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A SIMULATION-BASED APPROACH FOR OBTAINING OPTIMAL ORDER QUANTITIES OF SHORT-EXPIRATION DATE ITEMS AT A RETAIL STORE

Haixia Sang
Soemon Takakuwa

Graduate School of Economics and Business Administration
Nagoya University
Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8601, JAPAN

ABSTRACT

The uncertain demand of expiration-dated item often leads to scrap losses or opportunity losses, which result in resource wasting and the degradation of customer satisfaction. In this paper, a well known exponential smoothing method was modified to forecast the hourly demand of rice balls, by utilizing the concept of the newsvendor problem, and a simulation model was constructed to simulate the scrap loss and opportunity loss changes. The optimal order quantity's characteristics, which can maximize the retailer's expected profit, were clarified by using OptQuest and sensitivity analysis. The proposed approach was applied to a real store to confirm its effectiveness.

1 INTRODUCTION

The market for expiration-dated items, such as rice balls and boxed lunches is growing because of changes in life-style. Such items have become essential commodities in convenience stores of Japan. The opportunity loss that results from an item being out-of-stock leads to customer dissatisfaction and a loss of potential profits. However, products left on the shelves past their expiration dates must be scrapped, resulting in potentially large losses. Although many managers realize the importance of forecasting the demand of these items, because forecasts must be performed frequently and many of the forecasting techniques are difficult to implement, most managers rely on their own experience or consult a POS (Point of Sales) system to predict future demand and place purchasing orders (Chen and Ou 2009). This method does not always produce a good profit.

Exponential smoothing is an efficient technique for estimating the coefficients in a polynomial model. However, there are many time series processes that cannot be adequately described by a polynomial model. Winters' method improved these models and can forecast a time series with seasonal variation (Johnson and Montgomery 1974). Typically, the only input for a forecasting system is the past history of the demand data of the item. However, in Winters' model, the most recent demand information can be introduced easily and cheaply (Winters 1960). By utilizing Winters' method, the result shown in the forecast can almost always reflect the real demand trends and variability. However, a forecast is not always accurate on each day. It is still a problem to determine the optimal order quantity under an uncertain demand.

The classical newsvendor problem addresses a single-period inventory that obtains the maximum expected profit. Based on the newsvendor problem, a simulation model was constructed, and the forecasted demand was used as input data for the model to simulate the change of the scrap loss and the opportunity loss. Because of the existence of a common sales period, a multiple optimal order quantity is obtained, and sensitivity analysis is used to specify the order range for each delivery.

2 LITERATURE REVIEW

An extreme case of the stochastic inventory problem for expiration-dated items is the newsvendor problem. Because the newsvendor problem can be applied to many real life situations, many extensions to it have been proposed. These extensions include addressing different objectives and utility functions, different supplier pricing policies, multiple locations, and multiple products. Detailed reviews of how to solve this problem have been provided in Gallego and Moon (1993), Khouja (1999), and Petruzzi and Data (1999). Recently, many studies have shown that simulation is an important research methodology and is more suitable when studying complex issues (Xie and Chen 2004). For example, Zhan and Shen (2005) developed an iterative algorithm and a simulation-based algorithm to help newsvendors make pricing and inventory decisions in a stochastic price-sensitive demand environment. Li et al. (2007) developed a procedure to maximize profits with two products and verified the result using simulation. Dimitriou and Robinson (2005) used agent-based-simulation as an evaluation tool, to investigate the effect on suppliers and retailers by varying individual preferences with respect to contract efficiency. All of these studies have proven that simulation is a useful approach to solve the newsvendor problem.

Forecasting and planning for management has received considerable attention for many years because of its implications for decision making, both at the strategic level of an organization and at the operational level. According to Koehler et al. (2001), the method proposed by Winters (1960) is the most widely known and used forecasting techniques for seasonal time series. For example, Taylor (2003) used Winters' method to forecast the online short-term electricity demand. Burkom et al. (2007) compared three forecasting methods for biosurveillance, and the results showed that Winters' method performed best. Rajopadhye et al. (2001) considered the hotel industry as a practical application of forecasting using Winters' method. All of these papers show that Winters' method is a powerful tool for making an appropriate estimate.

In this paper, based on the newsvendor problem, a simulation-based approach was developed to optimize the order quantity of rice-balls for the next period. First, a basic description of the store and the rice balls are discussed. Then a flexible and stepwise procedure is proposed for obtaining the optimal order quantity. The proposed method is both practical and powerful when assisting a manager in order management decisions.

3 BASIC DESCRIPTION OF THE STORE

FamilyMart Company, Ltd., is one of the biggest franchise convenience store chains in Japan. The retail store in this study is managed directly from the FamilyMart headquarters office. It is located on the campus of Nagoya University, and it operates from 7:00 AM to 11:00 PM.

There are 3000 items, such as food, drinks, and other daily commodities that can be ordered by the store. By analyzing the POS data, expiration-dated items (such as rice balls, boxed lunches, sandwiches, fast food, and desserts) account for 38% of the total sales and are the best-selling items. However, at the same time, expiration-dated items constitute 83% of the total waste.

The rice ball is one of the traditional foods of Japan. This paper treats the rice ball as a typical example because the rice ball's life-cycle is complicated. Figure 1 shows one cycle time for the order deadline, delivery and scrapping of rice balls. From this Figure, it can be seen that the rice ball's selling time is short. Rice balls are shipped and scrapped three times each day. The retail manager must send all of the orders before 10:00 AM. The first delivery starts at 7:00 AM the next day, and the goods can be on sale until 4:00 PM. The second delivery is shipped at 10:00 AM, and the amount left at 11:00 PM is scrapped. The third delivery occurs at 4:00 PM, and the goods can be on sale until 11:00 PM (for short, the merchandise shipped in the first delivery is called D_1, and the merchandise from subsequent deliveries are labeled D_2 and D_3) .

In addition to the limited selling time interval, an uncertain demand is also a major reason for serious scrap loss. Figure 2 shows the 95% confidence intervals for the average demand on Fridays over the course of a day. From this figure, it can be seen that the demand for rice balls is variable. For the purpose of maximizing the store's expected profit and increasing its customer satisfaction through utilizing the historical data to forecast the demand and determine the optimal order quantity, maximizing retailer profit is an urgent issue to the manager. This paper addresses the optimal rice ball order quantity in the store, to determine robust solutions.

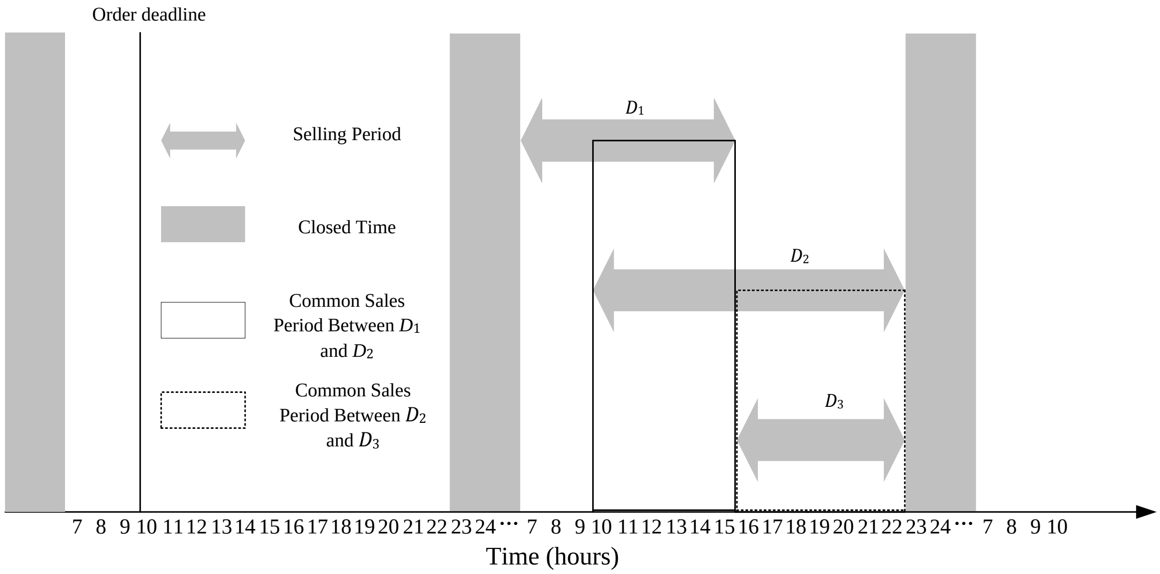


Figure 1: Information regarding rice ball delivery and scrap time.

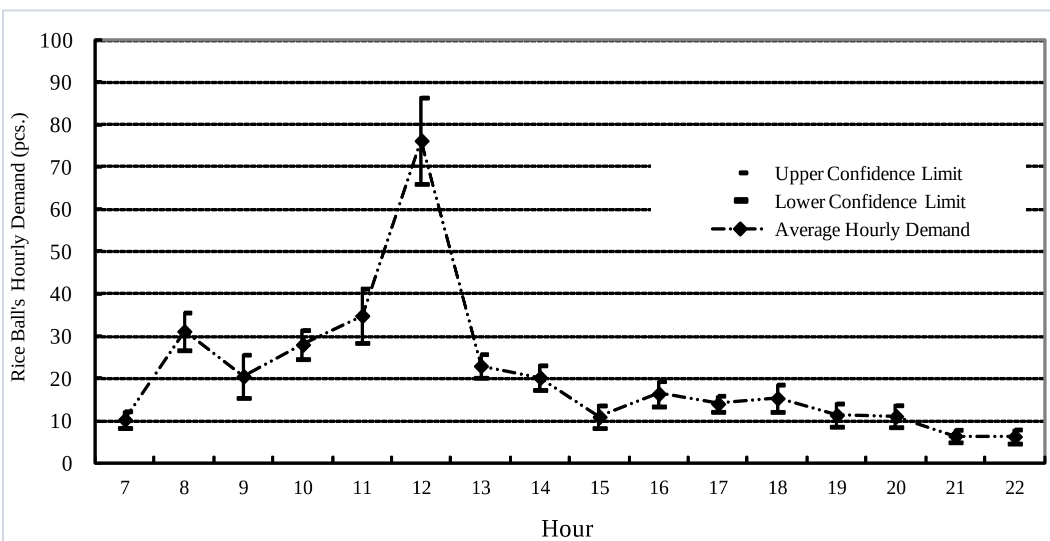


Figure 2: The 95% confidence interval for the daily demand of rice balls.

4 PRELIMINARY ANALYSIS

When attempting to define suitable forecasting procedures to address inventory data, it is obviously important to understand what such data typically look like. It might then be possible to link the known characteristics of the data to different forecasting methods (Fildes and Beard 1992).

Figure 3 illustrates the rice balls demand changes from January 1 to December 31 over the past five years. Because the main customers of the retail store are university students, depending on the university's semesters or vacations, the demand data can be divided into six categories. Even during the semester period, the shopping time and the shopping frequency depend on the university timetable. Therefore, to make the forecast more accurate, it is necessary to classify the semester period demand into seven data-sets, with each data-set representing a certain weekday.

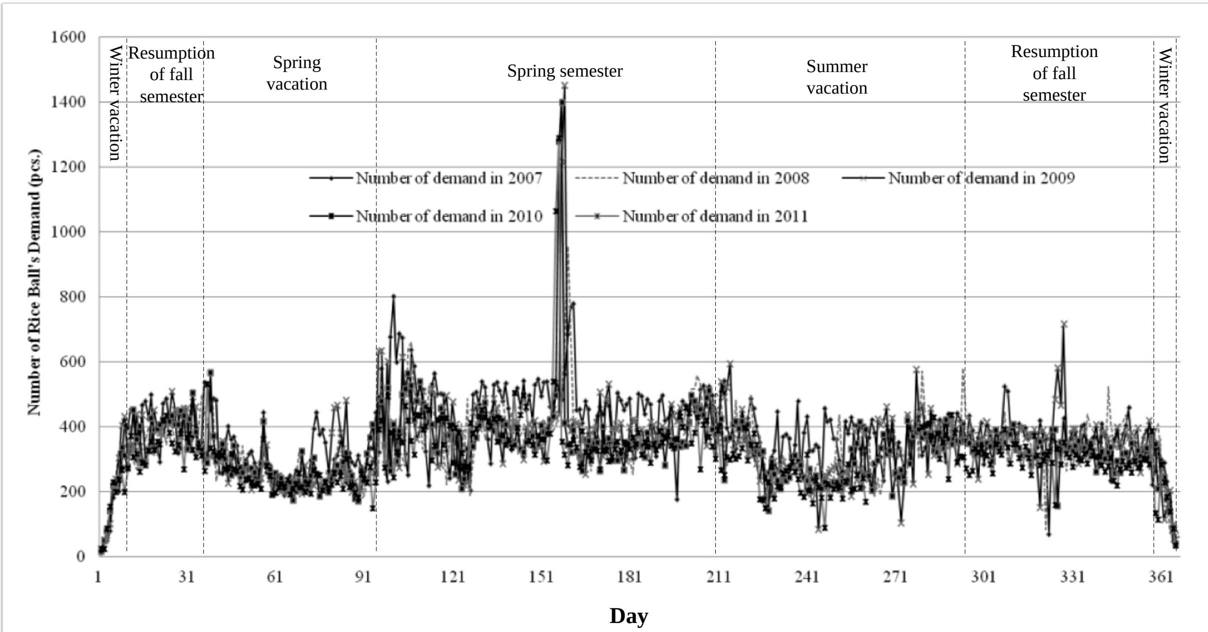


Figure 3: Changes in the daily demand for rice balls.

As Figure 1 and Figure 2 show, D_1, D_2 and D_3 have a limited selling time interval, and the demand in each time interval is uncertain. Let us denote the order quantities of three deliveries as Q_1, Q_2 and Q_3, respectively. Because the optimal order quantities Q_1^*, Q_2^* and Q_3^* of the three deliveries depend on the demand of each time interval, the essential forecast problem in this paper is to identify the demand during a specific time interval on the designated day of the week.

The objective of this paper is to describe an approach on how to determine the optimal order quantity for Fridays during the year 2012 spring semester. Thus, it is necessary to find the pattern of historical demand data for each time interval of the day. Figure 4 illustrates the demand change in the time interval from 12 noon to 1 PM. This specific time interval should be examined mainly because the demand at lunchtime almost accounts for one third of the total sales in a day. From the figure, it can be seen that on the second Friday of the spring semester, there is always a high demand. A decrease always tends to occur during two periods. The first is the 2nd Friday. The second is the 15th Friday. This preliminary analysis helped us find the appropriate method for forecasting future demands.

5 THE PROCEDURE TO SEEK THE OPTIMAL ORDER QUANTITY

5.1 Procedure

The newsvendor problem provides a procedure for determining the optimal order quantity under an uncertain demand. However, before utilizing a simulation-based approach, the item's average cost, profit and demand must be known. Winters' exponential smoothing methods is an efficient technique for estimating a time series that has seasonal variation in the model (Johnson and Montgomery 1974). This paper uses estimated demand data, which modified Winters' method to determine the optimal order quantity that maximized the retailer's profit. In contrast to the classic Winters' method, which uses the past 12 months

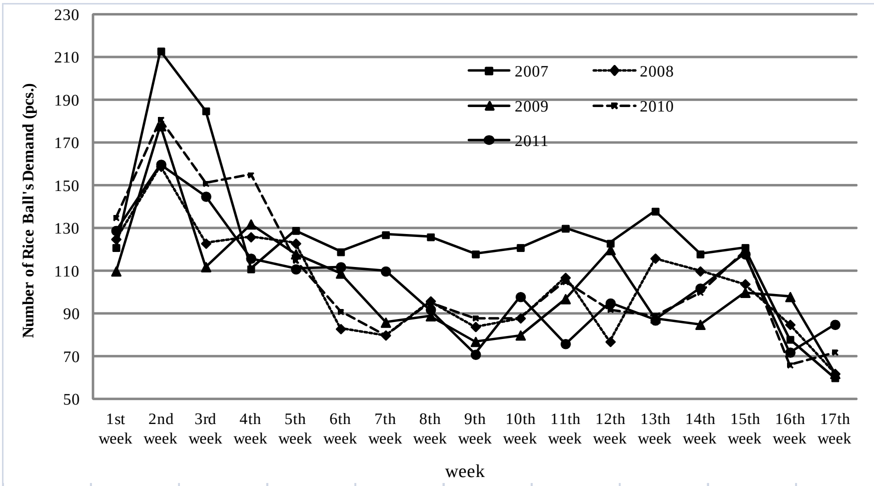


Figure 4: Demand change of rice ball in the time interval from 12 noon to 1 PM on Fridays during the spring semester.

of data to forecast future demands, this paper applies the concept behind Winters' method, and uses the designated time interval of a day of the week to forecast the future hourly demand. Through repeating the same forecast procedure, it obtains the hourly demand from 7 AM to 10 PM. The forecasted demand data were used as input data into the simulation model to obtain future weekdays' optimal order quantities. Thus, the procedure can be divided into two phases, which are shown in Figure 5. In this paper, the index of the time interval is used to present hourly demand of a day. For example, index 7 used for the time interval between 7 AM and 8 AM.

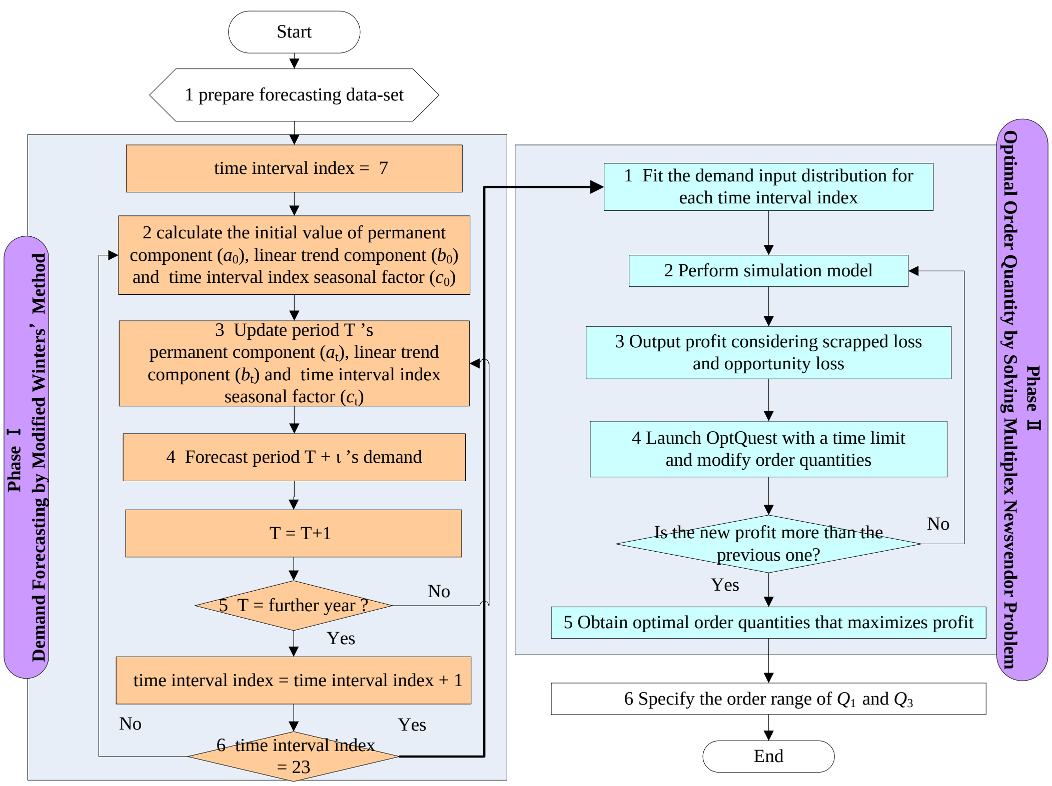


Figure 5: The procedure for seeking the optimal order quantity.

Phase 1: Modified Winters' method for forecasting demand

[step 1] Collect the historical demand data on the rice balls for past years.

[step 2] Use the historical demand data to calculate the initial value of the permanent component (a_0), linear trend component (b_0) and time interval seasonal factor (c_0).

[step 3] Update the value of the permanent component (a_t), linear trend component (b_t) and time interval seasonal factor (c_t) by utilizing the current year's historical demand data.

[step 4] Forecast the demand for period (T+ τ).

[step 5] Check the model to see whether the forecasted demand goes into the next year. If affirmative, return to step 2 to forecast the next time interval index's initial value; otherwise, return to step 3 to update a_t, b_t and c_t.

[step 6] Check the model to see if the time interval index is the 23. If affirmative, use the forecasted demand value to fit the demand distribution for each time interval; otherwise, return to step 2 and calculate a_0, b_0 and c_0 in the next time interval.

Phase 2: Optimal order quantity based on the multiplex newsvendor problem

[step 1] Use next year's forecasted demand data to fit the demand distribution for each time interval.

[step 2] Develop and perform the simulation model.

[step 3] Obtain an initial feasible solution that accounts for the opportunity loss and scrap loss.

[step 4] Launch the integer linear program OptQuest to obtain a different feasible order quantity; if the new profit is less than the previous profit, then keep the previous order quantity; otherwise, renew the new order quantity. Repeat this step with a limited number of simulations.

[step 5] Obtain the optimal order quantity that maximizes the expected profit.

[step 6] Specify the order range of Q_1^* and Q_3^* with sensitivity analysis.

5.2 Modified Winters' Method

Winters' method is a forecasting model that has either a ratio trend or a linear trend. In this paper, Winters' method was modified to forecast the hourly demand for the designated day of the week. To implement the method, the user must provide the initial value of the permanent component (a_0), the linear trend component (b_0) and the time interval seasonal factor (c_0). The smoothing constants α, β and γ must be identified as well.

The procedure for periodically revising the estimates of the model parameters and for forecasting is the following. At the end of any period T, after observing the current period's demand (D_t), we revise the estimate of the permanent component as follows:

$$a_t = \alpha \frac{D_t}{c_i'} + (1-\alpha)(a_{t-1} + b_{t-1}) \tag{1}$$

Then we revise the estimate of the trend component:

$$b_t = \beta(a_t - a_{t-1}) + (1-\beta)b_{t-1} \tag{2}$$

and we revise the estimate of the time interval seasonal factor for period T:

$$c_t = \gamma \frac{D_t}{a_t} + (1-\gamma)c_t' \tag{3}$$

The forecast for any future period (T+ τ) uses

$$\hat{D}_{t+\tau} = (a_t + b_t * \tau) * c_i' \tag{4}$$

where

0 < α < 1,

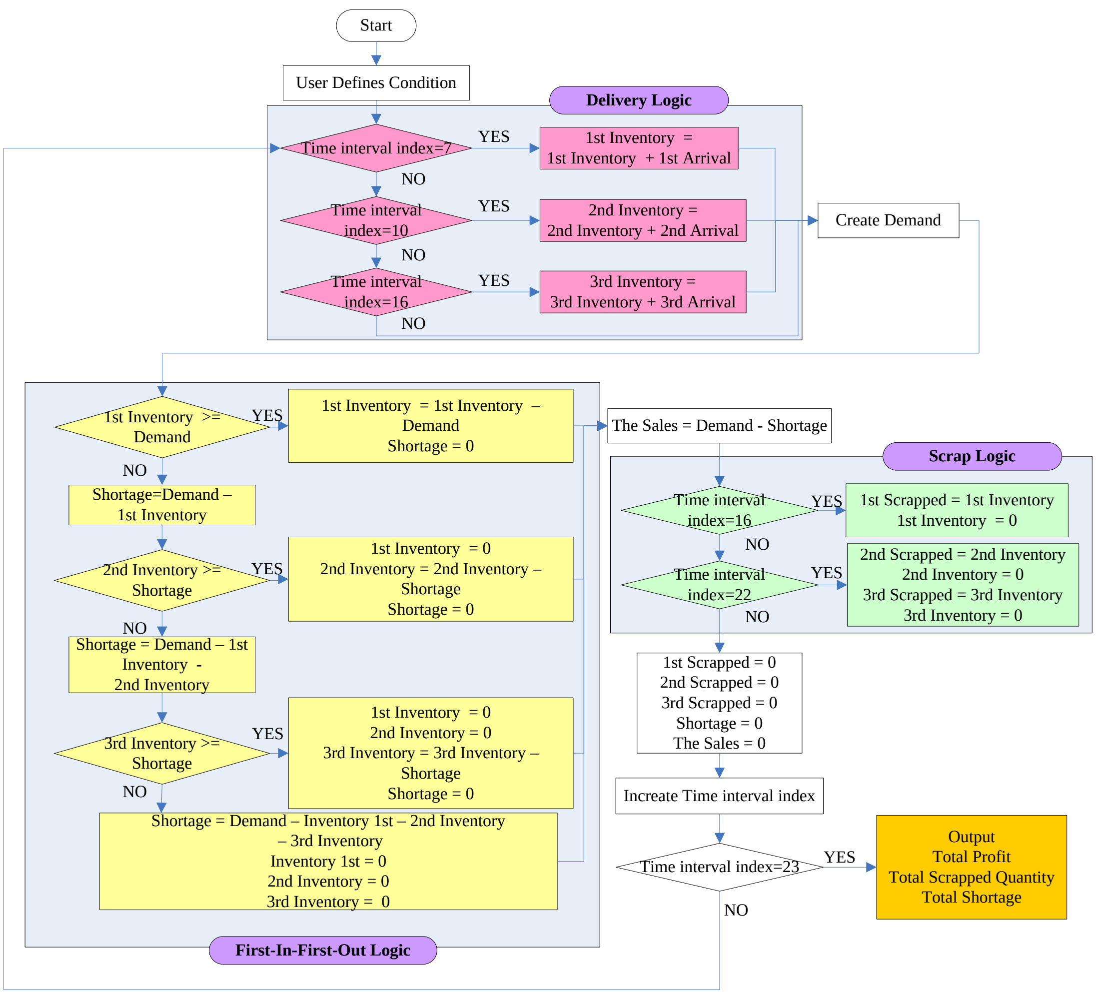
0 < β < 1,

0 < γ < 1, and

c_t' is the time interval seasonal factor of the designated day of the week of the previous years.

5.3 Simulation Analysis

A simulation model for the retail store was created using the simulation package Arena and the associated simulation logic is shown in Figure 6. The logic of a simulation model was composed of three parts: the delivery logic, the scrap logic and the first-in-first-out logic. The first-in-first-out logic means that, until the old item is sold out, the new item cannot be sold. The performance measure used in this paper is the expected profit, taking the opportunity loss and scrap loss into consideration.



1st Inventory : inventory of 1st
2nd Inventory: inventory of 2nd
3rd Inventory: inventory of 3rd
1st Arrival : order quantity of 1st
2nd Arrival : order quantity of 2nd
3rd Arrival : order quantity of 3rd
1st Scrapped: Scrapped Quantities of 1st
2nd Scrapped: Scrapped Quantities of 2nd
3rd Scrapped: Scrapped Quantities of 3rd
Demand: customer demand's at a given time
Total Shortage: all of Time interval index's total shortage
Time interval index: simulation run time
Total Profit: all of Time interval index's total profit
Shortage: inventory shortage at a given time
The Sales: sales quantity at a given time
Total Scrapped Quantities: all of three times total Scrapped quantities

Figure 6: Simulation flow chart.

The function used to calculate the profit is shown as follows:

$$W(I) = (r-c)\sum_{i=7}^{22} a_i - (r-c)\sum_{i=7}^{22} b_i - c\left(S_{16} + S_{22}\right) \tag{5}$$

where
a_i (pcs.): the sales during time interval i,

b_i (pcs.): the opportunity loss during time interval i,
c (JYen): the average cost per unit,
i (hour): the index for time interval,
r (JYen): the average selling price per unit,
S_{16} (pcs.): the scrap loss at time interval 16, and
S_{22} (pcs.): the scrap loss at time interval 22.

Equation (5) contains three terms. The first term is the revenue that is obtained from the sold items. The second term is the opportunity loss, and the last term is the scrap loss. If at time interval i, demand is larger than inventory (all of the items are sold out), then the scrap loss at time interval i is 0 and the expected profit equals the revenue $(r\text{-}c)\ a_i$ minus the opportunity loss $(r\text{-}c)\ b_i$. Otherwise, if at time interval i, demand is smaller than inventory (the retailer meets all of the customers' demands), then the opportunity loss is 0 and the scrap loss occurs at the time interval 16 or 22; thus, the expected profit is the revenue $(r\text{-}c)\ a_i$ minus the scrap loss $c(S_{16} + S_{22})$. By performing the simulation model, the total profit, the total scrap loss and the total opportunity loss are produced as outputs.

6 APPLICATION

6.1 Modified Winters' Method

This paper used five years of demand data, from 2007 to 2011, to estimate the year 2012 demand. The study duration period was set at 17 weeks, approximately from every year's April 10th to August 7th, which is Nagoya university's spring semester. As the authors mentioned before in the preliminary analysis section, to make the forecasting more accurate, the data were divided into seven data-sets on the days of the week, and this paper used Friday's data-set as the basis for estimates. The smoothing constants α, β, γ were set at 0.2, 0.1 and 0.1, respectively.

Figure 7 shows the actual demand and the forecast during the time interval from 12 noon to 1 PM on Friday. Through comparing the actual demand and the forecast, it was found that the forecast can almost reflect the actual demand's trend changes. However, from a certain day standpoint, the forecast result is still uncertain. The constructed simulation model, which is based on the newsvendor problem, can help the authors to solve this problem for the purpose of using the result in the simulation model. The demand distribution in the time interval of 12 was fit by triangular distribution with the parameters 66.5, 98.6 and 144.

Table 1 shows the result, which is updated hourly for each Friday in the year 2011 spring semester and which was used to forecast the year 2012 demand data. The hourly demand distribution for the year 2012 spring semester is also shown in Table 3. The demand distribution was input into the simulation model to simulate the profit change.

6.2 Simulation Analysis

The optimal order quantity is a function of the item's demand, cost and profit, which is stated in Nahmias (2006). After fitting the rice ball's demand distribution, it is necessary to calculate the rice ball's cost and profit. Based on the historical data, we next suppose that there were 84 items on sale during the research period. In addition, we suppose that the rice ball's average cost and average profit were 72 and 46 JYen, respectively.

The item's demand, cost and profit were set as functions into the simulation model, and the profit, the scrap loss and the opportunity loss are produced as the outputs of the model. It must be noted that although the simulation can provide estimates of performance measures, it cannot provide the optimal order quantities for Q_1^*, Q_2^* and Q_3^* to maximize the expected profit. Therefore, this study adopts the simulation together with the optimization tool to achieve the objective.

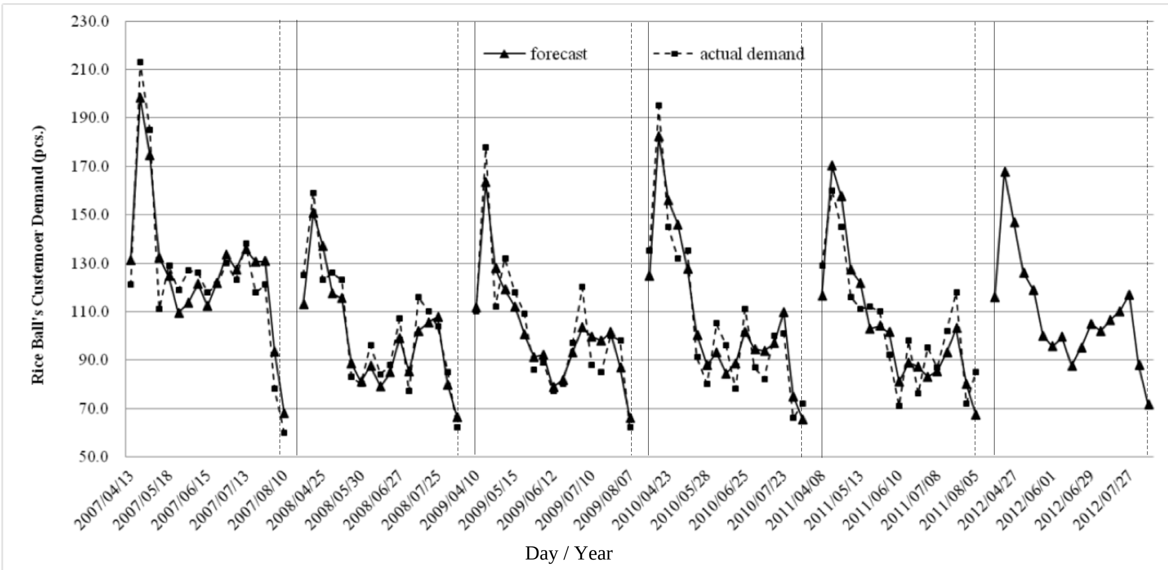


Figure 7: The comparison between the forecast and the actual demand during the time interval from 12 noon to 1 PM.

Table 1: The parameter and forecasted demands for rice balls on Fridays during the spring semester of 2012.

Time interval index	the Updated a_t, b_t, c_t for 2011										Forecasted Demand for 2012
	week 1			week 2			···	week 17			
	a_{2011}	b_{2011}	c_{2011}	a_{2011}	b_{2011}	c_{2011}	···	a_{2011}	b_{2011}	c_{2011}	
7	10.32524	0.08153	0.70834	10.85805	0.12666	0.96338	···	9.29416	0.01423	2.02508	TRIA(6.5,8,19.5)
8	28.69936	-0.34151	0.72021	24.63538	-0.71376	0.77127	···	24.97858	-0.66882	0.68543	TRIA(11.5,18.8,32.5)
9	19.10878	-0.11961	1.30962	16.99881	-0.31864	1.05469	···	18.40210	-0.16244	1.13093	TRIA(9.5,16,25.5)
···	· · ·										···
20	12.05296	0.03056	0.45895	10.56468	-0.12132	0.83977	···	13.17150	0.14253	1.18166	TRIA(5.5,14,20.5)
21	7.04300	-0.24519	0.79935	8.48822	-0.07614	1.27437	···	7.18233	-0.22775	0.95782	TRIA(2.5,3.71,9.5)
22	4.86118	-0.16090	0.62944	4.69781	-0.16115	0.64132	···	4.02783	-0.15319	1.17525	TRIA(0.5,2,5.5)

By executing the simulation model for 500 business days with 100 replications, OptQuest produces a set of best solutions, as shown in Table 2. The set of best solutions have the same average optimal profit of 13970.48 JYen, and the relationship of Q_1, Q_2 and Q_3 is obtained by the following:

$$Q_1 + Q_2 + Q_3 = 343 \tag{6}$$

In order to confirm that the resultant solution is the optimal order quantities, a series of simulation experiments with the OptQuest were performed. Q_1, Q_2 and Q_3's lower bound and upper bound for [115, 225],[65,180],[20,62] respectively, which is obtained from Table 2. The best solutions are shown in Table 3. Because the average optimal profit and the relationship of Q_1, Q_2 and Q_3 have not changed, thus all of the best solutions, which are shown on Table 2 and Table 3 must be optimal order quantities.

The existence of a common sales period caused multiple optimal solutions. If D_1, D_2 and D_3 have no common sales period, then Q_1^*, Q_2^* and Q_3^* can be achieved with the classic newsvendor problem and they would have only one optimal solution each. However, in this problem, during the common sales period, some items sold may be from different deliveries. For example, if Q_1^* decreases, then by adding the same quantity to Q_2^*, the maximization profit would not change. Similarly, the maximization profit can also be achieved by adding a quantity to Q_2^* and, at the same time, decreasing the quantity Q_3^*.

Table 2: Set of the best solutions.

Solution No.	Q_1 (pcs.)	Q_2 (pcs.)	Q_3 (pcs.)	Profit (JYen)	Opportunity Loss (pcs.)	Scrap Loss (pcs.)
1	145	178	20	13970.48	7.87	12.25
2	183	140	20	13970.48	7.87	12.25
3	158	150	35	13970.48	7.87	12.25
4	204	107	32	13970.48	7.87	12.25
5	115	180	48	13970.48	7.87	12.25
6	159	136	48	13970.48	7.87	12.25
7	184	109	50	13970.48	7.87	12.25
8	208	85	50	13970.48	7.87	12.25
9	225	65	53	13970.48	7.87	12.25
10	167	123	53	13970.48	7.87	12.25
11	132	149	62	13970.48	7.87	12.25
12	115	166	62	13970.48	7.87	12.25

Table 3: Set of the best solutions.

Solution No.	Q_1 (pcs.)	Q_2 (pcs.)	Q_3 (pcs.)	Profit (JYen)	Opportunity Loss (pcs.)	Scrap Loss (pcs.)
1	175	148	20	13970.48	7.87	12.25
2	130	175	38	13970.48	7.87	12.25
3	123	160	60	13970.48	7.87	12.25
4	214	93	36	13970.48	7.87	12.25
5	162	124	57	13970.48	7.87	12.25
6	127	174	42	13970.48	7.87	12.25
7	183	133	27	13970.48	7.87	12.25
8	220	88	35	13970.48	7.87	12.25
9	115	170	58	13970.48	7.87	12.25
10	204	115	24	13970.48	7.87	12.25
11	143	142	58	13970.48	7.87	12.25
12	189	122	32	13970.48	7.87	12.25
13	198	92	53	13970.48	7.87	12.25
14	117	164	62	13970.48	7.87	12.25

6.3 Sensitivity Analysis

Sensitivity analysis is the study of how the variation in the output of a statistical model can be attributed to different variations in the inputs of the model. In this case, the variation in the output is the maximal profit, and the variation in the input is Q_1^*, Q_2^* and Q_3^*. Because the maximal profit and the relationship of Q_1^*, Q_2^* and Q_3^* have been known (see equation (6)), by fixing Q_3^*, the sensitivity analysis can help us specify the range of Q_1^*. In the same way, by fixing Q_1^*, the sensitivity analysis can help us specify the range of Q_3^*. Figure 8 shows the result of the sensitivity analysis of Q_1^*. Q_3^* was fixed at the value of 20, and by changing $Q_1^*$and Q_2^*, it was found that if Q_1^* is between the range of 61 and 249; it would achieve a profit of 13970.48 JYen, which is the maximal value. Therefore, under the demand distribution on Fridays, the range of Q_1^* is [61,249].

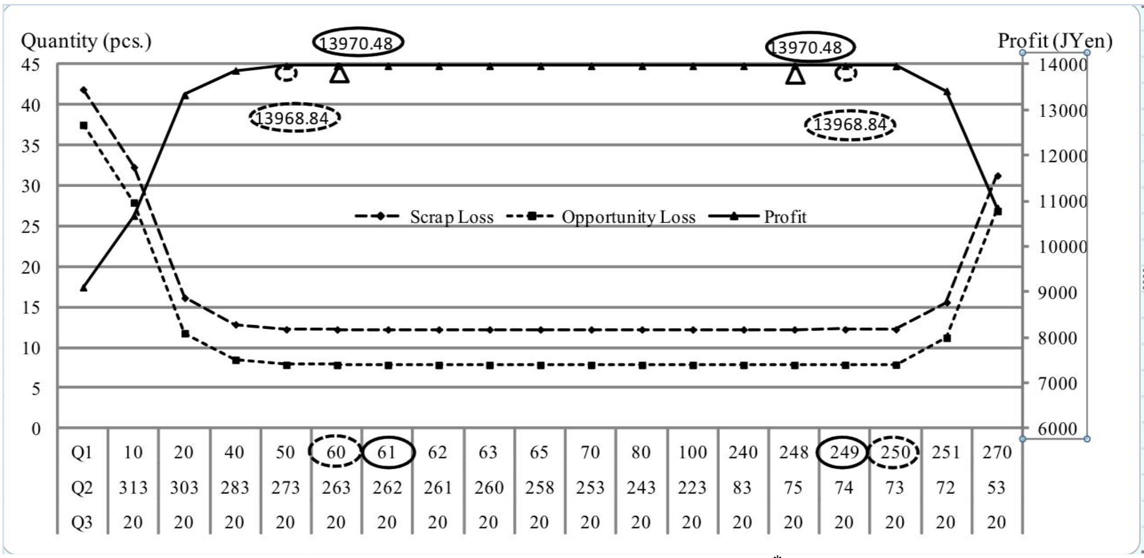


Figure 8: Sensitivity analysis of Q_1^*.

By using the same approach, the range of Q_3^* can be specified as [0, 65]. If Q_1^* and Q_3^* are set, then Q_2^* can be obtained by using equation (6).

7 CONCLUSIONS

In this paper, Winters' method was applied to forecast the hourly demand on the designated day of the week for the next demand period of a short-expiration-dated item, the rice ball. By formulating a multiplex newsvendor problem, a simulation model was constructed to obtain the optimal order quantities, reflecting the profit change under an uncertain demand. The performance measure in this paper was set to the expected profit, taking the scrap loss and the opportunity loss into consideration. By utilizing OptQuest and sensitivity analysis, the characteristics of the optimal order quantity were clarified. The proposed procedure was found to be powerful, especially from a practical standpoint.

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AUTHOR BIOGRAPHIES

HAIXIA SANG is a Ph.D. candidate at the Graduate School of Economics and Business Administration at Nagoya University in Japan. She received her B.Sc. and M. Sc. Degree in Economics from the Asahi University of Japan in 2005 and 2007. Her research interests include retail store management using simulation technology. Her email is sanghaixia7861@hotmail.co.jp .

SOEMON TAKAKUWA is a Professor at the Graduate School of Economics and Business Administration at Nagoya University in Japan. He received his B. Sc. and M. Sc. degrees in industrial engineering from the Nagoya Institute of Technology in 1975 and the Tokyo Institute of Technology in 1977, respectively. He obtained a Ph.D. in industrial engineering from Pennsylvania State University. He holds a Doctorate of Economics form Nagoya University. He holds a P.E. in Industrial Engineering. His research interests include the optimization of manufacturing and logistics systems, management information systems and simulation analysis on these systems in the context of hospitals. He prepared the Japanese editions of both Introduction to simulation using SIMAN and Simulation with ARENA. He serves concurrently as the senior staff of Department of Hospital Management Strategy and Planning at Nagoya University Hospital. His email address is takakuwa@soec.nagoya-u.ac.jp.