

Optimizing Unsold Inventory Decisions under the Newsvendor Model

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Abstract— Unsold products represent a persistent operational and financial challenge for manufacturers, wholesalers, and retailers. This paper aims to address the problem of unsold inventory management by developing a decision-support framework for clearance strategies. Based on the newsvendor model, the proposed approach jointly optimises supply chain profit from regular market sales and clearance sales. The optimisation relies on a qualitative risk-performance assessment of alternative clearance strategies, incorporating managers' industrial knowledge. A numerical illustration highlights the main drivers influencing the selection of an optimal clearance policy, namely acceptable risk levels, expected clearance revenues, and capacity constraints. The results provide actionable managerial insights and are synthesised into a practical decision-making approach to support practitioners in selecting effective clearance strategies. The proposed framework is applicable to both seasonal and non-perishable products.

Keywords— Newsvendor model, unsold inventory, uncertain demand, multi-objective optimization, piecewise linearization.

1. Introduction

The mismatch between supply and demand poses a significant challenge for many companies, leading to losses whether the supply exceeds or falls short of demand. Underestimating demand often results in low order quantities, leaving customers dissatisfied and causing revenue loss. Conversely, the accumulation of unsold inventory remains a major obstacle. From a conceptual perspective, the bullwhip phenomenon illustrates how small

deviations at the upstream stages of a supply chain can amplify into substantial operational distortions. Organizations using conventional planning approaches are particularly vulnerable to abrupt fluctuations in demand [1]. Inaccurate forecasts, lack of market knowledge, product returns, late deliveries, unreliable suppliers, failing to exchange reliable information throughout the supply chain, lead time variability and short product life cycles contribute to unsold inventory in various industries [2], [3], [4], [5], [6]. For instance, in the agribusiness sector, over 40% of products remain unsold [7], while electronic products (30%), cultural products (including CDs, DVDs, and books, 40%), and apparel (20%) face similar challenges [3]. The publishing industry contends with a staggering 60% unsold inventory [7].

Ref. [8] underlines that the unsold products not only occupy significant warehouse space, but also contributes to increased storage costs [4]. Therefore, efficiently managing unsold inventory is imperative [9]. Indeed, effectively managed, unsold goods can yield substantial financial benefits. Ref. [10] highlights the impact of excess inventories (for retailers and wholesalers) on margins and net earnings, emphasizing the importance of discounted prices in such a situation. With respect to customers, we even note that displaying too many products is not advisable, since overly crowded shelves may create an unfavorable perception [11].

Consequently, the secondary market, also referred to as the After-Retail Excess Inventory channel, has gained prominence [12]. Ref. [13] underlines that this channel aims to maximize returns by disposing of obsolete, scrap, excess, and waste goods, making it an essential facet of supply chain management. The secondary market's value is substantial, with estimates reaching \$15 billion for electronic components in 2008 [14]. In the pharmaceutical industry, it accounted for \$20 billion, representing 6% of the total pharmaceutical products market in 2007. The smartphone secondary market is poised for growth, projected to reach 222.6 million units with a total market value of \$30 billion by 2020 [13].

However, the fashion industry, driven by concerns of brand protection, often resists liquidating excess inventory on the secondary market, instead opting to destroy it. This practice has made fashion and apparel one of the most environmentally polluting industries. Excess inventory leads to the generation of hazardous waste, causing significant environmental harm. Sustainability has recently emerged as a critical factor for success and differentiation in multiple industries. Leading brands are now developing environmental, social,

and governance (ESG) initiatives to mitigate their environmental impact [15].

Consequently, we may underline that main objectives of companies when liquidating their unsold inventory are to maximize financial gains (generate profit even through zero-margin sales, which remains preferable to holding unsold inventory) and to optimize warehouse space. Therefore, managers must decide when to liquidate, how much to liquidate and how to liquidate.

Figure 1 shows a product lifecycle from its launch to liquidation. Two selling periods are considered, the market period and the selling-off one. During the first period, companies consider new items / collections and opt for a price markup policy. Then, they apply a price markdown policy throughout the selling-off period using clearance strategies. First, they maximize their financial benefits by proposing reduced prices on unsold items. Then, any remaining products are subsequently treated as dead or obsolete stocks and must be disposed of. However, if the company's main objective is to urgently save warehouse space, it can directly eliminate unsold items.

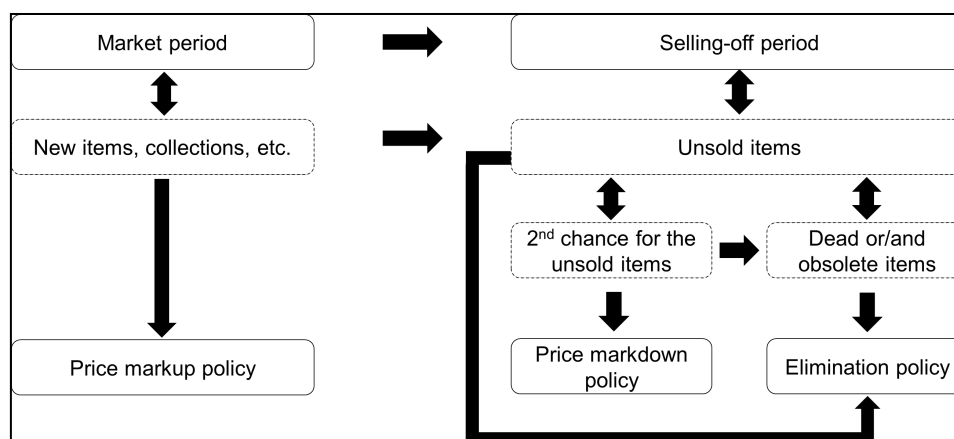


Figure 1. Product lifecycle

Ref. [2] proposes several clearance strategies to liquidate unsold amount. In this study, we aim to combine the proposed clearance strategies within the Newsvendor framework. We use the classical Newsvendor model (NVM) which aims to order the optimal quantity before the selling season. It optimizes the profit considering a selling price for the market period, a salvage revenue for the selling-off period and a shortage cost for the sales lost in the out-of-stock situation. Our main contribution

concerns the selling-off period, where we consider several salvage revenues, each one associated with a clearance strategy. We underline that each strategy has its own characteristics in terms of percentage of discount, advantage, performance, risks incurred, capacity etc. Therefore, selecting the most appropriate strategy(ies) in the light of the company's objectives represents a crucial step.

Consequently, this paper primarily focuses on generating profit from non-perishable seasonal

items' unsold inventory. It proposes a NVM that considers multiple clearance strategies, requiring their selection and quantity allocation before the market period, while simultaneously optimizing the total profit, supply chain clearance performance and the ordered quantity for the entire season. The optimisation is conducted through a qualitative risk-performance assessment of the clearance strategies. This simultaneous examination has not previously been addressed in the literature. As such, it contributes to research on clearance chain management and NVM, specifically in areas:

- At the start of the market period, how much to order and what clearance strategies to choose?
- How do clearance strategies (in terms of number, amount of liquidation, cost, etc.) impact company revenue and other performance metrics?
- What are the parameters or factors that are important in such a decision-making system?

While:

- Considering both cash-recovery and disposal clearance strategies.
- Assessing costs and performance metrics for each strategy.
- Evaluating total profit and overall performance.
- Incorporating a risk-based and capacity-constrained approach.

The remainder of this paper is organized as follows: Section 2 reviews relevant literature, while Section 3 details the proposed model. Section 4 presents a numerical example illustrating the proposed approach and includes a sensitivity analysis. Finally, Section 5 highlights the major results and provides concluding remarks.

2. Review of the relevant literature

The literature presented below is categorized into two sections: (2.1) practical clearance strategies and (2.2) the utilization of NVM to manage and / or decrease unsold stock levels.

2.1 Clearance strategies

Companies use different strategies to deal with their unsold inventory. Ref. [16] describes four main approaches: (a) return or reuse; (b) liquidate; (c) dispose; and (d) donate. However, it is usually preferable for companies to receive a cash return (through resale) or to donate unsold products to charitable organizations, rather than to resort to destruction or disposal methods because of environmental regulations. In some cases, the

donation of unsold stock is presented as the most attractive solution despite the small returns. Ref. [16] claims that donating represents an intelligent strategy to improve the company's brand image, to engage in social programs and to benefit from reduced taxes.

The secondary market provides a cost-effective method for reselling excess products through an alternative distribution channel [12]. This approach is a practical solution to liquidate unsold inventory and reduce the gap between supply and demand [17]. Ref. [18] mentions that off-price retailers, also known as discounters, serve as external partners and are a widely used clearance strategy. In addition, for many businesses, the use of markdown policies to liquidate unsold products and boost sales is of significant interest. Some papers underline that, substantial discounts even at high percentages, can increase sales without a loss of profit. Moreover, in the context of demand management through product rollover, ref. [19] reports that numerical simulations show that incorporating dynamic upgrade schemes and price markdown strategies can significantly boost profitability. Ref. [20] underlines that implementing markdowns can significantly improve the profits of all supply chain agents when analyzing fashion good supply chains. In practice, it can be challenging for businesses to implement a discount strategy [21]. Indeed, price markdowns allow a seller to increase profits by temporally segmenting the market. By initially setting a list price and strategically determining both the magnitude and timing of subsequent price reductions, the seller can effectively appropriate a significant share of consumer surplus. In real-world applications, companies use methods such as net present value, internal rate of return, and payback period to determine a discount strategy that achieves sales goals and maximizes profits for market demand [22].

Ref. [2] describes eight clearance strategies based on research papers and industrial practices. Strategies are classified into two categories: cash recovery and disposal (see Table 1). Clearance sales, factory outlets, online clearance, discounters, and clearance wholesalers are the top five cash recovery strategies. These strategies can be classified into two classes: internal and external. In addition, the disposal category includes three removal strategies (recycling, destruction, and donation). The authors suggest a compilation of risk and performance

metrics to assess these strategies. They benchmarked performance on three criteria: clearance price, flow speed, and drained volume. Risks related to cannibalization, negative impact on brand image, and changes in consumer purchasing patterns were also assessed. Furthermore, it is emphasized that a company may need to merge multiple strategies (clearance chain) to dispose of the entire volume of unsold inventory, given that the capacities of these strategies may be constrained

(because of storage space, the company's budget, or legislation, ...). To assess the overall performance of the clearance chain, we weight the performance of each strategy by the amount of liquidation to calculate a weighted score. However, the overall risk of the clearance chain is not affected by the amount of liquidation, so even a small amount of unsold inventory mismanaged can significantly damage the brand image of luxury brands.

Table 1. Clearance strategies [2].

Strategies	Comments	Classification	
S ₁ : Clearance sales	It drains a large quantity of unsold items.	In-house strategies	Cash-recovery category
S ₂ : Factory outlets	A store (specific to the brand) that sells discounted price items.		
S ₃ : Online clearance	Clearance websites		
S ₄ : Discounters (B to C)	Liquidators that buy unsold products and resale it at lower prices.	External strategies	
S ₅ : Clearance wholesalers (B to B)	They are like discounters but resell products in bulk to retailers.		
S ₆ : Recycling	Remanufacturing, repurpose or reuse. It is not applicable to all products. Generally used in electronics and textile sectors.	Disposal category	
S ₇ : Destruction	It preserves the brand image (for luxury goods). May be illegal in some countries.		
S ₈ : Donation	Companies donate unsold inventory to charity in exchange for a tax write-off.		

2.2 NVM and unsold inventory management

Over the past twenty years, researchers have presented several extensions to the classic NVM [23]. It would be a daunting task to cover all recent developments in the NVM field. Therefore, our review focusses only on the most pertinent studies on strategies to reduce and / or efficiently manage excess inventory in NVM. These studies focus on a variety of topics, including price-dependent demand, adjusting salvage revenue, implementing multiple markdowns, using discount stores, and incorporating donation-based models.

The price-dependent demand extension of the NVM has been well studied. This model assumes that consumer demand and the corresponding excess inventory are a function of the selling price, rather than being treated as exogenous factors. Since lower prices increase consumer demand and vice versa, the

goal is to manage demand by adjusting selling prices. Ref. [24] studies the optimal quantity to order while considering price-dependent demand and stochastic selling price. When information on customer demand is limited, researchers study a distribution-free approach for price-dependent demand [25]. Ref. [26] examines both additive and multiplicative demands to establish the optimal selling price and quantity of stock. The study also considers strategic and forward-looking consumers who may delay purchasing to take advantage of the salvage price at the end of the season. The authors emphasize that neglecting price-demand sensitivity can lead to suboptimal decisions.

The classical NVM assumes that all the unsatisfied demands of customers in a stockout situation turn to lost sales [27]. In addition, the salvage price is assumed to be constant and to be fixed in advance of the selling season. An approximation of the appropriate fixed salvage price based on historical

data is provided by [28]. The study compares different salvage price estimation methods, emphasizing that selecting the appropriate estimation approach is critical and can significantly affect expected profit. Several studies indicate that assuming a constant salvage value is not practical; instead, a variable salvage value depending on the leftover amount should be considered. A linear salvage price is studied by [29]. The paper concludes that it yields a profit at least equal to the optimal profit of the classical NVM. Authors also highlight an improvement in the ordered quantity. In ref. [30], authors combine on the nonlinear salvage value with nonlinear shortage cost. Meanwhile, findings demonstrate that using a variable salvage value in the limited clearance sale inventory NVM leads to improved expected profit and ordered quantity [31]. The salvage price is also examined as a decision variable in an NVM [32]. We underline that for additional information on the NVM price setting area in a single period, we may refer to a useful literature review developed by [33].

Applying multiple discounts to unsold inventory is a well-researched extension of the NVM. This approach utilizes successive discounts according to a discount scheme, which is classified as linear for uniformly spaced discount prices and as non-linear for other discount structures. In the beginning, the researchers solved the NVM of a single product under multiple price discounts [34]. Then, they extended it to include an additive demand that depends on the price. Finally, they extended it by considering: general demand distribution, many discounts, and additive and multiplicative price-demand relationships [35].

In recent years, researchers have explored alternative clearance strategies to the variable recovery price. Authors in [36] analyze a manufacturer's decision on quantity and selling price, considering the clearance chain type (outlet or off-price retailer). The findings indicate that the use of an integrated clearance chain (outlet) enhances the profitability of the manufacturer. Ref. [18] analyzes a supply chain involving a manufacturer, retailer, and off-price retailer selling unsold goods, showing that the use of the off-price retailer increases the expected profit of the manufacturer. However, depending on certain situations, the retailer's optimal expected profit may increase or decrease.

An NVM with the option of bartering is also examined [17]. This approach facilitates exchanging leftover goods for another commodity using a business-to-business e-marketplace. We underline then the use discounted prices and barter exchange simultaneously in the NVM, considering the additive uncertainty in demand [37]. Alternatively, barter exchange alternatives are considered under a multiplicative demand structure within the NVM to determine the optimal order quantity and retail price that maximize expected profit [38].

Ref. [39] studies the implementation of remanufacturing strategies and developed a novel value model that considers the quality of the returned products. Remanufacturing under stochastic demand and supply conditions is analyzed in [40]. Authors present a decision support tool for investment in the remanufacturing process that considers cost, revenue, and profit. The remanufacturing problem is also studied [41]. Authors consider the uncertainty of supply and subsidies. Two cases of stochastic supply, additive and multiplicative, are studied to investigate this uncertainty. Under the assumption that the quality of new and remanufactured products is similar, the optimal sourcing strategy for a firm switching from new to remanufactured products is identified [42].

Ref. [43] analyses two forms of donation within the NVM: pre-scheduled donations before the sales period commences and unscheduled donations utilized to liquidate unsold goods. They assess the impact of donation on price and order decisions for an NVM with two discount periods. In addition, they evaluate the impact of the tax deduction policy for donations on the decisions of the NVM for a random demand.

Table 2 lists relevant research focusing on NVM and strategies for managing excess inventory. Most NVM studies analyzed discuss multiple extensions simultaneously (price-dependent demand, multiproduct, additive, and multiplicative demand, uncertain demand, uncertain supply, etc.) while considering only one unsold product clearing strategy. This will be established at the beginning of the selling season. The consideration of more than one clearance strategy has been the subject of only a handful of studies (Table 2). The current work contributes to this literature by proposing an NVM that considers multiple clearance strategies when facing uncertain demands.

Table 2. NVM and clearance strategies.

Paper	Strategy to manage unsold inventory. F: Fixed salvage price V: Variable salvage price Di: Discounters / O: Outlet D: Donation / R: Recycling						Comments
	F	V	Di	O	D	R	
[29]		x					- Additive & Multiplicative demand. - Price-setting NV.
[26]	x						- Additive and multiplicative demand. - Price-setting NV.
[36]				x			- Uniformly distributed demand. - Price-dependent demand.
[44]		x					- Distribution-free approach. - Multiple discounts and upgrades.
[30]		x					- Additive demand. - Price setting (nonlinear salvage revenue and shortage cost).
[43]	x				x		- Multiplicative & Deterministic demand). - Two-period price-markdown.
[45]			x				- Multiplicative demand. - Random purchasing and selling prices. - Random yield (additive and multiplicative).
[18]			x				- Uniformly distributed demand. - Normally distributed demand.
[46]					x		- Stochastic demand. - Price-dependent demand. - Random procurement.
[41]	x					x	- Deterministic demand. - Product return / Remanufacturing. - Stochastic supply.
[17] [37] [38]			x				- Stochastic Demand. - Barter exchange.
[47]	x						- Stochastic Demand. - Rippled NV / Risk.
Our work	Many options to clear unsold inventory: clearance sales, factory outlet, online clearance, discounters, clearance wholesalers, recycling, destruction, donation.						Uniformly distributed demand.

We also propose to categorize the proposed methods according to their application periods: (a) pre-market, (b) during the market, and (c) post-market. The first group includes studies related to NVM. Next are methods that employ demand management strategies during the selling season, using price adjustments to either encourage or discourage sales.

Finally, there are studies that propose a variety of strategies to dispose of the remaining inventory at the end of the sales season. These include markdowns, discounts, and disposal options. It should be noted that professionals and academics often have a combination of solutions from several

categories. Based on the studied literature, three main conclusions are drawn:

- Discounted-price sales are a commonly utilized method to liquidate unsold inventory, accomplished through clearance sales, multiple markdowns, or discount retailers.
- Maximizing total expected profit is typically the primary objective for a company looking to liquidate its surplus.
- Using disposal strategies differs significantly from using cash recovery strategies.

In light of the review of literature surrounding clearance strategies and the utilization of Newsvendor Models (NVM) for managing unsold inventory, and building upon the insights gained from previous research and practical strategies, our approach aims to provide a comprehensive framework for addressing the challenges posed by unsold inventory in a dynamic and uncertain marketplace. In the following section, we will outline our novel methodology, which considers multiple clearance strategies, risk-performance evaluation, and real-world constraints. By doing so, we seek to contribute to the ongoing discourse in supply chain management and offer practical solutions for businesses seeking efficient management of unsold goods.

3. Proposed approach

This section presents a structured approach to optimizing the entire clearance chain. Firstly, a detailed problem description is given. Next, a mathematical optimization model is developed. Finally, various financial parameters are estimated, and a method is proposed to solve the problem.

3.1 Problem description

In this study, we examine a supply chain that sells a seasonal item with a short life cycle. The supply chain consists of a manufacturer, a wholesaler, and retailers, so customer demand is unknown at the time the order is placed. However, retailers have sufficient information about the distribution of demand. It should be noted that the wholesaler can only place a single order, and it needs to be placed before the selling season begins. Overstock or out-of-stock situations may arise due to demand uncertainty. If an item is out of stock, the company will incur a shortage cost due to a lack of customer satisfaction. If there is excess inventory, one feasible

option is to make a clearance decision at the end of the market period, when the amount of unsold inventory is known. The supply chain will experience additional inventory costs and will face the difficulty of managing warehouse space until the decision to liquidate inventory is finalized and executed. Furthermore, without an early clearance decision, options that require extensive setup and significant financial investment may no longer be viable. Therefore, it is essential to propose an approach for joint ordering and clearance decisions with clear visibility into the clearance process.

As mentioned previously, NVM is a mathematical model that is used to determine the optimal quantity to order seasonal products. The optimization process occurs before the beginning of the market period to ensure maximum efficiency. Therefore, the model considers random demand and balances the cost of out-of-stocks and the revenue from salvage. The cost of shortage is incurred when there is unfilled customer demand and may reflect costs associated with outsourcing operations, lost sales, and so on. On the other hand, the model assumes that the unsold inventory at the end of the sales period is efficiently disposed of at a salvage price. Here, to address unsold inventory we suggest incorporating the clearance strategies outlined in [2]. To maximize the overall supply chain profits, it is necessary to jointly optimize NVM and select clearance strategies. Therefore, it is important to select the appropriate clearance strategies and determine their appropriate quantities before the market period begins. Thus, the purpose of this study is to help managers make decisions before the start of the sales season about the optimal quantity to order, the relevant clearance strategies to select, and the optimal quantity to allocate to each selected strategy, considering the stochastic demand of a seasonal product.

A study on the management of unsold products in the apparel industry is presented in [48]. The author emphasizes the need to distinguish between the various stages (manufacturing, distributing, and retailing) of the apparel supply chain to clearly identify the actors involved in the management of unsold products. The author emphasizes the necessity of distinguishing between private labels and brands. As outlined in the study, a branded chain is owned by a brand marketer who assumes responsibility for the design, production, and distribution of the product. It is important to note,

however, that the brand marketer does not necessarily operate its retail locations. Private labels, on the other hand, are products sold by retailers who have a brand license but are not involved in the manufacturing process, as opposed to national brands, that are produced by manufacturers and sold under a brand name.

In addition, it is important to understand the specific rules and restrictions that apply to the implementation of clearance practices in the apparel supply chain, including trade and environmental regulations:

- The clearance sale is available exclusively to retailers during a specific period.
- The "Factory outlet" has a formal definition, whereas a "retail outlet" is legally prohibited

[49]. Additionally, an outlet should be situated near the factory or in outlet shopping centers.

- Recycling and destruction facilities are typically owned by manufacturers. However, third-party services can be used for these operations by both manufacturers and retailers.

As previously mentioned, Table 1 outlines eight clearance strategies commonly used for liquidating remaining inventory. However, companies tend to select only a subset of these strategies based on a variety of factors, including regulations, business transactions (such as selling and reselling), and relationships among supply chain actors (such as services providers, manufacturers, wholesalers, and retailers). Figure 2 provides an overview of the clearance process flowchart. It also outlines the scenarios for selling at a loss.

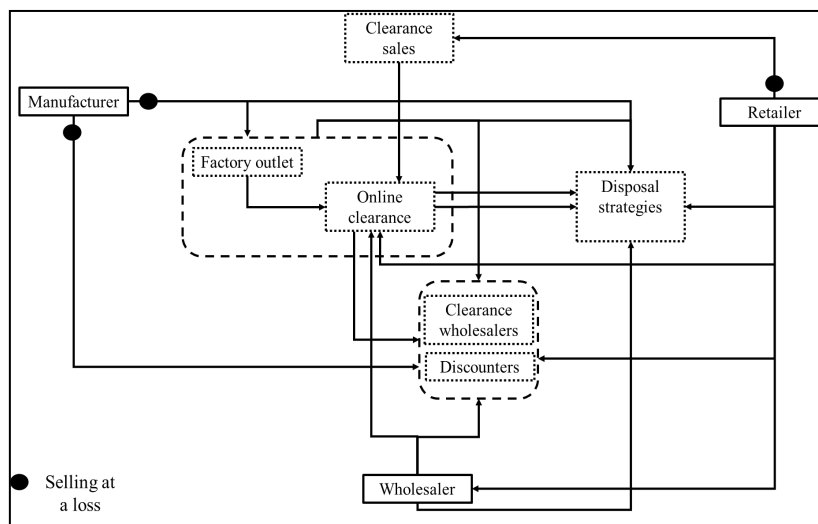


Figure 2. Clearance process flowchart.

In the following, the developed mathematical model based on the single period NVM, and the proposed solution are presented.

3.2 Model formulation

Selecting the appropriate clearance strategies is based on several criteria. These criteria include:

- The assessment of the risk and performance of each strategy.
- The salvage revenue is composed of an income of clearance for the cash recovery strategies and of a tax deduction for S6 and S8, or zero for S7.

- The cost of implementation refers to the cost of adopting the clearing strategy. It includes both fixed and variable costs. Fixed costs are associated with capital expenditures, labor, and space rental, while variable costs are associated with operational management expenses.

In terms of optimizing expected profit, the problem is similar to the case of classical NVM. In addition, a second objective is introduced to measure the overall performance of the clearance chain. Table 3 summarizes the differences between the classical NVM and the proposed model.

Table 3. Decision making in the classical NVM vs the proposed model.

	Classical NVM	Proposed model
Decisions (Before the selling period)	Order quantity.	- Order quantity. - The most suitable clearance strategies. - Allocate the appropriate liquidated quantities.
Objectives	Maximization of the expected profit.	- Maximization of the expected profit - Maximization of the clearance chain performance.
Constraints	- Excess inventory is salvaged at a fixed value. - No salvage capacity	- Excess inventory is salvaged at different salvage values according to the selected strategy. - A clearance risk evaluation constraint is considered. - Clearance strategy capacity is considered

3.2.1 Problem Parameters

The parameters of the problem are outlined in Table 4.

Table 4. Problem parameters.

Parameter	Description
S_s	Strategy s
$\tilde{D}$	Random demand
C_p	Selling price in the market (seasonal) period
CC_s	Clearance price in the selling-off period by S_s
PC	Purchasing (or manufacturing) cost per unit
SC	Unit Shortage cost
P_s	Performance of S_s
R_s	Risk value of S_s
R_{max}	Maximum accepted strategy risk value
C_s	Capacity of S_s
Cf_s	Fixed implementation cost of S_s
Cvr_s	Variable implementation cost of S_s (cost per unit)

3.2.2 Decision variables

Our decision variables are:

- Z : the ordered quantity before the selling period.
- x_s : the liquidated quantity using the strategy S_s .
- y_s : a binary variable that is equal to 1 if S_s is used (i.e., $x_s > 0$), and 0 otherwise.

3.2.3 Objective functions and constraints

The first objective function is to maximize the total profit, π_1 , computed as the difference between total revenue and total cost.

$$\pi_1 = \text{total revenue} - \text{purchase cost} - \text{shortage cost} + \text{clearance revenue} - \text{clearance strategy implementation cost}$$

The expected satisfied demand is given by the minimum between the ordered quantity Z and the uncertain demand $\tilde{D}$. As a result, it can be formulated as $E[\text{Min}(Z, \tilde{D})]$. Consequently, the uncertain quantity of unsold inventory is given by the eq. (1):

$$\tilde{Q} = Z - E[\text{Min}(Z, \tilde{D})] \quad (1)$$

According to [45], the second term of (1) can be written as:

$$E[\text{Min}(Z, \tilde{D})] = Z - E[\text{Max}(0, Z - \tilde{D})] \quad (2)$$

and

$$E[\text{Max}(0, Z - \tilde{D})] = \int_0^Z F_{\tilde{D}}(t) dt \quad (3)$$

where $F_{\tilde{D}}$ represents the cumulative distribution function of the demand $\tilde{D}$. As a result, the uncertain unsold quantity is expressed as:

$$\tilde{Q} = \int_0^Z F_{\tilde{D}}(t) dt \quad (1)$$

Hence:

- The total revenue = $C_v * E[\min(Z, \tilde{D})]$.
 - The purchase cost = $PC * Z$.
 - The shortage cost = $SC * E[\max(0, \tilde{D} - Z)]$,
- where: $E[\max(0, Z - \tilde{D})] - E[\max(0, \tilde{D} - Z)] = Z - E[\tilde{D}]$.
- The clearance revenue = $\sum_{s=1}^8 CC_s * x_s$.
 - The clearance implementation cost = $\sum_{s=1}^8 Cvr_s * x_s + \sum_{s=1}^8 Cf_s * y_s$.

Accordingly, the profit function can be expressed as follows:

$$\pi_1 = C_1 * Z - \left(C_2 * \int_0^Z F_{\tilde{D}}(t) dt \right) - SC * E[\tilde{D}] + (\sum_{s=1}^8 (CC_s - Cvr_s) * x_s) - \sum_{s=1}^8 (Cf_s * y_s) \quad (5)$$

where $C_1 = (C_v + SC - PC)$ and $C_2 = (C_v + SC)$. The second objective function is to maximize the total clearance chain performance, π_2 .

Ref. [2] mentions that for each strategy S_s is assigned a pair (R_s, P_s) to represent its assessment of risk and performance metrics. In this study, performance is assumed to be directly proportional to the amount of liquidation, while the level of risk depends on whether the clearance strategy is selected. Thus, the second objective, π_2 , is expressed in eq. (6):

$$\pi_2 = \sum_{s=1}^8 P_s * x_s \quad (6)$$

Accordingly, the proposed mathematical model is:

$$\begin{aligned} & \text{Max } \pi_1 \\ & \text{Max } \pi_2 \end{aligned}$$

s. to

$$\sum_{s=1}^8 R_s * y_s \leq R_{max} \quad (7)$$

$$\begin{cases} x_s \leq M * y_s \\ y_s \leq M * x_s \end{cases} \quad (8)$$

$$\sum_{s=1}^8 x_s = \int_0^Z F_{\tilde{D}}(t) dt \quad (9)$$

$$0 \leq x_s \leq C_s \quad (10)$$

$$y_s \in \{0,1\} \quad (11)$$

$$x_s, Z \geq 0 \quad (12)$$

In our view, the manager sets the risk threshold R_{max} in accordance with the company's business strategy. Constraint (7) ensures that the threshold R_{max} is not exceeded. The relationship between the liquidation quantity and the choice of strategy is given by constraint (8). Constraint (9) guarantees the liquidation of all unsold inventory. Constraint (10) ensures that the quantity to liquidate for a given strategy does not exceed its capacity. Constraints (11) and (12) represent the binary restriction and the non-negativity constraints.

3.3 Approximation and assumptions for financial parameters

In the proposed mathematical model, each strategy is assigned a clearance revenue and an implementation cost. This section deals with these financial parameters. We start by estimating the elements of implementing costs (Cvr_s , Cf_s) to analyze their impact on the overall profit. Next, we examine the approximation of clearance revenue, which is lower than the selling price during the market period.

3.3.1 Clearance Implementation Cost

Implementation cost represents the investment required to execute a clearance strategy. As mentioned above, there are both fixed and variable costs associated with this process. Table 5, based on a benchmark study of professional Web sites and academic papers, shows the various implementation costs and their definitions.

Table 5. Clearance implementation costs.

S_s	$CA_s = Cvr_s * x_s + Cf_s$		
	CA_s	Cvr_s	Cf_s
S_1	$CA_1 = Cvr_1 * x_1$	Storage and clearance management costs (discount stickers, etc.)	-
S_2	$CA_2 = H * PC * A_2 + Cf_2$ Where: A_2 : average inventory (depending on x_2) H : holding cost rate	Storage cost which includes the possession rate H (insurance, taxes, risks, etc.) $Cvr_2 = A_2 * H * PC$	Expenses concerning personnel, storage facilities, facility rental/ construction and used equipment.
S_3	$CA_3 = CA_2 + DL$ Where: DL : delivery cost	Storage cost.	- Expenses concerning personnel, storage facilities, facility rental/ construction and used equipment. - Delivery cost
S_4	$CA_4 = Cvr_4 * x_4$	Shipping cost (in some cases)	-
S_5	$CA_5 = Cvr_5 * x_5$	Shipping cost (in some cases)	-
S_6	$CA_6 = Cvr_6 * x_6 + Cf_6$	Recycling cost = Revenue from the recycled portion - processing cost - transportation cost - disposal cost.	Fixed recycling unit cost if the company has its own unit.
S_7	$CA_7 = C_{des} * x_7 + Cf_7$ Where: C_{des} : destruction cost/ton.	Destruction cost per ton	Fixed destruction unit cost in case the company has its own unit.
S_8	$CA_8 = 0$	-	-

In this study, recycling and destruction costs were determined based on [48]. The authors provided a formula for various costs in the electronics industry that we adapted to the recycling and destruction operations of the apparel industry. It should be noted that all the terms in the formula are represented as linear functions of quantity or volume, and further details can be found in [48].

3.3.2 Clearance Revenue

Revenue from the clearance strategy, S_s , is reduced by a discount rate, α_s , when compared to the seasonal selling price. The discount rate, α_s , varies between strategies due to regulations, supply chain players, and other factors. Therefore, the clearance price is expressed as:

$$CC_s = C_v * (1 - \alpha_s) \quad (13)$$

It is important to note that in the approximation of the different values of α_s , there are two distinct business transactions: sales and resales. The manufacturer sells at prices below cost. However,

retailers and wholesalers are not legally allowed to engage in the same practice, except for certain clearance sales. It is important to consider purchasing and manufacturing costs, as well as business transactions, when determining discount rates.

3.4 Solution approach

Based on [50] and [51], we can approximate customer demand by assuming a uniformly distributed demand. Therefore, we will assume that the demand is uniformly distributed between values a and b , where:

- The cumulative function $F_{\tilde{D}}$ is replaced with:

$$\left\{ \frac{1}{b-a} * \left(\frac{z^2}{2} - az + \frac{a^2}{2} \right) \right\}.$$

- The average demand $E[\tilde{D}]$ will be replaced by:

$$\left\{ \frac{b-a}{2} \right\}.$$

The Cplex software is utilized to solve the proposed model. As we are dealing only with linear equations, we must linearize equations 5 and 9 first. The piecewise linearization technique is commonly used in mathematical programming to accomplish this. As shown in Figure 3, it aims to approximate a nonlinear function through a set of small linear segments ([52],[53]). Obviously, the accuracy of the approximation depends on the number of intervals.

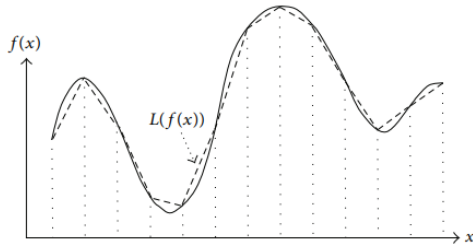


Figure 3. Piecewise linearization of (x) [53].
(N. B. $L(f(x)) \equiv$ Linearized $f(x)$).

The interval $[a, b]$ is subdivided into I intervals ($i \in [1..I]$). New decision variables and parameters are assigned for each interval, i :

- z_i : the quantity to purchase in the interval i .
- t_i : extra-binary variable equals to 1 if the interval i is selected (only one interval can be selected).
- x_{si} : liquidated quantity by S_s in the interval i .
- l_i and u_i : represent respectively the lower limit and the upper limit of the interval i such that $z_i \in [l_i, u_i]$.

Thus, the cumulative function, $F_{\bar{D}}$, is approximated as follows:

$$F_{\bar{D}} = \sum_{i=1}^I (A_i * z_i + B_i) * t_i \quad (14)$$

Where:

$$\sum_{i=1}^I t_i = 1 \quad (15)$$

Consequently, the linearized model is given as follows:

$$\begin{aligned} \text{Max } \pi_1 = & \sum_{i=1}^I C_1 * z_i - [C_2 * (\sum_{i=1}^I (A_i * z_i + \\ & B_i) * t_i)] - SC * \left(\frac{b-a}{2} \right) + ((CC_s - Cvr_s) * \\ & \sum_{s=1}^8 \sum_{i=1}^I x_{si}) - \sum_{s=1}^8 Cf_s * y_s \end{aligned} \quad (5')$$

$$\text{Max } \pi_2 = \sum_{s=1}^8 \left(\sum_{i=1}^I P_s * x_{si} \right) \quad (6')$$

s. to

$$\sum_{s=1}^8 R_s * y_s \leq R_{max} \quad (7)$$

$$\begin{cases} x_{si} \leq M * y_s \\ y_s \leq M * x_{si} \end{cases} \quad \forall s \quad (8')$$

$$\sum_{i=1}^I \sum_{s=1}^8 x_{si} = \sum_{i=1}^I (A_i * z_i + B_i) * t_i \quad (9')$$

$$0 \leq \sum_{i=1}^I x_{si} \leq C_s \quad \forall s \quad (10')$$

$$\sum_{i=1}^I t_i = 1 \quad (15)$$

$$z_i \leq u_i * t_i \quad (16)$$

$$z_i \geq l_i * t_i \quad (17)$$

$$y_s, t_i \in \{0,1\} \quad (11')$$

$$z_i; x_{si} \geq 0 \quad (12')$$

4 Numerical analysis

In this section, the application and validation of the proposed approach and model will be demonstrated through a case study from the textile industry.

4.1 Data generation

Based on the literature, professional websites, and real cases ([54], [9]), the numerical approximations are carefully constructed. We consider a supply chain of a brand marketer where:

- Customer demand $\bar{D}$ is uniformly distributed in the interval $[2, 5]$ millions of items.
- $C_v = 30, PC = 13$ and $SC = 5$. Consequently, $C_1 = 30 + 5 - 13 = 22$ and $C_2 = 35$.

The assessment of clearance strategies is provided by P_s and R_s . The study focused on medium to high range textiles, considering French guidelines for both clearance and donation strategies.

In [50], four subintervals to approximate the nonlinear function. In this study, we increase the number of subintervals to achieve greater accuracy. Thus, the interval $[2,5]$ million is divided into 15 subintervals of 200,000 units. The parameter values implemented in the proposed approach are shown in Table 6.

Table 6. Numerical approximations.

S_s	P_s	R_s	C_s	CC_s	Cvr_s	Cf_s
S_1	0.22	0.09	500000	12	1.35	-
S_2	0.12	0.14	300000	18	-	100000
S_3	0.16	0.12	300000	21	4	-
S_4	0.08	0.20	200000	13.5	-	-
S_5	0.11	0.24		12.5	-	-
S_6	0.10	0.06	Unlimited	2	0.00875	-
S_7	0.06	0.10	Unlimited	-	0.0125	-
S_8	0.15	0.05	25000	18	-	-

It is important to note that to be eligible for clearance sales, products must be available for sale for at least one month. In our scenario, the product is in storage for three months with an annual inventory cost rate of 18%. We estimate C_1 by summing sales during the proposed markdowns until the percentage α_1 is reached.

Clearance sales are based on sequential markdowns, where the value of α_1 increases over time. Therefore, both the value of α_1 and the total quantity sold increase during markdowns. Thus, to effectively represent the amount of cumulative sales volume up to the percentage of α_1 , C_1 must be approximated by considering the proposed markdowns. We estimate α_1 at about 60%. In addition, the retailer must sell the remaining quantity to external partners. There is no possibility of selling at a loss.

Recycling and destruction activities will be outsourced to designated third parties. Both recycling and destruction capacities are unlimited. The financial benefit of the recycling strategy is dependent on the recycled material and the company's revenues. Thus, our approximate value is estimated to be around 150 million. The

experimental research presented in [48] has provided the basis for the determination of our approximation, in particular regarding the capacity limit.

4.2 Results and analysis

The numerical example is solved using the Cplex 12.9 software tool. The 'StaticLex' function is implemented to express a model with multiple objectives and criteria for lexicographic ordering [55]. In our case, we are looking first to optimise profit and then the performance of the clearance chain. Therefore, we will use *StaticLex* (π_1, π_2) which denotes a lexicographic preference structure where π_1 strictly precedes π_2 . Thus, the algorithm first finds the optimal value of π_1 , and then optimises π_2 .

This illustration shows sixteen different solutions (Table 7). The value of $\bar{R}_n$ ($n \in [1..16]$) represents the mean risk value of the interval RI_n ($n \in [1..16]$). The strategies chosen for a given interval RI_n , are shown in Figure 4. The correlation between the total liquidation quantity and the mean risk value ($\bar{R}_n$) is illustrated in Figure 5.

Table 7. Clearance channels results.

Sol^o	RI_n	π_1	π_2	S_s	$\bar{R}_n$	$\bar{Q}$	Z
1	$RI_1 = [0.84; 1.00]$	71435000	147600	6	0.920	1124317	4599020
2	$RI_2 = [0.79; 0.83]$	71251000	149350	5	0.810	1124317	4599020
3	$RI_3 = [0.75; 0.78]$	71227000	125700	5	0.765	1024357	4479020
4	$RI_4 = [0.60; 0.74]$	71065000	169600	5	0.670	1124317	4599020
5	$RI_5 = [0.55; 0.59]$	70881000	171350	4	0.570	1124317	4599020
6	$RI_6 = [0.40; 0.54]$	70495000	197600	4	0.470	1124317	4599020
7	$RI_7 = [0.35; 0.39]$	70255000	193920	3	0.370	1099327	4569020
8	$RI_8 = [0.31; 0.34]$	68072000	87744	3	0.325	624948	3936200
9	$RI_9 = [0.26; 0.30]$	67623000	83955	2	0.280	599628	3896200
10	$RI_{10} = [0.23; 0.25]$	66399000	116260	2	0.240	664827	3999200
11	$RI_{11} = [0.21; 0.22]$	66199000	128260	2	0.215	664827	3999200

12	$RI_{11} = [0.20; 0.20]$	62926000	86876	2	0.200	808757	4200900
13	$RI_{12} = [0.14; 0.20]$	62865000	113100	2	0.170	524767	3770900
14	$RI_{13} = [0.09; 0.13]$	62321000	109960	1	0.110	499819	3726900
15	$RI_{14} = [0.06; 0.08]$	58537000	66483	1	0.070	664827	3999200
16	$RI_{15} = [0.05; 0.05]$	40797000	889,5	1	0.050	5930	2199900

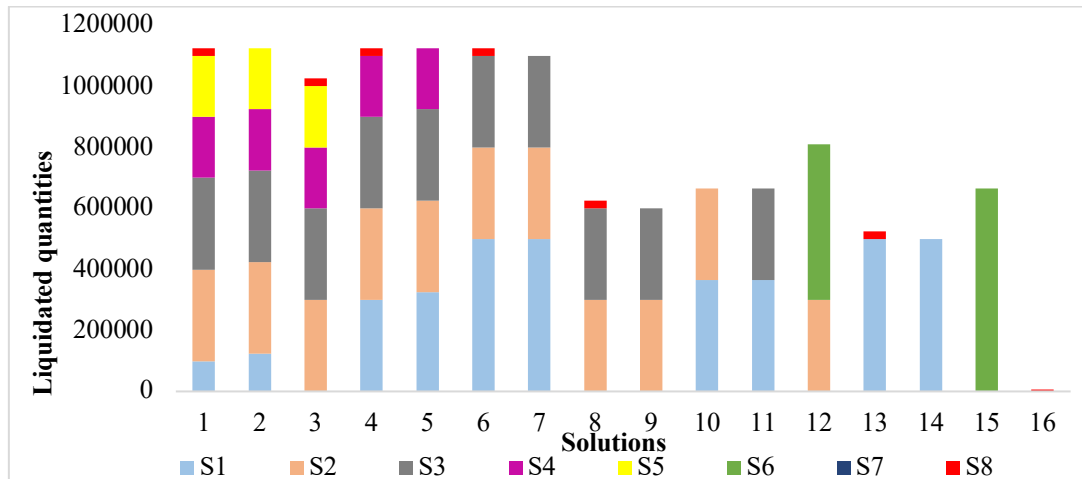


Figure 4. The chosen strategies in each clearance channel.

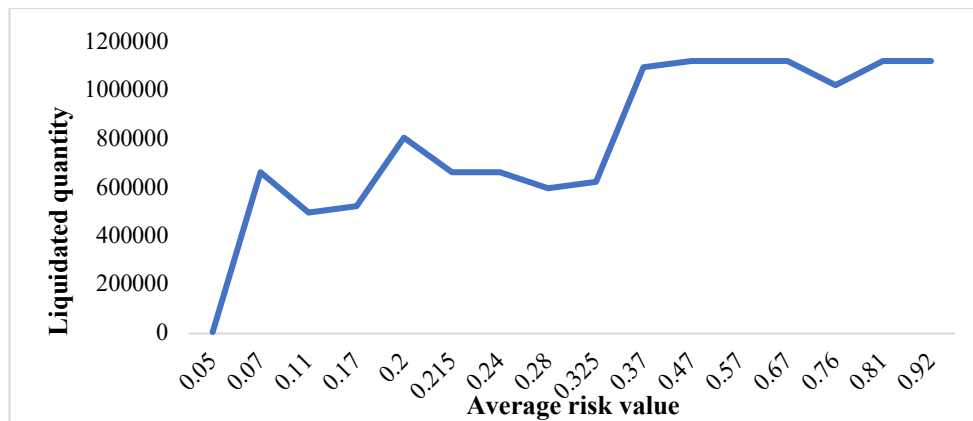


Figure 5. Variation in quantity liquigated depending on average risk values

Assumption 1: As the value of R_{max} decreases, the values of π_1 , π_2 and $\tilde{Q}$ decrease.

The constraint (7) should be relaxed for $R_{max} = 1$. As a result, the objective becomes maximizing π_1 and π_2 while satisfying the no-risk constraint. Figure 4 illustrates that in risk interval RI_1 , the solution includes six strategies, where the most profitable ones are saturated. Decreasing the value of R_{max} results on the decrease of the π_1 value (Table 7).

The number of strategies in the clearance chain has been reduced by half between the first and seventh solutions (RI_1 and RI_7 in Table 7). This resulted in an average risk reduction of 49%, which in turn, led to a performance improvement with π_2 increasing by 23.88%.

A decrease in R_{max} does not always result in a decrease in the liquigated quantity, as shown in Figure 5. Similarly, the results show that a decrease in π_1 value does not necessarily lead to decreasing the values of π_2 or the liquigated quantity (RI_1 compared to RI_4).

Outcome 1: Reducing the R_{max} value will only cause the π_1 profit to decrease. The selected strategies, their capacities and their qualitative performance evaluation have a significant impact on the results obtained for π_2 and $\tilde{Q}$.

Assumption 2: We assume that the selected strategies are the cost-efficient ones once the risk constraint is satisfied.

From Tables 6 and 7 and Figure 4, the selected strategies mainly lead to significant profit. Clearance revenue exceeds the cost of implementing clearance. Therefore, strategies with higher clearance prices are more cost effective.

The donation strategy (S_8) has been abandoned and its corresponding quantity has been assigned to the clearance sales (S_1) (by comparing the first and second solutions presented in Table 7) even though $CC_8 > (CC_1 - CA_1)$, due to the constraints on capacity. In fact, reducing the R_{max} value can significantly reduce the number of selected strategies. To meet the R_{max} constraint, the model retains only those strategies that generate profits.

Outcome 2: It can be assumed that strategies emphasizing cost efficiency may not always be the optimal choice for different values of R_{max} . Rather, chosen strategies must effectively maximize profit considering clearance revenue and capacity.

Assumption 3: Reducing the number of selected clearance strategies could reduce the quantity being liquidated.

As presented in Table 7, five clearance strategies were chosen for the RI_2 and RI_3 risk intervals. However, the liquidated quantity has progressively decreased. On the other hand, when comparing the solutions for RI_7 and RI_8 , although the same number of clearance strategies were used, a noticeable reduction in the liquidated quantity can be observed. Moreover, a reduction of the number of clearance strategies can even lead to a higher value of $\bar{Q}$, such as the case for RI_8 and RI_{10} .

Outcome 3: There is no direct correlation between reducing the number of clearance strategies used and the quantity that has been liquidated.

In the following section, we present additional insights derived from the numerical data:

- A significant reduction in the number of strategies does not have substantial impact on the solution's quality. From RI_1 to RI_7 (Table 7), we

underline that halving the number of strategies used leads to only 1.65% decrease in, π_1 , and 2.22% of the total liquidated amount compared to a reduced average risk ($\bar{R}_n$) of 49%.

- In-house strategies often provide cost-effective solutions, even in the case of liquidation at a loss, such as clearance sales. These strategies are typically implemented in most circumstances, as shown in Figure 4, even when the clearance price is lower than the purchasing cost.
 - The destruction was not chosen despite the R_{max} value, as there are no financial benefits. This outcome is predictable since destruction is mainly used for luxury goods to maintain the company image rather than for financial reasons.
 - Donating provides a cost-effective way to dispose of unsold inventory without taking on a significant risk. This outcome affirms the sustainable practice of small and medium-sized companies that typically donate unsold products as a final clearance step (following cash recovery strategies) to remove residual items.

4.3 Sensitivity analysis

To perform a sensitivity analysis, we suggest reducing the discount rate, α_1 . This situation results in an increase in the clearance sales revenue and a decrease in its capacity as follows: $\alpha_1 = 30\%$, $CC_1 = 21$ and $C_1 = 300000$. The comparison of the results for both scenarios is shown in Figure 6 (the initial histogram representing solutions for $\alpha_1 = 60\%$) and Figure 7.

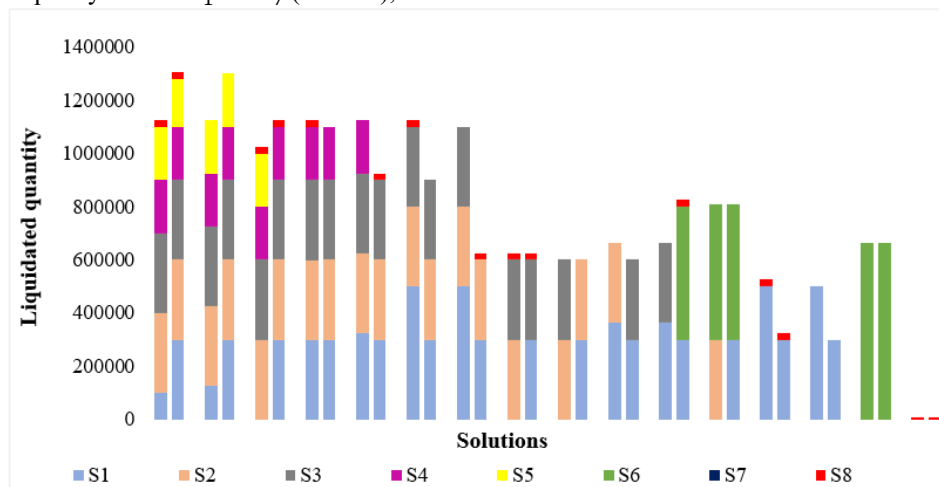


Figure 6. The used strategies in the clearance channels for $\alpha_1 = 60\%$ and $\alpha_1 = 30\%$.



Figure 7. Liquidated quantity shape vs the average risk values.

The findings, results and conclusions of the previous section can be objectively confirmed. However, we highlight the following two changes:

- The maximum quantity liquidated with $C_1 = 500000$ is less than that obtained with $C_1 = 300000$. It is expected that the model will increase the quantity liquidated with S_1 , and it may even saturate its capacity constraint, since it will not be more profitable.
- The relation between the liquidated quantity and the mean risk value (Figure 7) is much more established; a decrease in the R_{max} value mostly leads to a decrease in the liquidated quantity especially for $\bar{R}_n$ values in the interval $[0.22, 0.92]$.

As presented above, a deviation in the values of a strategy parameter may cause significant shifts in optimal decision-making and their resulting effects on profit and performance.

4.4 Limitations of the propose model

The propose model has some limitations such as:

- For future research, we recommend using an actual case study, particularly when determining capacity levels and evaluating the clearance risk and performance.
- The uniform distribution may not accurately reflect demand across all industry sectors. It is employed at this stage to evaluate the model, given that the expected outcomes are managerial and are aimed at assessing the model's feasibility rather than its technical performance. As a next step, we suggest incorporating a normal distribution to enhance its applicability and robustness.
- This model considers seasonal non-perishable products; it may be expanded by taking into account seasonal but perishable products. We

must thus deal with both the use-by date and the best-before date when analyzing product inventory decisions.

5 Conclusion and managerial insights

In conclusion, this study extends the classical single-period newsvendor model by integrating the management of unsold inventory with clearance decision-making. The proposed framework simultaneously determines the optimal order quantity and selects the most suitable clearance strategies used to liquidate unsold items under uncertain demand. All decisions are made prior to the start of the selling period. Eight clearance strategies were identified and categorized as either cash-recovery or disposal options. By incorporating a qualitative assessment of both risk and performance, the model aims to maximize total expected profit while enhancing the overall clearance chain performance, all within a predefined risk threshold. These contributions provide a comprehensive and practical approach for improving inventory and clearance management in uncertain market conditions.

Practical conclusions are drawn from the presented numerical example. The results analysis reveals three important factors for selecting the clearance channel: the risk threshold, the clearance revenue, and the capacity of each strategy. For a well-researched threshold value R_{max} (based on a benchmark survey), a company must be able to select the most appropriate clearance strategies.

Based on the numerical findings, we present a framework (Figure 8) to assist managers in their clearance decision-making process. If the achieved solution does not meet the company objectives for a fixed R_{max} value, the best option for remediation is

to redefine the R_{max} . In addition, minor changes can effectively improve an acceptable solution (Outcome 3). However, the adjustment of the R_{max}

value is the only approach to increase the profit π_1 (Outcome 1).

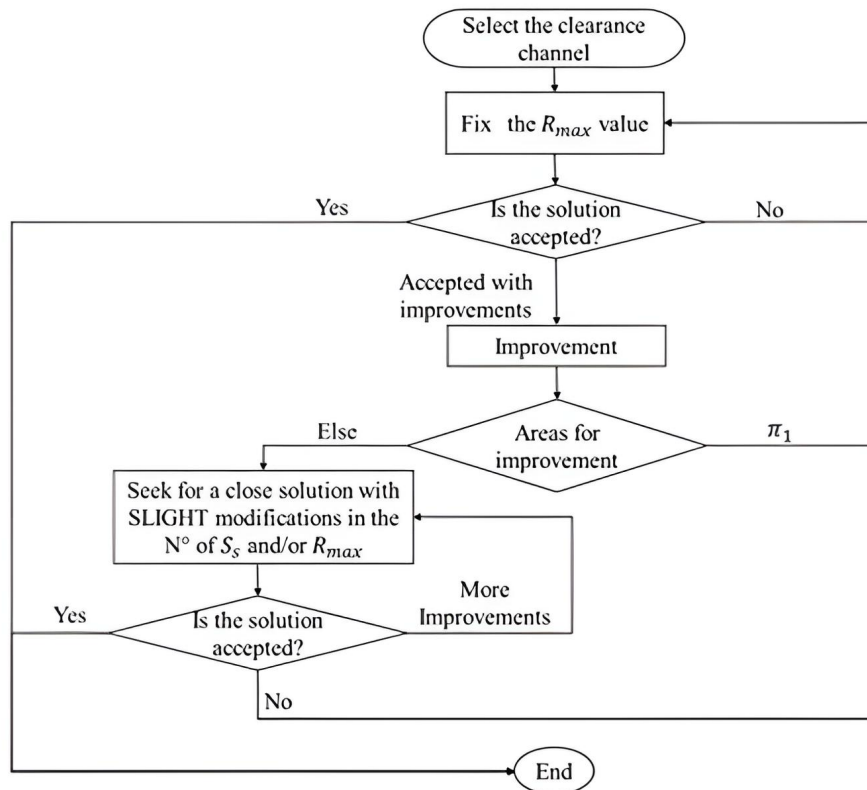


Figure 8. A framework for clearance channel choice and improvement.

The results are promising and valuable, but require further simulations, case studies, and exploratory research to confirm. In this study, we performed a sensitivity analysis on the characteristics of the clearance sales strategy. The primary result indicates that managers should accurately approximate the parameters of clearance strategies to optimize the clearance process.

Further analysis suggests a revision of the assumption of unlimited end-of-season demand in classical NVM [56]. This can lead to suboptimal decisions when the remaining inventory exceeds the satisfied end-of-season demand. Therefore, it would be more realistic to perform a more accurate analysis with a good approximation. Our goal is to efficiently estimate the capacities of different clearance strategies that correspond to the end-of-season demand for each of them. The capacity for clearance sales depends on the suggested price, while the capacities of discounters and clearance wholesalers depend on their market demand. Therefore, exploring the uncertain capacities of clearance strategies is a compelling extension of the proposed model.

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