Designed Experiments Contribute to 5% Printing Cost and 40% Setup Time Savings

A large printing company tasked a Lean Six Sigma project team with finding a way to reduce setup time and costs in a department consisting of 33 Kluge presses. Traditionally, operators set up a printing job by conducting a series of informal experiments on the press. The project team decided to explore a more scientific experimentation process using the design of experiments (DOE) method. “The experimental results led to a reduction of 5% in printing costs by moving to a less expensive foil for that job,” said Reed Wahlberg, an independent consultant and advisor to the project team. “More importantly, increased process knowledge from the DOE combined with other improvements has led to a 40% reduction in setup time over the last two years.”

Move to a more scientific method

In the past, operators would try various settings of pressure, temperature, and print speed until they were able to produce samples that were subjectively judged to be appropriate. Many combinations were often required in order to find one that worked. The average setup time across all of the company’s presses was 113 minutes per job in the year prior to the project. This added up to over 4000 hours of labor per year, equivalent to two full-time positions.

The project team felt that understanding the relevant importance of process factors and determining optimal targets for key factors would enable the operators to complete their setups more quickly. The team decided to increase knowledge about the setup process using designed experiments (DOE). They planned and executed experiments for a print job that was of large financial significance to the organization and one that was also typical of many other jobs so that insights gained from this experiment might benefit other jobs.

A “good” versus “bad” evaluation against unstated criteria was the traditional method used by setup people in evaluating a sample print to decide whether the machine was properly configured. This type of measurement system is not ideal in a designed experiment. Attributes (pass/fail) data convey less information about process performance than variables data. Much larger sample sizes are needed to reach statistical significance when attributes data must be used. Also, the unstated criteria would likely lead to significant noise in the measurement system making it hard to discern the signal from the experimental trials.

The project team proposed building a measurement system to evaluate printing quality. A manager of the printing company developed an objective measurement system that uses a Likert rating scale from 1 to 5 to rate print samples in four quality characteristics, each representing a different potential problem. These characteristics included bottoming out die, cutting through, spotting and foil marks.

Five product samples were purposely created to demonstrate each of the five levels of ratings in each quality characteristic. Prints generated during the experiment could be visually compared to the samples in each quality characteristic in order to accurately assign a rating. A Gage Repeatability and Reproducibility (R&R) study was conducted to verify the functionality of the new measurement system. Gage R&R is a statistical tool used to measure the amount of variation in a measurement system arising from the measurement device and the people taking the measurement. The samples were provided to various operators without any identification. The operators were asked to rate the samples. The study verified the functionality of the new measurement system.

Screening study

A screening experiment using Design-Expert® software from Stat-Ease, Inc. (Minneapolis, Minnesota) was designed with these objectives:

1) Determine which factors play a statistically significant role in setting up the print job to produce a defect-free sample. Significant factors would be studied in more detail in follow-up experiments.
2) Settle a long-term organizational dispute about the need to use a higher-quality and more expensive raw material.

The team chose Design-Expert due to its user friendliness and its strong analysis tools. “An additional strength of Design-Expert is the unbeatable support offered by the Stat-Ease team when problems are encountered or help is needed during the DOE process,” Wahlberg added.

The team decided to a conduct a full-factorial experiment which involves running every combination of factors at two levels. The four factors in this experiment could be studied in 16 runs. Fractional-factorial experiments usually provide adequate results in screening experiments. But in this case it was quick and easy to run additional trials so the extra statistical power of a full-factorial experiment could be obtained at little additional cost.

The screening study had four factors:

a) Foil type (standard quality vs. a higher quality, more expensive type)
b) Temperature (low temperature 250°F vs. high temperature at 300°F)
c) Pressure (low pressure with platen distance from chase to counter die of 1/16" vs. high pressure using a die cut platen with a distance of 1/8")
d) Press speed (slow at 5 cranks from baseline vs. fast at 25 cranks from baseline)

The four responses to be measured were:

a) Bottoming out die
b) Cutting through
c) Spotting
d) Foil marks

All four of the response models were statistically significant with p-values well below the typical .05 threshold. A sample of the ANOVA analysis for one of the response variables is shown below.

Response	1	Bottoming out die				
ANOVA for selected factorial model						
Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Model	28.44444	1	28.44	139.18	< 0.0001	significant
C-Pressu	28.44444	1	28.44	139.18	< 0.0001	
Residual	2.861111	14	0.20			
Cor Total	31.30556	15				

Figure 1: ANOVA results for bottoming out die in screening study

The models for two of the responses, bottoming out die and spotting, proved to have a very high statistical significance with R-Squared values above 90%. R-Squared, also called the coefficient of determination, is the proportion of variability in the data that is accounted for by the statistical model. The R-Squared value for cutting through was 39% and for foil marks it was 26%. Pressure was the dominant factor in the models for three of the four responses: bottoming out die, cutting through and spotting. In the model for foil marks, pressure and press speed were both important.

The screening experiment answered the question about the need to use the expensive foil. Foil was statistically insignificant in all four models meaning that the cheaper foil worked as well as the expensive one. This was exciting news as using the cheaper foil would be a source of significant savings.

Response surface study

A response surface study (CCD) was conducted to confirm results from the screening experiment and to check for non-linear effects. The study focused on the same factors used in the screening study minus foil type. Factor levels were adjusted slightly. Even though temperature had not proved statistically significant in the screening experiment, wisdom of the organization suggested that temperature was still an important factor. It was therefore included again in the experiment. The experiment consisted of 20 runs including several replicates in order to more accurately assess experimental error. The foil marks response was also eliminated.

All three of the models proved to be very statistically significant. The R-Squared was 86% for bottoming out die, 62% for cutting through and 83% for spotting. The models for bottoming out and spotting contained quadratic terms while the cutting through model proved to be linear. Lack of fit was insignificant in all three models. The analysis showed that pressure was again far and away the most significant factor. Optimal results were achieved at a fairly high pressure. Temperature and speed had less significance which was also very useful information. Running at higher speeds increases productivity and the study showed that this did not have a major negative impact on quality.

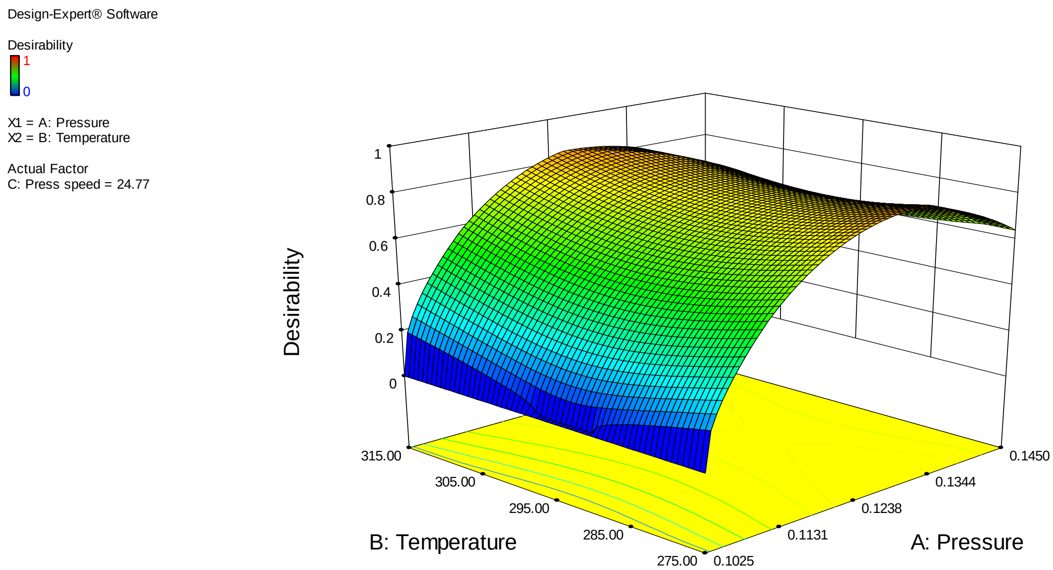

Figure 2: 3-D plot shows overall desirability achieved across various settings of pressure and temperature.

The response surface analysis showed once again that pressure was far and away the most important factor studied with optimal results achieved at fairly high pressure. Temperature and speed had less significance. These were desirable results for a number of reasons. Running at higher speeds increases productivity. Flexibility in temperature means that less time needs to be spent waiting for the press to reach very specific temperatures.

The perturbation plot below conveys information about factor control in press setup in graphical form by showing how the response changes for each one alone while holding all others constant. It shows that pressure, Factor A, is the variable that must be closely controlled. The steep slope for pressure suggests that small changes in the pressure level have dramatic impact on overall desirability. The slope of the plots for temperature and press speed (factors B and C respectively) is more horizontal suggesting that changes in level have less significant impact on overall desirability.

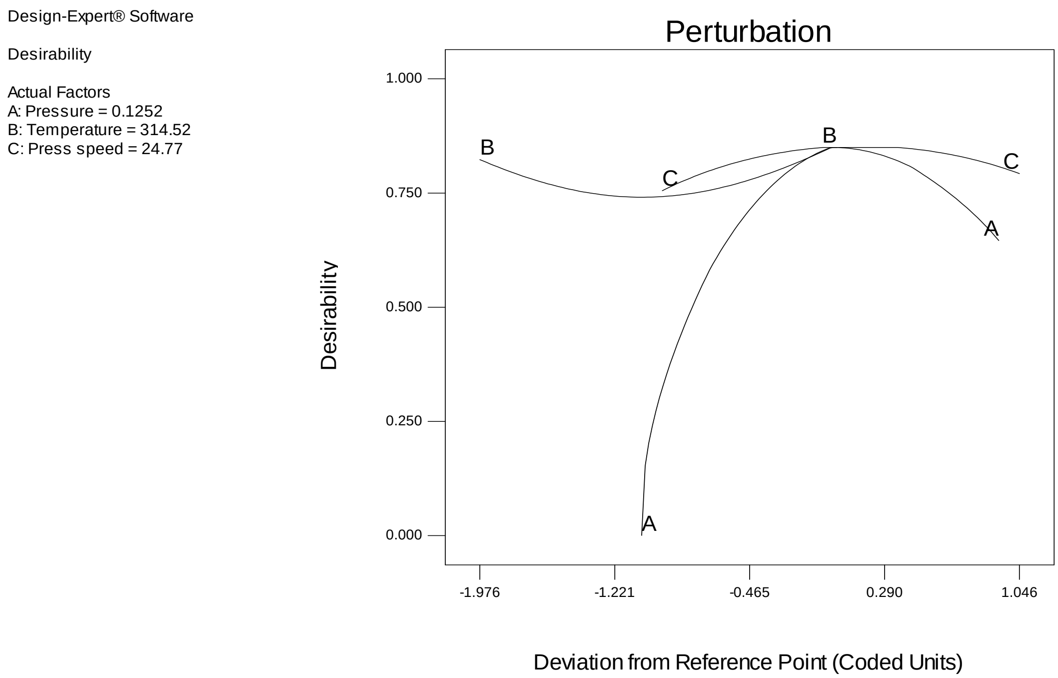

Figure 3: Perturbation plot

The strong statistical significance of pressure shown throughout all of the experimentation supported a significant investment decision that was being evaluated by the organization. The company was considering the purchase of an adjustable impression device that changes pressure by shortening or lengthening the side arms. The importance of pressure adjustment revealed by the experiments helped tip the scales in the decision-making process. The understanding of the sensitivities provided by DOE and the use of the new device were key factors in reducing average setup times by 40% to about 70 minutes per job.

“Our team felt very good about the results achieved in our DOE studies. The experiments were easy to conduct and provided useful insights into how to improve the setup process. Hopefully, our results show how DOE can be a useful tool for process improvement across the printing industry,” noted Wahlberg.

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