Inventory Allocation of Perishables: Guidelines

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Abstract. The purpose of this study is to investigate and propose guidelines for how to allocate perishables to improve the balance of freshness and availability in retail stores. Specifically, it is investigated how a single warehouse can make the allocation decision to stores with and without access to remaining shelf life information of the products in the stores. Contrary to complex decisions models, this study aim to develop simple guidelines that can be applied manually or easily integrated into existing decision support systems.

Keywords: Inventory allocation, Food supply chain, Perishables, Information sharing, Remaining shelf life

1 Introduction

Food supply chains separates itself from other supply chains and necessitates special logistical requirements due its characteristics of perishability of products, high demands on quality, and tractability requirements [1, 2]. Particularly, for products with a shelf life less than 30 days – known as perishables [3, 4] – where the quality of the products deteriorate over time, questions the applicability of non-perishable supply chain practices in food supply chains [5, 6].

In retail supply chains, stores in a particular geographical region may be supplied from a central warehouse or a smaller distribution centre. Inventory allocation policies consider how to distribute products among the requesting stores from the warehouse in case of shortage – also known as rationing policies [7, 8]. For perishables, this decision is further complicated as the products to allocate may have different remaining shelf life. Even if the warehouse has more stock on hand than what is requested from the stores (no rationing required) the products still needs to be allocated among the stores to reduce the risk of outdating. Consequently, it has been stated that for perishables the *age* of the allocated products may be as important as the *amount* allocated [9].

Rationing policies consider how to distribute the *amount* of products from the warehouse typically based on information about expected demand, inventory position, or safety stock levels at the stores [7]. The different *age* groups of products at the warehouse can be expressed by the remaining shelf life (RSL_W) of those products. To decide which stores that should receive products with the longest RSL_W the remaining shelf life of the products currently at the stores (RSL_S) appear useful and will be investigated. Hereby, a more even distribution of freshness across the supply chain may be obtained.

The literature on allocation of perishables in distribution systems is limited [10] and is often presented as comprehensive decision models [11, 12]. It has been noticed that advanced models and decision support systems faces some barriers of implementation (e.g. the underlying model is too complex and not understood nor trusted [13]). Subsequently, there is a need to investigate more real world settings of perishables [14].

In this study, we investigate and propose simple guidelines for how practitioners can allocate the amount and the age of perishables. As the allocation of the products is made at the warehouse, we assume access to RSL_W at all times. However, depending on the level of shared information the warehouse might not have access to the RSL_S. Thus, we investigate and propose guidelines for the following scenarios:

(1a) The warehouse has not access to RSL_S and no shortage at the warehouse
(1b) The warehouse has not access to RSL_S and shortage at the warehouse
(2a) The warehouse has access to RSL_S and no shortage at the warehouse
(2b) The warehouse has access to RSL_S and shortage at the warehouse.

The remainder of this paper is organized as follows: first, we present the relevant literature about rationing and inventory allocation of perishables. Afterwards, we restrict our attention to the development of the guidelines. Section four discusses the implications and applicability of the guidelines.

2 Background

For non-perishables the optimal control of divergent distribution systems follows the order-up-to policy under the balanced stock assumption [9]. The balanced stock assumption assumes that the inventory position across all downstream stocking points are balanced or at least negligible unbalanced, making it possible to consider a divergent system as a serial system [15]. For divergent systems typical rationing policies includes: *Fair Share* allocation which strives to obtain an even probability of stock-out at each downstream stocking point [7]. *Priority* allocation which ranks and allocate the amount available based on the importance of each customer. *Consistent Appropriate Share* allocation where downstream stocking points with higher safety stock receives a bigger ratio from the warehouse [7].

No equivalent optimal control mechanism exists for perishables in divergent systems due to the complexity created by the different ages of the products [9]. Divergent systems are of special interest as these reflects the common situation of food supply chains. Yet, the contributions for controlling perishables are limited in these systems [10]. Two main classes of policies can be identified: (1) rotation policies, where the remaining inventory from downstream stocking points is returned to the warehouse at the end of each period, and (2) retention policies where the downstream stocking points keeps all remaining inventory until sold or outdated [16]. As it is most common to apply the retention policy in food supply chains we restrict our attention to these.

Traditionally, the allocation decisions for perishables have been simplified to reduce complexity [9]. For instance assuming zero lead time [17] or infinite supply to the stores [10]. Also, in the policy by Prastacos [16] the only products of interest are products that outdate at the end of the next period, or in other words, only products with one day left of shelf life. Because it is assumed that the warehouse has a constant flow of products to the stores, the warehouse will never keep products with a remaining shelf life of one day. Hereof it follows that what the warehouse allocates to the stores do not influence outdating in the end of next period (the products that outdates are already in the stores), and the problem is reduced to minimize the risk of shortage.

To minimize shortage and outdating a common observation appear to have been found in literature: (1) the number of products soon-to-outdate should be distributed evenly and relatively to demand (for each location), and (2) the total amount allocated should equalize the probability of stock-out at each location [10, 16].

3 Development of guidelines

If the RSL_S are unbalanced among downstream stocking points it might not be sufficient to *just* focus on the soon-to-outdate products at the warehouse, and allocate them relatively to demand as suggested above. Three practical obstacles highlights this. Firstly, that allocation procedure do not consider how to allocate products which are not classified as “soon-to-outdate” and how this affect the freshness at the stores. Secondly, in food supply chain products are often shipped in multiplies of batch sizes [3], and the allocation sizes might end up being different from the number of batches – meaning the soon-to-outdate products cannot be evenly distributed. Thirdly, from the perspective of the pick-and-pack process it is more efficient if e.g. three batches from the same pallet (same RSL_W) is collected to one order instead of three batches from three different pallets.

Similar to literature about simple replenishment policies of perishables (see e.g. [4, 18], we aim to develop simple allocation policies for perishables which acts as guidelines to ensure its applicability. These guidelines should consider and accommodate the obstacles highlighted above.

The following section presents the guidelines if RSL_S information from the stores are not available to the warehouse, and the second section presents the guidelines if we assume RSL_S is available. All guidelines assumes there is access to RSL_W at all times. Some general notation is outlined below:

B : Batch size (order multiplier between the store and the warehouse)
Q_i : Order quantity (in batches) from store *i*
I_i : Current inventory level at store *i* (in SKUs)
I_0 : Current inventory level at warehouse (in batches)
L_i : Lead time for store *i*
R_i : Days till next review at store *i*
A_i : Amount of “old” products at store *i* whit a RSL_S less than or equal to R+L
WA_i: Weighted average RSL_S of A_i at store *i*

3.1 Allocation of perishables without RSL_S information

Inventory greater than demand

Rationing among stores are not necessary when the warehouse holds more inventory on hand than what is totally requested from the stores. This reduces the problem to how to allocate the different ages groups from the warehouse. To counteract the obstacles of batches and how to distribute different RSL_W to the requesting stores, we propose to rank stores according to expected sales until next delivery – stores with the highest expected sales receive the oldest products from the warehouse to increase the chance of selling these products before they outdate. The expected sales until next delivery ($L_i + R_i$) includes the order (Q_i) plus the current inventory level at the store (I_i), mathematically we formulate this ranking as:

$$Rank_1 = \frac{BQ_i + I_i}{L_i + R_i} \quad (1)$$

As an example, assume store A has 20 products currently on inventory (I_i) and ordered (Q_i) additionally 2 batches of 10 products, while store B has 40 products on inventory and also ordered additionally 2 batches. With both stores having a review and lead time (L_i+R_i) of totally 2 days, store A would obtain a $Rank_1$ score on (2*10+20)/2 = 20 and store B (2*10+40)/2 = 30. In this case store B should receive the oldest RSL_W as a higher sales is expected here compared to store A.

Inventory less than demand

If the warehouse holds less inventory than what is totally requested from the stores, rationing among the requesting stores are necessary. Thus, it is necessary to allocate the available amount and the different age groups from the warehouse. We propose a three-step procedure following the logic from the fair share allocation rule to calculate the amount to allocate.

Step 1 - Calculate the average supply chain wide service level:

Assuming a perfect balanced distribution of available products among the stores, we calculate the ratio between available products ($\Sigma I_i + I_0$) in the chain and the total demand across ($\Sigma BQ_i + \Sigma I_i$) the whole chain – giving an indication of the best case service level. Again, demand is considered as the sum of orders and current inventory levels from the stores.

$$SLA1_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i} \text{; for all } i \quad (2)$$

Similar, for each store the current service level can be calculated:

$$SL1_i = \frac{I_i}{I_i + BQ_i} \quad (3)$$

Continuing the example from above, and with 3 batches available at the warehouse (I_0) it can be calculated that $SLA1_{SC}$ is (40+20+10*3)/(10*2+10*2+20+40) = 90%. $SL1_A$ equals 20/(20+10*2) = 50% and $SL1_B$ 40/(40+10*2) = 66.67%.

Step 2 - Calculate the possible supply chain wide service level:
Stores which has a current service level ($SL1_i$) larger than average supply chain wide service level ($SLA1_{SC}$) is "overstocked", and should ideally receive negative quantities in order to distribute their surplus among "understocked" locations [7, 16]. However, as these types of transshipments is very uncommon food supply chains, we propose to exclude the overstocked locations and only distribute the available products from the warehouse to understocked locations by calculating a new supply chain wide service level:

$$SLP1_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i} \text{; for all } i \text{ where: } SL1_i < SLA1_{SC} \quad (4)$$

From the example, as both $SL1_A$ and $SL1_B$ is less than $SLA1_{SC}$ both stores are understocked and $SLP1_{SC}$ will in this case be equal to $SLA1_{SC}$.

Step 3 – Calculate allocation quantities:
$SLP1_{sc}$ specifies the service level at each store after allocation, thus the allocation quantity can easily be determined by subtracting the current inventory level (I_i):

$$QA1_i = \frac{(I_i + BQ_i)SLP_{SC} - I_i}{B} \text{; for all } i \text{ where: } SL1_i < SLA1_{SC} \quad (5)$$

$QA1_A$ would equal ((20+10*2)*90%-20)/10 = 1.6 and $QA1_B$ = 1.4. Hence, store A would receive 2 batches and store B 1 batch. Lastly, the stores are again ranked following $Rank_1$ to allocate RSL_W. Stores B will have the highest score and receives the oldest products.

3.2 Allocation of perishables with RSL_S information

Inventory greater than demand
As in section 3.1 when inventory is greater than demand the issue is reduced to how to allocate the different age groups from the warehouse to the requesting stores. With access to RSL_S information both the number of products soon-to-outdate (*A*) and the weighted average remaining shelf life of that amount (*WA*) can be calculated and used to improve the allocation. To compensate for either a high amount of products (*A*) or a low RSL_S (*WA*) for improving the allocation the ratio between those two are calculated:

$$RA_i = \frac{A_i}{WA_i} \text{; for all } i \quad (6)$$

This ratio may be used as a measure for comparing stores against each other – a smaller ratio indicates a smaller risk of products outdating. E.g. assume store A has 4 products soon-to-outdate with a weighted average RSL_S of 2 days (RA_i=4/2=2) compared to the bigger risk at store B with 15 products with a weighted average RSL_S of 2 days (RA_i=15/2=7.5).

However, this risk should be considered in relation to the expected sales of the two stores. As previously, stores with higher expected sales are expected to have a higher chance of selling products before the expire and should receive the oldest products from the warehouse. The risk of products outdating (RA_i) is compared to the expected sales:

$$Rank_2 = \frac{RA_i}{BQ_i + I_i} \tag{7}$$

Store A equals 2/(2*10+20) = 0.05 on $Rank_2$ while store B ranks with 7.5/(10*2+40) = 0.125 meaning that, proportionally to demand, store B has a higher risk that the products already in the store will outdate. Thus, store A (with the lowest $Rank_2$ value) receive the oldest product and store B receive the newest. Hereby, a more even distribution of freshness will be obtained across the chain.

Inventory less than demand

In case of shortage at the warehouse a similar procedure is followed as without RSL_S information - the difference is stores, which either has many products soon-to-outdate (A) or little RSL_S left (*WA*) which gets more weight relative to other stores. We use the *RA* ratio to make this comparison. A high value indicates that the store risks some products to outdate, thus it can be considered as an "extra demand" to be covered by the store. We adjust the steps and formula 2-5 accordingly:

Step 1 - Calculate the average supply chain wide service level:

$$SLA2_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i + \sum RA_i} \text{; for all } i \tag{8}$$

$$SL2_i = \frac{I_i}{I_i + BQ_i + RA_i} \tag{9}$$

Assuming 3 batches on the warehouse, $SLA2_{SC}$ can be calculated to (20+40+10*3)/(10*2+10*2+20+40+2+7.5) = 82.2%, $SL2_A$ to 20/(20+10*2+2) = 47.6% and $SL2_B$ to 59.2%.

Step 2 - Calculate the possible supply chain wide service level:

$$SLP2_{SC} = \frac{\sum I_i + BI_0}{\sum BQ_i + \sum I_i + \sum RA_i} \text{; for all } i \text{ where: } SL2_i < SLA2_{SC} \tag{10}$$

As both $SL2_A$ and $SL2_B$ is less than $SLA2_{SC}$ both stores are understocked and $SLP2_{SC}$ will in this case be equal to $SLA2_{SC}$.

Step 3 – Calculate allocation quantities:

$$QA2_i = \frac{(I_i + BQ_i + RA_i)SLP2_{SC} - I_i}{B} \text{; for all } i \text{ where: } SL2_i < SLA2_{SC} \tag{11}$$

$QA2_A$ would equal ((20+10*2+2)*82.2%-20)/10 = 1.45 and $QA2_B$ = 1.55. Hence, store A would receive 1 batches and store B 2 batches. Lastly, the stores are again ranked according to $Rank_2$. Stores A will have the lowest score and will receive the oldest products.

4 Conclusions

This study adds to the limited literature about allocation of perishables [10] by proposing guidelines for how practitioners can allocate perishables to improve the balance of freshness and availability in stores. Two main areas of concern is discussed in this section. Firstly, what is the implications[1] of applying guidelines like these in practice? Secondly, how widespread is the applicability and the ease of implementation?

The guidelines strive to balance the risk of shortage and outdating evenly across all downstream stocking points while accommodating practical obstacles like batch sizing and the efficiency of pick-and-pack process. $Rank_1$ is applied when there is no access to RSL_S information, and strives to ensure smaller stores with less sales receive products with the highest RSL. Often smaller stores only have deliveries few times a week, thus it is essential that the products they receive last as long as possible. On the contrary, bigger stores with higher sales will receive the less fresh products. The chances of a consumer willing to accept a lower RSL might be higher in these stores as they generally has more consumers through the store during the day. $Rank_2$ can be applied when the warehouse has access to the RSL_S information. It basically follows the same reasoning about fresher products to smaller stores. But, here the allocation (amount and RSL) are dynamically adjusted according to the RSL_S. Hereby, larger stores do not necessarily always get the products with lowest RSL.

Even though the guidelines can be considered applicable to most food supply chains, there is risk that some stores perceive themselves as having a lower priority if they continuously receive products with lower RSL than other stores. This should be considered, especially if the stores are independently owned or franchising of a larger retail concept. The benefits should be distributed to ensure those stores that may take a big risk of receiving products with low RSL also receive a corresponding reward. On the other hand, stores that are fully owned by the same retailer may prefer guidelines as these proposed in this study to improve the balance of freshness and availability across all its stores.

Lastly, it should be noticed, that using guidelines like these do not guarantee an optimum balance of freshness and availability and could be considered as a limitation – however, they provide an easier reasoning for the employees who has to apply them. As future research the guidelines should be tested either through simulation experiments or case implementation to quantify the impact on freshness and availability.

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[1] The guidelines will be tested through discrete event simulation to estimate the impact on freshness, waste, and available. The results will be presented at the APMS conference in Hamburg 2017 and will be available upon request, but is omitted in the paper due to space limitation.

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