The Role of Statistics in Experimentation

We know that statistics is the science of problem-solving in the presence of data variability. It is a scientific discipline devoted to the drawing of valid inferences from experimental or observational data.

Figure 1 below symbolizes the fact that statistics should play a role in every facet of data collection and analysis, from initial problem formulation to the drawing of the final conclusions.

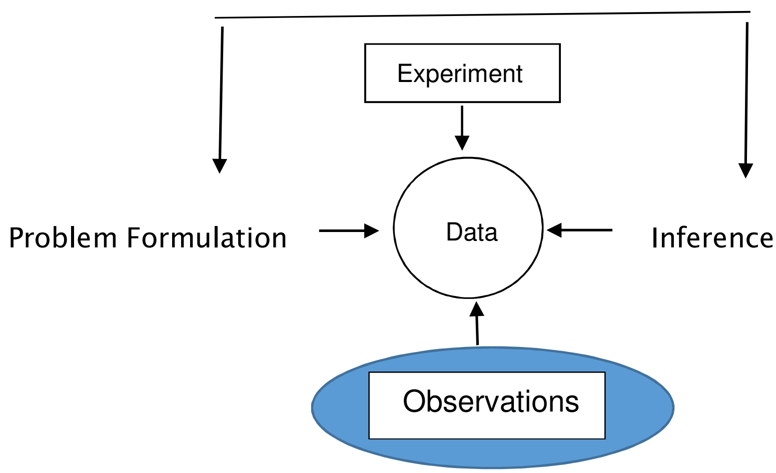

Fig 1 Critical stages of statistical input in scientific investigations

In experimental studies, many of the variables of interest (factors) can be controlled and fixed at pre-determined values for each test run in the experiment. But, all data are subject to a variety of sources that induce variation in the measurement process. This variation can occur due to:

- systematic difference among, say instruments or analysts,
- random differences due to changes in ambient conditions,
- measurement error in instrument electronic readings, or
- effects due to many other known or unknown influences.

A well planned statistical design of experiments (DOE) will be effective in:

- eliminating known sources of bias or systematic error,
- guarding against unknown sources of bias,
- ensuring that the experiment provides precise information about the responses of interest, and
- guaranteeing that excessive experimental resources are not needlessly wasted through the use of an uneconomical design.

When we wish to draw inferential conclusions about a process or a series of experiments, statistical data-analysis techniques can then help in clearly and concisely summarizing salient features of experimental data.

In most industrial processes or chemical analysis, there are numerous sources of possible variation. Frequent studies are conducted to study the causes of excessive variation. These studies could focus on a single source or simultaneously examine several sources. In chemical analysis, such variation can be due to:

a. different samples from a population
b. several analysts or laboratories carrying out the analysis
c. different test methods for same measurand (analyte)
d. conditions of reagents, temperatures, pressures, etc in a method validation process

Hence, an experiment can be statistically designed and analysed to ensure that relevant sources of variation could be identified and measured. The technique used to analyse the means from a designed experiment is called an analysis of variance (ANOVA). Variances of different sources are analysed to make inferences about the means of these sources.

The outcome of such experiment may reveal any systematic differences (biases) among the analysts, and in some instances, indicates the random inconsistency of the chemical analysis performed by a single analyst or laboratory. The quality of this data collection effort enables straightforward, unambiguous conclusions to be drawn. Such clear-cut inferences are often lacking when data are not collected according to a detailed statistical experimental design.

Secondly, a statistical design should be selected that controls, insofar as possible, variation from different sources. The design should allow the estimation of the magnitude of uncontrollable variation and the modelling of relationships between the measurements of interest and factors (sources) believed to influence such measurements.

Two general sources of uncontrollable variation are:

- Experimental error
- Measurement error

Experimental error is introduced whenever test conditions are changed whilst measurement error arises from the inability to obtain exactly the same measurement on two successive test runs when all experimentation conditions are unchanged, due existence of unavoidable random error, such as the random variation of electronic signals which are not controllable.

Third, a statistical analysis of the experimental results should allow inferences to be drawn on the relationships between the design factors and the measurements. And, the outcome of the first experimentation can guide the experimenter to an appropriate design and, if needed, a more appropriate model of the measurement process.

Hence, in summary, the role of statistics in engineering and scientific experimentation can be described below:

Table 1 Role of statistics in experimentation

Project Planning Phase

- What is to be measured?
- How large is the likely variation?
- Determine what are the influential variables or factors

Experimental Design Phase

- Determine how to set the known sources of variation to optimise response
- Determine where to set influential factors to minimize response
- Determine where to set influential factors to minimize the effect of the uncontrollable factors
- Permit an investigation of suitable models

Statistical Analysis Phase

- Make inferences on designed factors
- Guide subsequent designs
- Suggest more appropriate models, if necessary

To be competent in DOE, we must have a good grasp of basic applied statistics knowledge. Apart from the very basic application of significance testing, outlier checking, confidence intervals, etc., we have to learn what to do in single sample experiments, two-sample experiments & multi-factor experiments and study about the 2^k factorial design and other designs like nested, Latin Square, block (random and balanced incomplete), etc., and, also the graphic analyses of effect, amongst other subjects.