MODELING AGRICULTURAL SUPPLY CHAIN FLEXIBILITY: A CASE STUDY OF CASSAVA FARMING BUSINESS IN THAILAND

Pareeya SIRIWATTHANAPHAN [a], Sarawut JANSUWAN [b] and Anthony CHEN [c]
[a,b] *Graduate School of Applied Statistics, National Institute of Development Administration (NIDA), Bangkok, Thailand*
Email: s.pareeya@gmail.com [a], sarawutj@gmail.com [b]
[c] *Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, China*
Email: anthony.chen@polyu.edu.hk

ABSTRACT

The logistics and supply chain management for agricultural supply chain in Thailand has been more emphasized by both private and public sectors due to its importance to the national economy. The key performance indicators of agricultural supply chain traditionally consider three major dimensions including cost, lead time, and reliability. However, the supply chain flexibility which is an important indicator to assess the ability of all players in the agricultural supply chain can accommodate the additional demand is rarely explored. The objective of this study is to develop a mathematical programming model to assess the supply chain flexibility for cassava business. In this study, a stochastic programming approach is adopted for modeling the flexibility. The proposed model was divided into two stages. The first stage (BASE) evaluates the demand base pattern along the cassava supply chain networks. The second stage (ADD-VOL) is to assess the reserve capacity using the base pattern obtained from the first stage. The reserved capacity at each stage presents the flexibility of the supply chain that can accommodate additional demand. The proposed models could be used to identify the bottlenecks of the supply chain in order to enhance its capacity for better serving the future supply and demand changes.

Keywords: supply chain flexibility, agricultural supply chain, stochastic programming, reserved capacity

1. INTRODUCTION

Thailand is an agricultural-based country. The gross domestic product is predominately derived from agricultural sector. In 2016, agricultural commodities including rice, rubber, and cassava-related products are the top three major products produced for exporting. However, Food and Agricultural Organization of the United Nation (2011) have reported the major problems in the agricultural countries specifically for Thailand that obstruct the productivity of their business as follows: 1) the operations of market place in the sources of production are inefficient: the product distribution during the peak of production season cannot be done from the source of production effectively. The market place systems are lack of the management effective, lack of the basic facilities, and lack of information that could make the market conduct effectively 2) agricultural commodities price is still slump as well as the risen cost of production factors such as labor and shipping costs. Agricultural commodity price fluctuations by cropping season are normal phenomena especially in the developing countries. Consequently, the serious problem of slump price for major agricultural products makes the farmer loss and directly affects the well-being of famers and 3) the productivity passes through middleman and factories affect to the prices and the quality. The coordination and support system links trading between manufacturers of origin to buyer at destination still less. These issues indicate the inefficient supply chain system and avoidably consequence to the total operation costs including inventory, manufacturing, and transportation of the agricultural supply chain nationwide.

As can be seen, one of key performance indicators for building the supply chain efficiency is the well-managed linkages among players from upstream, to middle stream, and to downstream, or from farmers to manufacturers, from manufacturers to shippers, and from shippers to customers, respectively. The performance indicators in agricultural supply chain so far usually consider three dimensions of cost, lead time, and reliability. Though these three efficiency dimensions are well adopted and utilized to reflect the players' competitiveness (i.e., cost), responsiveness (i.e., lead time), and their ability to perform their required functions under stated conditions for a specified time period (i.e., reliability), they overlook the interaction among players due to the changes and uncertainties of demand and supply in the supply chain. Particularly, the agricultural supply chain has involved in wide spectrum of activities such as cultivation, warehousing, manufacturing, transport and distribution, and exporting, thus it leads to highly complex systems in terms of network structure and its capacity to accommodate the integration and player's coordination. Flexibility measure is an alternative performance indicator to measure the ability to accommodate, withstand or handle uncertainty. It describes the level of capability a system can handle or absorb uncertainties or changes. In systems engineering, flexibility is the characteristic of the interface between a system and its external environment (Correa, 1994). It has been widely researched in the field of manufacturing (i.e., Baemon,1999; Vokurka and O'Leary-Kelly, 2000; Chandra et al., 2005). The typical reason that manufacturing industries have adopted flexibility is to speed up the entire product cycles. Many sub categories, such as volume flexibility, delivery flexibility, machine flexibility, operation flexibility, and process flexibility, have been adopted as key strategies for improving market responsiveness in uncertain demand. Flexibility measure is also adopted in transportation network analysis (i.e., see works done by Morlok and Chang, 2004; Chen and Kasikitwiwat, 2011). In their studies, besides tackling the demand changes and uncertainties, the reserved capacity of transportation network such as railways, highways can be also derived from their flexibility frameworks. The flexibility in the supply chain have been also studied (Gong, 2008; Schutz and Tomasgard, 2011; Das, 2011) with the focuses of resources and manufacturing and processes. Nevertheless, to our best knowledge, limited studies have been developed quantitative measures of the supply chain capacity flexibility which addresses the up-, middle-, and down streams for agriculture product flow networks and address on the stochastic issues related to agricultural supply chain network.

The aim of this research is to quantitatively develop methods for assessing the supply chain network capacity flexibility and to apply the proposed model to the agricultural supply chain system. The two-stage stochastic model for assessing the capacity flexibility has been developed. The first stage is to evaluate the base pattern (BASE) along the supply chain networks using a profit-maximization. Noted that we adopt a profit-maximization scheme, not a cost minimization because it better reflects the business-related production especially if the additional volumes produced or delivered is higher than the additional revenue associated with multiple players' interest in the supply chain. Additionally, the uncertainty of demand variation based on the commodity specific price-demand functions is employed to represent the stochastic demand in the world's export market. The second stage allows for additional changes in demand volumes (ADDVOL) from the upstream levels. In the second stage, we can assess the reserved or residual capacity of each player in the connected supply chain network. To illustrate the model capability, the case study of tapioca starch (flour produced from cassava) supply chain in Thailand is used. Several data sources are the Office of Agricultural Economic, Cassava Farmer Cooperation, and cassava farmers, manufacturers and exporters are collected and further used in the proposed model.

2. MODELING AGRICULTURAL SUPPLY CHAIN FLEXIBILITY

2.1 The Cassava Supply Chain

The case study of cassava supply chain in Nakorn Ratchasima province, Thailand has been adopted. This province located 250 km. away from Bangkok is the biggest fresh cassava producer nationwide. There are few tapioca starch (produced from cassava) manufacturers located within the province. Figure 1 depicts the flows of cassava in the Tapioca starch supply chain. The supply chain sketch below consists of 6 primary nodes including: $i \Rightarrow j$: fresh cassava from 10 crop areas to the warehouse which located in the factory, $j \Rightarrow k$: fresh cassava from warehouse to the manufacturing, $k \Rightarrow g$: cassava's starch from manufacturing to warehouse, $g \Rightarrow m$: containerized cassava's starch from warehouse transported to provincial train station by truck, $m \Rightarrow n$: containerized cassava's starch from provincial train station transported to Bangkok port by truck, and $g \Rightarrow n$: containerized cassava's starch from warehouse transported to Bangkok port by truck.

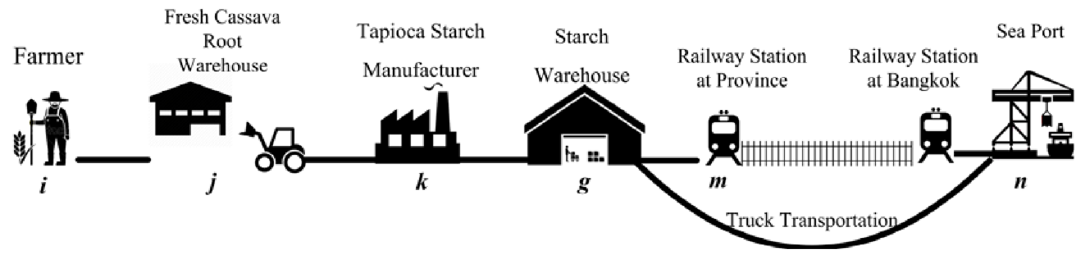

Figure 1. The Cassava Supply Chain (Case of Thailand)

2.2 Modeling Cassava Supply Chain Flexibility

In this section, we provide a quantitative assessment of supply chain capacity. The stochastic two-stage approach model including two-stage models: stage 1: BASE and stage 2: ADDVOL model. The first stage evaluates the base pattern (BASE) along the supply chain networks using a profit-maximization scheme while the second stage allows for additional changes in demand volumes (ADDVOL) from the upstream levels. Figure 2 depicts the concept of supply chain flexibility in the purposed framework. The nomenclature of the models is summarized in Table 1.

Table 1. Nomenclature

Index	
i	Index of crop areas; i = 1, 2, 3, …, 10
j	Index of factory yard; j = 11, 12
k	Index of tapioca starch machinery; k =13, 14
g	Index of tapioca starch warehouse; g =15
m	Index of railway station; m = 16
n	Index of port; n = 17
t	Index of time period; t = 1, 2, 3, 4
α	Index of scenario; α = 1, 2,..., 36
Parameter	
f	Cultivation and harvest costs of farmers (Baht/ton)
r	Transportation costs of farmers (Baht/ton)
$z^t_{j\alpha}$	Price of cassava roots at yard j for scenario α in period t (Baht/ton)
$z^t_{n\alpha}$	Export price for tapioca starch at port n for scenario α in period t (Baht/ton)
h_g	Holding cost at warehouse g (Baht/ton)
s^t	Tapioca starch production cost in period t (Baht/ton)
c^t_{gm}	Transportation cost from warehouse g to railway station m in period t (Baht/TEU)
c^t_{mn}	Transportation cost from railway station m to port n in period t (Baht/TEU)
c^t_{gn}	Transportation cost form warehouse g to port n in period t (Baht/TEU)
I^0_g	Initial tapioca starch inventory in warehouse g at $t=0$ (Tons)
U^t_j	Max capacity for cassava root buying from farmers at yard j in period t (Tons)
U^t_k	Tapioca starch production capacity of machinery k in period t (Tons)
U^t_g	Storage capacity for warehouse g in period t (Tons)
V^t_{mn}	Max containers capacity transported by rail from railway
W^t_{mn}	Loaded weight of rail transport from railway station m to port n in period t (Tons/TEU)
$F^t_{i\alpha}$	Cassava roots supply in crop area i for each scenario α in period t
β	Conversion factor from cassava root to tapioca starch
P_α	Probability in each scenario α
Decision Variable for Stage 1	
$x^t_{ij\alpha}$	Cassava root volume that farmers in area i sell at yard j in period t for scenario α (Tons)
$x^t_{jk\alpha}$	Cassava root inventory in yard j and were produce by machinery k in period t for scenario α (Tons)
$y^t_{kg\alpha}$	Tapioca starch volume after conversion from machinery k and store in warehouse g in period t for scenario α (Tons)
$y^t_{gm\alpha}$	Tapioca starch volume store in warehouse g and transport from railway station m to port n in period t for scenario α (Tons)
$y^t_{gn\alpha}$	Tapioca starch volume store in warehouse g transport by truck to port n in period t for Scenario α (Tons)
$y^t_{mn\alpha}$	Tapioca starch volume were transported by rail from railway station m to port n in period t for scenario α (Tons)
$I^t_{g\alpha}$	Tapioca starch inventory of warehouse g in period t for scenario α (Tons)
Decision Variable for Stage 2	
Δx^t_{ij}	Additional cassava root volume that farmers in area i sell at yard j in period t (Tons)
Δx^t_{jk}	Additional cassava root inventory in yard j and were produce by machinery k in period t (Tons)
Δy^t_{kg}	Additional tapioca starch volume after conversion from machinery k and store in warehouse g in period t (Tons)
Δy^t_{gm}	Additional tapioca starch volume store in warehouse g and

	station *m* to port *n* in period *t* (TEUs/day)		transport from railway station *m* to port *n* in period *t* (Tons)
V_{gn}^{t}	Available truck transport from warehouse *g* to port *n* in period *t* (Cars/day)	Δy_{gn}^{t}	Additional tapioca starch volume store in warehouse *g* transport by truck to port *n* in period *t* (Tons)
W_{gm}^{t}	Loaded weight of truck transport from warehouse *g* to railway station *m* in period *t* (Tons/TEU/Car)	Δy_{mn}^{t}	Tapioca starch volume were transported by rail from railway station *m* to port n in period *t* (Tons)

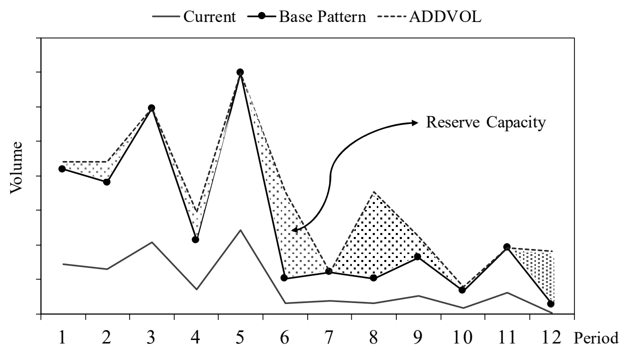

Figure 2. Concept of Supply Chain Flexibility

As shown in Figure 2, the BASE patterns are derived from the current demand pattern using the profit maximization scheme while the ADDVOL model attempts to quantify the additional volumes or reserve capacity that the system can still accommodate, which are governed by each player's capacity.
It is important to note that the tapioca starch products, similar to other agricultural commodities, in the world market are fluctuated based its varied price during different time period. To deal with the uncertainty of tapioca starch demand in the market and its price in each time period *t*, the stochastic programming for the first stage is formulated. The demand and price data for farmer-manufacturer and manufacturer-freight forwarders (i.e., Freight on Board (F.O.B)) were collected to construct the demand-price functions. The linear regression equations were constructed based on the secondary data. The first equation represents the relationship of cassava supply produced by the famer (y_1), exported tapioca starch demand (y_2), prices that manufacturer offers to the farmer (x_1), and F.O.B. prices (x_2): $y_1 = 136.62x_1 - 252{,}048.28$ (R-square=0.52) and $y_2 = -0.91x_2 + 17{,}253.13$ (R-square=0.79) respectively. BASE and ADDVOL models are formulated and shown as follows.

Stage 1: BASE model:

$$\begin{aligned}
\textit{Max Profit} = {} & \sum_{i}\sum_{j}\sum_{t}\sum_{\alpha} P_\alpha z_{j\alpha}^{t} x_{ij\alpha}^{t} - \sum_{i}\sum_{j}\sum_{t}\sum_{\alpha} P_\alpha f x_{ij\alpha}^{t} - \sum_{i}\sum_{j}\sum_{t}\sum_{\alpha} P_\alpha r x_{ij\alpha}^{t} + \\
& + \sum_{g}\sum_{m}\sum_{n}\sum_{t}\sum_{\alpha} P_\alpha z_{n\alpha}^{t}\left(y_{gm\alpha}^{t} + y_{gn\alpha}^{t}\right) - \sum_{j}\sum_{k}\sum_{t}\sum_{\alpha} P_\alpha z_{j\alpha}^{t} x_{jk\alpha}^{t} - \sum_{k}\sum_{g}\sum_{t}\sum_{\alpha} P_\alpha s^{t} y_{kg\alpha}^{t} \\
& - \sum_{g}\sum_{t}\sum_{\alpha} P_\alpha h_g I_{g\alpha}^{t} - \sum_{g}\sum_{m}\sum_{t}\sum_{\alpha} c_{gm}^{t}\left(\frac{P_\alpha y_{gm\alpha}^{t}}{W_{gm}^{t}}\right) - \sum_{m}\sum_{n}\sum_{t}\sum_{\alpha} c_{mn}^{t}\left(\frac{P_\alpha y_{mn\alpha}^{t}}{W_{mn}^{t}}\right) \\
& - \sum_{g}\sum_{n}\sum_{t}\sum_{\alpha} c_{gn}^{t}\left(\frac{P_\alpha y_{gn\alpha}^{t}}{W_{gn}^{t}}\right) \qquad (1)
\end{aligned}$$

Subject to

$$\sum_{j} x_{ij\alpha}^{t} \leq F_{i\alpha}^{t} \qquad ,\forall_i, \forall_t, \forall_\alpha \qquad (2)$$

$$\sum_{i} x_{ij\alpha}^{t} \leq U_{j}^{t} \qquad ,\forall_j, \forall_t, \forall_\alpha \qquad (3)$$

$$\sum_i x_{ij\alpha}^t \geq D_j^t \qquad ,\forall_j,\forall_t,\forall_\alpha \tag{4}$$

$$\sum_i x_{ij\alpha}^t - \sum_j x_{jk\alpha}^t = 0 \qquad ,\forall_\alpha \tag{5}$$

$$\sum_j \beta x_{jk\alpha}^t = \sum_g y_{kg\alpha}^t \qquad ,\forall_k,\forall_t,\forall_\alpha \tag{6}$$

$$\sum_g y_{kg\alpha}^t \leq U_k^t \qquad ,\forall_k,\forall_t,\forall_\alpha \tag{7}$$

$$I_{g\alpha}^{t-1} + \sum_k y_{kg\alpha}^t - \left(y_{mn\alpha}^t + y_{gn\alpha}^t\right) - I_{g\alpha}^t \leq U_g^t \qquad ,\forall_g,\forall_t,\forall_\alpha \tag{8}$$

$$I_{g\alpha}^{t-1} + \sum_k y_{kg\alpha}^t - \left(y_{mn\alpha}^t + y_{gn\alpha}^t\right) - I_{g\alpha}^t \geq D_g^t \qquad ,\forall_g,\forall_t,\forall_\alpha \tag{9}$$

$$\sum_g y_{gm\alpha}^t - \sum_n y_{mn\alpha}^t = 0 \qquad ,\forall_m,\forall_t,\forall_\alpha \tag{10}$$

$$\sum_n \left(y_{mn\alpha}^t / W_{mn}^t\right) \leq V_{mn}^t \qquad ,\forall_m,\forall_t,\forall_\alpha \tag{11}$$

$$\sum_n \left(y_{gn\alpha}^t / W_{gn}^t\right) \leq V_{gn}^t \qquad ,\forall_g,\forall_t,\forall_\alpha \tag{12}$$

$$\sum_g y_{gn\alpha}^t + \sum_m y_{mn\alpha}^t \geq D_{n\alpha}^t \qquad ,\forall_n,\forall_t,\forall_\alpha \tag{13}$$

$$x_{ij\alpha}^t, x_{jk\alpha}^t, y_{kg\alpha}^t, y_{gm\alpha}^t, y_{gn\alpha}^t, y_{mn\alpha}^t, I_{g\alpha}^t \geq 0 \qquad ,\forall_i,\forall_j,\forall_k,\forall_g,\forall_m,\forall_n,\forall_t,\forall_\alpha \tag{14}$$

The objective function of BASE model Eq. (1) is to determine the based demand pattern using the maximizing profit of all players. The profits are computed from the volumes that are sold by each player subtracted by their costs including farming and cultivating costs, tapioca starch manufacturer (purchasing the raw material, producing, and holding costs of tapioca starch), and transportation costs from factory's warehouse to port using two transportation modes: rail and truck. P_α is probability of scenario α (assumed Poison distributed) that represents the number of cassava sold by farmer and tapioca starch by producer at each certain market price (derived from freight on board or F.O.B prices). In our study, we consider annual sales which equal to 4 quarters. Eqs. (2), (3) represent the capacity of farmers to produce cassava, and producer warehouse capacity in each time period. Eq. (4) is the minimum quantity purchased by the producer. Eq. (5) indicates no fresh cassava is stocked. Eqs (6), (7), (8), (9) represent the processing, manufacturing, warehousing capacity. Eqs. (10), (11), (12) are the transportation capacity by rail and truck to Bangkok port. Eq. (13) indicates the customer demand for exporting and Eq (14) is the non-negativity constraint.

Stage 2: ADDVOL model

$$\begin{aligned} \textit{Maximize } Z = & \sum_i\sum_j\sum_t\sum_\alpha \left(x_{ij\alpha}^t + \Delta x_{ij\alpha}^t\right) + \sum_j\sum_k\sum_t\sum_\alpha \left(x_{jk\alpha}^t + \Delta x_{jk\alpha}^t\right) \\ & + \sum_k\sum_g\sum_t\sum_\alpha \left(y_{kg\alpha}^t + \Delta y_{kg\alpha}^t\right) + \sum_g\sum_m\sum_t\sum_\alpha \left(y_{gm\alpha}^t + \Delta y_{gm\alpha}^t\right) \\ & + \sum_m\sum_n\sum_t\sum_\alpha \left(y_{mn\alpha}^t + \Delta y_{mn\alpha}^t\right) + \sum_g\sum_n\sum_t\sum_\alpha \left(y_{gn\alpha}^t + \Delta y_{gn\alpha}^t\right) \end{aligned} \tag{15}$$

Subject to

$$\sum_j \left(x_{ij\alpha}^t + \Delta x_{ij\alpha}^t\right) \leq F_{i\alpha}^t \qquad ,\forall_i,\forall_t,\forall_\alpha \tag{16}$$

$$\sum_i \left(x_{ij\alpha}^t + \Delta x_{ij\alpha}^t\right) \leq U_j^t \qquad ,\forall_j,\forall_t,\forall_\alpha \tag{17}$$

$$\sum_{i}\left(x_{ij\alpha}^{t}+\Delta x_{ij\alpha}^{t}\right)\geq D_{j}^{t} \qquad ,\forall_{j},\forall_{t},\forall_{\alpha} \qquad (18)$$

$$\sum_{i}\left(x_{ij\alpha}^{t}+\Delta x_{ij\alpha}^{t}\right)-\sum_{k}\left(x_{jk\alpha}^{t}+\Delta x_{jk\alpha}^{t}\right)=0 \qquad ,\forall_{j},\forall_{t},\forall_{\alpha} \qquad (19)$$

$$\sum_{j}\beta\left(x_{jk\alpha}^{t}+\Delta x_{jk\alpha}^{t}\right)=\sum_{g}\left(y_{kg\alpha}^{t}+\Delta y_{kg\alpha}^{t}\right) \qquad ,\forall_{k},\forall_{t},\forall_{\alpha} \qquad (20)$$

$$\sum_{g}\left(y_{kg\alpha}^{t}+\Delta y_{kg\alpha}^{t}\right)\leq U_{k}^{t} \qquad ,\forall_{k},\forall_{t},\forall_{\alpha} \qquad (21)$$

$$I_{g\alpha}^{t-1}+\sum_{k}\left(y_{kg\alpha}^{t}+\Delta y_{kg\alpha}^{t}\right)-\sum_{m}\left(y_{mn\alpha}^{t}+\Delta y_{mn\alpha}^{t}\right)- \sum_{g}\left(y_{gn\alpha}^{t}+\Delta y_{gn\alpha}^{t}\right)-I_{g\alpha}^{t}\leq U_{g}^{t} \qquad ,\forall_{g},\forall_{t},\forall_{\alpha} \qquad (22)$$

$$I_{g\alpha}^{t-1}+\sum_{k}\left(y_{kg\alpha}^{t}+\Delta y_{kg\alpha}^{t}\right)-\sum_{m}\left(y_{mn\alpha}^{t}+\Delta y_{mn\alpha}^{t}\right)- \sum_{g}\left(y_{gn\alpha}^{t}+\Delta y_{gn\alpha}^{t}\right)-I_{g\alpha}^{t}\geq D_{g}^{t} \qquad ,\forall_{g},\forall_{t},\forall_{\alpha} \qquad (23)$$

$$\sum_{g}\left(y_{gm\alpha}^{t}+\Delta y_{gm\alpha}^{t}\right)-\sum_{n}\left(y_{mn\alpha}^{t}+\Delta y_{mn\alpha}^{t}\right)=0 \qquad ,\forall_{m},\forall_{t},\forall_{\alpha} \qquad (24)$$

$$\sum_{n}\left(\left(y_{mn\alpha}^{t}+\Delta y_{mn\alpha}^{t}\right)/W_{mn}^{t}\right)\leq V_{mn}^{t} \qquad ,\forall_{m},\forall_{t},\forall_{\alpha} \qquad (25)$$

$$\sum_{n}\left(\left(y_{gn\alpha}^{t}+\Delta y_{gn\alpha}^{t}\right)/W_{gn}^{t}\right)\leq V_{gn}^{t} \qquad ,\forall_{g},\forall_{t},\forall_{\alpha} \qquad (26)$$

$$\sum_{g}\left(y_{gn\alpha}^{t}+\Delta y_{gn\alpha}^{t}\right)+\sum_{m}\left(y_{mn\alpha}^{t}+\Delta y_{mn\alpha}^{t}\right)\geq D_{n\alpha}^{t} \qquad ,\forall_{n},\forall_{t},\forall_{\alpha} \qquad (27)$$

$$\Delta x_{ij\alpha}^{t},\Delta x_{jk\alpha}^{t},\Delta y_{kg\alpha}^{t},\Delta y_{gm\alpha}^{t},\Delta y_{gn\alpha}^{t},\Delta y_{mn\alpha}^{t}\geq 0 \qquad ,\forall_{i},\forall_{j},\forall_{k},\forall_{g},\forall_{m},\forall_{n},\forall_{t},\forall_{\alpha} \qquad (28)$$

The objective function in Eq. 15 is to maximize the cassava sale and flour produced, warehoused, transported by adding additional volumes. Constraints in Eqs. (16)-(28) are similar to those constraints in Eqs. (2)-(14) with additional volumes. The proposed models are formulated and solved using MS Excel Solver.

3. CASE STUDY AND RESULTS

3.1 Specific Data for Case Study

For the farmer units, the farming costs (f) of all quarters are assumed to be equal 1,637 THB/tonnage and transportation costs from 10 crop areas i to manufacture (r) are 220, 200, 200, 190, 220, 180, 180, 170, 150, 170 THB/tonnage, respectively. Parameters used for the manufacturers including offering price for the farmers, cost of tapioca starch production, exported demand for starch, conversation rate for fresh cassava to tapioca starch, capacity of fresh cassava warehouse, tapioca starch production capacity, capacity of tapioca starch warehouse are summarized in Table 2. Besides, information for transportation and export including number of trucks available in the company, transportation costs, truck-rail transportation costs and their capacities are also summarized in Table 2. This information will be used in both stages.

Table 2. Parameters for the models

Parameters	Unit	Q1	Q2	Q3	Q4	Parameters	Unit	Q1	Q2	Q3	Q4
h_g	THB/Ton	75	75	75	75	V_{gn}^{t}	THB/Ton	600	600	600	600
s^t	THB/Ton	2,750	3,000	3,000	2,900	V_{mn}^{t}	THB/Ton	350	350	350	350
I_g^0	Ton	0	-	-	-	W_{gm}^{t}	Ton	17	17	17	17
U_i^t	Ton	200,000	200,000	200,000	200,000	W_{mn}^{t}	Ton	17	17	17	17

U_k^t	Ton	44,000	30,000	30,000	30,000	W_{an}^t	Ton	17	17	17	17
U_a^t	Ton	35,000	35,000	35,000	35,000	c_{an}^t	THB / TEU	6,750	6,750	6,650	6,650
β	Ton	1: 0.24	1: 0.24	1: 0.24	1: 0.24	c_{am}^t	THB / TEU	600	600	600	600
D_i^t	Ton	10,000	10,000	10,000	10,000	c_{mn}^t	THB / TEU	6,100	6,100	6,100	6,100
D_a^t	Ton	1,000	1,000	1,000	1,000						

Note that information provided here are obtained from a single starch production manufacture in the province. Modeling multiple players with competitiveness effect on demand-price in the supply chain flexibility could be more challenge for the future research. Further, we generate the scenarios to represent the stochastic by using the demand-price models as mentioned previously. The probability of data distribution follows poison distribution. The assumption of the study is that the offering price from manufacturer and F.O.B. price are independent. The farmers have realized the offering price in the same time of F.O.B. price so that they can decide the amount of fresh cassava. Nine scenarios per quarter are generated accordingly. There are 36 scenarios totally for the case study.

3.2 Results

The results obtained from the stochastic two-stage program are depicted in Figures 3, 4, 5, and 6 below. Figure 3 depicts the flexibility of the farmer that sold the fresh cassava to the tapioca starch manufacturer. The percentages on the figures indicate the additional volumes that each player can accommodate at each quarter or the reserve capacity. As can be seen, the capacity flexibility (gap between additional and base pattern volumes) in quarter 1 is less than other quarters. This is because quarter 1 is the cropping season for cassava in Thailand. Consequently, it reflects the purchasing, warehousing capacity of the manufacturer in that quarter as shown in Figure 4. In quarter 2 and 3, however, there is less fresh cassava cultivated by farmers so the capacity of manufacturer slightly drops but the export demand still prevails.

The results show that the manufacturer has to import fresh cassava root form other regions to fulfill their needs. It implies the needs for off-season cassava farming for the farmers. In Figure 5, there is no flexibility of truck transportation throughout the year. This is because the manufacturer has limited number of truck in their fleet and they completely use their resources to transport tapioca starch to sea port. Interestingly, the BASE and ADDVOL patterns of farmer and manufacturer are similar as they are part of the inbound logistics. The first quarter is the most critical quarter for the cassava supply chain due to the cropping season as expected. The production capacity and stockpile inventory policy for the fourth quarter should be implemented so that it could accommodate additional demand. The transportation service by outsource are needed for this business. The reserved capacity of train transportation is still high in quarter 2-4 due to less tapioca starch transportation to sea port (shown in Figure 6). Though train transportation has residual capacity to accommodate tapioca starch transportation, it has been little used.

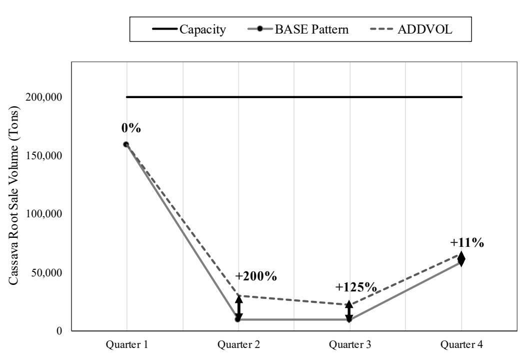

Figure 3. Capacity Flexibility of Farmer

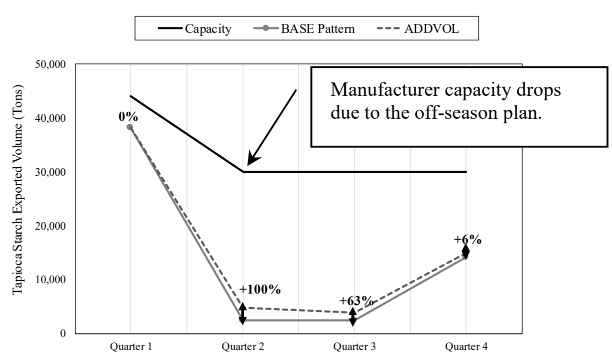

Figure 4. Capacity Flexibility of Manufacturer

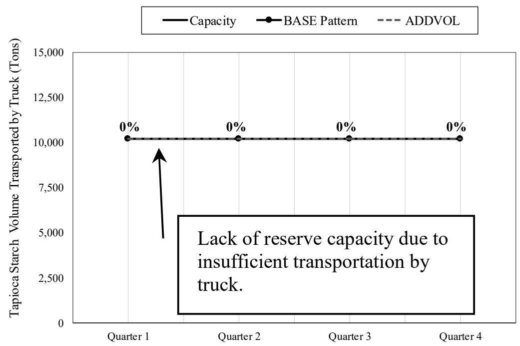

Figure 5. Capacity Flexibility of Truck Transportation

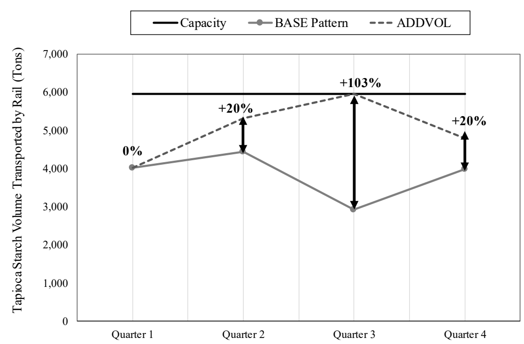

Figure 6. Capacity Flexibility of Rail Transportation

The disadvantage of train schedules and double handling process are the major problem that obstructed the use of train service. The policy that can promote multimodal transportation like hub and spoke (i.e., using truck as feeder to assembly point where the products are packed in the container and then transported to train station and to sea port, accordingly) may be needed to alleviate the congestion traffic from truck transportation during the cropping season in Thailand.

4. CONCLUSION REMARKS

The main aim of this study is to develop a mathematical programming model to assess the supply chain flexibility for cassava business and use case study of Thailand to demonstrate the capability of the purposed models. The results of reserved capacity at each stage indicate the flexibility of the supply chain that can accommodate additional demand. Few policy implications to improve the flexibility of agricultural supply chains can be drawn from the study. For instance, the multimodal transportation for agricultural products should be promoted to help the congestion during the cropping season. The coordination between manufacturer and famer for farming and cropping the fresh cassava should be implemented so the volumes in the supply chain could be more balanced. Additionally, the study on multiple players on price demand competitiveness and effects on supply chain flexibility should be explored in the future research.

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