A Mathematical Model for the Sugarcane Trading System in Thailand

Surattana Sungnul, Wisanlaya Pornprakun, Santipong Prasattong and Chanasak Baitiang

***Abstract*—In this work, the sugarcane trading system in Thailand is investigated. The price of sugarcane depends on its quality (sweetness) and weight. The objective of this work is to develop a mathematical model to find the optimal time to minimize gathering cost and maximize revenue. The ε-constraints method will be applied to solve the mathematical model by choosing gathering cost as the main objective function of the model. The optimal harvest time in the four regions of Thailand for crop years 2012/13, 2013/14, 2014/15 and 2015/16 were obtained and then compared to the results with paper [6] which used the ε-constraints method to solve the mathematical model by choosing revenue as the objective function of the model.**

***Index Terms*—A mathematical model, sugarcane trading system, ε-constraints method.**

I. Introduction

CU rrently, the sugarcane trading system of Thailand uses the 70:30 profit sharing system between agriculturists and factories which provides monetary support from the Cane and Sugar Fund to sugar cane producers. The funds are raised by itself, largely from yearly sugar sales. When the funds are not enough, it seeks loans from the state-owned Bank for Agriculture and Agricultural Cooperatives (BAAC). According to the Office of Cane and Sugar Board (OCSB) [1], Thailand will have to revoke its current 70:30 profit-sharing system since 1984, which will require cancelling its quota system and floating domestic sugar prices. Sirivuth Siamphakdee, the chairman of the Thai Sugar Millers Corporation Ltd (TSMC) reported that Thailand's plan is to revoke the sugar quota system, which sets aside three quotas each year to prevent sugar shortages. Quota A sets aside 2.2-2.5 million tons of sugar for domestic consumption, quota B sets aside 800,000 tons for state-run sugar exports and quota C sets the quantity of sugar to be exported by private sugar millers. Thailand also needs measures to deal with potential problems when it scraps the quota system, as global price rises encourage traders and profiteers to smuggle domestic sugar out of the country and sell outside. The sugar system will be changed in order to avoid being challenged by Brazil at the World Trade Organization (WTO). The government agency in charge of sugar policy, the Office of Cane and Sugar Board (OCSB) reported that Thailand has discussed this issue with Brazil twice. The two countries agreed in principle that Thailand is on track to overhaul its sugar system to be fair to all parties. The new laws and regulations on sugar are expected to be applied to the crop year 2017/18 according to senior governmental officers and industry officials.

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The price of sugarcane depends on quality (sweetness or C.C.S.) and weight. C.C.S. means the percentage of sucrose produced from a specific tonnage of sugarcanes. For example, if the C.C.S. is equal to 10, this indicates that 1 ton of sugarcane will obtain the maximum of 100 kg of sucrose.

In 2010, Maximiliano Salles Scarpari and Edgar Gomes Ferreira de Beauclair [2] used linear programming to develop an optimized plan for sugarcane farming in Brazil. The program language used was General Algebraic Modelling System (GAMS) as this system was seen to be an excellent tool to allow profit maximization and harvesting time schedule optimization in the sugar mill studied. The results supported this optimized planning model as being a very useful tool for sugarcane management. In 2012, Francisco Regis Abreu Gomes [3] studied a bi-objective mathematical model for choosing sugarcane varieties with harvest residual biomass in energy co-generation. This study developed a bi-objective mathematical model for choosing sugarcane varieties that result in maximum revenue from electricity sales and minimum gathering cost of sugarcane by harvesting residual biomass. The approach used to solve the proposed model was based on the ε-constraints method. Experiments were performed using real data from sugarcane varieties and costs and showed effectiveness of the model and method proposed. These experiments showed the possibility of increasing net revenue from electricity sale, i.e., discounting the cost increase with residual biomass gathering, by up to 98.44 %. In 2013, Hitoshi Yano and Kota Matsui [4] propose an interactive decision making method for random fuzzy multi-objective linear programming problems (RFMOLP) and applied to crop planning problem such as a farmer or an agricultural manager wants to maximize total profit and minimize working time by using farmland effectively. In 2015, Abdulkareem A Saka and et al. [5] studied production and characterization of bioethanal from sugarcane bagasse as alternative energy sources is aimed at poduction of bioethanol from sugarcane bagasse by 2^4 factorial experimental design method to investigate the influence temperature, time, catalyst concentration and mass of sugarcane bagasse on the yield of bioethanol. The regression model developed also shows that the operating parameters considered in this study have effect on the production of bioethanol from sugarcane bagasse. In 2017, Surattana Sungnul and et al. [6] studied a multi-objective mathematical model to discover the optimal time to harvest sugarcane. This paper applied the ε-constraints method to solve the mathematical model by choosing revenue as the objective function.

In this work, a model will be developed to find the optimal harvest time of sugarcane in order to minimize the gathering cost and to maximize the agriculturists revenue. The mathematical model will be formulated in a bi-objective optimization framework under the OCSB conditions. The ε-constraints method will be used to solve the bi-objective optimization problem by choosing the gathering cost as the main objective function. The obtained results of the optimal time to harvest sugarcane will then be compared with paper [6] covering crop years 2012/13, 2013/14, 2014/15 and 2015/16.

II. MULTI-OBJECTIVE OPTIMIZATION

A multi-objective optimization problem has a number of objective functions which are to be minimized or maximized. As in a single-objective optimization problem, the problem usually has a number of constraints which any feasible solution (including the optimal solution) must satisfy. In its general form, a multi-objective optimization problem (MOOP) can be stated as follows (see, e.g., [7]):

$$\begin{aligned} &Minimize && f_m(\vec{x}), \quad m = 1,2,...,M \\ &subject\ to && g_j(\vec{x}) \geq 0, \quad j = 1,2,...,J \\ & && h_k(\vec{x}) = 0, \quad k = 1,2,...,K \\ & && x_i^{(L)} \leq x_i \leq x_i^{(U)}, \quad i = 1,2,...,n \end{aligned} \tag{1}$$

A solution $\vec{x}$ is a vector of n decision variables : $\vec{x} = (x_1, x_2, ..., x_n)^T$. The last set of constraints are called variable bounds as they restrict each decision variable x_i to take a value within a lower bound $x_i^{(L)}$ and an upper bound $x_i^{(U)}$. The feasible region D for the MOOP is the set of vectors $\vec{x}$ that satisfy all constraints. If each objective function $f(\vec{x})$ is denoted by z_m and the vector of all objective functions is denoted by $\vec{z}$, then the objective function space can be defined as:

$$\begin{aligned} Z = \{\vec{z} = (z_1, z_2, ..., z_M) | z_m = f_m(\vec{x}), \\ \forall \vec{x} \in D, m = 1,2,...,M\} \end{aligned} \tag{2}$$

Since no solution optimizes simultaneously all objectives, one will search for an acceptable trade-off instead of an optimal solution. This compromise must be such that no strictly better solution exists, even though some solutions might be considered as equivalent. This involves a partial order of the objective space, defined by a dominance relation. The latte is used to characterize Pareto efficiency, a concept that replaces the optimal solution of single objective optimization problems.

Definition 1 Dominance relation Let $\vec{z}$ and $\vec{\bar{z}} \in Z$. We say that $\vec{z}$ dominates $\vec{\bar{z}}(\vec{z} \preceq \vec{\bar{z}})$ if and only if $\forall z_i \leq \bar{z}_i$ where at least one inequality is strict.

Definition 2 Pareto efficiency A solution $\vec{x} \in D$ is Pareto efficient in D, if and only if $\nexists \vec{x} \in D$ such that $f(\vec{\bar{x}}) \preceq f(\vec{x})$.

Definition 3 Efficient set The efficient set is defined by $E = \{\vec{x} \in D / \vec{x}$ is Pareto efficient in $D\}$.

Definition 4 Pareto front The Pareto front $F = \{f(\vec{x}) / \vec{x} \in E\}$.

The efficient set E contain all the Pareto efficient solutions defined on the solution space and Pareto front F contain all the non-domonated points in the objective space defined on the objective space.

In this work, the ε - constraints method [7] was used to solve the MOOP. This method consists of reformulating a multi-objective problem by choosing the most important objective while maintaining other objectives constrained by upper bounds defined by a decision maker. For example, if $f_\mu(\vec{x})$ is selected as the most important objective, then the problem can be reformulated as follows:

$$\begin{aligned} &Minimize && f_\mu(\vec{x}) \\ &subject\ to && f_m(\vec{x}) \leq \varepsilon_m, \quad m = 1,2,...,M; m \neq \mu \\ & && g_j(\vec{x}) \geq 0, \quad j = 1,2,...,J \\ & && h_k(\vec{x}) = 0, \quad k = 1,2,...,K \\ & && x_i^{(L)} \leq x_i \leq x_i^{(U)}, \quad i = 1,2,...,n \end{aligned} \tag{3}$$

where ε_m is an upper bound of objective m, $m = 1,2,...,M; m \neq \mu$ and D is the set of feasible solutions to the ε-constrained problem.

If the bounds (ε_m) were not properly selected, the subspace obtained by the constraints can be empty, i.e., the problem (3) has no solution.

III. MATHEMATICAL FORMULATION

In this section, the mathematical model is formulated in a bi-objective optimization framework under the Office of the Cane and Sugar Board (OCSB) conditions. The main purpose is to find the optimal harvest time of sugarcane in order to minimize the cost and maximize the agriculturist's revenue. This problem is a bi-objective optimization problem to minimize cost and maximize revenue. For the ε-constraint formulation, the minimum gathering cost of production of the sugarcane will be chosen as the objective function and the maximum of revenue from the sugarcane sale will be bounded by an ε-constraints.

Gathering cost of production[6]: The gathering cost of production can be separated into two parts: 1) average cost of production on the farm and 2) cost of transport. The total gathering cost $GC_{j,k}(i)$ baht/ton of sugarcane production from planted area j in the harvest at time k is given by

$$GC_{j,k}(i) = (C_j + C_{T_j}) a_{j,k}(i), \quad i = A, B \tag{4}$$

where C_j is the average total cost of production of sugarcane on farms in area j and C_{T_j} is cost of transport to factories for sugarcane produced in area j. The average total cost of production C_j consists of fixed costs such as farm rent and depreciation of equipment, and variable costs such as labor, materials and interest rates.

Revenue of selling[6]: The government determines the sugarcane prices which are based on two main factors; 1) weight and 2) commercial cane sugar (C.C.S.).

1) Revenue from the weight of sugarcane: The OCSB classifies sugarcane going into factories into 2 types; 1) fresh sugarcane and 2) fired sugarcane. As determined by the government, agriculturists who sell fired sugarcane will have 20 baht/ton deducted from the price of sugarcane based on weight. The factory will share this

amount of money between agriculturists who sell fresh sugarcane and increase their price based on weight by a maximum of 70 baht/ton.
The price of fired sugarcane based on weight $P_w(B)$ is therefore defined by

$$P_w(B) = P_w - 20, \tag{5}$$

where P_w is the basic price of sugarcane based on weight set by the government (baht/ton).
The price of fresh sugarcane based on weight $P_w(A)$ is defined by

$$P_w(A) = P_w + \frac{20a_{j,k}(B)}{a_{j,k}(A)}, \tag{6}$$

where $a_{j,k}(A)$ is the amount of fresh sugarcane (tons) from planted area j in the harvest at time k and $a_{j,k}(B)$ is the amount of fired sugarcane (tons) from planted area j in the harvest at time k. Reasonable values for the total planted areas of sugarcane were estimated from OCSB data. The actual values for $a_{j,k}$ were computed by the optimization program.
Therefore the revenue from weight of sugarcane is defined by

$$P_1(i) = P_w(i)a_{j,k}(i), \quad i = A, B \tag{7}$$

2) Revenue from C.C.S. of sugarcane. The price per ton based on C.C.S is defined by

$$P_2(i) = [P_c(1 + 0.06y_{j,k})]a_{j,k}(i), \quad i = A, B \tag{8}$$

where P_c is the price per ton determined by the government for sugarcane with 10 C.C.S., $y_{j,k} =$ C.C.S.-10, where C.C.S. is the average C.C.S. from sugarcane in planted area j in the harvest at time k. The factor 0.06 is the rate of change of price per 1 C.C.S. change from the base level of 10.
Therefore, revenue $[RV_{j,k}(i)]$ from the sale of sugarcane from planted area j in the harvest at time k is determined by adding Equation (7) and Equation (8) as shown in Equation (9),

$$\begin{aligned} RV_{j,k}(i) &= P_1(i) + P_2(i); \qquad\qquad i = A, B \\ &= \{P_w(i) + [P_c(1 + 0.06y_{j,k})]\}a_{j,k}(i). \end{aligned} \tag{9}$$

A. The Mathematical Model of Sugarcane

The mathematical model of sugarcane is described by Equation (10)–(14). The objective function Equation (10) is to minimize gathering cost of production. The constraint Equation (11) represents the second objective of the problem which is to maximize revenue from the sugarcane selling, with lower bound given by ε_e. The decision variables $X_{j,k}$ are defined by $X_{j,k} = 1$ means that planted area j is harvested at time k and $X_{j,k} = 0$ means that j is not harvested at time k. In the constraint set, Equation (12) and Equation (13) ensure that in each area the sugarcane is harvested only at one time k and the constraint Equation (14) means that sugarcane from planted area j in the harvested time k has to greater than 6 C.C.S..

$$Minimize \quad \sum_{j=1}^{m}\sum_{k=1}^{n} GC_{j,k}(i)X_{j,k}, \ i = A, B \tag{10}$$

$$subject\ to \quad \sum_{j=1}^{m}\sum_{k=1}^{n} RV_{j,k}(i)X_{j,k} \geq \varepsilon_e, i = A, B \tag{11}$$

$$\sum_{k=1}^{n} X_{j,k} = 1; \ \forall j = 1, 2, ..., m \tag{12}$$

$$X_{j,k} \in \{0, 1\}; \forall j = 1, 2, ..., m; \quad \forall k = 1, 2, ..., n \tag{13}$$

$$y_{j,k}X_{j,k} > -4 \tag{14}$$

The model will be solved for p values of ε_e defined as follows:

$$\varepsilon_{e+1} = \varepsilon_e + \Delta\varepsilon; \quad e = 1, 2, ..., p - 1, \tag{15}$$

where $\Delta\varepsilon = \frac{UB-LB}{p-1}$ and
LB and UB are lower and upper bounds defined as follows.
$LB = \varepsilon_1$ (Summation of minimum of revenue in each area j),
$UB = \varepsilon_p$ (Summation of maximum of revenue in each area j) and
p is number of experiments.

B. Data Used in Experiments

In this work, the optimal times to harvest sugarcane were determined for crop years 2012/13, 2013/14, 2014/15 and 2015/16 [8]. The harvest time in each crop year was divided the harvest time into 12 equal intervals ($k = 1, 2, ..., 12$) for example; the harvest time for crop year 2012/13 is 15 November 2012 to 16 May 2013. Therefore the harvest at time $k = 1$ means the time between $15-30$ November 2012 and so on until the harvest at time $k = 12$ means the time between $1 - 16$ May 2013. Data from Office of Cane and Sugar Board used in the experiments for crop years 2012/13, 2013/14, 2014/15 and 2015/16 are presented in Fig. 1 - Fig. 8 and TABLE I - TABLE V, respectively. Fig. 1 - Fig. 8 show quantity of fresh and fired sugarcane delivered to factories in the four regions, j of Thailand in each interval time k. TABLE I shows the price of the sugarcane and the average total cost of production and TABLE II - TABLE V show the average C.C.S. of the sugarcane in each area j. The data in TABLE II - TABLE V were used to determine the values of the $y_{j,k}$ in the C.C.S. price $P_2(i)$ for the sugarcane in Equation (8).

A comparison of the quantities of fresh and fired sugarcane delivered to the sugar factories over four crop years 2012/13, 2013/14, 2014/15 and 2015/16 are approximately 30% and 70%, respectively.

IV. RESULTS AND DISCUSSION

In this section, the results of the optimal time to harvest are given for both fresh and fired sugarcane covering crop years 2012/13, 2013/14, 2014/15 and 2015/16 are presented. The mathematical model for sugarcane is described by objective function Equation (10) subject to constraints Equation (11) - (14). The data from Fig. 1 - Fig. 8 and TABLE I - TABLE V were used in the bi-objective optimization model. The results are as follows.

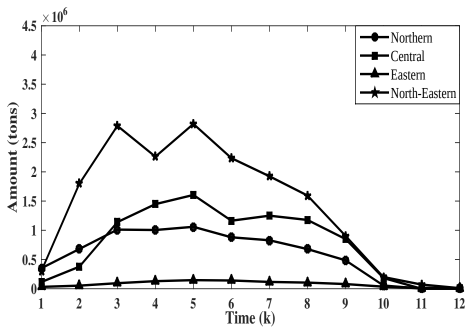

Fig. 1. The quantity of fresh sugarcane ($\times 10^6$ tons) delivered into factories covering four regions of Thailand for crop year 2012/13

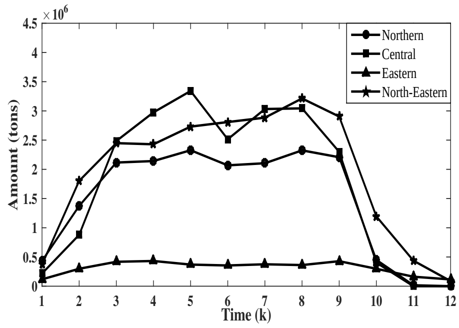

Fig. 2. The quantity of fired sugarcane ($\times 10^6$ tons) delivered into factories covering four regions of Thailand for crop year 2012/13

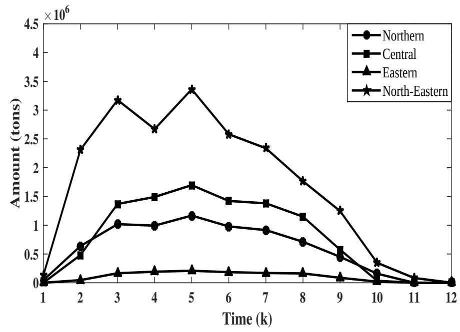

Fig. 3. The quantity of fresh sugarcane ($\times 10^6$ tons) delivered into factories covering four regions of Thailand for crop year 2013/14

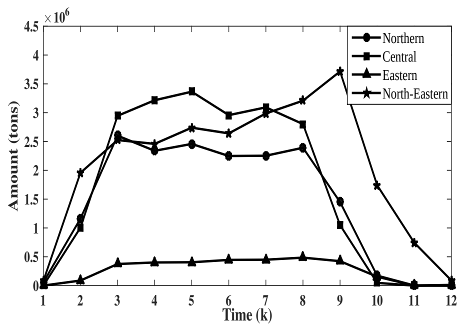

Fig. 4. The quantity of fired sugarcane ($\times 10^6$ tons) delivered into factories covering four regions of Thailand for crop year 2013/14

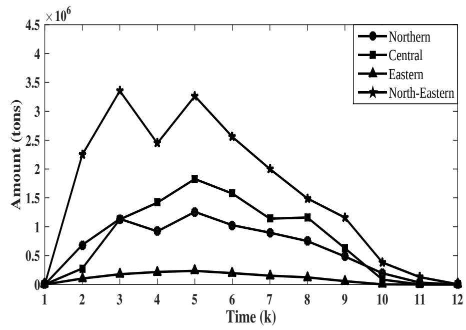

Fig. 5. The quantity of fresh sugarcane ($\times 10^6$tons) delivered into factories covering four regions of Thailand for crop year 2014/15

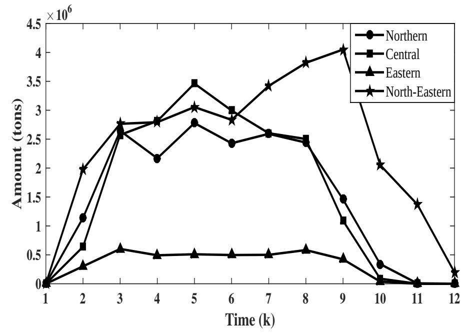

Fig. 6. The quantity of fired sugarcane ($\times 10^6$tons) delivered into factories covering four regions of Thailand for crop year 2014/15

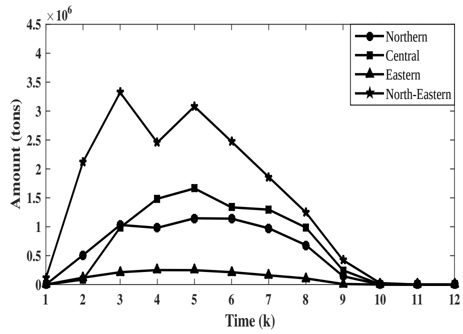

Fig. 7. The quantity of fresh sugarcane ($\times 10^6$tons) delivered into factories covering four regions of Thailand for crop year 2015/16

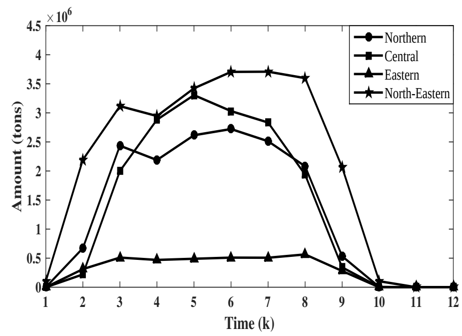

Fig. 8. The quantity of fired sugarcane ($\times 10^6$tons) delivered into factories covering four regions of Thailand for crop year 2015/16

A. Results for Crop Year 2012/13

1) Fresh Sugarcane: In the computations, 100 values of ε_e were used equally spaced between $LB = 1.479 \times 10^8$ and $UB = 7.041 \times 10^9$ in order to determine how the minimum gathering cost and the optimal cutting time changed as the lower bound on the revenue changed. The results of revenue from the fresh sugarcane sales and gathering cost for each ε_e are presented in Fig. 9. It

TABLE I
THE PRICE OF SUGARCANE AND AVERAGE TOTAL COST OF PRODUCTION (BAHT/TON)

Price and Cost of Sugarcane (baht/ton)	*Crop Year*			
	2012/13	**2013/14**	**2014/15**	**2015/16**
$P_w(A)$	198.47	194.67	197.41	196.77
$P_w(B)$	140	140	140	140
P_c	999.2	958.31	900	881.47
$C_{Northern}$	1113.49	1031.42	1323.16	1109.49
$C_{Central}$	1114.85	1015.04	1191.78	1068.95
$C_{Eastern}$	1077.65	1184.28	1313.9	1176
$C_{North-Eastern}$	963.45	1087.03	1218.83	1080.79

TABLE II
AVERAGE C.C.S. OF SUGARCANE FOR NORTHERN ($j = 1$)

Time	**2012/13**	**2013/14**	**2014/15**	**2015/16**
$15-30\ Nov\ (k=1)$	8.50	9.69	0.00	0.00
$1-15\ Dec\ (k=2)$	8.79	10.06	9.81	8.94
$16-31\ Dec\ (k=3)$	9.27	10.51	10.24	9.60
$1-15\ Jan\ (k=4)$	9.70	10.92	10.58	10.11
$16-31\ Jan\ (k=5)$	10.13	11.34	11.00	10.52
$1-15\ Feb\ (k=6)$	10.44	11.65	11.32	10.96
$16-28\ Feb\ (k=7)$	10.71	11.89	11.58	11.30
$1-15\ Mar\ (k=8)$	10.92	12.11	11.78	11.53
$16-31\ Mar\ (k=9)$	11.10	12.23	11.87	11.57
$1-15\ Apr\ (k=10)$	11.19	12.25	11.89	11.57
$16-30\ Apr\ (k=11)$	11.20	0.00	11.89	0.00
$1-16\ May\ (k=12)$	0.00	0.00	0.00	0.00

TABLE III
AVERAGE C.C.S. OF SUGARCANE FOR CENTRAL ($j = 2$)

Time	**2012/13**	**2013/14**	**2014/15**	**2015/16**
$15-30\ Nov\ (k=1)$	8.07	0.00	0.00	0.00
$1-15\ Dec\ (k=2)$	8.59	10.07	9.22	8.86
$16-31\ Dec\ (k=3)$	9.14	10.48	9.82	9.49
$1-15\ Jan\ (k=4)$	9.54	10.84	10.15	10.01
$16-31\ Jan\ (k=5)$	9.95	11.25	10.58	10.36
$1-15\ Feb\ (k=6)$	10.20	11.55	10.93	10.68
$16-28\ Feb\ (k=7)$	10.45	11.78	11.18	10.94
$1-15\ Mar\ (k=8)$	10.66	11.97	11.37	11.12
$16-31\ Mar\ (k=9)$	10.82	12.03	11.44	11.14
$1-15\ Apr\ (k=10)$	10.89	12.03	11.45	11.14
$16-30\ Apr\ (k=11)$	0.00	0.00	0.00	0.00
$1-16\ May\ (k=12)$	0.00	0.00	0.00	0.00

TABLE IV
AVERAGE C.C.S. OF SUGARCANE FOR EASTERN ($j = 3$)

Time	**2012/13**	**2013/14**	**2014/15**	**2015/16**
$15-30\ Nov\ (k=1)$	8.87	0.00	0.00	0.00
$1-15\ Dec\ (k=2)$	9.24	10.15	9.80	9.63
$16-31\ Dec\ (k=3)$	9.70	10.75	10.27	9.83
$1-15\ Jan\ (k=4)$	10.01	11.18	10.60	10.06
$16-31\ Jan\ (k=5)$	10.29	11.59	10.96	10.33
$1-15\ Feb\ (k=6)$	10.45	11.94	11.26	10.66
$16-28\ Feb\ (k=7)$	10.62	12.19	11.46	10.94
$1-15\ Mar\ (k=8)$	10.76	12.40	11.64	11.24
$16-31\ Mar\ (k=9)$	10.85	12.54	11.74	11.35
$1-15\ Apr\ (k=10)$	10.93	12.57	11.74	11.35
$16-30\ Apr\ (k=11)$	10.94	12.57	0.00	0.00
$1-16\ May\ (k=12)$	10.93	0.00	0.00	0.00

TABLE V
AVERAGE C.C.S. OF SUGARCANE FOR NORTH-EASTERN ($j = 4$)

Time	**2012/13**	**2013/14**	**2014/15**	**2015/16**
$15-30\ Nov\ (k=1)$	9.69	10.26	0.00	9.87
$1-15\ Dec\ (k=2)$	10.77	11.22	10.89	10.54
$16-31\ Dec\ (k=3)$	11.11	11.57	11.39	10.97
$1-15\ Jan\ (k=4)$	11.40	11.90	11.78	11.39
$16-31\ Jan\ (k=5)$	11.72	12.24	12.13	11.73
$1-15\ Feb\ (k=6)$	11.96	12.48	12.38	12.06
$16-28\ Feb\ (k=7)$	12.17	12.69	12.57	12.33
$1-15\ Mar\ (k=8)$	12.34	12.86	12.73	12.57
$16-31\ Mar\ (k=9)$	12.49	13.02	12.85	12.68
$1-15\ Apr\ (k=10)$	12.56	13.07	12.90	12.69
$16-30\ Apr\ (k=11)$	12.57	13.08	12.93	0.00
$1-16\ May\ (k=12)$	12.56	13.08	12.93	0.00

was found that the revenue increased at a rate greater than the increase of cost. The optimal harvest times in each area would be as follows: 1) Northern should

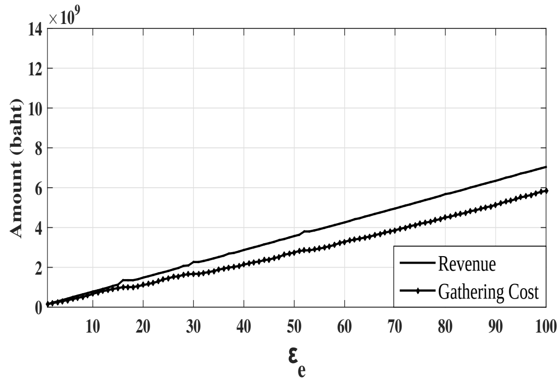

Fig. 9. Comparison between revenue from fresh sugarcane sales and gathering cost of production for crop year 2012/13

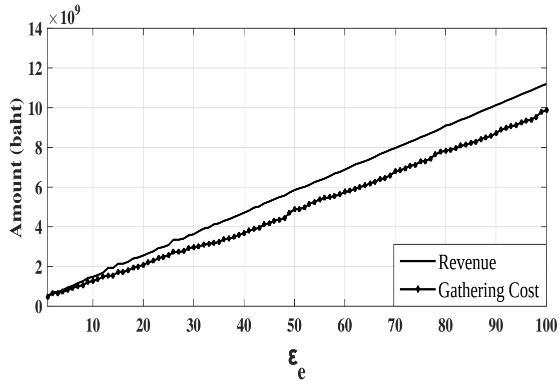

Fig. 10. Comparison between revenue from fired sugarcane sales and gathering cost of production for crop year 2012/13

be harvested in 16-30 April 2013, 2) Central should be harvested in 1-15 April 2013, 3) Eastern should be harvested in 1-16 May 2013 and 4) North-Eastern should be harvested in 16-31 January 2013.

2) Fired Sugarcane: The calculated revenues from the fired sugarcane sales and gathering costs for each ε_e will be the same process with the fresh sugarcane as shown in Fig. 10. It was again found that the revenue increased at a rate greater than the increase of cost. The optimal harvest times in each area were as follows: 1) Northern should be harvested in 16-30 April 2013, 2) Central should be harvested in 1-15 April 2013, 3) Eastern should be harvested in 1-16 May 2013 and 4) North-Eastern should be harvested in 1-15 March 2013.

B. Results for Crop Year 2013/14

The results of revenues from the fresh and fired sugarcane sales and gathering costs are shown in Fig. 11 and Fig. 12. It was found that in both cases the revenue increased at a rate greater than the increase of cost.

The optimal harvest time for fresh sugarcane were as follows: 1) Northern should be harvested in 15-28 February 2014, 2) Central should be harvested in 1-15 March 2014, 3) Eastern should be harvested in 1-15 April 2014 and 4) North-Eastern should be harvested in 16-31 January 2014. The optimal harvest time for fired sugarcane were as follows: 1) Northern should be harvested in 1-15 March 2014, 2) Central should be harvested in 1-15 March 2014, 3) Eastern

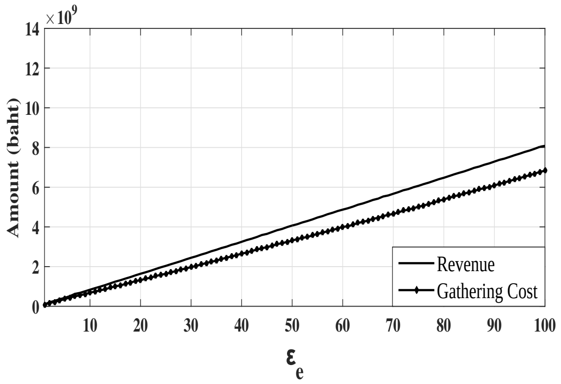

Fig. 11. Comparison between revenue from fresh sugarcane sales and gathering cost of production for crop year 2013/14

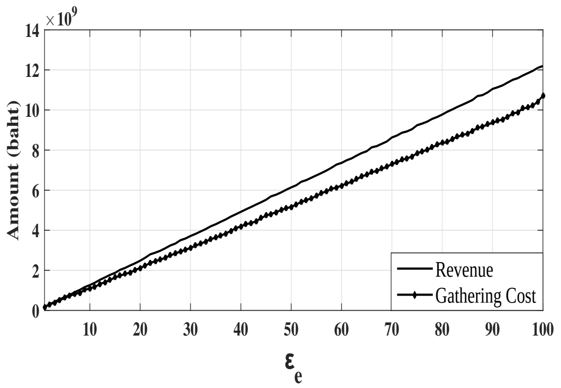

Fig. 12. Comparison between revenue from fired sugarcane sales and gathering cost of production for crop year 2013/14

should be harvested in 1-9 May 2014 and 4) North-Eastern should be harvested in 16-30 April 2014.

C. Results for Crop Year 2014/15

1) Fresh Sugarcane: The results of revenues from the fresh sugarcane sales and gathering costs for all ε_e are shown in Fig. 13. It was found that for this crop year only 21% of the ε_e values gave revenue greater than the gathering cost. We found only one region which is North-Eastern has optimal harvesting time in 16-31 March 2015.
2) Fired Sugarcane: For this crop year it was found that the revenue was less than the gathering cost for all ε_e as shown in Fig. 14. Therefore there was no optimal harvesting time in this case.

D. Results for Crop Year 2015/16

The results of revenues from the fresh sugarcane sales and gathering costs are shown in Fig. 15. It was found that only 3% of the ε_e values gave the revenue less than the gathering cost. The optimal harvest time for fresh sugarcane were as follows: 1) Northern should be harvested in 16-31 March 2016, 2) Central should be harvested in 16-29 February 2016 and 3) North-Eastern should be harvested in 1-15 February 2016. Eastern has no optimal harvesting time.

The results of revenues from the fired sugarcane sales and gathering costs as shown in Fig. 16. The optimal harvest time in each area were as follows: 1) Central should be harvested

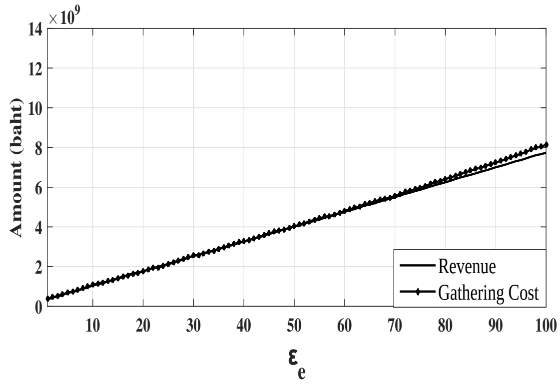

Fig. 13. Comparison between revenue from fresh sugarcane sales and gathering cost of production for crop year 2014/15

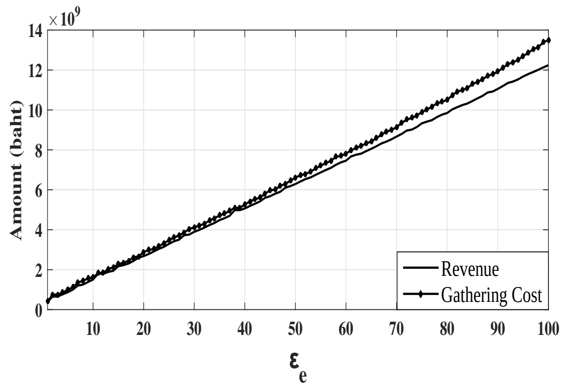

Fig. 14. Comparison between revenue from fired sugarcane sales and gathering cost of production for crop year 2014/15

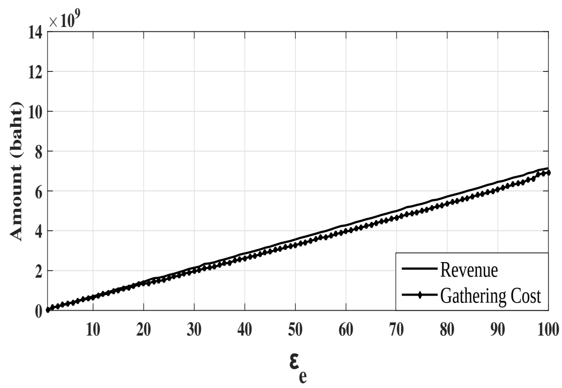

Fig. 15. Comparison between revenue from fresh sugarcane sales and gathering cost of production for crop year 2015/16

in 1-10 April 2016 and 2) North-Eastern should be harvested in 1-15 March 2016. Northern and Eastern have no optimal harvesting time.

The optimal time to harvest sugarcane in the four regions of Thailand for crop years 2012/13, 2013/14, 2014/15 and 2015/16 are shown in TABLE VI - TABLE IX and then compared the results with paper [6].

V. Conclusion

In this work, a bi-objective mathematical model has been presented using crop data from years 2012/13, 2013/14, 2014/15 and 2015/16 for the computation of the optimal time to harvest sugarcane in Thailand. The two objectives in the model were to minimize cost and maximize revenue.

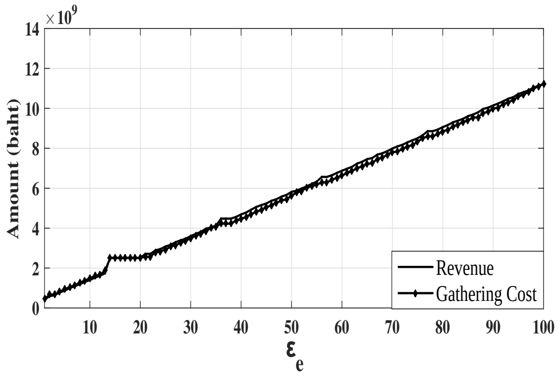

Fig. 16. Comparison between revenue from fired sugarcane sales and gathering cost of production for crop year 2015/16

TABLE VI
COMPARISON OF OPTIMAL HARVESTING TIME FOR FRESH SUGARCANE

Crop Year		*Northern*	*Central*
2012/13	Present	$16-30/04/13$	$1-15/04/13$
	Paper [6]	$16-30/04/13$	$1-15/04/13$
2013/14	Present	$15-28/02/14$	$1-15/03/14$
	Paper [6]	$1-15/03/14$	$15-28/02/14$
2014/15	Present	–	–
	Paper [6]	$16-30/04/15$	$1-15/04/15$
2015/16	Present	$16-31/03/16$	$16-29/02/16$

TABLE VII
COMPARISON OF OPTIMAL HARVESTING TIME FOR FRESH SUGARCANE (CONTINUED)

Crop Year		*Eastern*	*North-Eastern*
2012/13	Present	$1-16/05/13$	$16-31/01/13$
	Paper [6]	$1-15/04/13$	$16-31/01/13$
2013/14	Present	$1-15/04/14$	$16-31/01/14$
	Paper [6]	$1-15/04/14$	$16-31/03/14$
2014/15	Present	–	$16-31/03/15$
	Paper [6]	$1-15/04/15$	$16-31/01/15$
2015/16	Present	–	$1-15/02/16$

TABLE VIII
COMPARISON OPTIMAL HARVESTING TIME FOR FIRED SUGARCANE

Crop Year		*Northern*	*Central*
2012/13	Present	$16-30/04/13$	$1-15/04/13$
	Paper [6]	$16-30/04/13$	$1-15/04/13$
2013/14	Present	$1-15/03/14$	$1-15/03/14$
	Paper [6]	$16-31/03/14$	$1-15/03/14$
2014/15	Present	–	–
	Paper [6]	–	–
2015/16	Present	–	$1-10/04/16$

TABLE IX
COMPARISON OPTIMAL HARVESTING TIME FOR FIRED SUGARCANE (CONTINUED)

Crop Year		*Eastern*	*North-Eastern*
2012/13	Present	$1-16/05/13$	$1-15/03/13$
	Paper [6]	$1-16/05/13$	$1-15/03/13$
2013/14	Present	$1-9/05/14$	$16-30/04/14$
	Paper [6]	$1-9/05/14$	$16-30/04/14$
2014/15	Present	–	–
	Paper [6]	–	–
2015/16	Present	–	$1-15/03/16$

The ε-constraint method was used to change the bi-objective mathematical model into a single-objective model to minimize gathering cost subject to an ε-constraint of a lower limit on the revenue. The results of the computations are summarized in TABLE VI – TABLE IX. In this model, the main factor in determining the optimal harvest time is the change in C.C.S. as shown in TABLE II - TABLE V and the quantity of sugarcane as shown in Fig. 1 - Fig. 8. Moreover almost all the results (optimal harvesting time) were quite similar to the results in [6] which is the model to maximize revenue subject to an ε-constraint of an upper limit on the gathering cost.

In addition, we have compared the optimal profit which is the difference between the revenue and the gathering cost computed from the optimal harvesting time and the real profit computed from the real harvesting time for fresh and fired sugarcane in crop years 2012/13, 2013/14, 2014/15 and 2015/16 are shown in TABLE X – TABLE XIII. We found that the optimal profit is greater than the real profit. Moreover, we can see that some crop years, agriculturists loss from sugarcane selling (shown in "minus" sign).

TABLE X
COMPARISON OF PROFIT FOR FRESH SUGARCANE

Crop Year	*Northern* ($\times 10^8$ *baht*)		*Central* ($\times 10^8$ *baht*)	
	Optimal Profit	**Real Profit**	**Optimal Profit**	**Real Profit**
2012/13	10.99	5.89	12.68	7.68
2013/14	16.30	13.91	24.12	20.27
2014/15	–	−12.69	–	−5.33
2015/16	3.42	−0.28	4.78	2.62

TABLE XI
COMPARISON OF PROFIT FOR FRESH SUGARCANE (CONTINUED)

Crop Year	*Eastern* ($\times 10^8$ *baht*)		*North-Eastern* ($\times 10^8$ *baht*)	
	Optimal Profit	**Real Profit**	**Optimal Profit**	**Real Profit**
2012/13	1.68	1.31	57.04	56.19
2013/14	1.44	0.81	39	38.1
2014/15	–	−2.11	6.13	−2.57
2015/16	–	−1.05	18.18	13.80

TABLE XII
COMPARISON OF PROFIT FOR FIRED SUGARCANE

Crop Year	*Northern* ($\times 10^8$ *baht*)		*Central* ($\times 10^8$ *baht*)	
	Optimal Profit	**Real Profit**	**Optimal Profit**	**Real Profit**
2012/13	17.15	6.51	16.47	5.63
2013/14	32.27	24.94	40.26	32.13
2014/15	–	–	–	–
2015/16	–	−8.68	0.475	−4.03

TABLE XIII
COMPARISON OF PROFIT FOR FIRED SUGARCANE (CONTINUED)

Crop Year	*Eastern* ($\times 10^8$ *baht*)		*North-Eastern* ($\times 10^8$ *baht*)	
	Optimal Profit	**Real Profit**	**Optimal Profit**	**Real Profit**
2012/13	4.38	3.01	73.67	66.75
2013/14	1.99	0.625	46.87	37.38
2014/15	–	–	–	–
2015/16	–	−4.63	20.63	9.27

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REFERENCES

[1] Office of the Cane and Sugar Board. Retrieved September 2017 from http://www.bangkokpost.com/learning/advanced/1238849/sugar-cane-farmers-profit-from-high-output-high-prices

[2] M. S. Scarpari and E. G Ferreira, "Optimized Agricultural Planning of Sugarcane Using Linear Programming," *Revista Investigacion Operacional*, vol. 31, no. 2, pp. 126-132, 2010.

[3] F. R. A. Gomes, "Bi-objective Mathematical Model for Choosing Sugarcane Varieties with Harvest Residual Biomass in Energy Cogeneration," *International Journal of Agricultural and Biological Engineering*, vol. 5, no. 3, pp. 50-58, 2012.
[4] Hitoshi Yano and Kota Matsui, "Random Fuzzy Multiobjective Linear Programming Through Probability Maximization and Its Application to Farm Planning," *IAENG International Journal of Applied Mathematics*, vol. 43, no. 2, pp. 87-93, 2013.
[5] Abdulkareem A Saka, Ayo S. Afolabi and Ogochukwu M.U, "Production and Characterization of Bioethanol from Sugarcane Bagasse as Alternative Energy Sources," *Lecture Notes in Engineering and Computer Science: Proceedings of The World Congress on Engineering*, pp. 876-880, 2015.
[6] S. Sungnul, W. Pornprakun, S. Prasattong and C. Baitiang, "Multi-Objective Mathematical Model for the Optimal Time to Harvest Sugarcane," *Applied Mathematics: Scientific Research Publishing*, vol. 8, pp. 329-343, 2017.
[7] K. Deb, *Multi-Objective Optimization using Evolutionary Algorithms*, 1st ed. John Wiley and Sons, Chichester, 2001.
[8] Office of the Cane and Sugar Board. Retrieved 12 May 2015 from http://www.ocsb.go.th

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