Applying DOE to Microwave Popcorn

Design of experiments identifies which factors matter and which ones don't, as well as helping find optimal settings.

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Cook it hot enough, not too long, and a little bit off the floor of the oven. And preheating the oven by heating a glass of water for 1 min. has no effect. Don't even bother.

Those were the conclusions we made from applying the design of experiments (DOE) technique to the problem of preparing microwave popcorn. The study was conducted at home, using a common microwave oven designed for the consumer market. Since the study examined something with which everyone has some experience, it provides a good example for understanding how to apply DOE in adjusting process industry recipes.

In particular, cooking microwave popcorn demonstrated how DOE helps apply the Pareto principle. In other words, it helps to identify what Juran calls the vital few factors from among the trivial many.

Table 1: Factors and Levels

Factor	Low (-)	High (+)
Price	Generic	Brand
Time	4 min.	6 min.
Power	Medium	High
Preheat	No	Yes
Elevate	No	Yes

Independent variables

To begin, a brainstorming session was held to identify all possible factors that could be studied as independent variables. For this study, five major factors were selected from a broader range of ideas. The five factors were brand, cooking time, microwave oven temperature, preheat time, and tray elevation.

The idea for the study grew out of the last two factors. A quick study of microwave popcorn instructions at the local supermarket showed that all packages pretty much say the same thing. The instructions advise that the consumer perform a range-finding operation, cooking the popcorn pouch for 2-5 min. on a high setting until the rate of popping subsides to an interval of about one pop every three seconds.

Two unusual instructions caught our attention. One involved having the microwave bag resting on a microwave-safe rack at about the center of the chamber, as opposed to resting on the floor of the oven. The second involved the pre-heating step. One of these unusual factors did influence the results, the other didn't.

Our study was designed around a two-level factorial model. Some of the factors were by their nature discrete and binary; others were continuous. All variables had only two values. To limit the continuous variables, range-finding trials were conducted to set low and high levels for each of the experiments.

During some of the range-finding runs, the popcorn was seriously over-

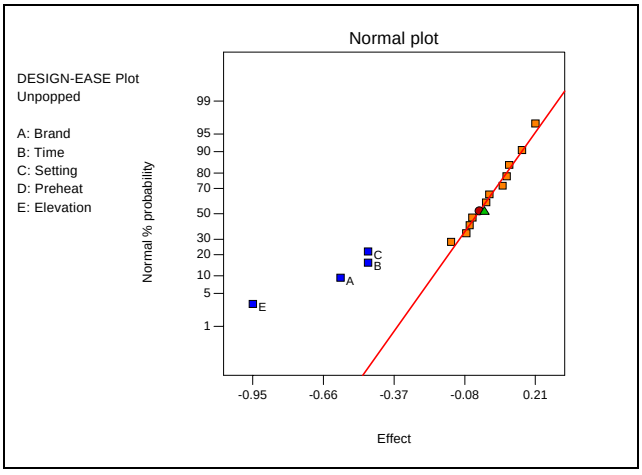

Figure 1: Analysis of unpopped kernels

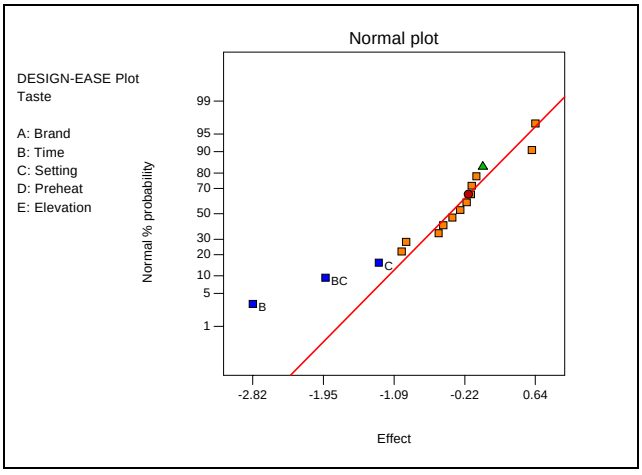

Figure 2: Analysis of taste

cooked. A kitchen filled with smoke, we found, was a small price to pay for the education gained.

The brand factor was selected based on the central intent of the study, to determine if there is a strong correlation between the quality of the finished product and the price of the package on the grocery store shelf. The brands tested were selected to contrast a nationally distributed big-name brand against a local grocery store (generic) brand of microwave popcorn. The national brand was purchased at $1.79 per package, the generic brand for $1.25 per package. (A complete listing of the two-level factors can be found in Table 1.)

Most of these factors should be familiar to the reader. The preheating variable may be unusual to some, so let us explain it in more detail. It was in fact a part of what initially raised our curiosity.

The instructions on one package of popcorn that we had tried suggested that using a preheating step could increase the yield of the cooking process. If the occurrence of corn that remains unpopped (we call these *bullets*) is high, the instructions suggested, the yield can be increased by operating the oven with a glass of water inside for a period of one minute.

Our question was, does this preheating step—which also would raise the humidity inside the oven—really help? We shall see.

A statistically desirable array of combinations of the low and high levels was built, for a total of 16 runs, half the total number (32) of combinations possible. Such a fractional factorial design is sufficient to learn all we needed to know about popping popcorn. In fact, making more runs would not add to our know-ledge. It is not necessary to run all 32 combinations to study the interactions between factors. The runs were randomized to protect the study against lurking variables—such as changes in the environment—that could otherwise confound the study. To simplify the administration of such a study, we used a Design-Ease® software for design of experiments. It handled randomizing the samples and the statistical analysis.

Table 2 shows the standard ("Std") array for five factors and 16 experiments. It also shows the run order and observed responses. To estimate pure error, two repeat runs were planned. These extra experiments were meant to be run at mid-level (coded as zero) of the time factor, with the other factors fixed at low (-) or high (+). However, the runs were not executed as planned. Also, one run in the standard array was botched and another one was missed. The software accommodated these accidental variations, and they had no impact on the results.

Response analysis

To measure the effects of the variable factors in each run, three response factors were considered. First the unpopped kernels (bullets) were weighed and the weight recorded. Likewise, burnt popcorn was collected from each sample run and weighed. However, this response turned out to be unreliable.

The third response - taste -was subjective, but finding people willing to serve on a judging panel was not difficult in this case. Taste evaluations were recorded using a scale from 1-10, with 10 being high or good. Observed values ranged from 1.0 to 9.0.

Observations from the 18 runs were then entered in the Design-Ease package. The software calculated the effect each independent variable and combination of variables had on the responses.

What yield told us…

The software automatically produced a graph, called the normal plot of effects, that helped isolate the factors that were key to determining the yield - the percentage of unpopped bullets. Figures 1 and 2 show the main effects and two-factor interactions for the two measurable responses. The trivial many factors, which had no influence, fall on a straight line near the zero effect level.

One of these factors was the preheating step (D). Preheating thus had no impact the responses. This is an important outcome because it means we don't have to wait an extra minute for the popcorn.

Table 3: Array of factors and responses

Std	Run	A	B	C	D	E	Bullets	Taste
1	12	-1	-1	-1	-1	1	1.5	7.5
2	9	1	-1	-1	-1	-1	1.4	8.0
3	6	-1	1	-1	-1	-1	1.9	9.0
4	18	1	1	-1	-1	1	0.6	6.5
5	1	-1	-1	1	-1	-1	1.8	7.0
6	14	1	-1	1	-1	1	0.3	7.5
7	7	-1	1	1	-1	1	0.2	2.5
8	5	1	1	1	-1	-1	0.9	1.0
9	17	-1	-1	-1	1	-1	1.7	7.0
10	15	1	-1	-1	1	1	0.8	6.0
11	3	-1	1	-1	1	1	0.6	4.5
12	16	1	1	-1	1	-1	0.9	4.0
13	4	-1	-1	1	1	1	0.6	9.0
14	13	1	-1	1	1	-1	1.3	7.5
15	NA	-1	1	1	1	-1	Missing	---------
16	NA	1	1	1	1	1	Missing	---------
x	2	-1	-1	-1	1	-1	3.2	8.5
x	8	1	0	1	1	1	0.1	4.0
x	11	1	0	1	-1	-1	0.8	5.0
x	10	-1	0	1	1	-1	1.6	5.5

The four remaining factors (brand, time, temperature, and elevation) significantly affected the bullets (see Figure 1). Residual analysis by Design-Ease revealed the possibility that run 2 was an outlier for bullets. This experiment produced an unusually low amount of popcorn, but since no special cause could be attributed to this, and it did not greatly affect the findings, it's included in the results.

Figure 2 shows the normal plot of effects for the taste response. It reveals a highly significant interaction between time (B) and power (C). The biggest effect comes from the time alone, but its impact depends on the level of power. As the interaction plot in Figure 3 shows, when the time was limited to its low (-) level of 4 minutes, the predicted taste responses were roughly equal, around 7.5. (The points fall within the 95 % confidence "least significant difference" bars displayed by the software.) With time set at its high (+) level of 6 minutes, however, the taste response varies significantly depending on other factors

- in this case, the temperature or setting of the microwave oven. When set on high, enough of the popcorn burned to pull the taste response value down to under 2. Set on medium-high, taste response dropped some-what less to around 6.

With this information, we feel - that preheating the microwave oven is a waste of time. On the other hand, elevating the pouch in the oven is a good idea. No matter how powerful your home oven is, cooking microwave popcorn at a high setting and for a shorter rather than a longer time probably produces a tastier result.

The results also suggest that a name brand performs better than a generic one, although our tests covered only the two brands. Clearly, more investigation is called for before changing one's brand preference.

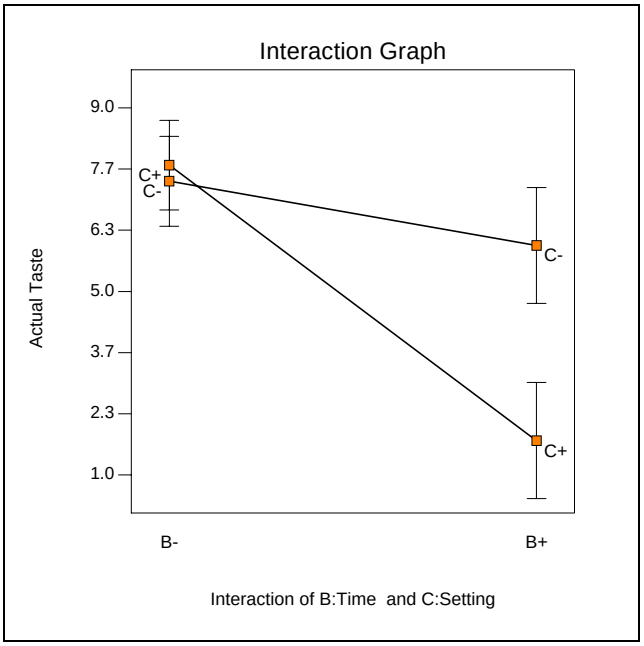

Figure 3: Interaction of time vs heat on taste

As a result of this study, however, we were able to reduce the presence of bullets or unpopped kernels by 80 percent, a significant gain in yield.

In addition to possibly making home movie or sports viewing more enjoyable, this study was intended as a learning opportunity for all participants. When talking about process improvement, this is the kind of analysis that has to be done to make breakthrough changes. Looking at one factor at a time in a traditional approach will not work. DOE provides the tools to uncover special causes.

Follow-up Study Reveals More Secrets for Making Popcorn

Our DOE on microwave popcorn unintentionally turned out to be a destructive test. The heat and smoke generated at the upper limits of time and power degraded the chamber to a point where we decided it might be best to get a new machine. We purchased a more powerful and sophisticated microwave that included a pre-programmed setting for popcorn. Not content to leave things be, we did a follow-up factorial at plus and minus times around the factory setting (factor C), and two additional factors: prechilling the bag (A), and putting it on a wind-up carousel (B). We did all the combinations plus 4 centerpoints on time for a total of 8 runs.

We thought the carousel (factor B) would distribute the microwaves more evenly, but as can be seen in Figure 4, it caused a significant increase in bullets, perhaps because it absorbs energy. Increasing the time caused a small but significant reduction in bullets. However, this was counteracted by a reduction in taste (see Figure 5). Prechilling did not significantly impact either the bullets or the taste, so it's unnecessary. As a result of this study, we decided to use the factory setting for popcorn and no carousel.

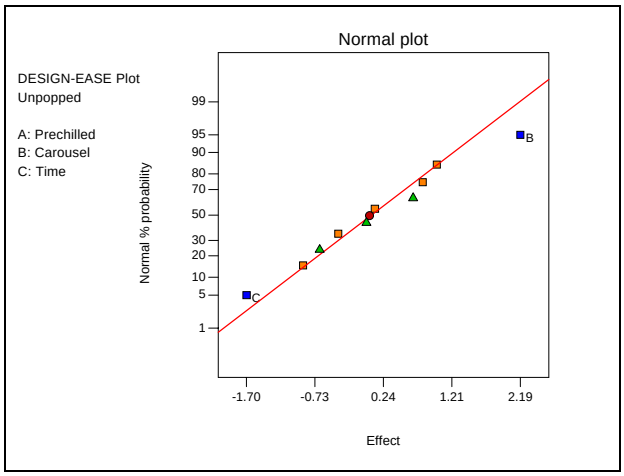

Figure 4: Follow-up DOE – Effects on Bullets

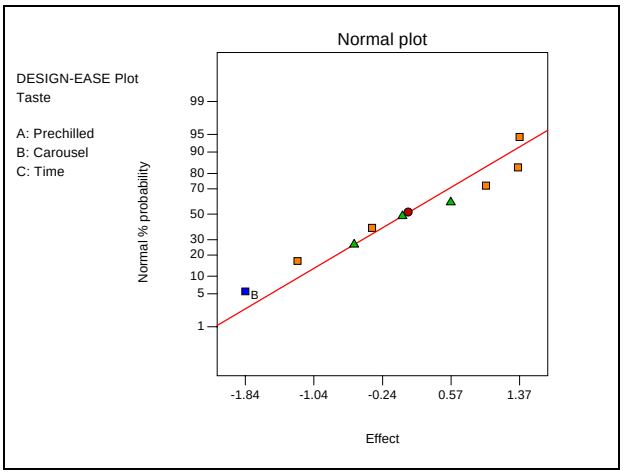

Figure 5: Follow-up DOE – Effects on Taste

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