Problem 7-2 (as stated in *RSM Simplified*)

This is a real-life example using a manufacturer's equipment specifications. No response data will be provided: We will consider only the design of experiments. A processor of high-tech plastic sought optimum levels for two key factors affecting operation of an extruder:

A. *Screw speed, 300–600 revolutions per minute (rpm).*

B. *Throughput, 600–1,400 pounds per hour (pph).*

They desired the highest possible throughput of product exhibiting maximum flex modulus (stiffness). However, due to torque limitations, only a limited amount of material, 600 pph, can be processed through the extruder when it runs at the lower screw speed (300 rpm). Only at the higher screw speed of 500 rpm can the maximum desired output (1,400 pph) be attained. It will not pay to break the machine so we must derive a multilinear equation to quantify the operating constraint. Unless you are really adept at math, even a simple specification like this will take some effort to translate, so we will do this one for you. (Someone has to do the math because the constraints must be put in a specific format for entry into the software.)

$$B \le 600 + \left((A - 300)\left(\frac{1400 - 600}{500 - 300} \right) \right)$$

$$B \le 600 + \left((A - 300)\left(\frac{800}{200} \right) \right)$$

$$B \le 600 + 4A - 1200$$

$$B \le 4A - 600$$

Using the provided software, set up an RSM design geared for a quadratic model (hint: Choose "D-optimal" and then click the Edit Constraints button to enter the multilinear constraint as B – 4A ≤ –600). Evaluate the resulting design and consider whether you could do any better.

Solution to Problem 7-2

You'd best set this up from scratch using Design-Expert® software: Here's how to do it. Start by running the program and selecting **File**, **New Design** or click the blank-sheet icon (🗋**)** on the toolbar. Then click on the tab marked **Response Surface**. There you must select the **D-optimal** design and accept the default of **Numeric Factors**, **2**. Enter for the **Name** of each factor what's shown in the screen shot on Figure 7-2.1.

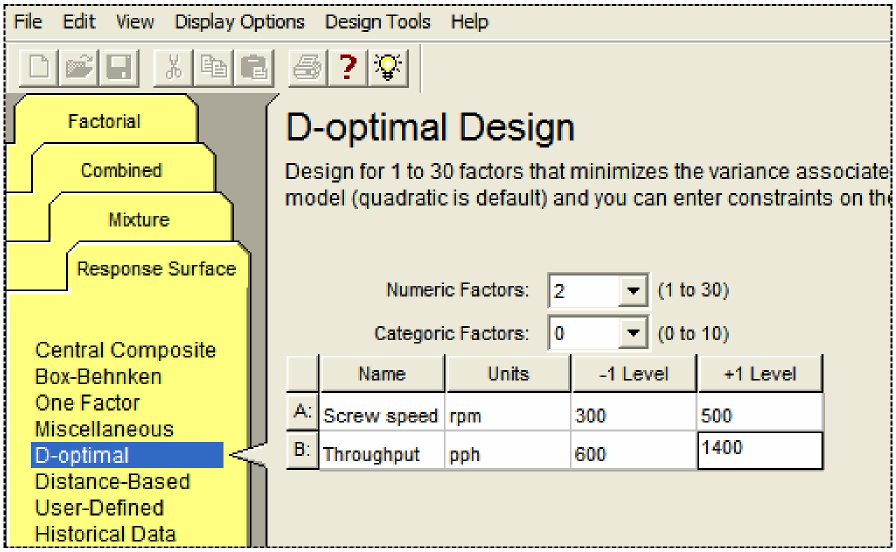

Figure 7-2.1: Entering factors for D-optimal design

Next, press the **Edit Constraints** button and enter the multilinear **Constraint** equation for the operating limit **– 4A + B** (OK to enter lower case letters) with **High Limit** of **–600**.

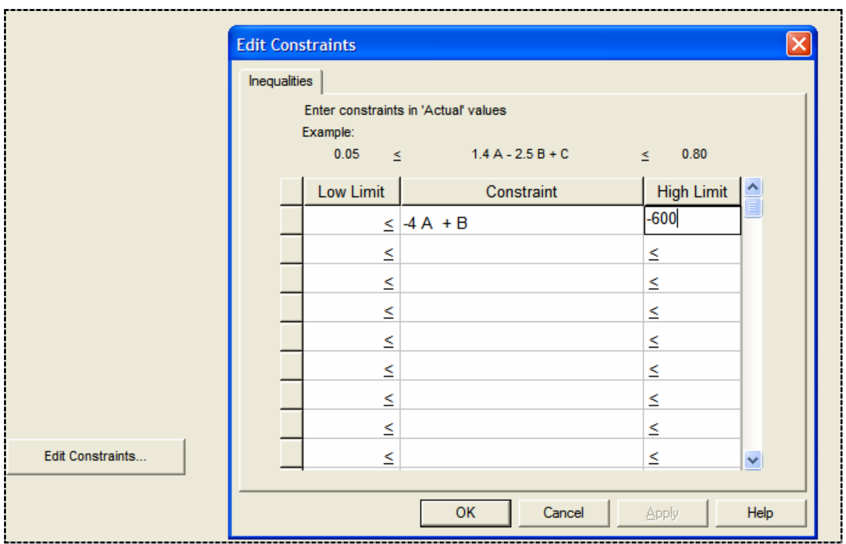

Figure 7-2.2: Entering multilinear constraint

Click **OK** on the Edit Constraints screen and then **Continue**. You now should see a screen for specifying how Design-Expert will set up the D-optimal design. If not already defaulted to this choice, click the option to **Use** for point selection the **Point Exchange** algorithm. Then press **Create Candidate Points** to get a count of how many points the software generates for the candidate set, from which it will pick d-optimally the number needed to fit the chosen model (defaulted to quadratic).

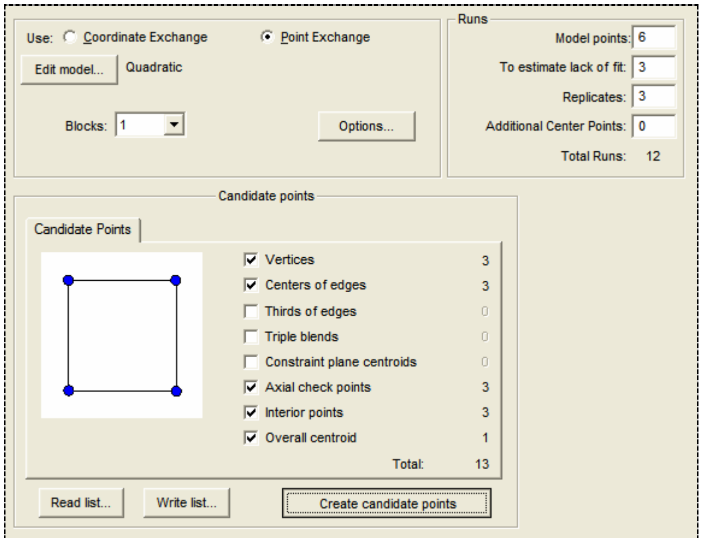

Figure 7-2.3: D-optimal design specification

Press **Continue** to accept all the defaults presented for this design. Then enter the response **Name** as **Flex Mod** and **Units** as **psi**.

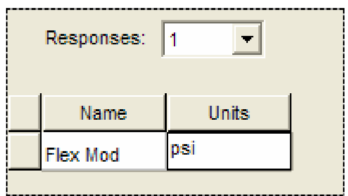

Figure 7-2.4: Response entry

Press **Continue** to get the design layout.

Now, click on the **Evaluation** node at the left of your screen.

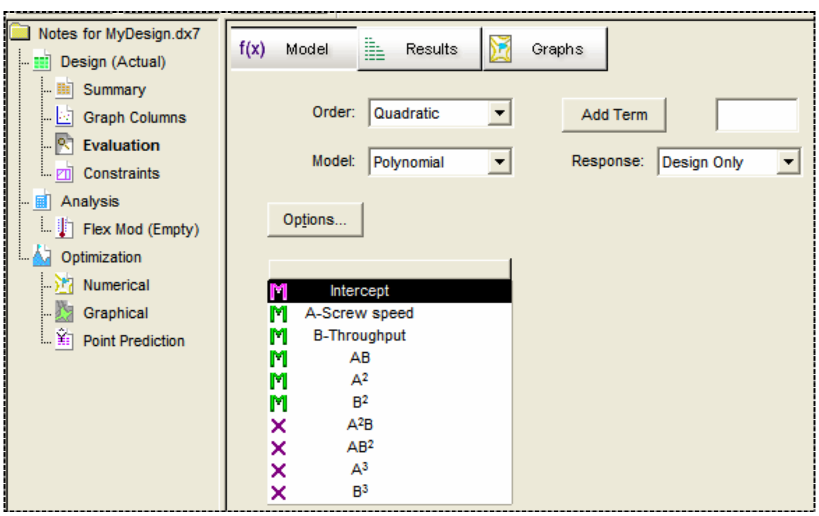

Figure 7-2.5: Design evaluation

Press the ***Graphs*** button to see where the design points are located and how their layout affects the standard error for prediction from the two-factor quadratic polynomial model.

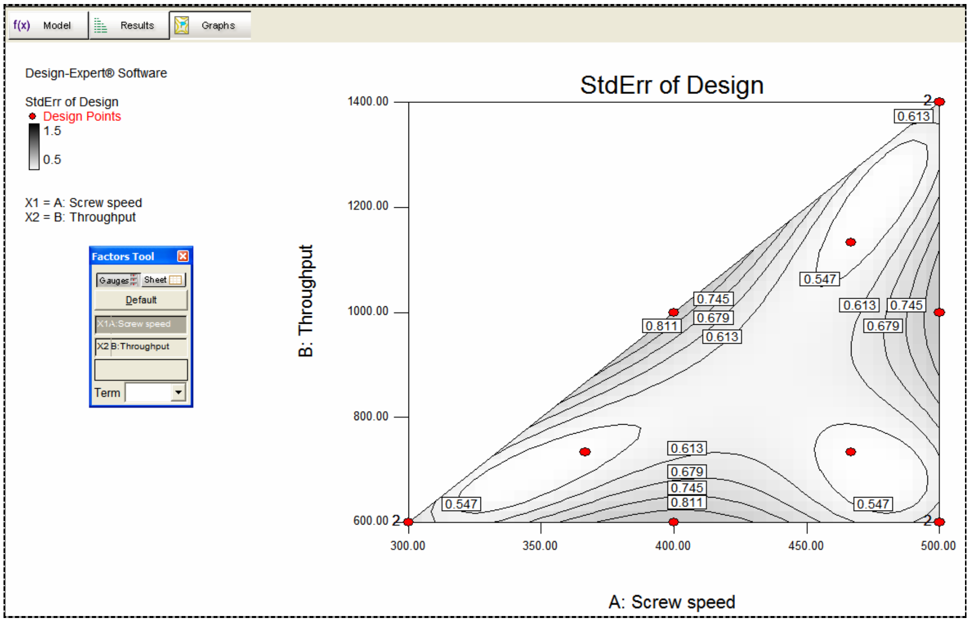

Figure 7-2.6: Graph of standard error

Notice the number "2" next to points at the corners of the triangular region for experimentation. Select **View**, **3D Surface** and play with the floating **Rotation** tool to get a better view of the standard error surface.

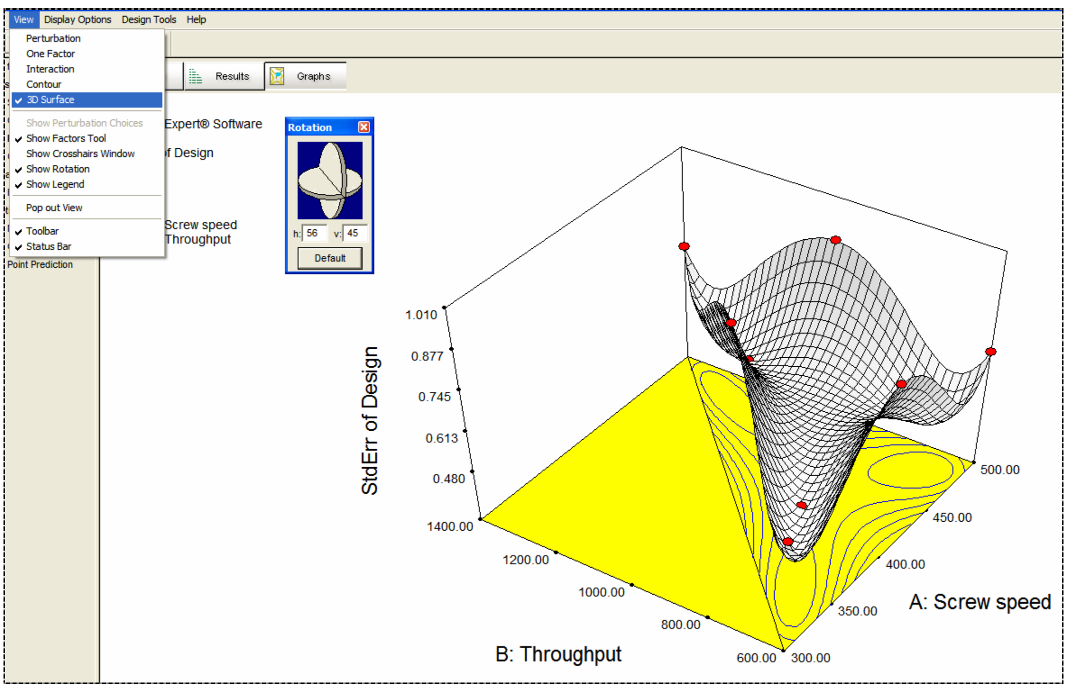

Figure 7-2.7: Graph of standard error

This looks like a reasonable design in that the best prediction occurs near the center of the region. However, notice the relatively high standard error along the diagonal operating constraint. It's very possible that the experimenters will push this limit in order to get the process running at maximum efficiency. Therefore, to see how a design can be modified in Design-Expert, let's replicate the point at the center of this constraint edge.

Select **View**, **Contour** to go back to the 2D graph and click on the point at 400 rpm screw speed and 1000 pph throughput as shown in Figure 7-2.8 (the point highlighted: ◙).

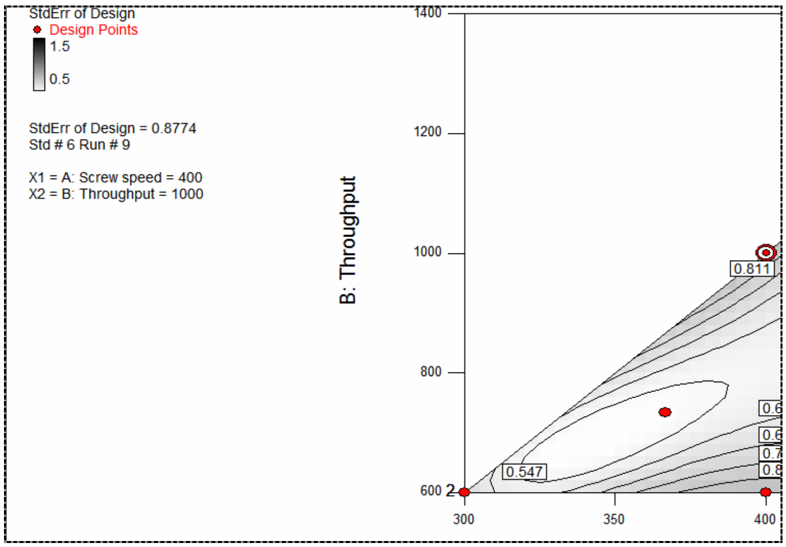

Figure 7-2.8: Design point highlighted on contour plot

Note that this is identified in the legend as standard order number 6 ("Std #6"). (The run numbers vary due to randomization.) Let's find this point and duplicate it. Click the **Design** node. To make it easier to compare notes, right-click on the **Run** column header and select **Sort by Standard Order**.

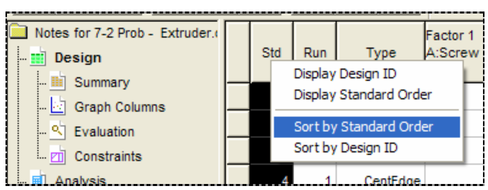

Figure 7-2.9: Sorting by standard order

Next, to get a better feel as to where each point is located geometrically, right-click on the header for the **Block** column and select **Display Point Type**.

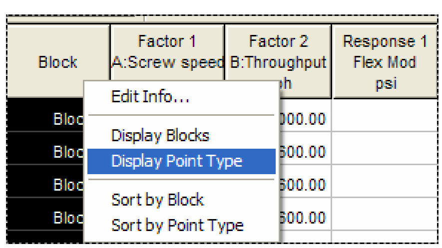

Figure 7-2.10: Displaying point type

Right-click the row button to the left of **Std** number **6** (the center of an edge) and select **Duplicate**. (If this is not labeled "CentEdge" and/or not at rpm of 400 and pph of 1000, then find the row that is and duplicate this one!)

Std	Run	Type	Factor 1 A:Screw spee rpm	Factor 2 B:Throughput pph	Response 1 Flex Mod psi
1	9	CentEdge	500.00	1000.00	
2	3	Vertex	300.00	600.00	
3	5	Vertex	500.00	600.00	
4	12	Vertex	500.00	1400.00	
5	10	CentEdge	400.00	600.00	
6	1	CentEdge	400.00	1000.00	
Insert Row		xialCB	366.67	733.33	
Set Row Status		xialCB	466.67	733.33	
Delete Row[s]					
Duplicate		xialCB	466.67	1133.33	

Figure 7-2.11: Duplicating a run by Std order *(run numbers randomly varied)*

Notice that a new row is added to the bottom of the design. How will this affect standard error? Check this out by going back to **Evaluation** and pressing ***Graphs***. Then select **View**, **3D Surface**. Then rotate the surface for a better view.

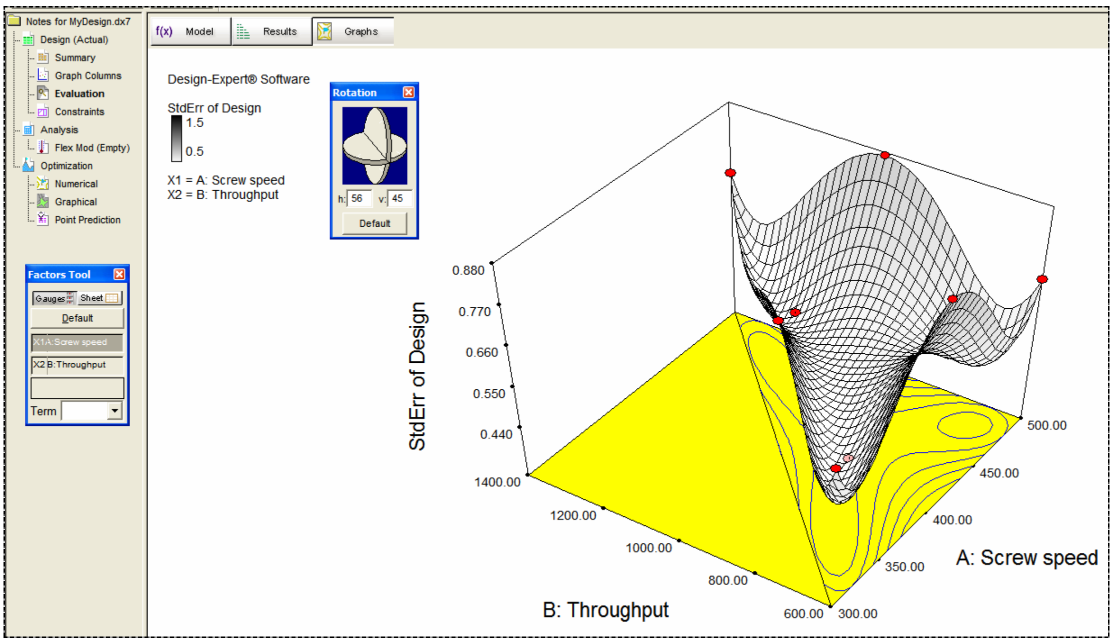

Figure 7-2.12: Impact of design change on standard error surface

That completes the solution to Problem 7-2, which only asked for the design setup and evaluation. However, for workshop purposes* we simulated responses for the process of plastic extrusion. These are saved with the file named "7-2 Prob - Extruder.dx7" – posted at the same site you found this solution. Feel free to open this file and analyze the results. Find settings that maximize the "Flex Mod." See whether the design modification (adding the extra run along the operating constraint) pays off.

*(Response Surface Methods for Process Optimization – for details on this workshop, see www.statease.com/clas_rsm.html).