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# **In-store replenishment procedures for perishable inventory in a retail environment with handling costs and storage constraints**

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## **Abstract**

At grocery retailers, customers prefer to withdraw the newest instead of the older perishable products that are displayed on shelves. To reduce the substantial cost of outdating caused by this withdrawal behavior, we suggest a procedure that limits the number of batches on the shelf with the same product lifetime to one. The remaining inventory is stored in the backroom, where we assume to have ample storage capacity. We show that for products with large available shelf space, short product lifetimes, expensive outdating, and low handling cost this procedure leads to substantial cost reductions compared with in-store replenishment procedures that do not take into account the withdrawal behaviour of the customers and the storage capacity of the shelf.

**Keywords:** Inventory, perishable, in-store logistics, simulation

# 1. Introduction

According to an article in The Economist newspaper, "billions of dollars' worth of food is dumped each year because of retailers' inefficiency" [1]. One way of reducing shrinkage for perishables products, such as fresh produce, dairy and meat, is reducing the amount of product on display in the stores. For products with a visible expiration date which are displayed in a self-service environment such as shelves at a grocery retailer, the customers prefer last in first out (LIFO) withdrawal. From a supply chain point of view, first in first out (FIFO) withdrawal is optimal [2]. Retailers as well as our whole society have an interest to limit LIFO withdrawal to avoid unnecessary waste of food.

The inventory management of perishables at grocery retailers is either done manually or the process is assisted by an Automated Store Ordering (ASO) system that was developed for non-perishables. In both cases, the inventory is assumed to be in one location, but for a large part of the assortment the inventory is split between the shelf and the backroom due to insufficient shelf space. For perishables with sufficient shelf space, storing the total inventory on the shelf leads to LIFO withdrawal when multiple batches are present on the shelf. A retailer can control the number of batches on the shelf by managing the in-store replenishment from the backroom to the shelf. In this paper we will investigate the possibilities to extend a perishable inventory system with multiple storage locations and controlled shipments between these locations. We expect that a technology like RFID will enable an efficient administration of both the quantity and the age of the inventory at multiple locations in the store, which is needed for controlling different batches in a store.

Our paper is an extension of the work of Broekmeulen & Van Donselaar [3] in which they presented a inventory control policy for products with a short remaining shelf life, where the customer can observe the expiration date of the items and is allowed to select the items, and inventory replenishment is done periodically in small batches with a lead-time of at least one period. Their EWA policy, which uses the age vector of the inventory in the store, is a good candidate to extend existing ASO systems due to its flexibility in handling different lead-times, week patterns in demand, and customer withdrawal behaviour. In this paper, we investigate the effect of in-store replenishments from the backroom to the shelf on the combined cost of purchasing, lost sales, outdating and handling.

The remainder of the paper is organized as follows. In the following section we review the existing literature on perishable inventory systems and handling models and in Section 3 we describe the problem characteristics. In Section 4 the in-store replenishment policies are described. A numerical study in order to compare the different replenishment policies is presented in Section 5. Based on the results, managerial insights and possible future research is discussed in Section 6. The paper ends with a short summary of our conclusions.

## 2. Literature review

The research on perishable inventory systems up to 2001 has been thoroughly reviewed Nahmias [4], Raafat [5], and Goyal & Giri [6]. Broekmeulen & van Donselaar [3] reviewed recent research on replenishment policies for a single echelon perishable inventory system with stochastic demand and a fixed lifetime equal to  $m$  periods to compare the EWA policy with other available policies in the literature. The EWA replenishment policy takes into account the full age distribution of the inventory and can deal with lot-sizing and FIFO and LIFO withdrawal. Especially for perishable inventory systems with LIFO withdrawal, there hardly exists any literature. Cohen and Prastacos [7] deal with the effect of FIFO versus LIFO withdrawal policies on both the system performance and ordering decisions for products restricted to  $m = 2$ . They derive approximations for the critical number for LIFO systems and compare these with the values for FIFO systems. The critical numbers turned out to be rather insensitive to the type of withdrawal policy although the optimal expected costs were significantly higher for LIFO. Nahmias [4] mentions that this result suggests that simple approximations for FIFO systems could also be used effectively in LIFO systems. Since Cohen and Prastacos [7] did not investigate replenishment policies other than critical number policies, our paper has added value in showing whether or not an age based replenishment policy leads to improved performance in a LIFO system.

The limited amount of available shelf space in retail stores results in shelf space allocations that are often insufficient to accommodate the demand. Ketzenberg et al. [8] propose dense retail stores, which rely on demand substitution and only marginal handling cost. Cachon [9] optimizes the shelf space allocation by making a trade-off between the shelf space cost, the inventory holding costs and the transportation costs. Since he assumes handling cost to be linear with demand, he is able to omit handling costs. Broekmeulen *et al.* [10] find that due to the

inflexible storage cabinets, a large number of products have excess shelf space. According to Van Zelst *et al.* [11], handling costs are a considerable part of the logistics costs for non-perishables. The additional activities needed to maintain perishables in a store, such as outdating, increase these costs further. De Koster *et al.* [12] describe the design and control of order picking in warehouses, which is the mirror activity of replenishing the shelves in a store. Kotzab & Teller [13] carried out an empirical study of grocery retail in-store logistics for dairy products. They describe the situation with two storage locations in the store, the shelf and the backroom, and the resulting additional handling needed to replenish the shelves.

### 3. Problem characteristics

We study a single perishable product with a fixed lifetime of  $m$  periods. We define the lifetime as the remaining shelf life for the products when they arrive in the store. Customer demand is probabilistic with mean  $\mu$  and variance  $\sigma^2$  for each period. We modelled the demand for each period with a discrete distribution fitted on the first two moments [14]. When the inventory in the store is insufficient to satisfy the demand, the excess demand is lost. The inventory is controlled with a periodic review system with review period equal to  $R$  periods and a fixed lead-time equal to  $L$  periods for the replenishment orders. Replenishment quantities are limited to multiples of an exogenous determined lot size  $Q$ , i.e., the case pack size. We assume that the supplier has ample stock.

The inventory in the store at the start of period  $t$  consists of one or more batches. A batch is defined here as a set of items available in the store, which all have the same remaining shelf life (i.e. the same age). The content of the batch can be located on the shelf and/or the backroom. We assume that the backroom has ample storage capacity, but the shelf has a limited storage capacity  $V$ . The amount of items available in store location  $s$  (0 for the shelf and 1 for the backroom) at the start of period  $t$  having  $r$  periods remaining shelf life is equivalent to  $B_{trs}$ . The number of different batches on the shelf is denoted by  $A_t = \sum_{r=1}^m \text{sign}(B_{tr0})$ . Customers withdraw items with positive remaining shelf life from the batches on the shelf, depending on their demand and preference for the highest remaining shelf life, i.e., LIFO withdrawal. Outdating  $O_t$  is the withdrawal by store clerks of items with 1 period remaining shelf life at the end of period  $t$ , since these items can not be sold the next period.

**Table 1: Summary of the used notation.**

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$A_t$	Number of different batches on the shelf in period $t$
$A^{MAX}$	Maximum number of different batches allowed on the shelf
$B_{trs}$	Amount of items available in store location $s$ at the start of period $t$ having $r$ periods remaining shelf life
$IP_t$	Inventory position at period $t$
$L$	Lead-time
$m$	Product life time at arrival
$M_t$	Order size at period $t$ [units]
$O_t$	Outdating of items with 1 period remaining shelf life at the end of period $t$ [units]
$R$	Review period
$Q$	Case pack size [units]
$s_t$	Reorder level at period $t$
SS	Safety stock level
$T_t$	Number of trips from the backroom to the shelf at period $t$
$V$	Shelf capacity [units]
$\mu$	Mean period demand
$\sigma^2$	Variance of demand
$sign(x)$	Returns 1 if $x > 0$ , -1 if $x < 0$ , and 0 otherwise
$\lceil x \rceil$	Rounds up $x$ to the nearest integer

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The in-store replenishment policy determines where the delivered replenishment orders from the supplier are put in the store and how frequent and in which quantities the items are moved from the backroom to the shelf. We assume that the in-store replenishment quantities are limited to the available storage capacity on the shelf and the number of different batches allowed on the shelf, denoted by  $A^{MAX}$ , such that  $A_t \leq A^{MAX}$ . Since we assume that case packs are unpacked in the backroom, the size of the replenishment quantity does not depend on the case pack size. The withdrawals from the backroom are always FIFO. The lead-time for the in-store replenishments

from the backroom to the shelf is assumed to be zero. We assume that the relevant handling costs only depend on the number of trips  $T_t$  between the backroom and the shelf. Table 1 summarizes the used notation.

For the replenishments from the supplier, we use an extension of the EWA policy [3] that takes the in-store replenishment policy into account. Compared to Broekmeulen & van Donselaar, we limited our investigation to environments with no week pattern in the demand, a lead-time of one period, a review period of one period and no holding costs. This is done because their sensitivity analysis showed only a marginal effect for week pattern and holding cost. Next to that, longer lead-times and review periods only increase the probability of outdating.

To compare the different in-store replenishment policies, we used a discrete event simulation model of the retail process of perishable products at a single store. The timing of events during a period in the model is: after opening the store, inventory decreases due to customers' demand, after closing the store outdated inventory is removed from the shelf and/or the backroom, remaining inventory is counted, and performance measures such as the service level are calculated, goods arrive at the backroom, and finally the orders are placed. The timing of the stacking of the shelf depends on the chosen in-store replenishment policy.

## 4. In-store replenishment policies

We assume that the retailer uses the EWA policy, which is a modified  $(R, s, nQ)$  policy following the notation of Silver et al. [15]. In such a policy, we create a replenishment order only when the inventory position at a periodic review moment is strictly below the dynamic reorder level  $s_t$ . Given a safety stock  $SS$  and the expected demand during lead-time plus review period  $\sum_{i=t+1}^{t+L+R} E[D_i]$ , we have

$$s_t = SS + \sum_{i=t+1}^{t+L+R} E[D_i] \quad (1)$$

In case of an order, the size of the order has to be sufficient to bring the inventory position back to or just above the reorder level  $s_t$ , but strictly less than  $s_t + Q$ . The order size is determined by the number of case packs, each with size  $Q$ . We define  $IP_t$  as the inventory position at period  $t$  just before an order is placed. Note that in the EWA policy the inventory

position is the sum of the inventory on hand in the store plus the inventory in transit minus the estimated amount of outdating, i.e.,

$$IP_t^{EWA} = IP_t - \sum_{i=t+1}^{t+L+R-1} \hat{O}_i \quad (2)$$

The order size  $M_t$  is now as follows

$$\text{if } IP_t^{EWA} < s_t \quad \text{then } M_t = \left\lceil \frac{s_t - IP_t^{EWA}}{Q} \right\rceil \cdot Q \quad (3)$$

To distinguish the estimated amount of outdating from the actual amount of outdating, we use the variable  $\hat{O}_i$  in (2) rather than  $O_i$ . Note that the estimation of the amount of outdating is done over  $L + R - 1$  periods, since the outdating on the  $(L + R)^{\text{th}}$  period has no effect on the sales during that period (executed after the sales period). The estimated amount of outdating is the only difference between the EWA policy and a regular  $(R, s, nQ)$  policy.

The system studied by Broekmeulen & van Donselaar [3] has only one storage location in the store. By introducing a backroom storage, we need an in-store replenishment policy for replenishing the shelves from the backroom. We will describe three different in-store replenishment policies, which all have different effects on the withdrawal behaviour and the amount of handling. These in-store replenishment policies are:

- A. Direct to shelf
- B. Full shelf
- C. Single batch

For non-perishables we observed at grocery retailers that deliveries are put directly on the shelf, thereby circumventing the backroom. This is only feasible if the shelf has ample capacity.

$$B_{t+L+1,m,0} = \text{Min} \left\{ M_t, V - \sum_{r=1}^{m-1} B_{t+L+1,r,0} \right\} \quad (4a)$$

$$B_{t+L+1,m,1} = M_t - B_{t+L+1,m,0} \quad (4b)$$

A measure for sufficient capacity is Maximum Inventory On Hand (MIOH), which is the upper bound on the required shelf space capacity. Broekmeulen *et al.* [10] give the following equation for MIOH in the case of a  $(R, s, nQ)$  policy.

$$MIOH_t = s_t - 1 + Q = SS + \sum_{i=t+1}^{t+L+R} E[D_i] - 1 + Q \quad (5)$$



When the shelf space is less than the MIOH, the probability increases that a delivery does not fit on the shelf and has to be stored in the backroom. This ‘Direct to Shelf’ policy applied to products with insufficient shelf space has a potential disadvantage for perishables, since it does not respect FIFO rotation. A fresh delivery occupies space on the shelf while the backroom could still contain remnants from a previous delivery. With the ‘Direct to Shelf’ policy, we also have the possibility of multiple batches on the shelf, i.e.,  $A_t > 1$ . The upper bound on the number of batches on the shelf is here  $A^{MAX} = V$ , since the number of batches is limited by the available shelf capacity in units.

In the ‘Full Shelf’ policy, all products are first delivered to the backroom, i.e.,  $B_{t+L+1,m,1} = M_t$ . We only replenish the shelf if the inventory on the shelf drops to zero, based on the assumption of zero lead-time to the shelf. Since we assume that case packs can be unpacked in the backroom, we have the opportunity to replenish in larger quantities than the expected order size  $E[M_t]$ . The size of the in-store replenishment is limited by the shelf capacity or the available inventory in the backroom. In the case of a large shelf capacity, the shelf can contain multiple batches with each a different remaining shelf life, i.e.,  $A^{MAX} = V$ .

The ‘Single Batch’ policy limits the number of batches on the shelf to one, i.e.,  $A^{MAX} = 1$ . As in the ‘Full Shelf’ policy, all products are first delivered to the backroom. This will result in more trips from the backroom to the shelf, but has the advantage that the customer has no choice during withdrawal. Therefore, the ‘Single Batch’ policy enforces FIFO withdrawal at the expense of additional handling.

Summarizing, the difference between the ‘Direct to Shelf’ policy and the ‘Full Shelf’ policy is the primary destination of a fresh delivery and the difference between the ‘Full Shelf’ policy and the ‘Single Batch’ policy is the number of batches allowed on the shelf. Our hypothesis is that the handling cost increases from the ‘Direct to Shelf’ policy to the ‘Single Batch’ policy, while outdating due to LIFO withdrawal decreases. Earlier research on the EWA policy [3] showed that LIFO withdrawal resulted for the retailer in a cost increase of on average 17% compared to FIFO withdrawal. The trade-off will depend on the relative cost difference between outdating and handling, but also on the size of the shelf. We hypothesize that a larger shelf capacity, up to  $MIOH_t$ , increases the difference between the three policies.

We state that the processes of customer withdrawal, in-store replenishment and outdating on a period  $t$  follow the procedure outlined below.

1. Let  $T_t := 0$ .
2. Sales is the minimum of demand and available inventory, i.e.,
$$S_t := \text{Min} \left\{ \sum_{i=1}^m \sum_{s=0}^1 B_{irs}, D_t \right\}$$
3. If  $S_t > 0$  then go to step 4, else proceed to step 8.
4. Withdraw items LIFO from the shelf, i.e., for  $r = m, m-1, \dots, 1$  do
  - i.  $W := \text{Min} \{ B_{tr0}, S_t \}$
  - ii.  $S_t := S_t - W$
  - iii.  $B_{tr0} := B_{tr0} - W$
5. If the shelf inventory is zero and the backroom inventory is positive, replenish from the backroom, i.e., if  $\sum_{i=1}^m B_{tr0} = 0$  and  $\sum_{i=1}^m B_{tr1} > 0$  then go to step 6, else proceed to step 3.
6. Withdraw items FIFO from the backroom up to the shelf capacity for storage on the shelf, i.e., set the replenishment quantity to zero, i.e.,  $F := 0$ , the number of batches on the shelf, i.e.,  $A_t := \sum_{r=1}^m \text{sign}(B_{tr0}) = 0$  and for  $r = 1, \dots, m$  do
  - i.  $W := \text{Min} \{ B_{tr1}, V - F, (A^{MAX} - A_t) \cdot V \}$
  - ii.  $F := F + W$
  - iii.  $B_{tr1} := B_{tr1} - W$
  - iv.  $B_{tr0} := B_{tr0} + W$
  - v. If  $W > 0$  then  $A_t := A_t + 1$
7. If we have a positive replenishment quantity, i.e.,  $F > 0$ , increase the number of trips with one, i.e.,  $T_t := T_t + 1$ . Next, go to step 3.
8. Outdate the oldest batch, i.e.,  $O_t := B_{t10} + B_{t11}$ ,  $B_{t10} := 0$ , and  $B_{t11} := 0$ .
9. Update the batches to account for aging, i.e., for  $r = 2, \dots, m$  let  $B_{t+1, r-1, s} = B_{trs}$

The withdrawal procedure described above is also the basis for calculating the estimated outdating quantities, which are needed in the EWA policy, as shown in formula (2). We estimate these outdating quantities by calculating for consecutive periods  $i$ , ranging from  $i = t + 1$  to  $i = t + L + R - 1$ , the withdrawal, the remaining batches and the outdating in period  $i$  under the assumption that in period  $i$  demand is equal to the expected demand. This implies the following estimation procedure, starting with  $i = t + 1$ :

1. Determine the estimated outdating and the estimated remaining batches available for the next period in period  $i$  using the withdrawal procedure with the parameters applicable for the chosen in-store replenishment policy by assuming that demand in period  $i$  was equal to the expected demand and the withdrawal in period  $i$  is equal to the estimated withdrawal.
2. While  $i < t + L + R - 1$  do  $i := i + 1$  and continue with Step 1, otherwise stop.

## 5. Numerical study

In order to compare the performance of the in-store replenishment policies, we measured the long-term average costs. The costs incurred during period  $t$  are given by:

$$C_t = C_Q \cdot Q_t + C_Z \cdot Z_t + C_K \cdot K_t + C_T \cdot H_t \quad (6)$$

with  $Q_t$  the amount of units ordered,  $Z_t$  the amount of units outdated,  $K_t$  the lost sales in units and  $H_t$  the average number of trips to the backroom in period  $t$ .

We did a factorial experiment in which we tested several levels for each of the eight input parameters. The experimental setup is given in Table 2. The range of the product lifetime is limited to situations for which outdating was shown to be significant by previous investigations [6]. The parameters for average demand, coefficient of variation and case pack cover (i.e. the case pack size expressed in number of periods expected demand) are based on parameters reported in Van Donselaar *et al.* [16]. We also included lot-for-lot (LFL) or  $Q = 1$  to investigate the effect of the lowest possible case pack size. We varied the shelf space for a product between  $Max\{\mu R, Q\}$ , which is the minimum expected order size at a service level of 100%, and the maximum inventory on hand  $MIOH$ , as defined in equation (5). For perishables, the expected

order size will be greater than  $Max\{\mu R, Q\}$  to compensate for outdating. With a shelf space close to the expected order size, the backroom is frequently needed to store the products. An available shelf space equal to the  $MIOH$  makes direct deliveries to the shelf possible without the risk of overflows that have to be stored in the backroom.

All cost parameters in the model are normalized on the purchasing costs  $C_Q$ , which is set equal to one cost unit. The relative outdating costs are varied between -0.5 and 0.5. Here the negative parameter reflects the situation in which the outdated products still generate some positive revenue. The relative lost sales costs are varied between 5 and 15, which results in relatively high service levels depending on the level of outdating. With low outdating, these lost sales costs lead to service levels up to 95%. For products with a short shelf life and high outdating cost, lower service levels down to 80% are more acceptable in practice, since the level of outdating would otherwise far exceed the level of sales. The relative handling costs are varied between 0 and 0.1. The value of zero corresponds to situations where handling costs are considered sunk. This is the case for sales departments for fresh products which have already sufficient staffing levels to provide value-added services. The average logistic cost at retailers is often close to 10% of the total operating costs, including purchasing costs. This gives an upper bound of 0.1 for the relative handling cost for each in-store replenishment. Since the average purchase price of a customer unit of a perishable product such as meat is around € 2.5, 10% should be enough to cover for the labour cost to execute a single replenishment from the backroom [13]. Deliveries direct to the shelf bypass the backroom and therefore do not incur these handling costs.

We considered one day as the base period, resulting in a review period and a lead-time of one day. These short periods are often encountered for perishables at grocery retailers.

**Table 2: Input parameters for the simulation experiment.**

Input parameter	Levels
Product lifetime $m$	{2,3,4,5,6}
Mean period demand $\mu$	{2,5,10}
Variance to mean ratio $\sigma^2/\mu$	{0.5,1.0,2.0}
Case pack cover $Q/\mu R$	{LFL,1,2}
Shelf capacity	{Max{\mu R, Q}, MIOH}
Outdating cost ratio $C_z/C_Q$	{-0.5, 0, 0.5}
Lost sales cost ratio $C_K/C_Q$	{5,10,15}
Handling cost ratio $C_T/C_Q$	{0, 0.05, 0.1}

Following Law and Kelton [17], the reported values for the simulation are the averages from at least 10 replications. In each replication, the first 500 periods were the warming-up periods and statistics are recorded for the last 7000 periods. We replicated until we reached an absolute precision for the customer service level  $P_2 \pm 0.002$  with 95% confidence.  $P_2$  is the fraction of demand delivered from stock, also known as the fill rate.

For each experiment  $e$  in the set of 7290 simulation experiments  $E$ , we ran the following three scenarios:

- A. Direct to shelf policy (DS);
- B. Full shelf policy (FS);
- C. Single batch policy (SB).

In all scenario's we determined for each parameter setting the optimal safety stock level  $SS$ , which minimized the average simulated costs.

For the comparison of different policies we denote the average costs for experiment  $e$  under the 'Direct to Shelf' policy by  $C_{DS,e}$ , the average costs under the 'Full Shelf' policy by  $C_{FS,e}$ , and the average costs under the 'Single Batch' policy by  $C_{SB,e}$ . The relative deviations of the costs for experiment  $e$  for policy  $p$  compared to policy  $q$  is defined as

$$\delta_{pqe} := \frac{C_{qe} - C_{pe}}{C_{qe}} \cdot 100\% \quad e = 1, 2, \dots, E \quad (7)$$

As performance measure, we consider the average of  $E' \subseteq E$  experiments, defined as follows

$$\bar{\Delta}_{pq} := \frac{1}{|E'|} \sum_{e \in E'} \delta_{pqe} \quad (8)$$

For each level the set of experiments to be aggregated  $E'$  is determined by all possible parameter combinations of the other levels.

In Table 3, we report the relative cost performance at selected percentiles of the 7290 experiments. The ‘Single Batch’ policy compared to the ‘Full Shelf’ policy leads on average to 3.6% lower costs. In 93% of the cases, the ‘Single Batch’ policy performs better or equal than the ‘Full Shelf’ policy. The worse performance of the ‘Single Batch’ policy is mainly with small shelf capacities and longer product lifetimes. In these cases, the additional handling is not compensated by the reduced outdating. The potential savings are much higher when compared to the ‘Direct to Shelf’ policy, but it is obvious that the ‘Direct to Shelf’ policy is a bad practice for perishables.

**Table 3: Performance of the different in-store replenishment policies for selected percentiles of the experiments plus the average and standard deviation.**

Percentile	$\bar{\Delta}_{SB,DS}$	$\bar{\Delta}_{FS,DS}$	$\bar{\Delta}_{SB,FS}$
0.00	-0.9	-2.3	-1.2
0.05	3.0	2.7	-0.2
0.10	5.5	5.0	0.0
0.25	9.9	8.9	0.0
0.50	15.8	13.1	0.5
0.75	22.5	17.8	6.2
0.90	28.4	22.3	11.8
0.95	31.4	24.7	14.8
1.00	44.2	35.2	27.4
Average	16.4	13.4	3.6
Std. Dev.	8.6	6.5	5.2

Table 4 shows the relative performance of the different in-store replenishment policies for a subset of all 7290 experiments, in which one input parameter was kept constant at a certain level. For the ‘Direct to Shelf’ policy in situations with large shelf capacity, the handling cost is zero, but the additional outdating costs due to LIFO withdrawal is large and comparable to what was

reported earlier for the EWA policy [3]. The negative effect becomes larger for short product lifetimes. In the remaining part, we will focus on the difference between the ‘Single Batch’ and the ‘Full Shelf’ policy.

The ‘Single Batch’ policy gives the largest improvements for a large shelf capacity, short product lifetime, and low mean demand. With a large shelf capacity, the probability of multiple batches on the shelf in the ‘Full Shelf’ policy is the highest. For short product lifetimes and low mean demand, we have the highest risk on outdating, especially with LIFO withdrawal. In the situations with large case pack sizes, the probability of multiple batches drops in the ‘Full Shelf’ policy, making the ‘Single Batch’ policy less interesting to reduce outdating. As expected, the advantage of the ‘Single Batch’ policy reduces with lower outdating costs, lower lost sales costs, and higher outdating cost. In these situations, we prefer to accept the additional outdating and/or the reduced customer service instead of intensifying the handling.

Apart from costs, we also considered the effects of the ‘Single Batch’ policy on other performance measures, such as the average inventory, the average outdating, and the freshness of products offered to consumers. Compared with the ‘Full Shelf’ policy, the ‘Single Batch’ policy increases the average inventory with on average 6%. Also a larger fraction of the store inventory is located in the backroom: 57% compared with 47%. Therefore, the ‘Single Batch’ policy has a higher outdating in the backroom compared with the ‘Full Shelf’ policy. The effect of keeping the newest batches in the backroom on the freshness of the products for the customers is relatively small. We observe on average 6.6% less remaining shelf life of the sold products under the ‘Single Batch’ policy compared to the ‘Full Shelf’ policy.

**Table 4: Average cost reductions of the different in-store replenishment policies.**

Parameter	Level	$\bar{\Delta}_{SB,DS}$	$\bar{\Delta}_{FS,DS}$	$\bar{\Delta}_{SB,FS}$
Product lifetime $m$	2	19.2	13.5	6.6
	3	19.2	15.5	4.5
	4	16.9	14.4	3.1
	5	14.5	12.7	2.2
	6	12.3	11.1	1.5
	Mean demand $\mu$	2	16.4	11.9
5		17.0	14.2	3.3
10		15.9	14.1	2.2
Variance to mean ratio $\sigma^2/\mu$	0.5	15.1	13.3	2.2
	1	16.9	13.9	3.6
	2	17.3	13.1	4.9
Case pack cover $Q/\mu R$	LFL	15.8	12.3	4.2
	1	16.0	13.0	3.7
	2	17.5	15.0	2.9
Shelf space	$Max\{\mu R, Q\}$	11.0	10.7	0.4
	<i>MIOH</i>	21.9	16.2	6.7
Outdating cost ratio $C_z/C_Q$	-0.5	12.4	9.9	2.9
	0	17.1	14.0	3.7
	0.5	19.8	16.5	4.1
Lost sales cost ratio $C_K/C_Q$	5	12.9	10.7	2.5
	10	17.1	14.0	3.7
	15	19.3	15.6	4.5
Handling cost ratio $C_T/C_Q$	0	17.0	13.9	3.8
	0.05	16.4	13.4	3.6
	0.10	15.9	13.0	3.4

LFL (lot-for-lot) denotes a case pack size of 1, and MIOH is maximum inventory on hand.



## 6. Managerial insights and future research

Our main insight from this research is that good in-store replenishment policies for perishables are important to reduce the outdating caused by LIFO withdrawal. The suggested policy to limit the number of batches on the shelf to one can lead to interesting cost savings. The ‘Single Batch’ policy is not difficult and easy to explain to people in the stores who are responsible for managing the inventory of perishable products.

With the ‘Single Batch’ policy, the customer withdrawal is changed from LIFO withdrawal to FIFO withdrawal. In such an environment, the benefit of the EWA policy over a more common  $(R, s, nQ)$  inventory control policy is less pronounced, especially with a review period and a lead-time of one day. In such situations, the investments in detailed registration based on RFID can be avoided. But in order to implement a ‘Single Batch’ replenishment policy, frequent inspection and timely replenishment of the shelves is needed. Real-time feedback from the point-of-sale data collected at the check outs to the store clerk responsible for maintaining the shelves with perishables is a possible alternative to frequent inspections in situations with accurate store execution. The situation with positive lead-time for the shelf replenishment is an area for future research.

From our numerical study we also observe that for the ‘Full Shelf’ policy large case pack sizes and/or small shelf capacities also result in a situation with a limited number of batches on the shelf, which is the aim of the ‘Single Batch’ policy. Too small shelf capacities will result in excessive handling without any benefit on the outdating. Too large case pack sizes can cause extra outdating if the case pack size is greater than the average demand during the product lifetime. We think that by using the ‘Single Batch’ policy, the retailer achieves a better balance between handling and outdating. The results for the ‘Direct to Shelf’ policy show that this in-store replenishment policy is not suitable for perishables.

An interesting area for future research is the in-store replenishment of perishables with a random product lifetime such as fresh produce. For these products, regular inspection by trained store clerks is needed to sort the products on display and to remove products that are below the quality level acceptable for sale [18]. For unobservable quality aspects, advanced measurement systems and quality change models could be used by the store clerks to improve the sorting [19]. By combining the handling activities needed for sorting with the replenishment of the shelves, a

retailer can reduce the outdating for these products or increase the quality of the products on display.

## 7. Conclusions

By limiting the number of batches on the shelf to one, the retailer can reduce the amount of outdating due to LIFO withdrawal at the expense of additional handling. This research shows that products with a short product lifetimes, large shelf capacities, expensive outdating and low handling cost profit most from a single batch in-store replenishment policy. More attention from the retailer, resulting in just in time replenishment of the shelf and improved execution of the store operations, has also a positive impact on the use of our natural resources beyond a mere cost saving.

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