# Towards a Socially Sustainable Inventory Optimization

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## ABSTRACT

Inventory optimization is one of the critical decisions in perishable product supply chain management. This study develops a bi-objective inventory optimization model for perishable products. The model can determine the optimal order quantities that fulfill customer demand over time while simultaneously maximizing the profit and minimizing the freshness loss of products at the point of demand fulfillment. The fresh-ness loss value is regarded as the social sustainability performance metric. It is expected that the minimization of freshness loss contributes to the improved well-being of customers. The proposed model can track the product's remaining shelf life and account for the amount of waste generated when it is expired. A numerical case is provided to demonstrate the utility of the model and the decision-making process that deals with the tradeoff between cost and freshness level. The proposed concept and methodology can serve as the basis for the future development of sustainable supply chain management, focusing on the social impacts.

***Keywords*:** *Inventory Optimization, Perishable, Freshness, Social Sustainability, Supply Chain Management.*

## 1 INTRODUCTION

All aspects of supply chain-related decisions can be related to the sustainable development of the supply chain. The decisions such as production planning, supplier selection, inventory management, and transportation optimization have contributed to improving cost efficiency, environmental impact mitigation, and the well-being of stakeholder communities. At any rate, among the three pillars of sustainability, the social aspect is still relatively underdeveloped. The development of indicators and quantitative measures and their implication in optimization modeling is still a research challenge to be addressed. The is a need for a systematic consideration and evaluation of the social impact, which can be classified into labor conditions, human rights, society, and product/service responsibility (Bubicz et al., 2019).

Inventory optimization is a critical supply chain management process, as its outcomes have a direct impact on a firm's cash flow and customer service level. The role of inventory optimization in contributing to social sustainability is an emerging research subject in sustainable supply chain management, as discussed in the literature review section of the paper.

Creating a firm's social reputation is made by establishing the linkage between their inventory's service level and customer satisfaction. This is rationale when considering customers as the main stakeholder. To contribute to the field, this study develops a bi-objective inventory optimization model for perishable products. The development of an inventory plan for perishable products is a complex task as the plan needs to account for not only the shelf life but also the demand-fulfillment ability of the remaining products and waste gene.

ration over time. We present the case where of inventory control that maximize the freshness of products at the point of their demand fulfillment. The key functions of our model are 1) the ability to track the remaining shelf-life of products and 2) the incorporation of freshness-based social impact indicators in one of the two optimization objectives. The epsilon constraint method is used to generate the tradeoff solutions. The problem, model formulation, and analysis details are provided in the subsequent parts of the paper.

The effects of changes in the products' lifetime or freshness on supply chain performance have been investigated by recent research. Shirzadi et al. (2021) solve the inventory routing problem where the quality decay of products and its consequence on customer's dissatisfaction cost is examined. Wei et al. (2020) consider a perishable product retailer where the time-varying freshness function is used. Their GA determines the optimal pricing and replenishment policy under the profit maximization objective. Chen et al. (2019) propose an approach capable of determining the optimal replenishment and pricing policies for short-life products with a random lifetime due to deterioration. They introduce the case where the deterioration rate is a function of the inventory level. Sebatjane and Adetunji (2020), Shen et al. (2020); Hashemi et al. (2020) present an inventory management model, capable of handling freshness- and price-dependent demand, for a perishable product supply chain.

While the effects of product deterioration on cost are commonly investigated, carbon emission is another interesting aspect of the effects explored by previous studies. Yavari and Zaker (2019) develop a network design approach for the perishable products supply chain. The cost and carbon emission impacts associated with the changes in the products' lifetime under the disruption condition are evaluated. Yu et al. (2020) consider the carbon emission due to the storage of perishable products over their lifetime in their inventory management approach.

There is a limited study that actually embeds product freshness or consumer's fresh-

ness perception within supply chain optimization objectives, mainly to explore the social sustainability design. These studies recognize consumers as the primary stakeholder and aim to strengthen the underdeveloped social sustainability pillar. Yakavenka et al. (2020) incorporate product freshness into their socially responsible network design goal. Their goal-programming model encompasses the goal that ensures the fresh deliveries of food products through the selection of transportation modes, facility location selection, and product flow determination. Liu et al. (2021) develop a sustainable supply chain management model that simultaneously considers the cost, carbon emissions, and freshness of perishable products. Jouzdani and Govindan (2021) demonstrate using their sustainable food supply chain network design approach that comprehensively considers the three pillars of sustainability. However, the social impact considered is related to the traffic congestion caused by the network design, not the freshness of products.

A research needs to integrate the interaction between product freshness and social sustainability into inventory optimization and supply chain management. Therefore, this study develops an inventory optimization model that focuses on tracking and maximizing the freshness levels and the amount of the perishable inventory that fulfills demand. The freshness satisfaction objective is formulated in terms of freshness loss minimization. The traditional cost and profit consideration is also made. The problem description and model formulation are presented next.

## 2 RESEARCH METHODS

The case of a perishable product distributor is considered in this study. The distributor needs to fulfill customer demand over a planning horizon of 14 periods. The decisions of how much and when to replenish the inventory are to be made. The replenishment cost, including ordering cost and product cost per unit, is lot-size dependent. Three lot sizes are assumed,

namely small (500 units), medium (1,000 units), and large (2,000 units). Larger lot sizes are assumed preferable for cost minimization due to the much smaller cost per unit. However, smaller lot sizes are assumed to be more favorable when maximizing the freshness of products. There is also a lower chance of having expired inventory and waste when ordering smaller lot sizes. The freshness-level values of products over the remaining shelf life period are assumed to be known. The life of a product is three periods. In addition to the replenishment cost, inventory cost and waste disposal cost are also taken into account. The problem will be solved using the proposed inventory model, consisting of two objectives. The analysis of single-objective and bi-objective scenarios is provided.

## 2.1 *The assumption*

This study considers the inventory optimization problem for one product over 14 periods ($T$). The mathematical model is developed based on the following assumptions:

- There is no initial inventory.
- The distributor can place one order per period.
- The distributor receives the product at the end of the ordering period.
- The customer demand is satisfied at the end of the period.
- The remaining inventory is computed at the end of each period
- The expired product (remaining life is zero) becomes waste and cannot be used for demand fulfillment

## 2.2 *Indices and parameters*

The indices, and parameters, embedded in the mathematical model, are presented as follows

### * Indices

| | |
|---|---|
| $T$ | Number of periods |
| $L$ | Number of order levels |
| $S$ | Number of product's shelf life |
| $t$ | Index for period ($t = 1, 2, \ldots, T$) |
| $l$ | Index for ordering level ($l = 1, 2, \ldots, L$) |

| | |
|---|---|
| $s$ | Index for product's shelf life ($s = 0, 1, \ldots, S$) |

### * Parameters

| | |
|---|---|
| $De_t$ | The customer demand at period $t$ |
| $StCap_t$ | The storage capacity of the distributor at period $t$ |
| $Weight$ | The disposal weight per unit of the product |
| $SaP_t$ | The sale price per unit of the product that the customer needs to pay at period $t$ |
| $PC_{lt}$ | The product replenishment cost (per unit) at period $t$, lot size $l$ |
| $IC_t$ | The inventory cost per unit of the product at period $t$ |
| $OC_l$ | The ordering cost corresponding to ordering lot size $l$ for the order placed by the distributor |
| $DC$ | The disposal cost when the shelf life of the product equals 0 |
| $OS_l$ | The number of products corresponding to the ordering lot size $l$ |
| $FL_{st}$ | The percentage of the freshness lost at different remaining shelf life $s$ and period $t$ |
| $BigM$ | A huge number |

## 2.3 *Decision variables*

| | |
|---|---|
| $OA_{lt}$ | The number of products in the order placed by the distributor at period $t$ |
| $YO_{lt}$ | This binary variable stands for whether the company places an order of level $l$ at period $t$. When the value is 1, the company places an order, otherwise, the value is 0. |
| $IA_{st}$ | The number of products in the inventory with the remaining shelf life $s$ at period $t$ |
| $X_{st}$ | This binary variable represents the availability of the inventory in a specific shelf life $s$. The value is 1 when there is some inventory with the remaining life $s$ at period $t$. Otherwise, the value is 0. |
| $Pr_{st}$ | The percentage of the customer demand fulfilled by the product with remaining shelf life $s$ at period $t$ |

*TWei*     The total weight of expired products over planning horizon $T$

## 2.4  *Single Objective Optimization*

*\* Single objective functions*

The model includes two objective functions, which are profit maximization (the first objective) and freshness loss minimization (the second objective).

*The 1$^{st}$ objective – Maximization of profit (TP):*

Objective:  Max *TP*

The total profit based on the revenue and costs is shown in (1). The total revenue (*TRev*) as shown in (2) is the total monetary gained from selling the product to customers over the 14 periods. The total cost *(TCost)* presented in (3) is the sum of the product cost, ordering cost, inventory cost, and waste disposal cost.

$$TP = TRev \text{ - } TCost \tag{1}$$

$$TRev = \sum_{t \in T} SaP_t * De_t \tag{2}$$

$$TCost = \sum_{l \in L}\sum_{t \in T} PC_{lt} * OA_{lt} + \sum_{l \in L}\sum_{t \in T} OC_l * YO_{lt} \tag{3}$$
$$+ \sum_{s \in S}\sum_{t \in T} IC_t * IA_{st} + DC * Weight * \sum_{t \in T} IA_{(s=0)t}$$

*The 2$^{nd}$ objective – Minimization of freshness loss (TFL):*

Objective:  Min *TFL*

The model expects to provide fresh products to customers. The total freshness loss (*TFL*) can be computed using (4).

$$TFL = \sum_{s \in S}\sum_{t \in T} FL_{st} * IA_{st} \tag{4}$$

*\* Constraints*

The models with the single objective optimization must satisfy the following constraints.

$$\sum_{l \in L} OA_{lt} = De_t + \sum_{s \in S} IA_{st} \qquad t=1 \tag{5}$$

$$\sum_{l \in L} OA_{lt} + \sum_{s=1}^{S} IA_{s(t-1)} = De_t + \sum_{s \in S} IA_{st} \qquad t>1 \tag{6}$$

$$YO_{lt} * OS_l = OA_{lt} \qquad \forall l, \forall t \tag{7}$$

$$\sum_{l \in L} YO_{lt} \leq 1 \qquad \forall t \tag{8}$$

$$IA_{st} = IA_{(s+1)(t-1)} - De_t * Pr_{st} \qquad t>1, s\leq 2 \tag{9}$$

$$IA_{st} = \sum_{l \in L} OA_{lt} - De_t * Pr_{st} \qquad \forall t, s>2 \tag{10}$$

$$IA_{st} = 0 \qquad t=1, s\leq 2 \tag{11}$$

$$\sum_{s=1}^{S} Pr_{st} = 1 \qquad \forall t \tag{12}$$

$$Pr_{st} = 0 \qquad \forall t, s=0 \tag{13}$$

$$\sum_{s=1}^{S} IA_{st} \leq StCap_t \qquad \forall t \tag{14}$$

$$IA_{st} \leq X_{st} * BigM \qquad \forall s, \forall t \tag{15}$$

$$IA_{st} \geq X_{st} \qquad \forall s, \forall t \tag{16}$$

$$Pr_{(s=3)t} \leq 1 - X_{(s=2)t} \qquad \forall t \tag{17}$$
$$Pr_{(s=3)t} \leq 1 - X_{(s=1)t} \qquad \forall t \tag{18}$$
$$Pr_{(s=2)t} \leq 1 - X_{(s=1)t} \qquad \forall t \tag{19}$$
$$TWei = Weight * \sum_{t \in T} IA_{(s=0)t} \tag{20}$$

$OA_{lt}$ , $IA_{st} \geq 0$, Integer $\hspace{2cm}$ (21)

$Pr_{st} \geq 0$ $\hspace{4cm}$ (22)

$YO_{lt}$ and $X_{st}$ are binary variables $\hspace{0.5cm} \forall l, \forall t, \forall ts$ $\hspace{0.5cm}$ (23)

Constraints (5) and (6) indicate that all the customer demands are satisfied at the end of each period. The customer demand depends on the ordering amount and the inventory amount. The ordering amount complies with the lot size order policy shown in constraint (7). The distributor is unable to place more than one order each period as presented in equation (8). Constraints (9), (10), and (11) are inventory constraints. The inventory amount at different remaining shelf life is controlled by constraints (9) and (10). There is no initial inventory, enforced by constraint (11). The $Pr_{st}$ is the proportion of customer demand fulfilled by the product with the remaining shelf life $s$ at period $t$. The summation of $Pr_{st}$ value in shelf life 1 to 3 at period $t$ is 1, as shown in constraint (12). Products with the remaining life of 0 cannot be used to fulfill customer demand. Thus, the $Pr_{st}$ with shelf life $s = 0$ must be 0, by constraint (13). Consequently, these products become waste and incur waste disposal costs, which can significantly affect the first objective value. Constraint (14) makes sure that the total inventory amount in every shelf life $s$ does not exceed the distributor's storage capacity at period $t$. In this regard, the model prioritizes to use older inventory to meet customer needs, which is restricted by constraints (15) to (19). Constraints (15) and (16) present that the newer inventory can be used to fulfill the demand only when the older inventory is insufficient. Constraint (20) allows the model to compute the total weight of expired products

at the end of the planning horizon $T$. Finally, constraints (21) – (23) are non-negativity, integer, and binary constraints, respectively.

## 2.5 Bi-Objective Optimization

To deal with the multi-objective, the model applies the Epsilon constraint method (Andersson, 2001). For the Epsilon constraint method, the Profit Maximization is selected for optimization. Additionally, there is an additional constraint (24) that limits *TFL* to be less than a constant (*eps*) as follows:

Objective: Max *TP*

Subject to: Equation (5) – (23)

$$\sum_{s \in S} \sum_{t \in T} FL_{st} * IA_{st} \leq eps \hspace{1cm} (24)$$

## 3 RESULTS AND DISCUSSION

This section shows the results obtained from both the single-objective and multi-objective models. The IBM CPLEX software is used in this study. Furthermore, the tradeoff solutions between the two objectives are attained using the Epsilon constraint method and Pareto chart analysis.

∗ *The result of single-objective model*

Table 1 exhibits the demand, ordering (replenishment) amount, and the remaining inventory with different shelf life across 14 periods. The customer demands are fulfilled by older inventory first. There is waste generated at periods 4 and 11.

Table 1. The amount of demand, replenishment, and remaining inventory (in unit)

| Period | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Demand (unit)** | 800 | 300 | 500 | 200 | 250 | 300 | 600 | 208 | 209 | 210 | 400 | 600 | 550 | 210 |
| **Ordering amount** | 2000 | 0 | 0 | 500 | 0 | 1000 | 0 | 500 | 0 | 0 | 1000 | 0 | 1000 | 0 |
| Remaining amount of product with a different shelf life | | | | | | | | | | | | | | |
| **Shelf life = 0** | 0 | 0 | 0 | 400 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 0 | 0 |
| **Shelf life = 1** | 0 | 0 | 400 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 0 | 0 | 0 |
| **Shelf life = 2** | 0 | 900 | 0 | 0 | 50 | 0 | 150 | 0 | 233 | 0 | 0 | 0 | 0 | 240 |
| **Shelf life = 3** | 1200 | 0 | 0 | 300 | 0 | 750 | 0 | 442 | 0 | 0 | 600 | 0 | 450 | 0 |

Table 2. The total profit and freshness score

| | **Max Profit** | **Min Freshness Loss** | **Bi-obj** |
|---|---|---|---|
| Profit | 83,165.40 | 62,980.53 | 75,573.87 |
| Freshness Loss | 1,191.00 | 200.70 | 200.70 |
| Small | 2 times | 7 times | 3 times |
| Medium | 3 times | 3 times | 4 times |
| Large | 1 time | 0 time | 0 time |

Table 2 shows the total profit and freshness score of single-objective scenarios and a bi-objective scenario. The profit maximization objective results in the highest profit. However, the freshness loss is the highest among the scenarios. The replenishment relies more on smaller lot sizes for the freshness loss minimization to feed customers with fresher products. Under the bi-objective scenario, we select the Pareto solution S2 from Figure 1. This solution also offers the minimum freshness loss at a reasonably high profit, compared to the other scenarios. The planners can observe and select their preferred solutions based on their desirable profit and freshness loss levels.

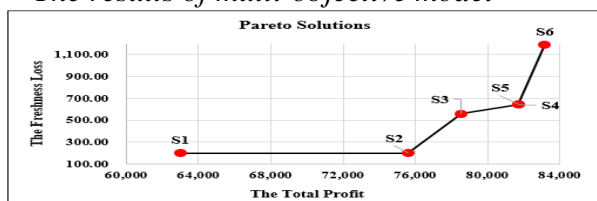* *The results of multi-objective model*



Figure 1. The Pareto chart showing the tradeoff between profit and freshness loss

It is worth noting that the main scholarly contribution of this paper is related to the consideration of freshness loss. Minimizing the products' freshness loss surely contributes to the improved well-being of customers, who are regarded as the main stakeholder. The model formulation that enables the tracking of remaining inventory with different shelf-life is another highlight of this work. The future study can focus more on the waste issue. Freshness satisfaction and waste consideration can be integrated into the waste-oriented sustainable supply chain management frameworks (Olapiriyakul, 2017, Bubicz et al., 2019, Olapiriyakul et al., 2019). This would allow us to engage in a more comprehensive social sustainability scope. There can be multiple locations of distribution points. The scope of decision makings can cover both inventory and network design. It would be interesting to consider the solid waste burden issues caused by the inventory of food and other perishable products.

REFERENCES

Andersson, J. 2001. *A survey of multiobjective optimization in engineering design*. Technical Report: LiTH-IKP-R-1097, Department of Mechanical Engineering, Linköping University, 581 83 Linköping, Sweden

Bubicz, M. E., Barbosa-Póvoa, A. P. F. D., & Carvalho, A. 2019. Incorporating social aspects in sustainable supply chains: Trends and future directions. *Journal of Cleaner Production,* 237(2), 117500.

Chen, L., Chen, X., Keblis, M. F., & Li, G. 2019. Optimal pricing and replenishment policy for deteriorating inventory under stock-level-

dependent, time-varying and price-dependent demand. *Computers & Industrial Engineering, 135*: 1294-1299.

Hashemi, T., Teimoury, E., Barzinpour, F. J. I. J. o. I. E., & Research, P. 2020. Coordination of Pricing and Inventory Decisions in a Fresh-product Supply Chain Considering the Competition between New and Old Products. *International Journal of Industrial Engineering & Production Research,* 31(3): 469-485.

Jouzdani, J., & Govindan, K. 2021. On the sustainable perishable food supply chain network design: A dairy products case to achieve sustainable development goals. *Journal of Cleaner Production,* 278(3), 123060.

Liu, A., Zhu, Q., Xu, L., Lu, Q., & Fan, Y. 2021. Sustainable supply chain management for perishable products in emerging markets: An integrated location-inventory-routing model. *Transportation Research Part E: Logistics and Transportation Review,* 150(2), 102319.

Olapiriyakul, S. 2017. Designing a sustainable municipal solid waste management system in Pathum Thani, Thailand. *International Journal of Environmental Technology and Management,* 20(1-2): 37-59.

Olapiriyakul, S., Pannakkong, W., Kachapanya, W., & Starita, S. 2019. Multiobjective Optimization Model for Sustainable Waste Management Network Design. *Journal of Advanced Transportation, 2019(2)*: 1-15.

Sebatjane, M., & Adetunji, O. 2020. A three-echelon supply chain for economic growing quantity model with price- and freshness-dependent demand: Pricing, ordering and shipment decisions. *Operations Research Perspectives, 7*, 100153.

Shen, L., Li, F., Li, C., Wang, Y., Qian, X., Feng, T., & Wang, C. 2020. Inventory Optimization of Fresh Agricultural Products Supply Chain Based on Agricultural Superdocking. *Journal of Advanced Transportation,* 2020, 2724164.

Shirzadi, S., Ghezavati, V., Tavakkoli-Moghaddam, R., & Ebrahimnejad, S. 2021. Developing a green and bipolar fuzzy inventory-routing model in agri-food reverse logistics with postharvest behavior. *Environmental Science and Pollution Research*, https://doi.org/10.1007/s11356-021-13404-9.

Wei, J., Liu, Y., Zhao, X., & Yang, X. 2020. Joint optimization of pricing and inventory strategy for perishable product with the quality and quantity loss. *Journal of Industrial and Production Engineering,* 37(1): 23-32.

Yakavenka, V., Mallidis, I., Vlachos, D., Iakovou, E., & Eleni, Z. 2020. Development of a multi-objective model for the design of sustainable supply chains: the case of perishable food products. *Annals of Operations Research,* 294(1): 593-621.

Yavari, M., & Zaker, H. 2019. An integrated two-layer network model for designing a resilient green-closed loop supply chain of perishable products under disruption. *Journal of Cleaner Production,* 230: 198-218.

Yu, C., Qu, Z., Archibald, T. W., & Luan, Z. 2020. An inventory model of a deteriorating product considering carbon emissions. *Computers & Industrial Engineering, 148*, 106694.