MAKE-TO-ORDER PRODUCTION PLANNING WITH SEASONAL SUPPLY IN CANNED PINEAPPLE INDUSTRY

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ABSTRACT

This research studies a make-to-order production planning problem in a canned pineapple industry. Pineapple is a seasonal perishable fruit. Thus, the cost of fresh pineapple which is the main raw material in canned pineapple products is inexpensive during its season because of its abandance. The color of the pineapple also determines the price of the canned pineapple. However, the availability of different colors (referred as "choice" and "standard") is dependent. Specifically, if for a given month the ratio of the choice-color pineapple increases, the ratio of the standard-color pineapple decreases. There are several costs involve such as fresh pineapple cost, can cost, sugar cost, water cost, labor cost, energy cost, and inventory holding cost. This problem is formulated as a mathematical model to maximize the total profit over four-months planning horizon. Two supply uncertainty cases are tested which are low and high ratios of the choice color. The results show that the profit depends on available color ratios of the pineapple. The production planning is best if it matches with the availability of the color ratios. In certain months, some fresh pineapple purchased exceed the need of the production because of the dependency of the two colors. The inventory holding cost also influences the production decision—whether to produce the canned pineapple in earlier months or it is better to produce only the canned pineapple when it is needed to serve the customer orders.

INTRODUCTION

Thailand is the global exporter of canned pineapple with the market share of 37.2% worldwide or USD 338.09 million in value, followed by the Philippines and Indonesia (based on the 2019 statistics) (TRIDGE, 2019). The three countries together cover about 70% of the world's market share (Wattanakul et al., 2020). Pineapple is a seasonal fruit but the demands for canned pineapple exist throughout the year. Therefore, canned pineapple manufactures must produce canned pineapple when the fresh pineapple fruits are abundant to secure a low raw material cost and top fruit quality.

There are variety of canned pineapple products depending upon the fruit colors ("choice" and "standard"), fruit cut (slice, chunk, and tidbit), can sizes, syrup sweetness level, and so forth. The choice color of pineapple refers to a deep dark yellow color of the pineapple meat. The color is preferred by most customers. Canned products made with the choice color pineapple are generally sold at a higher price than the same products made with the standard color fruit. However, the color of the pineapple cannot be identified until the fruit is peeled, but fresh pineapple is sold to the canned manufacturers in bulk and unpeeled. Only monthly ratios of pineapple with choice and standard colors can be estimated. Canned manufacturers must sometimes buy additional fresh pineapple to ensure that there are enough choice color fruits to serve the pre-ordered and future demands. Any leftover fruits after all demands are fulfilled must be processed right away as fresh pineapple is perishable by being canned and stored in the warehouse for future orders. Some leftover is discarded as waste because there is no room available in the warehouse or it is too costly to keep it as a safety stock. Under all these conditions, the objective of a canned pineapple manufacturer is to determine a production plan that maximizes the total profit.

Canned pineapple manufacturers are generally facing a production planning problem under seasonal supply of fresh pineapple. A number of decisions needs to be addressed in the planning, specifically multiple products (cuts and can sizes based on the available colors) to be manufactured over multiple planning periods and under a warehouse capacity constraint. There are also several production related costs involved, adding additional complexity to the problem.

Certain aspects of this production planning problem were studied by Kogan et al. (1996). Their planning was to be responsive to customer demands as much as possible with make-to-order production, while considering make-to-stock products and minimizing inventory and purchasing costs. Soman et al. (2006) tested a conceptual framework for production planning and inventory management in a food industry with a

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combined make-to-stock and make-to-order production. Chen et al. (2014) examined pricing and production of a combined make-to-stock and make-to-order system. Any demands that could not be immediately satisfied were backlogged or lost. They focused on monotonicity of the optimal control policy and the optimal price. Grillo et al. (2017) formulated a model that aimed to maximize two conflicting objectives, total profit and mean product freshness, of a fruit supply chain.

This paper focus on multi-products multi-periods production planning for make-to-order demands in the canned pineapple industry in which the raw material—fresh pineapple—is perishable and available seasonally. A challenge in this research is to determine the amount of fresh pineapple to purchase while the colors of the pineapple vary each month.

The organization of this paper is as follows. The next section describes the problem in more details, and the mathematical model is formulated. Then a numerical example in which certain data are based on a canned pineapple manufacturer in Thailand is presented, and its results are discussed. Finally, the last section concludes the paper.

PROBLEM FORMULATION

Problem Description

Since pineapple is a seasonal fruit, its acquiring price is cheapest when it is in season. Like many other fresh fruits, pineapple is perishable and must be processed as soon as it is harvested, often by canning or drying. Canned pineapple has a larger market than the dried one because of its longer shelf life and industrial standards are more acceptable worldwide.

Canned pineapple products are influenced by at least three factors: the color of the fruit, the cut, and the size of the can. In addition to fresh pineapple cost, several other costs are involved in the production such as can cost, sugar (to make the syrup) cost, water cost, labor cost, energy cost, and inventory holding cost. Warehouse storage availability during multiple planning periods is also a common issue for any canned pineapple manufacturer. Certain demands of canned pineapple are pre-ordered several months ahead of the delivery date to secure the goods at reasonable prices. The production planner of the canned pineapple manufacturer must determine the quantity of the fresh pineapple to purchase as well as the types of canned pineapple products and their quantities to manufacture in each time period in order to maximize the total profits. It is possible that some products are not sold right away but are stored in the warehouse to serve future demands. The products are usually palletized when kept in the warehouse. Each pallet contains a different number of cans depending on the can size.

Mathematical Model

The following mathematical model is a system of equations established to reflect the multi-products multi-periods production planning problem described above. Its objective is to maximize the total profit.

Indices

i	Pineapple color	$i = 1,2,3,\ldots,I$
j	Pineapple cut	$j = 1,2,3,\ldots,J$
k	Can size	$k = 1,2,3,\ldots,K$
t	Month	$t = 1,2,3,\ldots,T$

Parameters

$Profit$	Total profit (baht)
$Revenue$	Total revenue (baht)
$Cost$	Total costs (baht)
$D^t{}_{ijk}$	Demand of canned pineapple with color i cut j can size k in month t (cans)
$PO^t{}_{ijk}$	Price of canned pineapple with color i cut j can size k in month t (baht)
$InvO^t{}_{ijk}$	On-hand inventory of canned pineapple with color i cut j can size k in month t (cans)
CC_k	Cost per can of can size k (baht)
CE_k	Energy cost to manufacture a can of pineapple in can size i (baht/can)
CL_{jk}	Labor cost to manufacture a can of pineapple with cut j in can size k (baht/can)
CP^t	Average cost of fresh pineapple per kilogram in month t (baht/kilogram)
CS_k	Sugar cost to manufacture a can of pineapple in can size k (baht/can)
CW_k	Water cost to manufacture a can of pineapple in can size k (baht/can)
H	Inventory holding cost per pallet per month (baht/pallet/month)
QC_k	Quantity of can size k per pallet (cans/pallet)
WP_k	Weight of fresh pineapple needed to fill a can of size k (kilogram)
δ	Proportion of fresh pineapple by weight that can be canned (percentage)
$GP^t{}_i$	Proportion of pineapple color i available in month t (percentage)
Cap^t	Maximum product quantity that can be manufactured in month t (cans)
QCO^t_{max}	Maximum inventory that can be kept in month t (pallets)

Decision Variables

$X^t{}_{ijk}$	Quantity of canned pineapple product with color i cut j can size k to be produced in month t (cans)
QP^t	Quantity of pineapple that is bought in month t (kilograms)

Objective Function

The objective function is to maximize the total profits. Some costs are included for the completion of the model and may not affect the decision. They are also used as a means to communicate within the case study manufacturer.

Maximize *Profit*

$$Profit = Revenue - Cost \tag{1}$$

where *revenue* and *cost* are described by Equations (2) and (3)

$$Revenue = \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(PO^t{}_{ijk} \cdot D^t{}_{ijk}) \tag{2}$$

$$Cost = \sum_{t=1}^{T}(CP^t \cdot QP^t) + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(CC_k \cdot X^t{}_{ijk})$$
$$+\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(CE_k \cdot X^t{}_{ijk}) + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(CL_{jk} \cdot X^t{}_{ijk})$$
$$+\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(CS_k \cdot X^t{}_{ijk}) + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(CW_k \cdot X^t{}_{ijk})$$
$$+\sum_{t=1}^{T}\sum_{k=1}^{K}\left(H \cdot \left\lceil \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} InvO^t{}_{ijk}}{QC_k} \right\rceil\right) \tag{3}$$

where $InvO^t{}_{ijk}$ is described by Equations (4).

$$InvO^t{}_{ijk} = \left(InvO^{t-1}{}_{ijk} + X^t{}_{ijk}\right) - D^t{}_{ijk} \quad \forall\, i,j,k,t \tag{4}$$

and let $InvO^0{}_{ijk} = 0$ for all *i*, *j*, and *k*.

Constraints

1. For each color, the raw material usage cannot exceed the available raw material in each month:

$$\sum_{j=1}^{J}\sum_{k=1}^{K}(WP_k \cdot X^t{}_{ijk}) \le \delta \cdot GP^t{}_i \cdot QP^t \quad \forall\, i,t \tag{5}$$

2. The production cannot exceed the capacity in any month:

$$Cap^t \ge \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} X^t{}_{ijk} \qquad \forall_t \tag{6}$$

3. The stock kept must not exceed the warehouse space availability in each month:

$$\sum_{k=1}^{K}\left\lceil \frac{\sum_{i=1}^{I}\sum_{j=1}^{J} InvO^t{}_{ijk}}{QC_k} \right\rceil \le QCO^t_{max} \quad \forall_t \tag{7}$$

4. The monthly pre-ordered demands must be completely fullfilled:

$$InvO^{t-1}{}_{ijk} + X^t{}_{ijk} \ge D^t{}_{ijk} \quad \forall\, i,j,k,t \tag{8}$$

5. The decision variables and parameters must satisfy the following conditions.

$$InvO^{t-1}{}_{ijk} \ge 0 \qquad \forall\, i,j,k,t \tag{9}$$
$$QP^t \ge 0 \qquad \forall\, t \tag{10}$$
$$X^t{}_{ijk} \in integer \qquad \forall\, i,j,k,t \tag{11}$$
$$X^t{}_{ijk} \ge 0 \qquad \forall\, i,j,k,t \tag{12}$$

NUMERICAL EXAMPLE

In this paper, only eight canned pineapple products are considered with the following variety: color $i = 1$ (choice), $i = 2$ (standard); cut $j = 1$ (slice), $j = 2$ (tidbit) and can size $k = 1$ (0.6 kilograms per can), $k = 2$ (3 kilograms per can). The planning covers four consecutive months (t = 1,2,3,4). The average prices of fresh pineapple in month 1 to 4 are 6.4, 6.5, 6.7, 7.0 baht per kilogram, respectively.

The can cost (CC), energy cost (CE), labor cost (CL), sugar cost (CS), and water cost (CW) of each product are shown in Table 1. A pallet can accommodate up to 20 smaller size cans (k = 1), or 10 of the larger ones (k = 2). Each pallet incurs about 40 baht per month as its inventory holding cost.

Table 1: Production Costs by Product

Product			Production Cost (Bath/Can)				
i	*j*	*k*	CC	CE	CL	CS	CW
1	1	1	1	0.3	0.4	0.2	0.25
1	1	2	6	1.5	1.5	0.6	0.75
1	2	1	1	0.3	0.45	0.2	0.25
1	2	2	6	1.5	2	0.6	0.75
2	1	1	1	0.3	0.4	0.2	0.25
2	1	2	6	1.5	1.5	0.6	0.75
2	2	1	1	0.3	0.45	0.2	0.25
2	2	2	6	1.5	2	0.6	0.75

The price of different canned pineapple products (PO) often varies on a month basis and can be summarized in Table 2. The table also shows the monthly pre-ordered demands for all the canned products, and the ratio of choice-color pineapple estimated based on a monthly basis. This ratio is uncertain and may change year by year. Two scenarios of this ratio are explored. The first one is when the ratio varies in a larger range (LR) than from 0.3-0.7; and the other one is when it varies in a smaller range (SR) from 0.4-0.6.

Once a fresh pineapple is peeled and cored, only about 80% of the original weight is left to be processed and canned. Due to the warehouse space availability, the manufacturer may hold up to 4,500,000 cans in the warehouse in any time period, or an equivalence of 100,00 pallets.

Table 2: Monthly Price per Can and Pre-Ordered Demand by Product

Month	Product i	Product j	Product k	PO (Baht/Can)	Demand (Can)	Ratio of Choice-color Pineapple LR	Ratio of Choice-color Pineapple SR
1	1	1	1	16	600,000	0.7	0.6
	1	1	2	25	-		
	1	2	1	16	640,000	0.7	0.6
	1	2	2	59	160,000		
	2	1	1	15	-	0.3	0.4
	2	1	2	24	200,000		
	2	2	1	16	320,000	0.3	0.4
	2	2	2	56	60,000		
2	1	1	1	20	860,000	0.6	0.5
	1	1	2	25	-		
	1	2	1	17	880,000	0.6	0.5
	1	2	2	59	240,000		
	2	1	1	15	-	0.4	0.5
	2	1	2	24	280,000		
	2	2	1	16	440,000	0.4	0.5
	2	2	2	51	80,000		
3	1	1	1	16	248,000	0.4	0.5
	1	1	2	25	328,000		
	1	2	1	17	244,000	0.4	0.5
	1	2	2	59	272,000		
	2	1	1	15	-	0.6	0.5
	2	1	2	24	320,000		
	2	2	1	17	480,000	0.6	0.5
	2	2	2	62	276,000		
4	1	1	1	15	1,000,000	0.3	0.4
	1	1	2	25	-		
	1	2	1	17	960,000	0.3	0.4
	1	2	2	59	180,000		
	2	1	1	15	-	0.7	0.6
	2	1	2	22	640,000		
	2	2	1	14	1,000,000	0.7	0.6
	2	2	2	62	-		

Results

The production planning problem above was solved using Excel Solver. The results are shown Table 3.

From the table, the results show that in both scenarios the production plan tends to take advantage of low average fresh pineapple costs in earlier months by over-manufacturing certain products in the months prior to the delivery date even though inventory holding costs are incurred. Let a triplet (i,j,k) represents a product with color i, cut j and can size k. In the SR scenario for example, the production of product (1,1,1) and product (2,1,2) in month 3 exceed their monthly demand. The excess quantities of these products together with additional production in month 4 are to serve their demands in month 4. Similarly, in the LR scenario the production of product (1,1,1) in month 3 can accommodate both demands for months 3 and 4. Another example is product (1,2,2) in the LR scenario. Its production is accumulated over months 1, 2, and 3 to serve the demand in months 3 and 4. The results of some other canned pineapple products in Table 3 also exhibit similar early production.

Table 3: Production Plan for Large and Small Range of Choice-Color Pineapplr Ratios Compared to Demands

Month	Product i	Product j	Product k	Demand (Can)	Production Plan LR	Production Plan SR
1	1	1	1	600,000	600,000	965,599
	1	1	2	-	-	3,534
	1	2	1	640,000	640,000	640,002
	1	2	2	160,000	508,000	161,332
	2	1	1	-	-	-
	2	1	2	200,000	200,000	200,000
	2	2	1	320,000	320,000	320,000
	2	2	2	60,000	60,000	60,000
2	1	1	1	860,000	860,000	494,401
	1	1	2	-	-	7
	1	2	1	880,000	880,000	879,998
	1	2	2	240,000	324,000	238,668
	2	1	1	-	-	-
	2	1	2	280,000	280,000	280,000
	2	2	1	440,000	440,000	440,000
	2	2	2	80,000	80,000	145,554
3	1	1	1	248,000	448,125	1,248,000
	1	1	2	328,000	328,000	324,459
	1	2	1	244,000	244,000	244,000
	1	2	2	272,000	20,000	270,000
	2	1	1	-	-	-
	2	1	2	320,000	338,729	588,413
	2	2	1	480,000	480,000	480,000
	2	2	2	276,000	276,000	210,446
4	1	1	1	1,000,000	799,875	-
	1	1	2	-	-	-
	1	2	1	960,000	960,000	960,000
	1	2	2	180,000	-	180,000
	2	1	1	-	-	-
	2	1	2	640,000	621,271	371,587
	2	2	1	1,000,000	1,000,000	1,000,000
	2	2	2	-	-	-

From production planning results of both scenarios, the quantities of fresh pineapple to purchase each month must be determined to meet production plan as shown in Figure 1. From the figure, the quantities of fresh pineapple to purchase in both scenarios are the highest in month 3. This is because the price of the fresh pineapple increase in month 4, so it is worthwhile to manufacture some excess canned pineapple in month 3 and keep it in stock for a month before selling it in month 4. In general, the quantities of fresh pineapple to purchase in the SR scenario is lower or close to that in the LR one, except for month 3.

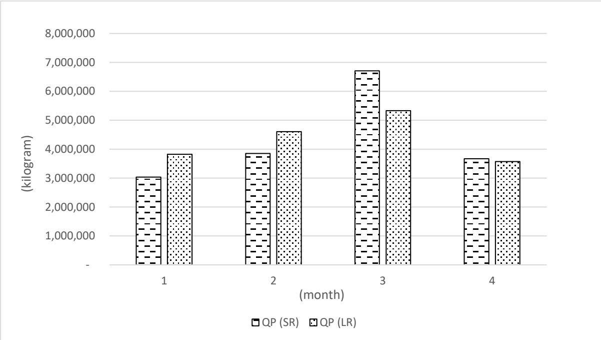

Figure 1: Quantity of fresh pineapple to be purchased each month in both scenarios (in kilogram)

Based on the pre-ordered demands and pre-determined revenue per can of all the canned pineapple products. The total revenue is 242,056,000 million baht. However, the production plans based on the two scenarios offer different total profit because they incur different costs, particular the pineapple cost and the inventory holding cost as shown in Table 4.

Table 4: Pineapple Cost, Inventory Holding Cost, and Profit in The Two Scenarios (In Baht)

Financial Item	Scenario	
	LR	SR
Pineapple Cost	114,571,382	114,449,393
Inventory Holding Cost	4,315,200	4,100,800
Other production Costs	48,799,600	48,799,600
Total Costs	167,686,183	167,349,793
Total Profit	74,369,817	74,706,207

Table 4 reveals that when the variation in the ratio of the choice-color pineapple fluctuates in a smaller range, the total profit is 336,390 baht higher than when this ratio varies in a larger range. This is because the fresh pineapple cost and the inventory holding cost in the SR scenario are lower than those in the LR scenario. A reason that the fresh pineapple (raw material) cost in the LR scenario is higher because in certain months the manufacturer needs to buy excess fresh pineapple so that there is enough choice-color pineapple to satisfy the product demands.

CONCLUSION

This paper studies a production planning problem that is normally experienced by a canned pineapple manufacturer. Pineapple is a seasonal fruit. Its price and availability of choice-color pineapple differ throughout the year. Several production and inventory holding costs are considered in this study. A mathematical model of this problem is formulated with eight different canned products under warehouse storage space limitation and pre-ordered demands over four consecutive months. The objective is to maximize the total profit. Two scenarios are experimented to examine how different ratios of choice-color pineapple availability affect the planning and total profit.

The numerical results show that the production plans in both scenarios tend to over-manufacture some products when the price of the fresh pineapple is low and allow to incur inventory holding cost to keep the excess products until they are later needed to serve the demands. The ratio of choice-color pineapple availability slightly affects the total profit. The scenario when the ratio of choice-color pineapple availability varies within a smaller range offers a lower fresh pineapple cost and inventory holding cost than those of the scenario when this ratio fluctuates within a larger range.

This study focuses on make-to-order production. Due to seasonal availability of the fresh pineapple, a common practice in the canned pineapple industry is to make-to-stock some of the products to serve future demands. This is because the cost of the fresh pineapple which is the main ingredient of the canned pineapple products are the cheapest and its availability is peaked during the pineapple season. The optimal production plans obtained consider various production and inventory holding costs, estimated ratios of choice-color pineapple availability, and warehouse storage limitation to serve pro-ordered demands.

Excess fresh pineapple acquired so that there would be sufficient choice-color products to serve the customers could be used to produce make-to-stock products before it is wested. Future research may suggest make-to-stock quantities of different canned pineapple products based on the forecasted demands.

The results of this research can be used as a guide to canned pineapple production planning when there are changes in fresh pineaaple prices and color ratios. With this guide, a raw material purchasing plan and selling promotions could be set ahead of time.

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