

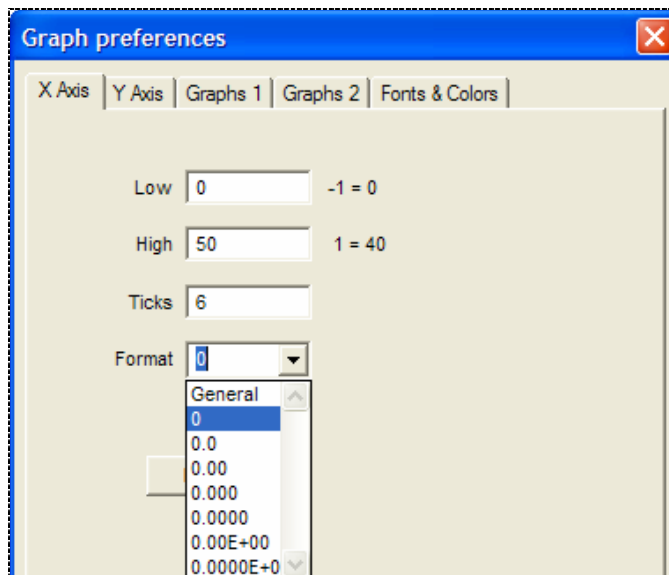
One-Factor RSM Tutorial (Part 2 – Advanced topics)

Exploring Graph Preferences



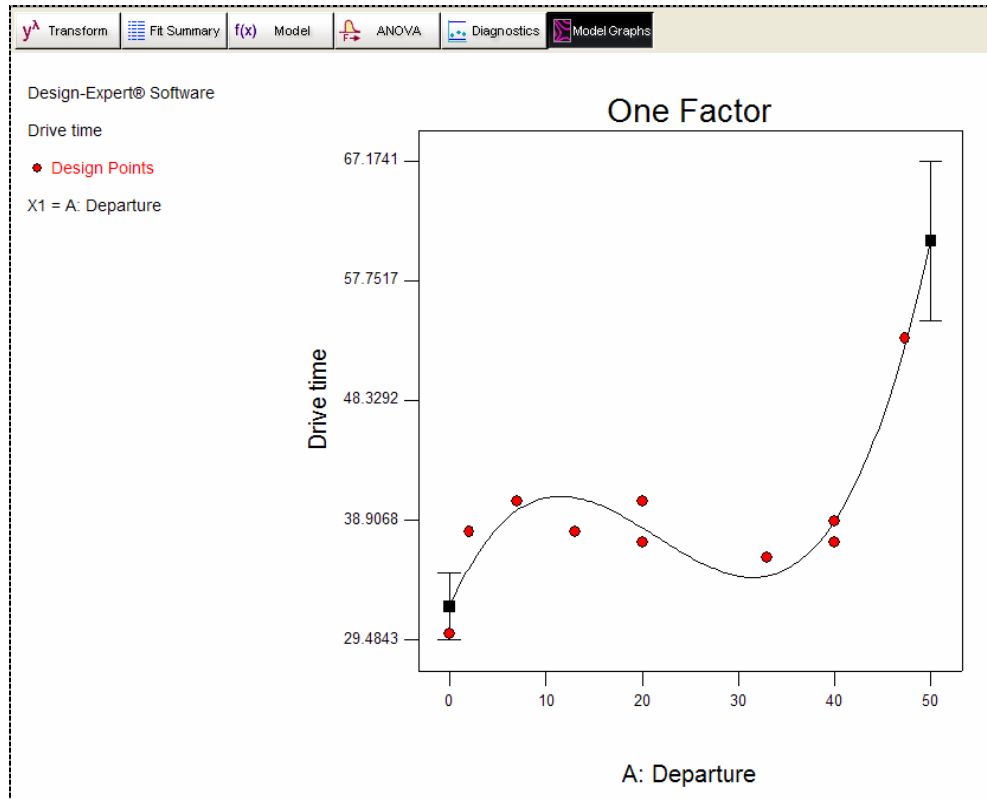
If you still have the driving data active in Design-Expert® software from Part 1 of this tutorial, continue on. If you exited the program, re-start it and use **File, Open Design** to open your data file (**Driving.dx7**). Otherwise, go back and set it up as instructed in One-Factor RSM Tutorial (Part 1 – The Basics). Then under the **Analysis** branch (you may already be here from before) click on the **Drive time** node and press the **Model Graphs** button. Recall from the preceding tutorial that the driver, Mark, woke up late one morning and got off to a bad start – at 50 minutes beyond the earliest time, not 40 as planned. Therefore you were instructed to right-click over the one-factor response plot, select **Graph Preferences** and on the **X Axis** dialog box, which comes up by default, change the **High** level to **50**.

Now let's check out other graph preferences. Start by changing the **Ticks** to **6** and the **Format** to **0**.



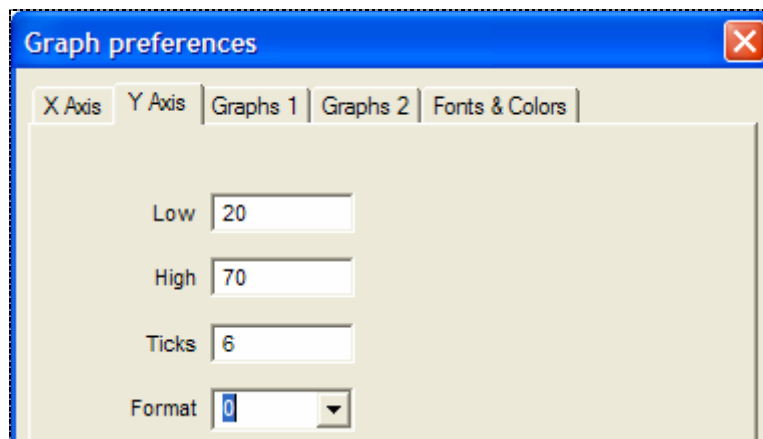
Graph preference options with high X increased to 50, ticks to 6 and format changed

Click **OK** to see how this changes the plot.



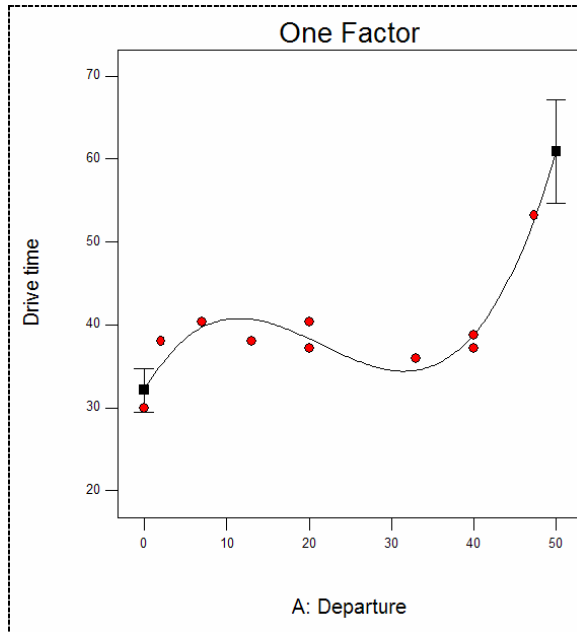
X-axis of plot modified

Now, again right-click over the one-factor response plot, select **Graph Preferences** and for **Y Axis** settings set the **Low** at **20**, **High** at **70**, the **Ticks** at **6** and **Format** of **0**.



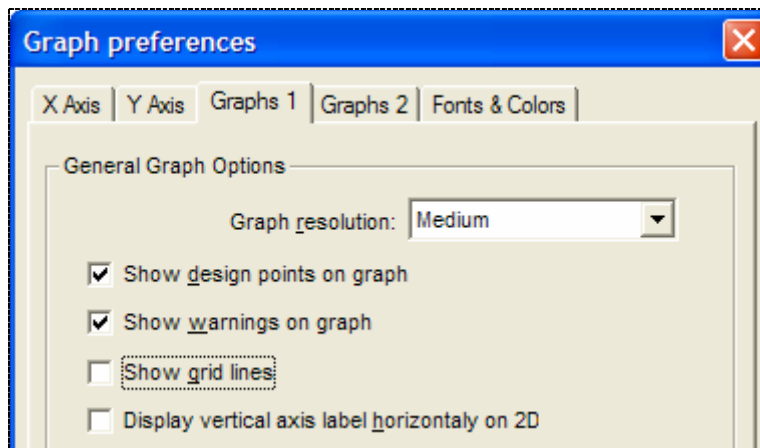
Changing Y-axis preferences

Click **OK** to see what this does for the plot.



Plot after fixing up the Y-axis

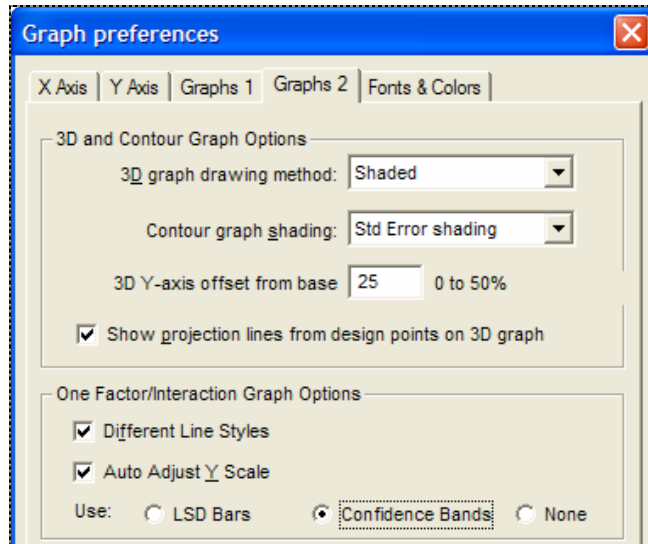
Much better! Let's explore more plotting options by right-clicking back to **Graph Preference** and pressing over to the **Graphs 1** tab. For example, you might like a plot that's 'ruled' for ease of reading off coordinates: Do this via the "Show grid lines" option.



Preference for show grid lines (and many other options)

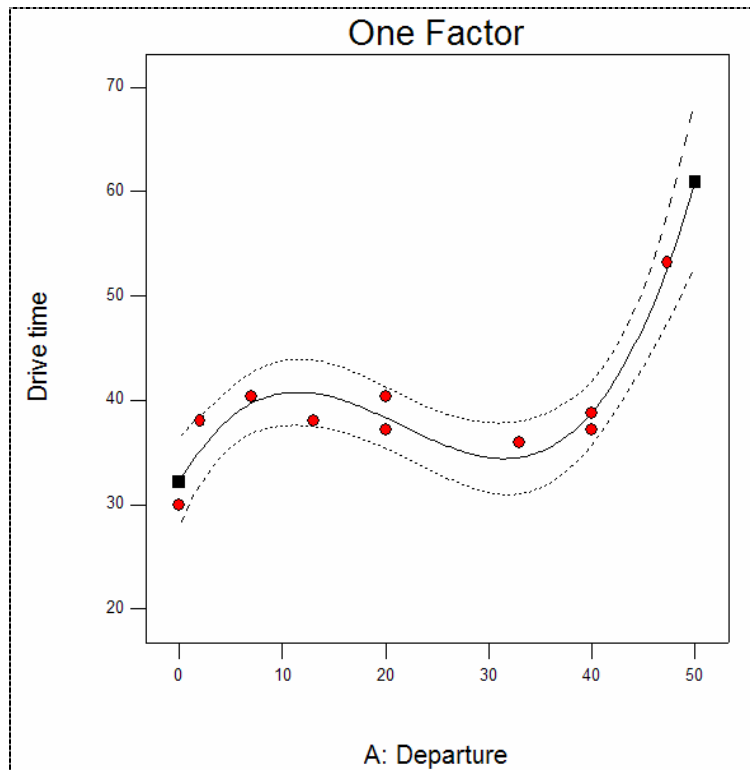
You may be tempted at this point to press the Apply button. This does apply changes; for example, if you press Apply and then Cancel out of Graph Preferences, the changes will still be applied, but Design-Expert cannot redraw the screen behind the property sheet until after you exit this dialog box. Therefore, the Apply button, a standard feature for this Microsoft interface, will not be worth much. However, it will not be too much trouble to try out some features like the grid lines, press OK to see their effect and then navigate back to Graph Preferences. Go ahead and do so not if you like.

Move on to the **Graphs 2** menu and select **Confidence Bands** as an alternative to the LSD (least significant difference bars) applied by default.



Confidence bands as preference versus LSD bars

Click **OK** to see how this affects your plot.

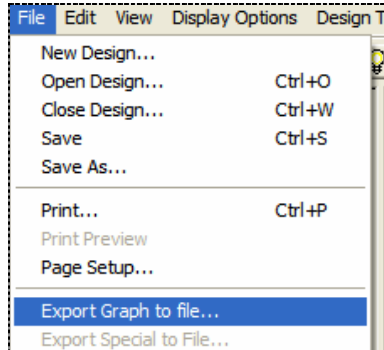


Confidence bands on one-factor response surface

You may've noticed before how much wider the LSD was at the latest departure. Similarly, the confidence band widens at the same point, which cannot be predicted as

precisely as responses from earlier departures. In fact, by changing the upper time to 50, the graph now goes above and beyond the actual experimental region into an area of extrapolation. However, if questioned about the accuracy of the predicted time for driving at this very late 50 minute departure, Mark would say that as sure as the sun rises in the East, the traffic from his suburban home to his downtown office will worsen the more he gets into the peak of the morning rush. Nevertheless, any extrapolation should be treated with great caution and verified by further experimentation.

Now that you have modified the response surface plot, it would be good to save it. This can be done via File, Export Graph to file.

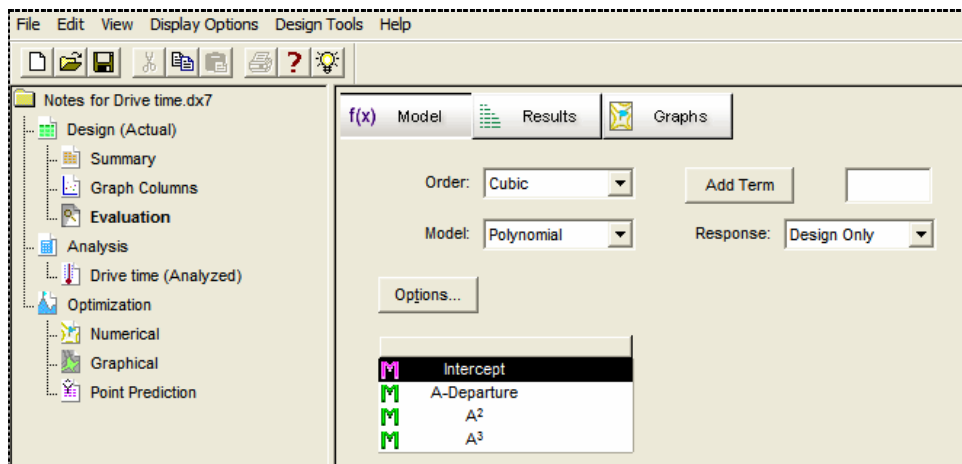


Export graph to file

It will then be saved as an enhanced metafile (.emf) that can be brought into Microsoft Word and the like via insert as a picture from a file.

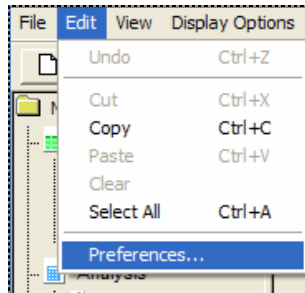
Adding Higher-Order Model Terms

The wavy curve you see on the response surface plot for drive time is characteristic of a third-order (cubic) polynomial model. Could an even higher-order model be applied to the data from this case? If so, would it improve the fit? Under the **Design** branch click the **Evaluation** node.



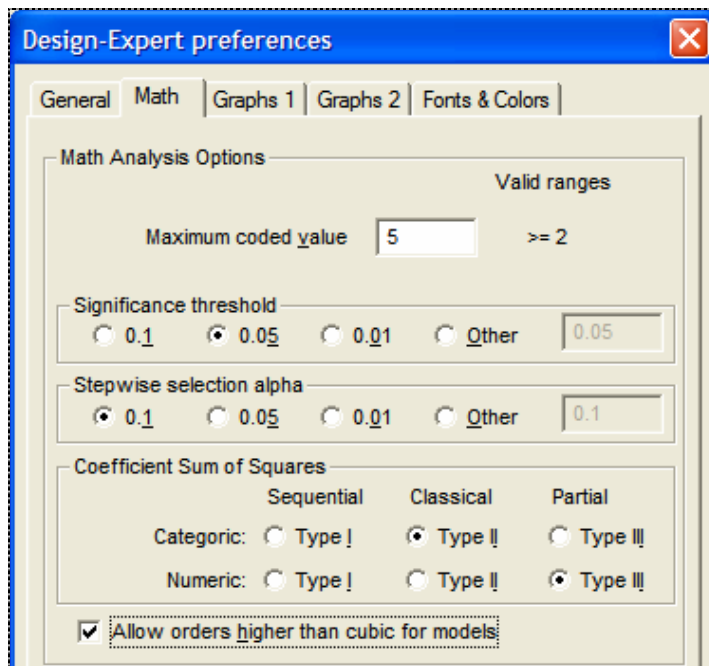
Design evaluation

Now select **Edit, Preferences**. The settings there must be changed to allow models of higher-order than cubic.



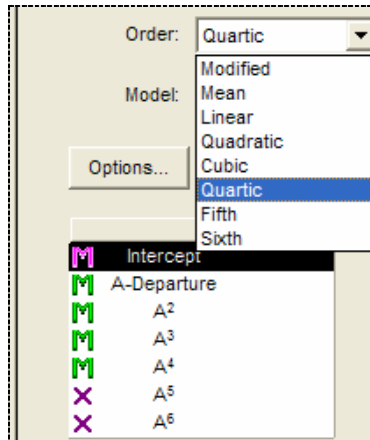
Edit preferences selection

Click the **Math** tab and turn on the option to **Allow orders higher than cubic for models** shown at the bottom of the dialog box.



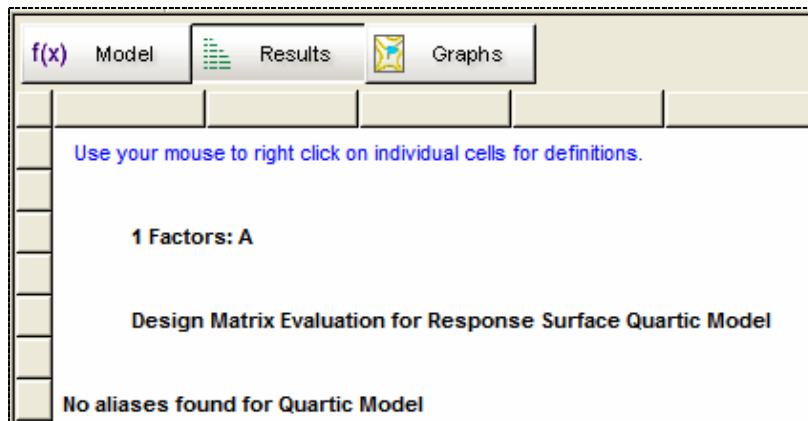
Math preferences – enabling high-order models

Feel free to look over all the other Preferences tabs: General, Graphs 1, Graphs 2 and Fonts & Color. Press **OK** to return to the design evaluation screen. Change the **Order** to **Quartic** or double-click the term A^4 to put it in the model (“M”).



Model changed to quartic (4th order)

Click **Results** to see the evaluation of this higher-order model.



Evaluation finds no aliases for quartic model

No aliases are found, but other aspects of the evaluation fall short of the ideal. Scroll down the output and pay close attention to the annotations. If you do not see these on-screen, go to View and select Annotated Evaluation.

View | Display Options | Design Tools | Help

✓ Annotated Evaluation

Show Cell Borders

Pop out View

✓ Toolbar

✓ Status Bar

Model | Results | Graphs

Degrees of Freedom for Evaluation

Model	4
Residuals	5
Lack Of Fit	3
Pure Error	2
Corr Total	9

A recommendation is a minimum of 3 lack of fit df and 4 df for pure error.
 This ensures a valid lack of fit test.
 Fewer df will lead to a test that may not detect lack of fit.

Annotated view – degrees of freedom detailed

Scroll down further to see statistics on power. Reading the annotations below, you will realize that going to the quartic model may not be such a good idea.

Term	StdErr**	VIF	Ri-Squared	Power at 5 % alpha level for effect of		
				0.5 Std. Dev.	1 Std. Dev.	2 Std. Dev.
A	1.56	15.78	0.9366	5.2 %	5.8 %	8.3 %
A ²	2.14	14.15	0.9293	5.4 %	6.7 %	12.0 %
A ³	1.78	29.86	0.9665	5.2 %	5.6 %	7.5 %
A ⁴	1.69	28.30	0.9647	5.7 %	7.8 %	16.3 %

**Basis Std. Dev. = 1.0

Standard errors should be similar within type of coefficient. Smaller is better.

Ideal VIF is 1.0. VIF's above 10 are cause for alarm, indicating coefficients are poorly estimated due to multicollinearity.

Ideal R-squared is 0.0. High R-squared means terms are correlated with each other, possibly leading to poor models.

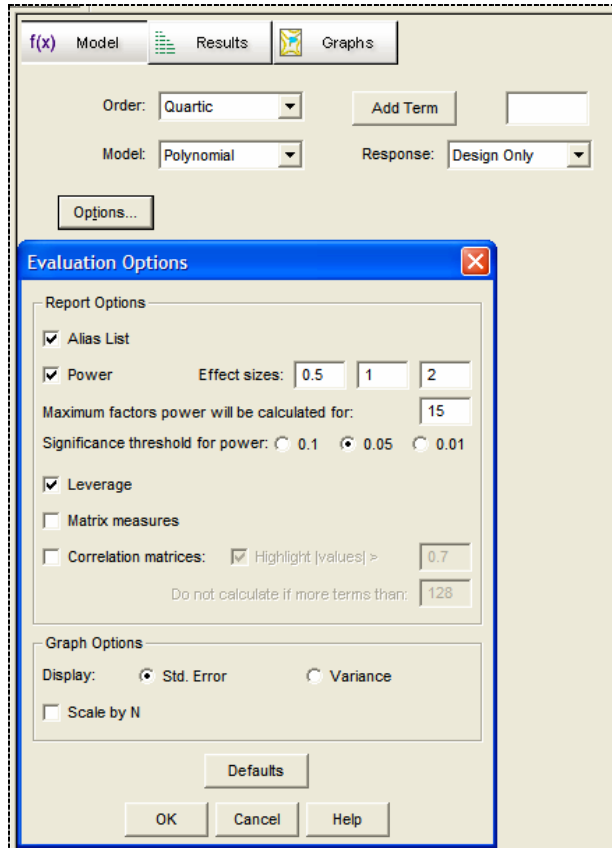
Power should be approximately 80% for the effect you want to detect.

Power statistics

Scroll down to the bottom of this report and view the leverages. Note the design point with the unusually high leverage of 0.9743. This is the late departure time near 50 minutes that occurred due to Mark oversleeping. This is what experts on DOE refer to as a 'botched' factor setting. It should not be surprising to come out poorly for leverage.

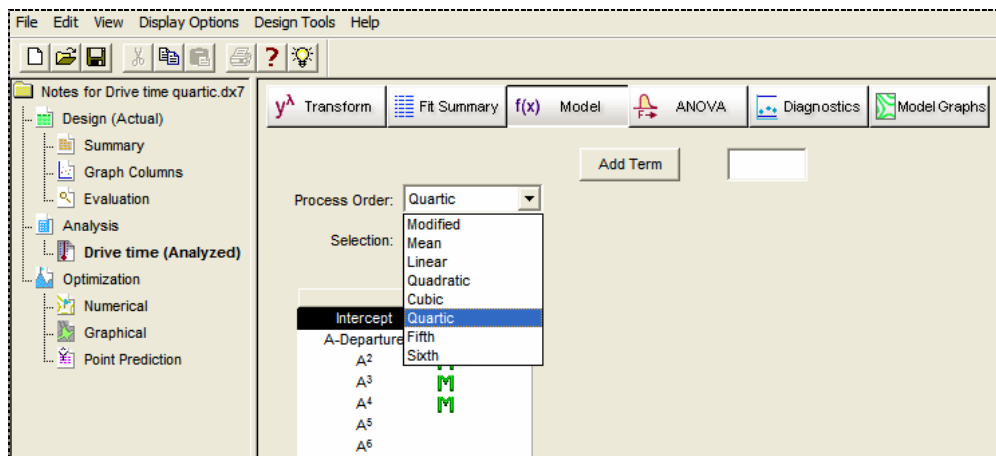
Believe it or not, many more evaluation statistics can be generated from Design-Expert if you like – the ones shown by default are those most easily digested by non-

statisticians. To enable additional measures and modify defaults click the Options under the Model screen.



Evaluation options

Let's not belabor the evaluation: Go back to the **Analysis** branch and click the **Drive time** node. Then press ahead to the **Model** and change the order there to **Quartic**.



Changing model to quartic for analysis

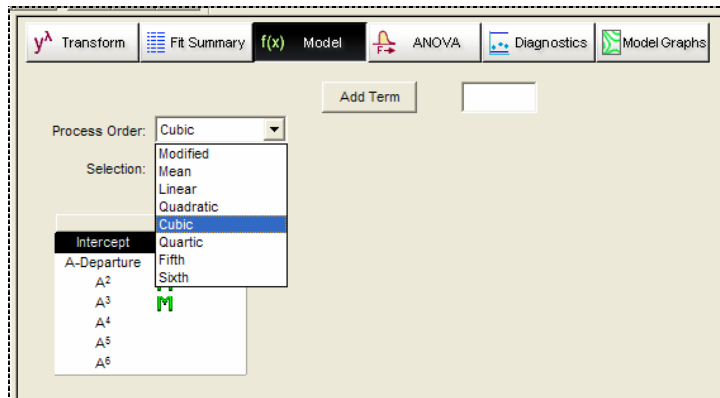
Then click the **ANOVA** button. Notice that not only does the A^4 term come out insignificant (p-value of 0.91), but the Pred R-Squared goes negative – not a good sign!

ANOVA for Response Surface Quartic Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	273.04	4	68.26	11.02	0.0108
A-Departure	33.51	1	33.51	5.41	0.0676
A ²	2.50	1	2.50	0.40	0.5533
A ³	47.39	1	47.39	7.65	0.0396
A ⁴	0.087	1	0.087	0.014	0.9102
Residual	30.97	5	6.19		
Lack of Fit	24.57	3	8.19	2.56	0.2933
Pure Error	6.40	2	3.20		
Cor Total	304.02	9			
Std. Dev.	2.49	R-Squared		0.8981	
Mean	38.92	Adj R-Squared		0.8166	
C.V. %	6.40	Pred R-Squared		-0.4639	
PRESS	445.04	Adeq Precision		11.655	

ANOVA for quartic model (annotations turned off in View menu)

Before moving on to the next topic, return to the Model button and re-set the Order to Cubic.



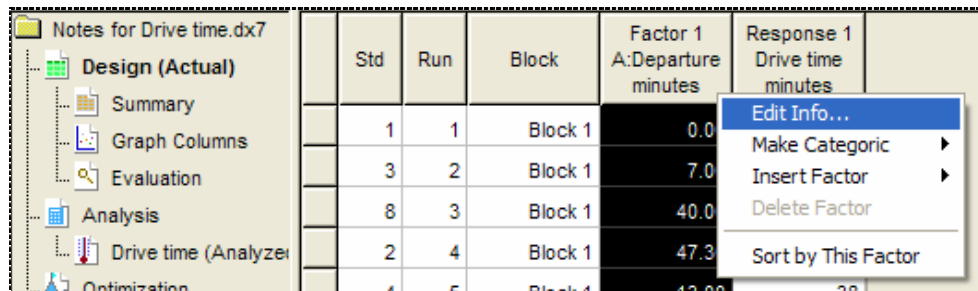
Back to the cubic model

By the way, Design-Expert knows enough in this simplistic one-factor case to add up to sixth order terms to the model list. However, in some cases, you may need to make use of the Add Term entry field. For example, in a two-factor RSM you can add terms such as A^2B^4 or A^3B^2 .

Propagation of Error (POE)

Seeing such a rapid increase in drive time predicted for late departures makes Mark more aware of how much the response depends on what time he leaves home. He realizes that a 5 minute deviation one way or the other would not be an unreasonable expectation. How will this cause the drive time to vary? Perhaps by aiming for a specific departure Mark might reduce drive time variation caused by day-to-day differences in when he heads off for work. Via its capability to calculate and plot propagation of error (POE), Design-Expert can provide enlightenment on these issues.

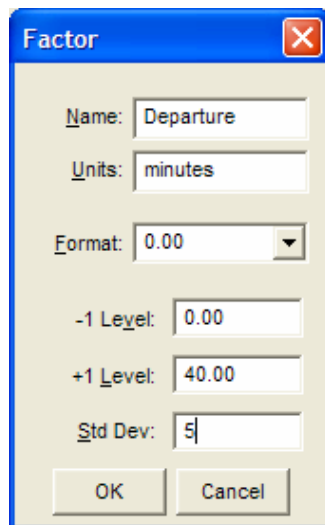
Click the Design branch to bring up the run-sheet for the experiment. Then right-click the column-header for the **Factor 1 (A:Departure)** and select **Edit Info**.



	Std	Run	Block	Factor 1 A:Departure minutes	Response 1 Drive time minutes
	1	1	Block 1	0.0	
	3	2	Block 1	7.0	
	8	3	Block 1	40.0	
	2	4	Block 1	47.3	
	4	5	Block 1	49.0	38.1

Editing info for the input factor

For **Std Dev** enter 5.



Factor

Name:

Units:

Format:

-1 Level:

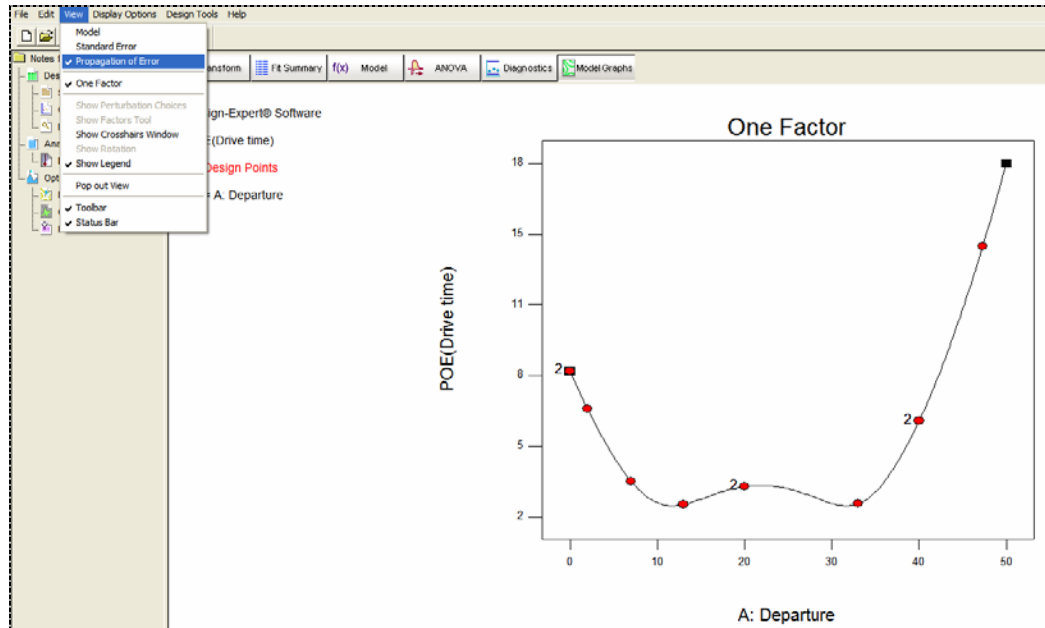
+1 Level:

Std Dev:

OK Cancel

Entering standard deviation for factor

Press **OK** and then go back to the **Analysis** branch, click the **Drive time** node and return to **Model Graphs**. Then from the **View** menu select **Propagation of Error**.



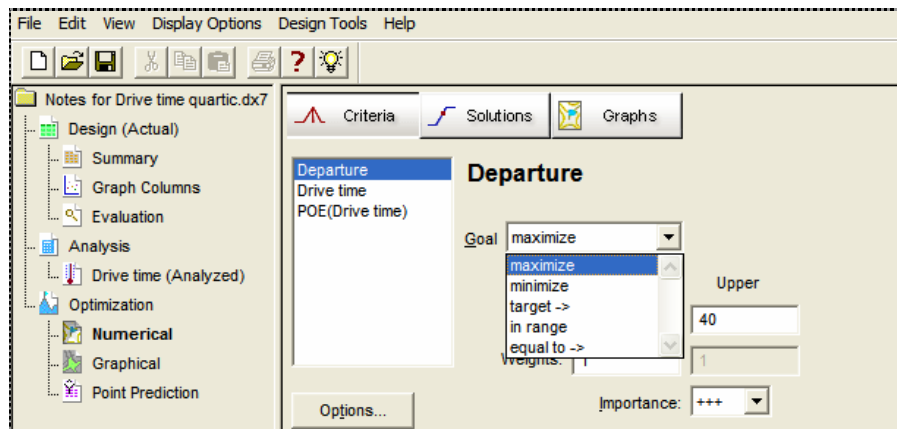
Plot for POE

Notice that POE is minimized at two times for departure, which correspond with flats on the wavy response plot you looked at earlier.

Multiple Response Optimization

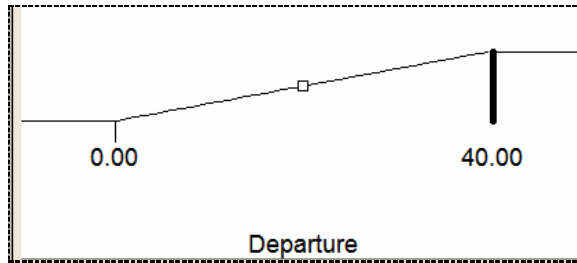
Ideally, Mark would like to leave as late as possible (to get more sleep every morning!) while minimizing his drive time but making it the least variable. These goals can be established in Design-Expert software so it can look for the most desirable outcomes.

Under the **Optimization** branch choose the **Numerical** node. For the Departure, which comes up by default, click the Goal and select maximize.



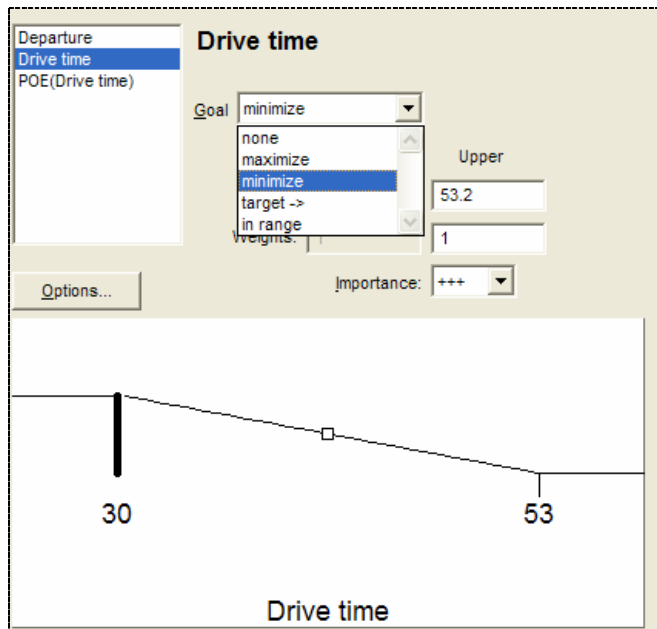
Setting goal for departure

The program pictures this goal as an upward ramp (/) to indicate that the higher this variable goes the more desirable it becomes.



Desirability ramp for departure – later the better (maximize)

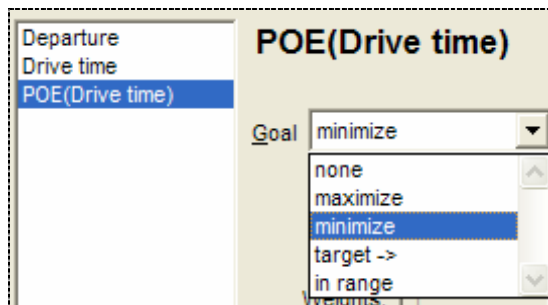
Next, click on the response for **Drive time** and for its **Goal** select **minimize**.



Drive time minimized

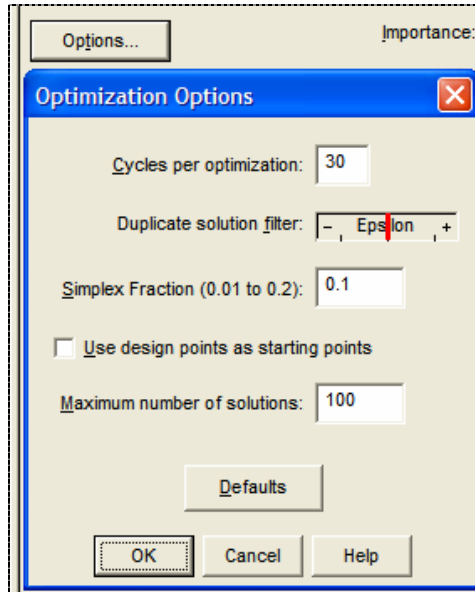
Notice the ramp now goes downward (\) to show that for this variable lesser is better, that is, more desirable.

Lastly, to reduce variation in drive time caused by deviation in departure, click **POE** and set its **Goal** to **minimize**.



Minimizing POE

Before pressing ahead, click the **Options** button.



Options for numeric optimization

The settings here will affect the hill-climbing algorithm that Design-Expert uses to find the most desirable combination of variables. For details, check Help. Click **OK** to accept the defaults.

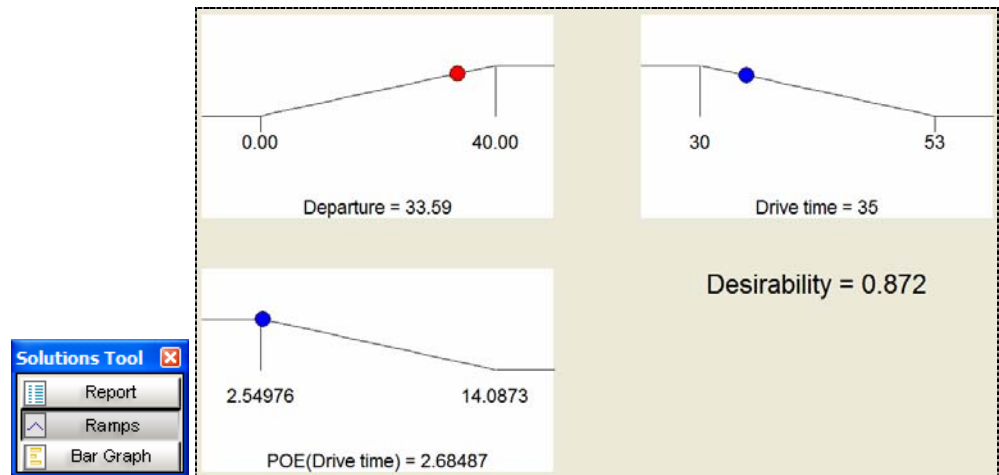
Press the **Solutions** button to see what Design-Expert recommends for the most desirable departure. The program now chooses a departure time at random and climbs up the desirability response surface. It repeats this process over and over (100 times by default), but in this case, the same point (within a value “epsilon” for the duplicate solution filter – see Optimization Options above) is found every time – a departure around 33 minutes beyond the earliest start acceptable by Mark for his morning commute. (Your result may vary somewhat due to the random starting points of the hill-climbing algorithm.)

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Departure	maximize	0	40	1	1	3
Drive time	minimize	30	53.2	1	1	3
POE(Drive time)	minimize	2.54976	14.0873	1	1	3

Number	Departure	Drive time	POE(Drive time)	Desirability	
1	33.59	35	3	0.872	Selected

Most desirable solution (your result may vary somewhat)

For a quick feel for optimal factor settings and the most desirable results, on the **Solutions Tool** click **Ramps**.



Ramps view of most desirable solution

Now Mark knows when it's best to leave for work while simultaneously maximizing the departure (and gaining more 'shut-eye'), minimizing his drive time, and minimizing propagation of error. Now the only thing that could possibly go wrong would be if all the other commuters learn how to use RSM and make use of Design-Expert. Mark hopes that none of you who are reading this tutorial live in his suburban neighborhood and work downtown.

