Transportation and Production Lot-size for Sugarcane under Uncertainty of Machine Capacity

Kanchala Sudtachat[1,a]

[1]*School of Manufacturing Engineering, Institute of Engineering, Suranaree University of Technology,111 University Avernue, Mueng, Nakhon Ratchasima, 30000,Thailand*

Abstract. The integrated transportation and production lot size problems is important effect to total cost of operation system for sugar factories. In this research, we formulate a mathematic model that combines these two problems as two stage stochastic programming model. In the first stage, we determine the lot size of transportation problem and allocate a fixed number of vehicles to transport sugarcane to the mill factory. Moreover, we consider an uncertainty of machine (mill) capacities. After machine (mill) capacities realized, in the second stage we determine the production lot size and make decision to hold units of sugarcane in front of mills based on discrete random variables of machine (mill) capacities. We investigate the model using a small size problem. The results show that the optimal solutions try to choose closest fields and lower holding cost per unit (at fields) to transport sugarcane to mill factory. We show the results of comparison of our model and the worst case model (full capacity). The results show that our model provides better efficiency than the results of the worst case model.

1 Introduction

The production system of sugar industry in Thailand obtains raw material from small fields that located around the mill factory. Currently, the farmers delivery units of sugarcane in a small lot size to mill factory by using farm trucks or six-wheeled trucks in which do not have schedule time accounting to production planning of the mill factory. Thus, large queues are waiting in front of machines (mills). Furthermore, the important problem of production system occurs due to breakdown time of the machines (mills) that affect to uncertainty of machine capacities. Therefore, one operation system is to schedule an arrival of sugarcane from fields to mill factory including considers a several possible way of production lot size planning based on random machine capacities occurring in real world problem. The operation system may encounter breakdown problems of machines (mills) that leading to situation of lower full machine capacities. In harvesting season, we employ a transportation lot size strategy. The decisions of transportation schedule are made before the harvesting season. In the production schedule of each period, we would determine the production lot size based on scenarios occurring of uncertainty of machine (mill) capacities. The objective is to minimize expect total cost. We develop a two stage stochastic programming model for integrated transportation and production lot size problem when the situation of plant is uncertainty of machine (mill) capacities. The model is investigated using a random input parameters in a small size problem.

[a] Corresponding author : kanchala@sut.ac.th

2 Literature Review

Essentially, the models for the sugarcane systems addressed a complex harvesting and transportation system. Guise and Ryland [1] presented an optimization model for the scheduling of production in sugar mills. Higgins et al. [2] introduced the model of the harvesting and transportation system. They evaluated the value chain and built a model for harvesting sugarcane and the transportation system, including the financial flow. In addition, Milan et al. [3] introduced mixed integer programming to formulate the model for sugar cutting and sugarcane transport problems. Grunow et al. [4] investigated the production of raw sugar in decisions related to cultivation, harvesting and dispatch planning. The objective was to minimize the associated costs of systems. Piewthongngam et al. [5] also presented a supply chain for the sugarcane operation system in terms of cultivation and harvesting using a mathematical model. The extension work addressing the supply chain for the sugarcane operation system was introduced by Khamjan et al. [6]. They proposed the location of sugarcane loading stations. The sugarcane fields were allocated to each loading stations. In this paper, we develop the mathematical formulation to analyze the transportation and production lot size models. Our model is presented by using the two stage programing model when the first decision is transportation lot size, after the capacity of machines (mills) realized that each machine (mill) can not operate in full capacity.

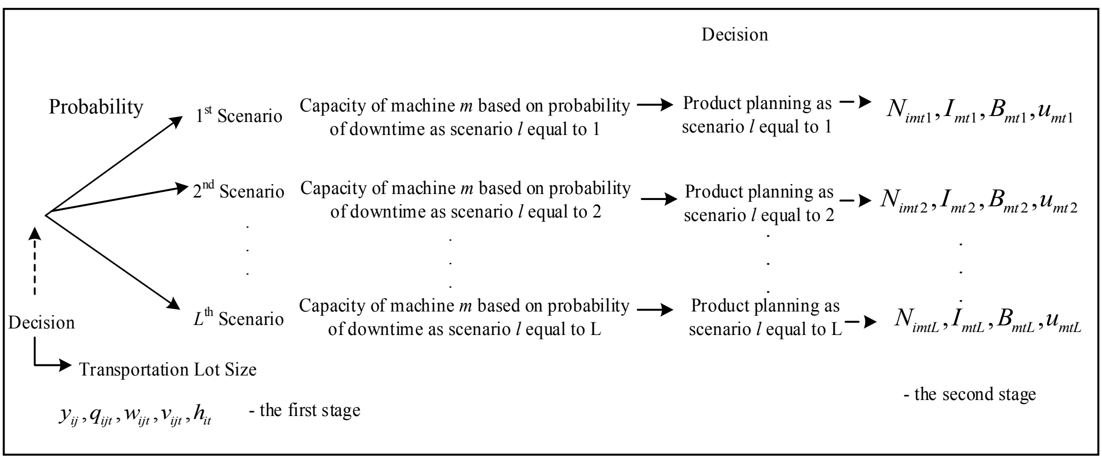

Figure 1. The two stage stochastic programming model of the transportation and production planning for sugarcane

3 Model Formulation of Transportation and Production Lot-size Model

3.1 Mathematical model

The proposed model can be used to determine the problem of how to make decisions of the transportation lot size of each field and assign trucks to transport sugarcane from fields to the mill factory for each period. We consider a single type of vehicle. At the mill factory, we consider a breakdown probability of machines (mill) that resulting in uncertainty capacity for each machine (mill) for each period after transporting sugarcane to front of mill occurs already. The problem is stated as how many of transporting lot size for each period given a number of vehicle, likelihood of machines capacity realized and determine the production lot size for each machine (mill) for each period. We formulated the model as the two stage stochastic programming model; the first stage of transportation lot size problem is to make decision before the transporting sugarcane for cane field to the mills occurs and evaluate the first state cost, while the second stage is to evaluate the cost of production lot size due to a realized of machine capacities. The second stage cost (recourse cost) is random variable dependent on the first stage transportation lot size decision for each field. The minimum overall expected cost is determined with respect to the random variables of probability of machine capacities. The extensive form of stochastic of transportation and production lot-size for sugarcane under uncertainty of machine (mill) capacity shows in Fig 1.

The parameters of transporting and production lot size models is shown below.

Notation	**Description**
Indices	
n	number of fields
J	number of trucks
T	number of time periods
L	number of scenarios
MC	number of machines (mills)
i	fields index as $i = 1, 2, \ldots, n$
j	existing trucks index as $j = 1, 2, \ldots, J$
t	time periods as $t = 1, 2, \ldots, T$
m	machines (mills) index as $m = 1, 2, 3, \ldots, MC$
l	scenarios as $l = 1, 2, \ldots, L$
$BigM$	a large integer number
Parameters	
d_{ij}	prepare cost of field i to factory by truck j
s_{ijt}	transportation cost per time (fixed cost) of truck j at time period t, where consist of load-unload cost, cutting cane cost and transportation cost
c_{it}	holding cost per ton of sugarcane leaving at field i at time period t
Q_{it}	yield (tons) of field i at time period t
$Setup_m$	setup cost of machine (mill) m
g_{imt}	production cost of sugarcane from field i produce on machine (mill) m at time period t
o_t	holding cost per ton of sugarcane at front of machine (mill) at time period t
b_t	lost production cost per ton of sugarcane at time period t
$prob_l$	probability of scenario l occurring for any time
p_{ml}	percent of capacity of machine (mill) m with scenarios l based on probability of breakdown of machine (mill) or stopping production line by any situations that make machine (mill) capacity being lower than full capacity
COS	number of trucks
COV	capacity of each truck
COM	capacity of machine (mill) at full capacity per time period
COF	requirement of factory for each time period
Decision variables	
y_{ij}	1 if we allocate truck j to transport sugarcane at field i; 0 otherwise
u_{mtl}	1 if we assign sugarcane at least a ton to machine (mill) m at time period t as scenario l; 0 otherwise
v_{ijt}	1 if we allocate truck j to transport sugarcane at field i at time period t; 0 otherwise
w_{ijt}	number of travels of truck j to transport sugarcane at field i at time t
q_{ijt}	quantity of sugarcane at field i, which transport by truck j at time t
h_{it}	holding units (tons) of field i, kept at its field at the end of time period t
N_{imtl}	quantity of sugarcane of field i at front of mill assign to machine (mill) m at time period t as scenario l
I_{mtl}	holding unit of sugarcane at front of mill for assigning to machine (mill) m at time period t as scenario l

B_{mtl}	lost production unit of sugarcane of machine (mill) *m* at time period *t* as scenario *l*
f	optimal value

Objective Function

$$Minimize\ f = \sum_{i=1}^{n}\sum_{j=1}^{J} d_{ij} y_{ij} + \sum_{i=1}^{n}\sum_{j=1}^{J}\sum_{t=1}^{T} s_{ijt} w_{ijt} + \sum_{i=1}^{n}\sum_{t=1}^{T} c_{it} h_{it}$$

$$+ \sum_{l=1}^{L} prob_l \cdot \left(\sum_{m=1}^{MC}\sum_{t=1}^{T} Setup_m \cdot u_{mtl} + \sum_{i=1}^{n}\sum_{m=1}^{MC}\sum_{t=1}^{T} g_{imt} \cdot N_{imtl} + \sum_{m=1}^{MC}\sum_{t=1}^{T} o_t \cdot I_{mtl} + \sum_{m=1}^{MC}\sum_{t=1}^{T} b_t \cdot B_{mtl} \right) \quad (1)$$

Stage I:

$$v_{ijt} \le y_{ij} \qquad \forall i, j, t \quad (2)$$

$$q_{ijt} \le Q_{it} \cdot v_{ijt} \qquad \forall i, j, t \quad (3)$$

$$\sum_{j=1}^{J} q_{ijt} \le Q_{it} \qquad \forall i, t \quad (4)$$

$$q_{ijt} \le COV(w_{ijt}) \qquad \forall i, j, t \quad (5)$$

$$w_{ijt} \le BigM(v_{ijt}) \qquad \forall i, j, t \quad (6)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{J} q_{ijt} \ge COF \qquad \forall i, t \quad (7)$$

$$h_{it} \ge h_{it-1} + Q_{it} - \sum_{j=1}^{J} q_{ijt} \qquad \forall i, t \quad (8)$$

Stage II:

$$BigM \cdot u_{mtl} \ge \sum_{i=1}^{n} N_{imtl} \qquad \forall i, m, t, l \quad (9)$$

$$I_{mtl} \ge I_{mt-1l} + \sum_{i=1}^{n} N_{imtl} - p_{ml} \cdot COM \qquad \forall i, m, t, l \quad (10)$$

$$\sum_{m=1}^{MC} N_{imtl} = \sum_{j=1}^{J} q_{ijt} \qquad \forall i, t, l \quad (11)$$

$$B_{mtl} \ge p_{ml} \cdot COM - \sum_{i=1}^{n} N_{imtl} - I_{mt-1l} \qquad \forall t, l \quad (12)$$

$$y_{ij} \in (0,1) \qquad u_{mtl} \in (0,1) \qquad v_{ijt} \in (0,1)$$

$$w_{ijt} \in \text{int}+ \qquad q_{ijt} \in \text{int}+ \qquad h_{it} \in \text{int}+$$

$$N_{imtl} \in \text{int}+ \qquad I_{mtl} \in \text{int}+ \qquad B_{mtl} \in \text{int}+$$

Objective function (1) the first term is a cost of preparing road of travel from vehicle *j* to field *i* which we assign vehicle *j* to transport sugarcane of field *i* based on distance between field *i* and vehicle *j*. The second term, we compute the setup cost for load, unload and transportation cost per time per period that the load and unload cost are constant value. However, the transportation cost depends on distance between field *i* and vehicle *j*. The third term is the holding cost for leaving sugarcane at field *i* at period *t* because we do not harvesting on time. The forth term, we present the probability of scenarios *l* occurring for machine (mill) that resulting from uncertainty capacity of machine (mill) *m*. The probability of scenarios *l* occurring for each machine (mill) is multiply by the recourse cost that occurring in the second stage. The equation consists of sum of four terms, the setup cost of machine (mill) *m* if we assign at least a ton to produce on machine (mill) *m*, the production cost of sugarcane production, the holding cost for keeping sugarcane at front of mills and the lost production cost for all periods. Constraint in the *Stage I*, constraints (2) and (3) if we transport sugarcane at least a ton from field *i* by vehicle *j* ensure y_{ij} equal one. The constraint (4) ensure that we transport tons of sugarcane from field i less than yield of field i. Constraint (4) ensure the transported sugar cane from field i by all vehicles is less than yield of field i. The constraints (5) and (6) use to calculate the number of travels of vehicle j to transport sugarcane from field i to the mill factory for each period. Constraint (7) ensure that the transported sugarcane from all field i by all vehicles is larger than requirement of the mill factory. The constraint (8) calculate number of holding unit of field i that do not harvest on time period. Constraint in *Stage II,* constraint (9) ensure if we assign only a unit of sugarcane to produce on machine (mill) m, the set up cost of machine (mill) m would be computed. Constraint (10) use to calculate the holding units of sugarcane at front of machine (mill) m for each period for each scenario. Constraint (11) ensure that we assign units of sugarcane to all machines is less than available number of units at front of mills. Constraint (12) calculate number of lost production units of sugarcane of machine (mill) m for each period for each scenario.

4 Numerical Examples

This section, we generate random data set to test the two stage stochastic programming model. We present the comparison of results of our model and a model that do not consider the full capacity of all machines (mills) called a worst case model. The models coded by using the IBM ILOG CPLEX Optimization Studio Version 12.5. The input parameters of problem size 10 fields, 4 vehicles, 2 machines (mills), 2 time period and 2 scenarios, capacity of each vehicle 30 tons and full capacity of each machine (mill) 400 tons.

4.1 Optimal solutions

The mathematical model is investigated using a small problem 10 fields, 4 vehicles, 2 mills, 2 time periods. The results show that we increase the tons of requirement, the expected total cost would be increased and the optimal policy choose the fields 2, 6, 7, 9 to transport sugarcane to the mill. The results show in Table 1. Because of two reasons, the holding cost per unit of sugarcane yield of fields 2, 6, 7, 9 are larger than other fields if we do not harvest and leave them at fields, there are higher cost than other fields, and these fields are located nearby the mill factory that resulting in lower transportation cost if we would choose them to transport sugarcane to the mill factory. The results of comparison of the expected total cost of our two stage model (optimal solutions) at which assumptions approach to realistic world problem and the worst case model (optimal solutions) that we assume at full capacity for each machine (mill) for current operation. The results show that our model provides lower cost than the results of the worst case model at average 9%. Figure 2 show a sensitivity analysis of the expected total cost when we increase the percent of each type of cost. The results of sensitivity shows that increased holding cost at fields will affect to the expected total cost more than increased holding cost at mill and increased lost production cost at mill. The results imply that the expected total cost depends on the function of holding cost at fields in linear function and not depend on the function of holding cost and function of lost production cost at mill.

Table 1. The expected total cost of the two-stage model (optimal solutions) that comparing to the total cost of worst case model (optimal solution) shown in Thailand currency (Bahts)

ID	Fields	Requirement of factory (Tons)	Chosen cane fields to transport in full yield	Two-stage model (optimal solutions)	Worst case model (optimal solution)	% Deviation
1	10	500	2, 6, 7, 9	23476	26194.4	10
2	10	525	2, 6, 7, 9	23816	26494.1	10
3	10	550	2, 6, 7, 9	24026	26717.4	10
4	10	575	1, 2, 6, 7, 9	24572	27017.1	9
5	10	600	1, 2, 6, 7, 9	25201	27310.6	8

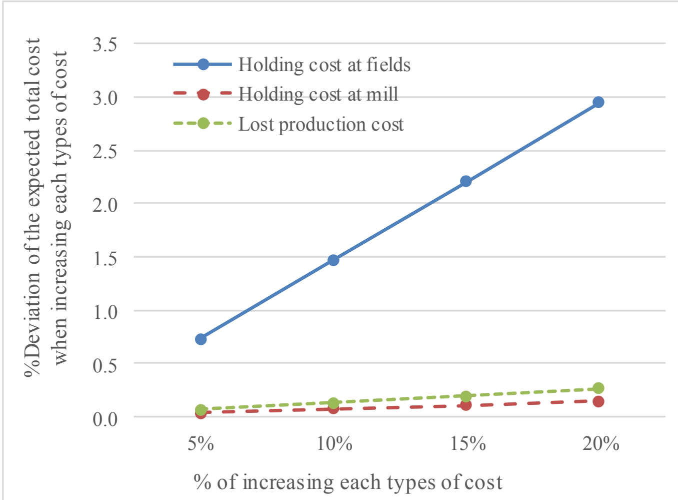

Figure 2. The sensitivity analysis of increasing percent for each types of costs; holding cost per ton at fields, holding cost per ton at the mill factory and lost production cost per ton at the mill factory

5 Conclusion

In this paper, we present the two stage stochastic programming model for the integrated transportation and production lot size problem that consider uncertainty of machine capacities into the model. We consider the probability of scenarios occurring as stage of system based on fluctuating of machine (mill) capacities. We showed the results of investigating the mathematical model for small size problem. The numerical results show that the optimal solution try to choose the closest fields and choose fields that are larger holding cost per unit of kept sugarcane at fields to transport sugarcane to mill factory. The comparison results of our model (optimal solution) and the worst case model (optimal solutions) showed that results of our model provides more efficient of system than the results of the worst case models.

References

1. J.W.B. Guise, G.J. Ryland, Production Scheduling and Profitability in Sugar Milling, *Economic Analysis and Policy*, **2**, 1, 18 (1971)
2. Higgins, G. Antony, G. Sandell, I. Davies, D. Prestwidge, B. Andrew, A framework for integrating a complex harvesting and transport system for sugar production, *Agricultural Systems*, **82,** 2, 99-115 (2004)
3. E. L. Milan, S. M. Fernandez, L. M. P. Aragones, Sugarcane transportation in Cuba, a case study, *European Journal of Operational Research* **174,** 1, 374-386. (2006)
4. M. Grunow, H. O. Günther, R. Westinner, Supply optimization for the production of raw sugar, *International Journal of Production Economics,* **110**, 1, 224-239. (2007)
5. K. Piewthongngam, S. Pathumnakul, K. Setthanan, Application of crop growth simulation and mathematical modeling to supply chain management in the Thai sugar industry. *Agricultural Systems* **102**, 1, 58-66 (2009)
6. W. Khamjan, S. Khamjan, S. Pathumnakul, Determination of the locations and capacities of sugarcane loading stations in Thailand, *Computers & Industrial Engineering* **66**, 4, 663-674 (2013)