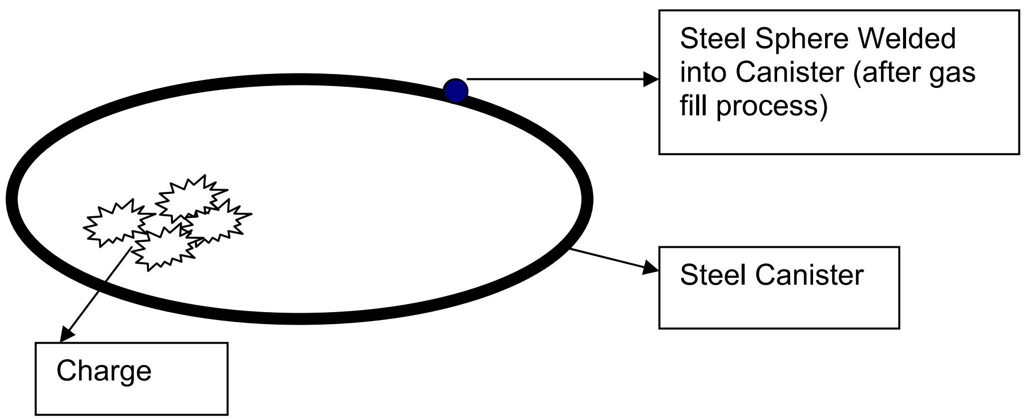
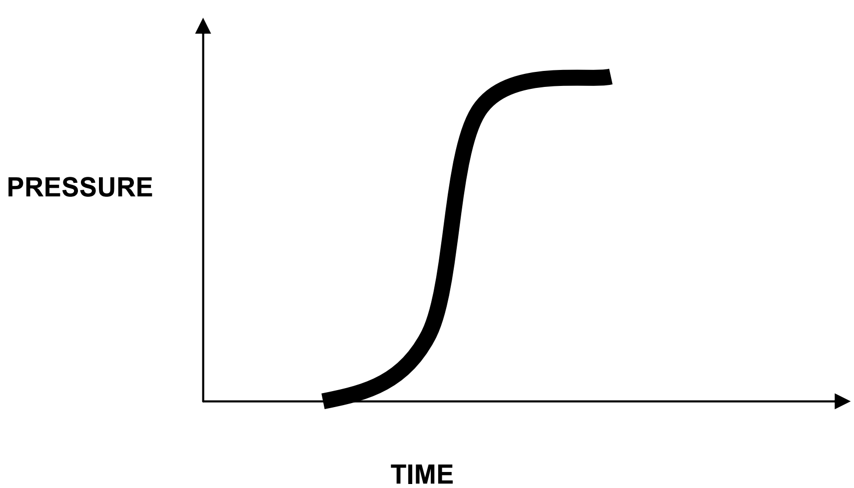
Note: This article is from the text "Engineering Today's Designed Experiments"
Why use an orthogonal array to orchestrate collection of data, rather than just conducting a series of trials? Historically, many scientists and engineers have not used an orthogonal array to orchestrate their investigation process. One popular approach is what we call the "educated guess approach". In what follows, the educated guess approach is used on a hypothetical research problem. Next, we will contrast the educated guess approach with an orthogonal array approach and compare the relative merits of the two approaches.

Suppose our task is to characterize a new engineering concept pertaining to the deployment of an automotive airbag system (see for example www.vectorscientific.com). The sub-system consists of a steel canister filled with gas and charge. After the canister is filled, the orifice is closed (with a steel sphere welded in place). Our development team believes the key variables of interest are orifice diameter, gas weight, propellant weight and type of charge. A rough sketch of the system is:



Fortunately, our customer is crystal clear in what they want. It is a pressure/time profile as shown in the following graphic.



The important characteristic, from the eyes of our customer, is the above time/pressure curve. Suppose we decide to rate the effectiveness of a design solution by selecting three points on the cure: Time to reading any pressure, maximum pressure delivered, and time to achieve 90 percent of the maximum pressure.

For maximum pressure, the requirement is 120, plus or minus 10. For time to first pressure, less than 3 is acceptable, but less than 2 is ideal. Time to 90 percent of maximum pressure has a requirement of 9, plus or minus 1.0.

The team has good (but partial) knowledge of the technology from their understanding of science. Specifically they believe:

1. For the response maximum pressure (Max p) there is a proportion relationship between propellant weight (Prop wt) and gas weight (Gas wt).
2. For time to 90 percent of maximum inflation (T90) there is an inverse relationship between orifice diameter (Orifice) and propellant weight.
3. For time to first pressure (First pre) there is an inverse relationship between orifice diameter and propellant weight.

(The team is unable to reach a consensus on the other possible relationships)

After some discussion and approximate calculations the team decides to conduct the following six trials:

Run	**Orifice**	**Type**	**Gas wt**	**Prop wt**	**T90**	**Max p**	**First pre**
1	.086	A	12.8	.9	10.0	105	2.8
2	.086	B	12.8	.9	11.1	106	3.7
3	.086	A	12.0	.9	9.8	103	2.8
4	.086	B	12.0	.9	10.6	103	3.6
5	.086	A	12.8	.85	10.3	100	3.1
6	.086	B	12.8	.85	11.5	101	3.6

Of the above 6 runs, runs 1 and 3 look best. For run 1, “T90” is barely in specification, “Max p” is definitely low, and “First pre” is on the slow side. Run 3 shows some promise, but after further discussions with purchasing, it is decided Type A makes better sense from a business standpoint. From this it is decided to use Run 1 as a baseline for further tests. Propellant weight is increased to 1.2 while gas weight in varied. The team deliberates and decides to conduct the following two runs:

Run	**Orifice**	**Type**	**Gas wt**	**Prop wt**	**T90**	**Max p**	**First pre**
7	.086	A	12.8	1.2	8.2	138	1.2
8	.086	A	12.0	1.2	8.3	137	1.5

Analysis of these two runs indicates we are operating too fast (T90) and the maximum pressure is high. Because of this, the team decides to reduce the propellant weight to 1.1 while retrying the above two runs. The results obtained are:

Run	Orifice	Type	Gas wt	Prop wt	T90	Max p	First pre
9	.086	A	12.8	1.1	8.4	125	1.8
10	.086	A	12.0	1.1	8.2	125	1.9

Runs 9 and 10 are better at matching the established criteria. Unfortunately, the maximum pressure is still above nominal while the time to first pressure has slowed somewhat, but is still in the acceptable zone, while time to 90 percent maximum pressure is just below nominal.

The team reconvenes and decides to try increasing the orifice diameter to help solve the problems with the last two runs. Three more trials were completed. They are:

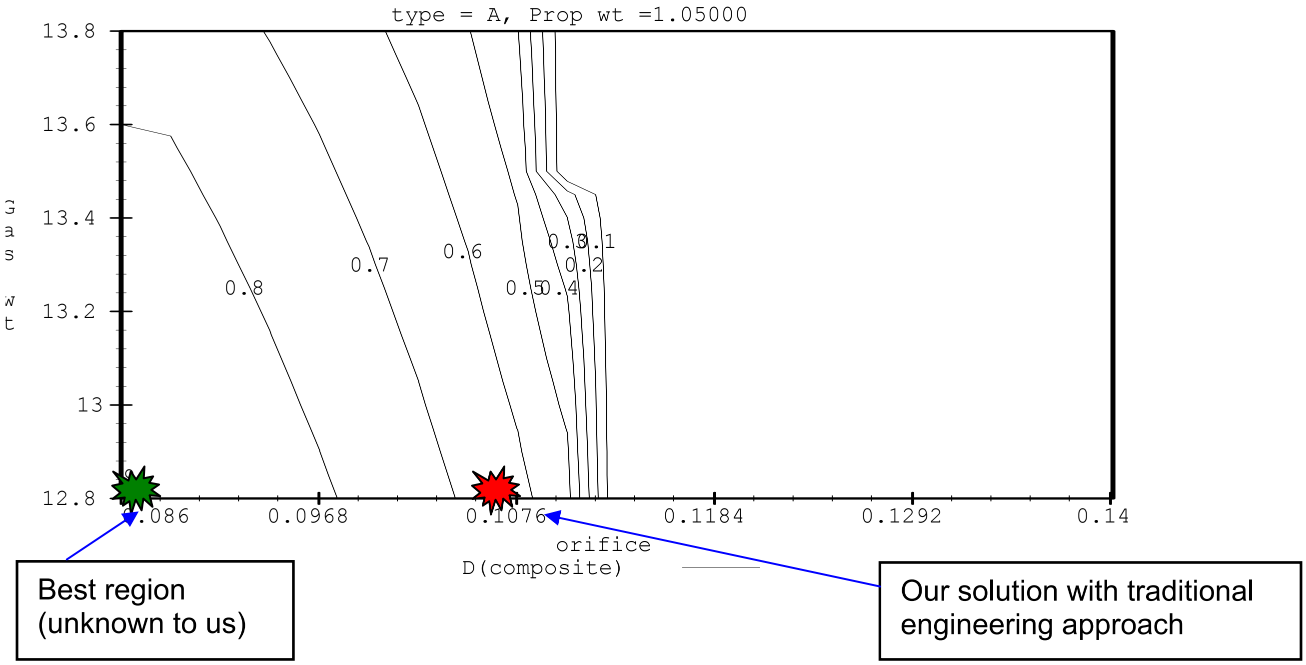
Run	Orifice	Type	Gas wt	Prop wt	T90	Max p	First pre
11	.106	A	12.0	1.1	8.6	127	1.9
12	.126	A	12.0	1.1	7.5	129	1.7
13	.146	A	12.0	1.1	7.0	133	1.6

Run 11 is the best of the three latest runs. After another team meeting, it is decided to work from run 11 (with increased gas weight) while reducing the propellant weight. We decide to conduct four additional trials. They are:

Run	Orifice	Type	Gas wt	Prop wt	T90	Max p	First pre
14	.106	A	12.8	1.05	8.6	123	1.9
15	.106	A	12.8	1.00	8.6	118	2.3
16	.106	A	12.8	.95	9.0	113	2.4
17	.106	A	12.8	.90	9.2	106	2.7

Since we have run out of time, as well as customer patience, and all of the responses are at least in the range of acceptability, the team declares run 14 a success and turns the initiative over to the Advanced Manufacturing Engineering group at the supplier site.

The optimal solution, unknown to us, is displayed in the following contour plot:



The graphic plots the relative benefit of all three responses simultaneously. This is a desirability plot, which will be covered in detail later. The Y-axis is a plot of gas weight. The X-axis is a plot of orifice diameter. The lines of contour represent the relative benefit of all three responses. Values closer to 1.0 are better, where a value of 1.0 indicates a perfect trade-off of the three responses. A value of 0.0 indicates at least one or more of the responses in question are in an unacceptable range. The above graphic suggests a perfect score of 1.0 was not possible. The best value is approximately .9 (in the lower left-hand corner).

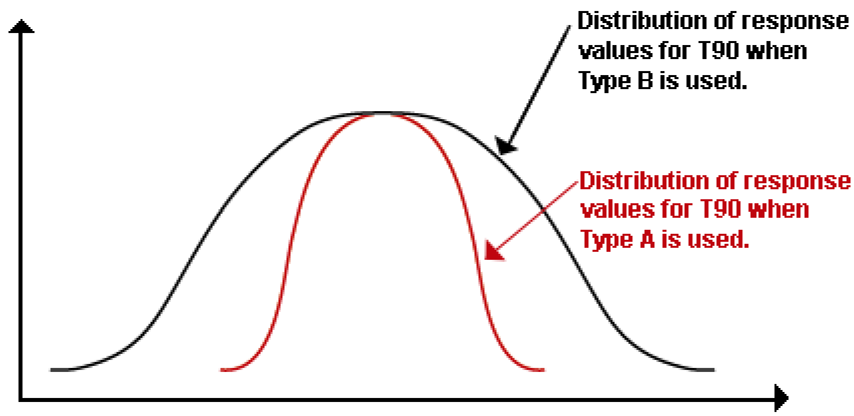
Unfortunately, big problems emerge when the client begins testing. Pilot testing indicates a number of failures at the customer site. From the experimental work that was previously completed, our tests indicated the following factor set points provided the best solution:

- ✓ Orifice = .106
- ✓ Type = A
- ✓ Gas wt = 12.8
- ✓ Prop wt = 1.05

This point is represented by the  in the above graphic. There are a number of short-comings associated with experiments of the above type. Some of these are:

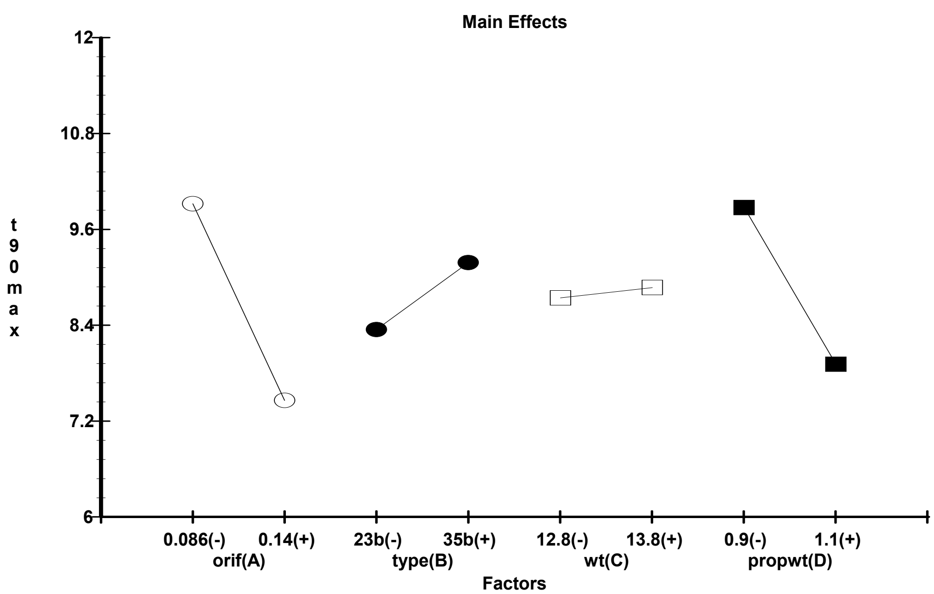
1. We did not reach the best set point for our factors so as to achieve optimal mean response values.
2. Since none of the trials were completed more than one time, there is no estimate of variation in any of the responses. As an example, suppose

propellant type has a great impact on variation in the response. Suppose, unbeknownst to the team, the real distributions for the response T90 (for each type) are:



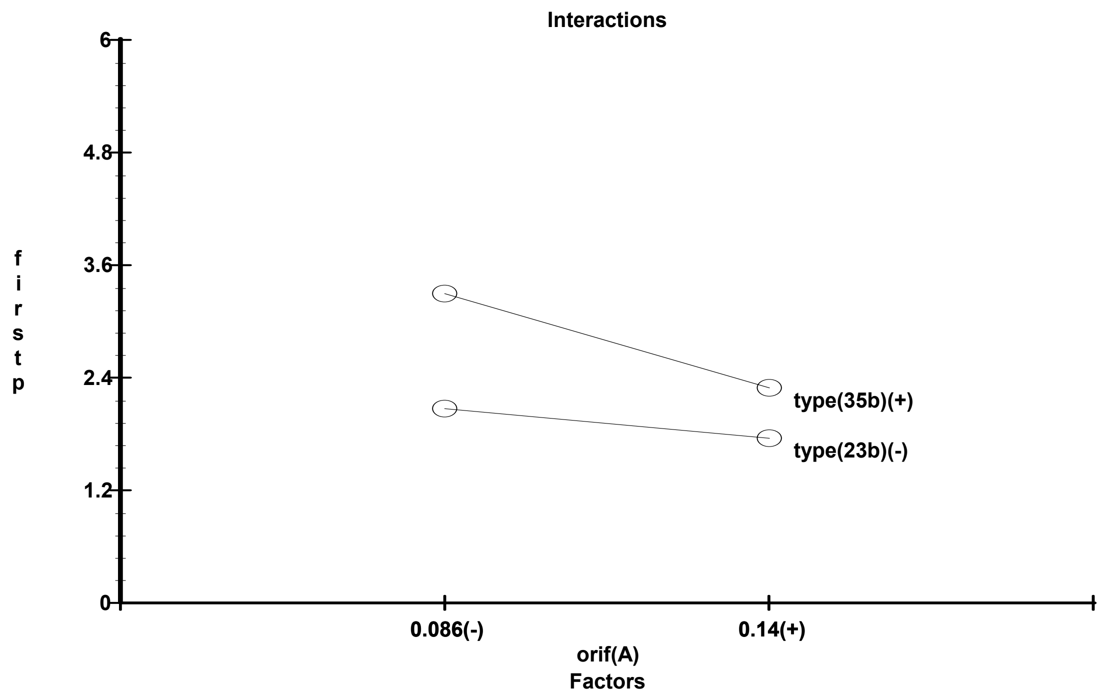
Using the above experimental strategy, we are unable to estimate the variation associated with the different factors associated with the responses. Using an experimental design approach, with an adequate number of replications, would allow us to estimate differences in the width of response distributions.

3. No simple estimate of the impact of each factor for each response is available. For example, using a designed experiment, the following graphic could have been obtained:



As shown in Chapter One (Engineering Today's Designed Experiments), the above simple graphic is very useful in making relative comparisons of the contribution of each factor.

4. Information has not been obtained regarding interactions between factors. Again, key interactions are best evaluated using a designed experiment with the correct number of runs. Particularly when attempting to characterize technologies, this information can be of great benefit.



5. The testing did little to enhance our understanding of the technology. The above experimental approach only helped us to confirm/refute our qualitative knowledge of the technology. Effective use of experimental design techniques helps us quantify relationships between factors and responses while allowing us to quickly further our knowledge of the technology. Experimental design is a powerful tool in allowing us to dramatically enhance the efficiency and effectiveness of our experimentation.

Bibliography

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