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# Instructor's Guide

# *Simulator*

Version 2.2

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# Table of Contents

<b>Chapter 1</b>	<b>Answers to Exercises</b>	<b>4</b>
1.1	Heat Sealer	4
1.2	Sheeting Extruder	11
1.3	Sonic Sealer	13
1.4	Flo-Former	17
1.5	Pump	21
<b>Chapter 2</b>	<b>Structure of Simulation Files</b>	<b>24</b>
2.1	File Structure	24
2.2	Header Section	25
2.3	Input Variables Section	26
2.4	Category Input Variables Section	29
2.5	Output Variables Section	30
2.6	Expressions	32

# 1

## Answers to Exercises

Program Simulator comes with 5 simulations. Chapter 1 describes these simulations and how to optimize the performance of each simulation. The files associated with these simulations are automatically installed in the same directory as the software. These files can be modified and new files added, as described in Chapter 2. In general, the goal is Six Sigma quality with  $P_{pk} \geq 1.5$  and  $P_p \geq 2$ .

### 1.1 Heat Sealer

This simulation involves developing a heat-sealing process to form the top seal of a plastic bag. This is an excellent simulation to let the students attempt by trial and error. Only 4 of the 8 inputs are significant, so it provides an excellent example for using a screening experiment. It also illustrates the importance of robust design. It is described in the book *Optimization and Variation Reduction in Quality* ([variation.com/ovr](http://variation.com/ovr)) and the VarTran User manual ([variation.com/vta](http://variation.com/vta)).

Forming the top seal closes the bag sealing its contents inside. The top seal is a tear seal. It must be torn open to remove the contents of the bag. Of interest is the seal strength. Too weak a seal can result in the bag breaking open during shipping and storage. Too strong a seal makes the bag difficult to open. Spec limits for seal strength have been set at 20 and 32 pounds.

The developer would like to:

- Target the process at 26 pounds,
- Reduce the variability of seal strength, and
- Establish a procedure for controlling the process.

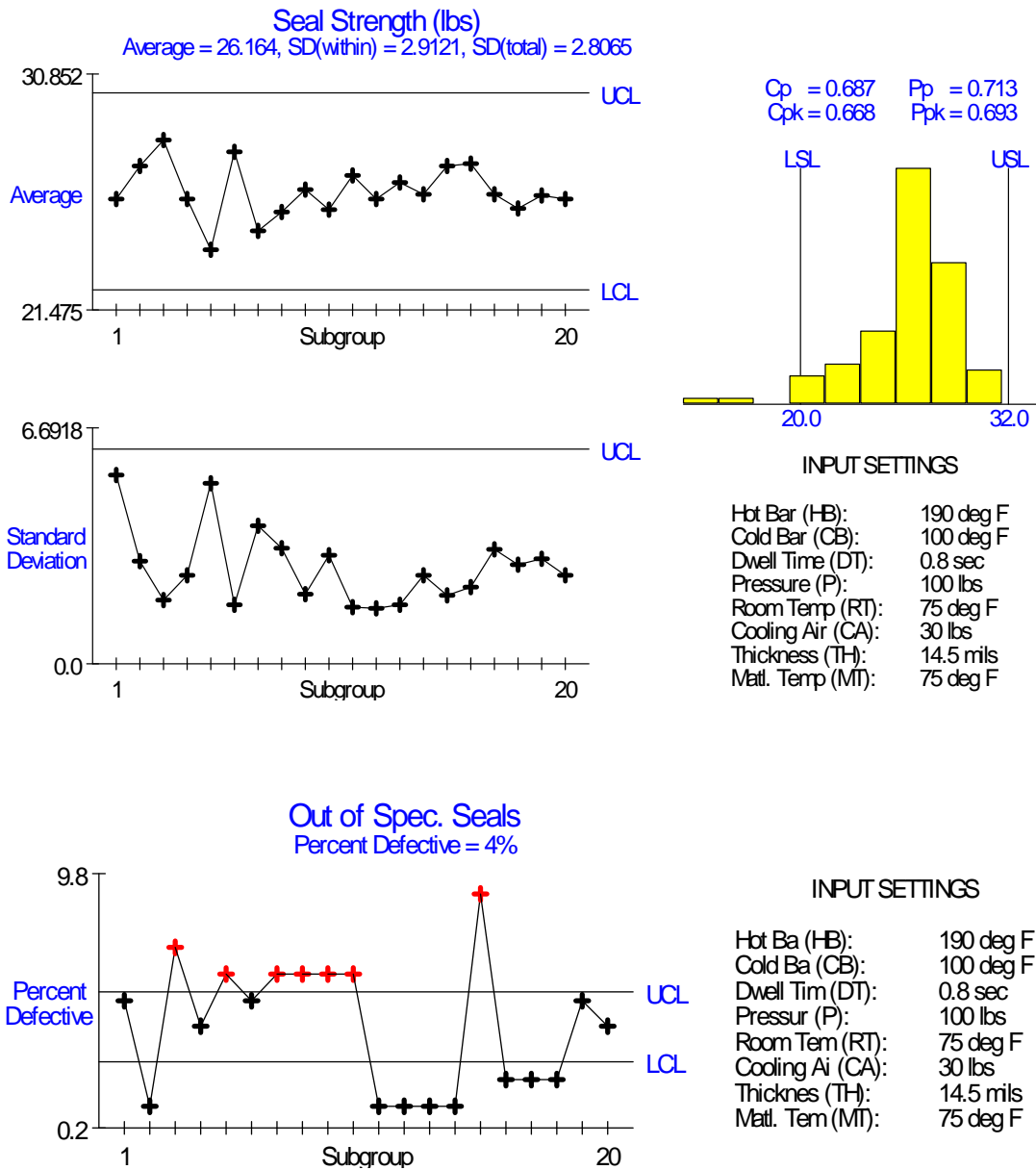
The plant has a heat sealer that is believed capable of performing the job. The manufacturer of the heat sealer has provided the following recommended cycle:

Temperature - Hot Bar	=	190 °F
Temperature - Cold Bar	=	100 °F
Dwell Time	=	0.8 seconds
Pressure	=	100 pounds
Cooling Air Pressure	=	30 pounds
Material Thickness	=	14.5 mils
Room Temperature	=	75 °F
Material Temperature	=	75 °F

The heat sealer works by clamping the material to be sealed between two bars. The top bar, called the hot bar, provides heat to melt the plastic material and cause them to flow together

to form the seal. The top bar moves up and down to control seal time and allow the material to be moved after sealing. The bottom bar is stationary and has cooling water running through it, allowing its temperature to be controlled. When the top bar comes down to make contact with the material, it is lowered until it exerts a preset pressure on the material. It is then held there for a preset time. Before moving the material, cooling air is blown on the seal to facilitate hardening.

There are two outputs: seal strength and out-of-spec seals. They are the same test but are reported as both an attribute and a variable. Results of a capability study at the recommended settings are shown below.



The process is averaging around 4% defective primarily due to excessive short-term variation (poor Cp). The focus should be on reducing the variation.

A screening experiment can be used to determine which are key inputs. Of the 8 inputs, only four are actually key inputs (included in the model). The targets selected for the other four inputs are entirely ignored. The four key inputs are:

HB	Hot Bar
DT	Dwell Time
P	Pressure
MT	Material Temp

The equation used to generate both output variables is:

$$\text{Seal Strength} = -403.5 + 3.6 \text{ HB} - 0.008 \text{ HB}^2 + 280.0 \text{ DT} - 80.0 \text{ DT}^2 - 0.96 \text{ HB DT} + 0.04 \text{ P} + 0.05 \text{ MT} + \text{Err}$$

Besides the 4 main effects, there are quadratic effects for HB and DT and an interaction between them. In a screening experiment, the group of interactions that includes the HB\*DT interaction should test significant. Also, if center points are included, you should detect significant curvature. Once the key inputs are identified, a response surface study can be used to model the equation.

The next step is to reduce the variation using a robust tolerance analysis. The first 4 of the 5 critical pieces of information required to perform a robust tolerance analysis are:

- Key Output(s) – Seal Strength
- The Specification Limits for the Key Outputs: 20-32
- The Key Inputs: HB, DT, P, MT from the screening experiment
- The Effect of the Key Inputs on the Output: Equation from response surface study

The last piece of information needed is:

- The Behavior of the Key Inputs

The students can be provided with the following standard deviations for the inputs obtained from capability studies on the inputs:

$$S_{\text{HB}} = 2 \text{ }^\circ\text{F}$$

$$S_{\text{D}} = 0.08 \text{ sec.}$$

$$S_{\text{P}} = 1 \text{ lb.}$$

$$S_{\text{MT}} = 4 \text{ }^\circ\text{F}$$

The actual model in Simulator includes the following sources of variation:

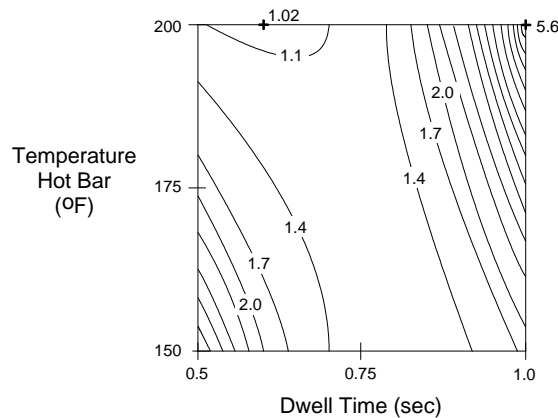
HB	Hot Bar	Trial-to-trial standard deviation of 2.0 °F
DT	Dwell Time	Unit-to-unit standard deviation of 0.08 sec
P	Pressure	Unit-to-unit standard deviation of 1 lb.
MT	Material Temp.	Unit-to-unit standard deviation of 0.08 sec
Err	Other Error	Unit-to-unit standard deviation of 0.8 pounds

In addition, for Err, each trial has a 1/5 chance of shift with a standard deviation of 0.8 pounds. The trial-to-trial variation by HB makes the process slightly unstable. However, the variation caused by dwell time dominates. Only tightening the tolerance to DT does any good.

However, before tightening any tolerances, robust design should be applied to identify which targets affect the variation. These serve as standard deviation knobs that can be set to minimize the variation. Because DT dominates and DT has a nonlinear effect, its target affects the variation. Also, because HB interacts with DT, its target affects the variation. A robust tolerance analysis, as described in the VarTran User manual ([variation.com/vta](http://variation.com/vta)) can be used to determine the optimal targets both how the variation dep.

To make the process robust to dwell time, the target of dwell time can be adjusted (due to quadratic effect), and the target of the hot bar can be adjusted (due to interaction). The targets of the other two key inputs only affect the average. The effect of the HB and DT targets on the variation is shown below:

**CONTOUR PLOT OF SEAL STRENGTH STANDARD DEVIATION**



This leads to the following strategy:

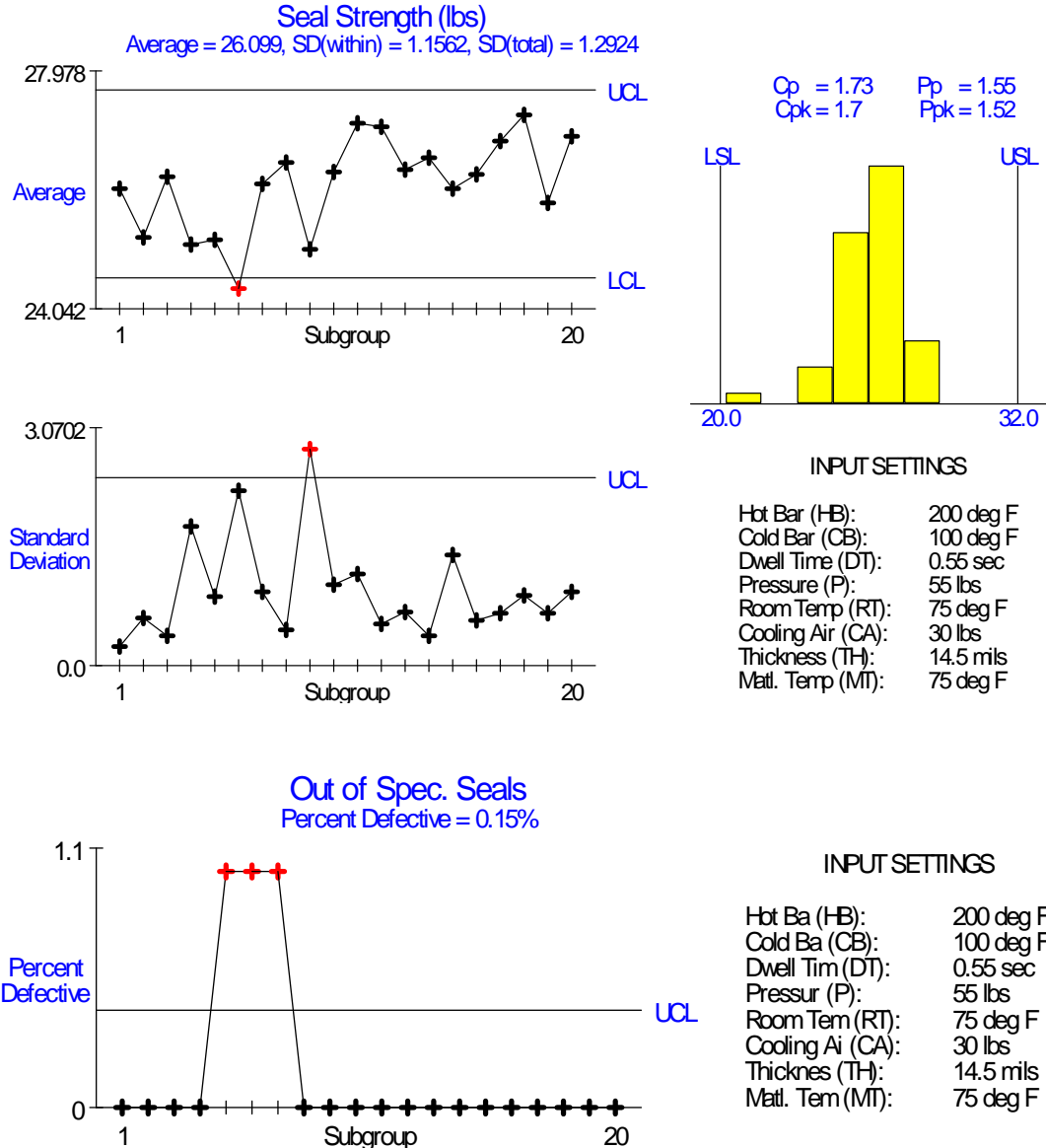
- Adjust HB and DT to minimize variation
- Adjust P and MT to get on target
- Set targets of the other 4 inputs to minimize cost (Ex: turn cooling air off).

Adjusting material temperature would require constructing a pre-heating chamber for the material. Instead, since pressure can be used to adjust the average, MT is fixed at the room

temperature of 75 °F. This requires the material to be in the room long enough for its temperature to reach room temperature. The optimal targets for the other inputs are:

HB	Hot Bar	200 °F
DT	Dwell Time	0.55 sec
P	Pressure	52.4 lbs.

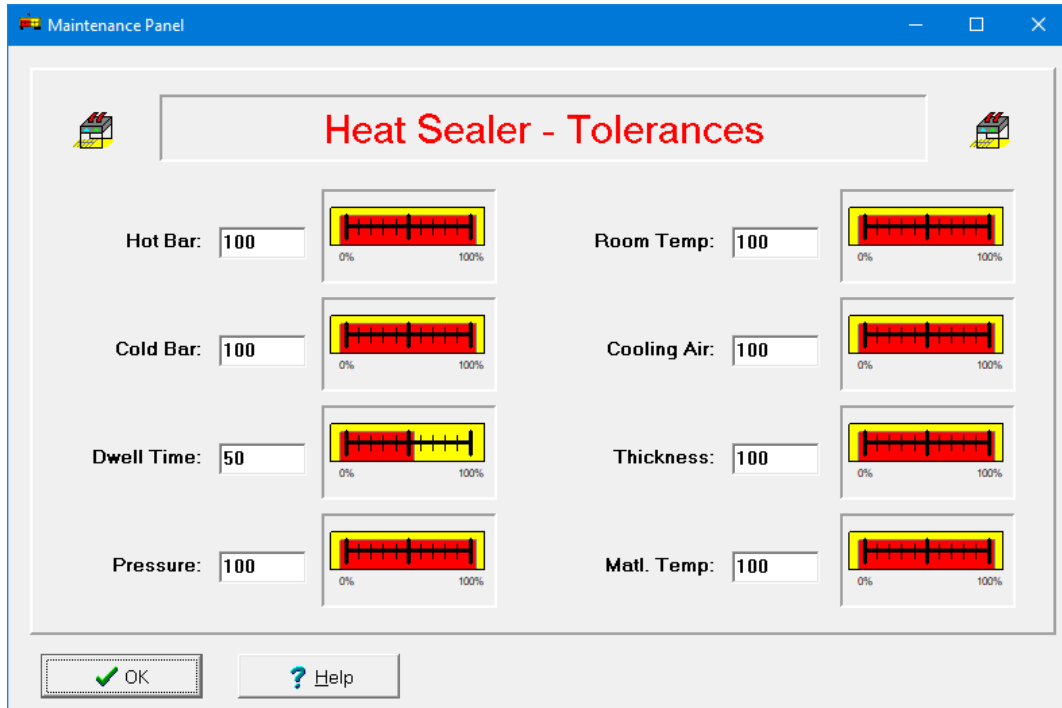
The improved performance is shown below. The process is now averaging around 0.15% defective with a  $P_{pk}$  of 1.52 and  $P_p$  of 1.55.  $P_p$  does not meet the Six Sigma goal of 2.



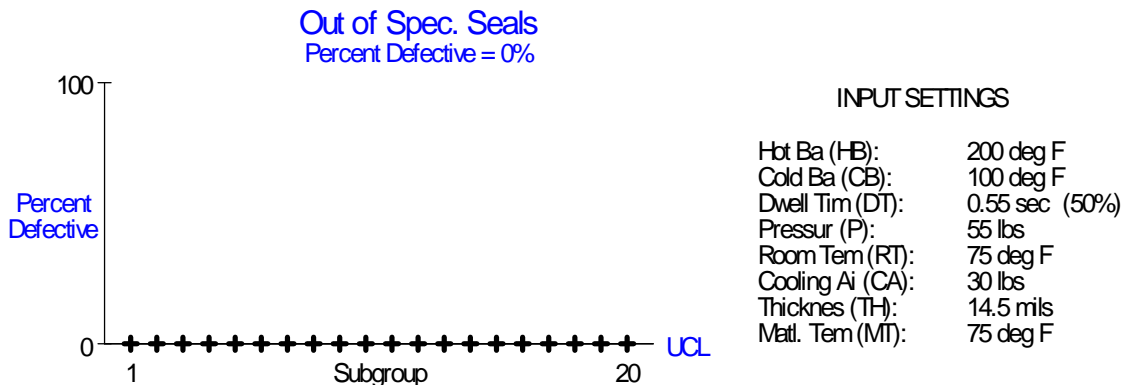
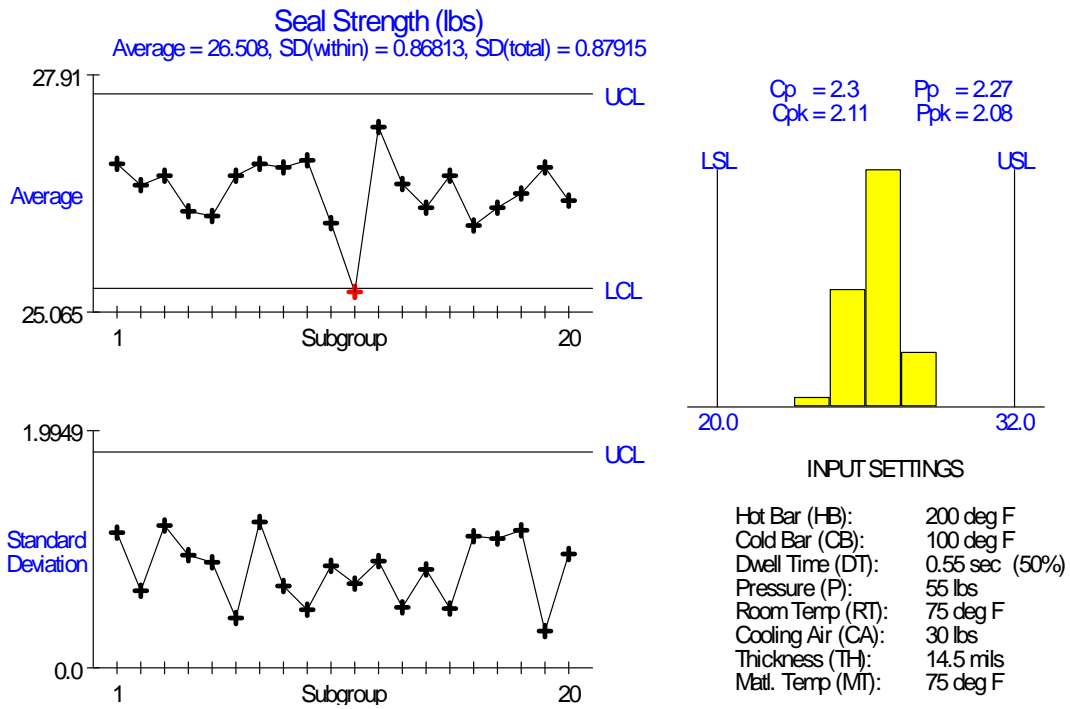
The operator should be restricted to using pressure to adjust the machine if it shifts off-target. Adjusting DT or HB increases the variation.



Further improvements must be made by tightening tolerances. The key to tightening tolerances is to identify which input(s) contribute the most to the variation. The contributions of the inputs to the variation can be determined using a sensitivity analysis (Pareto chart) as described in the VarTran User manual ([variation.com/vta](http://variation.com/vta)). This discovers DT is the leading source of variation. To tighten the tolerance of dwell time by 50% in Simulator, use the Maintenance dialog box, as shown below.



Tightening the tolerance of dwell time by 50% produces the following results. Now Six Sigma quality has been achieved.



The student needs to perform a tolerance analysis to determine which tolerance to tighten. The VarTran software package can be used to perform this purpose. It comes with a file for the heat sealer. The equation in this file was obtained using a response surface study rather than the actual equation. This difference does not affect the results.

A key lesson from this exercise is understanding the different roles of the input variables. Four are key inputs affecting the average. Two are standard deviation knobs used to adjust the standard deviation, HB and DT. One is the cause of the variation, DT.

## 1.2 Sheeting Extruder

This simulation involves optimizing a sheeting extrusion process. It is a simple example for starting with. It has only four inputs, all of which are important, making it most suitable for a response surface study. It cannot be used to illustrate robust design.

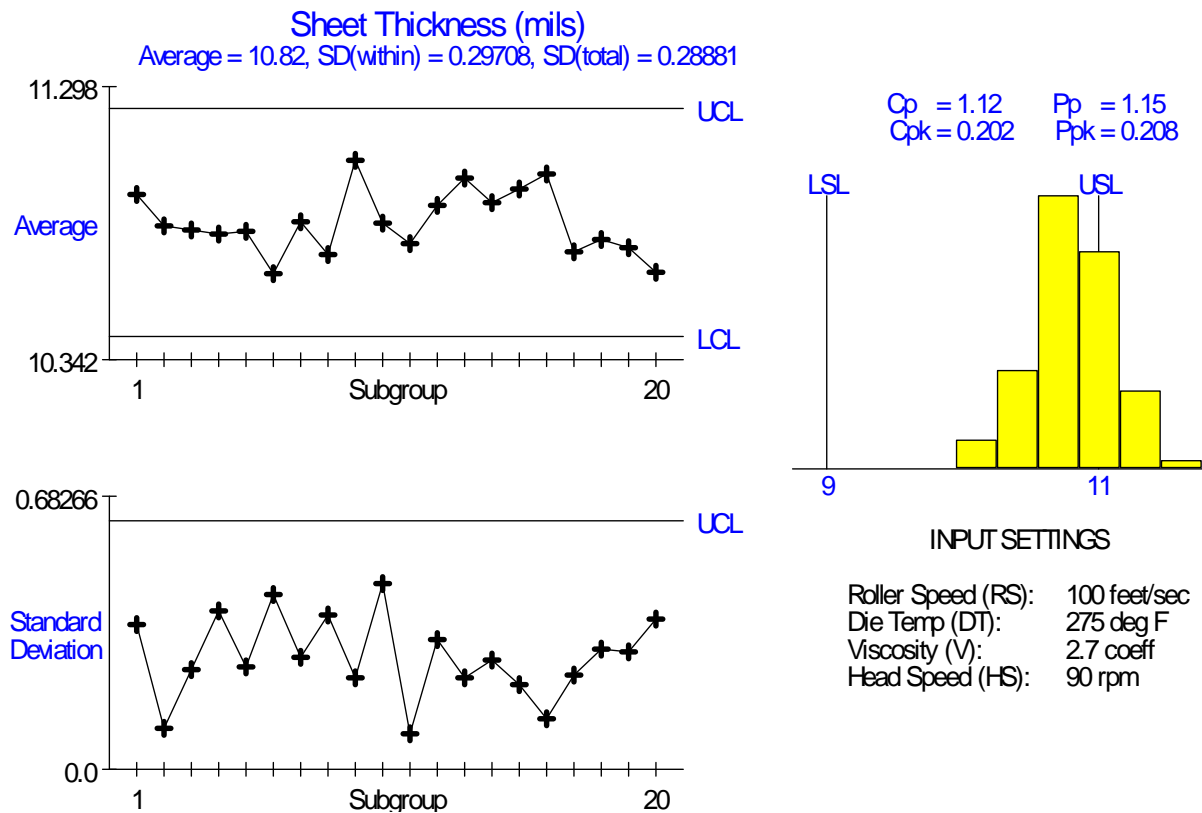
The output of interest is sheeting thickness. The target is 10.0 mils (thousands of an inch). The spec limits are 9.0 to 11.0 mils.

The current settings for the inputs are:

RS	Roller Speed	=	100 feet/sec
DT	Die Temp	=	275 °F
V	Viscosity	=	2.7 coeff
HS	Head Speed	=	90 rpm

The extruder works by forcing molten plastic through a die. The material is first heated to the die temperature. Increasing head speed increases the pressure the material is forced through the die. Roller speed is the speed at which the roller receiving the extruder sheeting is turning. Viscosity is a material property.

The current process is off-center:



The equation used to generate Sheeting Thickness is:

$$\text{Thickness} = -64.93479 - 0.10766 \text{ RS} - 0.001058 \text{ RS}^2 + 0.48434 \text{ DT} - 0.001058 \text{ DT}^2 + 0.001084 \text{ RS DT} + 5.0 \text{ V} + 0.0075 \text{ HS} + \text{Err}$$

Besides the 4 main effects, there are quadratic effects for RS, DT and an interaction between them.

The model includes only a single source of variation:

$$\text{Err} \quad \text{Other Error} \quad \text{Unit-to-unit standard deviation of 0.3 pounds}$$

This simulation cannot be used to illustrate robust design. Changing targets does not affect the variation. The goal is to adjust the variables to get the average on target. There are numerous combinations of the four inputs that center the process.

## 1.3 Sonic Sealer

This simulation involves optimizing a sonic sealing process. The model involved includes a three-way interaction making it difficult to model. It takes the right combination of the different inputs to get the process above the lower spec limit. It is an excellent final exam. It cannot be used to illustrate robust design.

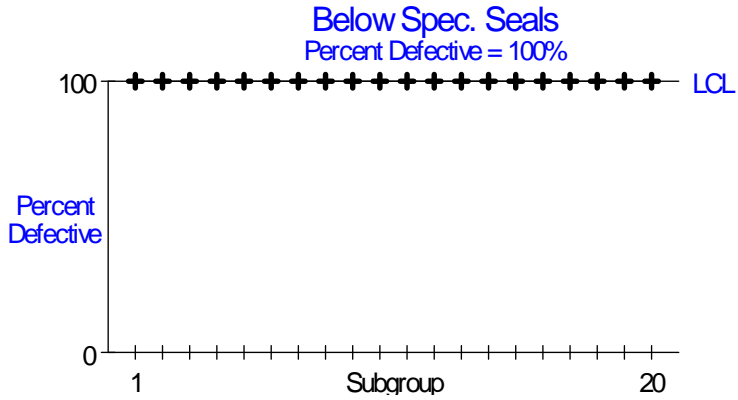
The output of interest is tensile strength. A small plastic disk is being sealed inside a hollow plastic tube. Tensile strength is the force required to pull the disk out. There is a lower spec limit of 20 pounds.

This is a new process. The goal is to demonstrate the feasibility of this approach rather than achieve Six Sigma. The inputs and one of the settings run are:

G	H/A Gap	=	14 mils
GF	Gauge Force	=	7 lbs
PF	Peak Force	=	120 lbs
HD	Horn Downtime	=	130 msec
BT	Bag Temp	=	65 °F
ST	Solution Temp.	=	45 °F

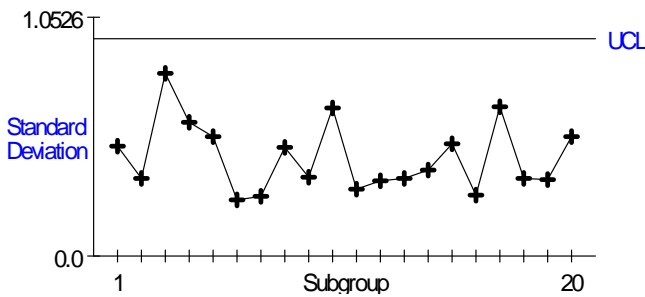
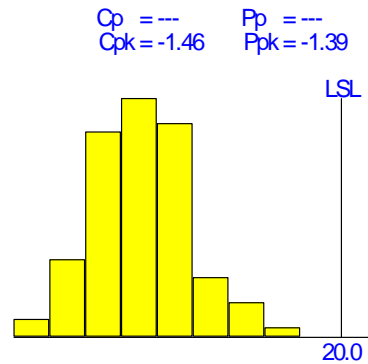
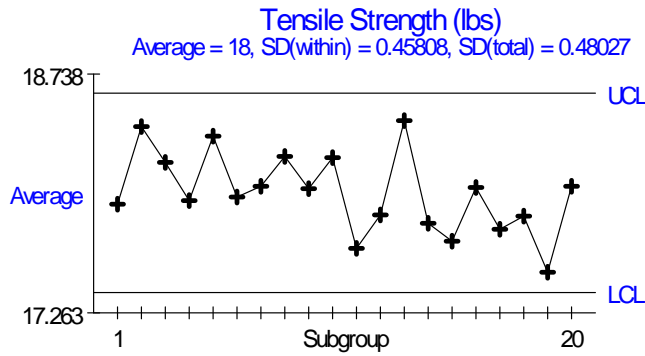
The sonic sealer works by focusing sound energy on the disk to get it to melt into the surrounding tube. The horn is the metal tooling inserted into the tube used to focus the sound energy on the disk. The tube has just been used to fill the sterile bag. The temperatures are the bag's temperature before filling and the solution's temperature when dispensed into the bag.

Dozens of different settings like the one given above have been tried without success. The results always look like the capability study below. Yes, that is the lower spec limit above all the values and a negative  $P_{pk}$  value. The project is about to be canceled. However, since you have been exhorting the benefits of designed experiments, you are being given the weekend to run a study (true story). Nobody expects much, but at least it will keep you quiet in the future. Don't expect to make the process Six Sigma, only to demonstrate feasibility.



INPUT SETTINGS

H/A Ga (G): 14 mils  
 Guage Forc (GF): 7 lbs  
 Peak Forc (PF): 120 lbs  
 H. Downtim (HD): 130 msec  
 Bag Temp (BT): 65 deg F  
 Solut. Temp (ST): 45 deg F



INPUT SETTINGS

H/A Gap (G): 14 mils  
 Guage Force (GF): 7 lbs  
 Peak Force (PF): 120 lbs  
 H. Downtime (HD): 130 msec  
 Bag Temp. (BT): 65 deg F  
 Solut. Temp. (ST): 45 deg F

There are two outputs, tensile strength and number of below spec seals. The same equation is used for both. One presents the data as a variable and the other as an attribute. The equation is:

$$\begin{aligned} \text{Tensile Strength} = & 39.2355 - 1.10625 G - 0.25625 HD - 1.1829167 ST + 0.015625 \\ & G HD + 0.07145833 G ST + 0.01204166 HD ST - 0.0007708 \\ & G HD ST + \text{Err} \end{aligned}$$

Only three inputs are in this equation: G, HD and ST. All three 2-way interactions between these variables exist and there is even a 3-way interaction. There are no quadratic effects.

The model includes only a single source of variation:

Err            Other Error    Unit-to-unit standard deviation of 0.5 pounds

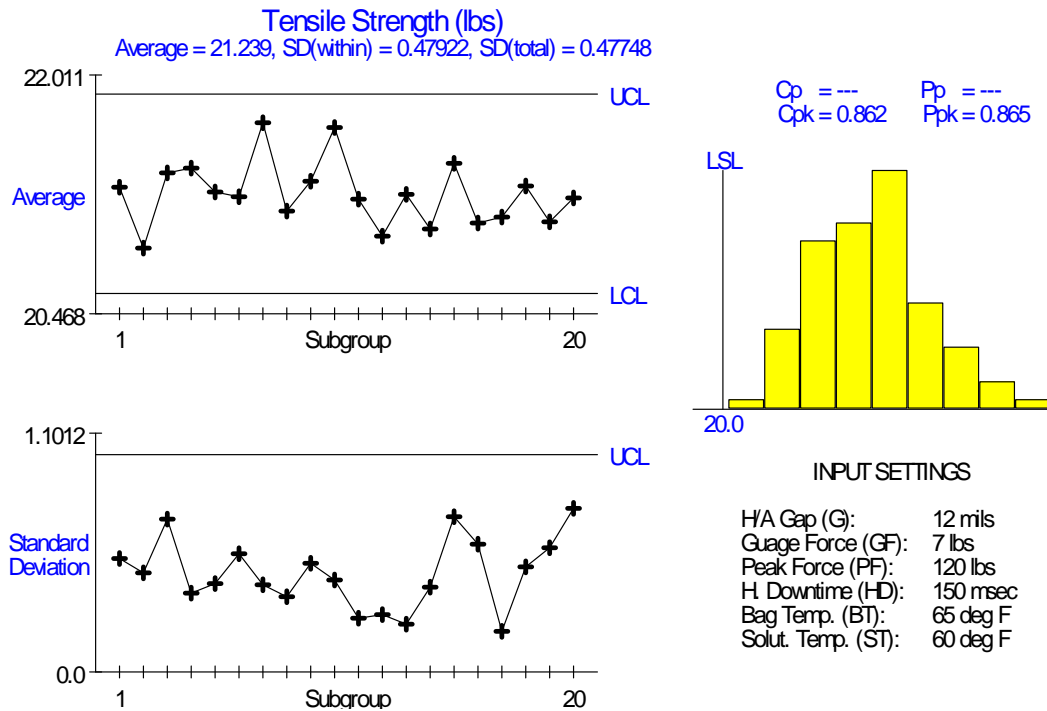
This simulation cannot be used to illustrate robust design. Changing targets does not affect the variation. The goal is to adjust the variables to get the average above the lower spec limit.

Running a screening experiment on this example generally identifies 4 key inputs. Three are the actual key inputs and the other is whatever is confounded with their 3- way interaction. One also detects at least three groups of interactions. Despite this error in picking up an extra variable, careful use of the interaction plots suggests 1 or 2 combinations of the inputs producing the optimal performance. If two, try them both.

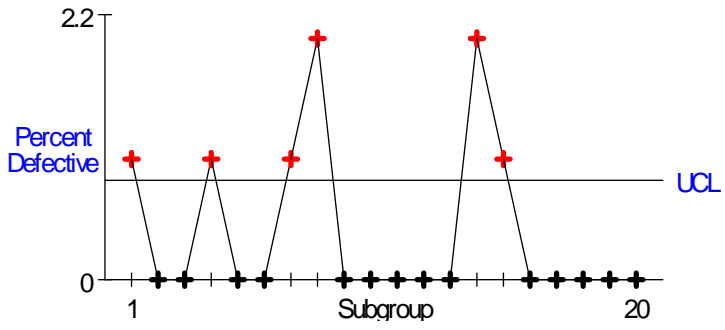
Running a response surface study correctly detects the 3 key inputs and sorts out interactions. Still, it does not include the 3-way interaction unless the students identify the highly interactive nature of the inputs and include it using a d-optimal design. Because there are no quadratic effects, the optimal must be a corner point. The setting that works is:

G	H/A Gap	= 12 mils
HD	Horn Downtime	= 150 msec
ST	Solution Temp.	= 60 °F

While the results are not Six Sigma, they demonstrate feasibility. The fact that the optimal is a corner point suggests widening the region of interest. Further, the surprising results caused theories about the effects of the variables to change and other changes. This process is now Six Sigma.



Below Spec. Seals  
Percent Defective = 0.4%



INPUT SETTINGS

H/A Ga (G): 12 mils  
Guage Forc (GF): 7 lbs  
Peak Forc (PF): 120 lbs  
H. Downtim (HD): 150 msec  
Bag Temp (BT): 65 deg F  
Solut. Temp (ST): 60 deg F



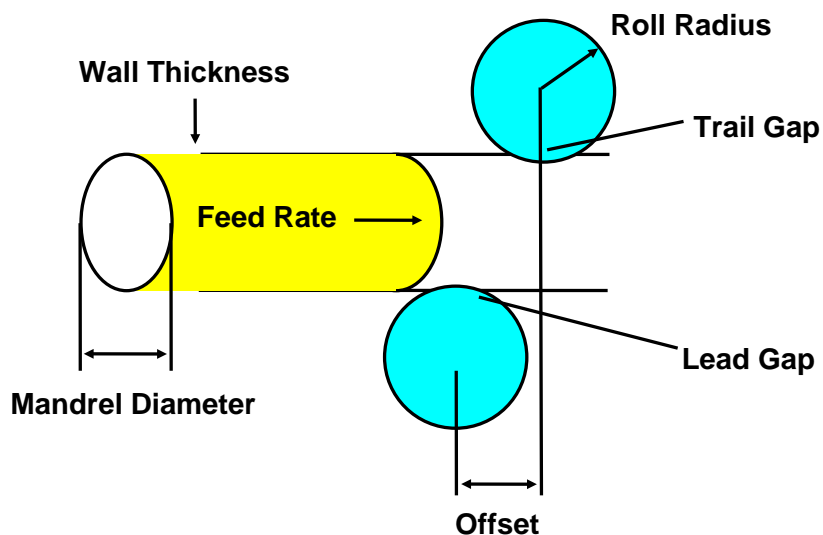
## 1.4 Flo-Former

This simulation involves optimizing a flo-former process. The model involves 8 candidate input variables which reduce to three key inputs. There are multiple sources of variation and interactions allowing for robust design. The complete set of tools, including screening and response surface studies, robust design and selectively tightening tolerances, all apply to this simulation. This example is borrowed from Tom Barker's course on robust design.

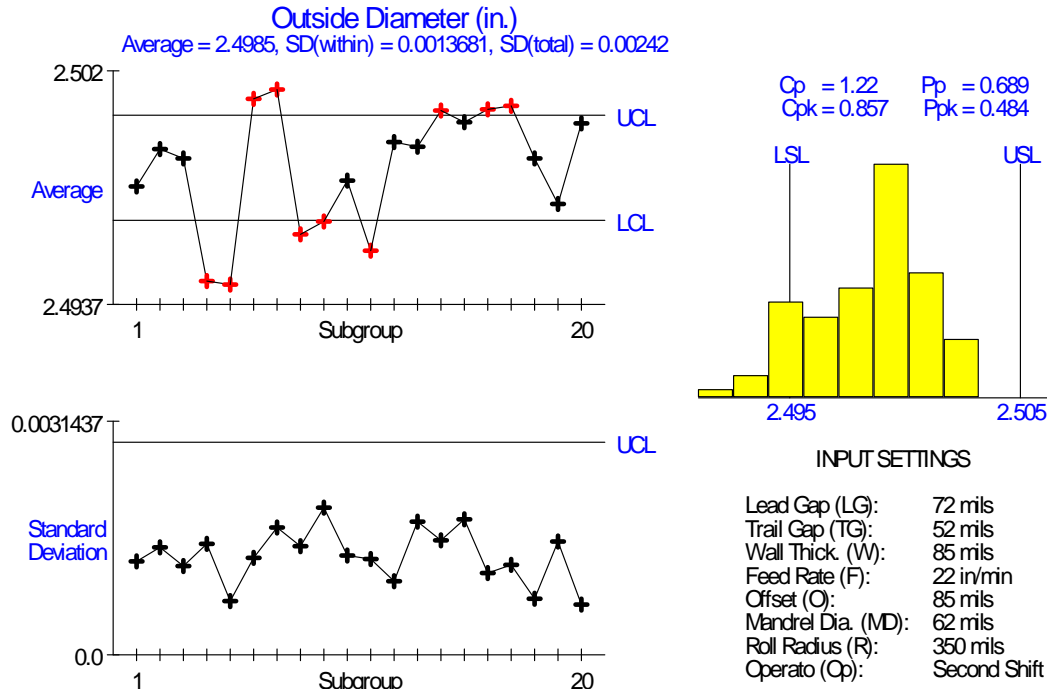
The flo-former process is used for crushing an extruded metal tube called a mandrel to the right size. The output of interest is the finished outside diameter. The target is 2.5 inches +/- 0.005. The mandrel is originally extruded slightly larger than needed and then crushed. The inputs, along with their current settings, are shown below:

LG	Lead Gap	=	72 mils
TG	Trail Gap	=	52 mils
W	Wall Thickness	=	85 mils
F	Feed Rate	=	22 in/min
O	Offset	=	85 mils
MD	Mandrel Diameter	=	62 mils
R	Roll Radius	=	350 mils
Op	Operator	=	Second Shift

Mandrel diameter and wall thickness are material properties. The remaining parameters are mostly machine settings. Many are setup related. The exception is the shift (operator). The mandrel is spun between several rollers that reduce the diameter. A diagram of the machine is given below:



A capability study of the current at the current settings is shown below. The process is unstable but also has excessive short-term variation ( $C_p < 2$ ).



There is one output, the outside diameter of the finished mandrel. The equation is:

$$\text{Outside Diameter} = 2.5 + (-466.3 + 5.19 \text{ LG} + 1.05 \text{ TG} + 4.15 \text{ W} - 0.051424 \text{ LG W} + \text{Err}) / 1000$$

Only three of the inputs are in this equation: LG, TG and W. There is a single 2-way interaction between LG and W. There are no quadratic effects

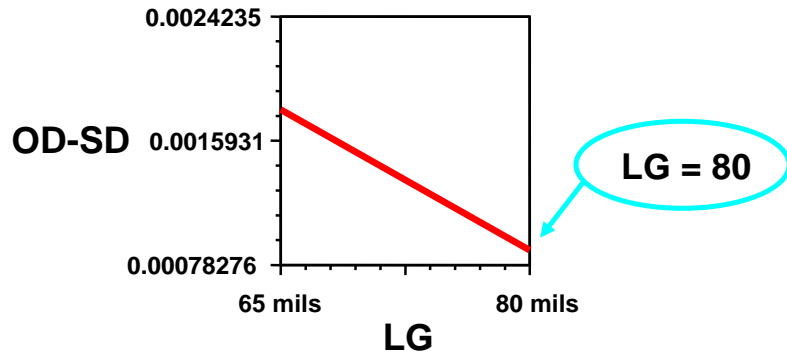
The model includes multiple sources of variation:

LG	Lead Gap	Trial-to-trial standard deviation of 1.0 mils
TG	Trail Gap	Trial-to-trial standard deviation of 1.0 mils
W	Wall Thickness	Unit-to-unit standard deviation of 2.0 mils plus Trial-to-trial standard deviation of 4.5 mils
Err	Other Error	Unit-to-unit standard deviation of 1.0 mils

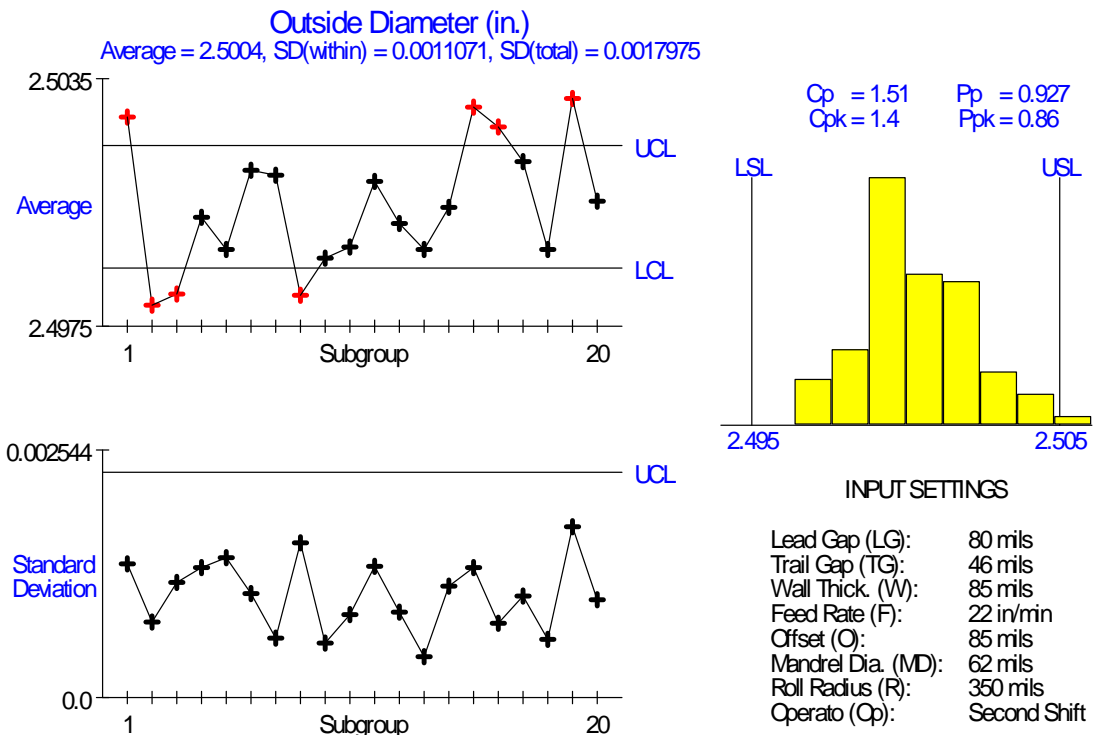
The setup parameters like trail and lead gaps only vary from trial to trial, so it may be the cause of instability. Changing targets affects the variation, so robust design can be explored. The goal is to reduce the variation, both causing the process to be unstable and short-term variation.

Running a screening experiment on this example generally results in identifying the 3 key inputs and one interaction group. The inclusion of center points identifies no curvature. The correct interaction in the group can generally be identified based on which individual terms test significant. From this, a model can be fit without going to a response surface study.

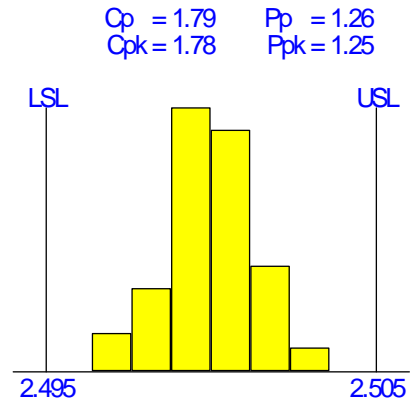
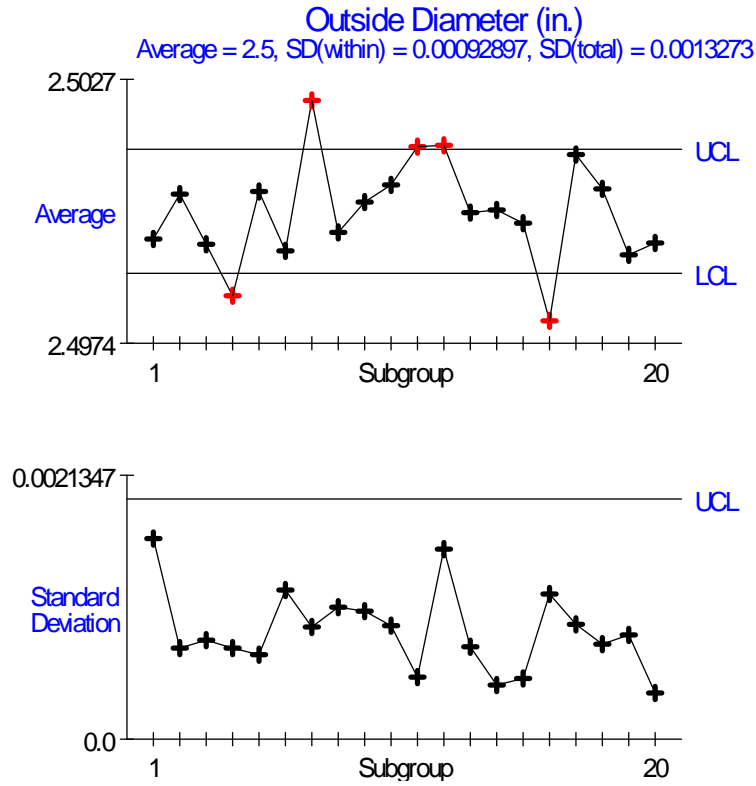
When analyzing the standard deviation as a response variable, only lead gap tests significant. A plot is shown below. The key to reducing the variation is setting lead gap to 80. This takes advantage of the LG\*WT interaction and makes the process robust to material.



Setting LG to 80 minimizes the variation. MT is a material parameter that is more difficult to change, so it is left alone. Trail Gap affects only the average and is used to adjust the average to 10 mils. Setting TG to 46 centers the process. The results are shown below.



While this represents a significant improvement, it is still not Six Sigma. Further improvements can only be obtained by tightening tolerances. Copying the equation into VarTran identifies LG as the primary cause of the variation. Cutting its tolerance by 50% improves the performance further, as shown below.



**INPUT SETTINGS**

Lead Gap (LG):	80 mils (50%)
Trail Gap (TG):	46 mils
Wall Thick. (W):	85 mils
Feed Rate (F):	22 in/min
Offset (O):	85 mils
Mandrel Dia. (MD):	62 mils
Roll Radius (R):	350 mils
Operato (Op):	Second Shift

## 1.5 Pump

This simulation applies to the design of a product rather than a process. The equation can be derived, so a designed experiment is not necessary. It provides a great example relative to robust design and tightening tolerances.

Design offers the first and best opportunity for reducing variation. To illustrate the strategies and tools required, consider the task of designing a new pump. Suppose that the pump must be capable of delivering solution at a constant rate of 10 ml/min. Customer usage requires that the flow rate remains between 9 and 11 ml/min. The first step is to develop a design concept. Taguchi calls this the system design. Suppose we decide to use a piston to push the solution. This concept requires a motor to drive the piston and a valve to control the direction of the flow. This is the creative part of design.

Now the work begins. We need to determine all the specifics, such as “How far should the piston travel?” and “How fast should the motor turn?” To accomplish this task, we need to make a list of all the factors affecting flow rate. Three obvious factors are the piston radius (R), the stroke length (L), and the motor speed (S). Another possibility is the amount of backflow through the valves (B). It is the output flow rate that we want to optimize the average and reduce the variation. This is accomplished by establishing requirements and controls for the inputs.

Initial settings for the inputs are shown below:

R	Piston Radius	= 0.1 inches
L	Stroke Length	= 0.5 inches
S	Motor Speed	= 48.2 rpm
B	Back Flow	= 0.5 ml/stroke

There is one output, the flow rate. The equation is:

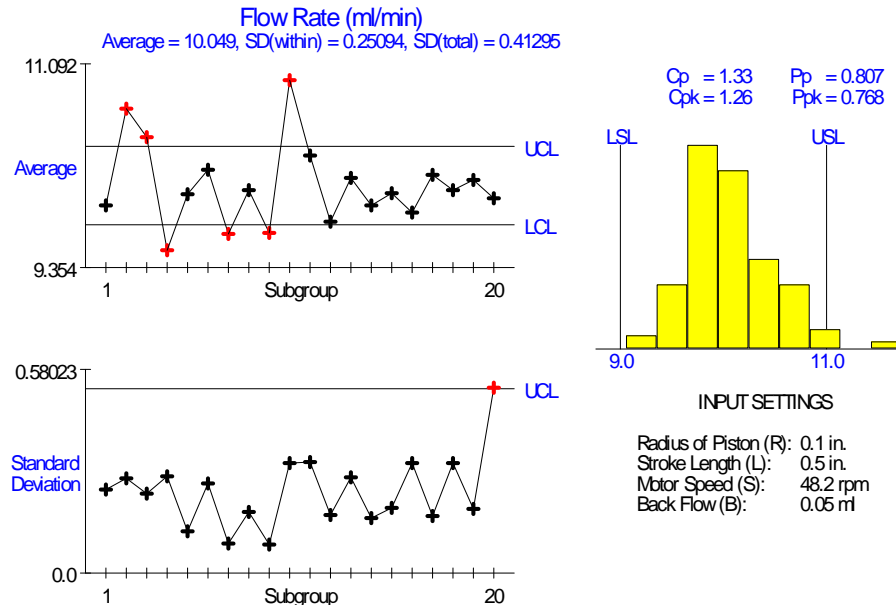
$$F = (16.388 \pi R^2 L - B) S$$

All four inputs are in the equation. R has a quadratic effect. The equation consists of two interaction B \* S and the more complicated  $R^2 * L * B$ .

The model includes multiple sources of variation:

R	Radius	Unit-to-Unit Standard deviation of 0.00005 inches plus Trial-to-trial standard deviation of 0.000075 inches
L	Stroke Length	Unit-to-Unit Standard deviation of 0.00167 inches plus Trial-to-trial standard deviation of 0.0025 inches
S	Motor Speed	Unit-to-unit standard deviation of 0.167 rpm Trial-to-trial standard deviation of 0.25 rpm
B	Back Flow	Unit-to-unit standard deviation of 0.005 ml/stroke plus Trial-to-trial standard deviation of 0.0075 ml/stroke

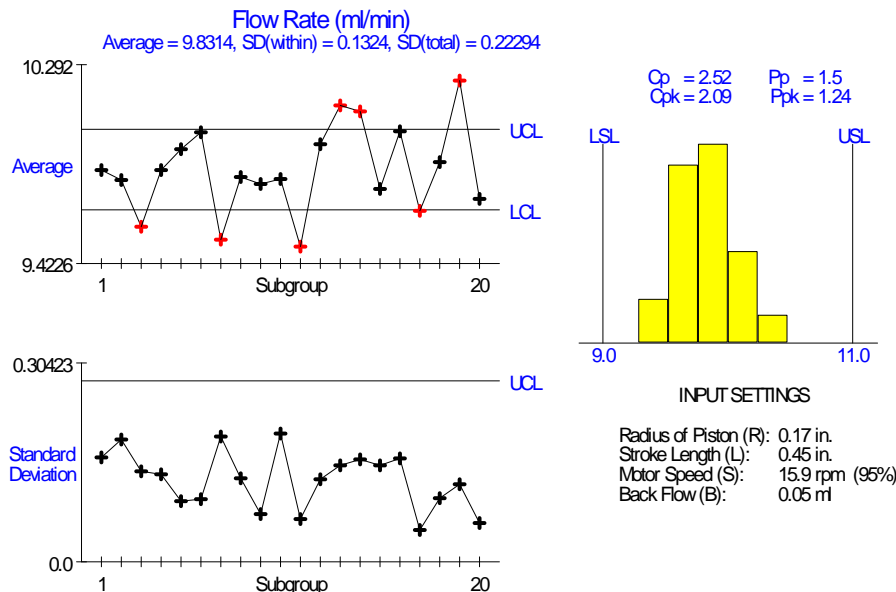
A capability study at the current settings is shown below. The process has excessive long-term and short-term variation.



The example file pump-pr.vta that is installed when VarTran ([variation.com/vta](http://variation.com/vta)) is installed can be used to solve this problem. Clicking on the Find Optimal Targets button gives:

R	Piston Radius	=	0.17 inches
L	Stroke Length	=	0.45 inches
S	Motor Speed	=	15.9 rpm

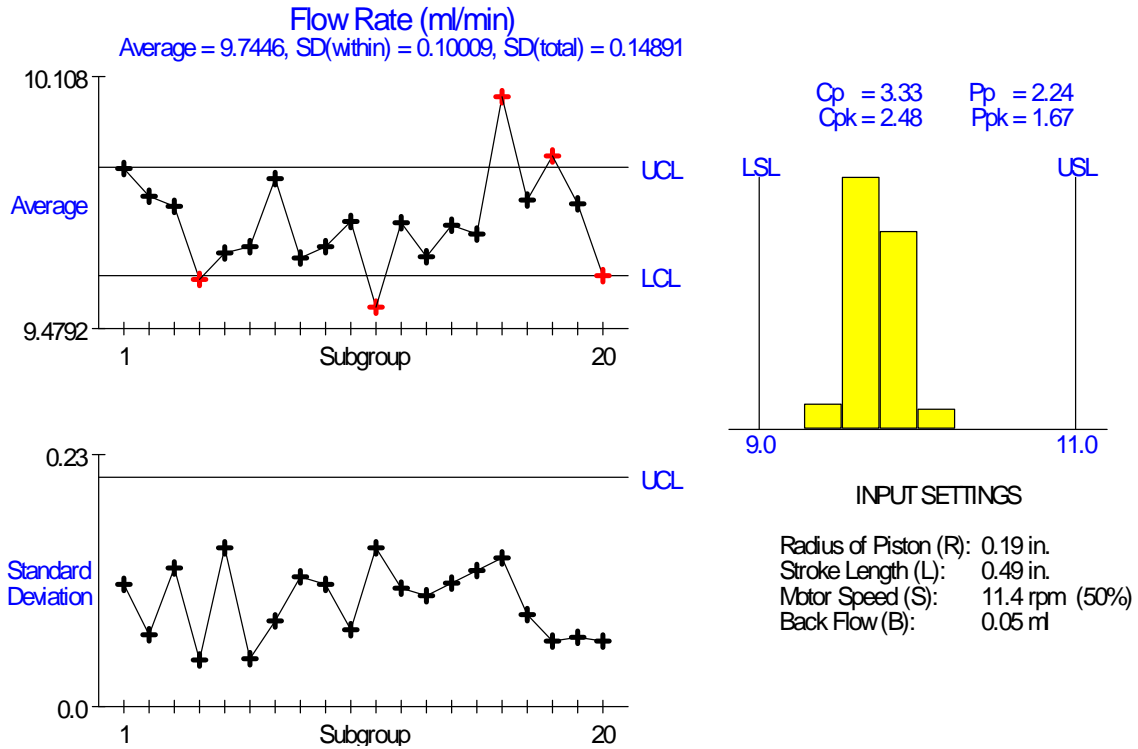
The fourth input, B, is not included in the optimization as it is not easily adjustable. A capability study at the optimal settings is shown below. The process has improved but still has excessive long-term variation.



Further improvements can only be obtained by tightening tolerances. VarTran identifies motor speed as the primary cause of the variation. Cutting its tolerance by 50% and reoptimizing gives:

R Piston Radius = 0.19 inches  
 L Stroke Length = 0.49 inches  
 S Motor Speed = 11.4 rpm

A capability study at the optimal settings is shown below. Six Sigma Quality has been achieved.



# 2 Structure of Simulation Files

The simulations for the program Simulator are set up using text files that can be easily edited and added or removed. When starting, Simulator checks the directory the program resides in for text files with the extension txt. It reads each text file to see if it contains a simulation and displays the simulations found in the Select Simulation dialog box shown when the program starts.

## 2.1 File Structure

Each simulation file contains the name of the simulation, a graphic and then a description of the input and output variables. The file for the heat sealer simulation is shown below:

```
"Simulator" 2.0
"sealer.bmp" "sealer.rtf" 1
"Heat Sealer"
9
"HB" "Hot Bar" "deg F" -5 "190" "150" "200" "0.0" "2.0" "0.0" "0.0" "100" 1 1
"CB" "Cold Bar" "deg F" -5 "100" "80" "120" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"DT" "Dwell Time" "sec" -5 "0.8" "0.5" "1.0" "0.08" "0.0" "0.0" "0.0" "100" 1 1
"P" "Pressure" "lbs" -5 "100" "50" "150" "1.0" "0.0" "0.0" "0.0" "100" 1 1
"RT" "Room Temp" "deg F" -5 "75" "70" "80" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"CA" "Cooling Air" "lbs" -5 "30" "0" "30" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"TH" "Thickness" "mils" -5 "14.5" "14" "15" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"MT" "Matl. Temp" "deg F" -5 "75" "70" "110" "4.0" "0.0" "0.0" "0.0" "100" 1 1
"Err" "Other Error" "lbs" -5 "0" "0" "0" "0.8" "0.0" "0.2" "0.8" "100" 0 0
0
2
"SS" "Seal Strength" "lbs" -5
"-403.5 + 3.6 HB - 0.008 HB^2 + 280.0 DT - 80.0 DT^2 - 0.96 HB DT + 0.04 P + 0.05 MT + Err"
1 1 1 "32.0" "20.0" "26.0" 5 5
"OS" "Out of Spec. Seals" "" -5
"-403.5 + 3.6 HB - 0.008 HB^2 + 280.0 DT - 80.0 DT^2 - 0.96 HB DT + 0.04 P + 0.05 MT + Err"
1 0 1 "32.0" "20.0" "26.0" 100 100
```

The file contains text strings and numbers. Text strings start and end with a quotation mark ("). Sometimes the text string contains an expression, as described in the last section. Numbers are of the form -XX.XXe-XX. The exponent, decimal point and signs are all optional. Any number of blank characters, tabs and line feeds can be inserted between text strings and numbers. The arrangement shown above could be changed to have all the values on one line or to have every value on a separate line.

The file is broken into 4 main sections:

- Header Information – first three lines above
- Input Variables – number followed by list
- Category Input Variables – number followed by list
- Output Variables – number followed by list

Simulator is consistent with the VarTran software package relative to its handling of the 3 types of variables. Each section is described separately.



## 2.2 Header Section

The Header section consists of the following lines:

```
"Simulator" 2.0
"sealer.bmp" "sealer.rtf" 1
"Heat Sealer"
```

There are six items which must be entered:

Name	Type	Description
Program Name	Text String	Must always be set to "Simulator". File will only be read if it starts with the text string Simulator. This prevents the program from accidentally reading other text files.
Version Number	Number	Files following the instructions in this document should have a version number of 2.0. This will allow future versions of the program to continue to read the file even if the format changes. The format does not change with version 2.1 of Simulator.
Graphics File	Text String	Name of a graphics file containing a picture to be displayed on the Select Simulation dialog box and elsewhere. The file must be in the same directory as the program and simulation text files. If no graphic is provided, enter the blank text string"". The file should be in bmp, jpg, ico, emf, or wmf formats. 30 by 30-pixel files will appear without distortion. All other files will be automatically shrunk or expanded to fit the space provided.
Description File	Text String	Name of a rich text file containing a description of the simulation that is incorporated into the help system. The file must be in the same directory as the program and simulation text files. If no description file is provided, enter the blank text string"". The file should be in rtf format. It can be created in Word using the Save As menu item.
Sequence Number	Number	The sequence number is used to control the order that the simulations appear on the Startup dialog box starting with the smallest number. Simulations with the same sequence number are sorted alphabetically by title.
Title	Text String	The name of the simulation as it is to appear on the Select Simulation dialog box, Control panel, and windows displaying the results of the simulation.

## 2.3 Input Variables Section

The Input Variables section consists of the following lines:

```

9
"HB" "Hot Bar" "deg F" -5 "190" "150" "200" "0.0" "2.0" "0.0" "0.0" "100" 1 1
"CB" "Cold Bar" "deg F" -5 "100" "80" "120" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"DT" "Dwell Time" "sec" -5 "0.8" "0.5" "1.0" "0.08" "0.0" "0.0" "0.0" "100" 1 1
"P" "Pressure" "lbs" -5 "100" "50" "150" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"RT" "Room Temp" "deg F" -5 "75" "70" "80" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"CA" "Cooling Air" "lbs" -5 "30" "0" "30" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"TH" "Thickness" "mils" -5 "14.5" "14" "15" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"MT" "Matl. Temp" "deg F" -5 "75" "70" "110" "0.0" "0.0" "0.0" "0.0" "100" 1 1
"Err" "Other Error" "lbs" -5 "0" "0" "0" "0.8" "0.0" "0.2" "0.8" "100" 0 0

```

It starts with the number of input variables. Then there are 14 items that must be entered for each input variable:

Name	Type	Description
Symbol	Text String	Symbol used to represent variable in the equation for output. Must be unique, consist of only letter, digits and underscores and cannot begin with a digit.
Name	Text String	More descriptive name for the variable for use on the Control Panel and windows displaying the results of the simulation.
Units	Text String	Units of measure used for specifying current, minimum and maximum targets.
Precision	Number	Number used to specify precision for displaying numbers. A positive integer and zero indicates the number of digits after the decimal number to report. A negative integer represents the number of significant digits to report. A value of -5 generally works well.
Initial Target	Text String Containing Constant Expression	The initial value to target the input at. It is frequently the current recommended setting used for process or the midpoint between the minimum and maximum targets. The value entered must be between the minimum and maximum targets. The initial target is entered as a text string that can contain a constant expression.
Minimum Target	Text String Containing Constant Expression	The minimum value the user can set the target to. The value entered must be less than the maximum target if the variable appears on the control panel. The minimum target is entered as a text string that can contain a constant expression.

Name	Type	Description
Maximum Target	Text String Containing Constant Expression	The maximum value the user can set the target to. The value entered must be less than the maximum target if the variable appears on the control panel. The maximum target is entered as a text string that can contain a constant expression.
Unit Standard Deviation	Text String Containing Expression	The standard deviation from unit-to-unit in the same trial. The unit standard deviation is entered as a text string that can contain an expression containing the symbol <b>Target</b> . This allows the unit standard deviation to depend on the target selected. For example, the expression "0.03 Target" causes the standard deviation to always be 3% of the target, i.e., sets the CV to 3%. The unit standard deviation must always be greater than or equal to zero.
Setup Standard Deviation	Text String Containing Expression	The standard deviation from trial-to-trial. The setup standard deviation is entered as a text string that can contain an expression containing the symbols <b>Target</b> and <b>UnitStandardDeviation</b> . This allows the setup standard deviation to depend on these two values. The setup standard deviation must always be greater than or equal to zero.
Probability of a Shift	Text String Containing Constant Expression	The probability that a shift in the average occurs between subgroups or trials. The probability of a shift is entered as a text string that can contain a constant expression. The probability of a shift must be between zero and one.
Shift Standard Deviation	Text String Containing Expression	Standard deviation of distance above or below target following a shift. Shifts are not cumulative. Each time a shift is determined to have occurred, a new distance from target is determined. This results in a stationary time series process that remains centered around the target. The shift standard deviation is entered as a text string that can contain an expression containing the symbols <b>Target</b> and <b>UnitStandardDeviation</b> . This allows the shift standard deviation to depend on these two values. The shift standard deviation must always be greater than or equal to zero.

Name	Type	Description
Percent Tolerance	Text String Containing Constant Expression	The standard deviations are all reduced by this quantity. Setting to 0% eliminates all variation of the input variable. This variable is generally set to 100 initially. The percent tolerance is entered as a text string that can contain a constant expression. The percent tolerance tightened must be between 0 and 100.
Display on Control Panel?	Number	A value of 1 causes this variable to be displayed on the control panel allowing its target to be adjusted by the user. A value of 0 hides this variable from the user. This allows sources of variation like measurement error to be added to the model that the user cannot adjust the target of.
Able to Tighten Tolerance?	Number	A value of 1 causes this variable to be displayed on the maintenance panel allowing the percent tolerance tightened to be adjusted. A value of 0 hides this variable from the user. If all are set to zero, the tighten tolerance panel will not be displayed.

## 2.4 Category Input Variables Section

The Category Inputs Variables section for the heat sealer file consists of the following line:

```
0
```

This indicates there are no category inputs in this simulation. When there are category input variables, the section would appear as follows:

```
2
"M" "Material" "type" -5 2 "N" "New" "O" "Old" 2
"C" "Cavity" "number" -5 4 "_1" "Cavity 1" "_2" "Cavity 2"
    "_3" "Cavity 3" "_4" "Cavity 4" 1
```

It starts with the number of category input variables. Then there are 8 items which must be entered for each category input variable:

Name	Type	Description
Symbol	Text String	Symbol used to represent a variable in an equation for an output variable. Must be unique, consist of only letter, digits and underscores and cannot begin with a digit.
Name	Text String	More descriptive name for the variable for use on windows displaying the results of the simulation.
Units	Text String	Units of measure. While this field must be entered for all variables, it is ignored for category input variables.
Precision	Number	Number used to specify precision for displaying numbers. While this field must be entered for all variables, it is ignored for category input variables.
Number of Categories	Number	Number of category or levels associated with variables. Must be at least 1.
Category Symbol	Text String	Symbol used to represent a category in an equation for an output variable. Must be unique, consist of only letter, digits and underscores and cannot begin with a digit. The category symbol and name are entered next to each other and then repeated for each category.
Category Name	Text String	More descriptive name for the category for use on windows displaying the results of the simulation.
Selected Category	Number	The selected category for performing simulations. Must be an integer between 1 and the number of categories.

## 2.5 Output Variables Section

The Output Variables section consists of the following lines:

```

2
"SS" "Seal Strength" "lbs" -5
"-403.5 + 3.6 HB - 0.008 HB^2 + 280.0 DT - 80.0 DT^2 - 0.96 HB DT + 0.04 P + 0.05 MT + Err"
1 1 1 "32.0" "20.0" "26.0" 5 5
"OS" "Out of Spec. Seals" "" -5
"-403.5 + 3.6 HB - 0.008 HB^2 + 280.0 DT - 80.0 DT^2 - 0.96 HB DT + 0.04 P + 0.05 MT + Err"
1 0 1 "32.0" "20.0" "26.0" 100 100

```

It starts with the number of output variables. Then there are 13 items which must be entered for each output variable:

Name	Type	Description
Symbol	Text String	Symbol used to represent a variable in equation for another output. Must be unique, consist of only letter, digits and underscores and cannot begin with a digit.
Name	Text String	More descriptive name for the variable for use on windows displaying the results of the simulation.
Units	Text String	Units of measure used for calculated values.
Precision	Number	Number used to specify precision for displaying numbers. A positive integer and zero indicates the number of digits after the decimal number to report. A negative integer represents the number of significant digits to report. A value of -5 generally works well.
Equation	Text String Containing Expression	Equation for output in format used by VarTran. Can contain numbers, symbols of other variables, operators and functions. The equation can reference any of the input variables and category input variables as well as other output variables. A complete description is given in Section 2.6.
Equation for Value?	Number	The value of 1 indicates the entered equation is for values of the output. The equation is then repeatedly evaluated as the inputs vary to generate data. A value of 0 indicates the equation is for the fraction defective. The equation is evaluated once for each trial to obtain the fraction defective and then the binomial distribution is simulated to obtain the number of defects.

Name	Type	Description
Report Values?	Number	This item is only applicable to the case where Equation for Value is set to 1. A value of 1 causes the programs to report the average and standard deviation of the values generated. A value of 0 causes the program to only report the percentage of values in spec. There are two ways to generate attribute data: (1) enter an equation for the fraction defective using the previous variable or (2) enter an equation for values and specify 0 for this variable.
Display Results For?	Number	A value of 1 causes results to be displayed for this variable for trials and capability studies. A value of 0 causes no results to be displayed. This allows complex models to be entered were one output variable to be defined in terms of other intermediate output variables without having to display the results for the intermediate outputs.
Upper Spec Limit	Text String Containing Number or Blank	Upper spec limit for values. Only applicable if the Equation for Values is set to 1. Set to blank string "" if no upper spec limit.
Lower Spec Limit	Text String Containing Number or Blank	Lower spec limit for values. Only applicable if the Equation for Values is set to 1. Set to blank string "" if no lower spec limit.
Target	Text String Containing Number or Blank	Target for values. Only applicable if the Equation for Values is set to 1. Set to blank string "" if no target. When there are two spec limits, the target is frequently the midpoint.
Number of Samples Per Trial	Number	Specifies the number of samples to be generated for each trial. A value of 5 is common when values are generated and a value of 100 is common for attribute data.
Number of Samples Per Subgroup	Number	Specifies the number of samples to be generated for each trial of a capability study. A capability study always consists of 20 trials. A value of 5 is common when values are generated and a value of 100 is common for attribute data.

## 2.6 Expressions

An expression consists of numbers, operators, functions, variables and parenthesis as described below.

**Numbers:** Examples are "1", "1.0", ".1", "1.1 10<sup>2</sup>", and "-1.1 10<sup>-2</sup>".

**Operators:** Unary operators: - and +. Binary operators: +, -, \*, /, and ^. If parentheses are omitted, the operations are performed in the order determined by the operator precedence and association rules. Multiplication operators may be omitted. For example, the expression "2 A Log[B C]" is interpreted as "2 \* A \* Log[B \* C]".

**Functions:** Of form "function [param1, param2, ...]". The following functions are supported: Log, Log10, Exponential, SquareRoot, Sine, Cosine, Tangent, ArcSine, ArcCosine, ArcTangent, HyperbolicSine, HyperbolicCosine, HyperbolicTangent, Gamma, LogGamma, Beta, LogBeta, AbsoluteValue, Minimum, Maximum, NormalDistribution, InverseNormalDistribution, pi, and e. Most functions require one parameter. Exceptions are Beta, LogBeta, Minimum, and Maximum, which require 2, and pi and e, which require zero. Squared brackets must be used with functions.

**Symbol:** Can enter the symbol of any input variable or output variable. For output variables circular or recursive references are not allowed.

**Category Input Variables:** Of form "Symbol {Symbol}". Examples are "M{New}" and "Cavity{<sub>3</sub>}". The first symbol is the symbol of the category input variable and the second symbol is the symbol for the category.

**Rounded Parentheses:** "(" and ")" are used to control the order that operations are performed. Without parentheses, the operations are performed in the order determined by the operator precedence and association rules. If in doubt about the order the operations will be performed, use parenthesis.

A constant expression is an expression that does not reference any symbols or variables.

Warning: Be sure to use rounded parenthesis for order of operation, square brackets for function calls and curved brackets for category input variables. "Log[A]" means to take the log of the variable A. "Log(A)" means to multiply the variables Log and A. "Log{A}" is the category A of the category input variable Log.