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Innovative Applications of O.R.

Joint optimal determination of process mean, production quantity, pricing, and market segmentation with demand leakage

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ABSTRACT

The selection of an optimal process mean is an important problem in production planning and quality control research. Most of the previous studies in the field have analyzed the problem for a fixed exogenous price. However, in many realistic situations, besides product quality, product pricing is a paramount factor that determines the purchase behavior in the market. In the experts' opinion an integrated framework that incorporates pricing as a decision tool could significantly improve a firm's profitability. Most of the manufacturing firms yield products with distinguishable characteristics and therefore it is desirable to sell these products on the market at differentiated prices. Whereas the market segmentation achieved using differentiated prices is often imperfect, a firm may experience demand leakages. Thus, an optimal price decision must incorporate demand leakage effects for the firm to benefit from its differentiated pricing strategy. In this paper, these issues are addressed by proposing an optimal framework for joint determination of process mean, pricing, production quantity and market segmentation using differentiated pricing. This research discusses a production process that manufactures multi-class (grade) products based on their quality attribute. The products are sold in primary and secondary market at differentiated prices while experiencing demand leakages. The nonconforming items are reworked at an additional cost. Mathematical models are developed to address the problem under both price-dependent deterministic and stochastic demand situations. We propose a harmony search meta-heuristic for solving the models. A numerical experimentation is presented to study the significance of the proposed integrated decision framework.

1. Introduction

In this paper we interface the contemporary Revenue Management (RM) tools for pricing with the process mean selection problem for a manufacturing firm and the consumer behavior for market segmentation. The process mean problem is among the topics of economics of quality control that has received much attention from researchers and industrial practitioners in the last 60 years. The problem, also known as targeting problem, mainly addresses the optimum selection of process mean which affects the expected profit/cost per item in production processes such as canning/filling, metal plating, fiber production, glass and steel industries (Duffuaa & El-Gaaly, 2013a,b; Park, Kwon, Hong, & Lee, 2011; Hariga & Al-Fawzan, 2005; Shao, Fowler, & Runger, 2000). A manufacturer often follows in the production process the specification limits of a quality performance measure which may comprise weight, volume, concentration, thickness, length, etc. A product is therefore graded as conforming product if the quality performance measure is within the specification limits. Otherwise, the product is classified as nonconforming and may be sold at a reduced price, or reprocessed or scrapped (Darwish, Abdulmalek, & Alkhedher, 2013; Roan, Gong, & Tang, 2000). Darwish et al. (2013) have reported one common industrial practice in manufacturing sector examined by USA federal agency, to set a higher mean of the production process in order to meet a given specification limit. This practice indeed leads to a 'giveaway' cost (see Roan et al., 2000 for more details). Alternatively, if a tight production process mean is selected, then the manufacturing process may result a large proportion of nonconforming items, rework costs, increased scrapped volume, etc. Thus, an optimum selection of the process mean is highly desirable to improve the profitability of a manufacturer.

Since Springer (1951) initiated the field of process targeting with cost minimization in a canning process, the problem evolved to integrate various decisions control. Bisgaard, Hunter, and Pallesen (1984)

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integrated pricing decisions in the targeting problem, proposing that the nonconforming products to be sold at a price proportional to the amount of material consumed by each nonconforming product. Golhar (1987) considered the problem of optimum process mean in a canning process where the cans filled above a specification limit are sold at a fixed price, while the under-filled cans are emptied and refilled at a reprocessing cost. Sampling inspection planning instead of full inspection was incorporated into the problem in Boucher and Jafari (1991). Optimal process mean with rectifying inspection was studied in Al-Sultan and Al-Fawzan (1997) for the targeting problem in a filling process with time dependent process mean. Shao et al. (2000) developed strategies for determining the optimal process mean of industrial processes when rejected goods can be held and sold to other customers in the same market at a later time. Bowling, Khasawneh, Kaewkuekool, and Cho (2004)'s work explored the targeting problem in the context of multi-stage serial production process. Darwish (2009) developed an integrated and hierarchical model of optimal process targeting in a single-vendor single-buyer supply chain. Based on a quality loss function, Chen and Kao (2009) determined the optimal process mean and screening limits. A reverse programming routine that identifies the relationship between the process mean and the settings within an experimental factor space was founded by Goethals and Cho (2011), and Goethals and Cho (2012). As identified here, the researchers have formulated different process targeting models for optimizing the firms' profitability in terms of product uniformity or cost reduction, by approaching products' characteristics in various production processes with multiple stages or inputs of production. The research field of process targeting evolved in many other directions, however, a detailed review of the specific literature is not in the scope of this paper.

Besides setting an optimal process mean, a manufacturer's objective is to maximize its profitability. The profitability of a firm depends on many factors and, as rightly described in Chen, Yan, and Yao (2004), pricing is a paramount factor that affects significantly the purchase behavior. In the field of Revenue Management (RM), commonly defined as the science of profitability, price differentiation is among the most successful tactics for improving profitability of a firm (Phillips, 2005; Talluri & Ryzin, 2004). Price differentiation is applied by many businesses, for example, in the online stores vs. retail stores, where products may be offered by a firm at discounted prices for online sales without the option of touch and feel, whereas retail stores sales are higher priced and the customers can interact with the products or the sales staff. Another common example is the airline ticket sales, when the price differentiation is practiced by offering early sales with deeply discounted prices for advanced purchases of tickets with restrictions in changes or cancelations. This type of sale targets especially the leisure (economy) class passengers, whereas for late arriving business class passengers with higher willingness to pay, the airlines reserve some cabin capacity. Price differentiation results in market segmentation which, in most of the related studies, is assumed to be perfect, and therefore demand cannibalization (demand leakage) is rather ignored in the models. While the evidence of increase profitability is proved under perfect segmentation, in most practical situations demand leakages are inevitable (Zhang, Bell, Cai, & Chen, 2010). The essentiality of fencing improvement has been recently addressed to mitigate the customers' spillover from one market segment to another in Zhang et al. (2010). The authors assumed predetermined market share (maximum perceived demand) for each market segment, with demand leakage from full price to discounted price market segment, depending on the difference of prices from the two market segments. Zhang and Bell (2012) presented an overview of price fencing in RM's practice and its taxonomy. In a contrast to this, Phillips (2005) proposed a price differentiation with customer's cannibalization to determine the optimal price and to segment a single market using differentiated pricing, for a price-dependent deterministic demand. The fundamental variant used in Phillips (2005) and in Zhang et al. (2010) is the notion of differentiation price. By using a differentiation price as in Phillips (2005), the market share can also be controlled unlike in Zhang et al. (2010). This important approach of differentiation price from Phillips (2005) is re-visited later in Raza (2015a,b). The author generalized the modeling framework by considering an optimal market segmentation with demand leakage effect and in addition to Phillips (2005), the studies considered the price-dependent stochastic demands with known distribution, as well as with unknown distribution when the distribution-free approach (see Raza, 2014 for details) was applied. Anderson and Xie (2014) integrated pricing and market segmentation decisions using opaque selling mechanisms. Xiaa, Chen, Jayaraman, and Munson (2015) studied competition and market segmentation in a call center service supply chain.

Integrating the targeting problem with production (inventory) decisions attracted for years the attention of many researchers. Gong, Roan, and Tang (1988) developed an integrated targeting-inventory model with constant process mean during the production cycle. This model was later generalized by Al-Fawzan and Hariga (2002) considering a time-dependent process mean. Roan et al. (2000) integrated the issues of production lot size and raw material procurement policy with the targeting problem. Hariga and Al-Fawzan (2005) determined simultaneously the optimal production lot size and the process mean for container-filling processes in multiple markets. Lee, Kwon, Hong, and Kim (2007) considered a targeting-inventory problem for a production process where multiple products are processed. The targeting problem was integrated with single-vendor single-buyer problem in Darwish (2004), assuming an equal size shipment policy and salvage value for scrapping nonconforming items. Chen and Lai (2007) formulated a model that finds the optimal process mean, specification limits and manufacturing quantity under rectifying inspection plan. Chen and Khoo (2009) addressed the targeting-inventory problem for serial production systems under quality loss and rectifying inspection plan. Darwish (2009) extended his earlier work and developed an integrated hierarchical targeting-inventory model for a two-layer supply chain. Park et al. (2011) established a profit model that determined the optimal common process mean and screening limits in a production process with multiple products. Recently, Darwish et al. (2013) developed a model that determines the optimal process mean for a stochastic inventory model under service level constraint. *To the authors' knowledge*, the issue of optimal price setting and market segmentation using a differentiated pricing with demand leakage in the context of process mean (targeting) problem has not been addressed. This paper is *expected to contribute* towards this research avenue by developing novel mathematical models for joint optimal determination of process mean, pricing, production quantities and market segmentation using a differentiation price. Two distinct models are developed considering the price-dependent deterministic demand and then the price-dependent stochastic demand. A Harmony Search (HS) meta-heuristic is applied to the optimization problem. We present a numerical experimentation with both models where we study the model related parameters onto the profitability of a firm and its optimal joint decision on control parameters.

The remainder of this paper is organized as follows. In Section 2, the problem is defined of a manufacturing firm that pursuits a joint optimal determination of process mean, production quantity, pricing and market segmentation, under price-dependent deterministic demand situation first, and later considering the price-dependent stochastic demand. In Section 3, a harmony search based meta-heuristic is proposed to solve the two models. Section 4 studies the models using a numerical experimentation obtained by applying the harmony search algorithm with data from related literature. Lastly, in Section 5 the conclusions of the results are discussed and the directions for future research are proposed.