A linear programming for sugarcane cultivation and harvest planning with cane survival rate

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Abstract: In Thailand, sugarcane mills have faced supply and demand imbalance problems. Solving such problems is complicated due to various substantial factors. Sugarcane cultivation and harvest are important processes since they are the early stages of the sugarcane industry. Cultivation and harvest planning can be designed by using optimization model in order to balance supply and demand. This paper proposes a linear optimization model used in sugarcane cultivation and harvest planning with multiple suppliers. Sugarcane survival rate is one of the important factors considered in the presented model. A case study of the large-size sugarcane mills in Thailand was investigated. Many other significant factors were considered such as cultivating land size, sugarcane type, harvesting capacity, and delivery contract with the mill. The objective function was to maximize commercially recoverable sugar content in sugarcane (C.C.S.) of the total amount of sugarcane supplied to mill. This model can be applied as a supply management tool for both farmers and the mill management based on real situation.

Keywords: optimization model, linear programming, sugarcane harvest, sugarcane cultivation

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1 Introduction

The sugarcane crop has known as one of valuable crop which influenced high export income for Thailand. The sugarcane cultivating areas have widespread in all areas of Thailand, especially in Northeastern region. It is the largest sugarcane planting area and can produce the large amount of sugarcane as the second crop next to rice. Total sugarcane cultivating area is around 541,797 farms which yields 4,880,497 t of cane. The average production is 9,480 kg per farm (Department of industrial works, 2013). Regularly, the operations are in two time-periods, the early rainy season and the late of rainy season. The sugarcane can be retained for ratoon (stump) in next cultivating season around 2 yr before new sugarcane plant be replaced. The sugarcane breeds include Philippines (Phil 66-07), Au-tong-I, K84-200, Q83, F, and H 43-3166.

The cultivation periods vary due to various factors which effect sugarcane quality; i.e. rainfall rate, soil type, and soil humidity. Basically, sugarcane cultivation in Thailand is depended on natural rainfall in rainy season. The suitable soil humidity and rainfall rate are main factors to enhance quality and increase growing rate in cultivating season (April-May). The new grow sugarcane productivity depends upon soil humidity and cultivating season and can be classified into three categories as follows.

1. Late rainy season cane—cultivated during August and September and the best period for cultivation is October 20 to December 15.

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2. Early rainy season cane—cultivated in clay and loam soil and the best period for cultivation is March 20 to May 15.

3. Irrigation cane—cultivation does not depend on rainfall rate, growing in clay soil and closely located to irrigation zone. It will be cultivated in January to March.

Each sugarcane category has different cultivation characteristics and cultivation time periods, which depended on season. Due to the different period of cultivation and harvest, mills have faced supply and demand imbalance problems. Causes of problems are illustrated as follows.

– Over supply which excesses mill's capacity in some periods
– Waiting time of delivering truck in line
– Decreased C.C.S. due to long waiting time after harvesting
– Increased queue management cost for truck unloading
– Unstable production process due to supply uncertainty,
– Poor quality cane such as fired cane, and polluted cane, and unclean cane (i.e. dust, stone, other contaminations)
– Inefficiency process

Cultivate and harvest processes should be examined in order to dilute such problems.

Hence, process productivity and management efficiency should be increased. Recently, sugarcane harvest and cultivate planning has been investigated in various aspects. In 2002, the optimal sugarcane harvest system selection was presented for sugarcane production in Louisiana. Sugarcane stalk weight and sugar per stalk equations were estimated in order to predict tonnage and sugar yields throughout the harvest season. These predicted yields were then adjusted to reflect field tonnage and sugar recovery for the combine and whole stalk harvesting systems. A mixed integer mathematical programming model was developed to determine the optimal harvest system under alternative sugarcane variety combinations, whole stalk harvester field recovery rates, and combine harvester sugar recovery rates (Salassi, Breaux and Naquin, 2001). Because of increased competition between agrifood supply chains has strained relationships between farmers and processing factories while reducing individual profit margins. Decisions at different levels of the supply chain can no longer be considered independently, since they may influence profitability throughout the supply chain. A decision support approach based on the MAGI® simulation tool was proposed, which aims to facilitate discussion and negotiation between stakeholders while collectively exploring satisfactory solutions. The simulation tool helps sugarcane growers and millers in designing and assessing new ways of organizing cane supply management within a mill area. It addresses key issues such as restructuring mill areas or changing cane delivery allocation rules in order to increase total sugar production and total net revenue at the mill area level (Lejars, Gal, and Auzoux, 2008). In 2011, an operational model was investigated to generate short term planning decisions for the fresh produce industry. The application was developed for the grower to maximize his revenues by making production and distribution decisions during the harvest season. The main motivation for this model came from the fact that the profitability of producers is highly dependent on the handling of short term planning in the harvest season. Some of the factors affecting profitability included the management of labor costs, the preservation of the value of perishable crops, and the use transportation modes that provide the best trade-off between time (quality of products) and cost. The proposed planning model result had shown that significant savings could be obtained by managing the trade-off of the freshness at the delivery of the product with the added labor and transportation cost at the grower's side. The dynamic, information based, management practices were preferred over traditional practices based in fixed labor allocation and distribution practices (Ahumada and Villalobos, 2011). A decision support system was provided for scheduling sugarcane harvesting operations in South Africa. The large number of fields and growing rate were considered in the model. Commercial growers had provided data suitable for regression modeling of the parameters that govern the values and costs involved, and had participated in two consecutive preliminary system evaluation and development experiments conducted during the 2009 and 2010 harvesting seasons. The optimization models underlying the decision support system were based on a time-dependent travelling salesman problem formulation and were solved approximately by means of a tabu search in a Microsoft Visual Basic for Applications (VBA) for Excel environment (Stray, Vuuren and Bezuidenhout, 2012). The harvest planning problems have risen in the production of sugar and alcohol from sugar cane in Brazil. The planning was performed for two planning horizons, tactical and operational planning, such that the total sugar content in the harvested cane was maximized. The tactical planning comprises the entire harvest season that averages seven months. The operational planning considers a horizon from seven to thirty days. The mixed integer programming was developed to solve the problems. The construction heuristic solutions, and dividing and sequentially solving the resulting MIP program were proposed (Jena and Poggi, 2013).

Other perishable product, a planning methodology was presented to match the random supply of annual premium fruits and vegetables from a number of contracted farms and the random demand from the retailers during the planning period. The supply uncertainty was due to the uncertainty of the maturation time, harvest time, and yield. The demand uncertainty was the uncertainty of weekly demand from the retailers. A planning methodology was investigated to determine the farm areas and the seeding times for annual plants that survive for only one growing season in such a way to maximize total profit. Both the single period and the multi period cases were analyzed depending on the type of the plant. The performance of the solution methodology was evaluated by using numerical experiments. These experiments show that the proposed methodology could be balanced random supply and random demand in a very effective way and improved profit (Tan and Comden, 2012).

This paper presents a linear optimization model for sugarcane cultivate and harvest schedule in order to satisfy mill capacity. The objective function is to maximize total commercially recoverable sugar content in sugarcane or commercial cane sugar index (C.C.S.) for mill's production in the harvest season with consideration of survival rate consideration.

2 Material and methods

2.1 Collecting Data

After visiting and managers interview in the largest sugarcane factory, the characteristics of problems and collect some data from its research center were illustrated as below.

1) Sugarcane breed planted by each farmer could not be defined because farmers normally mix various breeds. Therefore, most general ways to define sugarcane breeds is to classify them into big three types; hard breed, medium breed, and light breed.
2) They are different cultivating seasons and harvesting periods. Therefore, C.C.S. and production amount vary. The relationship of cultivating season and sugarcane breed are shown in Figure 1.

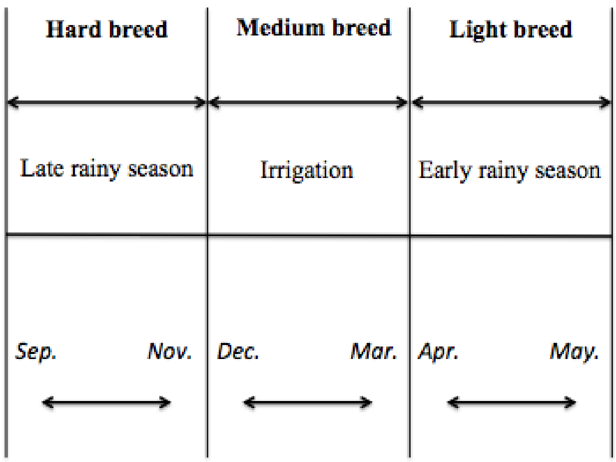

Figure 1. The relationship of cultivating season and sugarcane breeds

3) The increasing of sugarcane weight in different season could not be collected. However, the production rate per Rai can be investigated.

4) The mill has faced the problem of insufficient supply due to transportation problem and the lack of harvest labor in many areas since the beginning to the end of harvest season.

5) The proportion of sugarcane types, new grow versus stump, is approximately 1:2. The stump sugarcane would be retained for the next harvest season.

6) Based on real situation of sugarcane cultivation, the sugarcane type has different survival rate as presented below.

– New grow sugarcane has survival rate of 75 %

– Stump sugarcane has survival rate of 88.2 % (see Table 1, Table 2 and Table 3)

Table 1 The suitable period of sugarcane cultivation

Cane type	Proper soil type*	Productivity (t/Rai)	Sweet-ness (C.C.S)	Harvest age (Month)	Period of cultivate and harvest					
					Early rainy season		Late rainy season		Irrigation	
					Cultivate	Harvest	Cultivate	Harvest	Cultivate	Harvest
K 88-92	L, Lw,/S	15-20	10-12	12			Sep-Nov	Dec-Mar	Jan-Feb	Feb-Mar
K 92-80	L, Lw,/S	16-19	10-12	10-12			Sep-Nov	Dec-Mar	Jan-Feb	Feb-Mar
K 93-236	L, Lw,/S	17-19	11-13	12			Sep-Nov	Dec-Mar	Jan-Feb	Feb-Mar
K 90-77	L, Lw,/S	15-18	13-14	12	Apr-May	Feb-Mar	Sep-Nov	Dec-Mar	Feb-Mar	Jan-Mar
K 92-181	L, Lw,/S	12-15	12-13	12	Apr-May	Feb-Mar	Sep-Nov	Dec-Feb	Feb-Mar	Jan-Mar
Au-tong 3	L, Lw,/S	17-19	11-13	11-13	Apr-May	Feb-Mar	Sep-Nov	Dec-Feb	Feb-Mar	Jan-Mar
LK 92-11	C, Lw,/S	17-18	12-14	11-13	Apr-May	Feb-Mar	Sep-Nov	Dec-Feb	Feb-Mar	Feb-Mar
LK 92-14	C, Lw,/S	16-17	12-13	11-13	Apr-May	Feb-Mar	Sep-Nov	Dec-Feb	Feb-Mar	Feb-Mar
LK 92-17	C, Lw,/S	13-14	12-13	10-11	Apr-May	Feb-Mar			Feb-Mar	Feb-Mar

Note: * Proper soil type: L = Loose, Lw = Loose w, S = Sand, C = Clay

Table 2 Sugarcane weight (t/Rai: W_{ijlkm}) and commercial cane sugar index (C.C.S.: C_{ijlk}) and mill demand (t: d_l)

Zone	Breed	Type	Cultivating month	Harvesting month							
				24 (Dec.)		25 (Jan.)		26 (Feb.)		27 (Mar.)	
				Weight	C.C.S	Weight	C.C.S	Weight	C.C.S	Weight	C.C.S
1	Light	New grow	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
		Stump	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
	Medium	New grow	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
		Stump	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
	Hard	New grow	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
		Stump	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
2	Light	New grow	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
		Stump	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
	Medium	New grow	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
		Stump	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
	Hard	New grow	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
		Stump	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
3	Light	New grow	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
		Stump	16 (Apr.)					15	12	16	13
			17 (May)			15	12	16	13		
	Medium	New grow	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
		Stump	12 (Dec.)								
			13 (Jan.)					13	11	14	12
			14 (Feb.)			13	11	14	12	15	13
			15 (Mar.)	13	11	14	12	15	13		
	Hard	New grow	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
		Stump	9 (Sep.)	15	10	16	11	17	12	18	13
			10 (Oct.)	15	10	16	11	17	12	18	13
			11 (Nov.)	15	10	16	11	17	12	18	13
Mill demand/t				203,277		203,278		203,277		203,278	

Note: * Cultivating and harvesting month: 13rd month = Jan., 14th month = Feb., 15th month = Mar., and so on.

Table 3 Available cultivating area and sugarcane contract with mill (Rai, t: a_k, b_k)

Zone	Cultivating area, a_k (Rai)	Sugarcane contract, b_k (t)
1	33,945	290,785
2	24,344	217,740
3	12,220	118,320
Total	70,509	626,845

2.2 Model Description

A linear programming is modeled in order to design a schedule of cultivation and harvest to meet the mill demand. Factors involved in sugarcane planting are case breed, month of cultivate, month of harvest, cultivation zone, and type of sugarcane. Below is the explanation of indices, parameters, and variables. Month of cultivate and month of harvest would affect cane's sweetness and weight. Each is also an important factor affected yield.

1) Mathematical model index

i = Sugarcane breed; 1 = Light breed
2 = Medium breed
3 = Hard breed

j= Month of cultivate; $j = \{1, 2,\dots,J\}$

l = Month of harvest; $l = \{1, 2,\dots,L\}$

k = Cultivating zone; $k = \{1, 2,\dots,K\}$

m = Sugarcane type; 1 = New grow
2 = Stump

2) Parameters

a_k = Cultivating zone k ($k = 1,\dots,K$)

b_k = Sugarcane contract of zone k ($k = 1,\dots,K$)

C_{ijlkm} = Commercial cane sugar index of sugarcane breed i, cultivated in
month j, harvested in month l, in zone k
($i = 1,\dots,I$; $j = 1,\dots,J$; $l = 1,\dots,L$; $k = 1,\dots K$; $m = 1, 2$)

d_l = Mill demand in harvesting period of month l ($l = 1,\dots,L$)

W_{ijlkm} = Sugarcane weight of breed i, cultivated in month j, harvested in
month l, in zone k, of sugarcane type m
($i = 1,\dots,I$; $j = 1,\dots,J$; $l = 1,\dots,L$; $k = 1,\dots,K$; $m = 1, 2$)

S_m = Survival rate of sugarcane type m ($m = 1, 2$)

3) Variables

X_{ijlkm}= Number of area (in Rai) of cultivated sugarcane breed i in month j, in zone k of sugarcane type m

Z_{ijlkm}= Amount of harvested sugarcane breed i, cultivated in month j,
harvested in month l, in zone k, of sugarcane type m
(i= 1,…,I; $j = 1,\dots,J$; $l = 1,\dots,L$; $k = 1,\dots,K$; $m = 1, 2$)

Y_{ijlkm}= Amount of sugarcane breed i, cultivated in month j, harvested in
month l, in zone k,of sugarcane type m
($i = 1,\dots,I$; $j = 1,\dots,J$; $l = 1,\dots,L$; $k = 1,\dots,K$; $m = 1, 2$)

2.3 Optimization Model Formulation

The following mathematical model shows all factors influenced appropriated cultivate and harvest schedule which provides sufficient yield to meet mill demand, hence, minimizes waiting times which cause reduction of cane quality and process productivity (see Equation 1, Equation 2, Equation 3, Equation 4, Equation 5, Equation 6 and Equation 7).

Objective function

$$\text{Maximize} = \sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall k}\sum_{\forall m} C_{ijlkm}Y_{ijlkm}$$

Subject to

$$\sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall m} X_{ijlkm} \le a_k \qquad .(1)$$

$$2\sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall k} X_{ijlk1} = \sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall k} X_{ijlk2} \qquad .(2)$$

$$W_{ijlkm}X_{ijlkm} = Z_{ijlkm} \qquad .(3)$$

$$\sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall m} Y_{ijlkm} \ge b_k \qquad .(4)$$

$$\sum_{\forall i}\sum_{\forall j}\sum_{\forall k}\sum_{\forall m} Y_{ijlkm} = d_l \qquad .(5)$$

$$S_1 \sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall k} Z_{ijlk1} = Y_{ijlk1} \qquad .(6)$$

$$S_2 \sum_{\forall i}\sum_{\forall j}\sum_{\forall l}\sum_{\forall k} Z_{ijlk2} = Y_{ijlk2} \qquad .(7)$$

$$X_{ijlkm} \geq 0, Y_{ijlkm} \geq 0$$

The objective function is to maximize commercially recoverable sugar content in sugarcane (C.C.S.) of the total amount of harvested sugarcane.

Constraint (1): Cultivated area.

For each zone of cultivation, the total number of area (in Rai) must not exceed the available number of area of sugarcane farm for each sugarcane breed, in each month of cultivating, in each month of harvesting, in each cultivated zone, of each sugarcane type.

Constraint (2): Cultivated sugarcane type.

The stump sugarcane cultivated required area is approximately double amount of the area for new grow sugarcane, of each sugarcane breed, in each month of cultivating, in each month of harvesting, in each cultivated zone, of each sugarcane type.

Constraint (3): Harvested sugarcane supply.

Harvested sugarcane supply equation shows the growth of cane or relationship between number of cultivated farms with increasing of sugarcane weight and the amount of harvested cane of each sugarcane breed, in each month of cultivating, in each month of harvesting, in each cultivated zone, of each sugarcane type.

Constraint (4): Sugarcane contract.

Harvested sugarcane must not less than sugarcane contract requested by the mill before the harvest season, of each sugarcane breed, in each month of cultivating, in each month of harvesting, in each cultivated zone, of each sugarcane type.

Constraint (5): Mill demand.

The amount of sugarcane harvested from each zone must be balanced with mill capacity in each month, of each sugarcane breed, in each month of cultivation, in each month of harvesting, in each cultivated zone, of each sugarcane type.

Constraint (6): Survival rate of New grow sugarcane.

The amount of new grow sugarcane is calculated based on survival rate, of each sugarcane breed, in each month of cultivation, in each month of harvesting, in each cultivated zone.

Constraint (7): Survival rate of Stump sugarcane.

The amount of stump sugarcane is calculated based on survival rate of each sugarcane breed, in each month of cultivation, in each month of harvesting, in each cultivated zone (see Figure 2).

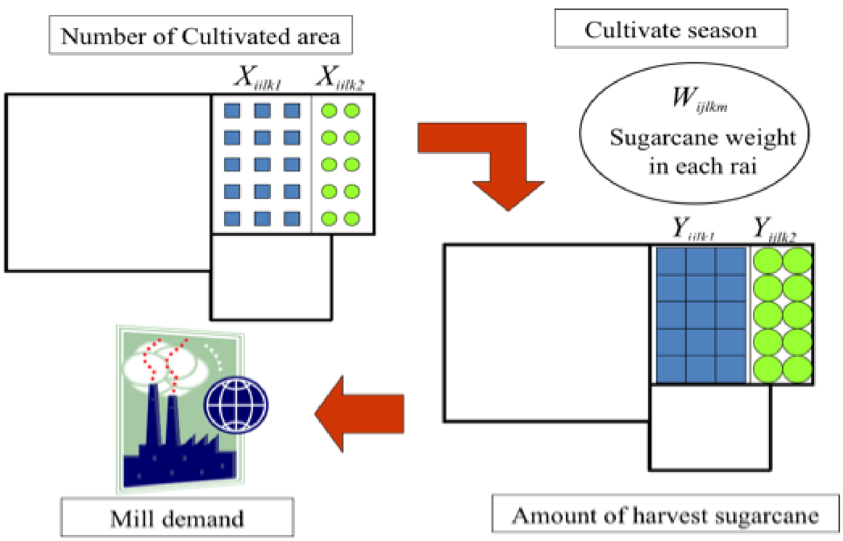

Figure 2 Variables *X* and *Y*

3. Results

According to the parameters given in Table 1, Table 2 and Table 3, and survival rate 75% of new grow sugarcane and 88.2% of stump sugarcane (S_1 = 0.75, S_2 = 0.882), the solutions of linear optimization model for next year plan (i.e. month 13=Jan., month 14=Feb., month 15=Mar., and so on.) with the objective value of maximized C.C.S. 9,960,622 are shown as following Table 4, Table 5, Figure 3 and Figure 4.

Table 4 The result of optimal cultivate area (Rai) (X_{ijkm})

Zone (*k*)	Breed (*i*)	Type (*m*)	Cultivating month (*j*)	Harvesting month (*l*) 24 (Dec.)	25 (Jan.)	26 (Feb.)	27 (Mar.)	Total cultivating (Rai)	Cultivation area, a_k (Rai)
1	1	1	17 (May)		18,069			28,309	33,945
	2	2	14 (Feb.)				3,555		
	2	2	15 (Mar.)	6,685					
2	2	2	15 (Mar.)	11,043		13,300		24,343	24,344
3	1	2	17 (May)			1,935		12,220	12,220
	3	2	11 (Nov.)				10,285		
Total cultivating (Rai)				17,728	18,069	15,235	13,840	64,872	70,509

Table 5 The result of optimal sugarcane amount (t) (Y_{ijkm})

Zone (k)	Breed (i)	Type (m)	Cultivating month (j)	Harvesting month (l) 24 (Dec.)	25 (Jan.)	26 (Feb.)	27 (Mar.)	Total harvesting (Ton)	Contract, b_k (Ton)
1	1	1	17 (May.)		203,278			319,930	290,785
	2	2	14 (Feb.)				39,999		
	2	2	15 (Mar.)	76,653					
2	2	2	15 (Mar.)	126,624		175,966		302,590	217,740
3	1	2	17 (May)			27,311		190,590	118,320
	3	2	11 (Nov.)				163,279		
Total harvesting (t)				203,277	203,278	203,277	203,278	813,110	626,845

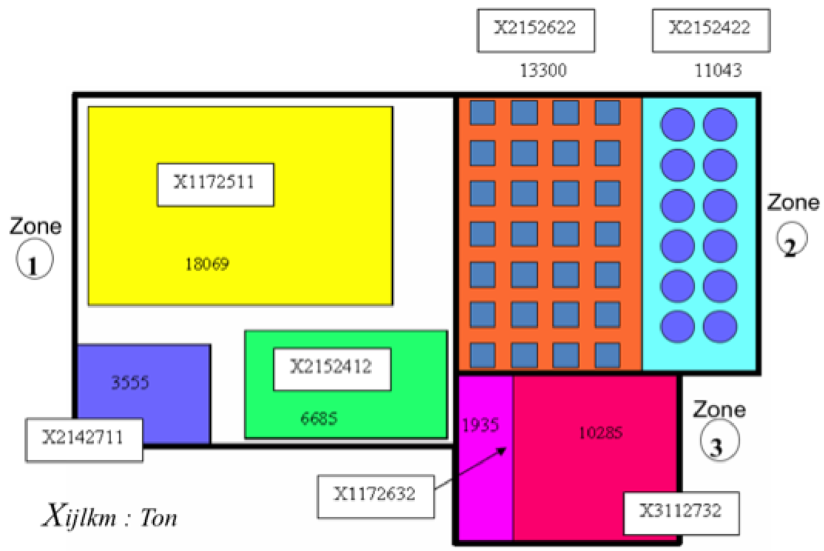

Figure 3 Cultivating area mapping (X_{ijkm})

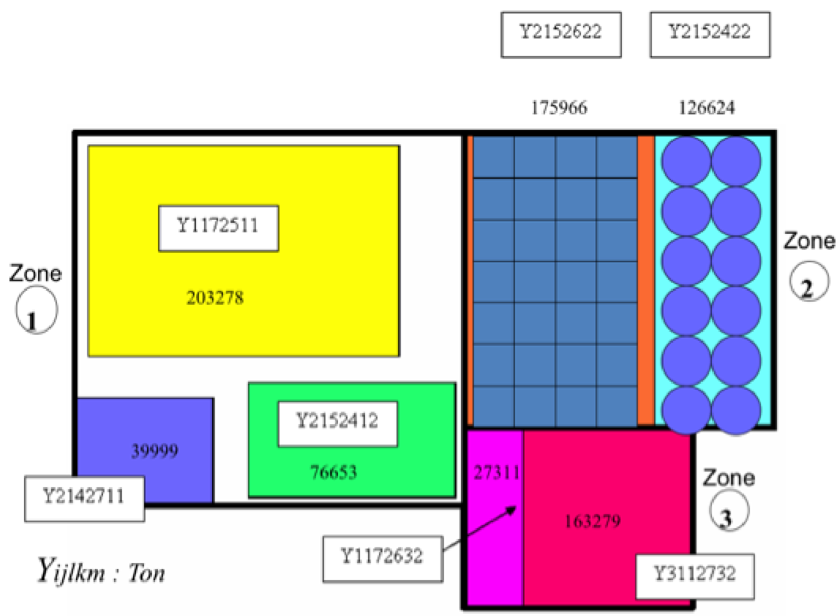

Figure 4 Optimal harvest amount mapping (Y_{ijkm})

4 Conclusion

As mentioned earlier, without appropriate cultivate and harvest planning, sugarcane mills confront with imbalanced demand and supply. Factory desired contract alone was not enough for sugarcane farmer to make a good cultivate plan. Many other factors as introduced in this study are very important and should be taken into account. As a conclusion, the solutions of this optimization model based on sugarcane survival rate provide important decisions; number of cultivated area and amount of harvested sugarcane. Many significant factors such as cultivating land size, sugarcane type, and delivery contract with the mill, as well as cane survival rate are considered. The objective value of maximized C.C.S. was significant in real situation.

Due to the limitation of information, only three cultivated zone were considered. In real situation, more than three zones are involved in one mill. For further study, more information such as increasing sugarcane weight and C.C.S. in each cultivating month, breed, harvesting month and cultivating zone for more areas should be considered. However, the linear optimization model presented in this study could be applied in general cases for sugarcane cultivate and harvest planning for both farmer and mill.

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