OPTIMAL PLANNING FOR PURCHASE AND STORAGE WITH MULTIPLE TRANSPORTATION TYPES FOR CONCENTRATED LATEX UNDER AGE-DEPENDENT CONSTRAINT

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KEYWORDS

Age-dependent, Optimal Planning, Perishable Product, Rubber

ABSTRACT

This paper presents the mathematical model to support decision planning over the multi-period for purchasing storage and transportion of concentrated latex for the rubber glove production under age-dependent constraint. The model considers multiple suppliers with different purchasing costs, varying product ages, multi-truck load capacity and costs, and storage times with respect to perishable product. The model is then applied to a rubber glove production case study and the sensitivity analysis is performed. The result reveals that the price of concentrated latex in each period and truck load capacity decision are critical factors for total cost reduction.

INTRODUCTION

Thailand has achieved particularly remarkable in the upstream sector of rubber industry over an extended period. In 2015, the country was the world leader in rubber producer and exporter which produced about 4.5 million tons of output, followed by Indonesia, China, India, and Malaysia, respectively (Thailand Industry Outlook 2016). Nowadays, Thailand has the advantage of expanding production area, especially in the Northeast and North part of the country, which can be divided into 10 regions of plantation areas (http//www.oae.go.th). Rubber is a key input into a number of significant manufacturing sectors, especially rubber gloves and tires. The most suitable raw material for the manufacture of gloves is natural concentrated latex. It was found that rubber gloves had contributed an enormous export values to Thai economy. Figure 1 illustrates the flow of production materials in gloves industry from upstream to downstream.

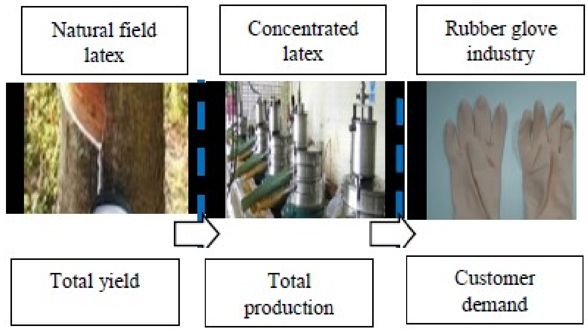

Figure 1. Flow of Production Materials in Rubber Glove Industry from Upstream to Downstream

Nevertheless, currently Malaysia becomes the world leader in developing the downstream part of the rubber value chain, particularly medical glove production. As such, the challenge for Thailand to gain competitive, decision planning of this industry is extensively required for purchasing and storage of the concentrated latex throughout the seasonal production cycle for the industry. It was found that the supply volume of field latex varies according to regions and seasons, which is a perishable in nature. As such, it is necessary to pay attention on production and transportation which is a generally complicated task.

According to the statistics report, most of rubber latex manufactures are located in the Middle, Southern and Eastern regions of Thailand account for 40%, 36.7% and 20% respectively (Plastics Institute of Thailand 2014). Due to the proximity of raw materials, the large size of the manufacturers is in the Southern (46%), and Eastern (38%) regions of the country. Generally, the delivery of field latex is made from the plantation to a latex concentration industry within the same region, as it is a perishable product latexes. However, the glove manufacturing factories will require concentrated latex according to their real demand which any shortages of raw material to the factories will result in higher costs. As a result, some concentrated latexes are supplied to the rubber glove companies in the same region when possible, and some of them are shipped across regions according to real demand. After that, the finish products

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will be exported to customers through the closest seaports from that factory.

Along with rapid change in the marketplace and the expansion of supply chains, highly coordination on purchasing, inventory, and transportation over a multi-echelon supply chain network or a multi-period time frame is vigorous, which has very much impact on customer service and profit margins of the supply chain members. Nonetheless, research related to simultaneous purchase and storage decisions of rubber latex with regard to aging limitations as well as considering a transportation cost at the same time is still quite rare. Most of the literature in the area of the rubber supply chain is focused on the structure of the rubber industry.
The literature of the rubber supply chain is related to the structure of the rubber industry. Haan *et al.* (2003) present the production flow in the rubber supply chain of India, using semi-structured interviews and analysis of the relationships of each part. For research relevant to marketing analysis of the rubber industry, Arifin (2005) studies the supply chain of rubber production in Indonesia and assess the transmission of the price to rubber growers. Fathoni (2009) analyzes rubber market systems and analyze marketing margins and prices for rubber in Jambi Province in Indonesia. Auckara-aree and Boondiskulchok (2010) design a raw material collection system by formulating Mixed Integer Programming for location routing with a step–price policy model to find the optimal solution. Somboonwiwat and Chanclay (2009) create value-added products by coherence of targets in different parts of the supply chain in Thailand. For research related to transportation, Kritchanchai and Chanpuypetch (2009) investigate gateway selections for Thailand rubber exports, using fuzzy analytic hierarchy processes. Klomsae *et al.* (2012) develop a mathematical model to determine the concentrated latex volume to purchase and storage. However, recently the perishable product management has been widely concerned in the logistics planning area, for example in the studies of Wu *et al.* (2015) and Liu *et al.* (2017). Hence, this paper presents the mathematical model for decision planning which simultaneously solve the volume of concentrated latex purchased and storaged in each age including transpotation type in multi-period time frame taking into consideration of product aging and deterioration through each time period. The parameters in the model include purchasing costs of product with varying price and age, transportation costs that vary by truck load capacity and distance between location of suppliers and manufacturers, storage costs, and expiration costs of outdated concentrated latex.

The organization of this paper is as the following. The next section describes the multi-period planning problem of purchasing and storage of concentrated latex from multiple suppliers and transportation types. Then the mathematical model is developed. A numerical example is presented to illustrate an application of the formulation. Finally, summary and concluding remarks are addressed.

PROBLEM DESCRIPTION

The rubber glove industry uses rubber concentrated latex to produce the glove products. The latex requirement is based on dependent demand which the latex can be purchased from different suppliers in differernet regions. The decision planning for purchase, storage and transportion of concentrated latex for rubber glove production begins with the determination of the volume of concentrated latex from different regions and multiple suppliers with number of round trips of different transportation types. The cost of transportation will depend on distance between location of suppliers and manufacturers, as well as size of truck and truck load capacity as well. Since age is significant factor in perishable latex requirement operations, the latex planning includes age of latex for each supplier and transportation type.

Figure 2 delineates the system of purchase, storage and transportation of perishable concentrated latex. There are multiple prices and ages of latex for each supplier. The number of round trips (X_{ijkt}) is decided for each supplier for each age of latex. The volume of purchased concentrated latex for supplier i at age j deliver by truck type k in period t (B_{ijkt}) and the volume of stored concentrated latex at the beginning of period t (I_{jt}^{B}) must be high enough for the demand of concentrated latex to glove producers (D_t). At the beginning of period t+1 the age of the concentrated latex is increased to j+1 ($I_{(j+1)(t+1)}^{B}$). The age of concentrated latex continues to increase until it reaches the expiration date, then that concentrated latex will be eliminated.

The primary objective of this paper is to develop a mathematical model for solving the concentrated latex requirement planning under age-dependent and multiple transportation types constrains. The decision criteria used is to minimize the total costs of purchasing, storaging, transportation and expiration.

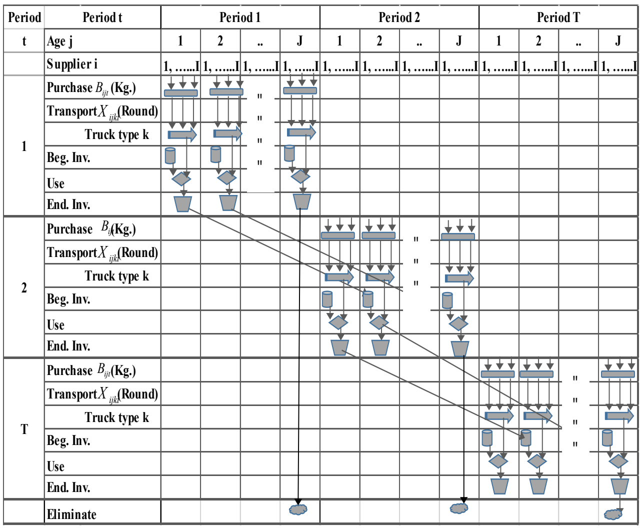

Figure 2. System of Purchase, Storage and Transportation of Concentrated Latex under Age-dependent Constraint

MATHEMATICAL FORMULATION

Indices

i Index of supplier (i = 1, 2, 3, …, I)
j Index of age of concentrated latex (j = 1, 2, 3, …,J)
k Index of transportation type (k = 1, 2, …,K)
t Index of time periods (t = 1, 2, 3, …, T)

Parameters

P_{ijt} Purchasing price of concentrated latex from supplier i for age j in period t
D_t Demand of concentrated latex for production in period t
C_{ijt} Concentrated latex capacity of supplier i for age j in period t
W_k Weight per round of concentrated latex transported by transportation type k
T_{ikt} Transportation cost of concentrated latex transported from supplier i by transportation type k in period t
H_{jt} Holding cost of concentrated latex to age j in period t
E_t Expiration cost of concentrated latex that expires in period t

Decision Variables

B_{ijt} Volume of concentrated latex purchase from supplier i for age j in period t
X_{ijkt} Number of round trips required to transport latex from supplier i for age j by transportation type k in period t
U_{jt} Volume of concentrated latex age j used in production in period t
I_{jt}^{E} Volume of concentrated latex inventory age j at the ending of period t
I_{jt}^{B} Volume of concentrated latex inventory age j at the beginning of period t
F_t Volume of concentrated latex that expires in period t

Objective Function

The objective function of the problem is to find the minimum total cost of the purchasing cost, storage cost, transportation cost and expiration cost of concentrated latex as shown in Equation 1.

$$\text{Minimize Total Cost} = \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J} P_{ijt}\,B_{ijt} + \sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} T_{ikt}\,X_{ijkt} + \sum_{t=1}^{T}\sum_{j=1}^{J} H_{jt}\,I_{jt}^{B} + \sum_{t=1}^{T} E_t F_t \qquad (1)$$

Constraints

In each period for each supplier the volume of concentrated latex at each age purchased is less than or equal to the available capacity at the same latex age.

$$B_{ijt} \le C_{ijt} \qquad \forall\ i, j, t \qquad (2)$$

In each period for each supplier, the number of round trips for concentrated latex at each age transported by each transportation type is greater than or equal to rate of volume of concentrated latex purchased from supplier i of age j in period t and weight per round of transported concentrated latex from by transportation type k.

$$X_{ijkt} \ge \frac{B_{ijt}}{W_k}; \qquad \forall\ i, j, k, t \qquad (3)$$

At each period, sum of total volume of concentrated latex purchased from supplier i for age j and total volume of concentrated latex inventory for age j-1 at the ending of period t-1 is greater than volume of demand of concentrated latex for production in period t.

$$\sum_{i=1}^{I}\sum_{j=1}^{J} B_{ijt} + \sum_{j=1}^{J} I_{(j-1)(t-1)}^{E} \ge D_t\ ; \quad \forall\ t \qquad (4)$$

At each period, volume of concentrated latex inventory for age j at the ending of period t equal to the sum of volume of concentrated latex inventory for age j in the beginning of period t and volume of concentrated latex purchased from supplier i for age j in period t, minus volume of concentrated latex for age j used in production.

$$I_{jt}^{E} = I_{jt}^{B} + \sum_{i=1}^{I} B_{ijt} - U_{jt} \qquad \forall\ j, t \qquad (5)$$

At period T, volume of expired concentrated latex equal to volume of concentrated latex inventory for age j at the ending of period t.

$$F_t \quad = \quad I^E_{jt} \qquad \forall\, t \qquad (6)$$

In order to determine the volume of concentrated latex of age j used in production in period t: if demand for concentrated latex for production in period t is greater than or equal to the sum of the volume of concentrated latex inventory for age j-1 at the ending of period t-1 and the volume of concentrated latex purchased from supplier i of age j in period t then: the volume of concentrated latex for age j used in production in period t will equal the sum of the volume of concentrated latex for age j-1 used in production in period t-1 and the volume of concentrated latex purchased from supplier i of age j in period t (Equation 7). But if this condition is not true, then: the volume of concentrated latex age j used in production in period t will equal to the demand for concentrated latex for the production in period t (Equation 8).

If $\quad D_t - (I^E_{(j-1)(t-1)} + \sum_{i=1}^{I} B_{ijt}) \quad \geq \quad 0$

True: $\quad U_{jt} \quad = \quad I^E_{(j-1)(t-1)} + \sum_{i=1}^{I} B_{ijt} \;; \qquad \forall\, t \qquad (7)$

False: $\quad U_{jt} \quad = \quad D_t \;; \qquad \forall\, t \qquad (8)$

The constraints address to determine the volume of concentrated latex for age j used in production in period t. For example, concentrated latex of the oldest age available for production is j=4 and determine the volume of concentrated latex available for production of age j=3, and determine the volume of concentrated latex available for production in period t as demonstrated in Equation 9 and Equation 10.

If $\quad (I^E_{(j-2)(t-1)} + \sum_{i=1}^{I} B_{i(j-1)t} - (D_t - U_{jt})) \quad > \quad 0$

True: $\quad U_{(j-1)t} \quad = \quad D_t - U_{jt} \;; \qquad \forall\, t \qquad (9)$

False: $\quad U_{(j-1)t} = I^E_{(j-2)(t-1)} + \sum_{i=1}^{I} B_{i(j-1)t} \;; \qquad \forall\, t \qquad (10)$

Non-negativity constraint:

$$B_{ijt}, X_{ijkt}, I^E_{jt}, I^B_{jt}, F_t, U_{jt}, \geq 0 \;; \qquad \forall\, j, k, t \qquad (11)$$

NUMERICAL EXAMPLE

In this example, the concentrated latex can be purchased from 2 suppliers which are transported from different regions to the production facilities by 2 transportation types. The age of the latex is tracked over varying periods, allowing for a maximum aging limit of 4 months. The problem is to determine the volume of concentrated latex at each age purchased from each supplier, the number of round trips for concentrated latex transported from suppliers to the production facilities, the volume of concentrated latex used in production, the volume of concentrated latex inventory stored in each period, and the volume of expired concentrated latex. The model is applied to an example data set in order to generate planning decisions for the purchase and storage of concentrated latex with multiple prices and ages. The latex volumes must vary in response to production demand for rubber glove production over a 3 period time interval. The prices and volumes of supplied latex are shown in Table 1. Production demand, holding cost and expiration cost are presented in Table 2. Transportation costs and weight per round of concentrated latex for each transportation type are shown in Table 3.

Table 1. Prices and Volumes of Supplied Latex

Supplier i		Period 1				Period 2				Period 3			
	Age j	1	2	3	4	1	2	3	4	1	2	3	4
1	P_{ijt} (baht)	36.99	36.43	35.7	0	35.16	34.81	34.46	0	35.75	35.39	35.04	34.86
	C_{ijt} (Ton)	1,350	1,350	350	0	1,350	1,350	1,350	0	1,350	1,350	1,350	1,350
2	P_{ijt} (baht)	36.74	36.19	35.45	0	34.91	34.56	34.21	33.86	35.5	35.15	34.79	34.44
	C_{ijt} (Ton)	1,420	1,420	1,420	0	1,420	1,420	1,420	1,420	1,420	1,420	1,420	1,420

Table 2. Demand, Holding Cost and Expiration Cost

Period	Period 1				Period 2				Period 3			
Age j	1	2	3	4	1	2	3	4	1	2	3	4
I (kg.)		13,000										
H_{kt} (Baht)	5	5	5	5	5	5	5	5	5	5	5	5
E_t (Baht)	11	11	11	11	11	11	11	11	11	11	11	11
D_t (kg.)	457,000				426,000				442,000			

Table 3. Transportation Costs and Weight per Round of Concentrated Latex for Each Transportation Type

Supplier i	Transportation type	T_{ikt} (Bath)	W_k (kg./Round)
1	10-wheel truck (k=1)	4,694	12,000
	Trailer (k=2)	8,605	25,000
2	10-wheel truck (k=1)	15,679	12,000
	Trailer (k=2)	21,877	25,000

Results

LINGO software is employed to solve this problem and the solution is presented in Table 4. The results show the optimal planning for purchasing, storage and transporting of perishable concentrated latex used in glove production over a 3-period time interval. The concentrated latex is purchased from both suppliers which purchasing cost is more sensitive to decision making than transportation and holding costs. Since the price of concentrated latex decreases when the age of concentrated latex goes up, so the purchasing decision is prioritized from the oldest to the youngest ones. For example, it can be seen from the planned purchase of concentrated latex of age 3 from supplier 1 and 2 in period 1, concentrated latex of age 4 from supplier 2 and of age 3 from supplier 1, and concentrated latex of age 4 from both suppliers in period 3. Then, the sensitivity analysis is performed by changing the purchase price of concentrated latex from the original price ranging from -30% to 30%. The computational results for a 3-period time interval each purchase price in details are presented in Table 5. The results indicate that the volume of concentrated latex purchased from supplier 1 increases and supplier 2 decreases if the purchase price of latex changes by -30%, as shown in Table 6. In the opposite way, if the purchase price of latex changes by +30%, the volume of concentrated latex purchase from supplier 1 decreases and supplier 2 increases, as shown in Table 7. Moreover, the result from sensitivity analysis also shows that the 25-ton trailers are normally selected as the transportation type. Due to the aging of latex and its holding cost, the results also suggest that the rubber glove industry should purchase the concentrated latex with the only required amount for each period.

Table 4. Results

Supplier i		Period 1				Period 2				Period 3			
	Age j	1	2	3	4	1	2	3	4	1	2	3	4
1	Purchase B_{ijt} (Ton)			344				1					442
	Transport X_{ijkt} (Round)												
	- 10-wheel truck (k=1)							1					
	- Trailer (k=2)			14									18
2	Purchase B_{ijt} (Ton)			100					425				
	Transport X_{ijkt} (Round)												
	- 10-wheel truck (k=1)												
	- Trailer (k=2)			4					17				
Use U_{jt} (Ton)			13	444				1	425				442
Ending Inventory I^E_{jt} (Ton)													
Eliminate F_t (Ton)													
Purchase Cost (Bath)		15,825,800				14,424,960				15,408,120			
Transportation Cost (Bath)		207,978				376,603				154,890			
Inventory Cost (Bath)													
Eliminate Cost (Bath)													
Total Cost (Bath)		46,398,351											

Table 5. Sensitivity Analysis for Changing Purchase Price

Supplier i	% Change	-30%	-20%	-10%	0%	10%	20%	30%
1	Purchase B_{ijt} (Ton)	1,212	1,212	787	787	787	787	362
	Transport X_{ijkt} (Round)							
	- 10-wheel truck (k=1)	1	1	1	1	1	1	1
	- Trailer (k=2)	49	49	32	32	32	32	15
2	Purchase B_{ijt} (Ton)	100	100	525	525	525	525	950
	Transport X_{ijkt} (Round)							
	- 10-wheel truck (k=1)							
	- Trailer (k=2)	4	4	21	21	21	21	38
Use U_{jt} (Ton)		1,325	1,325	1,325	1,325	1,325	1,325	1,325
Ending Inventory I^E_{jt} (Ton)								
Eliminate F_t (Ton)								
Purchase Cost (Bath)		32,138,480	36,732,840	41,090,020	45,658,880	50,228,740	54,788,920	59,125,030
Transportation Cost (Bath)		513,847	513,847	739,471	739,471	739,471	739,471	965,095
Inventory Cost (Bath)								
Eliminate Cost (Bath)								
Total Cost (Bath)		32,652,327	37,246,687	41,829,491	46,398,351	50,968,211	55,528,391	60,090,125

Table 6. Volume of Concentrated Latex Purchase for Changing Purchase Price -30%

Supplier i		Period 1				Period 2				Period 3			
	Age j	1	2	3	4	1	2	3	4	1	2	3	4
1	- 10-wheel truck (k=1)							1					
	- Trailer (k=2)			344				425					442
2	- 10-wheel truck (k=1)												
	- Trailer (k=2)			100									

Table 7. Volume of Concentrated Latex Purchase for Changing Purchase Price +30%

Supplier i		Period 1				Period 2				Period 3			
	Age j	1	2	3	4	1	2	3	4	1	2	3	4
1	- 10-wheel truck (k=1)							1					
	- Trailer (k=2)			344									17
2	- 10-wheel truck (k=1)												
	- Trailer (k=2)			100					425				425

CONCLUSION

The main contribution of this paper is the proposed mathematical model to support decision planning over the multi-period interval, as well as planning for purchasing of concentrated latex from different regions, from multiple suppliers with multiple transportation types under age-dependent constaints. Purchase and storage of concentrated latex with constraint of perishability through a multi-period time interval is a complex problem. The supply volume differs in different regions according to seasonal fluctuations, and the concentrated latex is perishable over time if stored for too long. This model can also be extended by including the quality of concentrated latex in each age. In addition, the matching between glove product and concentrated latex prices under uncertainty could be interesting to explore.

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