# 1

# Introduction to industrial experimentation

## 1.1 Introduction

Experiments are performed today in many manufacturing organizations to increase our understanding and knowledge of various manufacturing processes. Experiments in manufacturing companies are often conducted in a series of trials or tests which produce quantifiable outcomes. For continuous improvement in product/process quality, it is fundamental to understand the process behaviour, the amount of variability and its impact on processes. In an engineering environment, experiments are often conducted to explore, estimate or confirm. Exploration refers to understanding the data from the process. Estimation refers to determining the effects of process variables or factors on the output performance characteristic. Confirmation implies verifying the predicted results obtained from the experiment.

In manufacturing processes, it is often of primary interest to explore the relationships between the key input process variables (or factors) and the output performance characteristics (or quality characteristics). For example, in a metal cutting operation, cutting speed, feed rate, type of coolant, depth of cut, etc. can be treated as input variables and surface finish of the finished part can be considered as an output performance characteristic.

One of the common approaches employed by many engineers today in manufacturing companies is One-Variable-At-a-Time (OVAT), where we vary one variable at a time keeping all other variables in the experiment fixed. This approach depends upon guesswork, luck, experience and intuition for its success. Moreover, this type of experimentation requires large resources to obtain a limited amount of information about the process. One Variable-At-a Time experiments often are unreliable, inefficient, time consuming and may yield false optimum condition for the process.

Statistical thinking and statistical methods play an important role in planning, conducting, analysing and interpreting data from engineering experiments. When several variables influence a certain characteristic of a product, the best strategy is then to design an experiment so that valid, reliable and sound conclusions can be drawn effectively, efficiently and economically.

In a designed experiment, the engineer often makes deliberate changes in the input variables (or factors) and then determines how the output functional performance varies accordingly. It is important to note that not all variables affect the performance in the same manner. Some may have strong influences on the output performance, some may have medium influences and some have no influence at all. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance in products.

Design of Experiments (DOE) was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agricultural Field Research Station in London, England. His initial experiments were concerned with determining the effect of various fertilizers on different plots of land. The final condition of the crop was not only dependent on the fertilizer but also on a number of other factors (such as underlying soil condition, moisture content of the soil, etc.) of each of the respective plots. Fisher used DOE which could differentiate the effect of fertilizer and the effect of other factors. Since then DOE has been widely accepted and applied in biological and agricultural fields. A number of successful applications of DOE have been reported by many US and European manufacturers over the last fifteen years or so. The potential applications of DOE in manufacturing processes include:

- improved process yield and stability
- improved profits and return on investment
- improved process capability
- reduced process variability and hence better product performance consistency
- reduced manufacturing costs
- reduced process design and development time
- heightened morale of engineers with success in chronic-problem solving
- increased understanding of the relationship between key process inputs and output(s)
- increased business profitability by reducing scrap rate, defect rate, rework, retest, etc.

Industrial experiments involves a sequence of activities:

1. *Hypothesis* – an assumption that motivates the experiment
2. *Experiment* – a series of tests conducted to investigate the hypothesis
3. *Analysis* – involves understanding the nature of data and performing statistical analysis of the data collected from the experiment
4. *Interpretation* – is about understanding the results of the experimental analysis
5. *Conclusion* – involves whether or not the originally set hypothesis is true or false. Very often more experiments are to be performed to test the hypothesis and sometimes we establish new hypothesis which requires more experiments

Consider a welding process where the primary concern of interest to engineers is the strength of the weld and the variation in the weld strength values. Through scientific experimentation, we can determine what factors mostly affect the mean weld strength and variation in weld strength. Through experimentation, one can also predict the weld strength under various conditions of key input welding machine parameters or factors (e.g. weld speed, voltage, welding time, weld position, etc.).

For the successful application of an industrial designed experiment, we generally require the following skills:

- *Planning skills* Understanding the significance of experimentation for a particular problem, time and budget required for the experiment, how many people are involved with the experimentation, establishing who is doing what, etc.
- *Statistical skills* Involve the statistical analysis of data obtained from the experiment, assignment of factors and interactions to various columns of the design matrix (or experimental layout), interpretation of results from the experiment for making sound and valid decisions for improvement, etc.
- *Teamwork skills* Involve understanding the objectives of the experiment and having a shared understanding of the experimental goals to be achieved, better communication among people with different skills and learning from one another, brainstorming of factors for the experiment by team members, etc.
- *Engineering skills* Determination of the number of levels of each factor, range at which each factor can be varied, determination of what to measure within the experiment, determination of capability of the measurement system in place, determination of what factors can be controlled and what cannot be controlled for the experiment, etc.

## 1.2 Some fundamental and practical issues in industrial experimentation

An engineer is interested in measuring the yield of a chemical process, which is influenced by two key process variables (or control factors). The engineer decides to perform an experiment to study the effects of these two variables on the process yield. The engineer uses an OVAT approach to experimentation. The first step is to keep the temperature constant ($T_1$) and vary the pressure from $P_1$ to $P_2$. The experiment is repeated twice and the results are illustrated in Table 1.1. The engineer conducts four experimental trials.

The next step is to keep the pressure constant ($P_1$) and vary the temperature from $T_1$to $T_2$. The results of the experiment are shown in Table 1.2.

The engineer has calculated the average yield values for only three combinations of temperature and pressure: $(T_1, P_1)$, $(T_1, P_2)$ and $(T_2, P_1)$.

**Table 1.1 The effects of varying pressure on process yield**

| Trial | Temperature | Pressure | Yield | Average yield (%) |
|---|---|---|---|---|
| 1 | $T_1$ | $P_1$ | 55, 57 | 56 |
| 2 | $T_2$ | $P_2$ | 63,65 | 64 |

**Table 1.2 The effects of varying pressure on process yield**

| Trial | Temperature | Pressure | Yield | Average yield (%) |
|---|---|---|---|---|
| 3 | $T_1$ | $P_1$ | 55, 57 | 56 |
| 4 | $T_2$ | $P_1$ | 60, 62 | 61 |

The engineer concludes from the experiment that the maximum yield of the process can be attained by corresponding to ($T_1, P_2$). The question then arises as to what should be the average yield corresponding to the combination ($T_2$, $P_2$)? The engineer was unable to study this combination as well as the interaction between temperature and pressure. Interaction between two factors exists when the effect of one factor on the response or output is different at different levels of the other factor. The difference in the average yield between the trials one and two provides an estimate of the effect of pressure. Similarly, the difference in the average yield between trials three and four provides an estimate of the effect of temperature. An effect of a factor is the change in the average response due to a change in the levels of a factor. The effect of pressure was estimated to be 8 per cent (i.e. $64 - 56$) when temperature was kept constant at '$T_1$'. There is no guarantee whatsoever that the effect of pressure will be the same when the conditions of temperature change. Similarly the effect of temperature was estimated to be 5 per cent (i.e. $61 - 56$) when pressure was kept constant at '$P_1$'. It is reasonable to say that we do not get the same effect of temperature when the conditions of pressure change. Therefore the OVAT approach to experimentation can be misleading and may lead to unsatisfactory experimental conclusions in real life situations. Moreover, the success of OVAT approach to experimentation relies on guesswork, luck, experience and intuition. This type of experimentation is inefficient in that it requires large resources to obtain a limited amount of information about the process. In order to obtain a reliable and predictable estimate of factor effects, it is important that we should vary the factors simultaneously at their respective levels. In the above example, the engineer should have varied the levels of temperature and pressure simultaneously to obtain reliable estimates of the effects of temperature and pressure. Experiments of this type will be the focus of the book.

## 1.3 Summary

This chapter illustrates the importance of experimentation in organizations and a sequence of activities to be taken into account while performing an industrial experiment. The chapter briefly illustrates the key skills required for the successful application of an industrial designed experiment. The fundamental problems associated with OVAT approach to experimentation are also demonstrated in the chapter with an example.

## Exercises

1. Why do we need to perform experiments in organizations?
2. What are the limitations of OVAT approach to experimentation?
3. What factors make an experiment successful in organizations?

## References

Antony, J. (1997). A Strategic Methodology for the Use of Advanced Statistical Quality Improvement Techniques, PhD Thesis, University of Portsmouth, UK.

Clements, R.B. (1995). *The Experimenter's Companion*. Wisconsin, USA, ASQC Quality Press.

Montgomery, D.C. et al. (1998). *Engineering Statistics*. USA John Wiley and Sons.