The Planning and Analysis of Industrial Selection and Screening Experiments

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Abstract

The purpose of this article is to explain methodology for designing and analyzing industrial experiments when selection and screening, rather than hypothesis testing, is the goal. In rough terms, we say the goal is one of selection and/or screening when the scientific objective is to find the "best" treatment.

Empirical investigation, in the form of physical experiments, has been a key tool in the development of many advances in industrial product design, as well as online and offline improvements in manufacturing during the last 75 years. More recently, physical experiments have also been used to design products that are robust to the environmental conditions in which they are used or robust with respect to the manufacturing process itself.

Broadly speaking, at least three types of experiments have evolved. Historically, *physical experiments* were the earliest to be conducted; the first principles of the design and analysis of such experiments were developed in response to agricultural improvements, then later to meet industrial and medical needs. *Simulation experiments* are an attractive alternative to physical experiments when the experimenter has a complex physical system whose parts interact in a known manner but whose ensemble is not understood analytically. Such complex interacting structural components are typically combined with specified "noise" distributions to produce random output. Banks (1998) gives an overview of the field and Goldsman and Nelson (1998) provides a survey of methods useful for designing simulation experiments to identify best treatments.

In the last ten to fifteen years, a third form of experiment, commonly called a *computer experiment*, has become popular. In a computer experiment, a *deterministic* output is calculated for each set of input variables. Many phenomena that could only be studied using physical experiments can now be studied by these computer experiments. Computer experiments are possible when the mathematical model of the physical process of interest is known and an algorithm has been developed for solving the resulting mathematical system in a reasonable time frame on (fast) computing equipment. In engineering, dynamical models of physical systems implemented using finite-element methods are often the basis for computer code used in computer experiments. Because the output is deterministic, issues such as replication, randomization, and other fundamental tools for designing physical experiments are no longer appropriate. The special techniques used to design and analyze computer experiments are discussed in detail in the survey articles by Koehler and Owen (1996) and Sacks, Welch, Mitchell and Wynn (1989).

This article will discuss the design and analysis of physical and simulation experiments for frequently occurring industrial problems involving the identification of best or near-best treatments. Another very useful approach to the problem of identifying best treatments is that of forming simultaneous confidence intervals for "important" parameters related to this problem. Length considerations require this review paper to focus attention on selection and screening approaches, with one exception in Section 7, but we refer the reader to the seminal book-length treatment of simultaneous confidence intervals in Hsu (1996).

Sections 2 and 3 discuss the familiar one-way layout, illustrating statistical methods both for the problem of designing experiments to select best treatments and for analysis procedures to screen a given set of data to extract a (small) set of treatments containing best treatments. Section 4 reviews such problems for

the case of completely randomized full-factorial experiments. Section 6 considers screening for fractional-factorial experiments for the specific goal of finding most robust engineering designs for products or manufacturing processes. Section 5 considers the important case of designing and analyzing randomization restricted experiments; particular attention is given to identifying treatment combinations with largest means in split-plot experiments and selection of robust product designs for the same setup. Finally, Section 7 reviews statistical procedures for finding treatments associated with smallest variances and gives a set of simultaneous confidence intervals for comparing treatment variances.

We conclude this abstract by noting several other recent summary articles concerning selection and screening procedures. These include van der Laan and Verdooren (1989) and Gupta and Panchapakesan (1996) for general overviews, and Driessen (1992) and Dourleijn (1993) for results concerning subset selection in connected experiments.