Data-driven Food Supply Chain Optimization under Uncertain Crop Productions and Consumers' Demands

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Abstract: This paper proposes a mathematical model of multi-period food supply chain optimization maximizing the total profit based on the data-driven approach from the information system. Our propose model is focused on accommodating surplus foods among stores in a regional area. Our proposed model is formulated as a stochastic programming problem. With respect to a previous model, the explicit optimal ordering quantity at each time slot is obtained. However, it is hard to solve the formulated problem directly. Therefore, a scenario-based approach derived from POS data using the information system and deterministic equivalent transformations are introduced to apply our proposed model.

Key Words: Food supply chain optimization, Mathematical programming problem, Data-driven approach

1. Introduction

Many Japanese farmers recently face severe problems. For instance, young people do not get an agricultural job and the number of young farmers is decreasing, and hence, the aging of Japanese farmers is rapidly increasing. In addition, globalization of food production may also have various impacts on Japanese agriculture. Particularly, some Japanese farmers feel nervous about Trans-Pacific Partnership (TPP) which may have a negative influence on Japanese agriculture in terms of trade liberalization. Thus, these severe problems are nowadays discussed in some detail in terms of various aspects.

On the other hand, severe agricultural conditions could become a big opportunity to try and change traditional Japanese agriculture by introducing Information and Communication Technology (ICT). In the recent standard Japanese agricultural system, agricultural products were sold from farmers to a central wholesale market, and to retailers, and were finally sent to consumers. On the other hand, it is difficult for consumers to get to know detailed production information of the purchased agricultural products. In most recently, consumers begin to ask for getting to know how and where agricultural products were made, because they mind the safety of food due to usage of unnecessary agricultural chemicals for agricultural products. Therefore, the next agricultural system to use ICT and computer technologies is needed.

Many researchers recently developed various types of agricultural systems [3],[5],[8]. As some examples for our proposed model, Takatsudo et al.[11] introduced the ICT as a solution of agricultural successor problem. Kashima et al.[6] also developed a menu recommendation system which gathers data on

what people like to eat, and with that data, it can make automatic recommendations for an individual. This idea can be applied in developing the agricultural information system for urban markets, for the benefit of farmers and the local agriculture in Japan. Furthermore, Kashima et al.[7] proposed Farmer's Information System (FIS), which is a new business model for agricultural markets using ICT. The purpose of FIS is to change the Japanese domestic agriculture using ICT in terms of management stability of agriculture, stable supply and improvement in the value of agricultural products. FIS can also adjust their farming schedule in a way that by the time they grow agricultural products, and their products are actually sought upon by consumers.

Thus, several useful ICT-based agricultural systems are proposed, but there are few studies of quantitative and qualitative analyses of these agricultural systems from the mathematical viewpoint. As well as development of information systems, it is important to construct a mathematical model for the proposed FIS-based agricultural system to objectively and quantitatively evaluate it comparing with previous systems. Most recently, we [4] proposed a mathematical programming problem on the FIS-based agricultural system in terms of environmental load, and developed the algorithm to obtain the optimal ordering quantity. This algorithm is based on solving linear programming problems, and hence, it may be efficient. However, our previous proposed model considered only minimizing the total discarding volume under the multiperiod situation of real agricultural markets. In general, it is important for retailers to consider maximizing the total profit as well as minimizing the environmental load for FIS-based agricultural system. In addition, by using FIS, production volume and POS data of the agricultural product can be collected. Therefore, it is also important to formulate more general mathematical programming problems not assuming specific random distributions for consumers' demands and uncertain crop production, but applying a data-driven approach based on FIS. Furthermore, accommo-

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dating surplus foods among stores plays an important role in terms of minimizing the total discarding volume.

In this paper, as the more general model, we extend our previous model to a data-driven model, and obtain the explicit optimal ordering quantity based on a distribution-free approach. By obtaining the explicit optimal ordering quantity, we can analytically and easily compare previous models not considering accommodating surplus foods among stores in a regional area with our proposed model considering accommodating surplus foods.

This paper is organized as follows. In Section 2, we introduce some assumptions to formulate our proposed model and parameters considering the real-world application. In Section 3, we consider optimization approaches for both previous and our proposed model. Particularly, with respect to our proposed model, the formulation is complicate, and hence, it is difficult to apply the previous approach to obtain the explicit optimal solution such as a distribution-free approach. Therefore, we develop a data-driven approach for our proposed model. Finally, in Section 4, we conclude this paper.

2. Assumption of Our Proposed Model and Notation of Parameters

In this paper, we focus on maximizing sum of the total profit at each store to decide the optimal cultivated planning in the multi-period. We assume that the agricultural product is purchased from one contract local farmer considering local production for local consumption. One of the main topics is to compare the previous model not considering accommodating surplus foods among stores in a regional area with our proposed model considering accommodating surplus foods. Therefore, we consider the following specific assumptions for the previous model and our proposed model:

(Previous model)

- Each store purchases the agricultural product from one specific farmer. Total production volume in one period at each farmer is given as a constant value.
- Unsold volumes of the agricultural product at the store after one period must be discarded in terms of quality assurance.
- The decision variable is the ordering quantity of each store from one contract farmer.

(Our proposed model)

- A specific retailer purchases the agricultural product from one specific farmer. Total production volume from the farmer in one time slot is given as a random variable.
- Production volume of the farmer in one time slot is all shipped to the warehouse
- The retailer also serves in the role a warehouse to hold unsold volumes in two periods keeping them fresh. However, with respect to final time slot, the retailer must discard unsold volume of the agricultural product after final one time slot.

- The retailer distributes necessary quantities of the agricultural product to stores based on consumers' demands.
- Unsold volumes of the agricultural product to distribute to each store must be discarded.

From these assumptions, each store can quantitatively or qualitatively decide whether FIS is adopted or not.

Notation of parameters in this paper is as follows:

(For the multiperiod)

T : Total time slot of our proposed multi-period model, i.e., $t \in \{1, 2, \dots, T\}$.

(For one contract farmer)

S_t : Contract cultivated acreages at t th time slot (decision variable)

C : Contract fee per cultivated acreage of one contract farmer in our propose model

c_j : Contract fee per cultivated acreage requested from j th store in the previous model

Q_t : Amount of crop per cultivated acreages at one contract farmer at t th time slot. In the previous model, each Q_t is assumed to be a constant value. However, in the real-world, the amount of crop is dependent on current weather condition, and hence Q_t is assumed to be a random variable in this paper's model.

$\bar{Q}_t$: Mean value of random variable Q_t . In this paper, we use $\bar{Q}_t$ in the previous model.

(For the retailer (warehouse) of our proposed model)

h : Holding cost of unit volume for the unsold which is a constant value

β_0 : Discarding cost of unit unsold volume for two time slots at the warehouse which is a constant value

y_{jt} : Distributing volume at j th store from the retailer on t th time slot in our proposed model (decision variable)

(For stores)

n : Total number of stores

p_j : Selling price of unit volume at j th store which is a constant value not depending on time slots.

β_j : Discarding cost of unit unsold volume at j th store which is a constant value

s_j : Shortage cost at j th store which is also a constant value

(For consumers)

D_{jt} : Consumers demands at j th store on t th time slot

3. Formulation and Optimization of Previous and Our Proposed Models

We construct a multiperiod model for FIS-based agricultural system as a stochastic programming problem due to random demand D_{jt} . The main objective is maximizing the total profit of each store, and minimizing the environmental load, i.e., minimizing the sum of discarding volumes of agricultural product in the retailer and all stores over entire period T .

3.1 Total profit function at each store and explicit optimal purchasing volume in previous models

First, we consider a previous model to maximize sum of the total profit at each store not considering accommodating surplus foods among stores. We assume that each contract cultivated acreage S_t is a continuous decision variable, and hence, the total profit at each store is obtained as follows:

$$\sum_{t=1}^T \left\{ p_j \left(\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+ \right) - c_j \bar{Q}_t S_t - s_j [D_{jt} - \bar{Q}_t S_t]^+ - \beta_j [\bar{Q}_t S_t - D_{jt}]^+ \right\} \quad (1)$$

where $[x]^+ = \max\{x, 0\}$. In the total profit function, each term means as follows:

- $p_j \left(\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+ \right)$ means the revenue derived from sales volume $\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+$ on time slot t . From the second assumption of our proposed model, production volume $\bar{Q}_t S_t$ is all shipped to the warehouse. If demand D_{jt} is less than production volume $\bar{Q}_t S_t$, $[\bar{Q}_t S_t - D_{jt}]^+$ becomes $\bar{Q}_t S_t - D_{jt}$, and hence, $\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+$ becomes D_{jt} . On the other hand, if demand D_{jt} is larger than production volume $\bar{Q}_t S_t$, $[\bar{Q}_t S_t - D_{jt}]^+$ becomes 0, and hence, $\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+$ becomes $\bar{Q}_t S_t$.
- $c_j \bar{Q}_t S_t$ means the cost for the contract cultivated acreages at j th store on time slot t .
- $s_j [D_{jt} - \bar{Q}_t S_t]^+$ means the shortage cost on time slot t . If demand D_{jt} is larger than production volume $\bar{Q}_t S_t$, shortage volume becomes $D_{jt} - \bar{Q}_t S_t$. On the other hand, if demand D_{jt} is less than production volume $\bar{Q}_t S_t$, shortage volume becomes 0.
- $\beta_j [\bar{Q}_t S_t - D_{jt}]^+$ means the discarding cost on time slot t . If demand D_{jt} is less than production volume $\bar{Q}_t S_t$, holding volume becomes $\bar{Q}_t S_t - D_{jt}$. On the other hand, if demand D_{jt} is larger than production volume $\bar{Q}_t S_t$, holding volume becomes 0.

One of the main objectives is maximizing this total profit function, but it is difficult to optimize it directly, because this function includes random variables D_{jt} and we need to set some optimal criterion for randomness. In this paper, as one of the most basic approach in stochastic programming, we consider the mean value of function (1) as follows:

$$E \left[\sum_{t=1}^T \left\{ p_j \left(\bar{Q}_t S_t - [\bar{Q}_t S_t - D_{jt}]^+ \right) - c_j \bar{Q}_t S_t - s_j [D_{jt} - \bar{Q}_t S_t]^+ - \beta_j [\bar{Q}_t S_t - D_{jt}]^+ \right\} \right]$$

$$\Leftrightarrow \sum_{t=1}^T \left\{ (p_j - c_j) \bar{Q}_t S_t - s_j E \left[[D_{jt} - \bar{Q}_t S_t]^+ \right] - (p_j + \beta_j) E \left[[\bar{Q}_t S_t - D_{jt}]^+ \right] \right\} \quad (2)$$

This problem is a standard inventory model, called Newsboy or Newsvendor problem. In addition, if we get some scenarios derived from random variable D_{jt} as POS data based on FIS and calculate sample mean value μ_{jt} and variance σ_{jt}^2 from POS data, it is possible to apply a data-driven approach to obtain the contract cultivated acreage S_t at j th store from the retailer on time slot t . In this paper, we can use a distribution-free approach considering the upper limit of the expected excessive inventory quantity and the upper limit of the shortage quantity [1, 2, 9, 10] as follows:

$$\begin{aligned} & E \left[[D_{jt} - \bar{Q}_t S_t]^+ \right] \\ & \leq \frac{\sqrt{\sigma_{jt}^2 + (\bar{Q}_t S_t - \mu_{jt})^2} - (\bar{Q}_t S_t - \mu_{jt})}{2} \\ & E \left[[\bar{Q}_t S_t - D_{jt}]^+ \right] \\ & \leq \frac{\sqrt{\sigma_{jt}^2 + (\mu_{jt} - \bar{Q}_t S_t)^2} - (\mu_{jt} - \bar{Q}_t S_t)}{2} \end{aligned} \quad (3)$$

Therefore, the following function (4) is obtained based on mean value (2) and formula (3):

$$\begin{aligned} & R(S_t) \\ & = \sum_{t=1}^T \left\{ (p_j - c_j) \bar{Q}_t S_t - s_j \left(\frac{\sqrt{\sigma_{jt}^2 + (\bar{Q}_t S_t - \mu_{jt})^2} - (\bar{Q}_t S_t - \mu_{jt})}{2} \right) - (p_j + \beta_j) \left(\frac{\sqrt{\sigma_{jt}^2 + (\mu_{jt} - \bar{Q}_t S_t)^2} - (\mu_{jt} - \bar{Q}_t S_t)}{2} \right) \right\} \end{aligned} \quad (4)$$

Based on this revenue function and previous study [12], optimal purchasing volume S_t^* is obtained as follows:

$$\begin{aligned} & \frac{\partial R(S_t)}{\partial S_t} = 0 \\ & \Leftrightarrow \frac{1}{2} (p_j + s_j - \beta_j - 2c_j) \\ & - \frac{(p_j + s_j + \beta_j)}{2} \left(\frac{\bar{Q}_t S_t - \mu_{jt}}{\sqrt{\sigma_{jt}^2 + (\bar{Q}_t S_t - \mu_{jt})^2}} \right) = 0 \\ & \Leftrightarrow \begin{cases} S_t^* = \frac{\mu_{jt} + \sigma_{jt}^2 \theta_j}{\bar{Q}_t \sqrt{1 - \theta_j^2}} \\ \theta_j = \frac{p_j + s_j - \beta_j - 2c_j}{p_j + s_j + \beta_j} \end{cases} \end{aligned} \quad (5)$$

Thus, the optimal ordering quantity of each store is explicitly obtained.

3.2 Total profit function in our proposed model

Second, we consider our proposed model to focus on maximizing sum of the total profit at each store considering accommodating surplus foods among other stores. The main difference

between our proposed model and previous models is whether accommodating surplus foods is possible or not. In this paper, we represent accommodating surplus foods as freely distributing volume $\sum_{j=1}^n y_{jt}$ based on production volume $Q_t S_t$ from the farmer, that is, each store can freely trade surplus food without paying the trading cost.

The total profit function of our proposed model considering accommodating surplus foods is obtained as follows:

$$\begin{aligned} & \sum_{t=1}^T \sum_{j=1}^n p_j (y_{jt} - [y_{jt} - D_{jt}]^+) \\ & - \sum_{t=1}^T \sum_{j=1}^n s_j [D_{jt} - y_{jt}]^+ - \sum_{t=1}^T \sum_{j=1}^n \beta_j [y_{jt} - D_{jt}]^+ \\ & - \sum_{t=1}^{T-1} h \left[Q_t S_t - \sum_{j=1}^n y_{jt} \right]^+ \\ & - \sum_{t=1}^T \beta_0 \left[\left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ - \left[\sum_{j=1}^n y_{jt} - Q_t S_t \right]^+ \right] \\ & - \beta_0 \left[Q_T S_T - \sum_{j=1}^n y_{jT} \right]^+ - C \sum_{t=1}^T S_t \end{aligned} \quad (6)$$

In our proposed model, we decide optimal contract cultivated acreages S_t at t th time slot consider maximizing the total profit function. In addition, as constraints distribution volume $\sum_{j=1}^n y_{jt}$, we can set the following inequality considering shipping volume at t th time slot and holding volume from $(t-1)$ th time slot:

$$\sum_{j=1}^n y_{jt} \leq Q_t S_t + \left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ \quad (7)$$

($t = 1, 2, \dots, T$)

In this paper, we assume $Q_0 = 0, S_0 = 0, y_{j0} = 0$. From this constraint, the following equivalent transformations are obtained:

$$\begin{aligned} & - \sum_{t=1}^T \beta_0 \left[\left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ - \left[\sum_{j=1}^n y_{jt} - Q_t S_t \right]^+ \right] \\ \Leftrightarrow & - \beta_0 \sum_{t=1}^T \left(\left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ - \left[\sum_{j=1}^n y_{jt} - Q_t S_t \right]^+ \right) \\ \Leftrightarrow & \beta_0 \sum_{t=1}^T \left(\left[\sum_{j=1}^n y_{jt} - Q_t S_t \right]^+ - \left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ \right) \\ \Leftrightarrow & \beta_0 \sum_{t=1}^T \left(\left(\sum_{j=1}^n y_{jt} - Q_t S_t \right) + \left[Q_t S_t - \sum_{j=1}^n y_{jt} \right]^+ \right. \\ & \left. - \left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ \right) \\ \Leftrightarrow & \beta_0 \left\{ \sum_{t=1}^T \left(\sum_{j=1}^n y_{jt} - Q_t S_t \right) + \left[Q_T S_T - \sum_{j=1}^n y_{jT} \right]^+ \right\} \\ \Leftrightarrow & - \beta_0 \left\{ \sum_{t=1}^T \left(Q_t S_t - \sum_{j=1}^n y_{jt} \right) - \left[Q_T S_T - \sum_{j=1}^n y_{jT} \right]^+ \right\} \end{aligned} \quad (8)$$

Therefore, the expected value of total profit function (6) is defined as follows:

$$\begin{aligned} & E \left[\sum_{t=1}^T \sum_{j=1}^n p_j (y_{jt} - [y_{jt} - D_{jt}]^+) \right. \\ & - \sum_{t=1}^T \sum_{j=1}^n s_j [D_{jt} - y_{jt}]^+ - \sum_{t=1}^T \sum_{j=1}^n \beta_j [y_{jt} - D_{jt}]^+ \\ & - h \sum_{t=1}^{T-1} \left[Q_t S_t - \sum_{j=1}^n y_{jt} \right]^+ \\ & - \beta_0 \left\{ \sum_{t=1}^T \left(Q_t S_t - \sum_{j=1}^n y_{jt} \right) - \left[Q_T S_T - \sum_{j=1}^n y_{jT} \right]^+ \right\} \\ & \left. - \beta_0 \left[Q_T S_T - \sum_{j=1}^n y_{jT} \right]^+ - C \sum_{t=1}^T S_t \right] \end{aligned} \quad (9)$$

This expected value is equivalently transformed into the following function;

$$\begin{aligned} & \sum_{t=1}^T \sum_{j=1}^n p_j y_{jt} - \sum_{t=1}^T \sum_{j=1}^n s_j E \left[[D_{jt} - y_{jt}]^+ \right] \\ & - \sum_{t=1}^T \sum_{j=1}^n (p_j + \beta_j) E \left[[y_{jt} - D_{jt}]^+ \right] \\ & - h \sum_{t=1}^{T-1} E \left[\left[Q_t S_t - \sum_{j=1}^n y_{jt} \right]^+ \right] \\ & - \beta_0 \sum_{t=1}^T \left(Q_t S_t - \sum_{j=1}^n y_{jt} \right) - C \sum_{t=1}^T S_t \end{aligned}$$

Consequently, main problem is defined as follows:

$$\begin{aligned} & \text{Maximize} \quad \sum_{t=1}^T \sum_{j=1}^n p_j y_{jt} \\ & - \sum_{t=1}^T \sum_{j=1}^n s_j E \left[[D_{jt} - y_{jt}]^+ \right] \\ & - \sum_{t=1}^T \sum_{j=1}^n (p_j + \beta_j) E \left[[y_{jt} - D_{jt}]^+ \right] \\ & - h \sum_{t=1}^{T-1} E \left[\left[Q_t S_t - \sum_{j=1}^n y_{jt} \right]^+ \right] \\ & - \beta_0 \sum_{t=1}^T \left(Q_t S_t - \sum_{j=1}^n y_{jt} \right) - C \sum_{t=1}^T S_t \\ & \text{subject to} \quad \sum_{j=1}^n y_{jt} \leq Q_t S_t \\ & + E \left[\left[Q_{t-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+ \right], \\ & S_t \geq 0, y_{jt} \geq 0, \\ & (j = 1, 2, \dots, n; t = 1, 2, \dots, T) \end{aligned} \quad (10)$$

In the case we introduce the distribution-free approach in a ways similar to Section 2, problem (10) is transformed into a constrained nonlinear programming problem, and hence, it is hard to obtain the explicit optimal ordering quantity. In the

case we consider the real-world situation of FIS-based agricultural system, it is also important to deal with our proposed model efficiently as well as to obtain the explicit optimal solution. On the other hand, some numerical dataset of demands can be received from POS data using FIS. Therefore, we adopt a data-driven approach called a scenario-based approach derived to our proposed model. In this paper, we consider the following M scenarios derived from POS data of FIS:

$$\begin{aligned} D_{jt} &\rightarrow \mathbf{d}_{mt} = \{d_{m1t}, d_{m2t}, \dots, d_{mnt}\}, Q_t \rightarrow q_{mt} \\ \Pr\{D_{jt} = \mathbf{d}_{mt} \cap Q_t = q_{mt}\} &= \frac{1}{M} \\ (m = 1, 2, \dots, M; j = 1, 2, \dots, n; t = 1, 2, \dots, T) \end{aligned} \quad (11)$$

By substituting these M scenarios into problem (??), the following problem is obtained:

$$\begin{aligned} \text{Maximize} \quad & \sum_{t=1}^T \sum_{j=1}^n p_j y_{jt} \\ & - \sum_{t=1}^T \sum_{j=1}^n s_j \left(\frac{1}{M} \sum_{m=1}^M [d_{mjt} - y_{jt}]^+ \right) \\ & - \sum_{t=1}^T \sum_{j=1}^n (p_j + \beta_j) \left(\frac{1}{M} \sum_{m=1}^M [y_{jt} - d_{mjt}]^+ \right) \\ & - h \sum_{t=1}^{T-1} \left(\frac{1}{M} \sum_{m=1}^M \left[q_{mt} S_t - \sum_{j=1}^n y_{jt} \right]^+ \right) \\ & - \beta_0 \sum_{t=1}^T \left(\left(\frac{1}{M} \sum_{m=1}^M q_{mt} \right) S_t - \sum_{j=1}^n y_{jt} \right) - C \sum_{t=1}^T S_t \\ \text{subject to} \quad & \sum_{j=1}^n y_{jt} \leq \left(\frac{1}{M} \sum_{m=1}^M q_{mt} \right) S_t \\ & + \frac{1}{M} \sum_{m=1}^M \left[q_{mt-1} S_{t-1} - \sum_{j=1}^n y_{jt-1} \right]^+, \\ & S_t \geq 0, y_{jt} \geq 0, \\ & (j = 1, 2, \dots, n; t = 1, 2, \dots, T) \end{aligned} \quad (12)$$

In this problem, max functions $[d_{mjt} - y_{jt}]^+$, $[y_{jt} - d_{mjt}]^+$ and $\left[q_{mt} S_t - \sum_{j=1}^n y_{jt} \right]^+$ are equivalently transformed into the following linear constraints, respectively:

$$\begin{aligned} \xi_{mjt} &= [d_{mjt} - y_{jt}]^+ \rightarrow \xi_{mjt} \geq d_{mjt} - y_{jt}, \xi_{mjt} \geq 0 \\ \eta_{mjt} &= [y_{jt} - d_{mjt}]^+ \rightarrow \eta_{mjt} \geq y_{jt} - d_{mjt}, \eta_{mjt} \geq 0 \\ \omega_{mt} &= \left[q_{mt} S_t - \sum_{j=1}^n y_{jt} \right]^+ \\ &\rightarrow \omega_{mt} \geq q_{mt} S_t - \sum_{j=1}^n y_{jt}, \omega_{mt} \geq 0 \end{aligned} \quad (13)$$

Consequently, we can obtain the optimal ordering quantity of main problem by solving the following problem:

$$\text{Maximize} \quad \sum_{t=1}^T \sum_{j=1}^n p_j y_{jt} - \frac{1}{M} \sum_{t=1}^T \sum_{j=1}^n \sum_{m=1}^M s_j \xi_{mjt}$$

$$\begin{aligned} & - \frac{1}{M} \sum_{t=1}^T \sum_{j=1}^n \sum_{m=1}^M (p_j + \beta_j) \eta_{mjt} \\ & - h \sum_{t=1}^{T-1} \omega_{mt} \\ & - \beta_0 \sum_{t=1}^T \left(\left(\frac{1}{M} \sum_{m=1}^M q_{mt} \right) S_t - \sum_{j=1}^n y_{jt} \right) - C \sum_{t=1}^T S_t \\ & - \beta_0 \sum_{t=1}^T \left(\left(\frac{1}{M} \sum_{m=1}^M q_{mt} \right) S_t - \sum_{j=1}^n y_{jt} \right) - C \sum_{t=1}^T S_t \\ \text{subject to} \quad & \sum_{j=1}^n y_{jt} \leq \left(\frac{1}{M} \sum_{m=1}^M q_{mt} \right) S_t + \frac{1}{M} \sum_{m=1}^M \omega_{mt-1}, \\ & S_t \geq 0, y_{jt} \geq 0, \\ & \xi_{mjt} \geq d_{mjt} - y_{jt}, \xi_{mjt} \geq 0, \\ & \eta_{mjt} \geq y_{jt} - d_{mjt}, \eta_{mjt} \geq 0, \\ & \omega_{mt} \geq q_{mt} S_t - \sum_{j=1}^n y_{jt}, \omega_{mt} \geq 0, \\ & (j = 1, 2, \dots, n; t = 1, 2, \dots, T) \end{aligned} \quad (14)$$

This problem is a linear programming problem, and hence, it is easy to solve it using standard linear programming approaches such as Simplex method and Interior point method. Furthermore, it is also not difficult to solve large-scale problems of our proposed model using some efficient solvers such as CPLEX. Therefore, our proposed model will be useful in terms of real-world application.

4. Numerical example

In this section, in order to compare our proposed model considering accommodating surplus foods among stores with the previous standard model not considering accommodating surplus foods, we provide a simple numerical example. As a practical situation, we assume 3 time slots ($T=3$), one retailer and 3 stores ($n=3$) in our previous and proposed models. Each random distribution for production quantity Q_t or demand D_{jt} is assumed to be a continuous uniform distribution $U(a, b)$ where a and b are represented as both endpoints, and provided as the following Tables 1 and 2:

Table 1 production volume at one contract farmer

Q_1	Q_2	Q_3
U(4.5, 5.5)	U(4, 6)	U(3.5, 4.5)

Table 2 demands at stores

	t=1	t=2	t=3
Store 1	U(47, 53)	U(55, 65)	U(40, 60)
Store 2	U(45, 55)	U(40, 60)	U(48, 52)
Store 3	U(29, 31)	U(28, 32)	U(28, 32)

In addition, other parameters are also provided as the following constant values shown in Table 3:

From the provided numerical example, we first obtain the optimal ordering quantity at each store in the previous model shown in Section 2. We have already obtained the explicit contract cultivated acreages as solution (5) in constant production volume, and hence, we consider random variable Q_t as mean

Table 3 other parameters

	p_j	s_j	β_j	c_j
Store 1	60	20	15	3
Store 2	70	35	15	3
Store 3	40	10	10	3

h	β_0	C
15	15	3

value $\bar{Q}_i$ and the optimal solution at each store in this numerical is also obtained as the follow Tables 4 and 5:

Table 4 optimal contract cultivated acreages in the previous model

	t=1	t=2	t=3
Store 1	13.03	15.77	17.09
Store 2	14.57	15.13	17.79
Store 3	7.59	7.67	9.59
Total	35.19	38.58	44.47

Table 5 optimal ordering quantities in the previous model derived from Table 4

	t=1	t=2	t=3
Store 1	65.17	78.84	68.37
Store 2	72.84	75.67	71.15
Store 3	37.93	38.37	38.37

From these results, the total revenue (4) is calculated as 18651.65.

On the other hand, the optimal ordering quantities of stores in our proposed model are obtained by solving problem (14) with scenarios of demands and production volumes based on the random distributions. In this paper, we generate 100 sampling data each trial and repeat 10 times. Consequently, we obtain the mean value of 10 optimal solutions as the following Tables 6 and 7:

Table 6 optimal contract cultivated acreages in our proposed model

	t=1	t=2	t=3
Total	26.04	27.44	31.06

Table 7 optimal ordering quantities in our proposed model

	t=1	t=2	t=3
Store 1	49.84	59.74	49.45
Store 2	50.36	50.73	50.14
Store 3	29.98	29.97	29.97

From these results, the total revenue (10) is calculated as 21692.5. Comparing results shown in Tables 4 and 6, cultivated acreages on all time slots in our proposed model are less than those of the previous model. In addition, comparing results shown in Tables 5 and 7, all ordering quantities at stores on time slots in our proposed model are also less than those of the previous model. Therefore, by considering accommodating surplus foods among regional stores based on our proposed model, we can appropriately control production volume in terms of environmental load maintaining the high revenue.

5. Conclusions

In this paper, we proposed a mathematical model of multi-period food supply chain optimization maximizing the total

profit based on the data-driven approach from Farmer's Information System (FIS). We particularly focused on maximization of the total profit considering accommodating surplus foods among regional stores. The proposed model was initially formulated as a stochastic programming problem. In order to obtain the optimal contract cultivated acreages and distributing volume to each store in mathematical programming, we introduced a data-driven approach, and the initial main problem was equivalently transformed into a standard linear programming problem, which we can apply some efficient solvers to. Our proposed model is formulated to keep the FIS-based agricultural system, and hence, it is easy to objectively evaluate the FIS-based agricultural system comparing other agricultural systems.

As future works, in order to respond the optimal ordering quantity quickly for users of FIS-based agricultural system in terms of user-friendly, we need to construct more general mathematical model. Furthermore, in order to evaluate between our proposed model and previous models objectively, we will develop the strict algorithm to obtain the explicit optimal solution of our proposed model.

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