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Taguchi Designs

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Taguchi Design Overview

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions.

In robust parameter design, the primary goal is to find factor settings that minimize response variation, while adjusting (or keeping) the process on target. After you determine which factors affect variation, you can try to find settings for controllable factors that will either reduce the variation, make the product insensitive to changes in uncontrollable (noise) factors, or both. A **process** designed with this goal will produce more consistent output. A **product** designed with this goal will deliver more consistent performance regardless of the environment in which it is used.

Engineering knowledge should guide the selection of factors and responses [3]. Robust parameter design is particularly suited for energy transfer processes; for example, a car's steering wheel is designed to transfer energy from the steering wheel to the wheels of the car. You should also scale control factors and responses so that interactions are unlikely. When interactions among control factors are likely or not well understood, you should choose a design that is capable of estimating those interactions. MINITAB can help you select a Taguchi design that does not confound interactions of interest with each other or with main effects.

Noise factors for the outer array should also be carefully selected and may require preliminary experimentation. The noise levels selected should reflect the range of conditions under which the response variable should remain robust.

Robust parameter design uses Taguchi designs (orthogonal arrays), which allow you to analyze many factors with few runs. Taguchi designs are balanced, that is, no factor is weighted more or less in an experiment, thus allowing factors to be analyzed independently of each other.

MINITAB provides both static and dynamic response experiments.

- In a static response experiment, the quality characteristic of interest has a fixed level.
- In a dynamic response experiment, the quality characteristic operates over a range of values and the goal is to improve the relationship between an input signal and an output response.

An example of a dynamic response experiment is an automotive acceleration experiment where the input signal is the amount of pressure on the gas pedal and the output response is vehicle speed. You can create a dynamic response experiment by adding a signal factor to a design—see *Adding a signal factor for a dynamic response experiment* on page 24-8.

The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors. MINITAB calculates response tables and generates main effects and interaction plots for:

- signal-to-noise ratios (S/N ratios, which provide a measure of robustness) vs. the control factors
- means (static design) or slopes (dynamic design) vs. the control factors
- standard deviations vs. the control factors
- the natural log of the standard deviations vs. the control factors

Use these tables and plots to determine what factors and interactions are important and evaluate how they affect responses. To get a complete understanding of factor effects it is advisable to evaluate S/N ratios, means (static design), slopes (dynamic design), and standard deviations. Make sure that you choose an S/N ratio that is appropriate for the type of data you have and your goal for optimizing the response—see *Analyzing static designs* on page 24-29.

Note If you suspect curvature in your model, select a design—such as 3-level designs—that allows you to detect curvature in the response surface.

Taguchi design experiments in MINITAB

Performing a Taguchi design experiment may consist of the following steps:

1. Before you begin using MINITAB, you need to complete all pre-experimental planning. For example, you need to choose control factors for the inner array and noise factors for the outer array. Control factors are factors you can control to optimize the process. Noise factors are factors that can influence the performance of a system but are not under control during the intended use of the product. Note that while you cannot control noise factors during the process or product use, you need to be able to control noise factors for experimentation purposes.

2. Use **Create Taguchi Design** to generate a Taguchi design (orthogonal array)—see *Creating Taguchi Designs* on page 24-4.

   Or, use **Define Custom Taguchi Design** to create a design from data that you already have in the worksheet. **Define Custom Taguchi Design** allows you to specify which columns are your factors and signal factors. You can then easily analyze the design and generate plots. See *Defining Custom Taguchi Designs* on page 24-17.

3. After you create the design, you may use **Modify Design** to rename the factors, change the factor levels, add a signal factor to a static design, ignore an existing signal factor (treat the design as static), and add new levels to an existing signal factor. See *Modifying Designs* on page 24-18.

4 After you create the design, you may use **Display Design** to change the units (coded or uncoded) in which MINITAB expresses the factors in the worksheet. See *Displaying Designs* on page 24-21.

5 Perform the experiment and collect the response data. Then, enter the data in your MINITAB worksheet. See *Collecting and Entering Data* on page 24-22.

6 Use **Analyze Taguchi Design** to analyze the experimental data. See *Analyzing Taguchi Designs* on page 24-23.

7 Use **Predict Results** to predict S/N ratios and response characteristics for selected new factor settings. See *Predicting Results* on page 24-35.

Choosing a Taguchi Design

Before you use MINITAB, you need to determine which Taguchi design is most appropriate for your experiment. In Taguchi designs, responses are measured at selected combinations of the control factor levels. Each combination of control factor levels is called a run and each measure an observation. The Taguchi design provides the specifications for each experimental test run.

A Taguchi design, also known as an orthogonal array, is a fractional factorial matrix that ensures a balanced comparison of levels of any factor. In a Taguchi design analysis, each factor can be evaluated independently of all other factors.

When choosing a design you need to

- identify the number of control factors that are of interest
- identify the number of levels for each factor
- determine the number of runs you can perform
- determine the impact of other considerations (such as cost, time, or facility availability) on your choice of design

Creating Taguchi Designs

A Taguchi design, or an orthogonal array, is a method of designing experiments that usually requires only a fraction of the full factorial combinations. In a Taguchi design, the array is orthogonal, which means the design is balanced so that factor levels are weighted equally. Because of this, an orthogonal array is one in which each factor can be evaluated independently of all the other factors.

In robust parameter design, you first choose control factors and their levels and choose an orthogonal array appropriate for these control factors. The control factors comprise

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the inner array. At the same time, you determine a set of noise factors, along with an experimental design for this set of factors. The noise factors comprise the outer array.

The experiment is carried out by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, next to the factors settings for that run of the control factors in the inner array. For an example, see *Data* on page 24-24.

Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values indicate the factor settings for the run. By default, MINITAB's orthogonal array designs use the integers 1, 2, 3... to represent factor levels. If you enter factor levels, the integers 1, 2, 3, ..., will be the coded levels for the design.

The following table displays the L8 (2^7) Taguchi design (orthogonal array). L8 means 8 runs. 2^7 means 7 factors with 2 levels each. If the full factorial design were used, it would have 2^7 = 128 runs. The L8 (2^7) array requires only 8 runs—a fraction of the full factorial design. This array is orthogonal; factor levels are weighted equally across the entire design. The table columns represent the control factors, the table rows represent the runs (combination of factor levels), and each table cell represents the factor level for that run.

L8 (2^7) Taguchi Design

	A	B	C	D	E	F	G
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

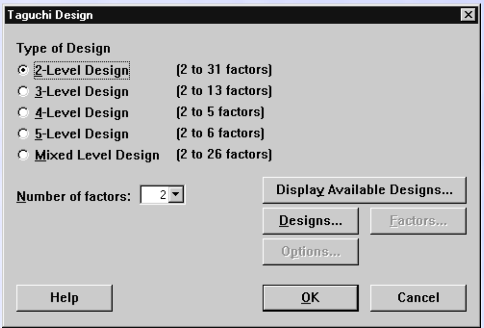
In the above example, levels 1 and 2 occur 4 times in each factor in the array. If you compare the levels in factor A with the levels in factor B, you will see that B1 and B2 each occur 2 times in conjunction with A1 and 2 times in conjunction with A2. Each pair of factors is balanced in this manner, allowing factors to be evaluated independently.

Orthogonal array designs focus primarily on main effects. Some of the arrays offered in MINITAB's catalog permit a few selected interactions to be studied. See *Estimating selected interactions* on page 24-10.

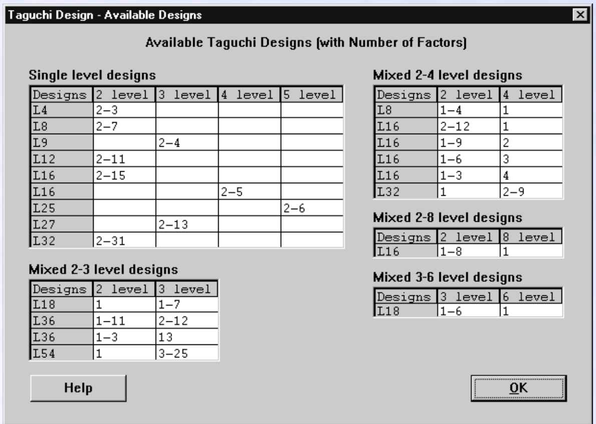
You can also add a signal factor to the Taguchi design in order to create a dynamic response experiment. A dynamic response experiment is used to improve the functional relationship between an input signal and an output response. See *Adding a signal factor for a dynamic response experiment* on page 24-8.

▶ To create a Taguchi design

1 Choose **Stat ➤ DOE ➤ Taguchi ➤ Create Taguchi Design**.



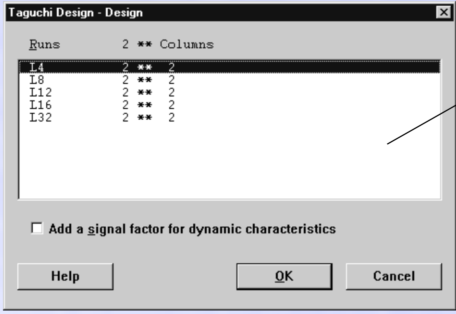
2 If you want to see a summary of the Taguchi designs available, click **Display Available Designs**. Click **OK**.



3 Under **Type of Design**, choose a design.

4 From **Number of factors**, choose a number. The choices available will vary depending on what design you have chosen.

5 Click **Designs**.



The designs that display depend on the number of factors and levels in your design.

6 In the **Designs** box, highlight the design you want to create. If you like, use the option described under *Design subdialog box* below.

7 Click **OK** even if you do not change any options. This selects the design and brings you back to the main dialog box.

8 If you like, click **Factors** or **Options** to use any of the options listed below, then click **OK** in each dialog box to create your design.

Options

Design subdialog box

- add a signal factor—see *Adding a signal factor for a dynamic response experiment* on page 24-8

Options subdialog box

- store the design in the worksheet—see *Storing the design* on page 24-9

Factors subdialog box

- select interactions to include in the design and allow Minitab to assign factors to columns of the array to allow estimation of selected interactions—see *Estimating selected interactions* on page 24-10
- assign factors to columns of the array in order to allow estimation of selected interactions—see *Estimating selected interactions* on page 24-10
- name factors—see *Naming factors* on page 24-12
- define factor levels—see *Setting factor levels* on page 24-13
- name signal factor and define signal factor levels—see *Adding a signal factor for a dynamic response experiment* on page 24-8

Adding a signal factor for a dynamic response experiment

You can add a signal factor to a Taguchi design to create a dynamic response experiment. A dynamic response experiment is used to analyze and improve the functional relationship between an input signal and an output response. Generally, you would use a signal factor when the quality characteristic operates over a range of values depending on some input to the system [3] [5]. An example is an automotive acceleration system, where the input signal is the amount of pressure on the gas pedal and the dynamic response is the speed of the vehicle. Ideally, there should be a linear relationship between the input signal and output response. Robustness requires that there is minimal variation in this relationship due to noise.

The signal factor values are repeated for every run of the Taguchi design (orthogonal array). Thus, the total number of runs (rows in the worksheet) will be the number of rows in the orthogonal array times the number of levels in the signal variable. For example, adding a signal factor with 2 levels to an L4 (2^3) design, which has 4 runs, creates a design with 8 total runs; adding a signal factor with 3 levels creates a design with 12 total runs.

Static design (No signal factor)

A	B
1	1
1	2
2	1
2	2

Dynamic design (Signal factor with 2 levels)

A	B	Signal factor
1	1	1
1	1	2
1	2	1
1	2	2
2	1	1
2	1	2
2	2	1
2	2	2

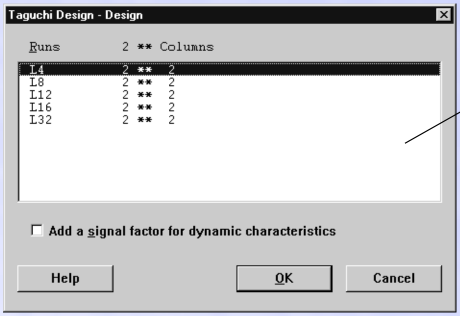
Dynamic design (Signal factor with 3 levels)

A	B	Signal factor
1	1	1
1	1	2
1	1	3
1	2	1
1	2	2
1	2	3
2	1	1
2	1	2
2	1	3
2	2	1
2	2	2
2	2	3

Note When you add a signal factor while creating a new Taguchi design, the run order will be different from the order that results from adding a signal factor using Modify Design—see *Adding a signal factor to an existing static design* on page 24-19. The order of the rows does not affect the Taguchi analysis.

▶ To add a signal factor for a dynamic response experiment

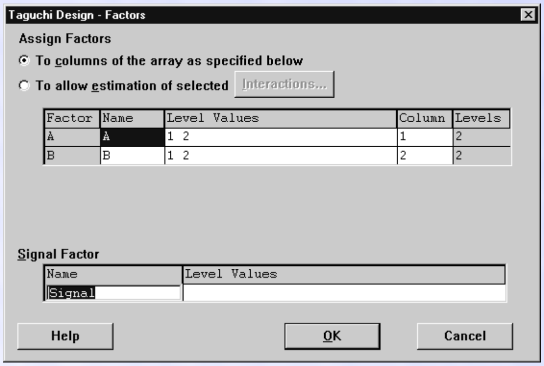
1 In the Create Taguchi Design dialog box, click **Design**.



The designs that display depend on the number of factors and levels in your design.

2 Check **Add a signal factor for dynamic characteristics**. Click **OK**.

3 In the Create Taguchi Design dialog box, click **Factors**.



4 If you like, in the signal factor table under **Name**, click in the first row and type the name of the signal factor.

5 Under **Level Values**, click in the signal factor row and enter numeric values. You must enter at least two distinct values. Click **OK**.

Note You can also specify signal factor levels using a range and increments. You can specify a range by typing two numbers separated by a colon. For example, 1:5 displays the numbers 1, 2, 3, 4, and 5. You can specify an increment by typing a slash "/" and a number. For example, 1:5/2 displays every other number in a range: 1, 3, and 5.

Storing the design

If you want to analyze a design or see whether or not selected interactions can be estimated from the design, you *must* store it in the worksheet. By default, MINITAB stores the design. If you want to see the properties of various designs before selecting the design you want to store, uncheck **Store design in worksheet** in the Options subdialog box.

Estimating selected interactions

Taguchi designs are primarily intended to study main effects of factors. Occasionally, you may want to study some of the two-way interactions. Some of the Taguchi designs (orthogonal arrays) allow the study of a limited number of two-way interactions. This usually requires that you leave some columns out of the array by not assigning factors to them. Some of the array columns are confounded with interactions between other array columns. Confounding means that the factor effect is blended with the interaction effect, thus they cannot be evaluated separately.

You can ask MINITAB to automatically assign factors to array columns in a way that avoids confounding—see *To select interactions* on page 24-11. Or, if you know exactly what design you want and know the columns of the full array that correspond to the design, you can assign factors to array columns yourself—see *To assign factors to columns of the array* on page 24-12.

Interaction tables show confounded columns, which can help you to assign factors to array columns. For interaction tables of MINITAB's catalog of Taguchi designs (orthogonal arrays), see Help. The interaction table for the L8 (2^7) array is shown below.

	1	**2**	**3**	**4**	**5**	**6**	**7**
1		3	2	5	4	7	6
2			1	6	7	4	5
3				7	6	5	4
4					1	2	3
5						3	2
6							1

The columns and rows represent the column numbers of the Taguchi design (orthogonal array). Each table cell contains the interactions confounded for the two columns of the orthogonal array.

For example, the entry in cell (1, 2) is 3. This means that the interaction between columns 1 and 2 is confounded with column 3. Thus, if you assigned factors A, B, and C to columns 1, 2, and 3, you could not study the AB interaction independently of factor C. If you suspect that there is a substantial interaction between A and B, you should not assign any factors to column 3. Similarly, the column 1 and 3 interaction is confounded with column 2, and the column 2 and 3 interaction is confounded with column 1.

Note Assigning factors to columns of the array does not change how the design is displayed in the worksheet. For example, if you assigned factor A to column 3 of the array and factor B to column 2 of the array, factor A would still appear in column 1 in the worksheet and factor B would still appear in column 2 in the worksheet.

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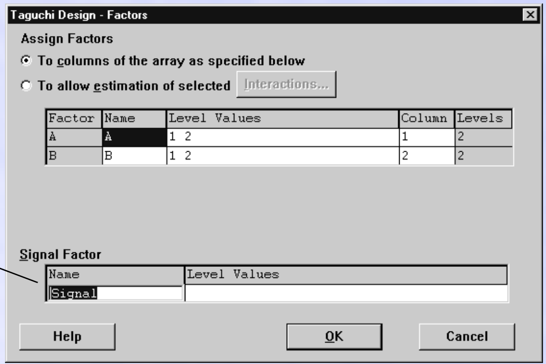
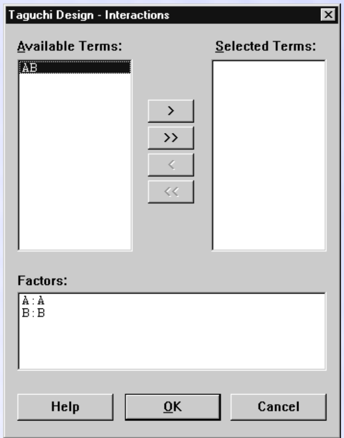
▶ To select interactions

1 In the Create Taguchi Design dialog box, click **Factors**.



This option only available when you have a dynamic design.

2 Under **Assign Factors**, choose **To allow estimation of selected Interactions** and then click **Interactions**.



3 Move the interactions that you want to include in the design from **Available Terms** to **Selected Terms** using the arrow buttons

- to move the interactions one at a time, highlight an interaction, then click [<] or [>]
- to move all of the interactions, click on [<<] or [>>]

You can also move an interaction by double-clicking it.

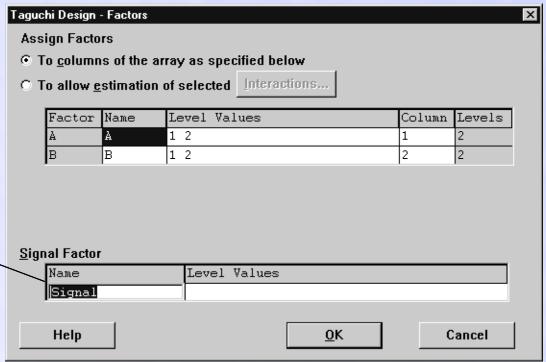
4 Click **OK**.

▶ To assign factors to columns of the array

Note Assigning factors to columns of the array does not change how the design is displayed in the worksheet. For example, if you assigned factor A to column 3 of the array and factor B to column 2 of the array, factor A would still appear in column 1 in the worksheet and factor B would still appear in column 2 in the worksheet.

1 In the Create Taguchi Design dialog box, click **Factors**.

This option is only available when you have a dynamic design.



2 Under **Assign Factors**, choose **To columns of the array as specified below**.

3 In the factor table, click under **Column** in the cell that corresponds to the factor that you want to assign. From the drop-down list, choose the array column to which you want to assign the factor. Then, use the ↓ key to move down the table and assign the factors to the remaining array columns. Click **OK**.

More See Help for interaction tables of MINITAB's catalog of Taguchi designs (orthogonal arrays).

Naming factors

By default, MINITAB names the factors alphabetically.

▶ To name factors

1 In the Create Taguchi Design dialog box, click **Factors**.

2 Under **Name** in the factor table, click in the first row and type the name of the first factor. Then, use the ↓ key to move down the column and enter the remaining factor names.

3 Click **OK**.

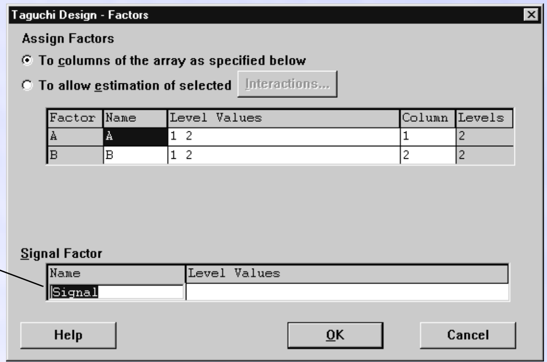
More After you have created the design, you can change the factor names by typing new names in the Data window, or with Modify Design (page 24-18).

Setting factor levels

By default, Minitab sets the levels of a factor to the integers 1, 2, 3, ... You may change these to other numbers, such as the actual values of the factor level, or to text levels.

One useful technique for customizing Taguchi designs (orthogonal arrays) is the use of "dummy treatments." You can create a dummy treatment in MINITAB by repeating levels for the same factor, as long as there are at least two distinct levels. See *Creating dummy treatments* on page 24-13.

1 In the Create Taguchi Design dialog box, click **Factors**.



This option is only available when you have a dynamic design.

2 Under **Level Values** in the factor table, click in the first row and type the levels of the first factor. Then, use the ↓ key to move down the column and enter the remaining levels. Click **OK**.

Creating dummy treatments

One useful technique for customizing Taguchi designs (orthogonal arrays) is the use of "dummy treatments." You can create a dummy treatment in MINITAB by repeating levels for a factor, as long as there are at least two distinct levels.

For example, if you wanted to use an L9 (3^4) array, which has four three-level factors, but had one factor with only two levels, you could use a dummy treatment to accommodate this. Here, the L9 (3^4) array is shown, both without and with a dummy treatment. In the dummy example, the factor levels for factor A are 1 2 1, where 1 is the repeated level for the dummy treatment.

L9 (3^4) array

Run	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

L9 (3^4) array (dummy)

Run	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	1′	1	3	2
8	1′	2	1	3
9	1′	3	2	1

Dummy treatments

In the L9 (3^4) orthogonal array with dummy treatment above, factor A has repeated level 1, in place of level 3. This results in an L9 (3^4) array with one factor at 2 levels and three factors at 3 levels. The array is still orthogonal, although it is not balanced.

When choosing which factor level to use as the dummy treatment, you may want to consider the amount of information about the factor level and the availability of experimental resources. For example, if you know more about level 1 than level 2, you may want to choose level 2 as your dummy treatment. Similarly, if level 2 is more expensive than level 1, requiring more resources or time to test, you may want to choose level 1 as your dummy treatment.

Summary of Available Taguchi Designs

Single-level designs

The table below summarizes the single-level Taguchi designs available. The number following the "L" indicates the number of runs in the design. For example, the L4 (2^3) design has four runs. The numbers in the table indicate the minimum and maximum number of available factors for each design. For example, an L8 (2^7) design can have from two to seven factors with two levels each; an L16 (4^5) design can have from two to five factors with four levels each.

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	Number of levels			
Designs	**2**	**3**	**4**	**5**
L4 (2^3)	2-3			
L8 (2^7)	2-7			
L9 (3^4)		2-4		
L12 (2^{11})	2-11			
L16 (2^{15})	2-15			
L16 (4^5)			2-5	
L25 (5^6)				2-6
L27 (3^{13})		2-13		
L32 (2^{31})	2-31			

Mixed 2-3 level designs

The table below summarizes the available Taguchi designs for mixed designs in which factors have 2 or 3 levels. The number in the table cells indicate the minimum and maximum number of factors available for each level. For example, an L18 (2^1 3^7) design can have one factor with two levels and from one to seven factors with three levels.

	Number of levels	
Designs	**2**	**3**
L18 (2^1 3^7)	1	1-7
L36 (2^{11} 3^{12})	1-11	2-12
L36 (2^3 3^{13})	1-3	13
L54 (2^1 3^{25})	1	3-25

Mixed 2-4 level designs

The table below summarizes the available Taguchi designs for mixed designs in which factors have 2 or 4 levels. The number in the table cells indicate the minimum and maximum number of factors available for each level. For example, an L8 (2^4 4^1) design can have from one to four factors with two levels and one factor with four levels.

	Number of levels	
Designs	**2**	**4**
L8 (2^4 4^1)	1-4	1
L16 (2^{12} 4^1)	2-12	1
L16 (2^9 4^2)	1-9	2
L16 (2^6 4^3)	1-6	3
L16 (2^3 4^4)	1-3	4
L32 (2^1 4^9)	1	2-9

Mixed 2-8 level designs

The table below show the available Taguchi design for mixed designs in which factors have 2 and 8 levels. The number in the table cells indicate the minimum and maximum number of factors available for each level. An L16 (2^8 8^1) design can have from one to eight factors with two levels and one factor with eight levels.

	Number of levels	
Design	**2**	**8**
L16 (2^8 8^1)	1-8	1

Mixed 3-6 level designs

The table below shows the available Taguchi design for mixed designs in which factors have 3 and 6 levels. The number in the table cells indicate the minimum and maximum number of factors available for each level. An L18 (3^6 6^1) design can have from one to six factors with three levels and one factor with six levels.

	Number of levels	
Design	**3 level**	**6 level**
L18 (3^6 6^1)	1-6	1

Defining Custom Taguchi Designs

Use Define Custom Taguchi Design to create a design from data you already have in the worksheet. For example, you may have a design you:

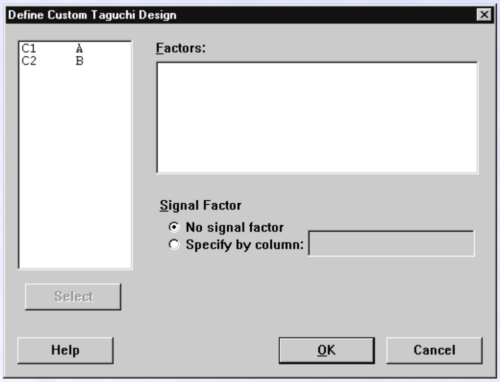
- created using MINITAB session commands
- entered directly in the Data window
- imported from a data file
- created as another design type in MINITAB
- created with earlier releases of MINITAB

You can also use Define Custom Taguchi Design to redefine a design that you created with Create Taguchi Design and then modified directly in the worksheet.

Define Custom Taguchi Design allows you to specify which columns contain your factors and to include a signal factor. After you define your design, you can use Modify Design (page 24-18), Display Design (page 24-21), and Analyze Taguchi Design (page 24-23).

▶ To define a custom Taguchi design

1 Choose **Stat ➤ DOE ➤ Taguchi ➤ Define Custom Taguchi Design**.



2 In **Factors**, enter the columns that contain the factor levels.

3 If you have a signal factor, choose **Specify by column** and enter the column that contains the signal factor levels. Click **OK**.

Modifying Designs

After creating a Taguchi design and storing it in the worksheet, you can use Modify Design to make the following modifications:

- rename the factors and change the factor levels for the control factors in the inner array—see *Renaming factors and changing factor levels* on page 24-18
- add a signal factor to a static design—see *Adding a signal factor to an existing static design* on page 24-19
- ignore the signal factor (treat the design as static)—see *Ignoring the signal factor* on page 24-20
- add new levels to the signal factor in an existing dynamic design—see *Adding new levels to the signal factor* on page 24-21

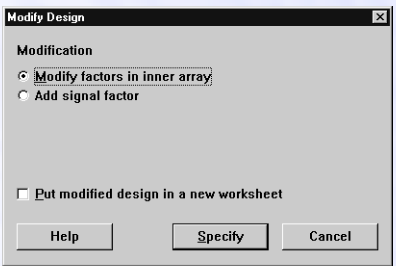
By default, MINITAB will replace the current design with the modified design. To store the modified design in a new worksheet, check **Put modified design in a new worksheet** in the Modify Design dialog box.

Renaming factors and changing factor levels

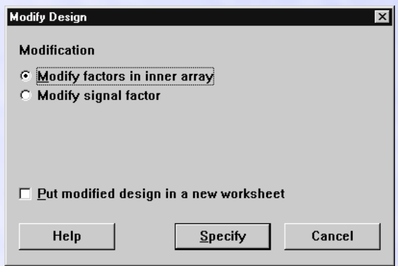
▶ To rename factors or change factor levels

1 Choose **Stat ➤ DOE ➤ Modify Design**.

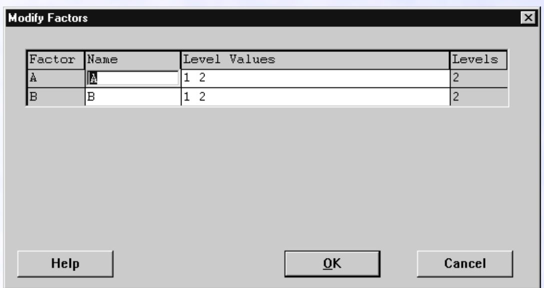
Static Design



Dynamic Design



2 Choose **Modify factors in inner array**. Click **Specify**.



3 Under **Name**, click in the first row and type the name of the first factor. Then, use the ↓ key to move down the column and enter the remaining factor names.

4 Under **Level Values**, click in the first row and type the levels of the first factor. Then, use the ↓ key to move down the column and enter the remaining levels. Click **OK** in each dialog box.

Adding a signal factor to an existing static design

When you add a signal factor to an existing static design, MINITAB adds a new signal factor column after the factor columns and appends new rows (replicates) to the end of the existing worksheet. For example, if you add a signal factor with 2 levels to an existing L4 (2^3) array, 4 rows (1 replicate of 4 runs) are added to the worksheet; if you add a signal factor with 3 levels, 8 rows (2 replicates of 4 runs) are added to the worksheet. A replicate is the complete set of runs from the initial design.

Static design (No signal factor)

A	B
1	1
1	2
2	1
2	2

Dynamic design (Added signal factor with 2 levels)

A	B	Signal factor
1	1	1
1	2	1
2	1	1
2	2	1
1	1	2
1	2	2
2	1	2
2	2	2

Dynamic design (Added signal factor with 3 levels)

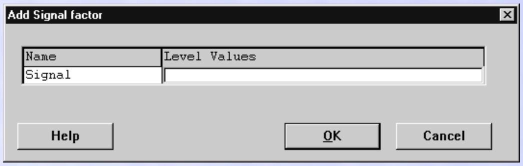
A	B	Signal factor
1	1	1
1	2	1
2	1	1
2	2	1
1	1	2
1	2	2
2	1	2
2	2	2
1	1	3
1	2	3
2	1	3
2	2	3

Note When you add a signal factor to an existing static design, the run order will be different from the order that results from adding a signal factor while creating a new design—see *Adding a signal factor for a dynamic response experiment* on page 24-8. The order of the rows does not affect the Taguchi analysis.

▶ To add a signal factor

1 Choose **Stat ➤ DOE ➤ Modify Design**.

2 Choose **Add signal factor**. Click **Specify**.



3 If you like, in the signal factor table under **Name**, click in the first row and type the name of the signal factor.

4 Under **Level Values**, enter the levels of the signal factor. You must enter at least two distinct values. Click **OK**.

Note You can also specify signal factor levels using a range and increments. You can specify a range by typing two numbers separated by a colon. For example, 1:5 displays the numbers 1, 2, 3, 4, and 5. You can specify an increment by typing a slash "/" and a number. For example, 1:5/2 displays every other number in a range: 1, 3, and 5.

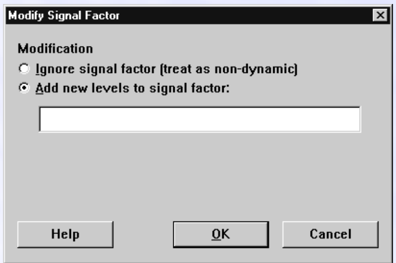
Ignoring the signal factor

You can choose to ignore the signal factor in a dynamic design and thus treat the design as static.

▶ To ignore the signal factor

1 Choose **Stat ➤ DOE ➤ Modify Design**.

2 Choose **Modify signal factor**. Click **Specify**.



3 Select **Ignore signal factor (treat as non-dynamic)**. Click **OK** in each dialog box.

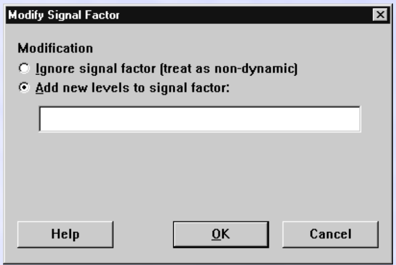
Adding new levels to the signal factor

When you add signal factor levels to an existing dynamic design, new rows (replicates) are appended to the end of the existing worksheet. For example, if you add 3 new signal factor levels to an existing L8 (2^7) design, 24 rows (3 replicates of 8 rows each) are added to the worksheet.

Note When you add new signal factor levels to an existing dynamic design, the run order will be different from the order that results from adding a signal factor while creating a new design. The order of the rows does not affect the Taguchi analysis.

1 Choose **Stat ➤ DOE ➤ Modify Design**.

2 Choose **Modify signal factor**. Click **Specify**.



3 Choose **Add new levels to signal factor**. Enter the new signal factor levels. Click **OK**.

Note You can also specify signal factor levels using a range and increments. You can specify a range by typing two numbers separated by a colon. For example, 1:5 displays the numbers 1, 2, 3, 4, and 5. You can specify an increment by typing a slash "/" and a number. For example, 1:5/2 displays every other number in a range: 1, 3, and 5.

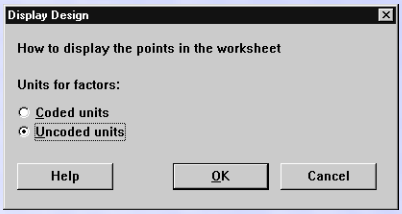
Displaying Designs

After you create the design, you can use Display Design to change the way the design points are stored in the worksheet. You can display the factor levels in coded or uncoded form.

If you assigned factor levels in Factors subdialog box, the uncoded (actual) factor levels are initially displayed in the worksheet. If you did not assign factor levels (used the default factor levels, which are 1, 2, 3, ...), the coded and uncoded units are the same.

▶ To change the units for the factors

1 Choose **Stat ➤ DOE ➤ Display Design**.



2 Choose **Coded units** or **Uncoded units**. Click **OK**.

Collecting and Entering Data

After you create your design, you need to perform the experiment and collect the response (measurement) data. To print a data collection form, follow the instructions below. After you collect the response data, enter the data in any worksheet column not used for the design.

Printing a data collection form

You can generate a data collection form in two ways. You can simply print the Data window contents, or you can use a macro. A macro can generate a “nicer” data collection form—see Help for more information. Although printing the Data window will not produce the prettiest form, it is the easiest method. Just follow these steps:

1 When you create your experimental design, MINITAB stores the factor settings in the worksheet. These columns constitute the basis of your data collection form. If you did not name factors or specify factor levels when you created the design and you want names or levels to appear on the form, see *Modifying Designs* on page 24-18.

2 In the worksheet, name the columns in which you will enter the measurement data obtained when you perform your experiment.

3 Choose **File ➤ Print Worksheet**. Make sure **Print Grid Lines** is checked, then click **OK**.

More You can also copy the worksheet cells to the Clipboard by choosing **Edit ➤ Copy** cells. Then paste the clipboard contents into a word-processing application, such as Microsoft Word, where you can create your own form.

Analyzing Taguchi Designs

To use Analyze Taguchi Design, you must

- create and store the design using Create Taguchi Design (page 24-4), or create a design from data already in the worksheet using Define Custom Taguchi Design (page 24-17) and
- enter the response data in the worksheet—see *Data* on page 24-24

Using Analyze Taguchi Design, you can

- generate main effects and interaction plots of the S/N ratios, means (static design), slopes (dynamic design), and standard deviations vs. the control factors
- display response tables for S/N ratios, means (static design), slopes (dynamic design), and standard deviations

The response tables and main effects and interaction plots can help you determine which factors affect variation and process location. See *Two-step optimization* on page 24-23.

Two-step optimization

Two-step optimization, an important part of robust parameter design, involves first reducing variation and then adjusting the mean on target. Use two-step optimization when you are using either Nominal is Best signal-to-noise ratio. First, try to identify which factors have the greatest effect on variation and choose levels of these factors that minimize variation. Then, once you have reduced variation, the remaining factors are possible candidates for adjusting the mean on target (scaling factors).

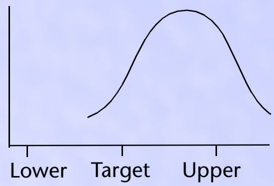
A scaling factor is a factor in which the mean and standard deviation are proportional. You can identify scaling factors by examining the response tables for each control factor. A scaling factor has a significant effect on the mean with a relatively small effect on signal-to-noise ratio. This indicates that the mean and standard deviation scale together. Thus, you can use the scaling factor to adjust the mean on target but not affect the S/N ratio.

CONTENTS INDEX MEET MTB UGUIDE 1 UGUIDE 2 SC QREF HOW TO USE

Use main effects plots to help you visualize the relative value of the effects of different factors.

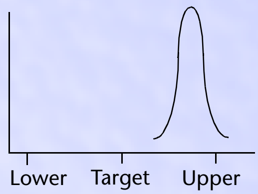
Initial process performance

- high variation
- process not on target



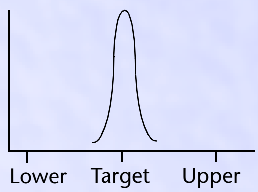
Step 1: Minimize variation

- find factor settings that minimize the effects of noise on the response
- variation minimized
- process not on target



Step 2: Adjust mean on target

- find factor settings that adjust the mean on target
- variation minimized
- process on target
- robust design



Data

Structure your data in the worksheet so that each row contains the control factors in the inner array and the response values from one complete run of the noise factors in the outer array. You must have from 2 to 50 response columns. Here is an example:

Time	Pressure	Catalyst	Temperature	Noise 1	Noise 2
1	1	1	1	50	52
1	1	1	2	44	51
1	2	2	1	56	59
1	2	2	2	65	77
2	1	2	1	47	43
2	1	2	2	42	51
2	2	1	1	68	62
2	2	1	2	51	38

This example, which is an L8 (2^4), has four factors in the inner array (Time, Pressure, Catalyst, and Temperature). Recall, the inner array represents the control factors. There are two noise conditions in the outer array (Noise 1 and Noise 2). There are two responses—one for each noise condition—in the outer array for each run in the inner array.

You can have 1 response column if you are using the Larger is Better or Smaller is Better signal-to-noise ratio and you are not going to analyze or store the standard deviation.

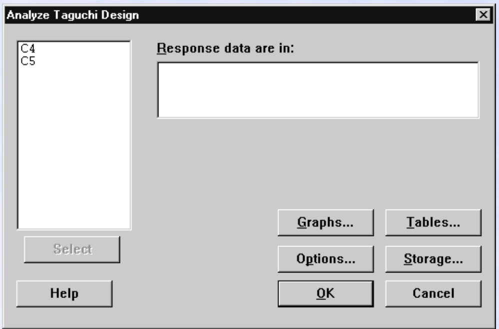
If you have a design and response data in your worksheet that was

- created using Minitab session commands,
- entered directly in the Data window,
- imported from a data file,
- created using as another design type in Minitab,
- or created with earlier releases in Minitab,

you can use Analyze Taguchi Design, which will prompt you to define your design—see *Defining Custom Taguchi Designs* on page 24-17.

▶ To fit a model to the data

1 Choose **Stat ➤ DOE ➤ Taguchi ➤ Analyze Taguchi Design**.



2 In **Response data are in**, enter the columns that contain the measurement data.

3 If you like, use any of the options listed below, then click **OK**.

Options

Graphs subdialog box

- for static designs, display main effects plots and selected interaction plots for the signal-to-noise (S/N) ratios, the process means, and/or the process standard deviations

- for dynamic designs, display main effects plots and selected interaction plots for the S/N ratios, the slopes, and/or the process standard deviations. Also, display scatter plots with fitted lines.
- display interaction plots for selected interactions—see *Selecting terms for the interaction plots* on page 24-28
  - display the interaction plots in a matrix on a single graph or to display each interaction plot on a separate page—see *Selecting terms for the interaction plots* on page 24-28

Tables subdialog box

- for static designs, display response tables for signal-to-noise ratios, the means, and the standard deviations—see *Displaying response tables* on page 24-29
- for dynamic designs, display response tables for signal-to-noise ratios, the slopes, and the standard deviations—see *Displaying response tables* on page 24-29

Options subdialog box

- for static designs, choose the signal-to-noise (S/N) ratio that is consistent with your goal and data—see *Analyzing static designs* on page 24-29
- for dynamic designs, enter a response reference value and a signal reference value for the fitted line or choose to fit the line with no fixed reference point—see *Analyzing dynamic designs* on page 24-30
- use natural logs in graphs and tables for standard deviations

Storage subdialog box

- for static designs, store the
  - S/N ratios
  - means
  - standard deviations
  - coefficients of variation
  - natural log of the standard deviations
- for dynamic designs, store the
  - S/N ratios
  - slopes
  - intercepts
  - standard deviations (square root of MSE)
  - natural log of the standard deviations

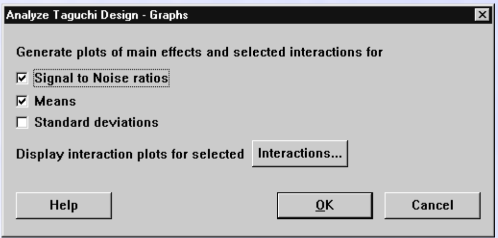
Displaying main effects and interaction plots

You can display main effects and selected interaction plots for signal-to-noise (S/N) ratios, means (static designs), slopes (dynamic designs), and/or standard deviations.

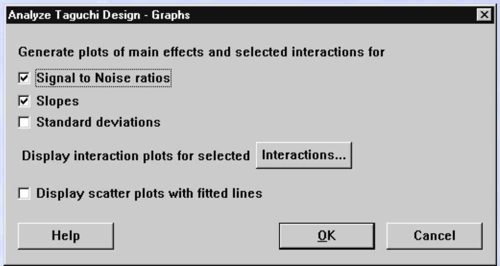
▶ To display main effects and interaction plots

1 In the Analyze Taguchi Design dialog box, click **Graphs**.

Static Design



Dynamic Design



2 Under **Generate plots of main effects and selected interactions for** check **Signal-to-noise ratios**, **Means** (for static design) or **Slopes** (for dynamic design), and/or **Standard deviations**. Click **OK**.

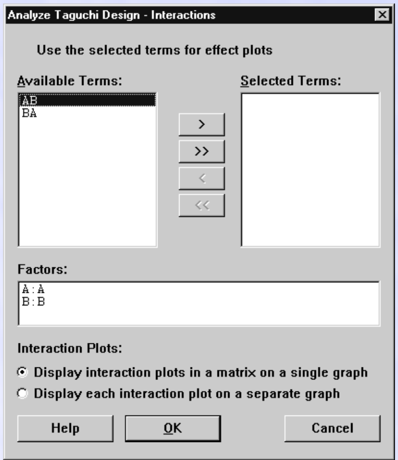
Selecting terms for the interaction plots

You can choose which interactions to plot. You can also choose whether to display the interaction plots in a matrix on a single graph or to display each interaction plot separately on its own page.

▶ To select which interactions to plot

1 In the Analyze Taguchi Design dialog box, click **Graphs**.

2 In the Graphs subdialog box, click **Interactions**.



3 Move the interactions that you want to include in the plot from **Available Terms** to **Selected Terms** using the arrow buttons.

- to move the interactions one at a time, highlight an interaction, then click ‹ or ›
- to move all of the interactions, click on ‹‹ or ››

You can also move an interaction by double-clicking it.

Note The available terms in the Interactions subdialog box list the interactions available to plot. The second factor in the term (B in AB) is used as the horizontal scale for the plot. Thus, you can view the AB interaction both ways by selecting both AB and BA.

Displaying response tables

You can display response tables for signal-to-noise (S/N) ratios, means (static designs), slopes (dynamic designs), and/or standard deviations.

▶ To display response tables

1 In the Analyze Taguchi Design dialog box, click **Tables**.

Static Design

Dynamic Design

2 Under **Display response tables for** check **Signal-to-noise ratios**, **Means** (for static design) or **Slopes** (for dynamic design), and/or **Standard deviations**. Click **OK**.

Analyzing static designs

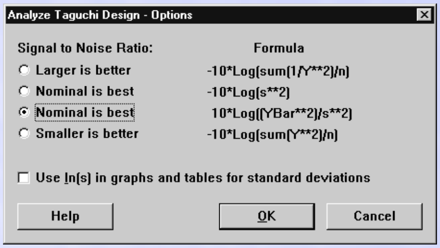
If you have a static design (no signal factor), you can choose signal-to-noise (S/N) ratios depending on the goals of your design. S/N ratios differ, therefore you should use your engineering knowledge, understanding of the process, and experience to choose the appropriate S/N ratio [3].

Choose...	Use when the goal is to...	And your data are...
Larger is better $S/N=-10(\log(\Sigma(1/Y^2)/n))$	Maximize the response	Positive
Nominal is best $S/N=-10(\log(s^2))$	Target the response and you want to base the S/N ratio on standard deviations only	Positive, zero, or negative
Nominal is best (default) $S/N=10(\log((\bar{Y}^2)/s^2))$	Target the response and you want to base the S/N ratio on means and standard deviations	Non-negative with an "absolute zero" in which the standard deviation is zero when the mean is zero
Smaller is better $S/N=-10(\log(\Sigma Y^2/n))$	Minimize the response	Non-negative with a target value of zero

Note The Nominal is Best (default) S/N ratio is good for analyzing or identifying scaling factors, which are factors in which the mean and standard deviation vary proportionally. Scaling factors can be used to adjust the mean on target without affecting S/N ratios.

▶ To select a signal-to-noise ratio

1 In the Analyze Taguchi Design dialog box, click **Options**.



2 Under **Signal-to-Noise Ratio**, choose the S/N ratio that best fits the goals of the design. Choose from one of the following:

- Larger is better
- Nominal is best
- Nominal is best
- Smaller is better

3 Click **OK**.

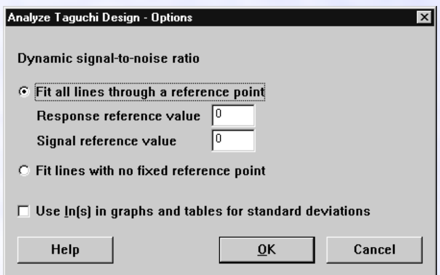
Analyzing dynamic designs

Dynamic response experiments are used to improve the functional relationship between input signal and output response, in other words, to optimize tunability. The output response should be directly proportional to the input signal. The ideal functional relationship between input signal and output response is a line through the origin.

In some cases, you may wish to choose a reference point, other than the origin, through which the line should pass. For example, your results may be generated far from zero, by specifying a reference point in the range of results you can enhance the sensitivity of the analysis. Or, you can choose to fit the line with no fixed reference point. In this case, the intercept will be fitted to the data.

▶ To specify a reference point for the response

1 In the Analyze Taguchi Design dialog box, click **Options**.



2 In **Response reference value**, enter a numeric value corresponding to the desired output (response) value.

3 In **Signal reference value**, enter a signal factor level corresponding to the response reference value. Click **OK**.

▶ To fit a line with no fixed reference point

1 In the Analyze Taguchi Design dialog box, click **Options**.

2 Select **Fit lines with no fixed reference point**. Click **OK**.

▶ Example of a static Taguchi design

Suppose you are an engineer and need to evaluate the factors that affect the seal strength of plastic bags used to ship your product. You have identified three controllable factors (Temperature, Pressure, and Thickness) and two noise conditions (Noise 1 and Noise 2) that may affect seal strength. You want to ensure that seal strength meets specifications. If the seal is too weak, it may break, contaminating the product and resulting in returns. If the seal is too strong, customers may have difficulty opening the bag. The target specification is 18.

1 Open the worksheet SEAL.MTW. The design and response data have been saved for you.

2 Choose **Stat ➤ DOE ➤ Taguchi ➤ Analyze Taguchi Design**.

3 In **Response data are in**, enter *Noise1 Noise2*.

4 Click **Graphs**. Under **Generate plots of main effects and selected interactions for**, check **Standard deviations**. Click **OK**.

5 Click **Tables**. Under **Display response tables for**, check **Standard deviations**. Click **OK** in each dialog box.

Session window output

Response Table for Signal to Noise Ratios

Nominal is best (10*Log(Ybar2/s**2))**

Level	Temperature	Pressure	Thickness
1	29.4219	21.9191	28.2568
2	27.0652	30.2117	29.0690
3	25.7842	30.1406	24.9455
Delta	3.6378	8.2926	4.1235
Rank	3	1	2

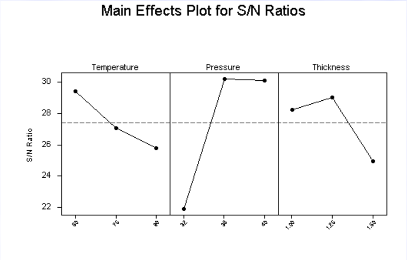
Response Table for Means

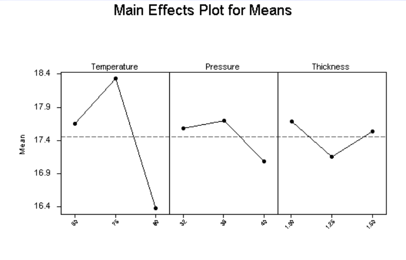
Level	Temperature	Pressure	Thickness
1	17.6500	17.5833	17.6833
2	18.3333	17.7000	17.1500
3	16.3833	17.0833	17.5333
Delta	1.9500	0.6167	0.5333
Rank	1	2	3

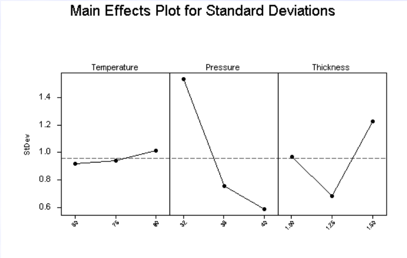
Response Table for Standard Deviations

Level	Temperature	Pressure	Thickness
1	0.91924	1.53206	0.96638
2	0.94281	0.75425	0.68354
3	1.01352	0.58926	1.22565
Delta	0.09428	0.94281	0.54212
Rank	3	1	2

Graph window output







Interpreting the results

The response tables show the average of the selected characteristic for each level of the factors. The response tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest average for each factor minus the lowest average for each factor. Ranks are assigned based on Delta values; rank 1 is assigned to the highest Delta value, rank 2 to the second highest Delta value, and so on. The main effects plot provide a graph of the averages in the response table.

Look at the response tables and main effects plots for the signal-to-noise (S/N) ratios to see which factors have the greatest effect on S/N ratio, which in this example is nominal-is-best.

In this example, the factor with the biggest impact on the S/N ratio is Pressure (Delta = 8.29, Rank = 1). If you look at the response tables and main effects plot for S/N ratio, you can see that Pressure 36 and Pressure 40 have almost the same average S/N ratio (30.2117 and 30.1406).

Here, the response table and main effects plots for mean both show that the factor with the greatest effect on the mean is Temperature (Delta = 1.95, Rank = 1). The response table and main effects plots for standard deviation both show that the factor with the greatest effect on the standard deviation is Pressure (Delta = 0.94, Rank = 1). Next, you may want to use Predict Results to see how different factor settings affect S/N ratios and response characteristics—see *Example of predicting results* on page 24-38.

▶ Example of a dynamic Taguchi design

Suppose you are an engineer trying to increase the robustness of a measurement system. A measurement system is dynamic because as the input signal changes, the output response changes. A measurement system ideally should have a 1:1 correspondence between the value being measured (signal factor) and the measured response (system output). Similarly, zero should serve as the fixed reference point (all lines should be fit through the origin) because an input signal of zero should result in a measurement of zero.

You have identified two components of your measurement system that will serve as the control factors: Sensing and Reporting. The signal factor is the actual value of the item being measured and the output response is the measurement. You have also selected two noise conditions.

1 Open the worksheet MEASURE.MTW. The design and response data have been saved for you.

2 Choose **Stat ➤ DOE ➤ Taguchi ➤ Analyze Taguchi Design**.

3 In **Response data are in**, enter *Noise1* and *Noise2*.

4 Click **Graphs**. Under **Generate plots of main effects and selected interactions for**, check **Standard deviations**.

5 Check **Display scatter plots with fitted lines**. Click **OK**.

6 Click **Tables**. Under **Display response tables for**, check **Standard deviations**.

7 Click **OK** in each dialog box.

Session window output

Response Table for Signal to Noise Ratios

Dynamic Response

Level	Sensing	Reporting
1	20.3270	18.3400
2	14.2224	16.2095
Delta	6.1047	2.1305
Rank	1	2

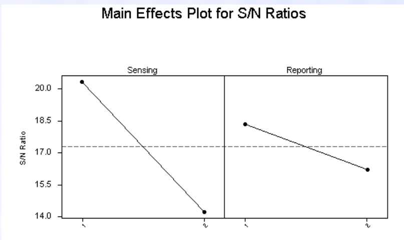
Response Table for Slopes

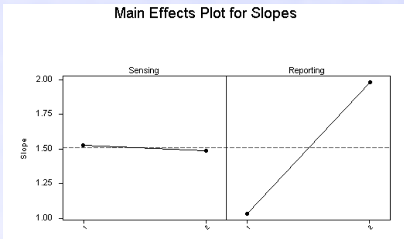
Level	Sensing	Reporting
1	1.52738	1.03293
2	1.48734	1.98179
Delta	0.04004	0.94886
Rank	2	1

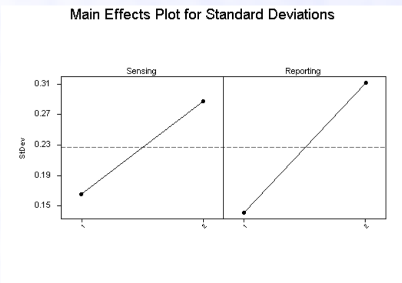
Response Table for Standard Deviations

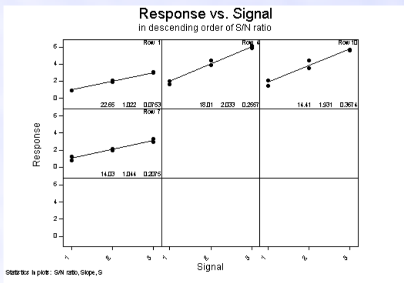
Level	Sensing	Reporting
1	0.165537	0.141439
2	0.287448	0.311545
Delta	0.121911	0.170106
Rank	2	1

Graph window output









Interpreting results

The response tables show the average of the selected characteristic for each level of the factors. The response tables include ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest average minus the lowest average for each factor. Ranks are assigned based on Delta values; rank 1 is assigned to the highest Delta value, rank 2 to the second highest Delta value, and so on. The main effects plot provide a graph of the averages in the response table.

Because you are trying to improve the quality of a measurement system, you want to maximize the signal-to-noise (S/N) ratio. If you examine the response table and main effects plot for S/N ratio, you can see that the Sensing (Delta = 6.1047, Rank = 1) component has a greater effect on S/N ratio than Reporting (Delta=2.1305, Rank = 2).

Here, the response table and main effects plots for slopes both show that Reporting (Delta = 0.94886, Rank = 1) has a much greater effect on slope than Sensing (Delta = 0.04004, Rank = 2). Thus, it is likely that Reporting can be used as a scaling factor to adjust the mean on target after minimizing sensitivity to noise.

The response table and main effects plot show that Reporting (Delta=0.1701,Rank=1) has a greater effect on standard deviation than sensing (Delta=0.1219,Rank=2).

Based on these results, you might first want to maximize S/N ratio using the low level of the Sensing factor and then adjust the slope on to the target of 1 using the Reporting factor.

Predicting Results

Use Predict Results after you have run a Taguchi experiment and examined the response tables and main effects plots to determine which factor settings should achieve a robust product design. Predict Results allows you to predict S/N ratios and response characteristics for selected factor settings.

For example, you might choose the best settings for the factors that have the greatest effect on the S/N, and then wish to predict the S/N and mean response for several combinations of other factors. Predict Results would provide the expected responses for those settings. You should choose the results that comes closest to the desired mean without significantly reducing the S/N ratio. You should then perform a follow-up experiment using the selected levels, to determine how well the prediction matches the observed result.

If there are minimal interactions among the factors or if the interactions have been correctly accounted for by the predictions, the observed results should be close to the prediction, and you will have succeeded in producing a robust product. On the other hand, if there is substantial disagreement between the prediction and the observed results, then there may be unaccounted for interactions or unforeseen noise effects. This would indicate that further investigation is necessary.

You can specify the terms in the model used to predict results. For example, you may decide not to include a factor in the prediction because the response table and main effects plot indicate that the factor does not have much of an effect on the response. You can also decide whether or not to include selected interactions in the model. Interactions included in the model will affect the predicted results.

Data

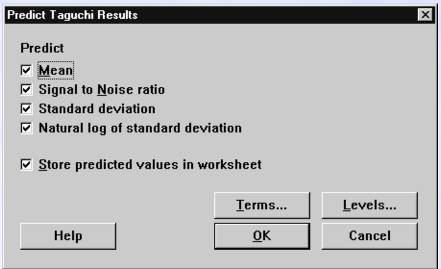
In order to predict results, you need to have

- created and stored the design using Create Taguchi Design (page 24-4) or created a design from data already in the worksheet with Define Custom Taguchi Design (page 24-17) and
- analyzed it using *Analyzing Taguchi Designs* on page 24-23

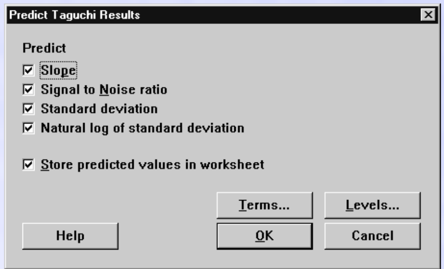
▶ To predict results

1 Choose **Stat ➤ DOE ➤ Taguchi ➤ Predict Results**.

Static Design



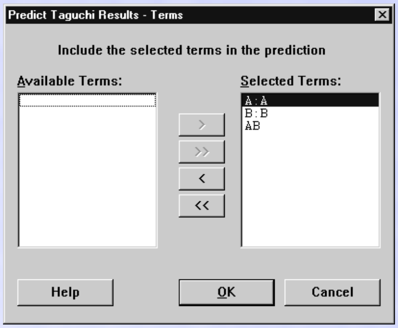
Dynamic Design



2 Choose to predict one or more of the following:

- mean (static design) or slope (dynamic design)
- signal-to-noise ratio
- standard deviations
- natural log of standard deviation

3 Click **Terms**.

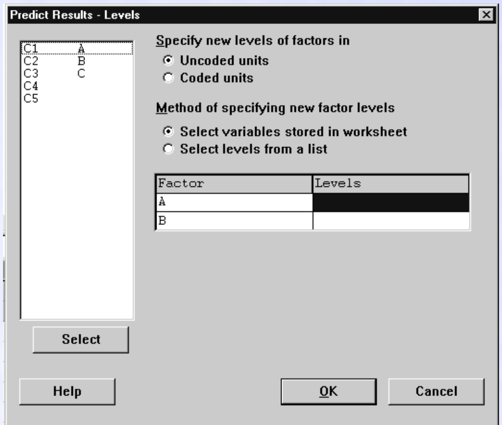


4 Move the factors that you do not want to include in the model from **Selected Terms** to **Available Terms** using the arrow buttons, then click **OK**.

- to move the terms one at a time, highlight a term, then click [<] or [>]
- to move all of the term, click on [<<] or [>>]

You can also move a term by double-clicking it.

5 Click **Levels**.



6 Do one of the following

- To specify factor levels that are already stored in a worksheet column
  – Choose **Select variables stored in worksheet**.
  – Under **Levels**, click in the first row and enter column containing the new levels of the first factor. Then, use the [↓] key to move down the column and enter the remaining factor level columns. Click **OK**.
- To select levels from a list of the existing factor levels
  – Choose **Select levels from a list**.
  – Under **Levels**, click in the first row and choose the factor level from the drop-down list. Then, use the [↓] key to move down the column and choose the remaining factor levels. Click **OK**.

Options

Predict results dialog box

- store the predicted values in the worksheet (default)

Terms subdialog box

- choose terms to include in the prediction model

Levels subdialog box

- enter the new factor levels in coded or uncoded units

▶ Example of predicting results

We will now predict results for the seal strength experiment introduced on page 24-31. You had identified three controllable factors that you thought would influence seal strength: Temperature, Pressure, and Thickness. Because you first want to maximize the signal-to-noise (S/N) ratio, you chose factor settings that increase S/N ratios: Temperature 60, Pressure 36, and Thickness 1.25.

1 Open the worksheet SEAL2.MTW. The design and response information have been saved for you.

2 Choose **Stat ➤ DOE ➤ Taguchi ➤ Predict Results**.

3 Click **Levels**.

4 Under **Method of specifying new factor levels**, choose **Select levels from a list**.

5 Under **Levels**, click in the first row and choose the factor level according to the table below. Then, use the ↓ key to move down the column and choose the remaining factor levels according to the table below.

Factor	Levels
Temperature	60
Pressure	36
Thickness	1.25

6 Click **OK** in each dialog box.

Session window output

Predicted values

```
S/N Ratio     Mean        StDev       Log(StDev)
33.8551       17.5889     0.439978    -1.03172
```

Interpreting results

The predicted results for the chosen factor settings are: S/N ratio of 33.8551, mean of 17.5889, and standard deviation of 0.439978. Next, you might run an experiment using these factor settings to test the accuracy of the model.

Note The predicted values for the standard deviation and log of the standard deviation use different models of the data.

References

[1] G.S. Peace (1993). *Taguchi Methods*. Addison-Wesley Publishing Company.

[2] J.H. Lochner and J.E. Matar (1990). *Designing for Quality*. ASQC Quality Press.

[3] W. Y. Fowlkes and C.M. Creveling (1995). *Engineering Methods for Robust Product Design*. Addison-Wesley Publishing Company.

[4] S.H. Park (1996). *Robust Design and Analysis for Quality Engineering*. Chapman & Hall.

[5] M.S. Phadke (1989). *Quality Engineering Using Robust Design*. Prentice-Hall.

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