MAKE LOVE, NOT WAR: COMBINING DOE AND TAGUCHI

SUMMARY

There is a tendency in the Quality World to compare methods in order to determine what method is the best. A typical example is the debate between ISO 9000 and TQM advocates. Even in more technical areas like Design Of Experiments (DOE) there is this debate, in particular between advocates and opponents of Taguchi Methods. In this article we will show that it is more interesting to combine and integrate the positive elements and ideas from classical DOE and Taguchi Methods, than to treat them as opponents. Some examples are given of how the combined use has lead to better process control, more robust and predictable processes and cost reduction.

KEY WORDS

Design Of Experiments, Taguchi Methods.

INTRODUCTION

The debate between advocates of classical DOE and of Taguchi methods is an old one and has filled many pages, in books and magazines. In some instances it is inspiring and interesting, but in many cases it is a debate in favor of or against Taguchi Methods. This results in either not admitting certain weaknesses or not acknowledging specific strengths and never looking for integration of methods and ideas.

When talking to potential customers about DOE training, I am often asked the question: “Should we go for classical DOE or for Taguchi Methods?”, more or less implying that it has to be the one <u>or</u> the other. My standard reply to this question is that combined knowledge and use of classical DOE and Taguchi methods will give them the best results, in other words one <u>and</u> the other.

When talking about “Classical DOE” I am looking at full factorial and fractional factorial designs at two or three levels and even Response Surface Methods for second order model building. These are the designs that are widely used and that are often compared to Taguchi Orthogonal Arrays. But designs are only part of the story, there are many ideas that can be used with both types of designs.

STRENGTHS TO BE COMBINED

Let us first look at the positive sides and at those ideas and methods that can be combined to give optimum results.

The big advantage of classical DOE is the transparency of the designs and in the case of fractional factorial designs the ability to use a stepwise approach in problem solving or process study. After a first fractional factorial we know exactly what we do not know (thanks to the well defined confounding patterns) and that is a major advantage! By adding the proper fraction to the originally selected fraction ambiguities on effects of interactions can be eliminated. This is the well known “de-aliasing”. For more info we refer to Box, Hunter and Hunter, 1978.

Another important strength of classical DOE is the potential to build models and to gradually increase the complexity of the models if this is needed. Again some fine examples of this have been described in Box, Hunter and Hunter, 1978.

Major strengths of Taguchi Methods are the following:

- Simple and very flexible designs, that also allow the use of various levels. By using dummy treatments and sliding levels even more flexibility is obtained. A dummy treatment is performed at a level that is just a repetition of another level. In this way in a design with three levels a factor at two levels can be included. When using a sliding level we determine the values of the levels of a factor in relation to the levels of another factor. In a two level analysis of a mechanical device we could have a length and a width of a component as factors to be examined. Working with absolute values may lead to impossible combinations or forms. A sliding level for the width could be : LOW= 20% of length, HIGH = 40% of length. In absolute values the width would have 4 values in the design, but NARROW versus WIDE could still be examined. This is also a way to avoid interactions (American Supplier Institute, 1992).
- The idea of robustness is obviously a major contribution of Taguchi. It involves two simple elements:
  - Do not only analyze the mean of a characteristic, but look at the variation too. This means that you always have to introduce repetitions.
  - Do not just repeat tests to get an idea of variation, but do this repetition under different conditions of so called noise factors. In this way you will see at what factor settings a process is

the most robust against changing conditions, changes that may also be expected to occur in normal production conditions.

- The importance of the choice of a good output characteristic. This is one of Taguchi's answers to the criticism that his highly fractionated designs do not allow analysis of interactions. If we choose a characteristic that is additive in nature (energy is a good example), we do not have to worry about interactions.
- The high emphasis on cost, combining the language of engineering (deviations from target value) with the language of management (money) in the loss function (Barker, 1989). This also focuses our attention to looking carefully at those factors that have no effect on a system, because it are these factors that can make money for us!

WEAKNESSES TO BE AVOIDED

In accordance with several other authors (Lochner and Matar 1990, Wheeler 1990) we do not recommend the use of only Signal to Noise ratios (S/N) for analyzing an experiment, certainly not in Smaller-the-better and Larger-the-better situations. Separate analysis of signal mean and logarithm of standard deviation is preferred.

As for classical DOE, we want to warn against the tendency of always trying to generate models and preferably very complex ones, even if they have little practical value. We have seen many companies start with DOE, but not being able to get it integrated in the business, mainly because it is perceived as too complex. This is very often due to the fact that too much emphasis is placed on the statistical analysis. When starting off with DOE, try to look at relatively simple problems with a limited amount of factors, but with practical value, so that people see that the technique can help them on the factory floor. The use of DOE is still too much limited to laboratory and research.

POSSIBLE WAYS OF COMBINING CLASSICAL DOE WITH TAGUCHI THINKING

There are several ways in which combinations of classical DOE and Taguchi Methods could be combined. A very important one is to always think very carefully about a good output characteristic, no matter what type of designs you will be using. This is specifically true in cases where the output is measured in terms of number of defects or defective units. As long as there are a lot of defects, this can work but once you have reached low defect levels it becomes very difficult to keep using this characteristic for further improvements. The ideas of dummy treatments and sliding levels are also applicable in classical designs.

A good combination is the use of classical designs but with an emphasis on robustness, performing repetitions under various levels of noise factors as proposed by Taguchi. The idea of robustness is universally applicable and is independent of the designs used. In addition you have the advantage of the transparency of classical designs and the possibility of de-aliasing.

When looking to built prediction models, you could first use Taguchi Methods to determine a working space with high robustness, and then use classical designs in this area to generate a model of high stability.

These are just a few examples of possible combinations. In the following paragraph, we will give some practical, real live examples of how this combination of ideas can work.

TWO PRACTICAL EXAMPLES

1. Modeling a paint process

To study a car body paint process we use a so called paintbrush: we spray a plate and afterwards measure the paint distribution on the plate. This was explained in more detail in Vandenbrande, 1998 and is illustrated in figure 1. It is very important to spray with the correct width so that the surface that has to be painted is covered and overspray is avoided. Overspray results in loss of expensive paint and can lead to quality problems on other parts of the car body.

Because the process is automated (painted with robots) we can program the entire paint cycle and simulate it on computer. By developing a mathematical model that predicts the width of the paint pattern in function of parameter settings we can determine optimum parameter settings for the required width up front, which can save a lot of run in time. When introducing a new or modified car model this can be a major advantage.

In order to make this model stable and more universal (applicable for different colors) we started off with a search for a working area that leads to widths that are least influenced by different disturbances. This is a typical Taguchi study, with 4 factors (type of spraygun, paint flow, fan air flow and atomising air flow) at three levels. This leads to an L9 inner array. For the noise factors we combined three factors (color, input air pressure and paint viscosity) at 2 levels in an L4 outer array.

The design and test results are given in figure 2. For reasons of secrecy the levels have only been indicated with 1,2 and 3 and not with the real parameter values. As our main concern here is to avoid variation, even under strongly different conditions in the repetitions (looking for robustness), our main interest lies in the analysis of the standard deviation of the four repetitions. The result is graphically presented in figure 3.

Out of this test the following conclusions were drawn:

- When using spraygun 3, more variation in width is obtained. We therefore decided not to use this gun for subsequent testing. As the difference between spraygun 1 and 2 is minimal, the most cost effective of the two was retained (in this case spraygun 1).
- The atomising air has the biggest influence on the stability of the width, with higher atomising air being the preferred setting.

As a result of this test we decided to work with spraygun 1 and in the high atomising air range to determine a mathematical model for the width. Because of other quality requirements a high atomising air must be connected with somewhat higher fan air. With the paint flow the width can than be regulated. In this way we determined the test window for the development of the mathematical model. In absolute values this test window is far from symmetrical. The settings for atomising air cover a narrow range around a high value, for fan air a somewhat larger range around a high value and for paintflow a wide range over an average setting is used.

We used a full factorial design with four centerpoints added to determine pure error and to check if a linear model was good enough. The design and the results are given in figure 4. Out of these results a model could be calculated to predict the pattern width in function of paint flow, fan air and atomising air. The model proved to be a linear one, with a high correlation coëfficiënt (R-Squared adj 0.98). Because it is located in an area of high stability it is robust to certain process disturbances. It has proven to be valid with sufficient accuracy for various colors of similar rheology.

2. **Increasing the strength of a butyl tape to metal glued connection**

In this example we look at a glued connection between a butyl rubber paint and a metal surface. The connection comes loose in a limited number of cases, but this always leads to a customer complaint. As happens so often in cases like this the present method of working is the result of several one at a time experiments. As a response characteristics the number of rubbers that came loose was used but this is a number that is always low. No statistical tests of significance were performed and the test results interpretation came down to impressions and feelings. All in all it has led to a very expensive process that includes pre-heating of the rubber tape, polishing of the metal and wet cleaning of the metal surface before applying the tape. A special tooling is used to press the rubber tape on the metal.

As part of a DOE training program a group of trainees from the assembly department decided to investigate this process using DOE techniques. The first problem they were faced with was the selection of an appropriate output characteristic. It became immediately clear that analyzing the number of loose coming rubbers would require a very high amount of repetitions and would lead to a very expensive test. In stead they decided to measure the strength of the connection, by developing a special tool that allowed them to pull the rubber from the metal and measure the required force to do so. The logic is simple: the chance that a rubber that requires a high force to be pulled off the metal comes loose, is small.

In a first experiment they used a simple fractional factorial design shown in figure 5. The results are given in figure 6. The conclusions are staggering: all cost adding elements of the process prove to be insignificant or (even worse) to have a negative effect on the strength of the connection! Removing the pre-polishing and the wet cleaning would result in a yearly saving of approximately 25.000 $. The pre-heating of the tapes was beneficial to the operator because it made the positioning of the tape easier, so there was no need to change this, although it had no positive effect on strength.

When these results were presented to production they were met with some disbelieve, because they more or less indicated that previous measures were at best no improvement and in some cases a significant disadvantage. Production people pointed out that certain disturbances could cause problems and that polishing and cleaning helped to overcome these disturbances. This obviously leads to typical tests for robustness, so it was decided to do a new test with slightly modified factors (a change in the tooling design allows a separate setting of applied force and application time of the force, pre-heating is standard and no longer part of the design, the supplier offered a new type of tape that is included in the test) but with repetitions that include the process disturbances mentioned by production. The inner array is a 2^{5-2} fractional factorial, the outer array is an L4 which combines three noise factors. To simulate the effect of sunshine high energy spots will be used. This kind of simulation is often needed to produce the noise levels we want. The test design is given in figure 7. At this point in time these tests have not yet been performed, but this example shows a combination of classical and Taguchi designs in the opposite order as in our first example.

CONCLUSION

There is no reason why there should be such debate between classical DOE and Taguchi Methods. In fact, overall in the Quality World, it would be a great improvement if more energy was spent in looking for synergies and added value of various methods, rather than trying to prove that approach A is superior to approach B. All contributions have value, lets use these positive elements and not become fundamentalists!

ILLUSTRATIONS

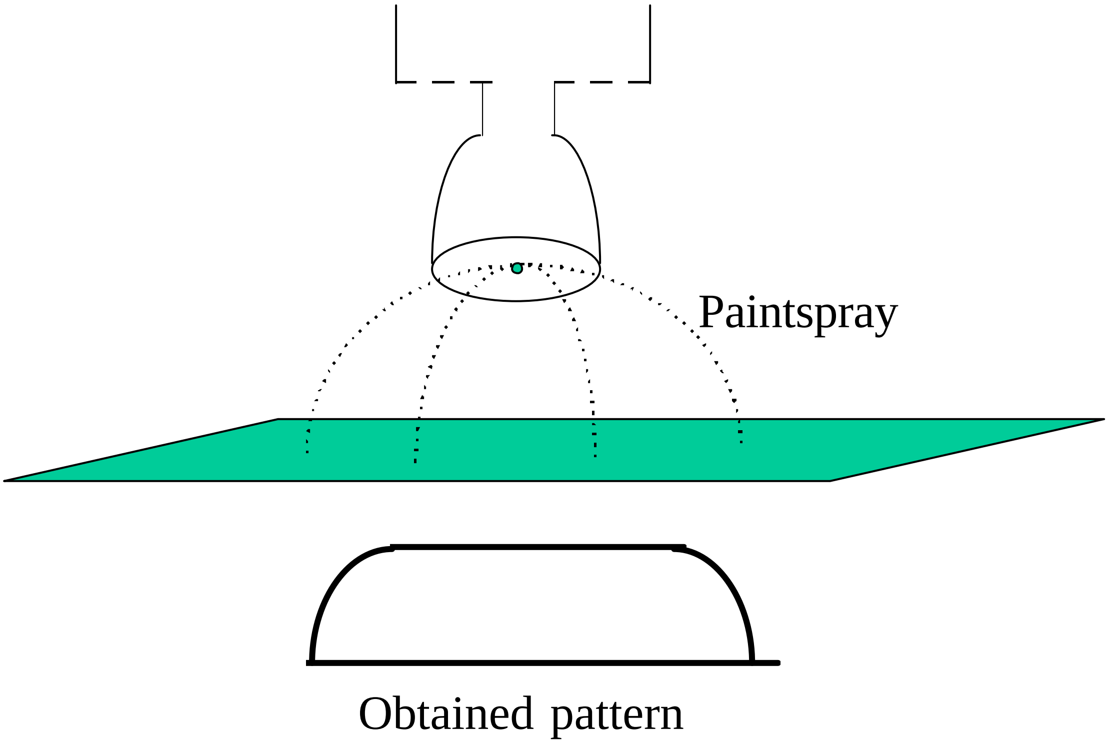

Figure 1: Schematic presentation of the paintbrush.

CONTROL FACTORS (Inner array)				NOISE FACTORS (OUTER ARRAY)				
Spraygun	Paintflow	Fan air	Atomising	1 1 1	2 2 1	2 1 2	1 2 2	Color Inlet air pressure Paint viscosity
1	2	2	2	43,2	42,4	36,9	42,1	
1	3	3	3	44	44,7	46,5	44	
1	1	1	1	36	40,4	31,8	35,1	
2	1	2	3	24,6	27,4	23,5	23,8	
2	2	3	1	46,2	41,7	42,1	50,7	
2	3	1	2	42	39	42,1	41	
3	1	3	2	49,8	32	42,5	48,5	
3	2	1	3	32,8	33,9	36,1	35,1	
3	3	2	1	46,2	43	28,2	46,8	

Figure 2: Design and test results robust area for the width (cm) of the paint pattern

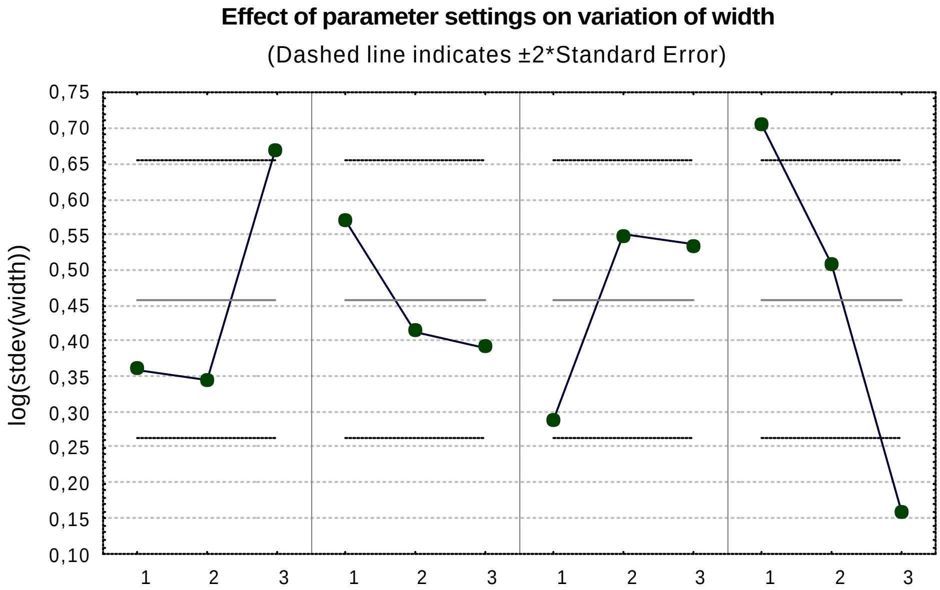

Figure 3: effect of parameter settings on variation in width

Paint Flow	Fan Air	Atomising	Width
-1	-1	-1	46.8
-1	-1	1	63.2
-1	1	-1	35.4
-1	1	1	45.0
1	-1	-1	50.2
1	-1	1	66.6
1	1	-1	37.2
1	1	1	50.8
0	0	0	48.8
0	0	0	49.6
0	0	0	49.2
0	0	0	49.0

Figure 4: Test design and results for determining the model of pattern width

Pre-heating	Pressure	Polishing	Cleaning method	Force
YES	HIGH	YES	WET	107.8
YES	LOW	YES	WET	101.6
NO	HIGH	NO	WET	100.3
NO	LOW	NO	WET	51.3
NO	HIGH	YES	DRY	100.8
NO	LOW	YES	DRY	114.5
YES	HIGH	NO	DRY	102.3
YES	LOW	NO	DRY	82.6
YES	HIGH	YES	WET	92.6
YES	LOW	YES	WET	78.3
NO	HIGH	NO	WET	87.5
NO	LOW	NO	WET	56.5
NO	HIGH	YES	DRY	133.7
NO	LOW	YES	DRY	89.4
YES	HIGH	NO	DRY	80.8
YES	LOW	NO	DRY	63.2

Figure 5: 2^{4-1} one time replicated design for studying strength of rubber – metal glued connection.

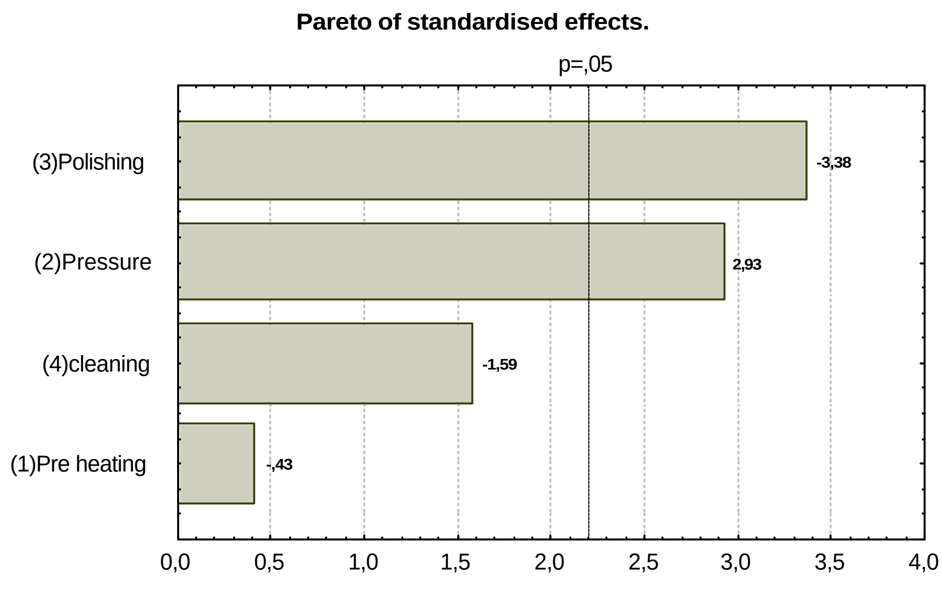

Figure 6: Effect of factors on strength of connection. The negative value for polishing shows that polishing results in lower strength. The same goes for wet cleaning (less significant). Increased tool pressure has a positive effect.

CONTROL FACTORS (Inner array)					NOISE FACTORS (OUTER ARRAY)				
Pressure	Time	Cleaning	Polishing	Type of tape	1 1 1	2 2 1	2 1 2	1 2 2	Metal cleanliness Production shift Outside temperature
LOW	SHORT	DRY	YES	NEW					
LOW	SHORT	WET	YES	OLD					
LOW	LONG	DRY	NO	NEW					
LOW	LONG	WET	NO	OLD					
HIGH	SHORT	DRY	NO	OLD					
HIGH	SHORT	WET	NO	NEW					
HIGH	LONG	DRY	YES	OLD					
HIGH	LONG	WET	YES	NEW					

Figure 7: Design to study the robustness of the rubber – metal connecting process

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