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Procurement Planning of Agricultural Products Using Truncated Distribution

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Abstract. This paper aimed to apply a truncation distribution to improve a procurement model for agricultural products. A procurement planning of agricultural products is complex because there are many uncertain parameters. For example, the factory demand, the number of supply coconuts harvested at contracted farms, and the number of supply coconuts purchased from collectors. These factors have different distributions in each time interval. The mixed-integer non-linear programming was formulated. The model was run for 500 replications and 500 trials and represented the possible total cost under uncertainty. The result is improved to consider the scenarios with the truncated distributions. In addition, truncating the distribution interval in three cases: lower truncate case, upper truncate case, and doubly truncate case. By reducing the data interval by 5 to 20%. The importance of factors that are less likely to occur was reduced. The result is compared with the scenarios which could be applied as the decision-making tools.

Keywords: agricultural product, procurement planning, mixed-integer non-linear programming, truncated distribution

1. Introduction

A procurement plan of agricultural products is important because agricultural products had uncertain factors such as purchasing price, selling price, and quantity of supply. A supply chain of agricultural products had lacked effective planning to manage the balance between harvesting capacity or procurement from the different sources and the demand of customers or factories. The products had different harvest ages and quantities of supply [1]. Planners or decision-makers must consider where raw materials should be procured from [2]. Willy and Njeru (2014) and Du et al. (2009) analyzed the effect of the procurement plan of the agricultural product which used the make-or-buy decision [1,3]. So planning or improving the efficiency of the supply chain should be consistent with the actual situation. Many researchers used the simulation to analyze the possible outcomes [4, 6, 7, 8].

Most of the factors involved in planning in the supply chain of agricultural products are uncertain which is caused by the uncertainty of the quantity of supply and demand at each time that factors depend on the seasonal and the selling prices depend on the market mechanism. If the planners or decision-makers manage these factors effectively, the cost of operations can be controlled. An application of truncation of distributions is used in situations where the data is in the range of random variables due to limitations of various factors and costs. Random variables are bounded from minimum or maximum values [9]. Several studies have looked at how different distributions are truncated such as Tokmachev (2018) simulated a truncated distribution of a Normal distribution [10]. Chen and Gui (2020) studied the approximation of unknown parameters of Normal distribution truncation [11]. For Zeng and Gui (2021), the truncation of the Normal distribution [12] and Gul et al. (2021) improved the truncation of the Weibull and Gamma distribution [13].

The objective of this paper is to improve procurement planning. The total cost is minimized and extended the solution of inbound logistics. We analyzed the truncated distribution of uncertain parameters of yearly procurement planning to decrease the events that are less likely to occur. The three cases were considered; lower truncated case, upper truncated case, and doubly truncated case.

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The outline of the paper is as follows. In section 1, we describe the introduction of this paper. Then, In Section 2 we describe the input data and the method to fit the distribution of uncertain parameters. Then, in Section 3, we describe the mathematical model of the agricultural product. In Section 4 we present computation results using the actual data. In Section 5 we consider the truncated distribution to find the minimization of the yearly total cost, and finally, a conclusion in Section 6.

2. Input Modeling

Procurement planning is an important activity because it concerns the operation costs and helps the factory save costs [14]. In this paper, we used the data in the aromatic coconut supply chain of a factory in Ratchaburi province which consists of farmers, harvesters, collectors, manufacturers, and customers, as shown in Fig. 1.

We collected data, such as the supply quantities, the number of harvests from contracted farms and collectors, the purchasing price, by interviewing the factory manager and the farmers. We accessed price data from http://taladsimummuang.com and compared it with the real data of the factory. In this section, we separated data into 2 groups: constant data and uncertain data. For constant data, we averaged the historical data. For uncertain data, we sought the appropriate method. The forecasting method is used for the purchasing price from farms and the Input Analyzer is used for the number of supply coconuts harvested at contracted farms, the number of supply coconuts purchased from collectors, and the demand for the factory.

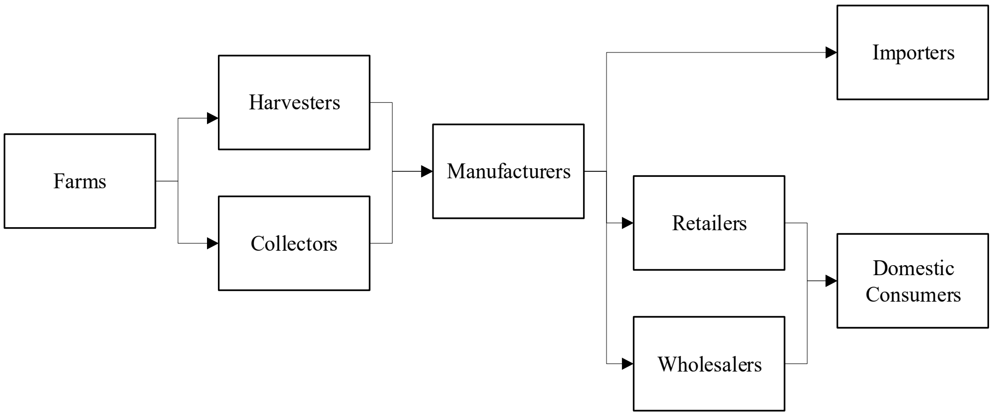

Fig. 1: An agricultural product supply chain in Thailand [14].

2.1. Forecasting Approach

We used the Top-Down hierarchical method to compare with the individual method [15]. The individual method is Damped Trend Non-Seasonal, Damped Trend Seasonal Additive, Damped Trend Seasonal Multiplicative, Simple Moving Average, Double Moving Average, Single Exponential Smoothing, Double Exponential Smoothing, Seasonal Additive, Seasonal Multiplicative, Holt-Winters' Additive, Holt-Winters' Multiplicative, and Box-Jenkins method. We choose the best individual method from MAPE (Mean Absolute Percentage Error) and TS (Tracking Signal). Box-Jenkins is the best method which has the lowest MAPE (Table 1).

Table 1. The MAPE of the individual method

Method	MAPE (%)
Box-Jenkins SARIMA(1,1,1)(1,0,1)	12.67
Damped Trend Non-Seasonal	15.27
Simple Moving Average	15.51
Single Exponential Smoothing	15.52
Double Exponential Smoothing	15.52
Seasonal Additive	15.54

Damped Trend Seasonal Multiplicative	15.54
Holt-Winters' Additive	15.55
Damped Trend Seasonal Additive	16.31
Seasonal Multiplicative	17.47
Holt-Winters' Multiplicative	17.98
Double Moving Average	22.02

The top-down method combined the forecasted data from Box-Jenkins in each month, the aggregate forecast. Then, we calculated the weight using the historical price (the year 2013 to 2020) to find the appropriate weights, as shown in Equations 1 to 4.

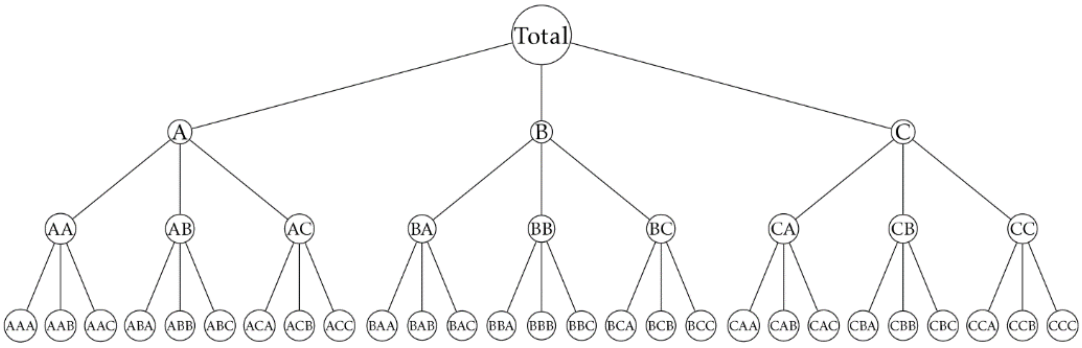

Fig: 2.A 3-level Hierarchical Tree Diagram.

We defined Wt as a weight of month t, is the forecast price at month t, FAgg is the aggregate forecast, Yt is the real price at month t, and N is the number of forecasted months.

$$\textit{Minimize}\ \text{MAPE} = \frac{\sum_{t=1}^{N} \frac{\left|\hat{Y}_t - Y_t\right|}{Y_t} \times 100}{N} \tag{1}$$

Subject to

$$\hat{Y}_t = W_t F_{Agg} \tag{2}$$

$$\sum_{t=1}^{N} W_t = 1 \tag{3}$$

$$0 \leq W_t \leq 1 \tag{4}$$

The objective function was to minimize the MAPE, as shown in Equation 1. Equation 2 calculates the forecast price. Equation 3, the sum of all weights is 1. Equation 4 is bound of weight and the decision variable is the weight of each month. The comparison of Box-Jenkins and Top-Down hierarchical method is shown in Table 2.

Table 2. The comparison of box-jenksins and top-down hierarchical method

Method	**MAPE (%)**
Box-Jenkins SARIMA(1,1,1)(1,0,1)	12.67
Top-Down hierarchical method	8.45

Moreover, we calculated TS to analyze the forecasted price each month. The calculation is as follows Equation 5 – 7. The tracking signal of each month is [-6, +6] [15] and shown in Fig. 3. The result showed that the tracking signal is in the range.

$$Bias_t = \sum_{t=1}^{N} (Y_t - \hat{Y}_t) \quad (5)$$

$$MAD_t = \frac{1}{N} \sum_{t=1}^{N} |Y_t - \hat{Y}_t| \quad (6)$$

$$TS_t = \frac{Bias_t}{MAD_t} \quad (7)$$

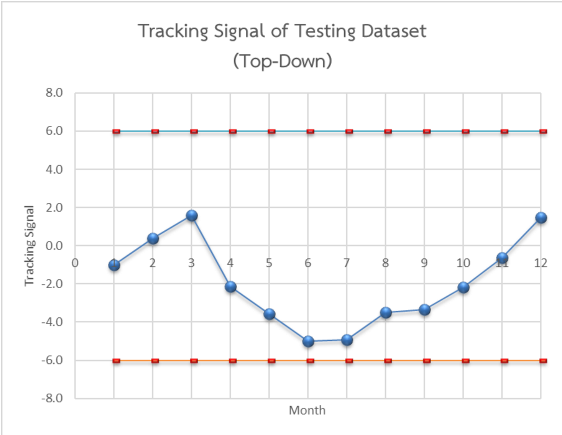

Fig. 3:The tracking signal of Top-Down method.

2.2. Input Analyzer

We used Input Analyzer in the ARENA simulation program to fit distributions of uncertain parameters. The tool chooses the distribution from the shape of the histogram and probability and density function [16]. For example, the PDF of the number of supply coconuts purchased from collectors is shown in Fig. 4. The distribution type is chosen from p-value that has more than or equal significance level at 0.05. The distribution is shown in Table 3.

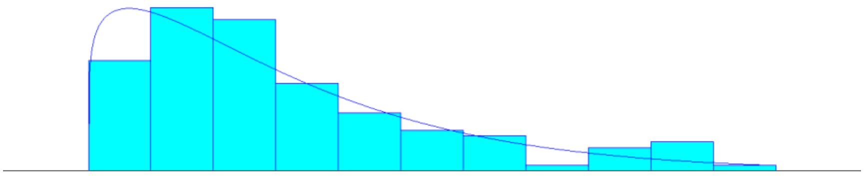

Fig. 4: PDF of The number of supply coconuts purchased from collectors.

Table 3. The distributions of uncertain parameters

Parameters	Month	Distribution
The number of supply coconuts harvested at contracted farms	1 – 4	Triangular
	5 – 8	Triangular
	9 – 12	Beta
The number of supply coconuts purchased from collectors	1 – 4	Weibull
	5 – 8	Normal
	9 – 12	Beta
The demand for factory	1 – 4	Normal
	5 – 8	
	9 – 12	

3. Mathematical Model

Mixed-Integer Non-Linear Programming (MINLP) was proposed based on the actual situation of the factory. The indices, sets, parameters, decision variables, objective function, and constraints are discussed below.

The assumptions of the model, there were two procurement sources: contracted farms and collectors. The sources have a good quality of coconuts. The vehicles are available throughout the planning horizon. The uncertain parameters were daily random variables.

3.1. Indices and Set

k is the vehicle index

t is the time index

K is the set of vehicles = $\{1,\dots,V\}$

T is a set of time horizon = $\{1,\dots,H\}$

3.2. Constant Parameters

V is the number of vehicles

H is the number of the planning horizon

J is the maximum number of shipments per day

P_t is the coconut price of harvested coconuts at contracted farms at time t

Q_t is the coconut price of purchased coconuts from collectors at time t

D_t is the factory demand at time t

F_k is the fixed cost of vehicle k (USD per round)

S_t is the number of supply coconuts harvested at contracted farms at time t

C_t is the number of supply coconuts purchased from collectors at time t

L_t is the loss of harvested coconuts at contracted farms at time t (percentage of loss)

G_k is the capacity of the vehicle (coconuts per vehicle)

3.3. Variable Parameters

X_t is the number of coconuts harvested at contracted farms at time t

Y_t is the number of coconuts purchased from collectors at time t

W_{kt} is the number of shipments at time t for vehicle k

$$Z_{kt} = \begin{cases} 1, & \text{If vehicle k is used at time t} \\ 0, & \text{otherwise} \end{cases}$$

3.4. Objective Function and Constraints

The objective was to minimize the total cost as shown in Equation (8). The total cost consists of the purchasing price of the contacted farms and the collectors, the transportation cost, and the labor cost.

$$Minimize \sum_t P_t X_t + \sum_t Q_t Y_t + \sum_k \sum_t F_k W_{kt} + \sum_k \sum_t A_k Z_{kt} \tag{8}$$

Subject to

$$X_t \le \frac{(1-L_t)}{100} S_t, \forall t \in H \tag{9}$$

$$Y_t \le C_t, \forall t \in H \tag{10}$$

Equation (9) and Equation (10) are used to ensure that the number of coconuts purchased from the contracted farms and the collectors is less than the supply.

$$X_t \le \sum_k W_{kt} G_k, \forall t \in H \tag{11}$$

Equation (11), the purchased coconuts from farms is less than the capacity of the vehicle.

$$W_{kt} \leq JZ_{kt}, \forall t \in H, \forall k \in K \tag{12}$$

Equation (12) showed that the shipment will occur when the vehicle was used.

$$L_t = \begin{cases} 0.05, & \text{if t = 1 to 120 and t = 241 - 365} \\ 0.15, & \text{if t = 121 to 240} \end{cases} \tag{13}$$

Then, Equation (13) is the percentage of coconut loss in each time interval.

$$X_t, Y_t \geq 0, \text{integer}, \forall t \in H \tag{14}$$

$$Z_{kt} = \text{binary}, \forall k \in K, \forall t \in H \tag{15}$$

$$W_{kt} = \text{binary}, \forall k \in K, \forall t \in H, W_{kt} \in \{0 \ldots J\} \tag{16}$$

Finally, Equation (14), Equation (15), and Equation (16) are bounds of decision variables. The model was run for 500 replications and 500 trials with a 95% confidence interval.

4. Truncated Distribution

We analyzed truncated distribution scenarios to decrease events with a less likelihood of occurrence that are the lower truncated case, upper truncated case, and doubly truncated case. Fig. 5 – 8 shows all cases examples of Normal distribution. And Table 4 shows the lower bound and the upper bound of each distribution [17].

Fig. 5:Nontruncated case.

Fig. 6:Lower truncated case.

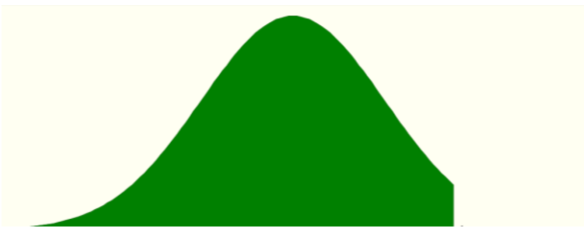

Fig. 7:Upper truncated case.

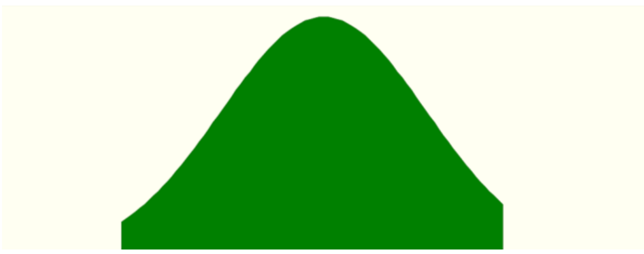

Fig. 8:Doubly truncated case.

Table 4. Range of distribution

Distribution	Range	
	Lower Bound	**Upper Bound**
Triangular	a	b
Beta	a	b
Weibull	0	+∞
Normal	–∞	+∞
Uniform	a	b

5. Results

A comparison of the truncated distribution scenarios is the yearly procurement planning. The result in scenario 1 is the traditional model. The others truncate the distribution interval in three cases: lower truncate case, upper truncate case, and doubly truncate case by reducing the data interval by 5 to 20% and seek for the optimum result.

The yearly total costs in TABLE V, the total cost of all cases are less than scenario 1 which is non-truncated distribution. The results showed the best case, the lowest cost is scenario 4 which decreases by 11.62%. In summary, the lower truncate of 15% is the minimum because the total cost is the lowest.

Table 5. The total cost (10^5 USD*) of truncated distribution scenarios

Scenario	Case	Truncate Range		Total cost
		Lower (a)	*Upper (b)*	
1	Nontruncated	–∞	+∞	41.08
2	Lower truncated	5%	+∞	37.46
3	Lower truncated	10%	+∞	36.88
4	Lower truncated	15%	+∞	36.40
5	Lower truncated	20%	+∞	36.31
6	Upper truncated	–∞	5%	37.09
7	Upper truncated	–∞	10%	37.61
8	Upper truncated	–∞	15%	37.49
9	Upper truncated	–∞	20%	37.85
10	Doubly truncated	5%	5%	37.64
11	Doubly truncated	10%	10%	37.31
12	Doubly truncated	15%	15%	38.27
13	Doubly truncated	20%	20%	40.09

*Calculated at 33.08 THB per 1 USD

6. Conclusion

The procurement plan of agricultural products using the mixed-integer non-linear programming under uncertainty such as the purchased price, the demand for factory, and the supply coconuts. The paper aimed to seek the number of coconuts harvested at contracted farms and the number of coconuts purchased from collectors which minimized the total cost. Most of the agricultural products face the planning problem and unbalance supply and demand. The decision-maker of the factory must have an effective solution. Aside from finding the best solution, planners must also figure out how to deal with the uncertainties of many factors, and the planning time must be covered by the operation. The truncation aids decision-makers in reducing situations that occur occasionally. As a result, the possible outcomes are current. The requisition is planned using operational choices at the factory. This is a daily decision with a short-term consequence, but it is made according to the uncertainties that have changed with the seasons.

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