A BASIC STUDY ON DEMAND PREDICTION FOR PLANT FACTORIES

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ABSTRACT

Much emphasis is now being given to research and development of fully closed and controlled plant factories, aimed at supplying various vegetables safely and constantly. The plant factories daily produce the large volume of the safely packed vegetables under the artificially controlled environment. One of the important issues in the management and control of the plant factories is to establish a systematic method for the planning for the production and the shipping of the daily produced vegetables to the various customers. The paper deals with a basic study on the demand prediction of the wholesale vegetable markets, aimed at forecasting the customers' demands to the existing plant factories. The demand prediction is very important for establishing a systematic planning method for production and shipping of the produced vegetables. Especially, an emphasis is given to the demand prediction model of the representative wholesale vegetable markets.

INTRODUCTION

Much emphasis is now being given to research and development of fully closed and controlled plant factories, aimed at supplying various vegetables safely and constantly. Many plant factories have been equipped and operated in suburban areas and downtowns in Japan for supplying the safe and high quality vegetables directly to the markets [1, 2]. The plant factories daily produce the large volume of the safely packed vegetables under the artificially controlled environment.

One of the important issues in the management and control of the plant factories is to establish a systematic method for production and shipping of the daily produced vegetables to various customers such as wholesalers, retailers including supermarkets and department stores, and end customers. The sizes of the orders depend on the individual customers and are dynamically changed day by day. The plant factories have to cope with the dynamic changes in the size of the daily orders from the individual customers.

The demands from the customers are deeply influenced by the demands in the wholesale vegetable markets, which are the open markets to trade the vegetables through the auction based processes, since the market share of the plant factories are very smaller than that of the wholesale vegetable markets.

The paper deals with a basic study on the demand prediction of the wholesale vegetable markets, aimed at predicting the customers' demands to the existing plant factories. The demand prediction is very important for establishing a systematic planning method for production and shipping of the produced vegetables. Especially, an emphasis is given to the demand prediction model of the representative wholesale vegetable markets. The following issues are discussed in the paper.

(1) Production process and market for the plant factories,
(2) Modeling and analysis of demand prediction model of wholesale vegetable markets, and
(3) Discussion on the demand prediction model.

PRODUCTION PROCESSES IN PLANT FACTORIES

Osaka Prefecture University has established a research and development center for the plant factories and a pilot plant producing the lettuces since 2010, in order to carry out the joint research projects among the universities and the companies. Figure 1 shows the outlines of the newest pilot plant equipped in 2014 and its production lines for producing about 6,000 pieces of the frill lettuces and the batavia lettuces [3].

As shown in Fig. 1 (a), the factory consists of a raising seedlings area, an initial cultivation area, a final cultivation area, a packing area and an operators’ room. The following four steps are needed to produce the lettuces.

(1) Raising seedlings: The lettuce seedlings are raised from the seeds on the beds.
(2) Initial cultivation: The raised seedlings are transplanted onto the palettes, and grown up the sizes to be transferred to the final cultivation area, since the sizes and the numbers of the
palettes for two cultivation areas are different for saving the spaces in the plant factories.

(3) Final cultivation: The raised lettuces are transplanted onto the palettes in the final cultivation area. The area is composed of a set of transfer lines to transfer the palettes for one step forward every day to the outlet.

(4) Harvesting and packing: The grown up lettuces are harvested and packed into the packages after the final cultivation.

The production processes of the lettuces are thought to be a transfer line type production system shown in Fig. 1 (b) consisting of three continuous lines. The processing time for the raising seedlings, initial cultivation and final cultivation are 6 days, 14 days and 18 days, respectively. In the production lines, the seeds are inputted to the raising seedlings line and the grown up lettuces are outputted from the final cultivation line every day. Therefore, the lot size and the cycle time of the lines are the daily production volume and one day, respectively.

The produced lettuces are then stored in the refrigerators for a few days to reduce their vital activity and to extend their shelf life. However, the shelf life of the lettuces is not so long as one week.

MARKET OF PLANT FACTORY MADE LETTUCES

The vegetables produced in the conventional farms are usually traded in wholesale markets based on both the selling orders and the buying orders. The volumes and the prices in the transaction are governed by the supply and the demand in the markets. The volumes and the prices in the wholesale market are therefore changed according to the seasonal changes of climate and weather, and due to bad weather like flood and typhoon.

The prices per unit weight of the factory made lettuces are three to four times higher than the ones produced in the conventional farms, and the plant factory made vegetables are not so competitive in price aspect. The market share of the factory made lettuces is also very small against the ones produced in the conventional farms. The factory made vegetables are therefore usually sold in outside of the wholesale markets due to their higher price and smaller volume in the markets.

The wholesalers, retailers and end customers are now recognizing that the lettuces produced in the plant factories are very clean and reduce the risk of food borne illnesses. For examples, the factory made lettuces keep their freshness for long time in the display shelves in the supermarkets. The end customers feel that these lettuces are clean and safe, and buy them even in the higher prices. From the viewpoint of the customers such as restaurants and hotels, the factory made lettuces provide them shorter pre-processing time due to their freshness and cleanliness.

The followings summarize the characteristic features in the production process and the market of the factory made lettuces in comparison to the conventional lettuces.

(1) The production lead time is relatively short, and it is not easy to change the product mix after the raising seedlings process. The lead time of the lettuces is about 40 days.

(2) The plant factory produces one lot size of products, stores them for a few days in the refrigerators, and delivers them to the customers. The lot size varies from 250 to 20,000 for typical plant factories in Japan [3]. However, the market share of the factory made vegetables are very small, and their price are deeply influenced by the price and volumes traded in the wholesale markets.

(3) The factory made lettuces are mainly sold in outside of the wholesale markets, based on the demands from the customers.

(4) The shipping volumes depend on the demands from the various customers including the wholesalers, retailers, supermarkets and end customers. The customers’ demand are deeply influenced by the daily status of both the demand and supply in the wholesale markets, since the market share of the plant factory made lettuces are very smaller than the conventional farm made ones traded in the wholesale market.

Therefore, the demand prediction system of the wholesale markets is required for the plant factories to forecast the daily changes in the demands from the various customers.
DEMAND PREDICTION

Analysis methods

Two major wholesale vegetable markets are considered for the analysis, based on the trading volumes of the markets and the available length of the trading records which are accessible from the WEB. They are, Ohta market and Tsukiji Market in Tokyo.

The following two methods are applied to the analysis of the demands of the markets.

(1) Time series analysis

The time series analysis method is firstly applied to the trade volume data of the wholesale markets, in order to investigate the basic characteristics of the dynamic demand changes in the markets.

(2) Regression analysis

The regression analysis method is secondly applied to get formulas, which predict the monthly trade volumes of the lettuces in the wholesale markets. Various time series data relating with not only the lettuces but also the other vegetables are considered in the analysis, to construct the prediction formulas for the demands of the lettuces.

Date and Preprocessing

The following time series data are selected as the variables relating to the demand volumes of the lettuces in the wholesale markets, based on the pre-analysis on the correlation coefficients between the demands of the lettuces and the variables. The data are obtained from the WEB site of the wholesale markets.

Markets: Ohta market, Tsukiji market.
Period: January, 2005 to December, 2012, total 96 months.
Vegetables: Lettuces, Cabbages, Mizuna greens.
Data: Trade volumes, trade prices.

The cabbages and the mizuna greens are very popular vegetables, and are used for the green salads and the other dishes in Japan. It is commonly understood that their trade volumes affect the demands of the lettuces in the wholesale markets.

All the data are normalized by applying the following equation.

\[
Y_j^i = (X_j^i - \mu^i) / \sigma^i
\]  

where,

\(i\) : item ID representing the trade volumes or the trade prices of the individual vegetables.
\(j\) : Indices of months.
\(X_j^i\) : Values of item \(i\) in the month \(j\).
\(\mu^i\) : Mean values of item \(i\).
\(\sigma^i\) : Standard deviations of item \(i\).

The time series analysis and the regression analysis are carried out by applying Oracle Crystal Ball\(^\circ\).

Time series analysis

Time series analysis is applied for investigating the basic characteristics of the dynamic demand changes in the two markets. The analysis results are summarized in Fig. 2 (a) and (b). In the figures, the green lines and the blue lines show the real trade volumes in the market and the predicted volumes obtained by the time series model, respectively. The obtained models are represented by the following formulas.

(a) Trade volume in Ohta market

\[
y_j = 0.2747 \ y_{j-1} + 0.9507 \ y_{j-12} - 0.9717 \ \epsilon_{j-1} - 0.5838 \ \epsilon_{j-12}
\]

RMSE=0.57

(b) Trade volume in Tsukiji market

\[
y_j = -0.0902 \ y_{j-1} + 0.1613 \ y_{j-2} + 0.9093 \ y_{j-12} - 0.4139 \ \epsilon_{j-1} - 0.5389 \ \epsilon_{j-2} - 0.4864 \ \epsilon_{j-12}
\]

RMSE=0.61

where,

\(y_j \) : Trade volume in \(j\) months before.
\(Y_j \) : Trade volume in \(j\) months before.
\(\epsilon_j \) : Differences between the predicted value and the real value of \(y_j\).
RMSE : Root mean square errors between the predicted values and the real values.

Formulas shown in Eqs. (2) and (3) obtained here show the following characteristics of the demand volumes.
(1) They include the one order of differenced item.
(2) They include the seasonal item of 12 months.
(3) They include both the AR (Auto Regressive) items and the MA (Moving Average) items. But, the orders of the items are different in the models of two markets.

Regression analysis
The regression analysis is applied to get the prediction formulas of the demand volumes of the lettuces. The following parameters are selected for constructing the prediction formulas, based on the results of the time series analysis.
(1) Trade volumes of the lettuces in 1 and 12 months before.
(2) Trade volumes of both the cabbages and mizuna greens in 1 month before.
(3) Trade prices of the lettuces in 1 and 12 months before.
(4) Trade prices of both the cabbages and mizuna greens in 1 month before.

The following formula is applied to the regression analysis.

\[ Y_j = a_0 + \sum a_i Y_i \]  

\( Y_j \): Trade volume of lettuces in month \( j \).
\( Y_i \): Items used for prediction of \( Y_j \).
\( a_i \): Coefficient for \( Y_i \).

The results of the regression analysis are summarized in Table 1 and Fig. 3. Table 1 shows the coefficient for the individual items, and the followings are clarified.

(a) The coefficient of the trade volume of lettuces in 12 months before is relatively large. This shows the seasonal effect is large.
(b) The effects of the trade prices of lettuces in the previous months are relatively small. On the other hand, the price of cabbages and mizuna greens in 1 month before have larger effects on the trade volume of lettuces. This may show that the markets and the customers consider the price trends of the alternative vegetables for the lettuces.
(c) The effects of the mizuna greens is little bit larger than that of the cabbages.
(d) The RMSEs of the regression model are not clearly improved against the time series model. One reason is that the differenced items are not considered in the regression model.

CONCLUSIONS
The demand prediction of the wholesale markets was discussed here, aimed at establishing a suitable production and shipping planning and management method for the plant factories of the lettuces. Both the time series analysis and the regression analysis were applied for investigation and prediction of the demand volumes of lettuces in representative wholesale vegetable markets in Ohta and Tsukiji, Tokyo.

The prediction results obtained in the research is not sufficient to predict the demand volumes in the real markets, and some improvement will be discusses in the future researches.

Table 1 Results of regression analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>( a_i ) for Ohta Market</th>
<th>( a_i ) for Tsukiji Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lettuce Volume ((j-1))</td>
<td>0.1885</td>
<td>0.4348</td>
</tr>
<tr>
<td>Lettuce Volume ((j-12))</td>
<td>0.5891</td>
<td>0.5167</td>
</tr>
<tr>
<td>Cabbage Volume ((j-1))</td>
<td>0.0449</td>
<td>0.0527</td>
</tr>
<tr>
<td>Mizuna G. Volume ((j-1))</td>
<td>0.2288</td>
<td>0.0839</td>
</tr>
<tr>
<td>Lettuce Price ((j-1))</td>
<td>0.1256</td>
<td>0.0043</td>
</tr>
<tr>
<td>Lettuce Price ((j-12))</td>
<td>0.1437</td>
<td>0.0199</td>
</tr>
<tr>
<td>Cabbage Price ((j-1))</td>
<td>0.2001</td>
<td>0.1497</td>
</tr>
<tr>
<td>Mizuna G. Price ((j-1))</td>
<td>0.3823</td>
<td>0.2051</td>
</tr>
<tr>
<td>( a_0 )</td>
<td>0.0939</td>
<td>0.0669</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.54</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Fig.3 Results of regression analysis

(a) Trade volume in Ohta market

(b) Trade volume in Tsukiji market

REFERENCES