Strategic Supply Chain Optimization for the Cassava Industry in Thailand

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Abstract—The objective of this study is to maximize profit through the cassava industry supply chain in Thailand. The mathematical model is developed by addressing the cassava supply chain industry in the view of the manufacturers that use the raw material (cassava roots) to produce finished products and generates maximize profit to the supply chain. Results show that the optimization of the supply chain presents clear advantages of the better planning on the given constraints. This study is tested by using data from the actual cassava industry supply chain. The model is validated and solved by using Excel Solver software. Sensitivity analysis on the proposed model is conducted in order to draw useful conclusions regarding the factors that play the most important role in the efficiency of the supply chain.

Key Words: Cassava supply chain, cassava products, cassava roots, mathematical model, optimization

I. INTRODUCTION

Cassava is the most important tropical root crop which the countries that can cultivate are the countries in the tropical zone. Cassava generally requires re-processing before consumed. Cassava is one of the important agricultural products in Thailand, as it is claimed as one of the largest cassava products exporters in the world. Cassava supply chain starts from cassava roots which cultivated by the farmers. They are supplied by the farmers or middleman and be supplied to the manufacturing (P.Parthanadee, 2009).

There’re no. of farmers who cultivate cassava more than 500,000 families in Thailand. It’s sold in form of cassava roots. The selling price and amount of cassava roots that sold vary from time to time depend on the agreeable price by farmers and the factory. Cassava roots are perishable product, which after harvest they have to be produced or used within a few days, otherwise they will ferment (Achimba, 2009).

The problems start from the fluctuation on the buying/selling price of cassava roots and cassava products, volume of sales and production, the ability to supply by the farmers, the capability to produce from the manufacturers, the demands and supply from the customers, etc. Since the price of both cassava roots and cassava products are not stable, it changes from time to time. The manufacturers must decide the best use of it (Lazaros Gg,Papageorgiou, 2011).

With the problems today on how to make the best use of it with the limited resources available. The management has to justify which kind of cassava product to produce in order to get the maximize profit. There are no study by any researchers on the topic despite that some researchers have done the optimization on other products.

In today’s marketplace, individual manufacturers produce the cassava products as the available of the raw material supply by the farmers and use their own experience and forecast on producing cassava products which makes the most profit to them.

In order to solve the following problems, the mathematical models are developed for making the decision to justify the amount and price to buy from the suppliers and sell with the competitive price to the customers.

The objectives of this study are to: 1) study on the factors which influence to its supply chain in Thailand 2) develop the decision support tools in order to assist the owners or the related parties in making the decision in producing the cassava products that generate the highest benefit 3) use the risk management technique to determine the factors that affect the supply chain 4) be used as tools for the government sector in the future in order to set up the new policy 5) use as the references and the foundation background to the cassava study in Thailand, or be used as the guideline to other agriculture products.

This study is validated by testing with the existing players in the industry. “Excel Solver” software is used as tools to solve the optimization model since there are a large no. of possibility alternatives result for study, which it can’t be calculated with manual and it needs the software to solve it.

II. LITERATURE REVIEW

A supply chain is the integration of various parties to work together in order to acquire raw materials and produce them into finished products, by adding value to the products and deliver them to the customers (Marcus, 2010). The supply chain also covers the transformation of supply chain inputs (information, material and finance) into
supply chain outputs (products, service) (Beamon, 2008). The definitions of supply chain management (SCM) have been presented by many researchers which mostly defined SCM as a synonym for logistics, and supply chain control.

The goal of SCM is to improve its competitiveness by increasing the customer service level, and lowering total cost of the chain. (Stanley E. Fawcett, 2008). All parties are collaborated to increase the supply chain performance (Wolfgang Ulaga, Andreas Eggert, 2006). In SCM processes, inventory management is so challenging since it directly impacts both cost and service (C. Clifford Defee, 2010). Uncertain of both demand &supply and production cycle time make it necessary to hold inventory at certain positions in the supply chain to provide adequate service to the customers (M. Braglia, 2010).

The farmers’ perceptions of cassava cultivation and the results showed that the farmers’ reasons for growing cassava are (i) ease of growing (ii) good prices; (iii) ease of selling and (iv) ability to grow on poor soils (U. Sopheap, 2011). Related to the needs of cassava as raw material, availability of cassava including quantity and quality was the most problem faced by the industry (I.B. Suryanigrat, 2015). As the demands in many industries are increasing, cassava roots production has to be improved to match high demand.

They have the problems how to minimize the loss during harvest and post-harvest (Diego Naziri, 2014). Most study about the cassava roots are to extend the shelf life of the cassava roots, reduce the loss during harvest or post-harvest, improve the efficiency of cassava production, increase the yield in cassava plantation (Adisak Suvittawatt, 2014).

Cassava pellets are regarded as a superior value-added product than cassava chips. The demand for cassava pellets are driven by the consumption of livestock products, and their price compared to substitute products (Sillar Associates, 2005). Since some changes in the regulation in EU market, it affected the Thai cassava chips and pellets were unable to compete in EU market (Orathai Chaisinboon, 2011).

Ethanol is a type of alcohol derived from plant fermentation to change starch from plant to sugar, then sugar will be converted to alcohol and purified to be 95% alcohol by distillation which can be used as fuel. Ethanol manufacturing to produce fuel in Thailand can be derived from various type of raw material such as cassava (Chutima Wichitchana, 2014). Originally, ethanol was manufactured by fermentation of molasses in Thailand but the production of molasses was not sufficient, therefore, the government supported R&D to conduct a study that used cassava to produce ethanol (Thu Lan T. Nguyen, 2007). Several factors that using cassava to produce ethanol: 1) drought resistant 2) minimum input requirements 3) available all year 4) easily processed into dried cassava chips (and keep) 5) easily transportable (Klanarong Siroth, 2010). The main objective of the development of ethanol production technology from cassava is to produce high yield of ethanol, to save energy and water (Kuako Piyachomkwam, 2011).

In Thailand, cassava plays a major role in the economy of the country. It is mainly used for food, feed and fuel. Cassava starch are used in both food and industry sectors. There are demands from both domestic and export markets. For ethanol production, cassava is used as raw material due to the low input cost of production and different agronomic characteristics compared to sugarcane. Cassava roots and chips are the major raw materials for ethanol manufacturing. Based on the types of raw materials, the yield of ethanol and production costs are different (Hnin Ei Win, 2017).

A common term optimize is usually used to replace the terms maximize or minimize. The mathematical function that is to be optimized is known as the objective function (Sarker & Newton, 2008). Linear Programming (LP) models can be viewed as part of development to best solution. The tools that used to formulate the problems in mathematical models, techniques for solving the models (algorithms) and engines for executing the steps of algorithms (Ahmed, 2015).

The optimization problems in agriculture are more difficult to use by normal optimization techniques since the complexity of the environmental aspects involved. The problems also deal with uncertainty and the mathematical programming models formulated should be treated using the methods of stochastic programming. However, the linear programming approach is still the one most spread in the field. The crop planning optimization belongs among the most typical optimization problems in the area of natural resources (Janová, 2012).

One of the key risks in cassava supply chain was cassava products demand and cassava roots supply. Minimizing risks is one of the most important purposes in business management (Nogueira, 2000).

III. MATHEMATIC FORMULATION

The cassava supply chain which starts from cassava roots ($X_d$) uses to produce cassava products and sell to the customers ($Y_d$) i.e. starch, chips, pellets, ethanol, etc. The supply chain starts from cassava roots that the manufacturers buys from the farmers ($f$)to produce various kinds of cassava products ($i$) to produce to the customer ($j$). For the farmers, they can supply cassava roots on any days ($t$) depend on the availability to supply by them.

The products in the supply chain have their own demands and supply. Some questions on the value chain is how to have the best use of it. Presently, the selling price and amount of cassava roots that sold varies from time to time depend on the farmers, the manufacturers and the customers. Moreover, the selling price of the cassava
products affect the competition in the supply chain since the high competitors among the manufacturers and the farmers other than the price, amount of buy & sell to make the production, and timing to buy & sell the products with the question how to utilize them with the best use of them.

The mathematical model is set up as the tools to help the manufacturers make the decision in producing the cassava products.

The indices, parameters, and sets associated with product portfolio optimization problems are listed.

Indices

\[ i = \text{The cassava products type}, \quad \text{whereas } i = 1 \text{ (starch chips)}, \quad 2 \text{ (chips)}, \quad i = 3 \text{ (pellets)} \]

\[ j = \text{The cassava products to produce and sell to the customer}, \quad \text{whereas } j = 1 \text{ (customer no.1)}, \quad j = 2 \text{ (customer no.2)}, \quad \ldots \]

\[ f = \text{The farmer that sold cassava roots}, \quad \text{whereas } f = 1 \text{ (farmer no.1)}, \quad f = 2 \text{ (farmer no.2)}, \quad \ldots \]

\[ t = \text{The day that the cassava roots are sold and used to produce the cassava products, whereas } t = 1 \text{ (day no.1)} \]

\[ 2 \text{ (day no.2)}, \ldots , t \text{ (day no.t)} \]

Parameters

\[ P_a = \text{Unit cost of cassava roots from farmer “f” on day “t”} \]

\[ A_o = \text{Unit price of product “i” that are sold to customer “j” on day “t”} \]

\[ H = \text{Cassava factory, unit inventory holding cost per day} \]

\[ N_s = \text{Quantity of cassava products “i” that kept in the inventory in day “t”} \]

\[ N_{\text{line} = t} = \text{Quantity of cassava products “i” that kept in the inventory in day “t”} \]

\[ M = \text{Quantity of cassava products from production line} \]

\[ M_s = \text{Quantity of cassava products, product “i” on day “t”} \]

\[ R_t = \text{Total inventory holding cost of cassava factory} \]

\[ Q = \text{Total operation cost of cassava production} \]

\[ M_0 = \text{Quantity of cassava products “i” to produce on day “t”} \]

\[ E_{M_0} = \text{Total cash flow at the end of day “t”} \]

\[ E_{M_s} = \text{Initial cash flow} \]

\[ F_i = \text{Operation cost per unit for product “i”} \]

\[ C_i = \text{Conversion factor from cassava roots to product “i”} \]

Decision Variables

\[ X_o = \text{Buy quantity of cassava roots from farmer “f” on day “t”} \]

\[ Y_{ij} = \text{Sales quantity of product “i” to customer “j” on day “t”} \]

Objective Function

Maximize \( z = [ \text{TR} - \text{TC} ] = [ \text{TC} - \text{RM} - [ \text{R} + \text{Q} ] ] \)

\[ \sum_{i=1}^{3} \sum_{j=1}^{2} (X_o \times A_o) - \sum_{i=1}^{3} \sum_{j=1}^{2} (Y_{ij} \times F_i) - \sum_{i=1}^{3} \sum_{j=1}^{2} (M_s \times C_i) + \sum_{i=1}^{3} \sum_{j=1}^{2} (R_t \times C_i) \]

To have the optimization value, it has to be justified the amount of cassava roots \( X_o \) that used to produce the cassava products \( i \).

Total revenue \( \text{(TR)} \): Selling all cassava products in the supply chain (the summation of the total revenue from selling all kinds of cassava products).

Total cost \( \text{(TC)} \): Total cost that occurs in the system. Total cost \( \text{(TC)} \) under this study consist of Total cost of the raw materials used \( \text{(RM)} \), total inventory cost \( \text{(R)} \) and total operating cost \( \text{(Q)} \).

A maximization of total profits begins from selling product “i” to customer “j” day “t”, minus raw material cost which buy from farmer “i” day “t”, inventory cost & operation cost.

Constraints

\[ R_t = \sum_{i=1}^{3} \sum_{j=1}^{2} (H \times N_s) \]

Inventory cost \( \text{(R)} \) calculate by handling unit cost per day \( (H) \) multiply stock quantity of product “i” on day “t” \( (N_s) \)

\[ \sum_{i=1}^{3} \sum_{j=1}^{2} N_s \leq 500,000 \quad ; \forall t \]

Inventory capacity is 500,000 Units for all finished products.

\[ N_{\text{line} = t} = N_{\text{line} = t+1} + \sum_{i=1}^{3} \sum_{j=1}^{2} Y_{ij} - \sum_{i=1}^{3} \sum_{j=1}^{2} X_o \quad ; \forall t \]

Daily inventory quantity equal to previous balance plus daily finished goods on that day. Assume that all products hold equal space per weight.

\[ Q = \sum_{i=1}^{3} \sum_{j=1}^{2} (F_i \times Y_{ij}) \]

Production cost \( \text{(Q)} \) calculate by production unit cost of product “i” multiply sales quantity to customer “j” of product “i” on day “t” \( (Y_{ij}) \)

\[ M_s = C_i \times X_o \quad ; \forall t \]

\[ E_{M_s} = E_{M_{s-1}} + \sum_{i=1}^{3} \sum_{j=1}^{2} (Y_{ij} \times A_o) \times \sum_{i=1}^{3} \sum_{j=1}^{2} (X_o \times P_i) \]

Total cash on each day equal to previous balance plus income from sale minus buying cassava roots cost

\[ E_{M_s} \geq 0 \quad ; \forall t \]

Cash on hand must not less than zero

\[ \sum_{i=1}^{3} \sum_{j=1}^{2} (X_o \times P_i) \leq E_{M_s} \quad ; \forall f, \forall t \]

To buy cassava roots, the factory must hold cash

\[ Y_{ij} \geq 0 \quad ; \forall i, \forall j, \forall t \]

Selling quantity must not less than zero

\[ X_o \geq 0 \quad ; \forall i, \forall t \]

Buying quantity must not less than zero

\[ \sum_{i=1}^{3} \sum_{j=1}^{2} Y_{ij} \leq N_o \quad ; \forall i, \forall j, \forall t \]

Total daily selling quantity on each product must less than daily inventory which includes finished goods on that day.

Other than high competitors among the buyers/seller affect the buying/selling pricing and amount of the products to produce, other constraints i.e. cash on hand or cash ability to buy the raw materials to produce the product “i” on the day of buy/sale transaction, (day “t”), ability of the inventory to keep stock and ability/capacity of the...
manufacturing to produce the product “i” also affects the optimization of the supply chain.

IV. MODEL VALIDATION

In order to obtain the data to set up the models, the interviews from the entrepreneur during Oct.2016-Sep.2017 were made to get data input with the information about the selling price and the buying price of each cassava products. The buying & selling amount are also needed.

The mathematical models that were developed can be applied in solving the optimization problems with the given constraints. To validate the model, all the parameters and decision variables will be tested by compare to the current market situation.

The mathematical models in this use Excel Solver software as tools to test and perform the data validation. With the given constraints, which kind of cassava products and amounts to be produced, and the selection of the farmers to produce and amount of cassava roots to be used in order to get the maximize profit of the supply chain.

Initial cashflow to produce EM, = 10,000,000 Baht to test with the models.

![Figure 1: The cassava supply chain flow](image)

Figure 1 illustrates the cassava supply chain flow, and Table 1 is the input data of cassava roots price from the farmers, and cassava products price to the customers.

Table 1: Data input of cassava roots from the suppliers (farmers), and cassava products to the customers

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The suppliers who sold with the competitive would be selected to supply cassava roots with the 1st priority, then the next supplier with competitive pricing is served until no more needs from the factory. Ethanol is chosen to produce with the 1st priority until there’s no more supply from this supplier, than the next competitive supplier would be chosen until it reaches max. capacity of the factory. This method, it generated max. profit of 13,075,943 Baht.

Table 2: The output from using Excel Solver software.

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<tr>
<th>OUTPUT NAME</th>
<th>VALUE</th>
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</thead>
<tbody>
<tr>
<td>EM</td>
<td>13,075,943</td>
</tr>
<tr>
<td>EM(1)</td>
<td>12,456,789</td>
</tr>
<tr>
<td>EM(2)</td>
<td>11,987,654</td>
</tr>
</tbody>
</table>

Normally, the software will perform more than 500 iterations for one calculation to get the result.

Pellets are less attractive product while ethanol is the competitive product for the manufacturers to produce.

In the past, most of cassava products were used to produce starch or chips. Presently, from the promotion campaign by the government to support the bio-diesel oil and gasohol to replace the petroleum oil. Cassava roots and molasses were used most to produce ethanol, it resulted in high demands on both products. For last year’s situation, cassava roots seemed to be the product that the entrepreneurs preferred to use to produce ethanol because the cassava roots price was rather low, while ethanol price was rather competitive and generated good margin.

It was coincided with this study that ethanol is the most attractive product for the cassava entrepreneurs to produce, although there’s some time frame that other products were more attractive but overall during the past 2 years, ethanol seemed to be the most attractive products that used cassava roots to produce.

V. SENSITIVITY ANALYSIS / OTHER HEURISTIC ALGORITHMS

A. Sensitivity Analysis

If there are some changes on the following constraints, how the results will change by changing the following constraints to the models i.e. cashflow on hand, production capacity, inventory capacity and view the outputs compare to the results in each result.

a) Cashflow on hand

The sensitivity analysis by changing the variable, cashflow on hand, into the model. From the study, the cashflow on hand will be varied from 5.50 Million Baht up to 15.0 Million Baht which the result is plotted between the changing cashflow on hand and the profit from the model as shown in the Figure 2.

![Figure 2: Graph shows the relationship between cashflow and output of profit](image)
it is noticed that the cashflow is increased until 11.0 Million Baht, the profit equation will not increase from this amount. The profit will remain at 14.207 Million Baht since it is limited by other constraints. From the model, it is limited by the inventory capacity. For the current constraints, cashflow and inventory capacity are limited by each other.

b) Production capacity
The sensitivity analysis in this paper will be performed by changing the production capacity of each cassava products into the model. The production capacity of each cassava products will be neutral to +/-50.0% change, the results of total profit are shown in Figure 3.

If there is the changing the production capacity of other products i.e. starch, chips and pellets, they are no effect in total profit since they aren’t produced in the system. Except increasing the capacity of ethanol, the profit of the factory will increase too. When the company increases the production capacity of the ethanol, it affects total profit too. The sensitivity analysis on changing the ethanol production capacity to plot to the graph with total profit as shown in Figure 3.

Figure 3: Graph shows the relationship between increase ethanol production capacity and profit.

From this case study analysis, at the neutral situation (0.0% change) in ethanol production, it generates total profit of 15.709 Million Baht. When the ethanol plant production is increased, the factory will gain more margin until it has the limited in one number which from this example, it’s the inventory capacity. If the factory increases the capacity until it’s larger than this figure, there will be no change in total profit.

c) Inventory capacity
The sensitivity analysis will be performed by changing the variable, inventory capacity into the model. From the study, the inventory capacity will be varied from 100,000 - 1,200,000 units by having the inventory capacity of 500,000 units as its base case. The results are shown in Figure 4.

Figure 4: Graph shows the relationship between inventory capacity and output of profit

From Figure 4, it is noticed that inventory capacity increased until 1,000,000 units, the profit equations seem to increase with the slow-down increasing rate. The profit equation increases with the inventory increase. From the case study, it resulted from the high demands in ethanol which presently it is rather benefit to the factory if the factory increases the inventory capacity, it will alleviate the factory to manage the risk more easily if they can increase the inventory capacity to keep more stock inventory.

The increase in the inventory capacity to one limited, then it won’t have any effect to generate more profit to the factory.

B. Perform heuristic algorithms
The solution algorithms that will be used to compare with LP model (optimization model) in order to justify the decision whether it makes the optimization (maximize profit) compare to the traditional methods which the factory choose to buy the cassava roots from the farmers (or suppliers) by the method: 1) buying from the suppliers that locate nearest to the factory (NFF) and 2) buying from the suppliers that carried with the largest volume first (LVF).

a) LP Method
By using LP method, after input the data into the models, the output from using Excel Solver that performed the mathematical model. Cassava roots were bought from supplier 1 for 2,328,418 Kg/day on day 1, and since day 2-10 the factory bought cassava roots from supplier 2 for 2,000,000 Kg/day and from supplier 3 for 328,418 Kg/day.

Ethanol was produced for 200,000 Lts., then Chips for 100,000 Kg would be produced for customer 1, then Starch amount 200,000 Kg would also be produced for 200,0000 Kg. to customer 3. It generated total profit of 13,075,943 Baht.

b) Nearest Farmers First (NFF) Method
For NFF method, the selection to buy cassava roots are selected by using the criteria that the factory will buy cassava roots from the farmers who locate near the factory as the 1st priority.

This case, the farmer no.1 locates nearest to the factory and the farmer no.2 is the next supplier that located near
the factory or the factory will buy the cassava roots as the 2nd priority from the farmer no.2.

By using the same data as LP method except the suppliers’ selection are different. The criteria in buying the cassava roots are the only difference. This method generated total profit of 7,827,989 Baht.

c) Largest Volume First (LVF) Method

For LVF method, the selection to buy cassava roots with the criteria that the factory will buy cassava roots from the farmers (or suppliers) who supply with the largest volume of cassava roots as the 1st priority, and the next largest volume suppliers are the next priority to buy.

By using the same data as LP method, except the suppliers’ selection are different. The criteria in buying the cassava roots are the only difference. This method generated total profit of 7,529,273 Baht.

Table 3: Compare the advantages and disadvantages of each solution algorithm

<table>
<thead>
<tr>
<th>No.</th>
<th>Solution Algorithm</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LP Method</td>
<td>- It generates the highest benefit to the supply chain.</td>
<td>- It needs a lot of data to input in order to make the best benefit to the models</td>
</tr>
<tr>
<td>2</td>
<td>Nearest Farmers First (NFF) Method</td>
<td>- It’s convenient for the factory since it buys from the nearest factory that closed to the factory</td>
<td>- The factory may buy cassava roots with higher price.</td>
</tr>
<tr>
<td>3</td>
<td>Large Volume First (LVF) Method</td>
<td>- It’s convenient for the factory since it buys from less suppliers</td>
<td>- The price may not be the best price that the factory buys.</td>
</tr>
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</table>

It can be concluded from the study that LP model generates the higher profit than other traditional selection methods which the factory use in the daily operation (in buying the cassava roots from the nearest first, or from the suppliers which supply the largest volume first).

VI. CONCLUSION

The study of this paper can meet the objectives:

1) Study on the factors which influence to cassava supply chain in Thailand: The entrepreneurs should manage the size of the production capacity in appropriate amount that they can serve the customer demands without making the business loss opportunity. However, inventory capacity should be synchronized in order not to have the bottleneck in the supply chain.

2) Develop the decision support tools in order to assist the related parties in making the decision in generating the highest benefit to them: Since there are some changes in the demands and supply especially on the price and amount of the product needs. It will reflect some changes in any decision making to the factory, the movement of them are dynamics. If the models are used as tools to help the management in justifying the cassava product to produce to get the maximize profit.

3) To use the risk management technique to determine the factors that affect the supply chain: There are many key risks in cassava industry supply chain, which one of the key risk is the farmers temporarily change the market in which they sell their cassava, and diversifying into other crops.

4) Be used as tools for the government sector in order to set up the new policy that related to cassava supply chain: The government sector can use it as tools in setting up the related policy etc. The collaboration among all parties with the government supports will help the overall supply chain.

5) Use as the references and the foundation background to the cassava study in Thailand or be used as the guideline to other agriculture products: The study will help them produce and manage the product that generates high margin.

REFERENCES


