TOPIC 7. INTRODUCTION TO DESIGN OF EXPERIMENTS

Introduction to Design of Experiments

- Experimental and Observational Studies
- Introduction to Experimental Design
- Application to Process Development
- Application to Engineering Design
- Difficulties in Experiments

WHAT IS EXPERIMENTAL DESIGN?

- Experiments are performed by investigators in virtually all fields of inquiry, usually to discover something about a particular process or system.
- Literally, an experiment is a *test*.
- A *designed experiment* is a test or series of tests in which purposeful changes are made to the input variables of a process or system so that we may observe and identify the reasons for changes in the output response.

EXPERIMENTAL STUDY

- Experimental Study:

The *design of an experiment* refers to the structure of the experiment, with particular reference to:

- The set of explanatory factors included in the study.
- The set of treatments included in the study.
- The set of experimental units included in the study.
- The rules and procedures by which the treatments are randomly assigned to the experimental units (or vice versa).
- The outcome measurements that are made on the experimental units.

- Comparative Experimental Study:

In a *comparative experimental study*, randomization is employed to assign a set of treatments to the experimental units, and the observed outcomes among the treatment groups are compared to assess treatment effects. The treatments are defined by the levels of one or more explanatory factors, referred to as *experimental factors*. Cause-and-effect relationships between the experimental factors and the outcome or response variable can be established in an experimental study.

OBSERVATIONAL STUDY

- Observational Study:

An observational study differs from an experimental study in that randomization of the treatments to experimental units does not occur. For example, a study of the effects of education and type of work experience of sales people on their sales volumes was made by selecting a random sample of sales people currently employed by a company and obtaining information on highest degree obtained, type of experience, and sales volume for each of the selected employees. This is an observational study because it is not possible to randomly assign the levels of the predictor variables of interest (education and type of experience) to the employees.

- Mixed Experimental and Observational Study:

A study involving factors in which some are experimental factors and some are observational factors.

HISTORICAL PERSPECTIVE (DOE)

- Sir Ronald A. Fisher was the innovator in the use of statistical methods in experimental design.
- For several years he was responsible for statistics and data analysis at the Rothamsted Agricultural Experiment Station in London, England in 1930's.
- Fisher developed and first used the analysis of variance as the primary method of statistical analysis in experimental design.
- For an excellent biography of Fisher, see J. F.Box (1978).
- While Fisher was clearly the pioneer, there have been many other significant contributors to the literature of experimental designs, including F. Yates, R. C. Bose, O. Kempthorne, W. G. Cochran, and G.E. P. Box.

HISTORICAL PERSPECTIVE (CONT'D)

- Many of the early applications of experimental design methods were in the agricultural and biological sciences, and as a result, much of the terminology of the field is derived from this heritage.
- The first industrial applications of experimental design began to appear in the 1930's, initially in the British textile and woolen industry.
- After World War II, experimental design methods was introduced to the chemical and process industries in the United States and Western Europe.
- Only in the recent 30 years, the semiconductor and electronics industry started using experimental design methods with considerable success.

An Example of Designed Experiment

- A metallurgical engineer is interested in studying the effect of two different hardening processes, oil quenching and saltwater quenching, on an aluminum alloy.
- The objective of the experimenter is to determine the quenching solution that produces the maximum hardness for this particular alloy.
- The engineer decides to subject a number of alloy specimens to each quenching medium and measure the hardness of the specimens after quenching.

Questions in Designed Experiment

1. Are these two solutions the only quenching media of potential interest?
2. Are there any other factors that might affect hardness that should be investigated or controlled in this experiment?
3. How many specimens of alloy should be tested in each quenching solution?
4. How should the specimens be assigned to the quenching solutions, and in what order should the data be collected?
5. What method of data analysis should be used?
6. What difference in average observed hardness between the two quenching media will be considered important?

Common Objectives of Experiments

1. Determining which variables are most influential on the response y.
2. Determining where to set the influential x's so that y is almost always near the desired nominal value.
3. Determining where to set the influential x's so that variability in y is small.
4. Determining where to set the influential x's so that the effects of the uncontrollable variables z_1 , z_2, . . . , z_q are minimized.

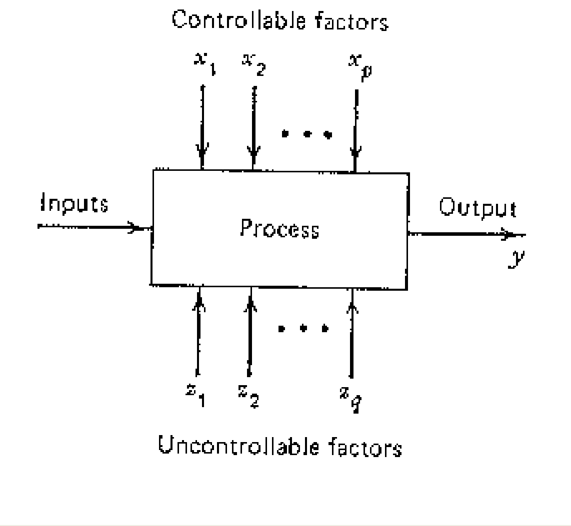


Figure 1-1. General model of a process or system.

Applications of Experimental Design in Process Development

1. Improved process yields.
2. Reduced variability and closer conformance to nominal or other requirements.
3. Reduced development time.
4. Reduced overall costs.

Applications of Experimental Design in Engineering Design

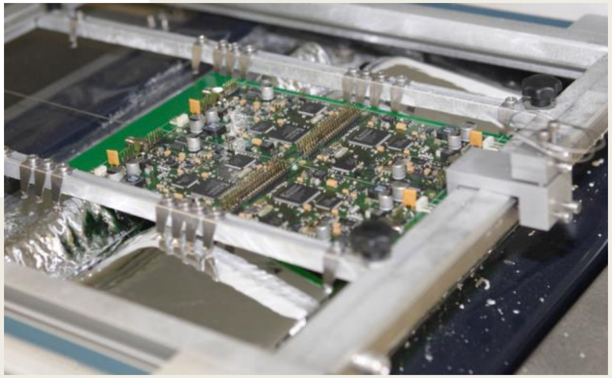
1. Evaluation and comparison of basic design configurations.
2. Evaluation of material alternatives.
3. Selection of design parameters so that the product will work under a wide variety of field conditions, that is, so that the product is *robust*.
4. Determination of key product design parameters that impact product performance.

Example of Characterizing a Process

A flow solder machine is used in the manufacturing process for printed circuit boards. The machine cleans the boards in a flux, preheats the boards, and then moves them along a conveyor through a wave of molten solder. This solder process makes the electrical and mechanical connections for the leaded components on the board.

- The process currently operates around the 1 percent defective level.
- Defective solder joints require manual retouching.
- The average printed circuit board contains over 2000 solder joints, a 1 percent defective level results in far too many solder joints requiring rework.
- The process engineer would like to use a designed experiment to determine which machine parameters are influential in the occurrence of solder defects.

Flow Solder Machine



http://useevn.com/en/wave-soldering-term-and-process/

Controllable Factors

1. Solder temperature.
2. Preheat temperature.
3. Conveyor speed.
4. Flux type.
5. Flux specific gravity.
6. Solder wave depth.
7. Conveyor angle.

Uncontrollable Factors

1. Thickness of the printed circuit board.
2. Type of components used on the board.
3. Layout of the components on the board.
4. Operator.
5. Production rate.

Example of Optimizing a Process

- In a characterization experiment, we are usually interested in determining which process variables affect the response.
- A logical next step is to optimize, that is, to determine the region in the important factors that leads to the best possible response.
- If the response is yield, we would look for a region of maximum yield.
- If the response is variability in a critical product dimension, we would seek a region of minimum variability.

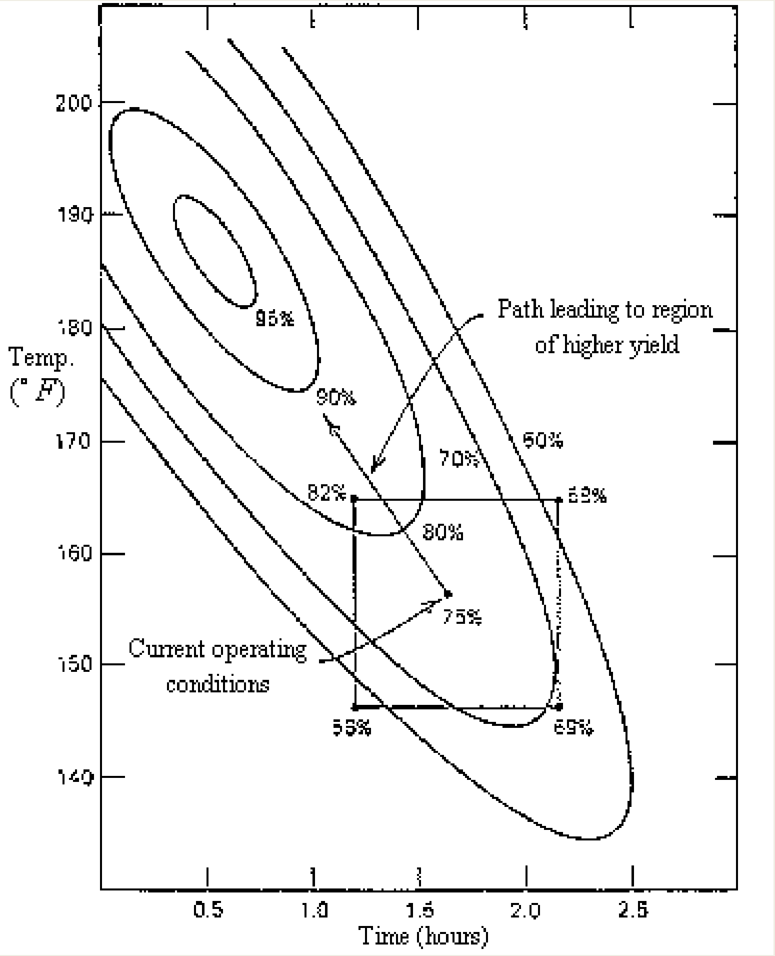


Figure 1-2. Contour plot of yield as a function of reaction time and reaction temperature, illustrating an optimization experiment.

DIFFICULTIES MITIGATED BY STATISTICAL METHODS

1. Experimental error (or noise).

2. Complexity of the effects studied.

Experimental Error

- Variation produced by disturbing factors, both known and unknown, is called *experimental error*.
- Important effects may be wholly or partially obscured by experimental error.
- Through experimental error, the experimenter may be misled into believing in effects that do not exist.
- The confusing effects of experimental error can be greatly reduced by adequate experimental design and analysis.
- Statistical analysis yields *measures of precision* of estimated quantities under study.
- Analysis makes it possible to judge whether there is any solid evidence of the existence of nonzero values for such quantities.

Complexity of Effects

- Consider an experimental study of the effects of alcohol and coffee on the reaction times of drivers operating a simulator.
- If no coffee was taken, one shot of whiskey increased the reaction time by an average of 0.45 second, and
- If no alcohol was taken, one cup of coffee reduced the reaction time by an average of 0.20 second.
- A great simplification would result *if* the effects were *linear* and *additive*.
- If they were linear, two shots of whiskey would increase the reaction time by 0.90 second [2(0.45) = 0.90], and three cups of coffee would reduce it by 0.60 second [3(-0.20) = -0.60].
- If the effects were additive, one shot of whiskey and one cup of coffee would increase the reaction time by 0.25 second (0.45 - 0.20 = 0.25).
- If they were linear and additive, 10 shots of whiskey and 23 cups of coffee would reduce the reaction time by 0.10 second [10(0.45) + 23(-0.20) = -0.10].

The Phases of Experimentation

	DESIGN:	ANALYSIS:
Phase 0 Concept		
↓		
Phase 1 Screening & Model Building	– Fractional Factorial	– ANOVA – Pareto – Graphical Analysis
↓		
Phase 2 Model Building	– Central Composite – Second Order Designs	– ANOVA – Regression
↓		
Phase 3 Verification	– Simple Designs – Confirmation Expt.	– Simulation – Simple Analysis

Operational Steps for Designing Experiments

1. Recognition and Formulation of Problem
2. Selection of Responses or Characteristics
3. Identification of Factors and Levels
4. Choice of Experimental Design
5. Performing Experiments
6. Analyzing Data and Results
7. Conclusions and Recommendations

FIGURE The iterative learning process.