Literature Review on Shortage Cost Modeling in Inventory Management

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Abstract: In this article, we emphasize on one hand the importance of quantifying the shortage cost in order to measure the optimal parameters for any selected inventory policy and thus enhance the performance of the supply chain and on the other hand the complexity of doing so. Then, we provide a detailed literature review of the existing various models for quantifying the shortage cost in an inventory management context along with a classification of this literature under three categories: Theoretical descriptive models, empirical approaches and simulation based models. Finally, we point out some gaps in this literature such as the lack of continuity of research in this field and the absence of generic fairly easy to apply but accurate methods and we suggest a few future perspectives.

1 INTRODUCTION

Competition in the various market segments is growing more and more intense. Hence, businesses are exposed to an increasingly uncertain demand which could be influenced by a large variety of factors. To cope with this variability, companies must improve their supply chain performance especially through finding and implementing the optimal inventory policy. First, the most appropriate inventory policy needs to be selected. Then, its optimal parameters have to be determined. This is easier said than done. In reality, finding these optimal settings raises two challenges: Economy of scale and safety in the face of uncertainties. The first challenge involves reconciling replenishment costs and carrying excess inventory costs. As for the safety issue, managers have a hard time balancing two types of risks. If demand is lower than forecasted, an excess inventory is carried. It is regarded as an over-investment. Otherwise, if demand exceeds the predicted quantity, a stock-out situation occurs. Therefore, customers' orders are backordered or lost.

To mediate between these risks, the best solution would be to minimize the average total cost composed of the overage and shortage costs (Babai, 2005).

The overage cost includes mainly the cost of carrying the excess inventory for a certain time span. Measuring it is relatively simple. Four cost categories must be considered (Lambert, 1975):

- Capital costs;
- Inventory service costs;
- Storage space costs;
- Inventory risk costs.

The shortage cost turns out much more difficult to be accurately assessed. It is composed of tangible and intangible components (Zinn and Liu, 2001).

The tangible part depends greatly on customers short-term responses to stock-outs. In fact, a customer that does not find the product might either choose an alternative (Substitute), postpone the purchase to a later date (Delay) or buy at the competition (Leave). Each one of these responses produces a different shortage cost.

The intangible components are even trickier to identify and measure. For example, they should capture how stock-out situations may reduce future purchases, how customers could mutually change their perceptions of stock-outs through negative comments and what kind of impact does a second or a third stock-out instance possess (Babai, 2005). The impairment losses of goodwill due to shortages should equally be estimated. Goodwill is considered

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an intangible asset and it reflects the value of a company's brand name, solid customer base, good customer relations, good employee relations, and any patents or proprietary technology. These elements have subjective values which makes it extremely hard to price any changes on Goodwill.

This list of components is not exhaustive. Any factor that could reflect customer long-term response to shortages must be included.

Generally, managers try to subvert the complexity of quantifying the shortage cost by adopting a control parameter known as the service level. The most applied measures of service level are (Silver and Peterson, 1991):

- Cycle service level;
- Ready rate;
- Fill rate;
- Average time between stock-out occasions.

These measures are used by decisions makers as constraints. One example is to minimize the total average cost of replenishment and carrying inventory while maintaining a pre-selected fraction of demand satisfied from shelf. Service level constraints simplify the complexity of the problem and decisions making becomes easier and faster. However, these decisions and their outputs remain far from optimal. Another downside is the lack of formal rules for selecting the most relevant measure and its desired threshold. Without these rules, the choice depends only on management recommendations and managers experiences.

Despite the high complexity, certain scientific papers addressed this issue and proposed different models for quantifying the shortage cost. Nevertheless, as far as we know, a comprehensive literature revue that regroups all these models has yet to be developed. Providing such literature revue is important since it will be a guide for researchers who want to venture in this area. Consequently, it may help to advance research in the topic.

In this paper, we provide a detailed literature review of the various models for quantifying the shortage cost in an inventory management context along with a classification of this literature. Three categories were identified:

- Theoretical descriptive models;
- Empirical approaches;
- Simulation based models.

The remainder of this study is structured as follows: First, we describe thoroughly each one of these categories. Then, we point out some deficiencies spotted in this literature and propose a few future perspectives.

2 THEORETICAL DESCRIPTIVE MODELS

2.1 Traditional Methods

When seeking to optimize inventory levels, simple shortage cost calculation approaches are regularly privileged. (Ernst and Powell, 1995) mentioned that the traditional method to decide between inventory policies assumes a fixed shortage cost that includes the additional costs of processing backorders and expediting shipments to satisfy backordered demand. Streamlined stock-out penalty functions were often applied. (Albright and Wayne, 2009) considered a fixed penalty cost to convey the negative repercussions of stock-outs. (Lee and Whang, 1999) used a linear penalty cost function to represent stock-outs in different internal levels of the same company. (Badinelli, 1986) tried to integrate a subjective evaluation of the shortage cost in optimizing the safety stock. His method defines a nonlinear decision makers' disvalue function for stock-out performance that reflects their uncertainty regarding trade-offs between holding inventory and incurring stock-outs.

2.2 Customers Future Demand Reduction

Other researchers analyzed the shortage cost from another perspective: The loss of dissatisfied customers' Goodwill. They emphasized that inappropriate inventory levels would lead to the reduction of the quantity of customers' future purchases (Campo et al., 2003). In this case, the shortage cost is assessed by looking at how future demand decreases in response to customers being discontent rather than by assigning an instant approximate penalty function to it.

(Schwartz, 1966) was among the first to propose a perturbed demand model, in which a disappointment factor was used to quantify the impact of stock-outs on the long-run demand, as a replacement for the traditional backorder penalty cost model. He assumed that when the amount of backordered units attains L, a quantity M is ordered. The disappointment factor α was defined as the ratio of backlogged demand during stock-out conditions to total demand or in other words as the complement of the demand fill rate.

$$\alpha = L / M \quad (1)$$

Furthermore, the expected long-run demand in the presence of stock-outs was expressed as follows:

$$\lambda(\alpha) = \lambda_0 \,/\, (1 + \alpha * I) \quad (2)$$

Where λ_0 is the hypothetical expected long-run demand in the absence of stock-outs and I is the average total number of units a disappointed customer will not order in the future after facing a single shortage situation.

Four years after, (Schwartz, 1970) broadened the scope of his deterministic model to cover the stochastic demand case. In fact, λ became a random variable and its expected mean value μ was calculated through a variant of equation (1).

$$\mu = \mu_0 \,/\, (1 + \alpha * I) \quad (3)$$

Where μ_0 is a hypothetical maximum demand rate.

On the other hand, the standard deviation was left unspecified. The author presented equally an example in which the demand behaved according to a Poisson distribution law.

(Caine and Plaut, 1976) further advanced the previous analysis. They generalized equations (1) and (2) to the stochastic demand case.

They defined an expected disappointment factor β such that:

$$\beta = \frac{\int_y^{\infty} (x - y) * \phi_0(x)\, dx}{\int_0^{\infty} x * \phi_0(x)\, dx} \quad (4)$$

Where y is the inventory level at the start of each period.

Additionally, they assumed that the probability density function of the long-run demand taking into account stock-outs $\phi_\beta(x)$ was a function of β and the probability density function of demand in the absence of shortage situations $\phi_0(x)$.

$$\phi_\beta(x) = g_\beta * \phi_0(g_\beta * x) \quad (5)$$

Where g_β is a function of β that satisfies the following requirement:

$$g_\beta \geq 1 \quad (6)$$

$$g_\beta \to 1 \quad \text{as} \quad \beta \to 0^+ \quad (7)$$

$$g_\beta \to +\infty \quad \text{as} \quad \beta \to 1^- \quad (8)$$

All the previous papers provided persuasive argumentations for the utility of the perturbed demand model. They introduced several variations of it as well. However, they did not solve any of them.

Most recently, (Liberopoulos et al., 2010) tried to address this issue. They submitted solutions for Schwartz's original model and its variations. These solutions helped deduce a formulation of the value of the backorder penalty cost coefficient used in the classical economic order quantity model with planned penalized backorders. An important conclusion of their work was that the optimal fill rate is always 0 or 1, implying a shortage penalty cost equal to 0 or ∞.

Some other papers approached the decreasing future demand problem in different ways.

(Ernst and Cohen, 1992) built a stochastic model describing the interactions between a retailer and a manufacturer. They employed a linear demand function that links the mean demand to the service level provided by the retailer to the market.

$$D(SL) = [1 + \eta * (SL - SL_0)] * D(SL_0) \quad (9)$$

Where SL_0 is the initial offered fill rate, SL is the achieved fill rate and η is a multiplier that determines the rate of change in demand as a result of the deviation of service from the initial condition.

To illustrate their methodology, the authors investigated the particular case of a demand following a Stuttering Poisson distribution (Arrivals are Poisson, and order quantities follow a Geometric distribution), in which they assumed that the standard deviation could be related to the fill rate by the same relationship as in equation (9).

(Ernst and Powell, 1995) commented the previous models and emphasized the fact that the standard deviation of demand have been always supposed, without convincing evidences, to increase, with the service level, in proportion to the mean. And, thus, they proposed an approach where these two parameters could respond independently to variations in the service rate.

(Robinson, 2016) developed a stochastic periodic review inventory model in a dynamic environment. He presumed that the mean demand varies from period t to the next, growing proportionally to the number of satisfied customers s_t and dropping with the number of dissatisfied customers d_t due to out-of-stock conditions.

$$\mu_{t+1} = a + b * \mu_t + r_s * s_t - r_d * d_t \quad (10)$$

Where a and b capture the underlying size and growth in the market and r_s and r_d transmit the response rate for satisfied and dissatisfied customers.

2.3 Uncertainty of the Shortage Cost

The aforementioned studies either poorly described or even disregarded the uncertainty of the shortage cost. Certain papers including (Ishii and Konno, 1998), (Petrovic et al., 1999), (Katagiri and Ishii, 2000) and (Vijayan and Kumaran, 2008) tackled this concern through fuzziness.

(Ishii and Konno, 1998) integrated fuzziness of the shortage cost into the classical newsboy problem. They assumed that the cost of a single stock-out is an L fuzzy number $\tilde{c}$. Then they multiplied this unit fuzzy cost by the random variable $\max\{Y - x, 0\}$, where Y is also a random variable representing the daily demand and x is the purchasing quantity, to get the total shortage cost:

$$\sum_{y=x+1}^{\infty} \tilde{c} * (y - x) * p(Y = y) \qquad (11)$$

This expression was used afterwards to write the expected profit function which in turn becomes a fuzzy number. Finally, they found an optimal ordering quantity that maximizes the fuzzy order of the profit function.

(Katagiri and Ishii, 2000) employed the same reasoning while investigating an allocation problem of perishable goods that needs to be distributed from a regional facility to n local centers. At each one of these centers:

- A periodic review inventory model was considered;
- Products were assumed to follow a LIFO issuing policy;
- The residual amount at the end of each period was sent back to the regional facility;
- Products that reached a certain age M were disposed of.

The main objective of this study was to find the optimal rotation allocation policy that minimizes the system total cost composed of the shortage and outdating costs at each local center and transportation costs between the regional facility and the local centers. They aimed also to explain the difference between the optimal solutions of the fuzzy and non-fuzzy shortage cost cases.

(Vijayan and Kumaran, 2008) explored both continuous review (Q, r) and periodic review (R, T) inventory models with a combination of backorders and lost sales in a fuzzy context. They introduced trapezoidal fuzzy numbers to represent cost components: Ordering, holding and shortage costs.

Among the scarce researches that tried to evaluate the shortage cost and its uncertainty through probabilistic measurement, we retain (Xu, 2017). He proposed a statistical model that estimates analytically the expected shortage cost and its variance. To this end, he considered the following assumptions:

- The probability of a stock-out happening is a decreasing function of the shortage quantity m. Thus, m's behavior is given by an exponential distribution;
- The shortage cost x grows with an accelerated pace according to the stock-out amount increase. Therefore, x is supposed to have a lognormal distribution which depends on m.

Subsequently, the marginal probability density function p(x) was derived by doing the integral of the joint probability function of (x, m). At last, using p(x), (Xu, 2017) calculated the mean and the variance of the shortage cost.

3 EMPIRICAL APPROACHES

Many attempts to estimate the shortage cost first start with studying customers' responses given their close relationship. On 1968, the Progressive Grocer study laid the foundation stone for the research conducted in the area of out-of-stocks and customers' responses. Two reports were published. The first one was dedicated to interview experts from various levels of the supply chain. Three points were treated: the importance of stock-out situations, potential consequences and suspected causes. The second part measured the frequency of stock-outs for items sold in stores and surveyed customers reactions. The results reported an average rate of unsatisfied demand equal to 12.2 %. This percentage was highly variable across stores, product categories and days of the week. After 1968, interest in this research area grew. Many papers studying customers' responses to stock-outs were issued. We propose to classify these researches into two categories:

- Empirical descriptive;
- Empirical explanatory.

3.1 Empirical Descriptive Studies

Papers from this category focused on establishing decision trees that chart all these responses and attempted to estimate the frequency of each SDL (Substitute, delay and leave) behavior as well.

(Walter and Grabner, 1975) surveyed the intended behavior of liquor store customers in Ohio following stock-outs. After analyzing data from 1433 anonymous questionnaires, they identified six response alternatives and measured their respective economic consequences using the revenue difference between the intended and the actual purchase. Table 1 regroups the most important findings. The first column is dedicated to enumerate the various alternatives and the last one to the expected value of the shortage cost which is the product of the revenue difference and the frequency for each behavior option. 83.4 % of the respondents stated to have turned to a substitute when facing a stock-out inducing an average loss of 0.36 dollars each. More important still, the cost of every shortage situation was estimated to reach 1.26 dollars on average.

Table 1: Financial implications of a stock-out (Walter and Grabner, 1975).

Options	Revenue Difference ($)	Frequency (%)	Expected Value ($)
Substitute (expensive brand)	+ 0.61	2.6	+ 0.02
Substitute (brand with same price)	0	59.1	0
Substitute (cheaper brand)	- 0.61	2.4	- 0.01
Substitute (another size)	- 1.93	19.3	- 0.37
Return trip	- 6.61	2.5	- 0.17
Visit another store	- 5.21	14.1	- 0.73
Expected shortage cost per unit of unsatisfied demand			- 1.26 $

(Schary and Christopher, 1979) carried out 1167 exit interviews with shoppers of a London supermarket chain. 343 interviewees who confronted at least one stock-out situation were asked to specify their reactions by choosing from the following list: No buy, postpone, substitute to other brand, substitute within brand, go to other stores. Furthermore, customers' response patterns were confronted to store image, brand loyalty and some demographics variables.

For four days, (Emmelhainz et al., 1991a) examined customers reactions to stock-out situations in a major discount grocery store. They set up a field experiment. Five product groups were picked and a shortage condition for a specific brand, variety and size of each group was introduced by retrieving it from the shelfs of the store. Availability of size, variety and brand substitutes was partly the reason why these groups were selected. 2810 individuals agreed to participate and 24 percent of them planned to purchase at least one of the five test product categories. A total of 375 customers could not find the item they were looking for. The authors identified 16 distinct response variations. The most frequent responses to stock-outs were: Substituting a different brand while keeping the same size and variety with 20.5 percent, substituting a different variety while keeping the same size and brand with 17.5 percent, and not substitute at all with a plan to go to another store with 13.7 percent. Implications for retailers were equally analyzed.

(Gruen et al., 2002) recognized the same five response options as in (Schary and Christopher, 1979). They further stated that distinguishing between substitute within same brand and substitute with other brand is important to examine the impact for suppliers.

(Sloot et al., 2005) discerned six reactions and ranked them from relatively high to relatively low brand loyalty: Store switch, item switch (switching to another variety of the same brand), postponement, cancel, category switch (buying a substitute product from another product category), brand switch (buying another brand within the same product category).

Table 2 summarizes SDL behavior results from various researches.

Table 2: SDL behavior frequencies.

	S (%)	D (%)	L (%)
(Progressive Grocer, 1968)	47.8	24	28.2
(Walter and Grabner, 1975)	83.4	2.5	14.1
(Schary and Christopher, 1979)	22.2	29.8	47.9
(Emmelhainz et al., 1991a)	36	25	39
(Verbeke et al., 1998)	51	25.2	23.8
(Zinn and Liu, 2001)	62	15.1	22.9

Only a handful of papers, such as, (Oral et al., 1972), (Perreault and Russ, 1976), (Dion et al., 1991), (Dion and Banting, 1995), tried to determine customers' responses after shortage conditions in a B2B environment.

(Dion and Banting, 1995) conducted several personal interviews and one mail survey of professional business to business market buyers. Their aim was to evaluate how these buyers perceive being stocked out by their suppliers and how would they react on their next purchase occasion. Figure 1 shows how buyers react according to Dion and Banting model.

Nearly 25 % of the buyers participating in the survey turned to another supplier for the unsatisfied

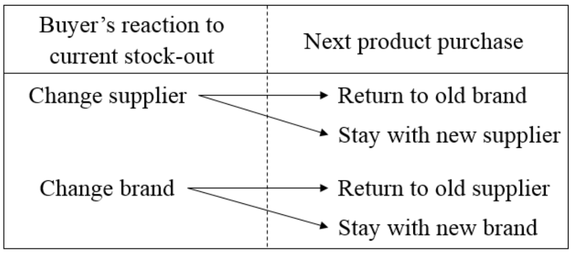

Figure 1: Current and future buyers responses to stock-outs in B2B environment (Adopted from (Dion and Banting, 1995)).

purchase and then 60 % of them went back to their original supplier. The same percentage sought an alternative brand but approximately 75 % returned to their original brand. The authors concluded equally that buyers were more loyal to brands than to suppliers.

3.2 Empirical Explanatory Studies

The second research stream changed its focus towards explaining the reasons and factors behind each behavior by developing and testing more theory based models.

(Zinszer and Lesser, 1981) were among the first to explore this research field. They analyzed how different demographic characteristics and promotions affect customers' responses. Sensibility of store image to stock-outs was also examined.

In the continuity of their previous work, (Emmelhainz et al., 1991b) investigated the effects of the perceived risks of switching to alternative brands, the urgency of purchase and the nature of use occasions on the likelihood of brand substitution.

(Verbeke et al., 1998), inspired by (Emmelhainz et al., 1991a and 1991b), carried out a similar field experiment which consists of removing deliberately five leading brands of different product categories. They studied the impacts of the following variables on customers' decisions: Availability of rival stores, temporary or permanent out-of-stock condition, store loyalty, size of the shopping trip.

The research of (Campo et al., 2000) is particularly noteworthy. They developed a theoretical framework to explain consumer OOS responses. They declared that a shopper facing a shortage situation has to choose between certain options. Each one of them generates specific costs. Then, they supposed that the most probable choice is the one that maximizes the net benefits or utility. The utility of choosing option j for shopper h in product category c on purchasing occasion t was given by:

$$U^{j}_{h,t,c} = -C^{j}_{h,t,c} + \varepsilon^{j}_{h,t,c} \quad (12)$$

Where $C^{j}_{h,t,c}$ is the total cost incurred by household h on occasion t, when choosing option j in product category c and $\varepsilon^{j}_{h,t,c}$ is a random utility component.

Further, they deduced that the probability of shopper h choosing option j in category c on occasion t, when $\varepsilon^{j}_{h,t,c}$ are independent and identically distributed double exponential random errors, was written as follows:

$$P^{j}_{h,t,c} = \frac{U^{j}_{h,t,c}}{\sum_k U^{k}_{h,t,c}} \quad (13)$$

To assess the total cost incurred, the authors considered three sub-costs: Substitution costs (Decreased utility of item switching), transaction costs (Search, handling and transportation costs), and opportunity costs (Costs of not consuming in the category).

(Zinn and Liu, 2001) analyzed the connection between SDL behavior and pre-selected variables which belong to one of these categories: Situational, consumer characteristics, perceived store characteristics, consumer demographics. Written questionnaires were handed to customers while exiting the store. From a total of 283 interviewees, only 230 experienced stock-outs. First, they pinpointed the differences in perceptions between customers who did and did not face a stock-out, notably in terms of store image. Then, they used multinomial logit modeling to explore the relationship between SDL behavior and the chosen variables. Table 3 synthetizes the most significant relationships spotted.

Table 3: Summary of significant relationships between SDL behavior and the chosen variables (Zinn and Liu, 2001).

	Substitute	Delay	Leave
Store prices	+	+	-
Urgency	+	-	
Brand loyalty	+		
Upset	-		
Surprise		-	+
Pre-visit agenda		+	

(Ghesquiere, 2007) used also questionnaires to collect data about store features, product features, consumer features and situational factors at the time of purchase. Then, she compared the characteristics of two groups: Those who experienced at least one stock-out condition and those who did not. She applied the Kruskal-Wallis non-parametric test to compare the quantitative variables common to both groups and conducted a Chi-square cross-tab test to estimate the similarities between the qualitative variables of the two groups. The results of the comparison show that individuals have different characteristics in terms of frequency of purchase, amount spent, level of satisfaction, store loyalty and whether or not the store studied is the main store at the 5 % threshold. On the other hand, similarities between consumers in the two groups were found regarding the intention to return to the same store, age, activity and gender at the 5 % threshold. Finally, she employed the multiple correspondence analysis method to study the factors influencing the behavior of consumers who faced a stock-out.

Several other articles examined the effect of various variables on store customers' choices after being in a stock-out situation. We mention, (Corstjens and Corstjens, 1995), (Hoch et al., 1999), (Fitzsimons, 2000), (Kucuk, 2004), (Anderson et al., 2006), (Van Woensel et al., 2007) and finally (Breugelmans et al., 2006) and (Dadzie and Winston, 2007) who looked at online stock-out reactions. For more details on these researches and their findings, we recommend reading (Sloot et al., 2005).

4 SIMULATION BASED MODELS

This kind of approaches is hard to come across in the literature.

(Farris et al., 1989) developed a simulation model and proved that distribution and market share were linked by a positive curvilinear function. They assumed that retailers prioritize filling the shelves with the best-selling brands. Additionally, they deduced that brands with larger market shares benefit the most from small share brands stock-outs.

(Langton and Geiger, 2011) concentrated on quantifying the opportunity cost of stock-outs using a knowledge based approach. They developed a Genetic Program capable of learning opportunity cost functions from case-based decisions made by experts. They further compared their model's results with results generated by Neural Networks.

5 DEFICIENCIES AND FUTURE PERSPECTIVES

We certainly found and presented the great majority of papers dealing with the shortage cost quantification. However, this number remain insufficient specially compared to the relevance of the problem and there are very few recent articles. Moreover, the models already introduced are either very simple and thus do not reflect reality or very complicated to the point they became highly context and company specific and therefore do not apply for a different finality than the one they were built for. We can also conclude that the most accomplished methods are hard to implement practically speaking because efforts to achieve them are greater than their benefits. Furthermore, we observe a little too many gaps in this literature:

- There are very few papers using probabilistic measurements to quantify the shortage cost and its uncertainty.
- Only a handful of papers discussed stock-out reactions for online shoppers and B2B buyers.
- There are very few papers that are interested in using simulation based models to measure the shortage cost.

As a result, future researches should address these shortfalls by proposing more generic, context neutral and applicable with reasonable effort methods. Researchers must renew their interest in this problem since there is still plenty to explore and it might be a good idea to start by bridging the gaps previously mentioned.

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