

APPLICATIONS OF MANAGEMENT SCIENCE

Edited by Kenneth D. Lawrence
and Dinesh R. Pai

APPLICATIONS OF
MANAGEMENT SCIENCE

VOLUME 20

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APPLICATIONS OF MANAGEMENT SCIENCE VOLUME 20

APPLICATIONS OF MANAGEMENT SCIENCE

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SECTION A

APPLICATIONS OF OPTIMIZATION

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MULTIOBJECTIVE NEWSVENDOR MODELS WITH CVAR FOR FLOWER INDUSTRY

Bartosz Sawik

ABSTRACT

The newsvendor problem is fundamental to many operations management models. The problem focuses on the trade-off between the gains from satisfying demand and losses from unsold products. The newsvendor model and its extensions have been applied to various areas, such as production plan and supply chain management. This chapter examines the study about newsvendor problem. In this research, there is a review of the contributions for the multiproduct newsvendor problem. It focuses on the current literature concerning the mathematical models and the solution methods for the multiitem newsvendor problems with single or multiple constraints, as well as with the risks. The objective of this research is to go over the newsvendor problem and bring into comparison different newsvendor models applied to the flower industry. A few case studies are described addressing topics related to the newsvendor problem such as discounting and replenishment policies, inventory inaccuracies, or demand estimation. Three newsvendor models are put into practice in the field of flower selling. A full database of the flowers sold by an anonymous retailer is available for the study. Computational experiments for practical example have been conducted with use of the CPLEX solver with AMPL programming language. Models are solved, and an analysis of different circumstances and cases is accomplished.

Keywords: Newsvendor problem; demand estimation; inventory optimization; flower selling; conditional value at risk; value at risk; mixed integer programming; exact methods

INTRODUCTION

The newsvendor problem has been subject to extensive research since it first appeared at the end of the 19th century. It is a conceptually simple, yet powerful model to set optimal policies in order to minimize replenishment costs (when setting only order quantities) or maximize profits (when setting both order quantities and selling prices) in the face of uncertain demand (Rubio-Herrero & Baykal-Gürsoy, 2019). The amount of research conducted on this model and its applications is so vast that a simple search in Google Scholar under the keyword “newsvendor” will return about 10,000 entries between 2013 and 2020.

This research consists on an optimization problem where the main idea is to optimize the amount of flowers that are planted in a flower store in order to be sold to smaller shops. It is an everyday problem that affects most of the sectors in business. Therefore, the main objective is to reach a solution to reduce or even to do away with the leftovers of this type of business.

The idea is extracted from the newsvendor problem, a mathematical model in operations management and applied economics used to determine optimal inventory levels. The main characterization of the model is the fixed prices and the uncertain demand for a random product. The problem faces both overage and underage costs if the order is in excess or in defect. By doing a review in the literature of the newsvendor problem, the different methods are analyzed to reach with the final and optimal solution of the problem.

In the present case, the solution consist on deciding the size of the order as well as the length of the flowers, their type, and the color for the following year based on the data from the past. This will lead to almost end up with the demand uncertainty and to reduce the overage and underage costs.

The research is developed by the study of similar cases and the construction of an appropriate model for the different cases from the present one.

The literature offers distinct methods to model this risk aversion, each of them having advantages and drawbacks. Examples of approaches under risk for determining optimal stock quantities include the well-known utility function framework as in Bouakiz and Sobel (1992); Eeckhoudt, Gollier, and Schlesinger (1995); Lau (1980), mean-variance analysis as in Chen and Federgruen (2000); Lau (1980), value at risk (Özler, Tan, & Karaesmen, 2009), and conditional value at risk (CVaR) (Ahmed, Çakmak, & Shapiro, 2007; Choi & Ruszczyński, 2008; Jammerneegg & Kischka, 2007; Rubio-Herrero & Baykal-Gürsoy, 2019). Important feature of this problem is the demand for the goods. Often, the demand is assumed to take on values according to a statistical distribution. In other cases, the stochasticity of the demand is only given by a random perturbation of a function. This function usually depends on a much reduced number of variables. It is common, for example, to consider that the demand is represented as a decreasing function of the price and modified according to a random variable (Federgruen & Heching, 1999; Karlin & Carr, 1962; Mills, 1959; Petruzzi & Dada, 1999; Rubio-Herrero & Baykal-Gürsoy, 2019).

The newsvendor model is a mathematical model in operations management, and applied economics used to determine the optimal inventory levels. The

multicriteria decision problem (Steuer & Na, 2003) is often optimized by the expected cost reduction or the expected profit improvements, by ignoring in most of the cases the risk preference of decision maker. If the order quantity is greater than the demand of the market, the newsvendor then has to dispose the excess order as a loss. Otherwise, if the order quantity is lower than the demand of the market, there is some shortage penalty for the lost sales to the newsvendor. Therefore, to maximize the expected profit, the newsvendor must reach a balance about how much is ordered. Multiproduct newsvendor problem (MPNP) can also be considered as a problem of determining the best product portfolio among all the possible alternatives.

LITERATURE REVIEW

This section provides some important publications concerning the newsvendor problem and the solutions that have been tried by experts during the history. Furthermore, it introduces some of the experiments done and a summary of the results obtained. This will help to understand better the problem and to reach a solution by basing in the past facts.

The mathematical problems appears to the date back in 1888 when Edgeworth used the central limit theorem to determine the optimal cash reserves to satisfy random withdrawals from deposits.

The well-known newsvendor problem has attracted much scholarly attention since the 1950s (Whitin, 1955), reviews of which are available in Khouja (1999), Petruzzi and Dada (1999), and Qin, Wang, Vakharia, Chen, and Seref (2011). The newsvendor problem focuses on the trade-off between the gains from satisfying demand and losses from unsold products. Decision is biased between the actual order and optimal decision.

Since the introduction of the multiproduct newsvendor model by Hadley and Whitin (1962, 1961a, 1961b), many researchers have extended the model to two or more ex ante linear constraints, such as budget or volume constraints. Most of them researched on problem-solving approach to this problem with special demand distribution or general demand distribution, not considering risk preference.

For example, Sankarasubra-Manian and Kumarasamy (1983) consider a single-period stochastic inventory problem in which it is required to determine the product order quantity that maximizes the probability of realizing a pre-determined level of profit.

It was then in 1985 when Pasternack first studied the two-echelon newsvendor problem, and subsequently, many literatures for this direction were published, such as references Iyer and Bergen (1997) and Shao Ji and (2006). In some of the literatures, several retailers were considered.

Meanwhile, Lau and Lau (2003) explored the two-product newsvendor problem deeply and developed a model that maximizes the probability of exceeding a predetermined fixed target profit. They consider the maximization of the probability of achieving a target profit in a two-product newsvendor problem.

Parlar and Weng (2003) investigate the satisfaction probability value maximization objective in the classical newsvendor problem. They also develop a model that integrates this objective with the standard expected profit maximization objective.

In a sequel of articles, Abdel-Malek et al. (2004), Abdel-Maleka and Montanari (2005), and Abdel-Malek and Areeratchakul (2007) introduce several approaches to solve the constrained MPNP. In their publication, they present exact, approximate, and generic solution methods for the model with budget constraint.

Niederhoff (2007) provides an approximating programming technique to solve the constrained MPNP for any demand distribution by taking advantage of the separable nature of the problem.

In the same year, Chen et al. (2007a, 2007b) incorporate risk aversion through utility maximization in multiperiod inventory models involving pricing strategies.

Practically, companies with newsvendor structures as such sell more than one type of product, so Gotoh and Takano (2007) and Zhou, Chen, and Wang (2008) independently consider the CVaR minimization in a multiproduct newsvendor setting. It is shown that the CVaR minimization problem in this setting can be represented as a linear program.

Some researchers further introduced the CVaR measure to newsvendor problem and got some interesting results. Chen, Sim, Simichi-levi, and Sun (2003) proposed a model about CVaR of profit for newsvendor problem and obtained the optimal order quantity. Gotoh and Takano (2007) provided analytical solutions and linear programming formulation for minimizing CVaR in the newsvendor problem. Cheng, Wan, and Wang (2009) introduced a bilevel model for the two-echelon newsvendor problem where CVaR is given as the objective of the newsvendor. Based on CVaR, Chen et al. (2009) obtained the optimal pricing and ordering decisions for a risk-averse newsvendor facing stochastic price-dependent demand.

Xu and Li (2010) concluded that if the shortage penalty for lost sales as well as CVaR criterion is considered, the optimal order quantity of the newsvendor might be more or less than the profit maximizing order quantity, which depends on the demand distribution.

Approach made by Wächter and Mazzoni (2013) have shown that it is possible to use spectral risk measures to model risk-averse behavior of a decision maker whose preference relation is consistent with the dual theory of choice.

More recently, Katariya et al. (2014) investigated the relationship between risk-neutral and risk-averse newsvendor problems under the CVaR measure. All these papers aim to control the potential risks and to reduce losses, either by maximizing the CVaR about profit or by minimizing the CVaR about cost for the risk-averse newsvendor.

The research (Rubio-Herrero & Baykal-Gürsoy, 2018) considered a mean-variance analysis of the single-product, single-period, price-setting newsvendor problem with additive, price-dependent demand. The main goal (Rubio-Herrero & Baykal-Gürsoy, 2018) was to use a mean-variance framework to solve any

risk-sensitive instance and find conditions under which the unimodality of the problem is guaranteed.

Study (Bai, Wu, & Zhu, 2019) examines the joint optimization of pricing and ordering decisions for a loss-averse newsvendor with reference dependence. Researchers (Bai et al., 2019) explored the effects of reference dependence and loss aversion from various aspects.

Rahimian, Bayraksan, and Homem-de-Mello (2019) use distributionally robust optimization to model a general class of newsvendor problems with unknown demand distribution. The goal is to find an order quantity that minimizes the worst-case expected cost among an ambiguity set of distributions. The ambiguity set consists of those distributions that are not far – in the sense of the total variation distance – from a nominal distribution. The maximum distance allowed in the ambiguity set (called level of robustness) places the DRO between the risk-neutral stochastic programming and robust optimization models. Research (Rahimian et al., 2019) was focused on a single-product setting and derives explicit formulas and properties of the optimal solution as a function of the level of robustness. Authors (Rahimian et al., 2019) demonstrate the practical and managerial relevance of our results by applying our findings to a healthcare problem to reserve operating room time for cardiovascular surgeries.

In recently published research (Rubio-Herrero & Baykal-Gürsoy, 2019), a mean-variance analysis of the single-product, single-period newsvendor problem with two decision variables, price and stock quantity. The demand is price-dependent, multiplicative, and elastic, and the product sold is price-elastic. Main goal was to completely characterize a framework where most risk sensitivities can be studied and find conditions under which the unimodality of this mean-variance performance measure is guaranteed (Rubio-Herrero & Baykal-Gürsoy, 2019). The main contribution (Rubio-Herrero & Baykal-Gürsoy, 2019) is that, with very few and mild assumptions, we complement currently existing results for the uniqueness of the solution in the presence of price-inelastic products by extending the applicability of the lost sales rate elasticity to the problem with price-elastic goods and assess its unimodality, when the decision maker is risk-neutral or risk-sensitive.

In the paper by Feng and Gao (2020), the authors have investigated the impacts of the decision support system's recommendations on decision makers' psychology and decision behaviors under uncertain contexts where optimal solutions exist. The newsvendor problem is studied by using the method of laboratory experiments.

RISK MEASURES IN NEWSVENDOR PROBLEM

In light of the related literature, a review of the classical model of the MPNP, as well as the loss-averse newsvendor and finally both the VaR and the CVaR is presented.

Nowadays, the business world is characterized by a fast product development, short selling season, and high volatile demand. Therefore, all these facts lead to the increase of the uncertainty in the demand of many types of products. As a

consequence, companies are increasingly focusing on the incorporation of risk control in decision-making in order to achieve efficiencies in supply chains. However, how to decide ordering quantities has to be hard studied.

The MPNP is one of the classical problems in the literature on inventory management on which companies can be based to reach solutions. It is based on deciding on the ordering quantity before market demand is realized. The main fact of this problem is that the product demands are considered independent and there exist a specific time in which several units of product must be sold; on the contrary, the product must be discarded producing losses both in the profit and in the efficiency of the business.

The MPNP bases on the seller's determination of the optimal supply levels under the assumptions of stochastic demand and fixed product prices. The classical model focuses on a unique objective, whether maximizing the expected profit (in most of the cases) or minimizing the expected cost. The decision maker of the classical newsvendor problem has to decide on the order quantity to be procured, taking this decision prior to the realization of the actual demand. Upon demand realization, either leftover inventory or stock-out will occur at the end of the selling period. The decision maker should consider both of these possibilities during the decision-making process.

However, this classical model omits that different decision makers have different risk preferences, assuming that the newsvendor is risk-neutral. In other words, this formulation does not take into account the risk of earning less than a desired target profit or losing more than an acceptable level due to the randomness of demand. Although nonempirical study on the MPNP proves that the risk of preference will impact the optimal ordering quantity, it is crucial to take into account risk control and decision maker's risk preference into the decision-making process.

As a consequence of some unpredictable disasters such as earthquakes or economic crises which have disrupted supply operations and brought great losses to a newsvendor, the newsvendor has learnt to be more loss-averse in selecting the order quantity and to pay more attention to loss reduction rather than profit maximization. They are called the loss-averse managers. Managers with risk averse in the real world may be more concerned with the large loss brought by uncertain demand. Furthermore, it is also proved that a loss-averse newsvendor's optimal order quantity may increase in the wholesale price and decrease in the retail price, which can never occur in the risk-neutral newsvendor problem. As mentioned above, compared with maximizing the profit, a loss-averse newsvendor prefers to choose an order quantity to minimize the loss. Especially, when a time is established.

However, this expected performance measure ignores the risks arising from the fluctuation of market demand, which may lead to great losses to the loss-averse newsvendor. So in order to measure and control such risks, we introduce the CVaR measure for the loss-averse newsvendor problem. It could have been also possible to use VaR, a popular risk measure which has achieved high status of being written into industry regulations (Canelas, Pinto-Varela, & Sawik, 2020; Sawik, 2020), but the problem of controlling VaR is very difficult to solve using