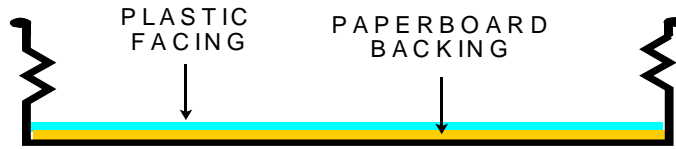


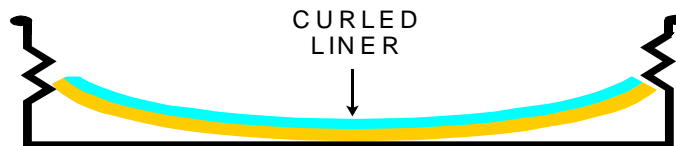
# Example 1: Liner Curl

## Product Description



**Cross Section of Cap & Liner Assembly**

The product consisted of a paperboard backing, adhesive, and saran film laminated together for use as a cap liner in mayonnaise container sealing applications. Saran film, a plastic facing, is a food contact surface that forms an oxygen barrier to prevent spoilage and separates the food from the metal closure (cap).



**Cross Section of Cap with Curled Liner**

## Problem Background

Defects occurred when the lamination warped or "curled" after installation inside the metal shell of the cap. The condition was not evident during the cap manufacturing process, but it appeared after the product was packaged and moved to warehouse locations. This defect occurred primarily about one axis and the liner started to deform in a "u" shape.

Food processors, the users of the cap/liner assemblies, moved them from warehouse facilities to the mayonnaise container filling stations via an air conveyance system. Defective liners were blown out of caps during the conveyance process and mayonnaise containers were subsequently capped without the saran-faced liner. This condition created the potential for product spoilage and entire lots of production were returned to the cap manufacturer.

The loss attributed to this condition was \$2,000,000 per year in 1989.

## Summary of Results

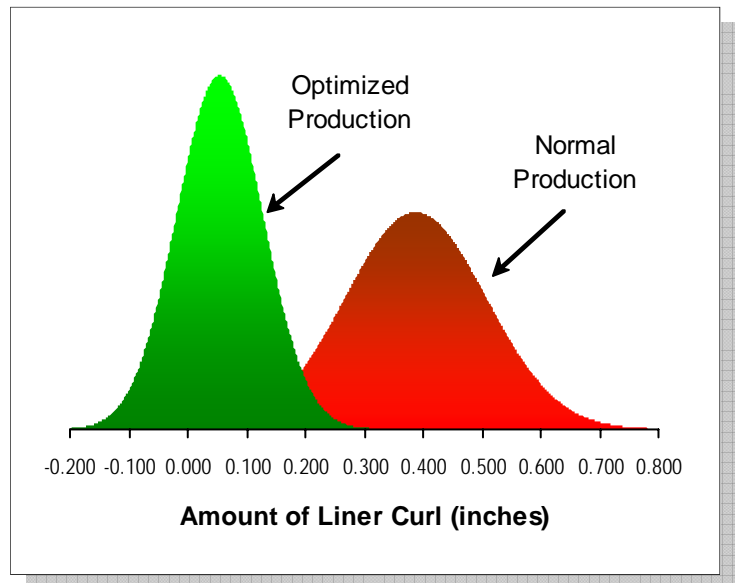
The graph at right illustrates the amount of liner curl for both the normal production and for the optimized product that was produced after completion of experimentation.

The “normal” production had an average liner curl of 0.388 inches. The standard deviation for this product was 0.121 inches.

The post experiment or “optimized” production was targeted closer to zero with an average liner curl of approx. 0.055 inches. It also demonstrated reduced product variation with a standard deviation of 0.083 inches.

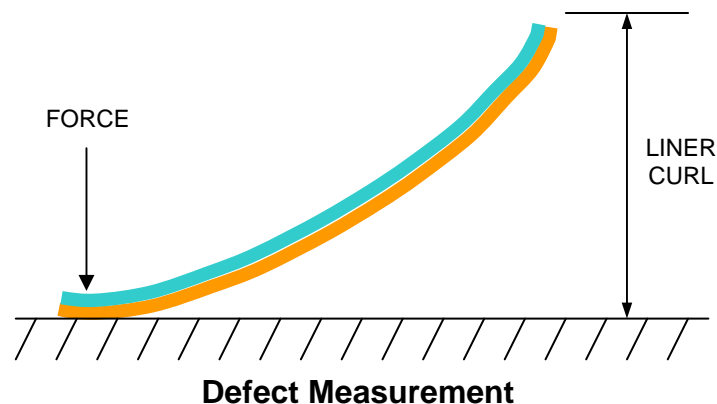
The combination of improved targeting and reduced variation was sufficient to prevent liner separation from the metal closures and completely eliminate customer returns for this defect.

Because experimentation revealed opportunities for cost reduction beyond the elimination of returns, the annual savings for this project exceeded the \$2,000,000 customer return rate mentioned earlier.

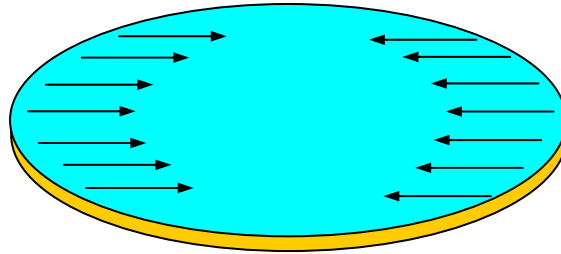


## Detail of Problem Solution

For the purposes of this experiment, the magnitude of deformation was determined by placing the liner on a flat surface and pressing an edge in the warped area firmly against the surface. The height of the liner on the opposite edge was measured to quantify the amount of curl.

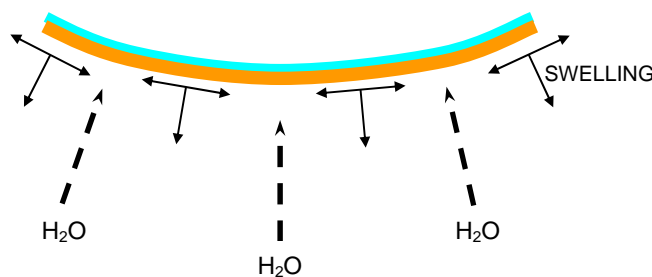


The curled liner phenomena had been a common, if somewhat intermittent occurrence, for many years. There were a number of long-held beliefs about the defect's root cause. The first was that tension applied to the plastic film during lamination caused residual stresses in the facing as shown in the figure below. It was thought these residual stresses caused the liner to warp. For many years the lamination of these materials was kept at low tension to minimize the residual stresses. Low tension created other difficulties, however, because the facing material had to be taut enough to prevent wrinkles in that layer of the lamination.



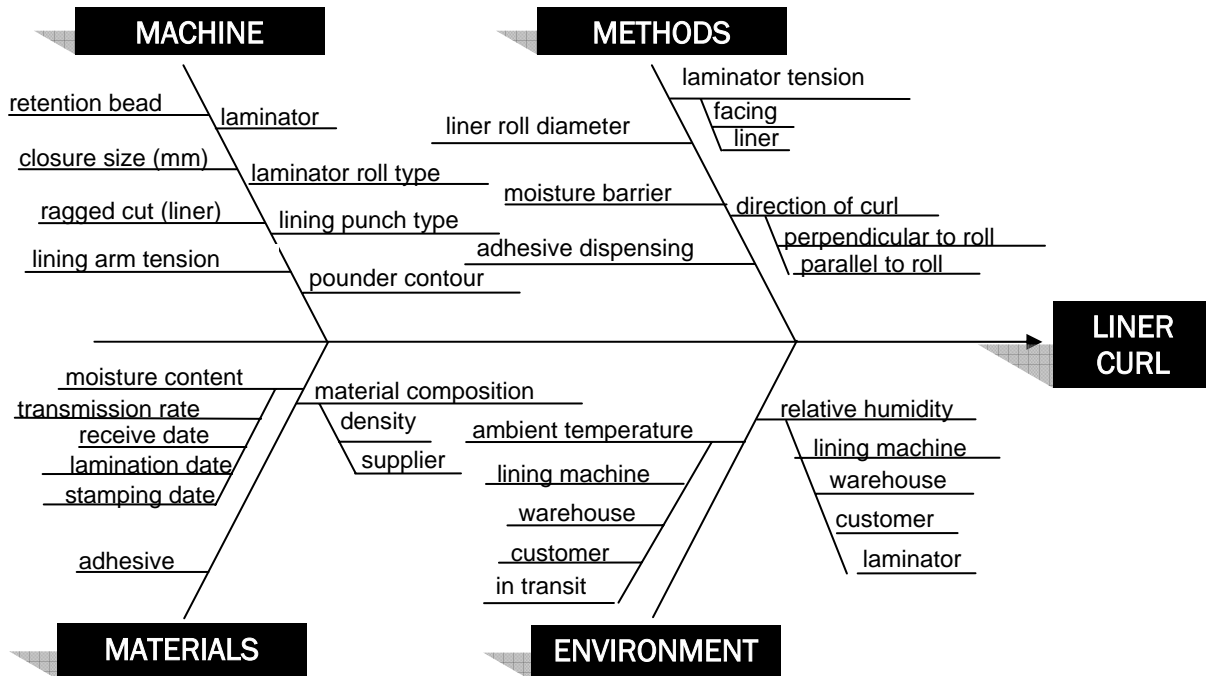
### Theorized Residual Stresses in Plastic Facing

Another failure theory postulated that curling was due to the absorption of moisture in the paperboard backing. Since the top face of the liner was a plastic material under tension, the manufacturer thought the liner would curl around that face as the backing absorbed moisture and swelled to occupy a larger volume. The actions taken to eliminate this cause were the conditioning of materials to control moisture prior to the laminating process, and the application of a wax layer onto the paperboard backing, at additional cost, to impede moisture absorption after lamination.



### Moisture Absorption Theory

All of the factors brainstormed as potential causes for this problem are shown on the cause & effect diagram that follows.



The personnel who developed the cause & effect diagram voted on which factors they thought were most likely to cause the liner curl. The inputs, or control factors, that received the most votes are listed in the following table:

Label	Control Factor	Level 1	Level 2
A	Adhesive Type	1	2
B	Backing Type	1	2
C	Supplier	1	2
D	Facing Type	1	2
E	Backing % Moisture	low	high
F	Backing Wax	no	yes
G	Laminator Tension	low	high

Laminating Process Control Factors

The optimization effort was designed to ensure that any solution to the liner curl problem would work on both lamination machines, on both manufacturing shifts, and for all wraps taken from the master roll of paperboard. These factors, inputs that were deemed too difficult or too expensive to completely control, are known as “noise” factors.

Noise Factor	Level 1	Level 2
Machine	1	2
Operator	1	2
Roll Position	start	End

#### Laminating Process Noise Factors

The first two factors are somewhat self-explanatory. "Machine" simply referred to the lamination line used to process the paperboard and facing. "Operator" referred to the employee assigned to setup and run the lamination line. The third factor, "roll position" referred to the degree of deformation or “set” inherent in the paperboard. The paperboard was purchased in large rolls approximately 4’ in diameter. Since the outer wraps were from a full roll, they were curved less than the inner wraps that were closer to the roll's mounting core. The "start" level corresponded to the outer wraps, and the "end" level corresponded to the inner wraps.

A Taguchi experimental array was chosen to investigate the contribution that each of the selected inputs made to the amount of liner curl in the finished product. The control factors were placed in an  $L_8$  array, and the noise factors were included in an  $L_4$  array. The actual layout of the  $L_8 \times L_4$  array is shown on the following page.

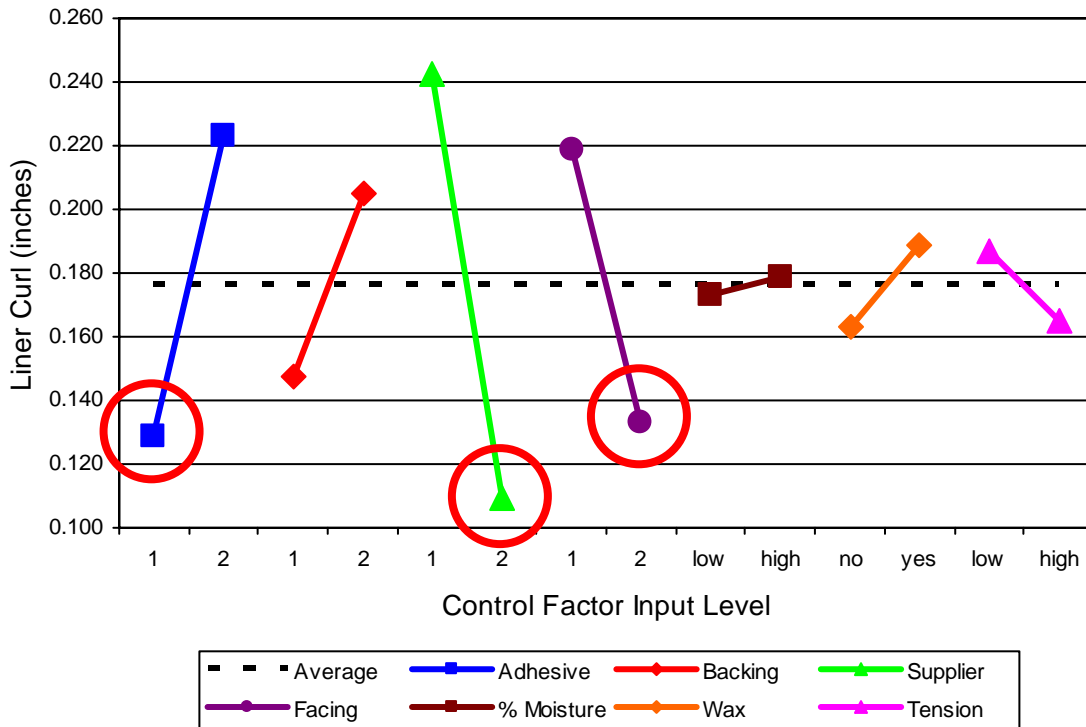
Since the optimized process needed to manufacture acceptable product on both machines and both shifts, the manufacturing trials were run on both laminating lines, with two operators. Sample liners for measurement were taken from both the beginning and end of the each master roll. This necessitated running each one of the 8 array trials under all of the conditions shown in the noise factor array. A total of 32 short manufacturing runs were made, with the average amount of liner curl resulting from each shown in yellow on the following page. The overall average, along with a measurement of variability, for each trial is highlighted in green.

**L<sub>8</sub> X L<sub>4</sub>**

		NOISE FACTORS								RESPONSE						
		Roll	start	end	end	start	end	start	end							
Mach.		1	1	2	1	2	1	2	1	2	Run 1	Run 2	Run 3	Run 4	Trial Ave (inch.)	S - N Ratio (dB)
Oper.		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T R I A L		CONTROL FACTORS								RESPONSE						
A	B	C	D	E	F	G										
Adhesive	Backing	Supplier	Facing	Moisture	Wax	Tension										
1	1	1	1	low	no	low										
2	1	1	2	high	yes	high										
3	2	2	1	low	yes	high										
4	2	2	2	high	no	low										
5	1	2	1	high	no	high										
6	1	2	2	low	yes	low										
7	2	1	1	high	yes	low										
8	2	2	2	low	no	high										

By analyzing the data in the array's response column (calculations not shown), the contribution each distinct control factor made to the liner curl response was isolated and plotted in the graph below.

**Liner Curl Response Graph**

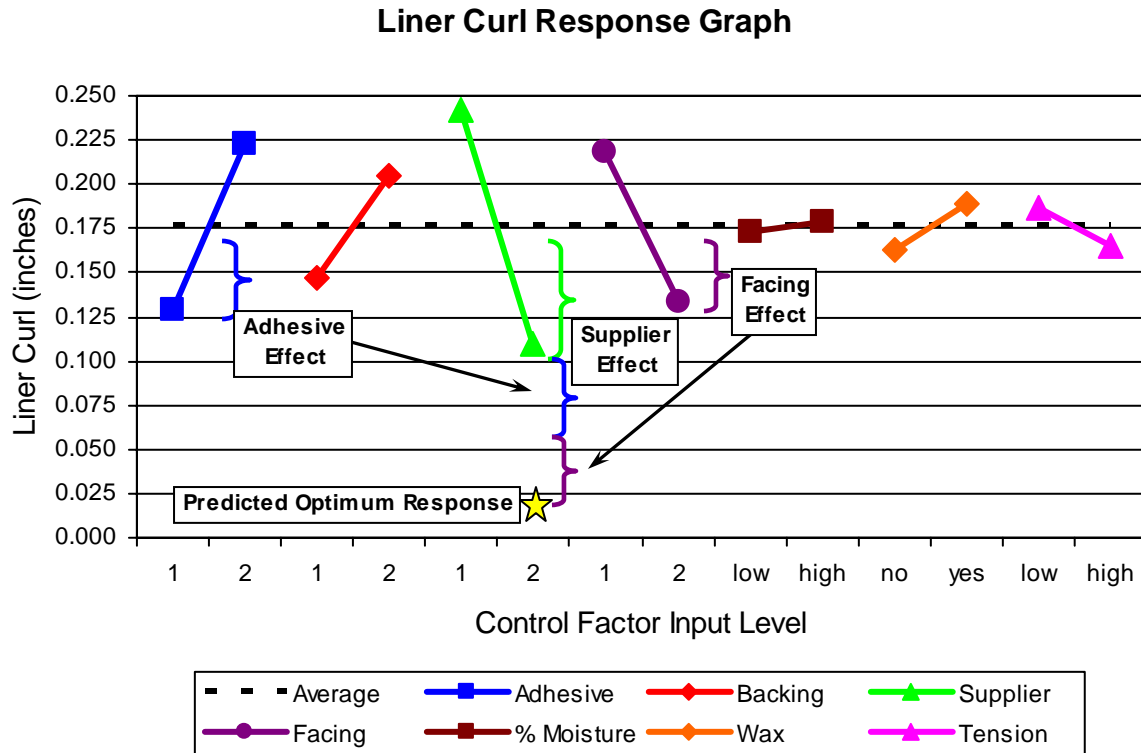


A visual scan of the response graph indicated the most significant inputs were factor C (supplier), factor A (adhesive), factor D (facing), and possibly factor B (backing). The red circles on the graph illustrate the desired factors and levels needed to minimize the magnitude of liner curl.

Interestingly, the three items/factors related to the long-held beliefs about liner curl (moisture, waxing to prevent moisture absorption, and laminator tension) demonstrated no significant influence on the magnitude of the average curl response. This is a pattern that is frequently seen in process optimization efforts – the inputs that the manufacturer believes are controlling a process often do not matter. (Think about it, if the manufacturer had identified the correct factors, they would not have had a problem with the process!)

In this instance, the manufacturer was trying to minimize liner tension, adding wax to the pulp backing to inhibit moisture absorption, and trying to control the storage conditions of the rolls of pulp prior to manufacturing. All were unnecessary and added additional costs to their manufacturing process.

The purpose of the designed experiment was to identify and isolate the contributions of each input to the overall amount of liner curl. These contributions were plotted on the response graph, and if valid, they would be independent of every other factor in the experiment. This “independence” is illustrated below.



If the inputs that effect liner curl were truly independent of one another, they would each contribute to the reduction or increase of liner curl separately, and they would be additive. The supplier effect, for instance, tended to reduce the average liner curl by approximately 0.066 inches, and would reduce the curl amount from the plotted average of 0.176 inches to a value of 0.110 inches. The adhesive effect was 0.047 inches, and the facing effect was 0.043 inches. The predicted liner curl resulted from all three factors and was found by adding all of their individual effects (or subtracting, in this case) from the observed experimental average.

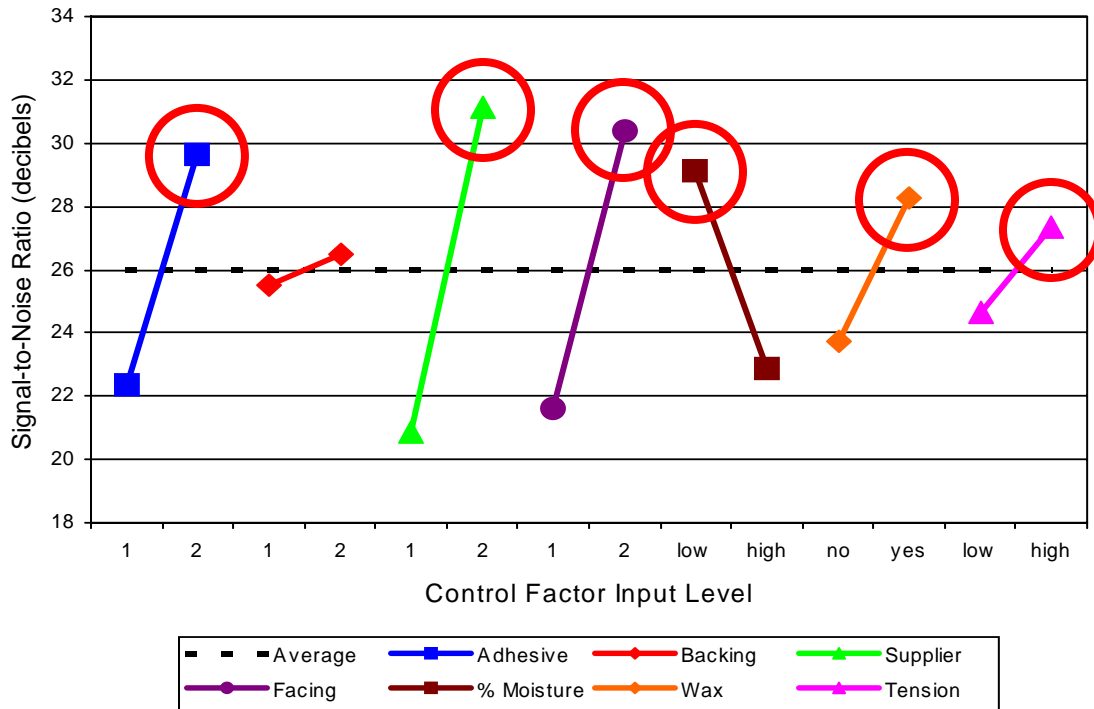
$$Ave_{pred} \approx 0.176 - 0.066 - 0.047 - 0.043$$

$$Ave_{pred} \approx 0.020 \text{ inches}$$

The normal production settings for this process coincided with the input levels of Trial 7 in this experiment, and the historical average was 0.388 inches.

The graph below plotted the signal-to-noise ratio (calculations not shown), or SNR, for each factor level of the inputs evaluated. The SNR is a measure of the average process variability. Variation is minimized when the SNR is high. The higher SNR's represented the preferred settings to minimize the variability of the liner curl.

**Liner Curl Signal-to-Noise Ratio**



A visual scan of the signal-to-noise ratio response graph indicated factor B (backing type) was the least significant control factor with respect to variation in the liner curl response. The other inputs all produced a significant effect on variation. Even factor G, which seemed to graph as a small effect relative to A, C, D, E, and F, caused an average change in the SNR response of 2.7 decibels. For output characteristics such as liner curl, every 3 decibel increase in SNR corresponds to a 50% reduction in the variance ( $\sigma^2$ ) of the response.

As with the previous graph, the red circles indicated which input levels were chosen to optimize this process. In this instance, these selections would tend to minimize the variability of the process output, i.e., liner curl. When both graphs were examined concurrently, however, a conflict was evident. Adhesive at level 1, for instance, minimized measured liner curl, but adhesive a level 2 minimized variation. This conflict, and manufacturing cost, were addressed by tabulating the results in the table shown on the following page.

Process Input Levels								
Response Category	Goal	Adhesive	Backing	Supplier	Facing	Moisture	Wax	Tension
Average	0	1	-	2	2	-	-	-
Variation	↓	2	-	2	2	low	yes	high
Cost	↓	-	1	1	1	high	no	low
Optimized Response		1	1	2	2	high	no	low

The table above indicated the three aspects of the process output that were considered in the optimization effort: average liner curl (targeting), the variability of the resulting liner curl (the standard deviation of the process), and the manufacturing cost of the liner. In this case, these three considerations were not assigned equal weight. The customer return rate of \$2,000,000 per year was deemed to have resulted largely from the average amount of liner curl in the process. For this manufacturer, the \$2MM price tag made the “Average” row the primary consideration, with “Variation” and “Cost” carrying roughly an equal amount of weight as secondary considerations.

The three factors and levels that were most significant in minimizing the “Average” (adhesive, supplier, and facing) were selected for the “Optimized Response” setting. Of these, two (supplier and facing) also tended to minimize variability in the process output. The remaining four factors (backing, moisture, wax, and tension) were all selected at levels to minimize the product’s manufacturing cost.

The manufacturer, having selected the desired levels for the inputs, predicted the signal-to-noise ratio of the optimized process by examining the effect that each factor had on the process when it was run at the selected levels:

$$\begin{aligned}
 SNR_{pred} &\approx Ave + Adhesive_{eff} + Supplier_{eff} + Facing_{eff} + Moisture_{eff} + Wax_{eff} + Tension_{eff} \\
 SNR_{pred} &\approx 26.00 + (22.35 - 26.00) + (31.12 - 26.00) + (30.41 - 26.00) \\
 &\quad + (22.90 - 26.00) + (23.76 - 26.00) + (24.66 - 26.00) \\
 SNR_{pred} &\approx 26.00 - 3.65 + 5.12 + 4.41 - 3.10 - 2.24 - 1.34 \\
 SNR_{pred} &\approx 25.20 \text{ decibels}
 \end{aligned}$$

To verify the accuracy of the predicted average and signal-to-noise ratio for the optimized process, the manufacturer ran one additional trial to confirm the validity of the experimental results.

Confirmation Trial Results	Run 1	Run 2	Run 3	Run 4	Average Response	S-N Ratio (dB)
	0.014	0.152	-0.016	0.068	0.055	22.65

The confirmation run was successful, that is, it confirmed the validity of the experimental results. The confidence limits about the predicted result had been calculated, and the confirmation run average response of 0.055 inches fell within those bounds. The confirmation run result was dramatically different than the normal production average of 0.388 inches. In addition, the signal-to-noise ratio of 22.65 dB from the confirmation run was higher than the normal production SNR of 18.40 dB, denoting less variability of the result.

After the completion of this experiment, the standard operating procedures for the manufacturing process were established to run at the “optimized” settings. This provided better targeting, reduced variation, and minimum manufacturing costs for the optimized process. After implementation, customer returns for this defect category, which were occurring at a rate of \$2,000,000/year, ceased to exist.

## Additional Comments

The manufacturer could have chosen other levels to run the process at, which would have resulted in even less variability of the process output. For instance, the results from Trial 6 indicate the process would produce an average response of 0.106 inches with a signal-to-noise ratio of 42.71 decibels. This would have been a much more consistent process, but it would have required the manufacturer to select process settings that would have increased product cost.

The “optimization” settings actually chosen allowed the manufacture of product at lower cost and eliminated customer returns. Customers would not have perceived any additional value had the product been manufactured at the levels from Trial 6, since their only concern was that the liners stay in the caps.

Designed experimentation sometimes reveals an option for minimal variation that exceeds a customer’s expectations. This level of performance only has value if it is visible and valuable to the customer. When it is not visible or valuable, the best choice is to make a product that meets the customer’s expectations at minimal cost.