Designed Experiments in a Heavily Constrained Operational Space

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Executive Summary

This paper addresses the issue of creating test designs in a heavily constrained operational space. The approach entails using a point exchange algorithm to select test runs from a candidate list of potential test scenarios. The methodology was successfully implemented on the Army's Common Infrared Counter Measure System (CIRCM) test program and allowed for the development of an overarching test strategy that enabled the cross validation of test results from multiple facilities. Tutorials on how to create and evaluate these designs using different software packages are presented.

Keywords: Optimal Designs, Constraints, Design of Experiments, Prediction Variance

Introduction

Designing experiments in a Department of Defense (DoD) test and evaluation (T&E) environment presents some unique and complex challenges that are not normally encountered in industry.

In industry:

- Design of experiments (DOE) is commonly applied to a fairly mature system and/or process with the aim of improving performance.
- The factor/test space explored in industrial experiments is usually a much smaller subset of the entire region of operability. These regions are usually described as an unconstrained spherical or cuboidal region.
- It is usually a good assumption that the response surface (the function describing performance across the test space) can be modeled with a fairly simple, low-order polynomial function with some main effects, two-factor interactions, and quadratic terms.
- Testers can build up their designed experiment sequentially, using a test-analyze-test approach that allows for flexibility and promotes resource efficiency.

In contrast, in a defense T&E environment:

- The system under test is usually immature and still in development.
- Testers are tasked to explore the entire region of operability or a rather large space of the likely operating conditions the system may encounter.
- The region of experimentation can be rather complex to describe, with numerous constraints on factor settings and thus exhibit a highly irregular shape.
- Because the system is immature, subject matter experts (SMEs) may find it difficult to estimate what the response surface should look like and therefore may want to examine the space as thoroughly as possible in order to allow for the modeling of higher order terms (cubic, quartic models, etc.).

- A test-analyze-test approach may not be feasible, so designed experiments tend to be large and with only one opportunity to collect data.

This best practice presents a test strategy that was employed by the Army's CIRCM program and which addressed many of the challenges listed above. The strategy required building several designed experiments in heavily constrained experimental regions. We present tutorials on how to build these designs using various statistical software suites (R, Design-Expert, and JMP). We also provide recommendations on how best to evaluate these designs and how to deal with the potential issues that may arise in their development