“Ryokan” Fresh Ingredients Inventory Model Considering Purchase Price Fluctuations and Product Deterioration

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Abstract: Recently, the “cost increase of ingredients” has been listed as the critical management issue in “Ryokans” (traditional Japanese inns). The characteristics of food inventory management in the Ryokan business are considered, namely, the high proportion of fresh ingredients in Ryokans’ meal service, purchasing price fluctuations, and the freshness of ingredients. Inventory management of fresh ingredients, by their nature, usually confront the reality of dynamic purchase prices and deterioration. This paper considers inventory models to decide the special order quantity of fresh ingredients in the Ryokan business domain when the supplier offers a one-time-only lower price. In this study, the concept of depreciation in corporate accounting is introduced to define deterioration. Numerical examples using real data from Ryokan A in Tsukuba City are presented to confirm the usefulness of the proposed model.

Key Words: Fresh ingredients, Purchase price discount, Deterioration, Depreciation.

1. Introduction

Recently, the “Ryokan” (traditional Japanese inns) hospitality industry is facing challenges. Figure 1 shows that the number of Ryokans is on a declining trend and room numbers have declined 17% from 2010 to 2015 [1]. There has thus emerged a need for improving their management.

[2] analyzed the profit and loss of Ryokans from the Japan Ryokan Association and posited that it is necessary to reduce personnel expenses and food ingredient costs from the difference in cost structure between the Ryokans in deficit and those in surplus. According to the survey by [3], the “cost increase of food materials” is listed as the critical management issue surpassing “availability of human resources” and “cost of hiring.” Since many Ryokans provide Japanese course meal services and hotels’ food services account for a higher proportion of sales than ever before, it is evident that effective food materials inventory management should be acknowledged as a measure that can directly contribute to cost reduction.

The characteristics of food materials to be considered with respect to inventory management in the Ryokan business are shown in Table 1.

As illustrated by Table 1, Ryokans are peculiar in that they can easily predict food inventory needs from accommodation reservations and many of the ingredients used are fresh produce. The purchasing price of fresh ingredients is a dynamic function of crop yields and the control of inventory levels by suppliers in the wholesale market. When a supplier temporarily offers a lower price, it is possible for buyers to reduce costs by placing a special order. On the other hand, the loss of freshness due to deterioration must also be taken into account. This study will focus on the characteristics of fresh ingredients and develop a new inventory model to decide the one-time, special order quantity.

The numerical examples present comparisons between four ordering policies with their relative costs, using empirical ordering data obtained from Ryokan A.
2. Literature Review

According to [4]’s review paper, there are two major types of discount: temporary discounts (one-time discount offer) and quantity discounts (discount based on the amount of products). This study focuses on the case of fresh ingredients and temporary discounts, mainly because the changes in price of these ingredients are mostly due to yield and prevailing meteorological conditions rather than quantity discount.

The inventory model that considers temporary unit price discounts to decide the special order quantity so as to reduce the costs was devised by research conducted by [5],[6], and [7],[8] considered that buyers reflect the discounted purchase price in their selling price, which results in an increase in demand.[9] presented a model for temporary price reductions and considers that backlogging is available.[10] developed and evaluated models based on five different discount sale scenarios: (1) coincidence of sale period with replenishment time, (2) non-coincidence of sale period with replenishment time, (3) sale period is longer than a cycle, (4) discounted price as a function of the special ordering quantity, and (5) incremental discount.[11] extended the special order model considering backorders and minimum-order quantity.[5]-[11] have considered two ordering policies. The first assumes that buyers procure a special order $Q_s$, which is larger than $Q$, to take advantage of the lower unit cost.[5]-[11] have shown how the special order can reduce the total cost when a price discount is offered.[5]-[11] explicate ordering models assuming discounted purchasing prices but do not discuss the problem of deterioration in the context of these special orders.

Inventory shelf life is an empirical reality, particularly for food inventories. On the issue of deterioration of inventory stock,[12] first derived an economic order quantity on the basis of the assumption that the variation of inventory level $I(t)$ is dependent on the demand $D$ and deterioration $\theta$, as shown in Eq.(1).

$$\frac{dI(t)}{dt} = -\theta I(t) - D, 0 < t < T$$

(1)

Therefore, most subsequent inventory models that take inventory deterioration into account have used (1) as a base and mostly explore the effects of stock deterioration and demand rates or the allowance of the backorders ([12],[13]). However, as [14] have indicated that, generally speaking, inventories do not at all times decrease at the same rate due to deterioration; rather, they drop consequent to disposal after a certain period of time (best-before date). In actuality, fresh ingredients used in Ryokans may tend to be consumed before their best-before dates because of the certainties afforded via accommodation reservations. Treating stock deterioration as either an incremental decrease in stock amount or a disposal cost incurred because sales could not keep pace with deterioration may not be suited to the actual conditions in the Ryokan business. Therefore, this study takes the freshness of ingredients into account to better emulate inventory deterioration and considers that it is necessary to optimize both inventory cost and freshness objectives.

In addition, to validate empirical applicability, it is necessary to examine a numerical example based on actual data that have not been applied in previous research.

3. Model formulation

This section presents the derivation of the optimal special order quantity for deteriorating items when a lower price is provided. With respect to [10]’s five different discount sale scenarios, in this study, we evaluate two cases that many Ryokans may experience. The first is when a reorder coincides with a lower price, and the second is when a lower price falls at the order interval between the placing of regular orders. In both cases, regular and special orders are assumed. Through interviews with the manager of Ryokan A, even though the prices of ingredients are fluctuating in the current situation a small lot is ordered regardless of changes in purchase price. For that reason, we use a regular order to represent Ryokan A’s ordering in the model. Subsequently, we use a special order to represent the ordering responses to a one-time discount. The buyer has two options when the supplier offers a one-time-only lower price. In order to find the optimal special order quantity, the objective is to maximize cost saving against the regular order.

3.1 Notations and Assumptions

The notations used in model formulation are shown in Table 2.

| symbol | definition |
|--------|------------|
| $T(Q)$ | total cost of regular orders |
| $T(Q_s)$ | total cost of special orders |
| $A$ | ordering cost per order |
| $P_0$ | purchase price per unit |
| $P$ | discounted price per unit |
| $\delta$ | difference between the prices, $\delta = P_0 - P$ |
| $S_{P_0}$ | deterioration cost per time per unit |
| $h$ | inventory holding cost per time per unit |
| $t_r$ | time of general orders |
| $t_s$ | time of special orders |
| $t_b$ | time of best-before date |
| $I(T)$ | inventory level at time $t$ |
| $Q$ | order quantity of general orders |
| $Q_s$ | order quantity of special orders |
| $T$ | regular-order longevity |
| $T_s$ | special-order longevity |

In this paper, it is assumed that demand is constant. One special order can be placed before the purchase price increases. The order quantity of a regular order is called EOQ (economic order quantity). Replenishments will be made immediately. Ordering costs are identical for regular and special orders. Supply capacity and warehouse capacity are both omitted.

The provision of price information seems to cause a decrease in profit for the supplier; however, considering a
stable business relationship rather than dealing in fits and starts, it is regarded as desirable behavior when handling fresh items. Consequently to interviewing the manager of Ryokan A, some suppliers send catalogs and the price for the following week.

In addition to the purchase price, in the Ryokan business domain, they put a high value on freshness so that there is no discount due to the elapsing of the expiration date. Therefore, the discount price is set to be independent of the food’s expiration date. Case 2: Price discount before replenishment

Case 2 assumes a situation wherein the supplier is offering a discount price $P$ when the inventory level reached the reorder point. The unit price will increase to $P_0$ after the order. The buyer can either place a special order to take advantage of the cheaper unit price or neglect it. The inventory level increases to $Q_s$, when the buyer places a special order, and the ordering cycle will be $Q_s/D$. As shown in Figure 2, the continuous line represents the regular order and the dashed line is the special order.

3.3 Total cost model of Case 1

The total cost is defined as order cost + purchase cost + inventory cost + deterioration cost. Figure 2 indicates where a special order or regular order is made when inventory runs out. In this case, the first regular order is placed at purchase price $P$ and thereafter placed at $P_0$. The total regular order cost $T(Q)$ is shown in (4).

$$T(Q) = A + (P_0 - \delta) \times Q + h \times \frac{Q}{2} \times \frac{Q}{D} + S_P \times \frac{Q}{2} \times \frac{Q}{D} \times \left(\frac{Q_s - Q}{D}\right) + \left[A \times \frac{Q}{D} + P_0 \times D + h \times \frac{Q}{2} + S_{P_0} \times \frac{Q}{2}\right]$$

The total cost when one special order $T(Q_s)$ is placed is shown in (5). Since special orders are only for one lot, the first to fourth terms of (5) are the ordering cost, purchasing cost, inventory-keeping cost, and deterioration cost of the first regular order lot, and the fifth term represents the total cost in each regular order lot after the first.

$$T(Q_s) = A + (P_0 - \delta) \times Q_s + h \times \frac{Q_s}{2} \times \frac{Q_s}{D} + S_P \times \frac{Q_s}{2} \times \frac{Q_s}{D} \times \left(\frac{Q_s - Q_s}{D}\right) + \left[A \times \frac{Q_s}{D} + P_0 \times D + h \times \frac{Q_s}{2} + S_{P_0} \times \frac{Q_s}{2}\right]$$

From (4) and (5), the cost saved by placing a special order against a general order during the period wherein
placing a special order is given by $T(Q) - T(Q_s)$ is shown in (6).

$$T(Q) - T(Q_s) = (P_0 - \delta) \times (Q - Q_s) + h \times \left( \frac{Q^2 - Q_s^2}{2D} \right) + S_P \times \left( \frac{Q^2 - Q_s^2}{2D} \right) + \left( \frac{Q_s - Q}{D} \right) \times [A \times \frac{Q}{D} + P_0 \times D + h \times \frac{Q}{2} + S_{P_0} \times \frac{Q}{2}]$$

The first partial derivative of (6) with respect to $Q_s$ is shown in (7).

$$\frac{\partial}{\partial Q_s} (T(Q) - T(Q_s)) = -P_0 + \delta - \frac{hQ_s}{D} - \frac{S_P Q_s}{D} + \left( \frac{AD}{Q} + P_0D + \frac{hQ}{2} + \frac{S_{P_0}Q}{2} \right)/D$$

Taking the second partial derivative of (6) with respect to $Q_s$ then yields (8).

$$\frac{\partial^2}{\partial^2 Q_s} (T(Q) - T(Q_s)) = -\frac{S_P}{D} - \frac{h}{D}$$

Since $\frac{\partial^2(TC_n - TC_s)}{\partial^2 Q_s} < 0$, $(TC_n - TC_s)$ is convex in $Q_s$, and there is a global maximum. Solving $\partial(TC_n - TC_s)/\partial Q_s = 0$, the order quantity $Q_s$ that maximizes the cost saving can be obtained by (9)

$$Q_s = \frac{Q^2}{2} \times (S_{P_0} + h) + 2 \times D \times (Q \times \delta \times A) \times \frac{2 \times Q \times (S_P + h)}{2 \times Q \times (S_P + h)}$$

$Q_s$ increases with demand and the difference between the prices but is limited by deterioration cost and inventory holding cost. Note that if the discounted price is zero ($\delta = 0$) and there is no deterioration of the item, $Q_s$ reduces to the economic order quantity $Q$. When substituting $\delta = 0$, $S_{P_0} = S_P = 0$ in (6), $Q_s$ can be written as

$$Q_s = \frac{Q}{2} + \frac{2AD}{2Qh}$$

From the equation of EOQ shown as (11)

$$Q = \sqrt{\frac{2AD}{h}}$$

$$\frac{Q}{2} = \frac{2AD}{2Qh}$$

Substituting (9) to (7), $Q_s$ is equivalent to $Q$ when there is zero price discount and zero deterioration.

### 3.4 Total cost model of Case 2

As indicated in Figure 3, the discounted price is offered at the replenishment of the last regular order. In this case, the inventory level increases to $Q_s + I(t_s)$ because of the special order at $t_s$. Thus, the total cost then includes the time period of $I(t_s)/D$ for the remaining stock and the time period of $Q_s/D$. The total cost of a regular order $T(Q)$ is shown as (13). The first and second terms of (13) are the inventory keeping cost and deterioration cost of the remaining last order lot, and the third term represents the total cost in each regular order lot after the last lot is consumed.

$$T(Q) = h \times \frac{I(t_s)}{D} \times \frac{I(t_s)}{D} + S_P \times \frac{I(t_s)}{D} \times \frac{I(t_s)}{D} + \frac{Q_s}{D} \times [A \times \frac{D}{Q} + P_0D + h \times \frac{Q}{2} + S_{P_0} \times \frac{Q}{2}]$$

The total cost when one special order is placed is shown as (14)

$$T(Q_s) = A + (P_0 - \delta) \times Q_s + h \times (\frac{Q_s + I(t_s)}{D}) \times (\frac{Q_s + I(t_s)}{D}) + S_{P_0} \times \frac{I(t_s)}{D} \times \frac{I(t_s)}{D} + S_P \times \frac{Q_s}{2} \times \frac{Q_s}{2}$$

The cost savings during the replenishment by special order in Case 2 is given by (15)

$$T(Q) - T(Q_s) = h[I(t_s)^2 - (Q_s + I(t_s))^2] + S_P[I(t_s)^2 - Q_s^2] + \frac{Q_s}{D} \times [\frac{AD}{Q} + P_0D + \frac{hQ}{2} + S_{P_0} \frac{Q}{2} - S_P I(t_s)] - A - (P_0 - \delta)Q_s$$

The first partial derivative of (15) with respect to $Q_s$ is shown in (16).

$$\frac{\partial}{\partial Q_s} (T(Q) - T(Q_s)) = \delta + \frac{[\frac{AD}{D} + P_0D + \frac{hQ}{D} + S_{P_0} \frac{Q}{D} - S_PI(t_s)]}{D}$$

The second derivative of (15) with respect to $Q_s$ is

$$\frac{\partial^2}{\partial^2 Q_s} (TC_n - TC_s) = -\frac{S_P}{D} - \frac{h}{D}$$

This is convex in $Q_s$ and then solving $\partial(TC_n - TC_s)/\partial Q_s = 0$ for $Q_s$, the optimal special order quantity is obtained by (18).

$$Q_s = \frac{Q^2 \times (S_{P_0} + h) + 2 \times D \times (Q - \delta \times A)}{2 \times Q \times (S_P + h)} - I(t_s)$$

(18) indicates that the special order quantity is related to the inventory $I(t_s)$ at the time of special order remnant.
4. Numerical examples

Here, we offer two numerical examples parametrized according to Table 2, based on empirical data including order records and details regarding costs obtained from Ryokan A, a traditional Japanese inn in Tsukuba City. The food ingredients used in Ryokans are diverse and full of variety; our two numerical examples are defined in terms of food items: "Chinese cabbage" and "lettuce" consequent to interviewing the kitchen for examples of price fluctuation.

4.1 Calculation of the order cost and holding cost

Inventory cost parameters are fundamental to every inventory decision model. However, very little relevant research explains how the costs should be calculated in numerical analyses. We present the approaches applied in our numerical examples for setting the ordering cost and the holding cost.

The order cost $A$ is assumed to increase with the number of orders and the cost per order can be calculated by the payment placed for purchasing an order. It is converted by the payment that calculated as following.

\[ A = \text{Hourly wage} \times \left( \text{Hourly wage} \right) \times (\text{ordering operation time}) / \text{every day about 10 kinds} \]

The holding cost $h$ is the cost associated with maintaining the stock such as storage per time per unit. Most previous studies such as [10] and [11] assume this cost is in proportion to the inventory investment and consider it as the interest rate. In this study, we calculate the cost per time per unit by attributing stocktaking operational payments and business electricity charges for running the freezer in proportional terms (target items as a percentage of the whole stock).

4.2 Numerical example I

Using order records from April 2015 when the unit price of a Chinese cabbage increased from 400 yen to 700 yen, we consider the special order quantity. We assume that the shelf life (freshness period) of Chinese cabbage is 14 days on the basis of [15] and its monthly demand of cabbages is 24 units.

Table 3 parameters associated with numerical example I

| $\delta$ /unit | $\theta_{p0}$ /day | $\theta_{p}$ /day | $h$ /unit/day | $D$ /day | $A$ /per order | $Q$ |
|---------------|----------------|----------------|-------------|--------|---------------|-----|
| 800           | 50             | 28.57          | 11.71       | 0.8    | 30            | 2   |

By calculating the special order quantity from (9) and rounding to the nearest integer, we obtain $Q_s = 8$ (units) and $T_s = 10$ (days).

To assess the proposed model, the comparison between "reorder quantity determined by Ryokan A," "regular order," "special order considering deterioration (proposed model)," and "special order without considering deterioration" is presented in Table 4 and Figure 4. It should be noted here that "reorder quantity determined by Ryokan A" reflects an ordering record that places an order sufficient to meet three days of demand.

\[ Q_s \]

4.3 Numerical example II

Taking another example from the order records of August 2015 when the unit price of a box (8 kg) of lettuce increased from 2800 yen to 3600 yen. Here, we assume that the freshness period of lettuce is 5 days (on the basis of Ref. 16) and that the monthly demand is 15 boxes.

Table 5 parameters associated with numerical example I

| $\delta$ /unit | $\theta_{p0}$ /day | $\theta_{p}$ /day | $h$ /unit/day | $D$ /day | $A$ /per order | $Q$ |
|---------------|----------------|----------------|-------------|--------|---------------|-----|
| 800           | 720            | 560            | 21.25       | 0.5    | 30            | 1.17 |

By calculating the special order quantity from (9), we obtain $Q_s = 1.45$ (boxes) and $T_s = 2.91$ (days). Since "special order without considering deterioration" clearly
leads to substantial waste, it is not included in the following comparison. Table 6 and Figure 5 show the comparison between "reorder quantity determined by Ryokan A," "regular order," and "special order considering deterioration (proposed model)."

Table 6 results for numerical example II

| Ordering policies | Results for numerical example II | Total cost (actual payment) | Days remaining until the best-before date |
|-------------------|---------------------------------|----------------------------|------------------------------------------|
| Reorder quantity determined by Ryokan A | $4,506 | 3.00 |
| Regular order | $4,304 | 2.66 |
| Special order considering deterioration (proposed model) | $4,136 | 2.09 |
| Total cost savings (regular order-proposed special order) | $168 |

Fig. 5 results for numerical example II

According to Table 6 and Figure 5, the total cost of the proposed model is the minimum, but it can be seen that there is no substantial difference in the results due to short shelf life. This indicates that the shorter shelf life of the item under consideration, the smaller the low unit cost advantage.

4.4 Sensitivity analysis

Sensitivity analysis of the special order quantity is carried out by changing the parameters of purchasing price, demand, holding cost, order cost, and deterioration cost used in numerical example I to -50%, -25%, +25%, and +50%, respectively. The calculated results are shown in Table 7.

Table 7 results of sensitivity analysis for numerical example I

| Parameter | % changed | Changed parameter | Changed \( Q_s \) |
|-----------|-----------|------------------|------------------|
| \( P_0 \) | -50%      | 350              | -96.97%          |
|           | -25%      | 525              | -48.85%          |
|           | 25%       | 875              | 47.38%           |
|           | 50%       | 1050             | 95.50%           |
| \( D \)   | -50%      | 0.4              | -36.94%          |
|           | -25%      | 0.6              | -22.20%          |
|           | 25%       | 1                | 10.98%           |
|           | 50%       | 1.2              | 22.47%           |
| \( h \)   | -50%      | 8.78             | 9.60%            |
|           | -25%      | 14.64            | -7.35%           |
|           | 25%       | 17.56            | -13.62%          |
|           | 50%       | 22.47%           |                   |
| \( A \)   | -50%      | 15               | -6.74%           |
|           | -25%      | 22.5             | -2.98%           |
|           | 25%       | 37.5             | 2.99%            |
|           | 50%       | 45               | 5.52%            |
| \((S_{P0}, S_P)\) | -50% | (33.33, 19.05) | 24.17%          |
|          | -25% | (40, 22.86) | 12.99%          |
|          | 25% | (66.67, 38.1) | -14.62%         |
|          | 50% | (100, 57.14) | -31.94%         |

Interpretations of the results in Table 7 are as follows. From the perspective of \( P_0 \), since \( P \) is fixed, it can be seen as the changes in \( \delta \). When \( P_0 \) increases or decreases, the special-order quantity increases or decreases in the same direction, as illustrated in Figure 6. In other words, the larger the price difference, the more pronounced the special-order effect. Conversely, when there is not much difference in price, it considers the freshness and does not place a special order. In case of numerical example I, the special order will not be used when the price difference is only 20 yen.

Fig. 6 sensitivity analysis of \( P_0 \)

From the perspective of deterioration cost, it can be seen that when deterioration cost increases or decreases, the special order quantity increases or decreases in the opposite direction, as shown in Figure 7. This suggests that the faster deterioration, the less cost saving by special order. Similar results were seen in numerical example II focusing on lettuce, which has a shorter longevity compared with that of Chinese cabbage.

Also, special order quantity changes in the same direction with \( D \) and \( A \). Since demand influences the purchasing cost directly and the replenishment cycle of the special order is longer than that of the regular order, the higher the ordering cost \( A \), the more cost saved by placing a special order. However, \( A \) does not vary substantially, at least in absolute terms, compared with \( P_0 \), as shown in Table.
4.5 Application example using wholesale market price

To implement the proposed model with daily price changes, we used the daily wholesale market price reported by [17] to substitute purchasing price. The example of Chinese cabbage used in numerical example I is re-applied here. We calculated the average multiples between wholesale price data and Ryokan A’s records to convert the daily wholesale price into the daily purchasing price. Then using the converted purchasing price with the parameters used in numerical example I to calculate each $Q_s$.

The results in terms of regular orders and special orders for April 2015 are shown as Figure 8. The blue continuous line represents regular orders, the green dashed line is special orders, and the yellow continuous line presents the changes in purchase price.

Figure 8 shows that special orders are not placed every time there is a difference in price. It can be seen that special orders are placed according to demand, the difference between prices, as well as deterioration and inventory holding costs.

5. Conclusions

This paper developed and operationalized an inventory model that considers a temporary price discount and the deterioration of items to decide the special order quantity in the context of purchasing fresh ingredients for commercial preparation and selling. We derived two special order quantities in Case 1 and Case 2. We also presented numerical examples using empirical data from Ryokan A to confirm the utility of the proposed model.

As per our criterion, the proposed model minimizes total cost relative to the costs incurred according to the three alternative ordering policies. From the viewpoint of freshness, the stock ordered by special order is consumed before the relevant best-before date, but the freshness is lower than that associated with the regular order. The special order quantity $Q_s$ increases as the demand and the discount increase but is limited by deterioration cost and holding cost increases.

The results provide useful theoretical and empirical insights into fresh ingredients inventory modeling by taking into account price fluctuations and deterioration.

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