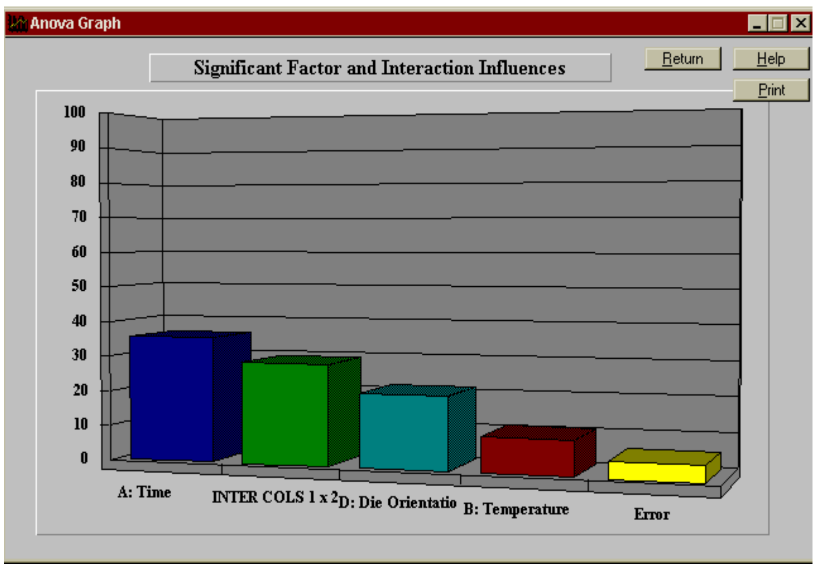
In case you want QT4 to pool all factors that do not meet the minimum C.L., you will be asked about the minimum C.L. you desire. Enter a number between 0 and 99.99 and click OK. QT4 readily pools all factors which fail to meet the desired C.L and displays the revised NOVA.



Color coding of the Pie Diagram indicates the area proportional to the influence of the column to the variation of the results.



When there is large number of factors involved, a limited number of column effects are shown at a time. Click the scroll button to move column above and below the column numbers on the display.

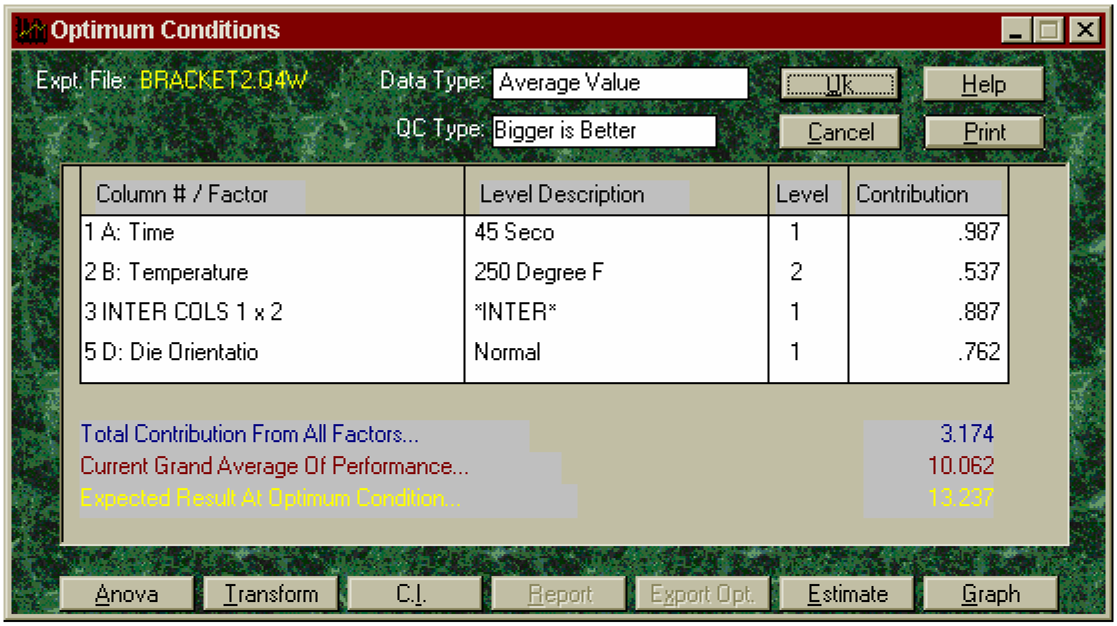


When at the ANOVA screen, click OK to proceed to the Optimum screen.

7. Determine Optimum Condition and Estimate Performance

The optimum screen displays the Optimum condition and the performance at the Optimum condition. The performance calculated is only an estimate as it is based on a linear function of the individual column contributions. The Optimum condition and the prediction of performance is always based on the significant factors only as the estimate produced this way is the most conservative.

The most common activities in this screen are to calculate the Confidence Interval (C.I.) and review of the stacked Graph. For some experiment, estimation of the performance at any arbitrary factor level might of interest.



Click on the C.I. button when you want to calculate the confidence interval. The C.I. is calculated for a given C.L. and only when the error DOF is non-zero. Thus if the error DOF is zero or too small, QT4 cannot calculate the C.I .

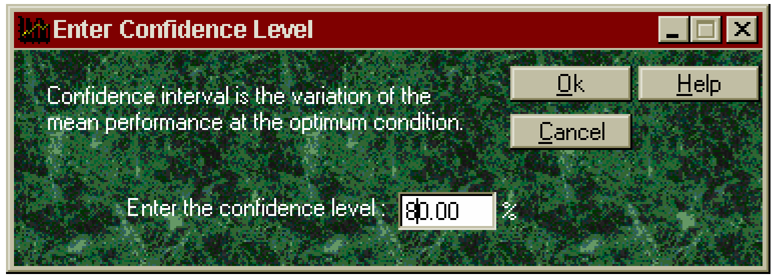
The C.I. is a number in the same units of measurement as the performance and it represent the accepted variation of the mean performance from a population tested at the Optimum condition. Thus the C.I. in comb ination with the estimate of performance forms the yardstick for confirmation of the prediction based on the experimental results.

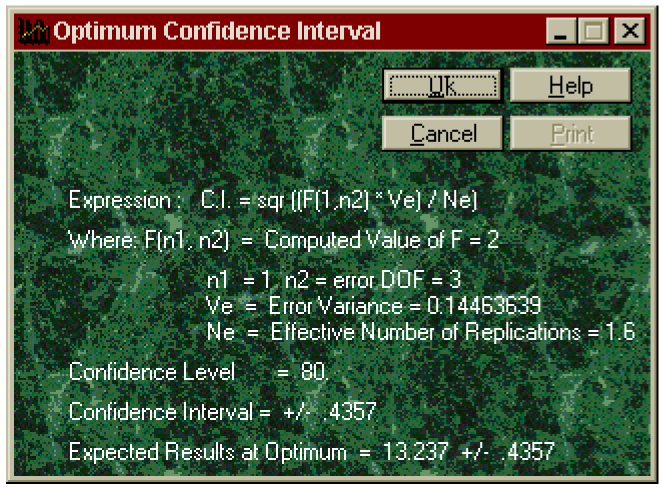
C.I . Computation Routine

Calculation of C.I. requires the use of F-ratios. Most common books contain several tables of F-ratios. Instead of referring to a fixed set of lookup table, QT4 utilizes the original equation for the F-ratios. Unfortunately the expression for the F-ratio in terms of C.L, factor DOF and the error DOF, etc. is quite complex requiring iterative solution. Furthermore, unlike the manual method where F-ratio is selected from the table for a given C.L, the expression is directly solvable for C.L given a F-ratio and not vice versa. Therefore, the solution QT4 determines is most close to the C.L. desired and may not exactly match the text book values.

C.L for calculation of C.I.

If C.I. is not calculated even though the error DOF>0, then lower the C.L.





Calculated C.I.

Units of C.I are the same as that of the optimum performance**.**

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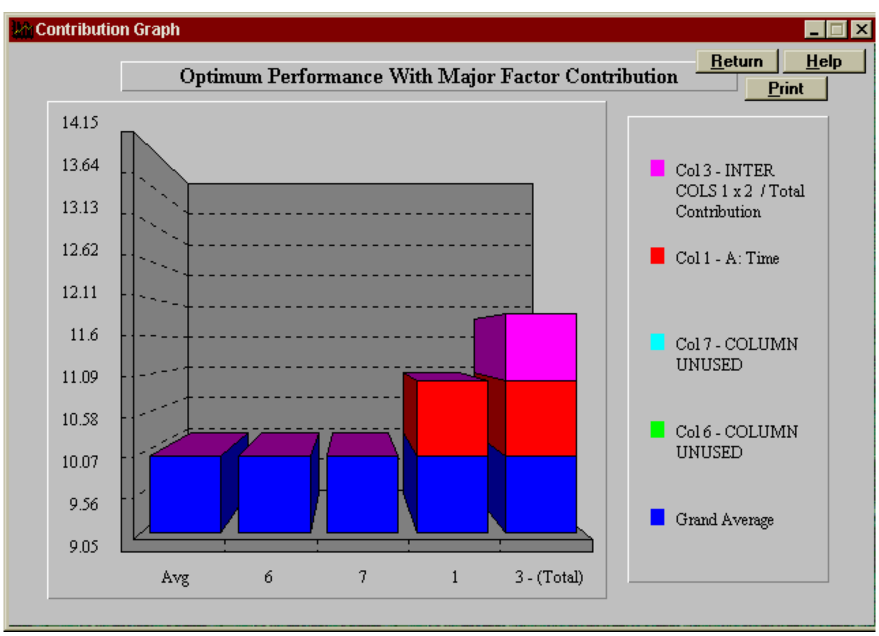
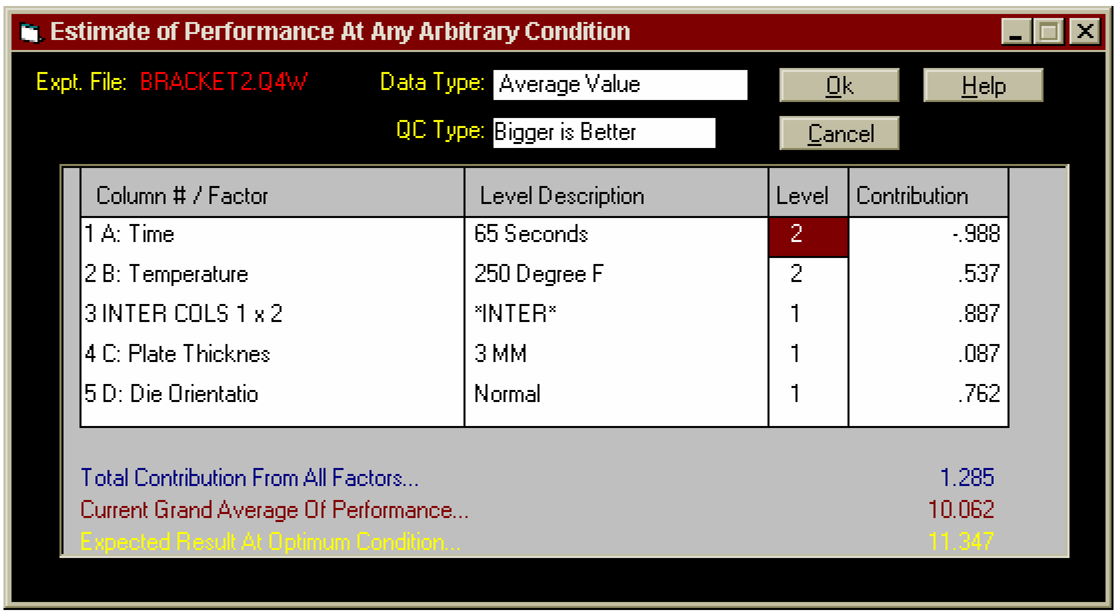


The Bar Graph of the factor contributions show the additional effect of individual factor and interaction which are added to the average performance to produce the estimated performance at the optimum condition (Yopt).

Estimate Performance at Any Arbitrary Condition

Although optimum condition yields the best performance, there are situations when setting the optimum level is not immediately possible because of cost or other difficulties. By clicking on the ESTIMATE button you will be able to calculate the performance at any levels of the factors. Note that QT4 sets the interaction levels automatically based on the levels of the interacting factors: If the levels of both factors are either 1 or 2 (A1B1 or A2B2), the level of the interaction AxB will be at 1. On the other hand if levels of the factors are different, the level of the interaction will be at 2 (AxB at level 2).

To estimate performance, click on the level number and enter the level number desired. Notice that as the level number is entered the level description and the performance values are instantaneously adjusted.



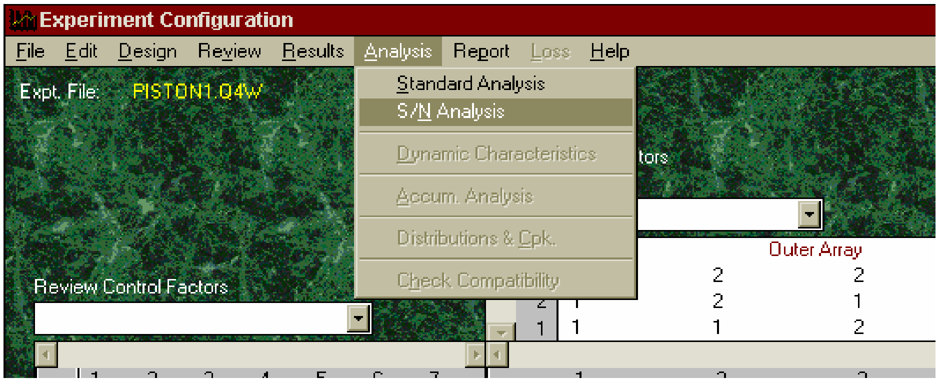
When done with estimation, click OK to return to Optimum screen. At optimum screen click OK to return to the main screen. Now that the analysis is completed, you may enter into report option and print reports of the key analysis steps, cost savings and variation reduction reports.

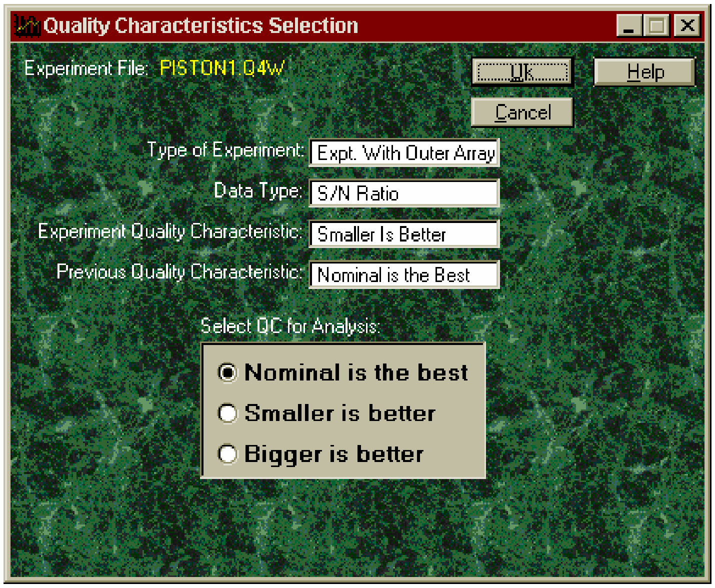
Analysis of Multiple Sample Results (S/N ratios)

When your experiments include multiple samples per trial condition, analysis using S/N ratios of the results is strongly recommended. This would be the case when there is an outer array or otherwise there are multiple samples per trial condition. In this analysis approach, S/N ratios of the trial results are used for analysis instead of the average of trial results in the Standard Analysis. All calculations for Main effect, ANOVA and Optimum condition are carried out with S/N ratios. You must remember to transform the Optimum performance back to the original units of result when interpreting the improvement or predicting expected performance.

1. Select menu Option

Open the experiment file you desire and be in the main screen. Select S/N Analysis from the ANALYSIS menu option. Experiment file PISTON1.Q4W is selected for discussion of S/N analysis.

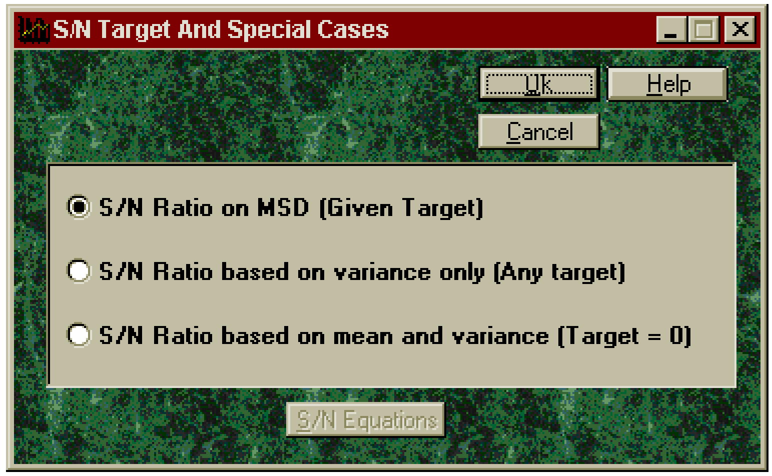




2. Pick Quality Characteristic for Analysis

Depending on the performance objectives of your project, your experiment will have one of the three Quality Characteristic(QC). For analysis purposes, however, you can select any one that you like and carry out the same three different ways. The experiment QC and the QC selected in the previous analysis are also shown in the screen.

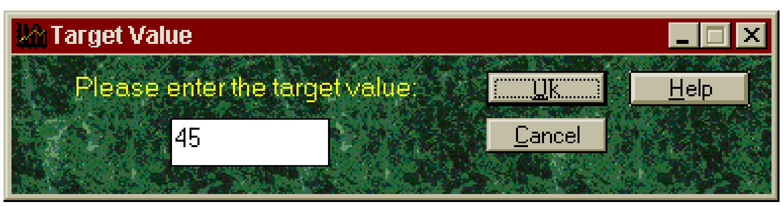
Suppose that analysis using Nominal QC is desired. Check Nominal QC and click OK to proceed.



3 select S/N Type

There are several expressions of S/N ratios for the static systems, which are common kinds of experiments. The most popular among them is the one based on the MSD.

Check the expression you desire if different from the default MSD expression. Click OK to proceed.



4. Enter Target Value

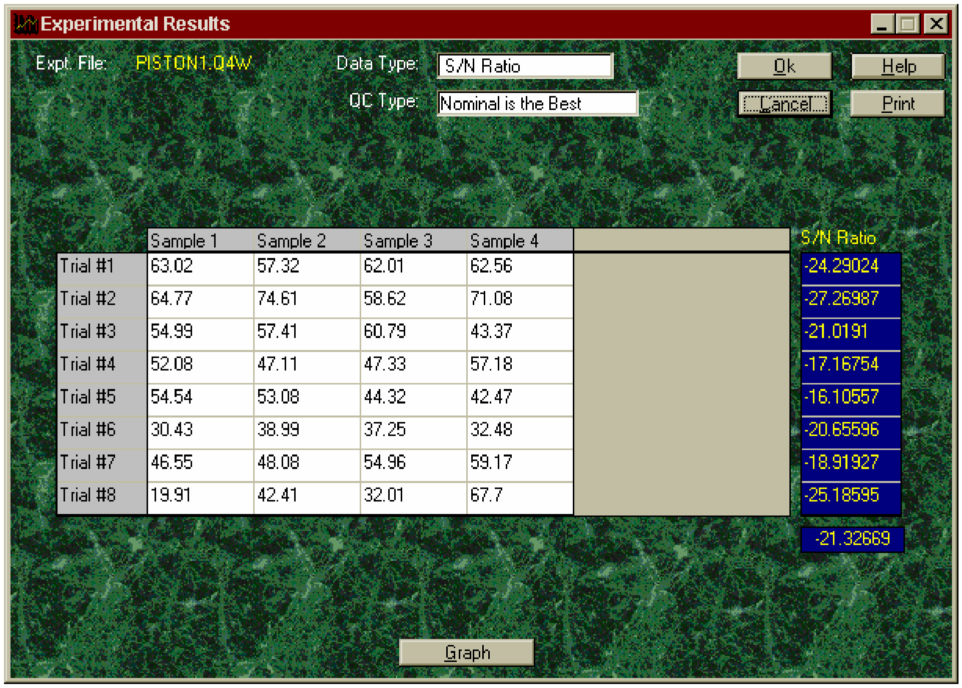
When Nominal QC is the choice for analysis, QT4 requires you to supply the nominal (same as Target) value of the performance.

Type in the target value and click OK to proceed.

5. Review Results and S/N

S/N ratios of the results of individual trial conditions are shown on the right, with the number of results in each trial.

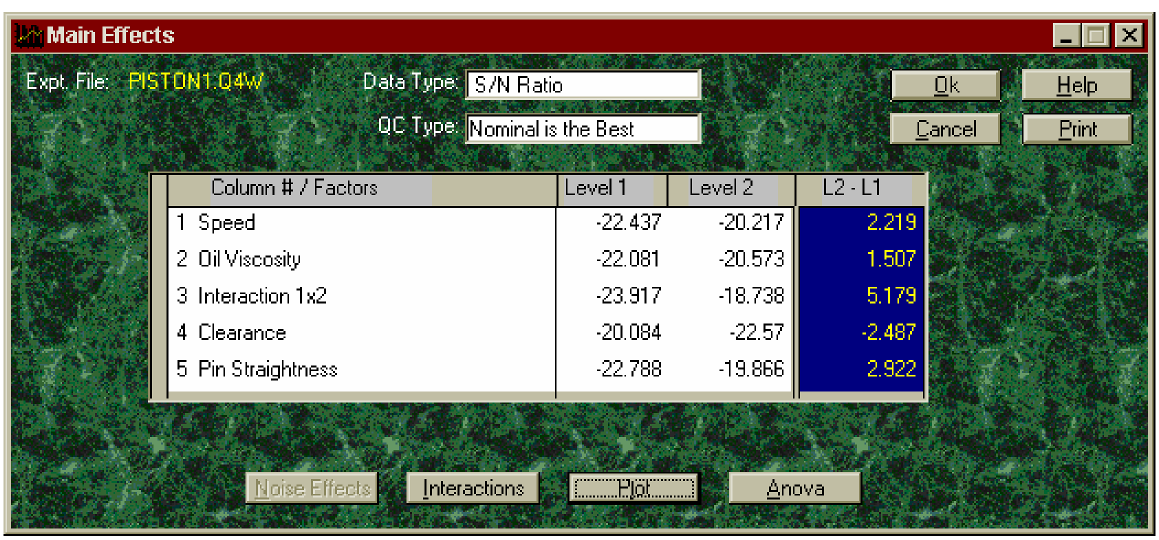
Click OK to proceed for Main Effect calculations.



6. Review Main Effect and Interaction Plots

In the analysis using S/N, all calculations involved in the analysis is performed using the column of S/N values (the original results are not used). Therefore, the factor average effects shown in the screen are all in S/N ratios. Remember all S/N values are not always negative, as shown in this example; it depends on the magnitude of the results and the QC used for the analysis.

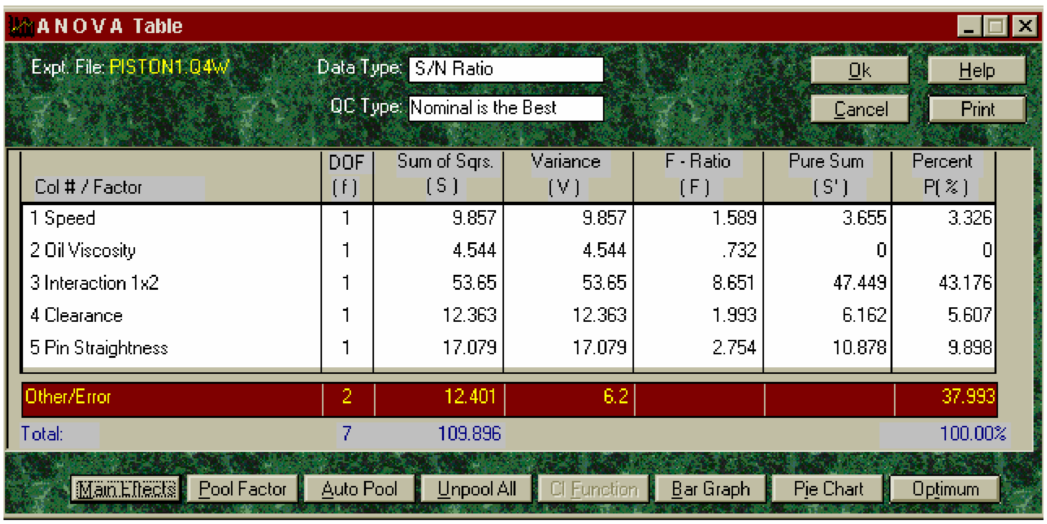
For discussions about how to review the Main Effect graphs and the Interaction plots, refer to the earlier section on analysis of simple experiments. Click OK to proceed to ANOVA.



8. Review ANOVA and Pool Insignificant Factor and Interaction Effects

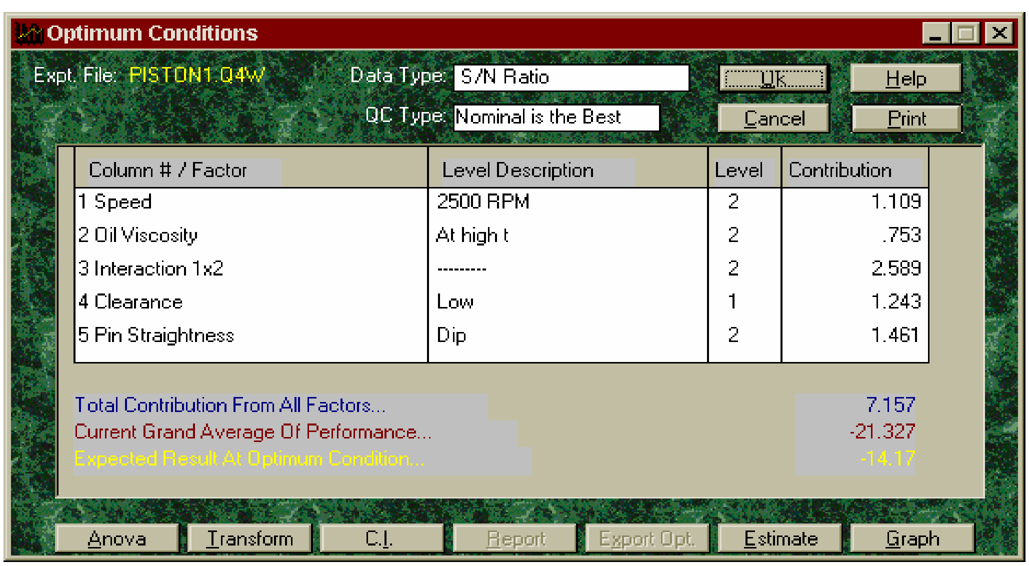
Like Main Effects, ANOVA numbers are also in the transformed state, except the last column which is always expressed in terms of percent influence to the variation of the results. Pool factor one at a time or several at a time using the Auto Pool button.

For detailed procedure refer to the previous section. Click OK to proceed to Optimum screen.

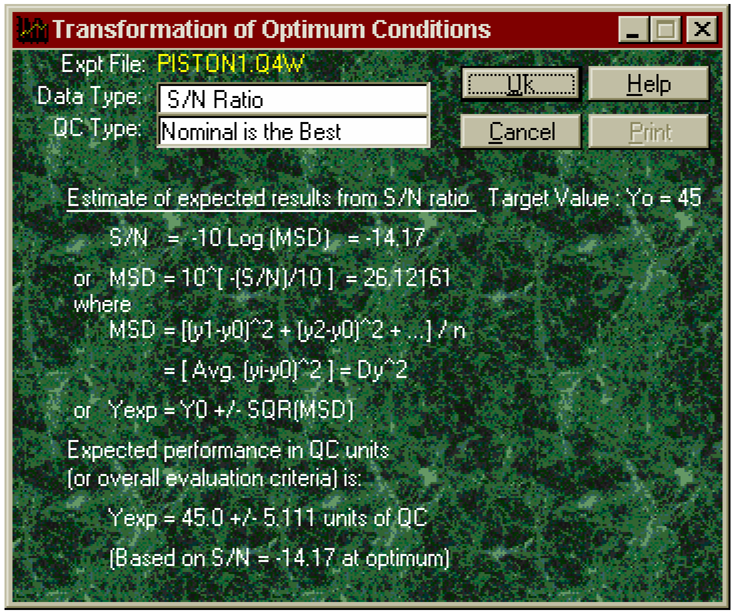


9. Establish Optimum condition and Estimate Performance

As with the Main Effect and ANOVA, the factor contributions and the expected performance are also expressed in S/N ratios. The Optimum factor levels and their descriptions are shown in the table. Click on the transform button to convert the performance value from S/N to the original units of the results.



10. Transform Expected S/N into Result Units



Conversion of S/N into expected results can be only an approximation. The method of transformation is different for different Quality Characteristic as is the definition of MSD.

In the example shown, the expected performance in terms of S/N is -14.17. Since the nominal value is 45 (QC = Nominal is the best), the expected performance in the measured units of result becomes 45.0 +/- 5.11. This transformation is important since most people will relate to this number and the confirmation test results can be compared with this value.

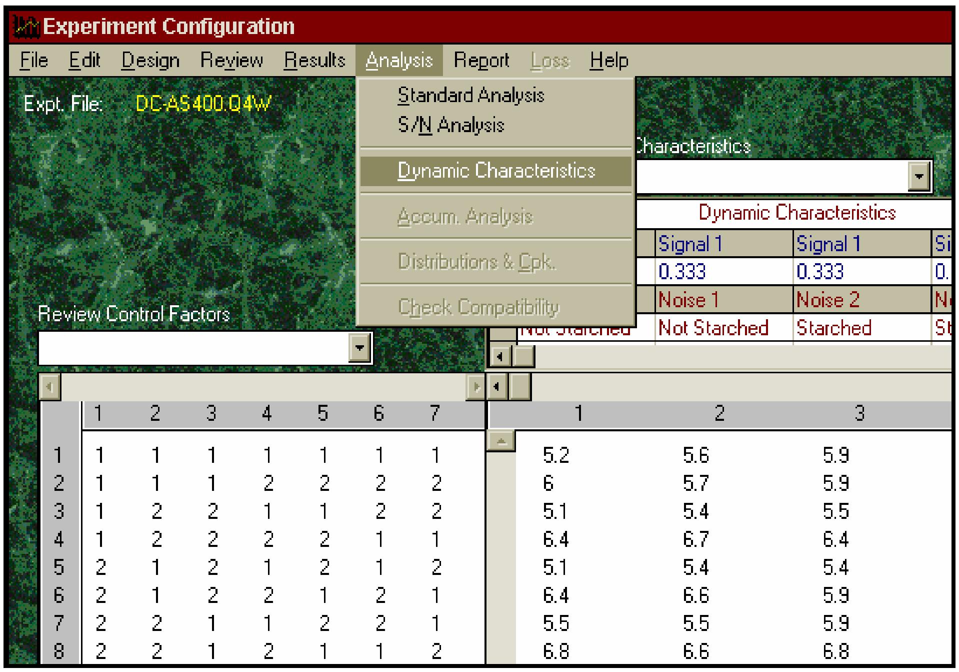
Click OK when done with this screen. While at the Optimum screen, click OK button to return to the main screen.

Analysis using Dynamic Characteristic

Analysis of results from a dynamic system requires the use of Dynamic Characteristic. This is a special form of Nominal is the Best Quality Characteristic. The option to select Dynamic Characteristic (DC) will only be available when the experiment design is created using DC and the results are collected by conducting the test prescribed. However, QT4 will allow you to perform S/N analysis if for some reason you wish to carry out such analysis.

1. Select Menu Option

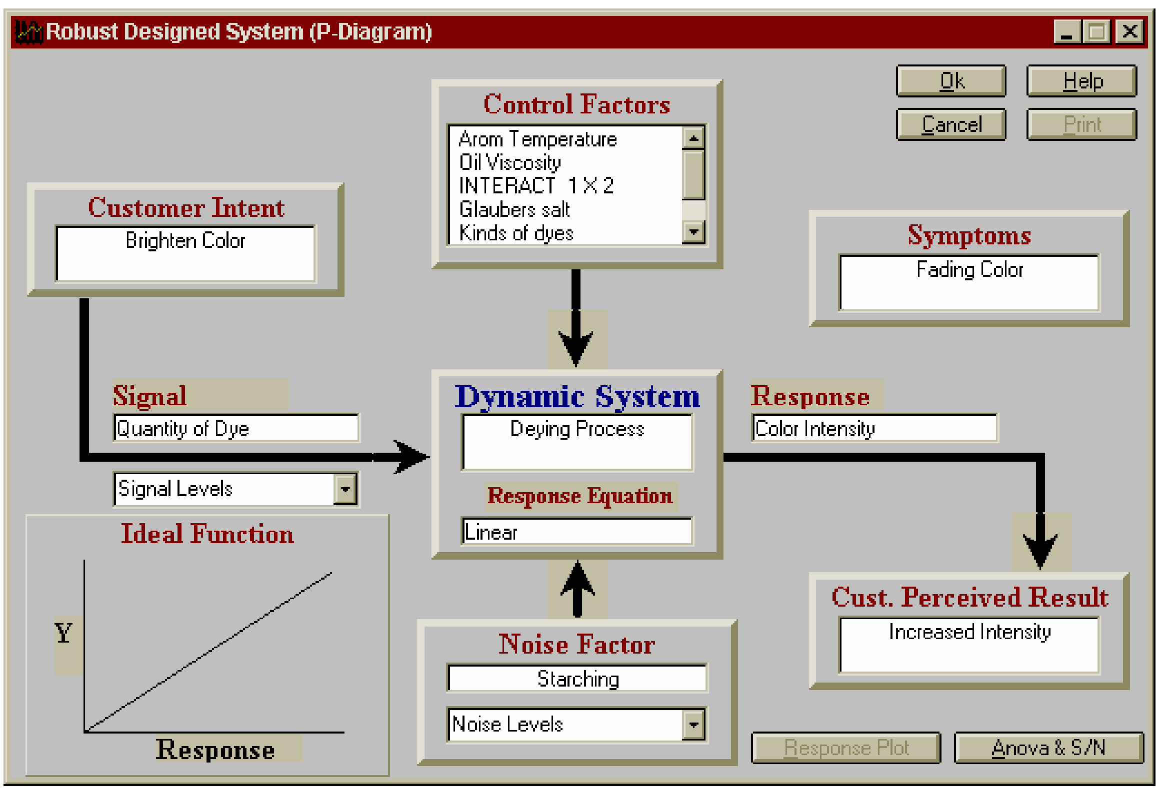
Open the file of your choice. Example experiment DC-AS400.Q4W will be used following descriptions. From the main screen, click on the ANALYSIS menu and select Dynamic Characteristic option.



2. Review P-Diagram for the Dynamic System

The Process Diagram(P-Diagram) for the system graphically displays the system function with components of Signal and the Response. The Symptoms, the Customer Intent and the corresponding Perceived Responses are also identified. This screen only allows review of the descriptions. Should you wish to edit any item displayed or the results which would be analyzed as you proceed, return to the main screen and select EDIT menu options.

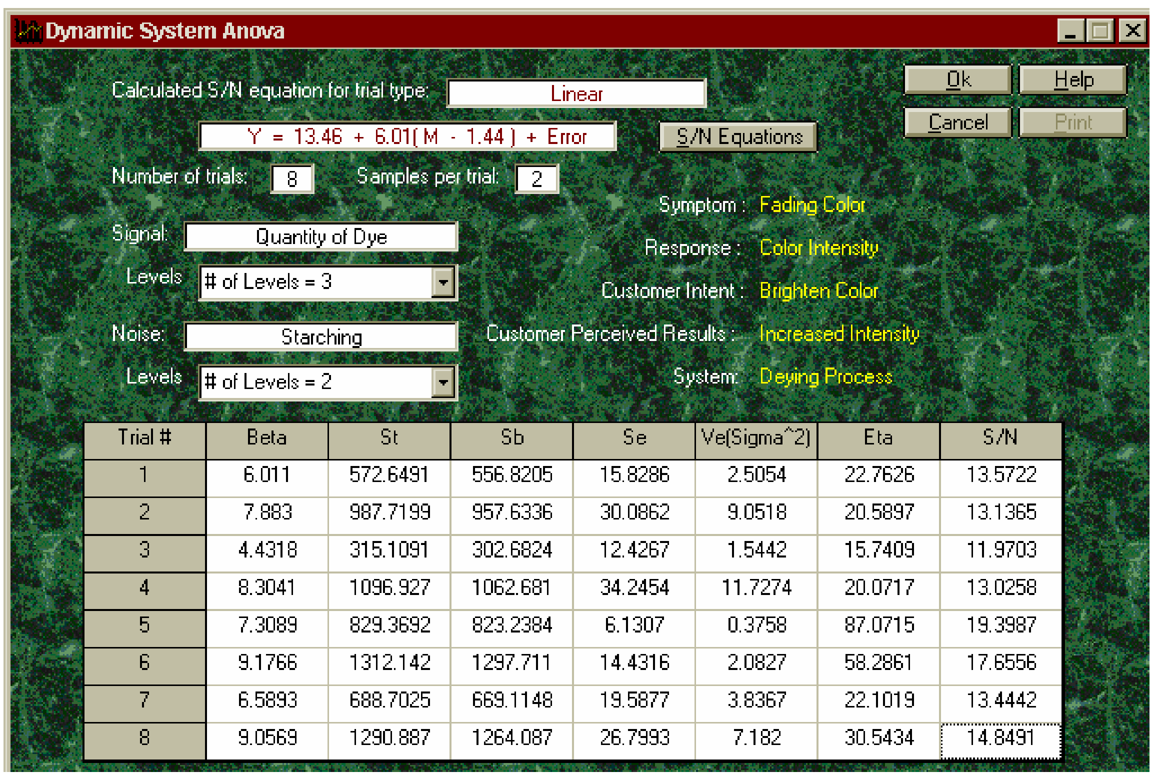
Click OK to proceed to the Trial ANOVA screen.



3. Review Trial ANOVA for the Dynamic System

Similar to the S/N analysis, Dynamic Characteristic also generates S/N for individual Trial results, but the procedure for calculation differs. In this case the components which produce ANOVA may be of interest to better understanding of the system. Thus, the individual component values are displayed in this special ANOVA table. The notations used are what commonly used in the popular texts on the subject (see references).

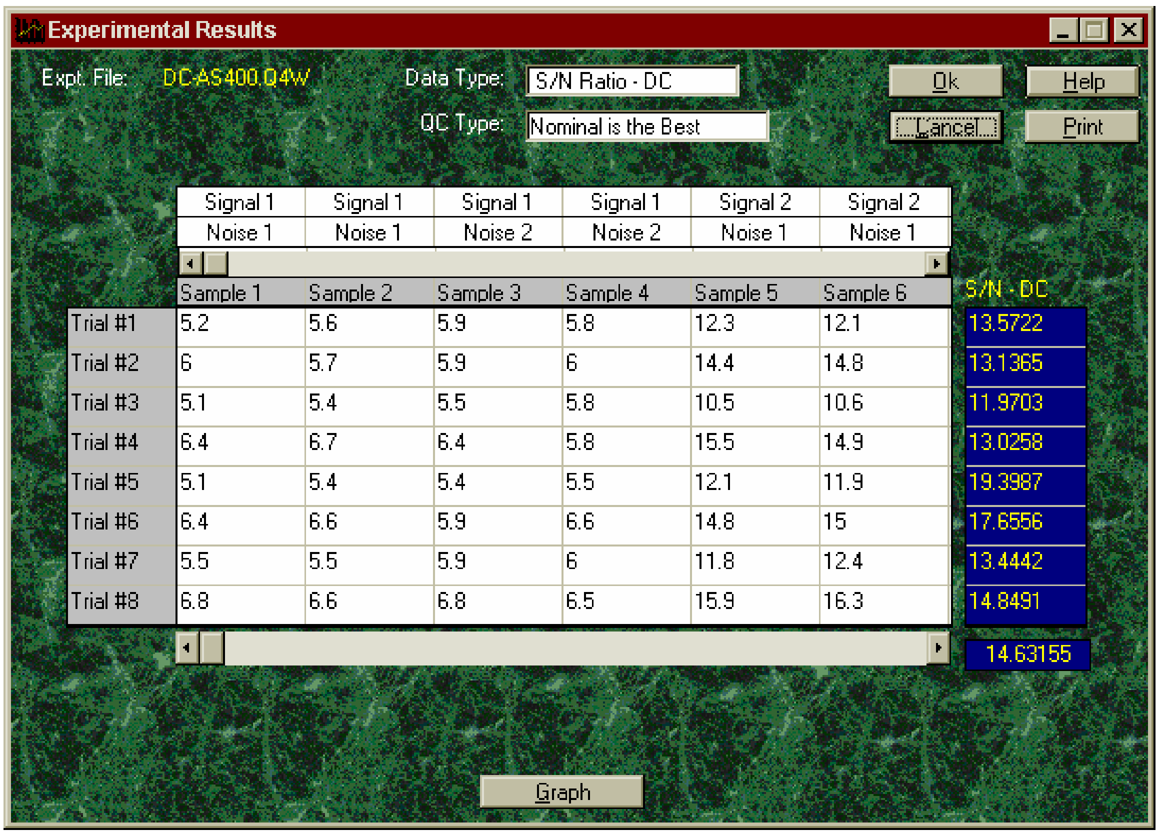
The quantities in the right most columns represent the S/N ratios for the trials and are used for analysis purposes just as done for the Analysis using S/N ratios in the previous section. Click OK to proceed to the screen where the results and the calculated trial S/N are shown.



5. Review Results and Trial S/N Ratios

This screen allows you to review results of your Dynamic System and the calculated S/N for the individual trial conditions. The steps in analysis beyond this point are identical to that for analysis using S/N ratio described in the previous section.

Click OK to proceed to the Main Effect screen and follow through with the complete analysis process.



Estimate Savings and Variation Reduction

These two items may serve as good component of a management report at the conclusion of an experiment. Since the main reason for the experimental study should be to improve quality by reducing variations, its impact on the reduction of costs from reduced scraps and warranty is of immense interest to the management. These options allows you to produce graphical representations of the cost savings resulting from the corresponding variation reduction.

Calculation of Savings using Loss Function

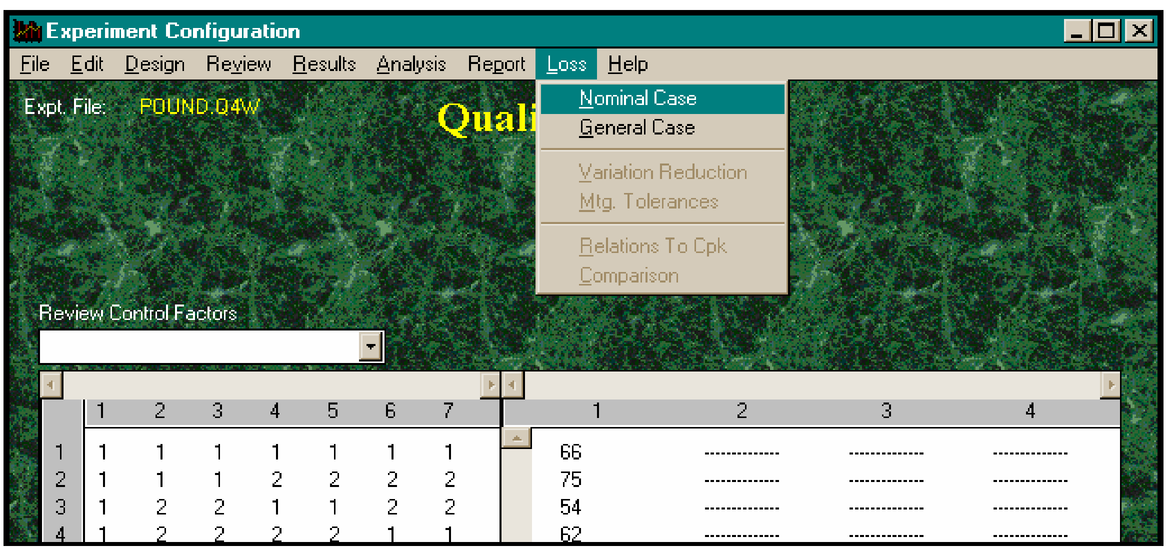
The savings from improvement is calculated by using the analytical model (Loss Function) proposed by Dr. Genechi Taguchi. A company manufacturing and selling parts will always have scraps and warranty. Therefore, theoretically speaking it will always incur a loss. So it is the reduction of loss which is attributed as savings.

1. Select Option

Open the file you want to work with. Carry out complete analysis of results. This is necessary, since the calculated values of S/N for the optimum performance may be used for calculations of savings.

From the main screen, click on Loss menu and select Nominal or General option depending on the information you have available and the quality characteristic(QC) of your experiment.

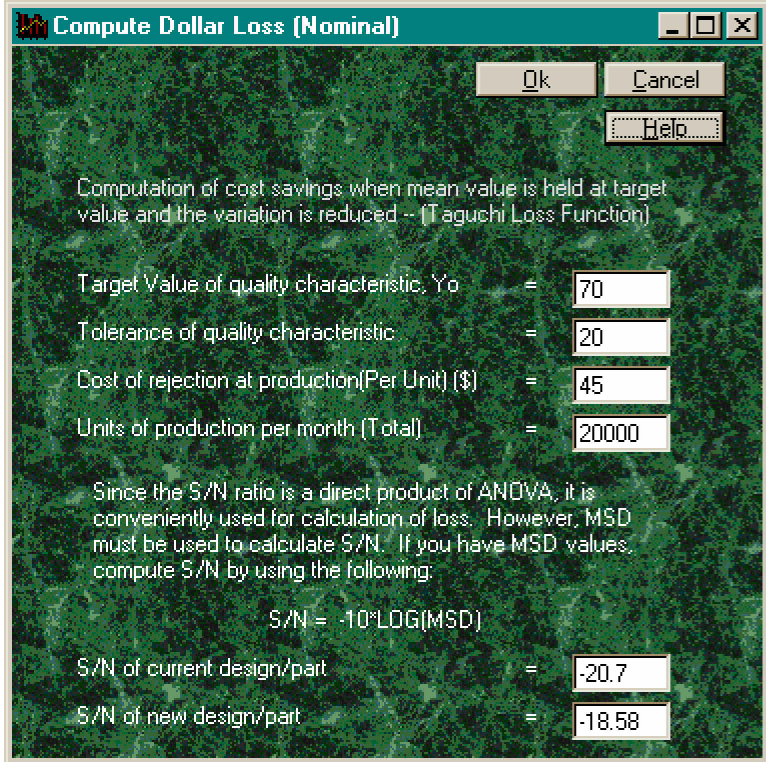
If your result bears Nominal QC, you will use the Nominal option for calculation of loss. This option will require that you know CUSTOMER TOLERANCE and other production information. If on the other hand, you do not know customer tolerance, but know current LOSS, current S/N and improved design S/N, then you should go for the General case.



(a) Calculate Loss with Nominal Quality Characteristic

Target value is the nominal value of the measured results. The Tolerance refers to the Customer Tolerance. This quantity is the key to the accuracy of the calculation. The better you can estimate/assume this value the better will be your Loss estimate. It may or may not be known for your product/process. In that case you will need to assume a value.

Current S/N ratio represents the status of the current production part/process. If current production is unavailable, then average of the all trial S/N's should be taken as this value.



The S/N for the new design (of part/process) should be the value obtained by running confirmation tests, or if confirmation tests are not done, it is the S/N estimated at the Optimum condition from the experimental results.

The loss formulas:

$L = K\,(y - y_o)^2$ for a part

$L = K\,(MSD)$ for a population of parts

Steps:
- Calculate constant K by substituting the boundary condition, L= cost of rejection when y = +/- Tolerance.

- Calculate Loss using L = K(MSD), where MSD is found from given S/N values.

(b) Calculate Loss (general case)

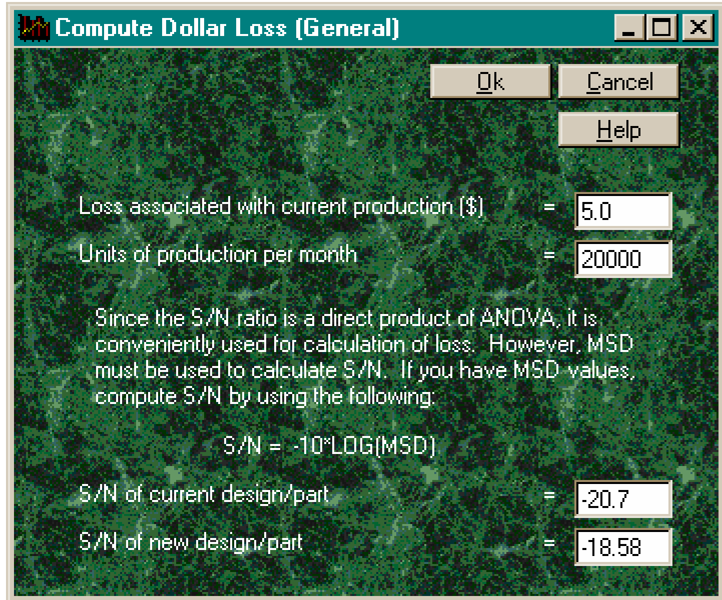
Since the Loss function for a population of part is expressed as

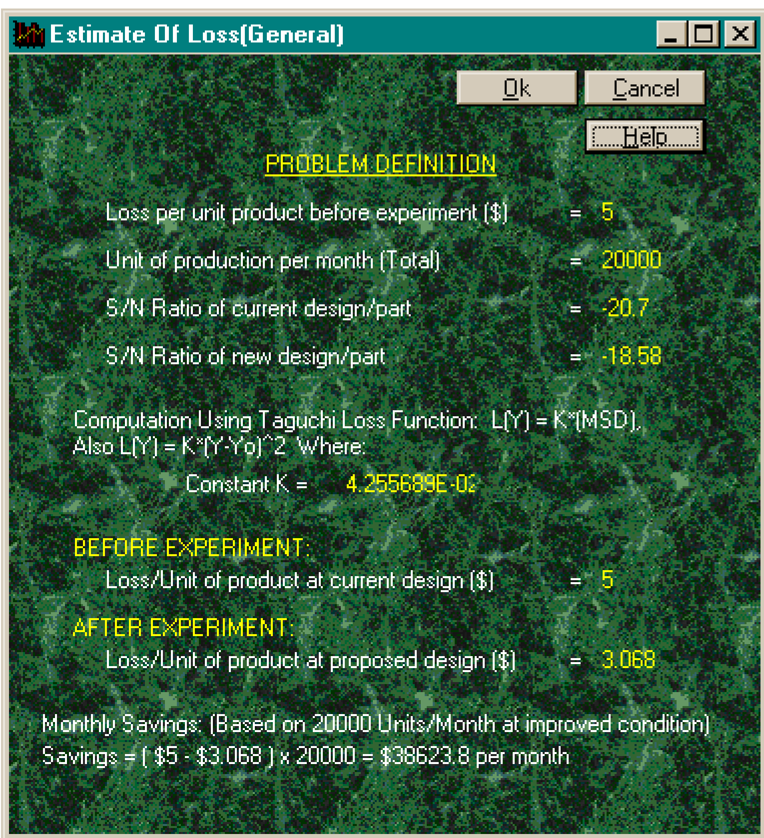
$$L = K\,(MSD)$$

the Loss associated with a population perforance can be calculated if MSD or S/N is known. However, for complete solution , the constant K must be determined from a known value of L and MSD. Thus if Loss and the S/N at current design is known, the constant K can be calculated as

$$K = L_{current} / MSD_{current}$$

where $MSD = 10^{-[S/N]/10}$





The Loss must always be expressed in terms of extra cost associated with production of unit part. Its value ranges between 0 and the cost of production of unit part. If all parts are made out of specifications, then the Loss/unit is same as the cost of production. If no part is made out of specifications, then the Loss/part is zero.

Appendix

Printing Reports and Graphs

There are two common ways to prepare a report of your experiments.

(I) CAPTURE AND PASTE METHOD: Your report is much more versatile when you capture and paste Qualitek-4 screens of your choice on to your Word report documents.

(II) QUALITEK-4 PRINT OPTION: You can use the PRINT button from Qualitek-4 screens to produce the desired number of experimental output pages to attach to your formally prepared report.

STANDARD REPORT CONTENT: Factors and Levels, Inner and Outer Arrays, Results, Main Effect, ANOVA, Optimum, Main effect Graphs, ANOVA Graphs, Interaction Graphs, variation Diagram, etc.

Suggested Report Content

1. Project Title
   - *include names of team members* (participants in the study)
2. Brief Description of the project function and the purpose of the study
   - *indicate reasons for the study and the benefits derived*
3. Evaluation Criteria
   - *discuss how different objectives were measured*
4. Factors and Levels
   - *explain how factors were selected from a long list*
   - *discuss the rationale for number of levels and their values*
5. Noise Factors and Interactions, if any
   - *discuss how interaction (if included) were selected*
   - *justify use of noise factors in the design (if included)*
6. Orthogonal Array and the design
7. Main Effects – *indicate trend of influence of factors and interactions*
8. ANOVA – *list factors with higher relative influence to the variation*
9. Optimum Condition and Performance (convert if in S/N)
   - *indicate any factor level adjusted for interaction*
10. Confidence Interval (C.I.)
11. Expected Savings from the new design
12. Conclusions and Recommendations
    - *based on the results, what do you propose for further study*
    - *explain when you would know that the experiment is satisfactory*

Preparing Comprehensive Electronic Report Document

Upon completion of analysis of results, you will be able to prepare a comprehensive report using Microsoft WORD. To start, prepare a WORD document with the above content space. Run Qualitek-4 with your experiment file and collect screen images you want following the guidelines below. A sample report is shown at end of this chapter.

Capturing and Pasting Qualitek-4 Screens
Before capturing a screen, start WORD (procedure true for version 6.0) and be in the page you want to paste the screen. Now run Qualitek-4 and follow these steps. (It is assumed that you are familiar with multitasking)

(1) Be in the screen you want to capture. Hold down Alt key and press PrntScreen key.
This action stores the captured screen in Windows Clipboard.

(2) Switch to the WORD document. From the Edit menu select PASTE. The screen in the Clipboard is now placed on the document.

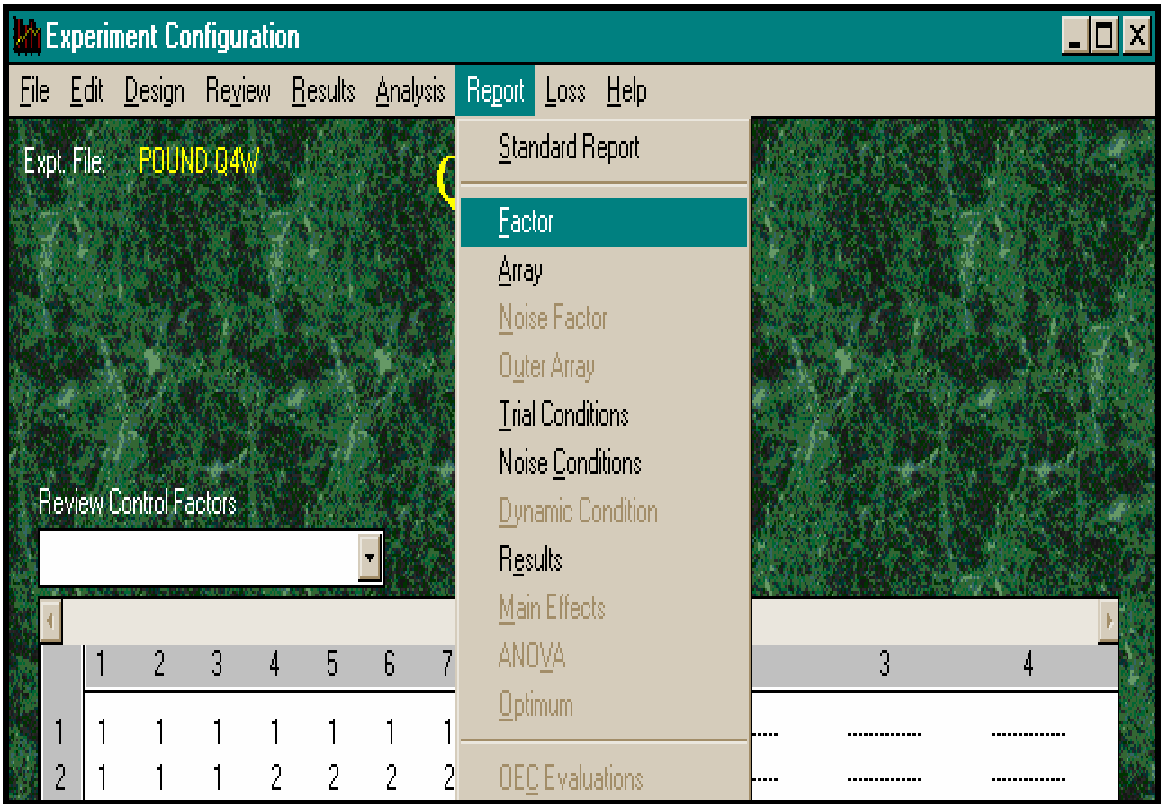
Cropping Captured Screens Using WORD Capabilities
(3) Optionally, for better control and easy positioning of the pasted screen, select the picture by clicking on it, then from the INSERT menu select FRAME. It is also possible to CROP(cut and size) the picture using standard WORD capabilities. To CROP, select the picture and place mouse pointer on any HANDLE, press Shift key down and DRAG the mouse to desired sizing location.

On Screen Printing

Reports for each individual experimental parameter such as Factors, Array, Results, etc. can also be printed while creating or editing the information and it is on display. Additionally it can be printed from the REPORT menu option from the main screen. Options that are currently available and are logically appropriate will be highlighted. The options unavailable are dimmed.

1. Select Option

Open the experiment file you want to work with. Go through with the analysis process if you wish to print reports of Main Effect, ANOVA, Optimum Condition, etc. Then select REPORT menu item from the main screen. Most item can be printed by displaying that item and clicking on the Print option displayed on the top right corner of the screen.



Example Case Study Report

Project Title: Piston Bearing Durability Life Optimization Study
Experiment was conducted by: (Industrial users)

Brief Description of the project function and the purpose of the study:
Recent warranty study indicated high rate of field failure of the Piston Bearing (type DX30) due to excessive wear and vibration related malfunction. This study was undertaken to enhance the durability life under field relevant 80Th percentile application load.

Evaluation Criteria:
Experimental bearing samples were tested and performance evaluated by observing durability life (in hours, weighted at 60%) and by measuring force generated due to unbalanced vibration (g force, weighted at 40%). These two criteria of evaluation were combined to produce an overall result used for the analysis. The scheme to calculate the Overall Evaluation Criteria (OEC) is not shown here. The *Quality Characteristic* (QC) of OEC is *Bigger is Better*.

Factors and Levels:

Brainstorming with the team members and other project personnel identified seven Factors. Among the factors, three uncontrollable factors were held fixed for the purpose of the experiments. *Four* remaining *factors* and an interaction between two factors were considered for the study.

	Factors	Level 1	Level 2
1	Speed	2000 RPM	2500 RPM
2	Oil Viscosity	At Low te	At high t
3	INTERACT 1 X 2	*INTER*	------------
4	Clearance	Low	High
5	Pin Straightness	Perfect	Dip
6	UNUSED/UPGRADED	*UNUSED*	------------
7	UNUSED/UPGRADED	*UNUSED*	------------

Noise Factors and Interactions:

Interaction between Speed and Viscosity was considered most important.
Many noise factors were identified, but not included in this study.

Orthogonal Array and the design

Three samples in each of the eight experimental conditions were tested. The observed readings for durability life and vibration force were combined for each sample (45 for the first sample in experiment#1).

	1	2	3	4	5	6	7	1	2	
1	1	1	1	1	1	0	0	45	56	64
2	1	1	1	2	2	0	0	34	45	53
3	1	2	2	1	1	0	0	67	65	60
4	1	2	2	2	2	0	0	45	56	64
5	2	1	2	1	2	0	0	87	81	69
6	2	1	2	2	1	0	0	78	73	68
7	2	2	1	1	2	0	0	45	56	52
8	2	2	1	2	1	0	0	42	54	47

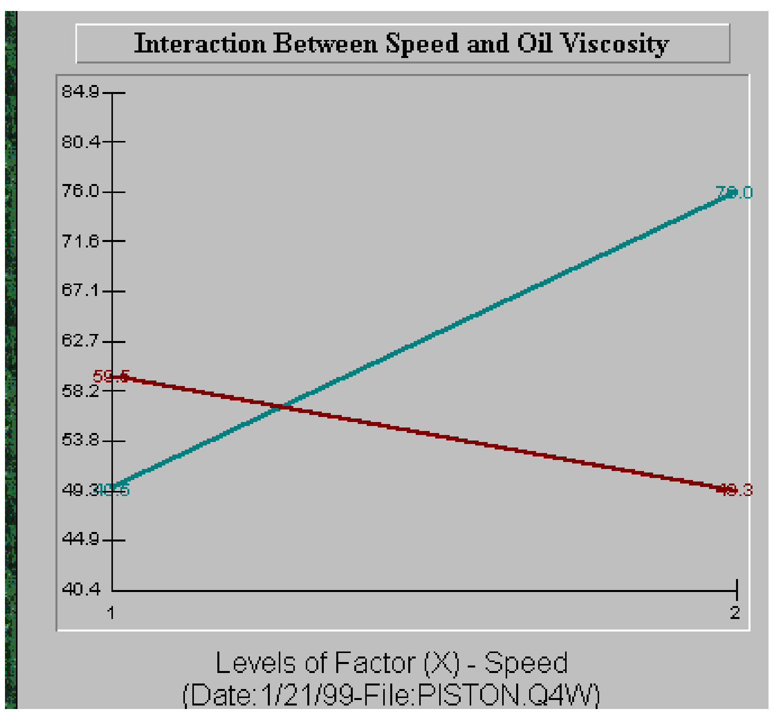
Inner Array — Result

Main Effects

The average factor influences showed trend of influence of various factors, which helps to determine the desirable condition for the QC. It also helped determine the levels of the interacting factors (Speed and Oil Viscosity) most suitable for the desired performance.

Column # / Factors	Level 1	Level 2	L2 - L1
1 Speed	54.5	62.666	8.165
2 Oil Viscosity	62.75	54.416	-8.335
3 INTERACT 1 X 2	49.416	67.75	18.334
4 Clearance	62.25	54.916	-7.335
5 Pin Straightness	59.916	57.25	-2.666

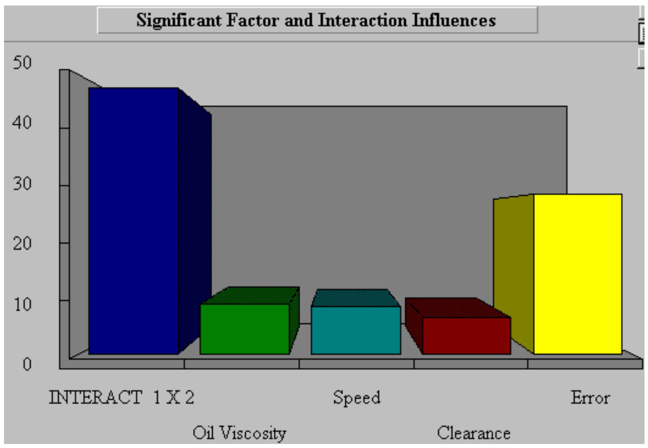
From Test of Presence of Interaction showed that *Speed* at Level 2 and *Oil Viscosity* at Level 1 are to be included in the Optimum Condition



ANOVA:
ANOVA shows the relative influence of the factors and interaction to the variation of results. The most influence is due the interaction included in the study, followed by factors Oil Viscosity, Speed, and Pin Straightness.

Col # / Factor	DOF (f)	Sum of Sqrs. (S)	Variance (V)	F - Ratio (F)	Pure Sum (S')	Percent P(%)
1 Speed	1	400.168	400.168	7.792	348.817	8.442
2 Oil Viscosity	1	416.667	416.667	8.114	365.317	8.841
3 INTERACT 1 X 2	1	2016.667	2016.667	39.272	1965.317	47.565
4 Clearance	1	322.667	322.667	6.283	271.317	6.566
5 Pin Straightness	(1)	(42.668)		POOLED	(CL= *NC*)	
Other/Error	19	975.66	51.35			28.586
Total:	23	4131.832				100.00%

The Other/Error (28%) indicates the influence from all factors, not included in the study and the experimental error, if any.



Optimum Condition and Performance

The expected performance at optimum condition (79.664) shows an increase of 21.08 points from the average performance. Improvement = (79.66-58.58)/58.58 = 36% Levels of interacting factors are the same as indicated otherwise. Thus no adjustments of factor level are necessary.

Column # / Factor	Level Description	Level	Contribution
1 Speed	2500 RPM	2	4.083
2 Oil Viscosity	At Low te	1	4.166
3 INTERACT 1 X 2	------------	2	9.166
4 Clearance	Low	1	3.666

Total Contribution From All Factors... 21.08
Current Grand Average Of Performance... 58.583
Expected Result At Optimum Condition... 79.664

Confidence Interval (C.I.)

At 90% confidence level the Mean of the population performance is expected to fall within 74.39 and 84.93.

For confirmation/validity of the analysis and predicted performance, a set of samples were tested in the Optimum Condition and the average performance was found to be 81.5
.

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

Where: F(n1, n2) = Computed Value of F = 3

n1 = 1 n2 = error DOF = 19
Ve = Error Variance = 51.35059213
Ne = Effective Number of Replications = 4.8

Confidence Level = 90.

Confidence Interval = +/- 5.27398

Expected Results at Optimum = 79.664 +/- 5.27398
(74.39, 84.938)

Expected Savings from the new design

Savings = 46 cents for every dollars loss
Variation reduction: Cpk increased from 1.0 to 1.359