A Modified Desirability Function Approach for Mean-Variance Optimization of Multiple Responses

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ABSTRACT

A generic problem encountered in process improvement involves simultaneous optimization of multiple responses (so-called ‘critical response/output characteristics’). These types of problems are also referred to as ‘multiple response optimization (MRO) problems’. The primary goal of any process improvement initiative is to determine the best process operating conditions that simultaneously optimizes various critical ‘response characteristics’. Conventional desirability function approach uses response functions, target values, specifications to convert a MRO problem to a composite single objective optimization problem. The single objective function is maximized to determine near optimal conditions based on specific metaheuristic search strategy. The solution quality is expressed in terms of closeness of mean to target values and reduced variance around targets. Researchers generally impose hypothetical boundary conditions on variance to achieve satisfactory solutions. In this paper, an unconstrained modified desirability function is proposed, which do not require boundary conditions on variance, to determine efficient solution for MRO problem. Various case studies from open literature are selected to verify the superiority of the proposed approach over conventional desirability approach.

Keywords: Desirability Function, Mean-Variance Optimization, Metaheuristic Search, Multiple Response Optimization (MRO), Response Functions

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1. INTRODUCTION

In the context of manufacturing, a multiple response optimization problem may be stated as determining the setting conditions of input variables (which can include in-process machine variables and raw material compositions) that simultaneously optimize multiple response or quality characteristics. Simultaneous optimization of correlated multiple quality characteristics is generally referred to as ‘multiple response optimization’ (MRO) (Khuri, Ghosh & Rao, 1996; Bera, 2012). In practice, MRO problem typically involves responses that are correlated. In other words, improving or moving towards improved solution, either by statistical experimentation or simulation search strategy, for a particular response can result in sacrificing the best solution of another response. Thus, there always exist trade-off solutions in case of correlated conflicting responses. Determining superior solution quality for a typical MRO problem considering mean and variance of responses is a continual research endeavor.

The conventional graphical approach that can handle multiple response problem is overlaying contour plot (Lind, Goldin, & Hickman, 1960). However, the number of input (independent) variables in this approach is practically limited to two. Harrington (1965) first proposed a desirability function approach to convert a higher dimensional MRO problem into a single objective optimization problem, using suitable desirability scale transformation function. The desirability function approach is still preferred by many researchers to handle MRO problems (e.g. Kim & Lin, 2006, Mukherjee & Ray, 2008; Bera & Mukherjee, 2010; Bera & Mukherjee, 2012; Sikdar & Mukherjee, 2011). However, the conventional desirability function approach (Derringer & Suich, 1980) does not consider inherent variability of the responses (Kim & Lin, 2006) to arrive at optimal or near optimal conditions. Considering equal variance of all responses may lead to an unrealistic pseudo or suboptimal solutions (Lin & Tu, 1995).

Many researchers attempted to solve simultaneous optimization of mean and variance for multiple response problem (Chiao & Hamada, 2001; Kim & Lin, 2006; Costa, Pereira & Lourenco, 2011). Khuri and Conlon (1981) proposed a generalized distance-based optimization scheme for MRO problems. Polynomial regression model(s) is (are) used to build the input-output relationship(s). A major limitation of this approach is that the input-output relationship is based on same set of input variables and same order of polynomial regression model. Pignatiello (1993) proposed a loss function approach for multi-response optimization, considering the interactions between response characteristics. Elsayed (1995) presented a quadratic loss function approach, which can include manufacturing costs as an optimality criterion for multiple response optimization. Su and Tong (1997) proposed a multi-response method, which integrate Taguchi’s loss function with principal component analysis (PCA). Vining (1998) proposed a new definition of loss function, which takes into account the quality of prediction. Chiao and Hamada (2001) proposed assessing and optimizing the proportion of conformance or simultaneously maximizing the probability of all responses to meet their respective specification(s). However, the approach is constrained by assumption of multivariate normality. Extending the work of Derringer and Suich (1980) and Barton and Tsui (1991), Plante (2001) considered achievement of multiple targets as multiple criteria optimization problem. Chiao and Hamada (2001) proposed an approach that determines parameter settings by maximizing the probability of all responses simultaneously meeting their respective specification(s). However, the approach is constrained by assumption of multivariate normality. Extending the work of Derringer and Suich (1980) and Barton and Tsui (1991), Plante (2001) considered achievement of multiple targets as multiple criteria optimization problem. Chiao and Hamada (2001) proposed an approach that determines parameter settings by maximizing the probability of all responses simultaneously meeting their respective specification(s). Ribeiro and Fogliatto and Albin (2000) illustrated an approach that considers distance-to-target and prediction CV (or coefficient of variation) as the two optimization criteria for a multiple response optimization. Plante (2001) proposed maximization of process capability as the criterion for selecting input parameter settings of multiple response process. Ko, Kim and Jun (2005) proposed a new loss function approach combining the strength of Pignatiello (1993) and Vining (1998) approach. Ko, Kim and Jun (2005) proposal an expected
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