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Chili sauce production planning model considering raw material availability: An application of Mixed Integer Linear Programming Method

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Abstract. PT Bina Usaha Keluarga Sedep Roso is one of agroindustry located in Padang producing chili and soy sauces. Chili and soy sauces main ingredients are sweet potato and black soybean, respectively. Both chili and soy sauces have a broad market in West Sumatera, Indonesia. The problem often faced by companies is that the demand for chili sauce product cannot be fulfilled because of seasonal and perishable factors of the sweet potato. It became scarce and expensive outside the harvest season otherwise the excessive supply and low price in the harvest season. This paper proposes an application of mixed integer linear programming to manage production planning of chili sauce to minimize total operational cost and increase the service level considering raw material availability and production capacity of chili sauce companies. The mixed integer linear programming method is applied because there are some constraints on the problem. The mathematical model is developed to obtain the optimal solution in allocating the available resources with given constraints regarding raw material availability and production capacity. The numerical example is given to illustrate the model and show results. Sensitivity analysis is performed to see the changes in the optimal solution caused by the changes in the input parameters of the model.

1. Introduction

PT Bina Usaha Keluarga Sedep Roso is one of food processing industry, located in Padang, which produces chili sauce and soy sauce. Chili sauce and soy sauce main ingredients are sweet potatoes and black soybean, respectively. Both chili sauce and soy sauce products have a broad market in West Sumatra. It has a variety of partners such as retailers, wholesalers, and various traders that order to this company. Furthermore, the number of incoming orders to the company is referred to as demand.

Suryaningrat et al. (2015) found that common problems in processed cassava industries such as formality of raw material procurement contract with wholesalers or retailers to maintain information about price, number, and quality of the product because of high numbers of raw materials requirement. These indicate that procurement of raw materials is one of the most important components of the supply chain, which facilitates any organization for achieving its goal of increasing the value creation by minimizing the cost. Related to the agro-industrial system, Suryaningrat (2016) showed that some



problems associated with the food industry found are the shortage of raw material, quality, lack of continuous supply of seasonal raw material, inadequately trained labor force, expensive imported packing material, infrastructure, and technological deficiencies. Some problem aforementioned is also happening in PT Bina Usaha Keluarga Sedep Roso, particularly in the chili sauce production. The demand of the chili sauce has not fulfilled by the company's production as the good quality sweet potatoes became scarce outside the harvest season as shown in figure 1. However, in the harvest season, the excessive supplies of sweet potato happen over the production capacity of the company.

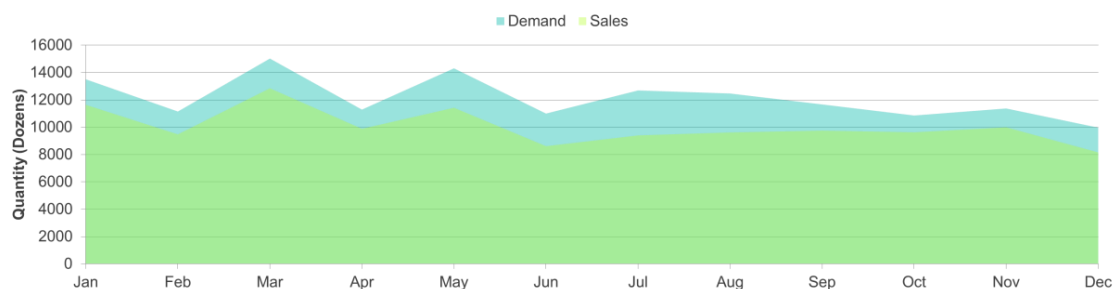


Figure 1. Chili sauce demand and sales in 2017.

Many agricultural products are perishable, although their shelf life can be extended through special treatment of storage. Some of the agricultural products are seasonal products and purchased once a year in the harvest season, then are sold until the next harvest season. In this study, we focus on the main raw material of chili sauce, sweet potato, that is perishable and seasonal. It causes that sweet potato to need a different approach to decide the optimal purchase quantity of the sweet potato to minimize operation cost of chili sauce production considering the capacity of production and availability of sweet potatoes to meet the demand. Liu et al. (2017) addressed the decisions for optimal purchase and inventory retrieval quantities for a perishable seasonal agricultural product considering the costs of storage, underage and overage, prospects of future prices and demand, and product deterioration. The results of the study show that the optimal policy can raise the expected profit by 22.4 percent in 2014 and reduce the expected loss by 10.2 percent in 2015 in that case.

The study in East Java, as a central of fruit production in Indonesia, Suryaningrat (2016) identified the determinant factors in fruit processing industries. The required data obtained from 63 selected industries for further analysis such determined the correlation between basic component factors and total performance of fruit processing industries and classified the results of correlation into very strong (more than 0.8), strong (0.61-0.8), medium (0.4-0.6), and weak (less than 0.4). The conclusion shows that continuity and availability of raw material are the factors in raw material procurement that have very strong and strong relationship ($r=0.81$ and $r=0.70$, respectively) with total performance in fruit industries. The research illustrates that the continuity and availability of raw material is more important than quantity and quality. Reflecting the study, the perishable and seasonal factors of sweet potato as the main raw material and the production management of chili sauce provide a bad performance and service level of PT Bina Usaha Keluarga Sedep Roso. Therefore, This paper proposes a production planning model of chili sauce subjected to the availability of raw material and production capacity to minimize the operational cost using a mixed integer linear programming method. The rest of this paper consists of system characteristics in section 2, the mathematical model in section 3, a numerical example and analysis in section 4 and the conclusion in the last section.

2. System characteristics

The production process of chili sauce from the sweet potato needed to perform a new production planning to know how the flow of sweet potato and supporting ingredients, machine, energy, and information that exist on the system. The schematic of a chili sauce production plant in PT Bina Usaha Keluarga Sedep Roso shown in Figure 2.

The main raw material used of this system is sweet potato. Sweet potato purchase from 4 different suppliers that comes in turn to the production plant every week. Sweet potato sent from the supplier to the plant will be stored in the storage for a while, then transfer to the washing machine to clean from dust for about 10 minutes with the electrical power used of the washing machine is 2.5 kW, and the capacity of the washing machine is 400 kg each run. Furthermore, the clean, sweet potato transfer to the large metal vessel for steaming process. Firewood used to produce chili sauce in the steaming process. Firewood is burned into the kiln to boil the water in the boiler. The heated vapor of water transfer to the large metal vessel for steaming sweet potato. There are four large metal vessels for steaming sweet potato that connected to the boiler to transfer the heated vapor. It can be turned on or off to control heat vapor into the metal vessel for steaming process. The steaming process run about 3 hours for maximum two metal vessels are in the on mode. Each metal vessel for steaming capacity is 800 kg of sweet potato. Approximately, every metal vessel for steaming sweet potato need one cubic firewood. The next process to produce chili sauce is the mixing process. The steaming and mixing process place in the same metal vessel, but the process is different, so the amount of materials in the steaming and mixing process is the same. There is a mixer place in every metal vessel with the electrical power used is 22 kW and 15 minutes run for each mixing process. The next process is packing the chili sauce into the finished product with 0.6 kg for each pack and then grouped into a dozens (12 pack/dozens). The packing machine used 1.5 kW of electrical power that can produce one pack of chili sauce every 5 seconds. Through the process of mixing the main raw material and the supporting material, each metal vessel fulfilled with the 800 kg of sweet potato produce 180 dozens of chili sauce as a finished product.

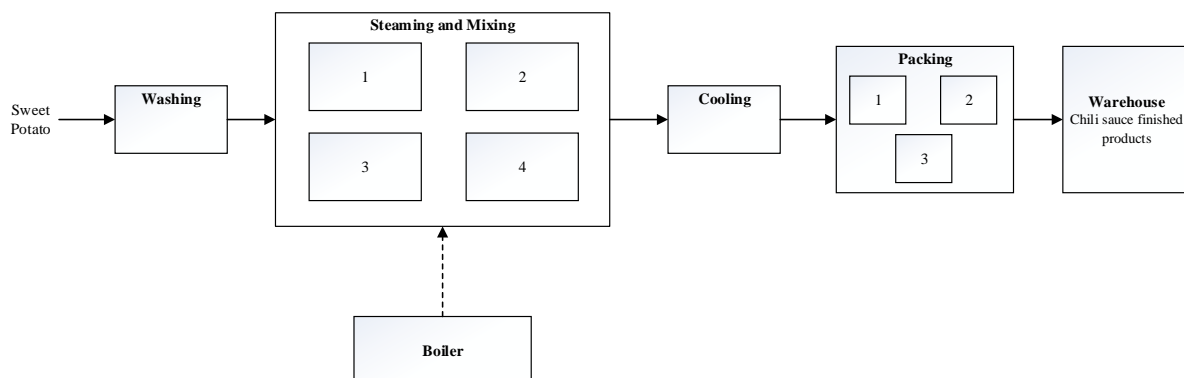


Figure 2. The schematic of the chili sauce production plant.

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Chili sauce produced will be stored in the warehouse with a capacity of 10,000 dozens of chili sauce. In producing chili sauce from sweet potato, the factory must consider how much sweet potato that will be produced into chili sauce every day. The rest of the sweet potato not produced at the plant on that day will be stored in the storage. The quantity of sweet potato that is produced must meet the production capacity, supplier capacity, and chili sauce demand.

Chili sauce market area consists of retailers, wholesalers, and various traders that order to this company and directly pick up the chili sauce from the warehouse because the company only provide direct purchases to the factory. Total demand for chili sauce is greater than the sweet potato availability from the supplier, causing the factory cannot meet all the demand for chili sauce.

Due to the perishable nature of the sweet potato as raw materials, we cannot store the raw materials in the storage for a long time, but the finished products of chili sauce can keep for up to 6 months (based on the interview with the owner of the company). To optimize the cost, the company should manage the quantity of chili sauce produce in every period to store as the inventory and sell in the market or retrieve periodically. Based on this situation, turning it from a problem into opportunity maybe can be a good suggestion for the company, propose a new production planning of chili sauce to minimize the unit cost and increase the service level needed to solve the company's current problem.

Chili sauce production planning in PT Bina Usaha Keluarga Sedep Roso resolved by using mixed integer linear programming method. Mixed integer linear programming is the linear programming model with additional restriction where the variables have integer values. Many kinds of research in production planning model using mixed integer linear programming had been developed [5,6,7]. This method obtains the most optimal solution to allocate the available resources for the production with given constraints to minimize the operational cost. In this case, this method optimizes the sweet potato purchasing quantity to minimize the operational cost considering the sweet potato availability and production capacity. Chili sauce production planning model by using mixed integer linear programming method is developed in the mathematical model.

3. Mathematical Model

Formulation of the mathematical model is based on the integer programming model [3], meat packing plant production planning model [8], and binary integer programming model for raw mill and cement mill scheduling [13]. The aim of this model formulation is how to minimize the unit cost of chili sauce production consider sweet potato availability.

3.1. Assumptions, notations, symbols, and units

This stage will explain the assumptions, notations, and symbols used to model production planning optimization of chili sauce. The assumptions used in the development of chili sauce production planning optimization model are as follows.

- The sold chili sauce that takes from the warehouse, and the sweet potato takes from the storage follow FIFO (first in first out) rule.
- There is no inventory cost for sweet potato because it has been used up in a week.
- Minimal requirement of sweet potato availability is 1600 kg (or enough to fulfilled two steaming machines) during a day to decide whether the production run or not on that day.
- All parameters (all coefficients in the objective function and the constraints) are deterministic.

Notations, symbols, and unit are used in the optimization model of chili sauce production planning presented as follow:

Subscriptions

i	= weeks,	$i = 1, 2, \dots, 52$
j	= supplier,	$j = 1, 2, 3, 4$
d	= days,	$d = 1, 2, \dots, 6$
y	= machine,	$y = 1, 2, 3, 4$

Parameters

V	= variable cost per dozen (Rp/dozen)
L	= labor cost per month (Rp)
O	= overhead cost per month (Rp)
f	= fixed cost per month (Rp)
Cx_{ij}	= cost of sweet potato purchase at week i from supplier j (Rp/bag)
a_i	= sweet potato availability at week i (kg)
d_i	= ending inventory of sweet potato at the end of week i (kg)
P_i	= quantity of chili sauce produced at week i (dozen)
S_i	= quantity of chili sauce sold at week i (dozen)
D_i	= demand of chili sauce at week i (dozen)
I_i	= ending inventory of chili sauce at the end of week i (kg)
s_i	= number of stockout (dozen)
H	= inventory carrying cost of chili sauce per week per dozen (Rp/week/dozen)
SC_{ij}	= Supply capacity of supplier j at week i (bag)
Cs	= stockout cost per dozen (Rp/dozen)
A_i	= chili sauce availability at week i (dozen)
W_{id}	= number of washing machine run in day d at week i
Ce	= electrical cost (Rp/kWh)
Cw	= firewood cost per cubic (Rp/cubic)
P_{id}	= number of chili sauce packed at week i in day d (pack)

Decision variables

x_{ij}	= sweet potato purchasing quantity at week i from supplier j (bag)
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b_{idy} = binary variable for running the process of steaming and mixing at week i in day d for machine y

3.2. A mathematical model of the unit cost of chili sauce production

The objective function of the chili sauce production planning model is to minimize the total operational cost of chili sauce production in PT Bina Usaha Keluarga Sedep Roso. The unit cost of chili sauce production is the total cost of chili sauce production divided by the number of chili sauce production. The total cost of chili sauce production consists of the summed and weighted multiple objectives involving fixed costs, sweet potato purchasing costs, variable costs, chili sauce inventory carrying costs, stockout costs, and fuel costs (electrical and firewood).

Fixed costs per month = the summed of labor cost and overhead cost every month.

$$f = L + O \quad (1)$$

Sweet potato purchasing costs = the summed of sweet potato purchasing quantity \times the cost of sweet potato per unit bag from each supplier every week.

$$\sum_{i=1}^{52} \left[\sum_{j=1}^4 \{X_{ij} \cdot Cx_{ij}\} \right] \quad (2)$$

Variable costs = the summed of the quantity of chili sauce production \times variable cost per unit every week.

$$\sum_{i=1}^{52} [V \cdot P_i] \quad (3)$$

Chili sauce inventory carrying costs = from the summed of the quantity of chili sauce store at the end of the week \times the cost of inventory carrying the cost per week per unit in every week

$$\sum_{i=1}^{52} [I_i \cdot H] \quad (4)$$

Stockout costs = the summed of the quantity of stockout \times stockout cost per unit every week.

$$\sum_{i=1}^{52} [S_i \cdot C_s] \quad (5)$$

Washing machine electrical usage cost = the summed of how long washing machine run during a day \times power used by washing machine \times electrical cost per kWh

$$\sum_{i=1}^{52} \left[\sum_{d=1}^6 \left\{ W_{id} \cdot \left(\frac{1}{6} \right) \cdot (2.5) \cdot Ce \right\} \right] \quad (6)$$

Mixer electrical usage cost = obtained from the summed of how long mixer run during a day \times power used by mixer \times electrical cost per kWh.

$$\sum_{i=1}^{52} \left[\sum_{d=1}^6 \left\{ \sum_{y=1}^4 b_{idy} \cdot \frac{1}{4} \cdot (22) \cdot Ce \right\} \right] \quad (7)$$

Press machine electrical usage cost = obtained from the summed of how long press machine run during a day \times power used by press machine \times electrical cost per kWh.

$$\sum_{i=1}^{52} \left[\sum_{d=1}^6 \left\{ p_{id} \cdot \frac{1}{720} \cdot (1.5) \cdot Ce \right\} \right] \quad (8)$$

Firewood costs = the summed of the binary variable of the metal vessel for steaming sweet potato during a day production \times the cost of 1 cubic of firewood per week.

$$\sum_{i=1}^{52} \left[\sum_{d=1}^6 \left\{ \sum_{y=1}^4 b_{idy} \cdot Cw \right\} \right] \quad (9)$$

Fuel costs = the summed of washing machine electrical usage cost, mixer electrical usage cost, firewood costs, and press machine electrical usage cost.

$$\sum_{i=1}^{52} \sum_{d=1}^6 \left\{ W_{id} \cdot (2.5) \cdot \left(\frac{1}{6} \right) \cdot Ce + \sum_{y=1}^4 b_{idy} \cdot Cw + b_{idy} \cdot \left(\frac{1}{4} \right) \cdot (22) \cdot Ce + p_{id} \cdot \left(\frac{1}{720} \right) \cdot (1.5) \cdot Ce \right\} \quad (10)$$

The complete formulation of the operational cost of chili sauce production planning in PT Bina Usaha Keluarga Sedep Roso is as follow.

Minimize:

$$\left(12f + \sum_{i=1}^{52} \left[\sum_{d=1}^6 \left\{ \sum_{j=1}^4 \{x_{ij} Cx_{ij}\} + V \cdot P_i + I_i + H + s_i \cdot Cs_i + \right. \right. \right. \\ \left. \left. \left. W_{id} \cdot \left(\frac{1}{6} \right) \cdot (2.5) \cdot Ce + \sum_{y=1}^4 \left\langle b_{idy} \cdot Cw + b_{idy} \cdot \left(\frac{1}{4} \right) \cdot (22) \cdot Ce \right\rangle + \right. \right. \right. \\ \left. \left. \left. p_{id} \cdot \left(\frac{1}{720} \right) \cdot (1.5) \cdot Ce \right\} + \right] \right) \cdot (P_i)^{-1} \quad (11)$$

Constraints of the mathematical model of the operational cost of chili sauce production planning at PT Bina Usaha Keluarga Sedep Roso subjected to availability of sweet potato and production capacity consist of:

The quantity of sweet potato purchase during a week is less than or equal to the supply capacity of sweet potato from the suppliers.

$$X_{ij} \leq Sc_{ij} \quad (12)$$

The quantity of chili sauce production during a week is less than or equal to the production plant capacity (4320 dozens).

$$P_i \leq 4320 \quad (13)$$

The quantity of chili sauce stored at the end of the week is less than or equal to chili sauce inventory capacity (10000 dozens).

$$I_i \leq 10000 \quad (14)$$

The quantity of chili sauce sold during a week is less than or equal to demand.

$$S_i \leq D_i \quad (15)$$

Ending inventory of chili sauce is computed as initial inventory plus production minus sales.

$$I_i = I_{i+1} + P_i - S_i \quad (16)$$

Because of the finished product is in dozen unit, so the number of production during a week is equal the sum of chili sauce packed in a week divided by 12.

$$P_i = \frac{\sum_{d=1}^6 P_{id}}{12} \quad (17)$$

The quantity of chili sauce packed during a day.

$$p_{id} = 2160 \sum_{y=1}^4 b_{idy} \quad (18)$$

To fulfill sweet potato in one steaming machine needs $2 \times$ capacity of the washing machine to wash sweet potato. So, the number of washing machine run during a day is the sum of steaming machine run in a day $\times 2$.

$$W_{id} = 2 \sum_{y=1}^4 b_{idy} \quad (19)$$

Minimal requirement of sweet potato availability is 1600 kg (or enough to fulfilled two large metal vessel for the steaming process) during a day to decide whether the production run or not on that day.

$$\begin{aligned} \sum_{y=1}^4 b_{idy} &\neq 1, \\ \sum_{y=1}^4 b_{idy} &\in \{0, 2, 3, 4\} \end{aligned} \quad (20)$$

The quantity of sweet potato washed is less than or equal the amount of sweet potato availability.

$$400 \sum_{d=1}^6 W_{id} \leq a_i \quad (21)$$

Sweet potato availability is computed as an initial inventory plus sweet potato purchasing quantity.

$$a_i = a_{i-1} + 55 X_i \quad (22)$$

All variables ≥ 0 .

4. Numerical Example and Analysis

A numerical example is given to illustrate the practical value of the model. The aim of the model developed is to optimize the production activities of the existing plant subjected to availability of sweet potato and production capacity. The purchased sweet potato quantity and production planning carried out by the company for four weeks can be seen in Table 1 and Table 2.

Table 1. Sweet potato purchased quantity

Week	X_{ij}				
i	J				X_i
	1	2	3	4	
1	42	77	50	63	232
2	59	60	125	46	290
3	95	57	0	124	276
4	2	104	56	55	217

Table 3 presents the total operational cost of chili sauce for four weeks is Rp 378.889.553,-. Table 1 and Table 2 also show how many sweet potatoes purchased from the supplier, how many chili sauces produced, sold, and stored to minimize the operational cost of chili sauce.

Table 2. Chili sauce production planning

a_i	d_i	$-\sum_{d=1}^6 W_{id}$	$-\sum_{d=1}^6 \sum_{y=1}^4 b_{idy}$	$\sum_{d=1}^6 P_{id}$	P_i	A_i	S_i	I_i	Di	si
12774	0	32	16	34491	2874	2874	2400	474	2400	0
15950	0	40	20	43065	3589	4063	4063	0	4063	0
15173	0	38	19	40968	3414	3414	3414	0	3414	0
11920	0	30	15	32184	2682	2682	2682	0	2682	0
					12559	12559	12559			

The total operational cost incurred by the system for four weeks is shown in table 3 below.

Table 3. Total operational cost of chili sauce

Week <i>I</i>	Sweet potato purchasing costs	Variable costs	Inventory carrying costs	Stockout costs	Electrical used costs	Firewood costs	Total production costs
1	Rp 57.658.788	Rp 20.694.600	Rp 59.281	Rp -	Rp 13.307	Rp 2.874.250	
2	Rp 73.610.000	Rp 25.839.000	Rp -	Rp -	Rp 16.615	Rp 3.588.750	
3	Rp 68.753.636	Rp 24.580.800	Rp -	Rp -	Rp 15.806	Rp 3.414.000	
4	Rp 52.068.182	Rp 19.310.400	Rp -	Rp -	Rp 12.417	Rp 2.682.000	
Total	Rp 252.090.606	Rp 90.424.800	Rp 59.281	Rp -	Rp 755.866	Rp 12.559.000	Rp 378.889.553

5. Conclusions

1. This paper has proposed a mixed integer linear programming model of chili sauce production planning to minimize the operational cost considering the raw material availability and production capacity.
2. Based on the numerical example has been conducted for the chili sauce production planning at PT Bina Usaha Keluarga Sedep Roso, it was proved that the model provides the optimal solution to produce chili sauce subjected to the availability of sweet potato and production capacity. According to the solution of the model, during four weeks of production planning, the operational cost of chili sauce is less than current policy. It has shown that the solution of the model can improve the performance of the company.

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