General One-Factor Tutorial (Part 1 – The Basics)

Introduction

In this tutorial you will build a general one-factor design using Design-Ease® software. This type of design can be very useful for simple comparisons of categorical treatments, such as:

- Who will be the best supplier,
- Which type of raw material should be selected,
- What happens when you change procedures for processing paperwork.

If you wish to experiment on a continuous factor, such as time, which can be adjusted to any numerical level, consider making use of response surface methods (RSM) instead. This is covered in a separate tutorial.

The data for this example come from the Stat-Ease bowling league. Three bowlers must compete for the last position on the team. They each bowl six games (see data below).

Game	Pat	Mark	Shari
1	160	165	166
2	150	180	158
3	140	170	145
4	167	185	161
5	157	195	151
6	148	175	156
Mean	153.7	178.3	156.2

Bowling scores

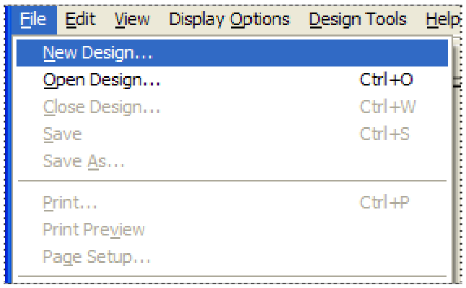
The captain knows better than to just simply pick the bowler with the highest score. Maybe it's a fluke that Mark scored highest and Pat's score is low. He wants to know if the scores are significantly different, given the variability in individual scores.

This one factor case study provides a good introduction to the power of simple comparative design of experiments (DOE). It will exercise a number of handy features provided by Design-Ease software. We won't explain all features displayed – some will be covered in follow-up tutorials. Many other features and outputs will be covered only in the help system, which can be accessed by clicking on Help on the main menu, or in most places via a right click or by pressing the F1 key (context sensitive).

Design the Experiment

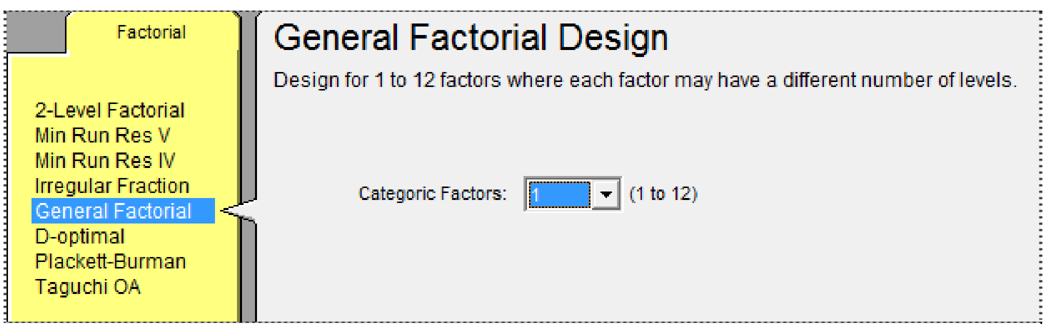
We will assume that you are familiar with the graphical user interface on your computer and the use of a mouse. Start the program by finding and double clicking on the icon for Design-Ease. You will then see the main menu and icon bar.

Click on **File** in the main menu. (Unavailable items are shown in a secondary color.) (If you prefer using the keyboard, press the Alt key and underlined letter, in this case Alt F, simultaneously.)



File menu

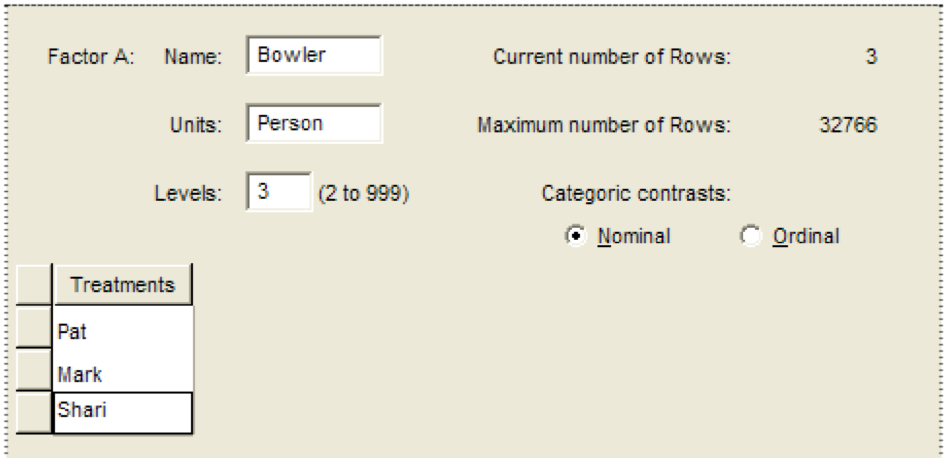
Select the **New Design** item with your mouse. (The blank-sheet icon 🗋 on the left of the toolbar is a quicker route to this screen. If you'd like to check this out, press Cancel to re-activate the tool bar.) The **Factorial** tab comes up by default. Select **General Factorial** for this design because the factor is categorical. (If your factor is numerical, such as temperature, then you would use the One Factor option under the Response Surface tab – available only with the 'parent' of this program: Design-Expert® software.) Leave the number of factors at its default level of **1** and then click on **Continue**.



General Factorial design

Enter the Design Parameters

Type **Bowler** as the name of the factor. Tab to the **Units** field and enter **Person**. Then **Tab** to the **Levels** field and enter **3**. Click on the **Treatments** field and enter **Pat**, **Mark**, and **Shari**.



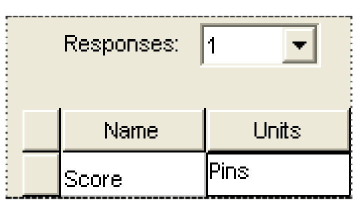
General Factorial design-builder dialog box – completed

Leave **Categoric contrasts** at its default setting of **Nominal** which will allow names to be entered. The optional contrast for "ordinal" applies to treatments which can be placed in numerical order. This obviously is not what's needed for this case, but if for example, our treatments were defined by something quantitative, such as height of bowler, you'd chose this alternative contrast to generate statistical analysis that would be more consistent with response surface methods (RSM). Reminder: As we've already suggested, if you are setting up an experiment on a numeric factor, consider doing so via the One Factor design on Design-Expert's Response Surface tab.

Press **Continue** to specify the remaining design options. In the **Replicates** field, which becomes active by default, type **6** (each bowler bowls six games). **Tab** to the Blocks field but leave it blank. Design-Ease now recalculates the number of runs for this experiment: 18.

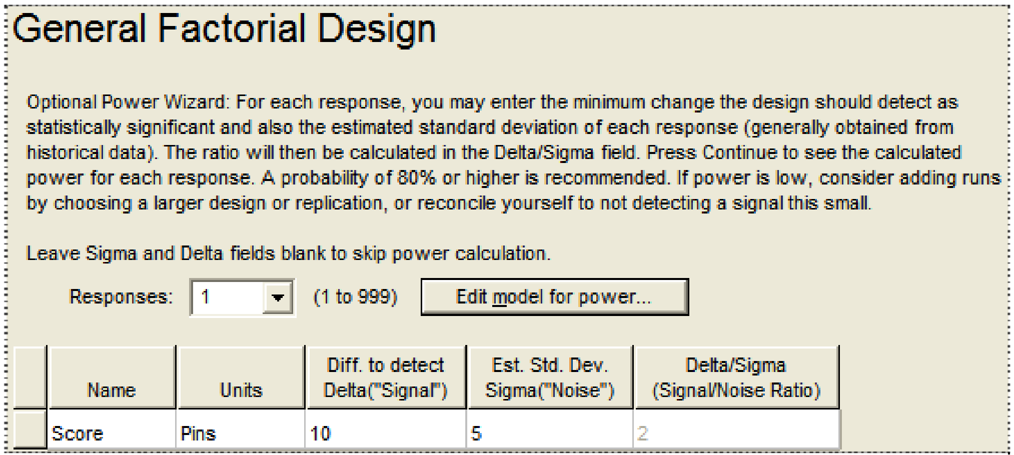
Design options entered

Press **Continue**. Let's do the easy things first. Leave the number of **Responses** at the default of **1**. Then click on the **Name** box and enter **Score**. **Tab** to the **Units** field and enter **Pins**.



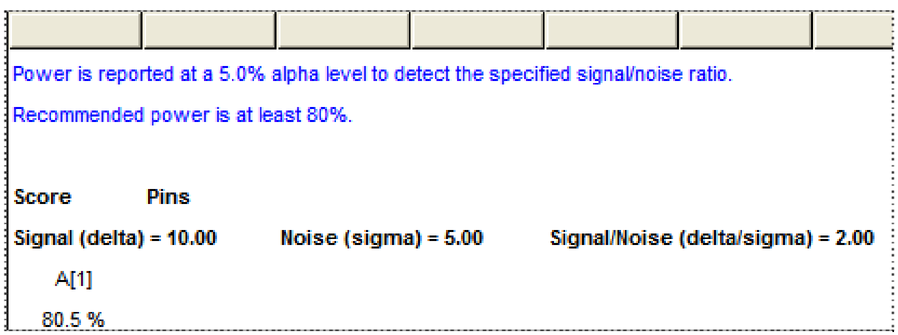
Response name dialog box – completed

At this stage one can skip the remainder of the fields and continue on. However, it will be good to gain an assessment of the power of your planned design of experiment. In this case the bowling captain does not care if averages differ by less that **10** pins and his records provide the standard deviation of **5**. Enter these values as shown below so Design-Ease can compute the signal to noise ratio – for this design: 2.



Optional power wizard – necessary inputs entered

Press **Continue** to see the happy outcome – power that exceeds 80 percent probability of seeing the desired difference.

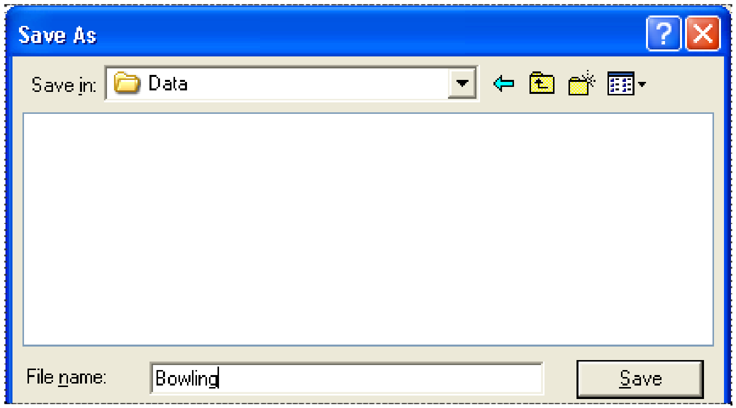


Results of power calculation

Click on **Continue** for Design-Ease to create the design and take you to the design layout window.

Save the Design

When you complete the design setup, save it to a file by selecting **File**, **Save As**. Type in the name of your choice (such as **Bowling**) for your data file, which will be saved as a *.de7 type.

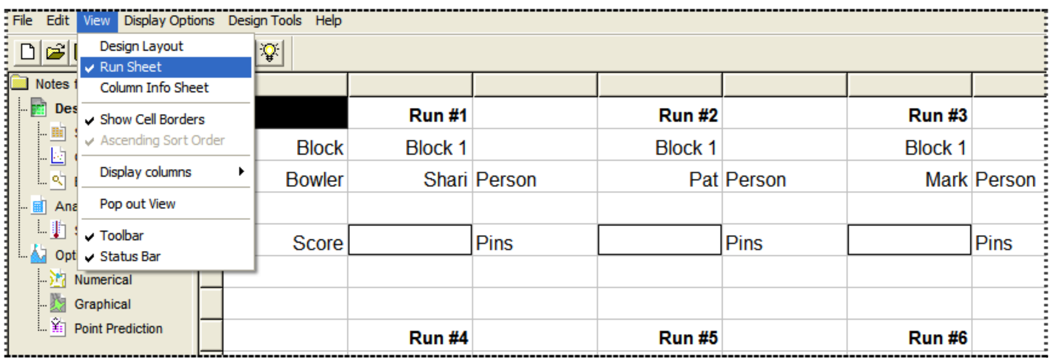


Save As dialog box

Then click on **Save**. Now you're protected in case of a system crash.

Create a Data Entry Form

Go to the **View** menu and select **Run Sheet** from the menu to get a recipe sheet of your experiments. It provides space to record the responses on a printed sheet of paper. (Note: this view of the data does not allow response entry. To type results into the program you must switch back to the home base – the Design Layout view.)

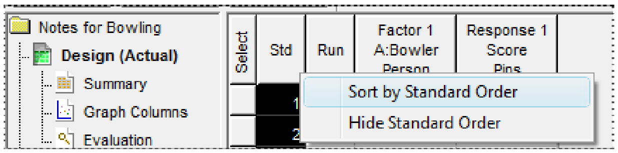


Run Sheet view (your run order may differ)

It's not necessary for this tutorial, but if you have a printer connected, you can select File, Print and OK to make a hard copy. (You can do the same from the basic design layout if you like that format better.)

Enter the Response Data

When you do your own experiments, you will need to go out and collect the data. Simulate this by doing a **File**, **Exit**. Click on **Yes** if you are prompted to **Save**. Then re-start Design-Ease and use **File**, **Open Design** (or file open icon on the toolbar) to open your data file (**Bowling.de7**). You should now see the data tabulated in the standard design layout. (If not, go to View and select Design Layout.) For an actual experiment, the runs would have been performed in randomized run order, which is the order Design-Ease defaults to. This run order will be different each time a design is created from scratch. For this example, you must enter the data in the proper order to match up with the correct bowlers, so right click at the top of the **Std** column and choose **Sort by Standard Order**.



Sort runs by standard (std) order

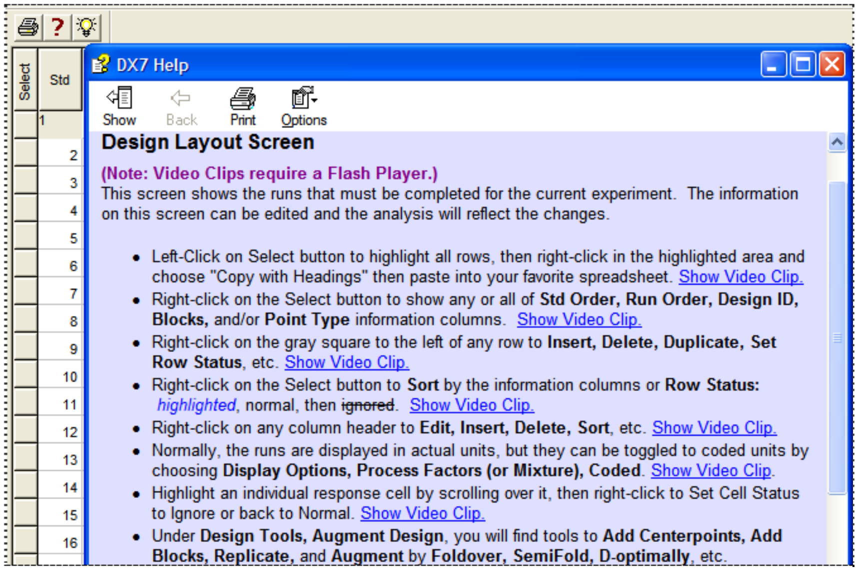
Then enter the responses from the table on page one, or use the following screen.

Std	Run	Factor 1 A:Bowler Person	Response 1 Score Pins
1	9	Pat	160
2	7	Pat	150
3	2	Pat	140
4	16	Pat	167
5	8	Pat	157
6	5	Pat	148
7	6	Mark	165
8	15	Mark	180
9	4	Mark	170
10	11	Mark	185
11	14	Mark	195
12	3	Mark	175
13	10	Shari	166
14	1	Shari	158
15	17	Shari	145
16	12	Shari	161
17	18	Shari	151
18	13	Shari	156

Design Layout in standard order with response data entered

Your design layout window should now look like that shown above, except for run order. When you do your own experiments, be sure to do the runs and enter the response(s) in randomized order. Standard order should only be used as a convenience for entry of pre-existing designs.

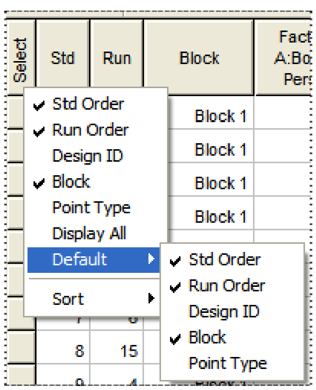
Save your data by selecting **File**, **Save** from the menu (or the save icon on the toolbar). OK, now you're backed up in case you mess up the data. That's good, because now we will advise you of all sorts of things Design-Ease allows you to do with its design layout. Start by pressing the screen tips button (or select Help, Screen Tips) for enlightenment on the screen currently displayed. Be sure to play the video clips that are offered for most of the detailed features – these movies make it far clearer than static, written tutorials can on how to make use of advanced tools.



Tips on features for Design Layout screen

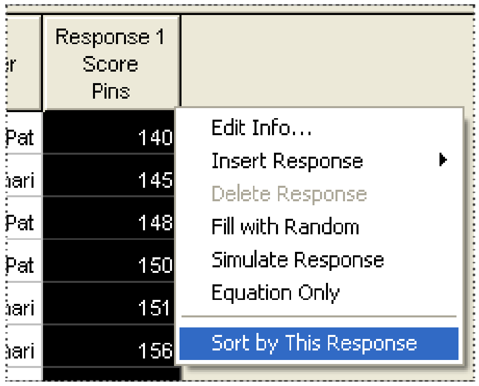
Note the reference to "DX." This and other screen shots were taken from the identical file saved in Design-Expert software – the 'parent' program for Design-Ease.

Try some of the features highlighted in the Design Layout tips. For example, right-click the **Select** button. This allows you to control what Design-Ease displays.



Select button for choosing what you wish to display in the design layout

Press the **X** button at the upper-right corner of this help screen to close it down. Now, to get a feel for the bowling results, order them from low-to-high by right-clicking on the **Response** column and selecting **Sort by This Response**.

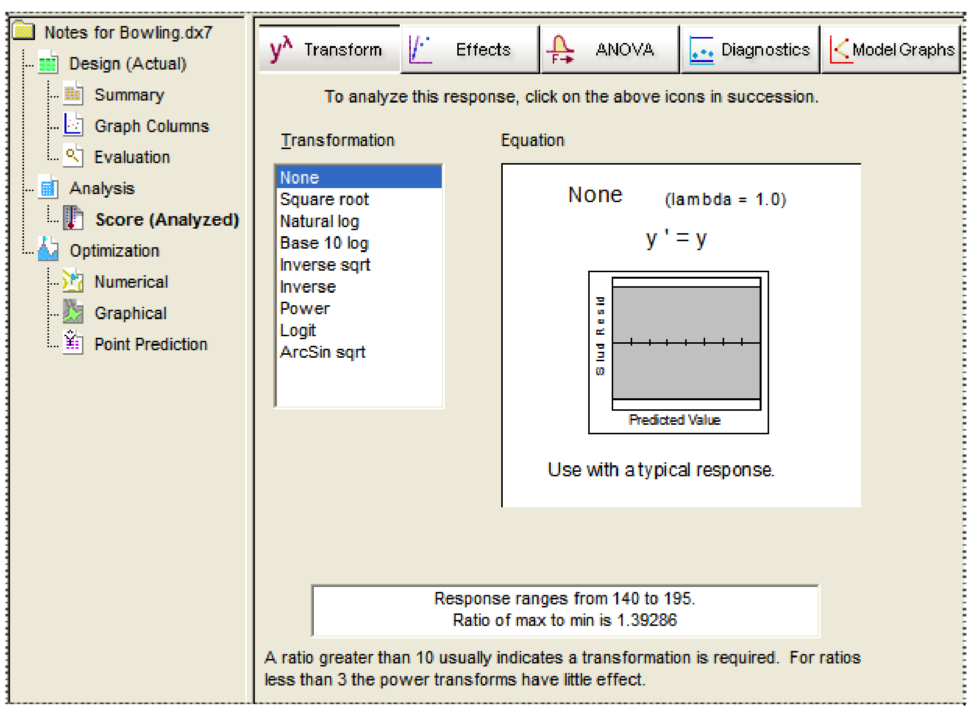


Sorting on a response column (also works for factors)

This is a very useful feature. It works on factors as well as responses. In this case you get a quick 'heads-up' that the highest games were bowled by Mark.

Analyze the Results

Next, begin the data analysis. Under the **Analysis** branch of the program (on the left side of your screen), click on the **Score** node. The ***Transform*** dialog box will be displayed in the main window of Design-Ease on a progressive tool bar. You will click these buttons from left to right and do the complete analysis. It's a very easy process. The first dialog box gives you the option of selecting a transformation for the response, which may improve the statistical properties of the analysis.

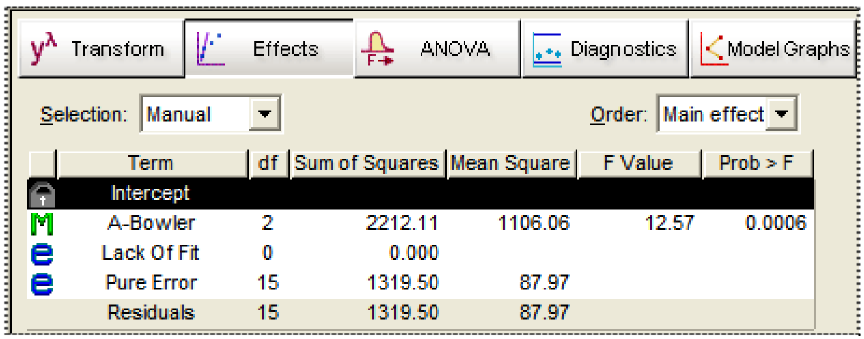


Transformation button – the starting point for the statistical analysis

If you need some background on transformations, first try the Tips. Then, for all the details, go to the Help command on the main menu and select Contents. Search on "transformations." The program provides some data-sensitive advice at the bottom of the screen. In this case, it does not indicate the need for a transformation, so press ahead with the default of **None** by clicking on the ***Effects*** button.

Examine the Analysis

By necessity, things get a bit statistical from here on out. If this becomes intimidating, we advise you attend a basic class on regression, or better yet, a workshop on DOE such as Stat-Ease's Experiment Design Made Easy.

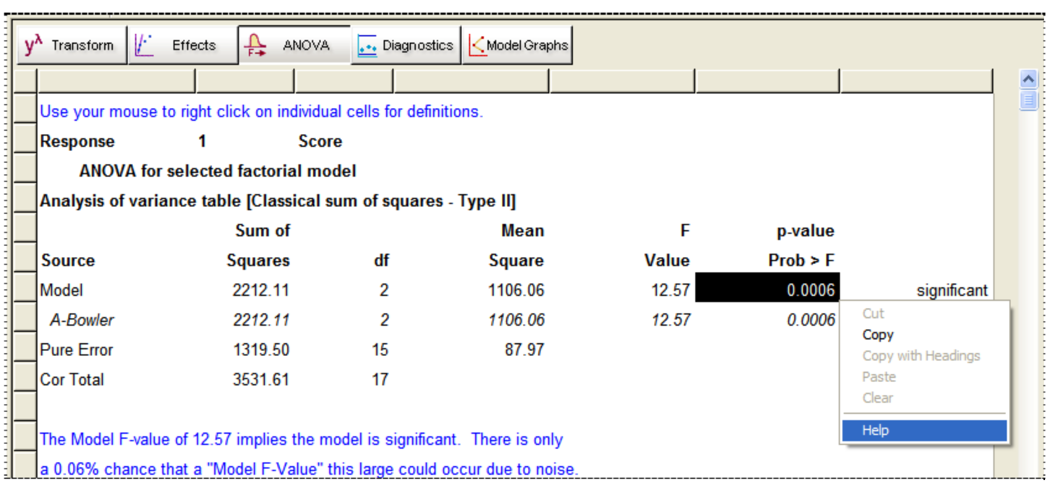


	Term	df	Sum of Squares	Mean Square	F Value	Prob > F
	Intercept					
M	A-Bowler	2	2212.11	1106.06	12.57	0.0006
e	Lack Of Fit	0	0.000			
e	Pure Error	15	1319.50	87.97		
	Residuals	15	1319.50	87.97		

Effects button results

The really important outputs on the effects are the F-value and associated probability ("Prob>F"). In this case, there's a very small probability, near 0.06%, that the differences in bowling averages (the term "A-Bowler" designated "M" for model) are due to chance variation (the term "Pure Error" labeled "e" for error, generated by the within-bowler multiple games). In other words, it appears at this stage that the difference between bowlers is significant.

To get more details press the ***ANOVA*** (Analysis of Variance) button. Notice that Design-Ease verifies that the results are significant.



Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2212.11	2	1106.06	12.57	0.0006	significant
A-Bowler	*2212.11*	*2*	*1106.06*	*12.57*	*0.0006*	
Pure Error	1319.50	15	87.97			
Cor Total	3531.61	17				

ANOVA results (annotated), with context-sensitive Help enabled via right-click menu

Now select **View**, **Annotated ANOVA**. Notice that all the comments disappear so you can make a clean printout for statistically-savvy clients. Re-select **View**, **Annotated ANOVA** to 'toggle' back all the helpful hints. Before moving on, take the first hint: "Use your mouse to right click on individual cells for definitions." For example, try this on the p-value of 0.0006 as shown above (select Help off the pop-up menu). There's a wealth of information to be brought up from within the program with a few simple keystrokes: Take advantage!

Next you see a section of the output that reports various summary statistics.

Std. Dev.	9.38	R-Squared	0.6264
Mean	162.72	Adj R-Squared	0.5766
C.V. %	5.76	Pred R-Squared	0.4620
PRESS	1900.08	Adeq Precision	6.442

The "Pred R-Squared" of 0.4620 is in reasonable agreement with the "Adj R-Squared" of 0.5766.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 6.442 indicates an adequate signal. This model can be used to navigate the design space.

Summary statistics

The annotations tell you what you need to know, but don't be shy about clicking on a number and getting on-line Help via a right-click (or try the F1 key). In most cases you will then get helpful advice on the particular statistic.

Now click on the scroll down arrow (at the bottom right side of screen) until you get to the next section of output illustrated below.

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High
Intercept	162.72	1	2.21	158.01	167.43
A[1]	-9.06	1	3.13	-15.72	-2.39
A[2]	15.61	1	3.13	8.95	22.27

Coefficient estimates

Unless you're a statistician, this detailing of model terms and their confidence intervals ("CI") probably will be of little value, although you may notice the intercept is simply the mean score of the bowlers. You may wonder why only two terms, A1 and A2, are provided for a predictive model on three bowlers. It turns out that the last model term, A3, is superfluous because it can be inferred once you know the mean plus the averages of the other two bowlers.

Now continue on to the next section labeled "Treatment Means."

Treatment Means (Adjusted, If Necessary)

	Estimated Mean	Standard Error
1-Pat	153.67	3.83
2-Mark	178.33	3.83
3-Shari	156.17	3.83

Treatment means

Here you see the averages for each of the three bowlers. As you can see below, these are compared pair-wise in the following part of the ANOVA report.

Treatment	Mean Difference	DF	Standard Error	t for H_0 Coeff=0	Prob > |t|
1 vs 2	-24.67	1	5.41	-4.56	0.0004
1 vs 3	-2.50	1	5.41	-0.46	0.6509
2 vs 3	22.17	1	5.41	4.09	0.0010

Values of "Prob > |t|" less than 0.0500 indicate the difference in the two treatment means is significant.

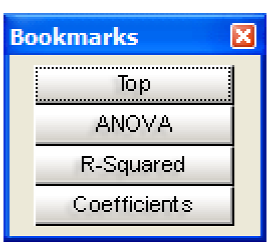
Values of "Prob > |t|" greater than 0.1000 indicate the difference in the two treatment means is not significant.

Treatment means

You can conclude from the treatment comparisons that

- Pat differs significantly (worse!) from Mark (1 vs 2)
- The 2.5 pins mean difference between Pat and Shari (1 vs 3) is not significant (nor is it considered important by the bowling team's captain – recall in the design specification for power that a 10-pin difference was the minimum of interest)
- Mark differs significantly (better!) from Shari (2 vs 3).

Before pressing ahead, notice the floating **Bookmark** too and see it work by pressing **Top**.

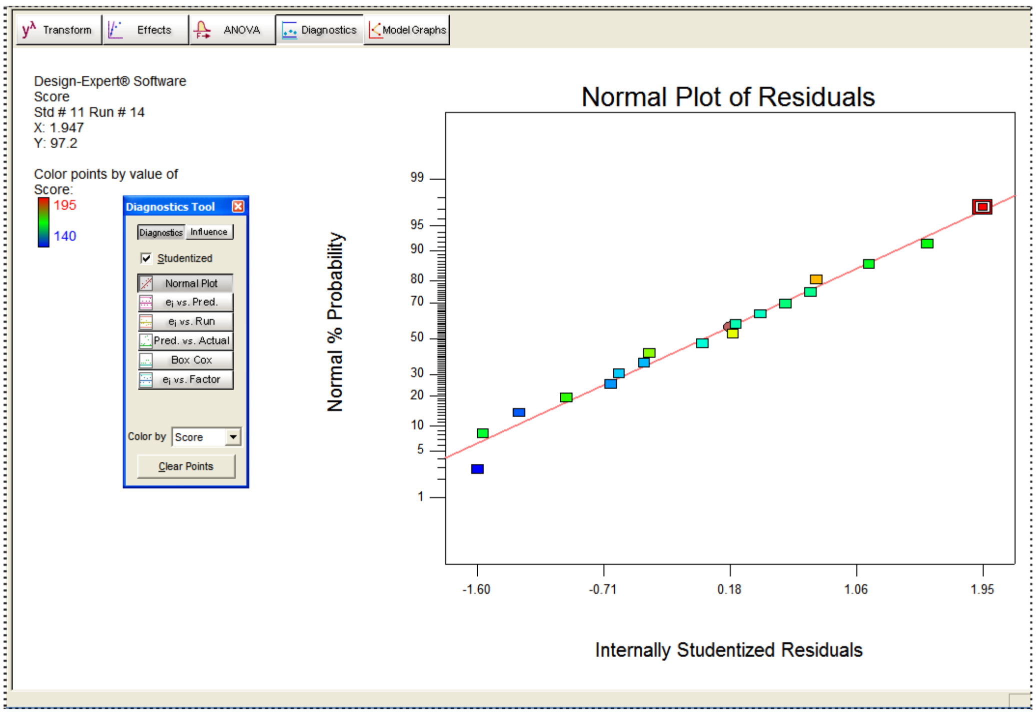


Handy bookmarks for long reports

Analyze Residuals

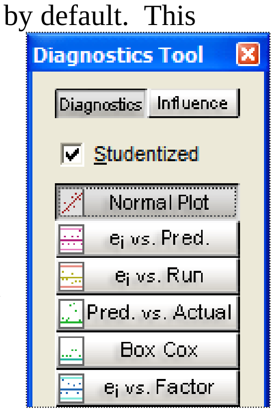
Click on the ***Diagnostics*** button to bring up the normal plot of residuals. Ideally this will be a straight line, indicating no abnormalities. If you've got a pencil (or whatever), hold it up to the graph. Does it cover all the points? Yes – so then it passes the "pencil test" for normality. You may reposition the line by dragging the line (place the mouse pointer on the line, hold down the left button, and move the mouse) or its "pivot point" (the round circle in the middle). However we do not recommend you bother doing this – the program generally puts the line in the ideal place.

Notice that the points are coded by color to the level of response they represent – going from cool blue for lowest values to hot red for the highest. For example, the red point is Mark's outstanding 195 game. Pat and Shari think it ought to be thrown out because it's too high. Is this fair? Click this point so it will be highlighted on this and all the other residual graphs available via the Diagnostics Tool (the 'floating' palette on your screen). *Your screen says Design-Ease Software, not Design-Expert as shown here.*



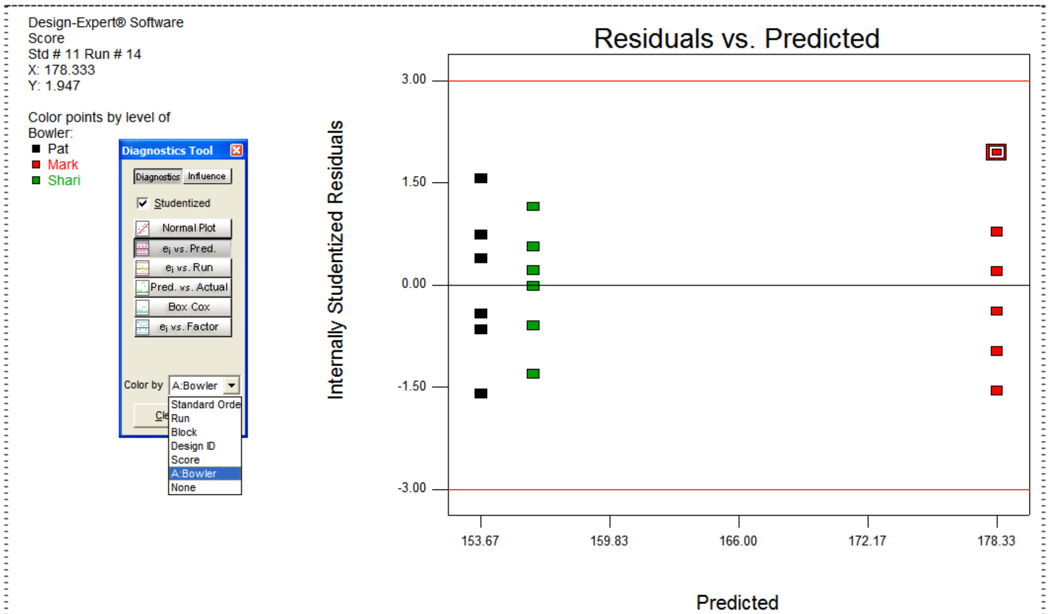
Normal probability plot of studentized residuals (195 game highlighted)

Notice on the Diagnostics Tool that "Studentized" is checked on by default. This converts raw residuals, reported in original units – 'pins' of bowling for this case, to a dimensionless number based on standard deviations, which comes out in plus or minus scale. More details on studentization can be found Help. The raw residuals can be displayed by un-checking this default mode on the Diagnostics Tool. Check it out! However, when some runs have greater leverage (another statistical term to look up in Help!), only the Studentized form of residuals will produce valid diagnostic graphs. For example, if Pat and Shari succeeded in getting Mark's high game thrown out (don't worry – they



won't!) then each of his remaining five games would exhibit a leverage of 0.2 (1/5) versus 0.167 (1/6) for each of the others' six games. Due to potential imbalance of this sort, we advise that you always leave the Studentized feature checked (as done by default).

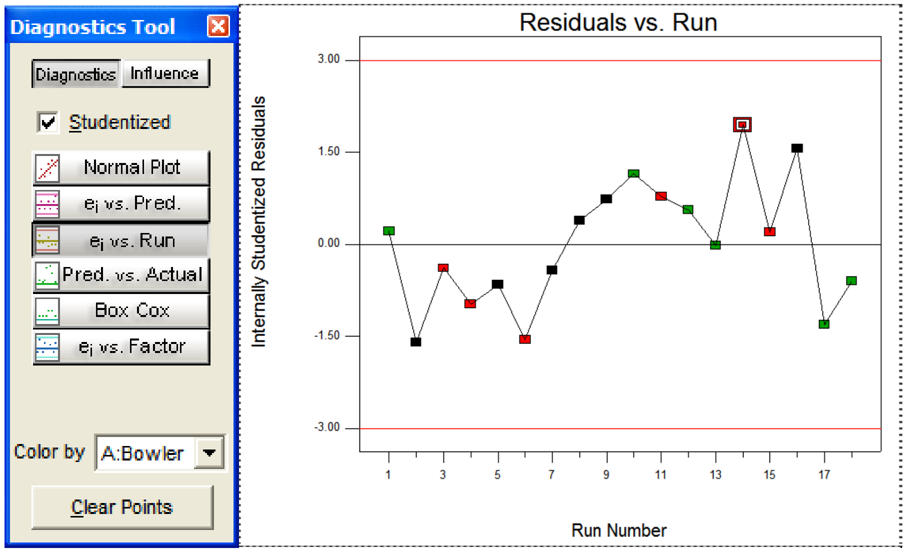
On the **Diagnostics Tool**, select **e_i vs. Pred.** to generate a plot of residuals for each individual game ("e_i") versus what is predicted by the response model. *[Sidebar: Supposedly "residuals" were originally termed "error" by statisticians, but the management people got upset at so many mistakes being made!]* Let's make it easier to see which residual goes with which bowler by pressing the down-list arrow for the **Color by** option and selecting **A:Bowler**.



Residuals versus predicted values, colored by bowler

The size of the studentized residual should be independent of its predicted value. In other words the spread of the studentized residuals should be approximately the same for each bowler. In this case the plot looks OK. Do not be alarmed that Mark's games stand out as a whole: The spread from bottom-to-top is not out of line with his competitors, despite their protestations about the highest score (still highlighted).

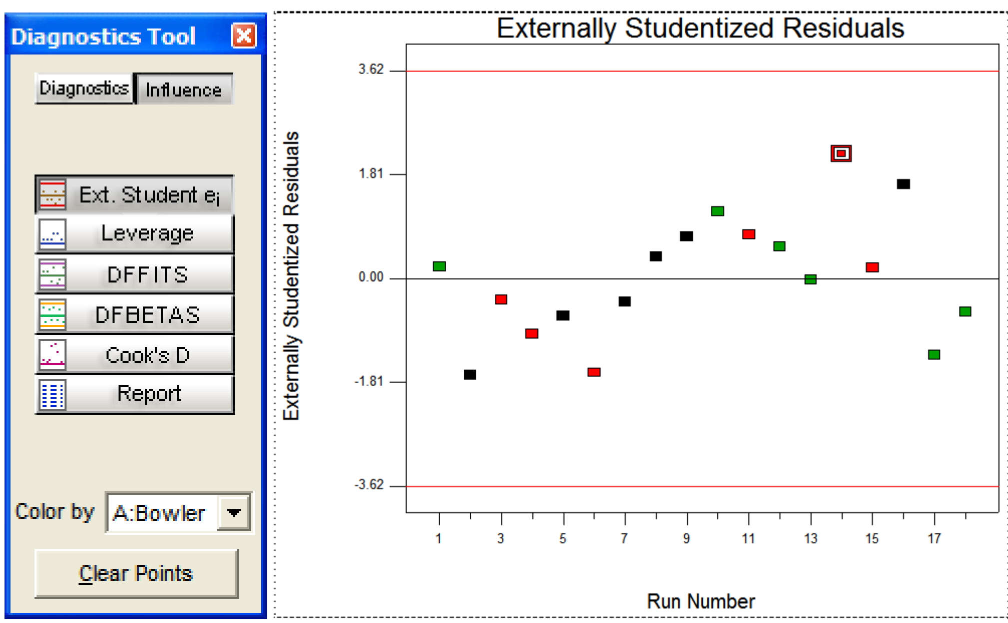
Bring up the next graph on the **Diagnostics Tool** list – **e_i vs Run** (residuals versus run number. *(Note: your graph may differ due to randomization.)*



Residuals versus run chart (<u>Note: your graph may differ due to randomization</u>)

Here you might see trends due to changing conditions in the alley, tiring of the bowlers or other time-related lurking variables. (Note the pattern on your graph may differ from what we show here due to the randomized run order, but that will not be relevant to our discussions.) In this case things look relatively normal. However, even if you observed a pronounced upward, downward or shift change, it would probably not bias the outcome because the runs were completely randomized. To insure against your experiment being sabotaged by uncontrolled variables, always randomize!

On the **Diagnostics Tool** click the **Influence** side. Then select **Ext. Student e_i** (externally studentized residuals) to see if any points stand out.



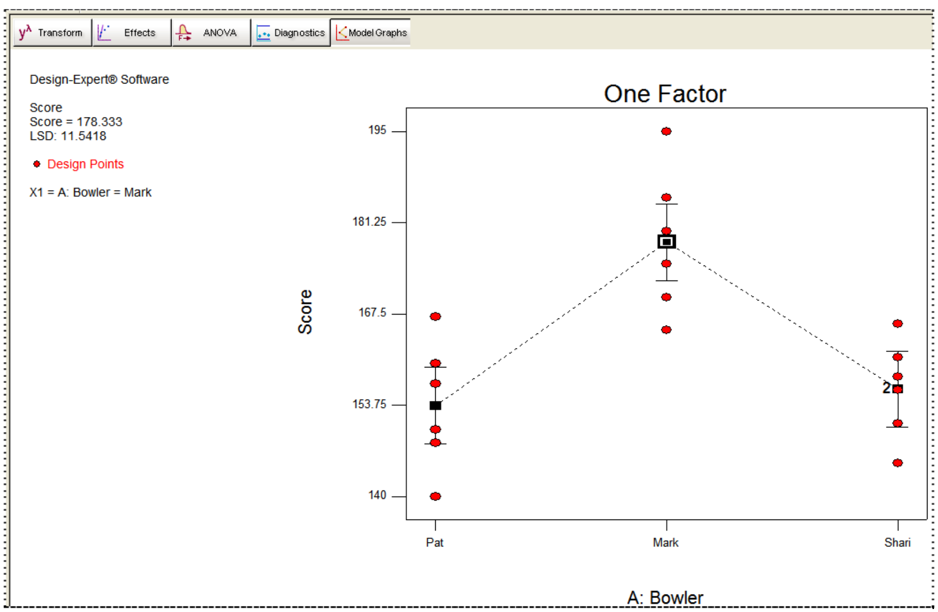
Externally studentized residuals graph (your graph may differ due to random runs)

On this graph, also known as “outlier t,” we are looking for points outside the plus and minus control limits. Again, for details on the meaning of external studentization, refer to Help, but in a nutshell this graph differs from the run chart in the previous figure by excluding each run, such as the one in question by Mark, prior to calculating the residual on a scale of standard deviation. In this case, all points fall within the limits (calculated at the 95 percent confidence level). In other words, Mark’s high game does not exhibit anything more than common-cause variability, so it should not be disqualified!

Since there’s no indication of abnormality, it’s OK to move on to the model graph. This will tell the story about the effect of changing bowlers. It will make a good final report to the Stat-Ease team on who they should invite as a new member. Unfortunately only one person can be chosen. ☹

View the Means and Data Plot

Select the ***Model Graphs*** button from the progressive tool bar to display a plot containing all of the response data and the average value at each level of the treatment (factor). This plot gives an excellent overview of the data and the effect of the factor levels on the mean and spread of the response.



One factor effects graph with Mark’s predicted score (mean) highlighted

The squares on this effects plot represent the predicted responses for each factor level (bowler). Click on the one representing Mark. Notice that Design-Ease displays the prediction for this treatment level (reverting back to the jargon of DOE) on the legend at the left of the graph. The vertical bars represent the 95% least significant difference (LSD) intervals for each treatment. Mark’s LSD bars do not overlap with Pat’s or Shari’s, so we can say with at least 95% confidence that Mark’s mean is significantly higher than the means of the other two bowlers.

Oh, by the way, maybe you noticed that the numerical value for the length of the LSD bar appeared when you clicked the square for Mark. You can also click on any round points to get the actual score. Check it out!

Pat and Shari's LSD bars overlap, so we cannot say which of them bowls best. It seems that they must spend a year in a minor bowling league and see if a year's worth of games reveals a significant difference in ability. Meanwhile Mark will be trying to live up to the high average he exhibited in the tryouts and thus justify being chosen for the top Stat-Ease bowling team.

That's it for now. Save the results by going to **File**, **Save**. You can now **Exit** Design-Ease if you like, or keep it open and go on to the next tutorial – part two for general one-factor design and analysis, which delves into advanced features via further adventures in bowling.