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GOAL SETTING IN THE NEWSVENDOR PROBLEM WITH UNIFORMLY DISTRIBUTED DEMAND

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Abstract

In the paper we introduce the newsvendor problem with a satisficing-level objective, which is defined as maximization of the probability of exceeding the moving target. This target is defined as the expected profit, multiplied by a positive constant. The constant is chosen by the management and it indicates whether the low or the high goal should be achieved. We obtain closed form solutions of this newsvendor model with uniformly distributed demand. Additionally, we consider a bicriteria problem with the satisficing-level and the classical objective.

Keywords: inventory control, newsvendor problem, bicriteria.

1 Introduction

The newsvendor problem is one of the main stochastic inventory models (Arrow et al., 1951; Khouja, 1999; Muller, 2011; Stevenson, 2009). In the classical newsvendor problem one has to determine the order quantity which maximizes the expected profit. Several authors have also introduced many relaxing assumptions to the basic inventory newsvendor problem. For a review of various kinds of newsvendor models we refer to Qin et al. (2011) and the references therein.

Sometimes companies, instead of maximizing the expected profit, make decisions based on profit targets (or goals). The profit goal can be chosen by external forces such as market conditions or by internal ones according to the budget level. For that reason another choice of newsvendor objective involves the maximization of the probability of exceeding a prespecified target profit – this is called the satisficing-level objective. The use of this objective assumes

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risk aversion; it is a more descriptive measure for the company's decision making (cf. Dechow and Skinner, 2000). This objective provides more information on how companies make decisions. The literature on management behaviour of firms indicates that meeting various profit goals is an important issue for their accounting. This subject is treated in Kabak and Shiff (1978); Lau (1980); He and Khouja (2011). The first researchers, who considered the satisficing--level objective were Kabak and Shiff (1978). Next, (Lau, 1980), developed a mathematical discussion of achieving optimal solutions under the assumption of different demand distribution rates. Recently, He and Khouja (2011) have studied the satisficing objective in the form of the maximal expected profit, but with a fixed profit target. For more information on the satisficing-level newsvendor we refer to Shi and Guo (2012).

It appears that the fixed-profit goal is sometimes specified arbitrarily. The main problem is that the profit goal does not depend on the order quantity. Hence, a more appropriate objective is introduced, namely the maximization of the probability of exceeding the expected profit. The expected profit is a moving target, since it depends on the order quantity; the probability of exceeding this goal is called survival probability. The survival probability approach is studied first in Parlar and Weng (2003) and then in Arcelus et al. (2012), Bieniek (2016; 2017). More precisely, in Parlar and Weng (2003) the problems: with the classical objective and an objective with survival probability are considered simultaneously. Their approximate result is then applied to the case of normally distributed demand. Arcelus et al. (2012) continued this research for uniform distribution, which allowed to derive precise analytic results. Recently, the present author (Bieniek, 2016; 2017) has studied the satisficing-level newsvendor for exponentially distributed demand. Bicriteria optimization discussed in the papers listed is a branch of multicriteria decision making (cf. Stevenson, 2009).

Goal-setting theory has certain psychological aspects. This issue is comprehensively described by Locke and Latham (2013) and Cyert and March (1963). It has been proven that goals affect performance and also direct attention and effort toward goal-relevant activities. High goals lead to greater effort than low goals. Faced with more difficult goals, one can work more intensely. Finally, higher goal levels result in higher performance, but they do not lead to a higher satisfaction. Goals can be a standard tool for judging satisfaction. A person trying to attain a goal will not be satisfied unless he/she attains it. Not reaching one's goal creates increasing dissatisfaction. There is a paradox that people setting difficult goals are the least satisfied ones. This is because people with high goals produce more because they are dissatisfied with less (cf. Locke and Latham, 2013).

Here we consider the survival probability, which is defined as the probability of exceeding the expected profit, multiplied by a positive constant β with values from the interval $(0,1]$. This constant is assigned by the management and it is based on the company's strategy. We use a moving goal profit taking into account the strategy of the firm. The bigger the constant β, the more difficult the goal to be achieved by the decision maker. A company is doing well if it achieves "almost" the expected profit. Note that under the assumption of a positive expected profit, it is obvious that the probability of exceeding a lower profit target is greater than the probability of exceeding a higher one. It appears that when the profit target constant β is greater than 1, a solution to the satisficing--level model may be trivial. This problem needs additional assumptions but it is beyond the scope of our paper. For that reason we limit our study to the case when $\beta \in (0,1]$, because then a solution is non-trivial for all values of the order quantity. Another reason is that achieving almost the expected profit is regarded by the management as sufficiently good and the probability, that the expected profit will be exceeded is usually very small.

We also study the bicriteria newsvendor problem, which takes into account two objectives simultaneously. One of them is the maximization of the survival probability and the second one is the classical objective of the expected profit maximization. We propose a solution to the problem similar to that presented in Arcelus et al. (2012), since in our paper customer demand is also uniformly distributed, but with the profit target involving β. All results are precise and they are given in terms of that constant. Finally, we present numerical results and graphs for various values of β.

2 Satisficing-level newsvendor with uniform distribution

First we introduce the basic notation used throughout the paper. We use the notation from Arcelus et al. (2012), since we continue the problem studied in that paper. Let $p > 0$ be the unit revenue, $c > 0$ be the unit purchase cost, $s > 0$ be the unit shortage cost and $v \in R$ be the unit salvage value. The standard assumption is that $v < c < p$. The demand is a uniformly distributed random variable X on the interval $[A, B]$, with a known density function $f(x) = 1/(B - A)$. The order quantity Q is the only decision variable in the newsvendor model.

If the realized value of the demand is x, then the profit is given by

$$\pi(Q) = \begin{cases} px + v(Q - x) - cQ, & \text{if } \mathrm{x} \leq \mathrm{Q}, \\ pQ - s(x - Q) - cQ, & \text{if } \mathrm{x} > Q. \end{cases}$$

Note that the profit is random since it depends on the random demand X. Let the one-period random profit be denoted by $\pi(\mathrm{X}, Q)$. Then the expected profit function $E(Q) = E[\pi(\mathrm{X}, Q)]$ for uniformly distributed demand is given by

$$E(Q) = (p - v)(A + B)/2 + (v - c)Q - (p + s - v)\int_{Q}^{\infty} (x - Q)f(x)dx$$

(cf. Parlar and Weng, 2003).

The aim is to determine the optimal quantity Q which depends on the adopted optimality criterion. In the classical solution to this problem, the quantity Q which maximizes the expected profit is selected. Note that although $E(0) = -s\mu$ and $E(\infty) = -\infty$, we assume that the maximal expected profit is positive. The order quantity maximizing the expected profit for uniform distribution is equal to

$$Q_E^* = \frac{p+s-c}{p+s-v}(B - A) + A \quad (1)$$

(cf. Arcelus et al., 2012). An alternative optimality criterion, proposed by Parlar and Weng (2003), is to maximize the probability $P[\pi(X, Q) \geq E(Q)]$ of exceeding the expected profit. For this problem they give an approximate solution. They also suggest to consider the survival probability in the form $P[\pi(X, Q) \geq \beta E(Q)]$, where β is a positive constant. However, they state that for $\beta > 1$ some limitation on the order quantity should be imposed, which ensures that

$$\beta E(Q) \leq \pi_{\max}(Q), \quad (2)$$

where $\pi_{\max}(Q) = (p - c)Q$. For $\beta > 1$ inequality (2) does not have to be satisfied. In this case it can happen that $\beta E(Q) > \pi_{\max}(Q)$, which implies $P[\pi(X, Q) \geq \beta E(Q)] = 0$. Since we want to solve the given satisficing-level problem in general, without any conditions on Q, we study the case when $0 < \beta \leq 1$. This ensures that (2) is satisfied and the optimal order quantity can take any value from the set of all possible Q without limitations. On the one hand, we use the factor β which gives flexibility to the problem and on the other hand, we provide precise solutions, which is possible for uniformly distributed demand.

From Parlar and Weng (2003) we know that the survival probability $H(Q, \beta) = P(\pi(X, Q) \geq \beta E(Q))$ can be written in the form

$$H(Q, \beta) = \int_{D_1(Q,\beta)}^{D_2(Q,\beta)} f(x)dx,$$

where the integral limits $D_1(Q, \beta)$ and $D_2(Q, \beta)$ are functions of the order quantity Q and β. Determining the variability of the limit functions is crucial to the optimization of the survival probability. First, note that for uniform distribution $D_1(Q, \beta) = \max(A, \xi_A(Q, \beta))$, where $\xi_A(Q, \beta)$ is given by

$$\xi_A(Q, \beta) = \frac{\beta E(Q) + (c - v)Q}{p - v}$$

and $D_2(Q, \beta) = \min(\xi_B(Q, \beta), B)$, where $\xi_B(Q, \beta)$ is defined by

$$\xi_B(Q, \beta) = \frac{(p + s - c)Q - \beta E(Q)}{s}.$$

Now let Q_A and Q_B be the zeros of the limit functions defined by the equations

$$D_1(Q_A, \beta) = A \text{ and } D_2(Q_B, \beta) = B.$$

Solving these quadratic equations with respect to the order quantity Q we get the expressions for Q_A and Q_B. In computations the formula for $E(Q)$ with uniformly distributed demand is used, given by

$$E(Q) = \frac{(p-v)(A+B)}{2} + (v-c)Q - \frac{(p+s-v)(B-Q)^2}{\mathrm{B}-\mathrm{A}}.$$

Lemma 1

For $0 < \beta \leq 1$

$$Q_A = B - \frac{B-A}{\beta(p+s-v)}((c-v)(\beta-1)+\sqrt{\alpha}), \tag{3}$$

and

$$Q_B = B - \frac{B-A}{\beta(p+s-v)}(p+s-c+\beta(c-v)-\sqrt{\gamma}), \tag{4}$$

where

$$\alpha = (c-v)^2(\beta-1)^2 + \frac{\beta(p+s-v)}{B-A}((p-v)(\beta B-(2-\beta)A) + 2B(c-v)(1-\beta)), \tag{5}$$

and

$$\gamma = (p+s-c+\beta(c-v))^2 - \frac{\beta(p+s-v)}{B-A}(2B\big(p-c+\beta(c-v)\big) -\beta(p-v)(A+B)). \tag{6}$$

We obtain the following conclusions concerning the shape of the limit functions. For $0 < \beta \leq 1$ the function $D_1(Q, \beta)$ is constant and equal to A on $(A, Q_A]$, and it is increasing on (Q_A, B). The function $D_2(Q, \beta)$ is increasing on (A, Q_B), and then constant and equal to B on $[Q_B, B)$.

Now we have to analyze the variability of the difference between $D_1(Q, \beta)$ and $D_2(Q, \beta)$. Since condition (2) has to be satisfied, we have $D_2(Q, \beta) - D_1(Q, \beta) = \frac{p+s-v}{s(p-v)}((p-c)Q - \beta E(Q)) \geq 0$. In some cases the minimum distance between $D_2(Q, \beta) - D_1(Q, \beta)$ exists for some $Q = Q_M$. Minimizing the difference between $D_1(Q, \beta)$ and $D_2(Q, \beta)$ we get the following lemma.

Lemma 2

Let $0 < \beta \leq 1$. If

$$s + \left(1 - \frac{1}{\beta}\right)(p-c) > 0 \tag{7}$$

then the difference $D_2(Q, \beta) - D_1(Q, \beta)$ is minimized at the unique point Q_M given by

$$Q_M = A + \frac{B-A}{p+s-v}\left(s + \left(1 - \frac{1}{\beta}\right)(p-c)\right). \tag{8}$$

Otherwise, if

$$s + \left(1 - \frac{1}{\beta}\right)(p - c) \leq 0$$

then $D_2(Q,\beta) - D_1(Q,\beta)$ is an increasing function of Q for all $A \leq Q \leq B$.

Proof

Since

$$D_2{}'(Q,\beta) - D_1{}'(Q,\beta) = \frac{p+s-v}{s(p-v)}[(1-\beta)(p-c) - \beta s + \beta(p+s-v)F(Q)],$$

then from the equality $D_2{}'(Q_M,\beta) - D_1{}'(Q_M,\beta) = 0$ we get (8). Moreover, the second derivative $D_2{}''(Q,\beta) - D_1{}''(Q,\beta) = \frac{\beta(p+s-v)^2}{s(p-v)}$ is positive for all $Q \geq 0$. Therefore, the difference $D_2(Q,\beta) - D_1(Q,\beta)$ is a convex function of Q and it attains its minimum value at Q_M. The existence of Q_M follows from the constraint (7), which ends the proof.

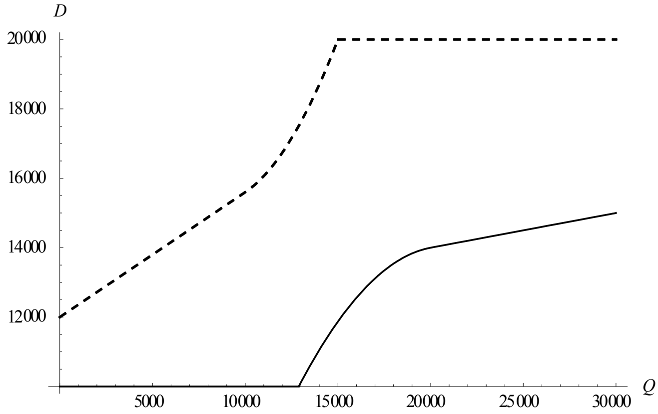

Figure 1: Limit functions D_1 (solid) and D_2 (dashed) for $\beta = 0.8$

Examples of graphs of functions D_1 and D_2 are presented in Figure 1. It should be emphasized here that if the demand is uniformly distributed then the minimum distance between the limit functions translates to the minimum probability $H(Q,\beta)$. Hence the survival probability attains the local minimum at the point Q_M if such a minimum exists. In the following theorem we study the monotonicity of $H(Q,\beta)$ when $0 < \beta \leq 1$. The results of Arcelus et al. (2011) for $\beta = 1$ can be obtained from the Theorem 1.

Theorem 1
If $0 < \beta \leq 1$ and Q_M, as defined by (8), exists then $H(Q,\beta)$ is increasing with respect to Q on (A, Q_A), decreasing on (Q_A, Q_M), increasing on (Q_M, Q_B), and finally decreasing on (Q_B, B) and

$$H(Q_A, \beta) = \frac{(p+s-c)\beta + c - v - \sqrt{\alpha}}{\beta s},$$

$$H(Q_B, \beta) = \frac{p+s-c+\beta(c-v) - \sqrt{\gamma}}{\beta(p-v)},$$

where Q_A and Q_B are defined by (3) and (4) and α and γ are given by (5) and (6), respectively. Then $H(Q,\beta)$ attains its maximum value Q_H^* at Q_A or Q_B and its local minimum at Q_M. If Q_M does not exist then $H(Q,\beta)$ is increasing on (A, Q_B) and decreasing on (Q_B, B), so it attains its maximum value at Q_B.

The proof of Theorem 1 follows directly from Lemma 1. Examples of graphs of the survival probability with constant $\beta = 0.8; 0.9; 1.0$ are presented in Figure 2.

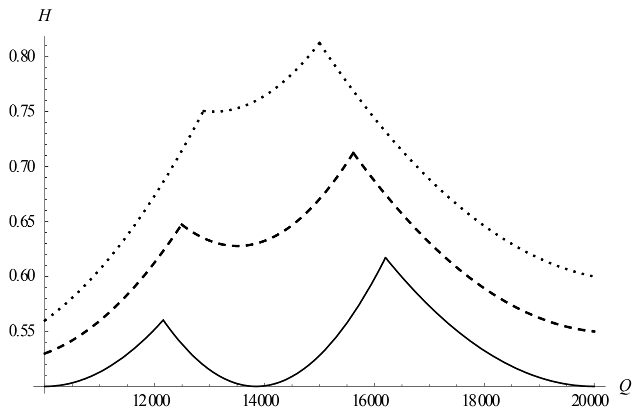

Figure 2: $H(Q,\beta)$ for uniform distribution and the model parameters $(A, B, v, c, p, s) =$ (10000,20000,10,30,50,25) with $\beta = 0.8$ (dotted); $\beta = 0.9$ (dashed); $\beta = 1.0$ (solid)

3 Bicriteria problem

In the next lemma we give inequalities for Q_E^* as defined by (1), Q_A and Q_B, which are used for solving the bicriteria problem.

Lemma 3
The order quantity Q_E^* satisfies the inequalities

$$Q_A < Q_E^* < Q_B, \quad \text{if} \quad p + s - \sqrt{\gamma} < c,$$

or

$$Q_A < Q_E^* = Q_B, \quad \text{if} \quad p + s - \sqrt{\gamma} = c,$$

or

$$Q_A < Q_B < Q_E^*, \quad \text{if} \quad p + s - \sqrt{\gamma} > c.$$

Now we recall the so-called bicriteria index, i.e. a measure which combines the classical newsvendor and the satisficing models. Let $E^* = E(Q_E^*)$ and $H^*(\beta) = H(Q_H^*, \beta)$. Then the bicriteria problem is to find the order quantity Q_Y^*, which maximizes the bicriteria index $Y(Q,\beta)$ with the non-negative weight $w \in [0,1]$ defined by

$$Y(Q,\beta) = wE(Q)/E^* + (1-w)H(Q,\beta)/H^*(\beta).$$

This is a kind of a vector optimization problem with defined weights. Here the model is transformed into a scalar optimization problem. The constants E^* and H^* normalize the weighted objective function since the values of two objectives can generally be very different. For $w = 0$ the problem reduces to maximizing the survival probability and for $w = 1$ it reduces to maximizing the expected profit. For detailed discussion on this subject see Chankong and Haimes (1983), Osyczka (1984).

The constant β influences the bicriteria index since it determines Q_H^*. There are several other methods for finding a compromise solution in multiple criteria problems.

In the light of Lemma (3) we have four cases, which give the position of the order quantity Q_Y^*:

Case 1: $H(Q_B,\beta) > H(Q_A,\beta)$ and $Q_E^* > Q_B$
Case 2: $H(Q_B,\beta) > H(Q_A,\beta)$ and $Q_E^* < Q_B$
Case 3: $H(Q_B,\beta) < H(Q_A,\beta)$ and $Q_E^* > Q_B$
Case 4: $H(Q_B,\beta) < H(Q_A,\beta)$ and $Q_E^* < Q_B$.

The solution in each case for $\beta = 1$ reduces to those given in Arcelus et al. (2012). In Case (1) we get the following theorem.

Theorem 2

If $H(Q_B,\beta) > H(Q_A,\beta)$ and $Q_E^* > Q_B$ then $Q_B \le Q_Y^* \le Q_E^*$ with

$$F(Q_Y^*) = 1 - \frac{c-v}{(p+s-v)Z}\left(\frac{w}{E^*} - \frac{(\beta-1)(w-1)}{(B-A)(p-v)H^*(\beta)}\right), \tag{9}$$

where $X_\beta = w/E^* - \beta(1-w)/[(B-A)(p-v)H^*(\beta)]$ and

$$w > \frac{\beta E^*}{\beta E^* + (B-A)(p-v)H^*(\beta)}. \tag{10}$$

Proof

First we show that $Y(Q,\beta)$ is decreasing for $Q > Q_E^*$ and increasing for $Q < Q_B$. Note that $E'(Q) = (p+s-v)(1-F) - (c-v)$ and $H'(Q,\beta) = -\frac{c-v+\beta E'(Q)}{(B-A)(p-v)}$. Moreover, $Y'(Q,\beta) = X_\beta E'(Q) - (1-w)(c-v)/[(B-A)(p-v)H^*(\beta)]$, where X_β is defined in the theorem. Then $Y'(Q,\beta)|_{Q_E^*} < 0$ since $E'(Q)|_{Q_E^*} = 0$, which implies that $Y'(Q,\beta) < 0$ for $Q > Q_E^*$. Furthermore, both $H(Q,\beta)$ and

$E(Q)$ are increasing on (Q_M, Q_B) and therefore so is $Y(Q, \beta)$. The optimality is proved by:

$$Y'(Q_Y^*, \beta) = 0, \text{which implies that equality (9) holds,}$$

and $Y''(Q, \beta) < 0$ if $X_\beta > 0$, which implies that condition (10) holds.

The feasibility is implied from

$0 \leq F(Q_Y^*) \leq 1$ if $X_\beta > 0$, which implies that the condition (10) holds and completes the proof.

In the next theorem Case (4) is considered.

Theorem 3

If $H(Q_B, \beta) < H(Q_A, \beta)$ and $Q_E^* < Q_B$ then $Q_E^* \leq Q_Y^* \leq Q_B$ with

$$Q_Y^* = F^{-1}\left\{\frac{p+s-c}{p+s-v} + \frac{(1-w)(p-c)}{(B-A)s(p-v)X_\beta H^*(\beta)}\right\},$$

where $X_\beta = w/E^* - \frac{\beta(1-w)(p+s-v)}{(B-A)s(p-v)H^*}$ and

$$w > \frac{1/s + 1/(p-v)}{(H^*(\beta)(B-A))/(\beta E^*(p+s-v)) + 1/s + 1/(p-v)}.$$

Note that Theorem 2 is applicable to Case (3) and Theorem 3 is applicable to Case (2); the optimal solution Q_Y^* satisfies

$\min\{Q_E^*, Q_B\} \leq Q_Y^* \leq \max\{Q_E^*, Q_B\}$.(11)

The solution to the bicriteria problem for $w = 1$ is the same as to the expected profit maximization problem. Additionally, there exists $w_r \in [0,1)$ such that the solution to the bicriteria problem is equal to Q_Y^* for some $w > w_r$, and it is the same as the solution to the probability maximization model Q_H^* for $0 \leq w < w_r$. Tables 1 and 2 below present numerical examples for Case (1). We use the same values of parameters as in [1], but additionally the constant β is involved. Note that the above expression for $\beta = 1$ reduces to the results known from Arcelus et al. (2012). We present them here to complete the overview of the problem. A numerical example is given below. Let $Y^*(\beta) = Y(Q_Y^*, \beta)$.

Table 1: Retailer policies – Case (1): $H(Q_B, \beta) > H(Q_A, \beta)$ and $Q_E^* > Q_B$ with $(A, B, v, c, p, s) = (10000,20000,10,30,50,15)$

Q_E^* =16364		**E^* =236364**	
β	0.8	0.9	1
$Q_A(\beta)$	12333	11866	11472
$Q_B(\beta)$	13435	14368	15222
$H(Q_A(\beta), \beta)$	0.855	0.68	0.54
$H(Q_B(\beta), \beta)$	0.9	0.77	0.66

Table 2: Retailer policies – Case (1): Bicriteria solution, parameters the same as in Table 1

$\boldsymbol{\beta}$	$\mathbf{0.8}$		$\mathbf{0.9}$		$\mathbf{1.0}$	
w	$\boldsymbol{Q_Y^*}$	$\boldsymbol{Y^*(\beta)}$	$\boldsymbol{Q_Y^*}$	$\boldsymbol{Y^*(\beta)}$	$\boldsymbol{Q_Y^*}$	$\boldsymbol{Y^*(\beta)}$
1.0	Q_E^*	1.0	Q_E^*	1.0	Q_E^*	1.0
0.9	16083	0.979	16030	0.985	15960	0.99
0.8	15679	0.961	15526	0.973	15309	0.98
0.7	15048	0.947	14679	0.968	Q_B	0.989
0.6	13926	0.941	Q_B	0.972	Q_B	0.991
0.5	Q_B	0.95	Q_B	0.977	Q_B	0.992
0.4	Q_B	0.96	Q_B	0.981	Q_B	0.994
0.3	Q_B	0.97	Q_B	0.986	Q_B	0.995
0.2	Q_B	0.98	Q_B	0.991	Q_B	0.997
0.1	Q_B	0.99	Q_B	0.995	Q_B	0.998
0.0	Q_B	1.0	Q_B	1.0	Q_B	1.0

Let us analyse Case (1). From Table 1 we see that if constant β increases from 0.8 to 1.0 then the maximal survival probability $H(Q_B, \beta)$ decreases from 0.9 to 0.66, but the optimal order quantity Q_B increases from 13435 to 15222. Moreover, the order quantity Q_A decreases from 12333 to 11474. Summarizing, for greater values of β the values of Q_A increase but the values of Q_B decrease. We also see that the probability of achieving a target profit greater than 80% of the expected profit is significantly greater than the probability for $\beta = 1$ (about 27%). Because of this, one should considered setting a goal slightly lower but one that is much more likely to be achieved.

Next, in Table 2 we see that for given β the compromise solution Q_Y^* increases from Q_B to Q_E^* as the weight w increases. Note that if we assume that $w > w_r = 0.5$ and that condition (11) is satisfied, we have $Q_Y^* = Q_B$ for $\beta = 0.8$. If $\beta = 0.9$ and $w \leq 0.6$ then $Q_Y^* = Q_B$. Finally, for $w \leq 0.7$ and $\beta = 1.0$ we get also $Q_Y^* = Q_B$.

4 Conclusions

In this research note we extend the results of Arcelus et al. (2012) concerning the solution to the bicriteria newsvendor optimization problem with uniformly distributed demand. The authors of the cited paper studied both the classical and the satisficing-level objectives simultaneously. We modify the satisficing-level objective by introducing the target profit as the expected profit multiplied by a positive constant with values from the interval (0,1]. This constant is fixed by the company management; the larger the constant is, the more difficult task for the staff is required. We limit our considerations to the interval (0,1], because setting this constant greater than one requires additional assumptions on the order quantity. Finally, we investigate the bicriteria newsvendor problem in the numerical example for various values of this constant.

We emphasize here that for the general distributions in the satisficing-level problem only bounds on the optimal order quantity can be obtained (cf. Parlar and Weng, 2003). Because of that, we use uniformly distributed demand, which substantially simplifies the expressions obtained and allows to obtain precise solutions. After the introduction of the constant to the goal profit, the derivations are not automatically transformed from the results of Arcelus et al. (2012). The constant used in the goal profit substantially changes the solutions. The model developed here can be viewed, as a tool to assist the management in determining the target level.

In future research one can investigate the problem with a high goal and the constant greater than one. Additionally, other methods, which provide precise solutions to the satisficing-level problem for any demand distribution should be found and methods other than bicriteria decision making can be proposed. Moreover, a new measure of satisfaction using the survival probability studied here can be created. In our paper the satisfiction is defined in terms of goal setting theory as the satisfaction of attaining the goal. Only two states are therefore possible: being satisfied or not. One can probably consider measuring satisfaction using a continuous measure based on our paper.

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