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Research Paper

Design of Experiment Methodologies

Engineering

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ABSTRACT

When a product is to be designed or modified or to be optimized there are number of factors which affect the performance of the product. Design Of Experiments (DOE) is a tool for determining the significance of the different variables affecting the process quality and calculating optimal configuration for controlling factors. Around 1920 Sir Ronald Fisher started research related to Design Of Experiments (DOE). Since then lots of research work is done in this field and so many methodologies are developed. From these methodologies some famous methodologies are Factorial Method, Taguchi Method, and Response Surface Methodology which are explained in this paper.

INTRODUCTION

Design Of Experiments (DOE) is a tool for determining the significance of the different variables affecting the process quality and calculating optimal configuration for controlling factors. DOE provides effective and efficient procedure for planning experiments. The fundamentals of the DOE method are Replication, Local control (Blocking) and randomization. Where first two increases the precision in the experiment , the last one is used to decreases bias.

Replication is the repetition of the experiments under investigation to different experimental units. Replication may require repetition of entire experiment or some part of the experiment. Replication is important in two aspects (1) It allows the experimenter to obtain an estimate of the experimental error (2) It permits the experimenter to obtain a more precise estimate of the factor/interaction effect.

Local control(Blocking) is a method of eliminating effect of extraneous variation due to noise. By reducing the noise factors it increases the efficiency of the experimental design.

Randomization is one of the methods experimenters often depends on to reduce the effect of experimental bias. By properly randomizing the experiment, the effects of noise factors that may be present in the process can be averaged out. In other words, randomization can ensure that all levels of a factor have an equal chance of being affected by noise factors. [1-6].

METHODOLOGY FOR DOE [1, 2]

Some researchers divide the methodology of DOE into four phases while some divides into seven phases. The four phase methodology is as under

1. Planning phase
2. Designing phase
3. Conducting phase and
4. Analysing phase.

Planning phase

The planning phase is made up of the following steps.

Problem definition- A clear and sufficient statement of the problem can create a better understanding of what needs to be done. The statement should contain a specific and measurable objective that can yield practical value.

Selection of response or quality characteristic- The selection of a suitable response for the experiment is critical to the success of any industrial designed experiment. The response can be variable or attribute in nature. Experimenters should define the measurement system prior to performing the experiment in order to understand what to measure, where to measure, who is doing the measurements, etc.

Selection of process variables or design parameters- Some possible ways to identify potential process variables are the use of engineering knowledge of the process, historical data, cause-and-effect analysis and brainstorming.

Classification of process variables-

Having identified the process variables, the next step is to classify them into controllable and uncontrollable variables. Controllable variables are those which can be controlled by a process engineer/production engineer in a production environment. Uncontrollable variables (or noise variables) are those which are difficult to control or expensive to control in actual production environments.

Determining the levels of process variables- A level is the value that a process variable holds in an experiment. The number of levels depends on the nature of the process variable to be studied for the experiment and whether or not the chosen process variable is qualitative or quantitative.

List all the interactions of interest-

Interaction among variables is quite common in industrial experiments. In order to effectively interpret the results of the experiment, it is highly desirable to have a good understanding of interaction between two process variables. The best way to relate to interaction is to view as an effect, just like a factor or process variable effect

Designing phase

In this phase, one may select the most appropriate design for the experiment. Experiments can be statistically designed using classical approach advocated by Sir Ronald Fisher, orthogonal array approach advocated by Dr Genichi Taguchi or variables search approach promoted by Dr Dorian Shainin. The size of the experiment is dependent on the number of factors and/or interactions to be studied, the number of levels of each factor, budget and resources allocated for carrying out the experiment, etc. During the design stage, it is quite important to consider the confounding structure and resolution of the design. It is good practice to have the design matrix ready for the team prior to executing the experiment. The design matrix generally reveals all the settings of factors at different levels and the order of running a particular experiment.

Conducting phase

This is the phase in which the planned experiment is carried out and the results are evaluated. Several considerations are recog-

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nized as being recommended prior to executing an experiment, such as:

- Selection of suitable location for carrying out the experiment.
- Availability of materials/parts, operators, machines, etc. required for carrying out the experiment.
- Assessment of the viability of an action in monetary terms by utilising cost– benefit analysis.

Analysing phase
The next phase is to analyse and interpret the results so that valid and sound conclusions can be derived. In DOE, the following are the possible objectives to be achieved from this phase:

- Determine the design parameters or process variables that affect the mean process performance.
- Determine whether further improvement is possible.

DOE methods
Various DOE methods are follows.
- Factorial design.
- Response surface methodology.
- Taguchi method.
- Random Experiment method.

FACTORIAL DESIGN[7,8]
Factors are experimental factors or independent variables for which an investigator is interested to measure their effect on output.

a full factorial experiment is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. A full factorial design may also be called a fully crossed design. Such an experiment allows the investigator to study the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable.

2k is the simplest method in factorial design. When experiment investigate several factors (say K) and it is necessary to study the joint effect of these factors on specific response then 2k method is used. In this method each of the factors is set to two levels High and Low. Table-1 shows all possible experiments to be run to understand the effect of K factors on the output.

Table -1
Experiments for 2k design

Factors(K)	Experiments
2	4
3	8
4	16
5	32
6	64
7	128
8	256
9	512
10	1024

If there are two variables say A and B then they combines in following ways

Table-2
Experiments for two factors

Run	Factor A	Factor B	Response
1	high	high	Y_1
2	Low	high	Y_2
3	High	low	Y_3
4	low	low	Y_4

The effect of the two variables on output is measured by following equation

$$\text{Effect of A} = \frac{(Y_1 + Y_3)}{2} - \frac{(Y_2 + Y_4)}{2}$$

$$\text{Effect of B} = \frac{(Y_1 + Y_2)}{2} - \frac{(Y_3 + Y_4)}{2}$$

RESPONSE SURFACE METHODODLOGY (RSM)
RSM is well known approach for optimization of the input parameters whether the model based on physical experiments or simulations. RSM is collection of mathematical and statistical techniques used for modeling and analysis of the problem in which objective function to be optimized is affected by the several variables.[9] These approximated model should be first checked and then go for optimization. The input parameters sometimes called independent variables and the objective function is response.

RSM is less expensive than traditional methods. With this method the objective function can be easily solved and considerable amount of time and computation can be saved. RSM problems have a functional relation between response and independent variables. The relation between the response and the independent variables is explained in the form of polynomial[10,11].

$$\eta = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i} \sum_{j} \beta_{ij} X_i X_j + \varepsilon$$

Where, η is the measure of the response, β_0 is constant , β_i , β_{ii} and β_{ij} represents the coefficient of linear, quadratic and cross product terms, respectively. X denotes the coded variable.
The basic approach of the RSM is to use regression method based on least square method. The method of the least square is typically used to measure the regression coefficient.

TAGUCHI METHOD[12-15]
Taguchi method of parametric optimization was introduced by Dr. Genichi Taguchi (1980). This method is an important tool for robust design and powerful and efficient technique for DOE. It can improve process performance by minimum number of experiment. It reduces rework cost, manufacturing cost. Taguchi method finds optimum values of the process parameters and thus finds the optimum manufacturing objective function. The application steps of the taguchi method are as follows.

Brainstorming This is a necessary first step in any application. The session should include individuals with first-hand knowledge of the project. The main things to be decide in this step is to identify all influencing factors and those to be included in the study. To determine the factor levels ,noise factor and the condition of repetitions.

Designing experiments Using the factors and levels determined in the brainstorming session, the experiments now can be designed and the method of carrying them out established. The main tasks of this step are to select the appropriate orthogonal array. Assign factor and interaction to columns. Describe each trial condition. Decide order and repetition of trials.

Running experiment Run experiments in random order when possible.

Analysing results before analysis, the raw experimental data might have to be combined into an overall evaluation criterion. This is particularly true when there are multiple criteria of evaluation. Analysis is performed to determine the optimum design. Influence of individual factors. Performance at the optimum condition & confidence interval.

CONCLUSION
While designing or optimising any product with DOE methods,

it is very important to select proper method. For small number of variables with few levels full factorial method is good but when variable increases it becomes tedious. For variables 3-50 Taguchi method is proper. If variables are more than 50 then Random experiments will be easy.

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