Computers and Electronics in Agriculture 110 (2015) 42–55

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Harvest scheduling algorithm to equalize supplier benefits: A case study from the Thai sugar cane industry

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ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 16 September 2014
Accepted 5 October 2014

Keywords:
Grower clustering
Optimization model
Heuristic algorithm
Sugar cane
Tabu search

ABSTRACT

In this study, the harvest scheduling problem of a group of cane growers in Thailand is addressed. Each member in a group is required to consistently supply sugar cane to a mill for the entire harvest season. However, the current scheduling does not account for the time-variant cane production of each cane field, which leads to unequal opportunities for growers to harvest. A portion of growers could have the opportunity to harvest in periods that provide higher sugar cane yields, while others in the same group do not. This inefficient harvest scheduling causes conflicts between growers and unnecessary loss of sugar cane and sugar yields. An artificial neural network is applied to estimate cane yield over a harvest season. Then, an optimization model and a heuristic algorithm with the objective of maximizing the estimated sugar cane yield under the condition of fair benefits for all of the growers in the group were developed to determine the most suitable sugar cane harvest schedule for a cluster of sugar cane fields. For the heuristic, the initial solution is first constructed based on the yield trends, and the solution is then improved by the tabu search approach. The results indicated that there are potential benefits from applying the model to cane scheduling within a group of heterogeneous yield trends. Sensitivity analysis showed that the more that the yield trends in a group differ from one another, the higher the benefit the group is likely to gain from adopting the proposed framework.

1. Introduction

Harvest scheduling has become one of the most important tasks in the sugar cane industry. It is obvious that an efficient harvest schedule could increase the sugar yield, which improves the profitability of the entire supply chain. Research related to the sugar cane harvesting problem has steadily increased (e.g., Higgins et al. (1998), Salassi et al. (2002), Jiao et al. (2005), Grunow et al. (2007), Piewthongngam et al. (2009), Stray et al. (2012)). As with other agricultural products, the complexity of the harvest scheduling problem can be attributed to the biological characteristics of sugar cane, which are uncertain and variable, and production variations, such as a grower's skill and the number of farms involved in the scheduling plan.

Although researchers agree on the benefit of collaboration between the sugar mill and cane growers, different concepts to tackle harvest operations plans have been proposed. The concepts proposed in the past are usually around situations that pertain to involving parties in each of the sugar-producer countries. For example, in Australia, most growers are large scale. Hauler and rail systems are the main transportation modes. Growers implemented a self-rotation strategy such that no grower finishes harvesting ahead of others (Higgins, 1999). In Venezuela, Brazil and other South American countries, mills own and administer a large share of the cane field. Grunow et al. (2007) proposed a harvest plan for the South American case by designing a cultivation plan that, in turn, roughly set a harvesting time slot for each field. They divided the harvest plan into three levels: cultivation, harvesting decisions and the dispatching of harvest equipment. While the model portrays innovative and holistic concepts in the South American case, it encompasses a plan for large size fields for which all of the decisions, including the decisions to use equipment and transportation, are not under the control of the mill. Due to the large field sizes, harvesting a plot in the case of South Africa could take several days. Each plot is harvested in a single round. As stated by Stray et al.

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http://dx.doi.org/10.1016/j.compag.2014.10.005
0168-1699/

(2012), this case is not in a sugar cane-producing country such as South Africa or Thailand, where small farm growers make their own decisions with regard to their cultivation plan. In South Africa and Thailand, a central plan was implemented by the Mill Group Board for South Africa and by the millers for Thailand.

For the case that is proposed here, there is a small scale with highly different environments and constraints. We propose to develop a flexible yield estimation model that can account for the heterogeneous conditions in the fields. To maintain the maximum cane production for the whole joined operation group, it is not necessary to maintain individual members' maximum profits. Some members in the group must unequally sacrifice to harvest their cane far beyond their highest yield. Hence, to maintain maximum cane production for each cane grower, we propose the concept of finding the optimum point at which each grower harvests an equivalent amount less than his/her maximum yield. In other words, suppose that one's maximum production is 100 tons and another's is 200 tons. Additionally, the model suggests harvesting at 98% of the maximum production of each. Hence, the grower with 100 tons should be assigned to harvest until he obtains 98 tons of cane, while the latter should harvest until the time at which he has 196 tons of cane. In this sense, the maximum yield of the whole group also means that each one sacrifices its own maximum yield proportionately. Although this study addresses a group harvest rotation in the cane industry, the concept is applicable to other crops for which a large number of growers share harvest equipment and schedules.

Group rotation system for the Thai cane industry

In Thailand, sugar cane is grown mainly in the northeastern region of the country, where there are thousands of farms supplying sugar cane to a sugar mill. Most of these farms are small, and their sugar cane production is less than 300 tons per crop year. To simplify the harvest planning, a sugar mill planner organizes the small farms into groups. Growers are asked to form a group voluntarily. Each group is a set of farms whose total estimated sugar cane production is greater than or equal to the transportation quota specified by the mill. For example, if the transportation quota is 1000 tons, then the farms whose sugar cane yield is less than 1000 tons will be grouped with others. The number of growers in each group varies, ranging from 2 to 8 growers and covering 10 to 50 fields per group. The members in a group share their resources such as laborers, harvesting equipment and trucks. Typically, as in this study, a group of growers has only one force of laborers and a delivery truck to be shared. Additionally, the harvesting operation is performed manually by a labor force and not a harvesting machine.

The harvest season in Thailand usually starts at the end of November or the beginning of December, and it ends in early- to mid-April. To ensure that a mill will have a supply of cane that is equal to its capacity for the entire season, the sugar mill divides the harvest season into many rounds, typically 100–120 rounds, where each round lasts 25–28 h. Each farm group must consistently supply sugar cane for the entire season. Currently, the growers within a group decide the harvest schedule among themselves. Basically, the harvest schedule is a simple calculation. For example, in a harvest season, the number of transportation round-trips is set to 100, and the transportation quota is approximately 1000 tons. Consider a farm group that consists of 2 growers and assume that the estimated sugar cane supplied to a sugar mill for the entire harvest season is 800 tons for grower 1 and 200 tons for grower 2. If a 10-ton truck is used to transport the sugar cane from the farms to the mill, then the number of transportation round-trips required for this group is 100. The number of round-trips to transport the harvest for grower 1 will be 4 times greater than that for grower 2. The harvest schedule is shown in Table 1. The schedule can be altered among the growers based on various criteria such as the sugar cane ripening time, the financial needs of the members, or the availability of laborers, but this pattern is typical. Moreover, for the purpose of harvest labor management, two main harvesting patterns are always practiced in the harvest scheduling within a group. In the first pattern, once the harvesting of a field has started, all of the cane in that field must be harvested without interruption. In the second pattern, no more than one field is harvested in the same harvest period, except for in the period where harvesting has finished in one field and has started in another field. This pattern is based on the situation that the group of growers shares a labor force and a delivery truck. The field-by-field harvesting operation is practiced to prevent the mixing of cane from different fields in one delivery truck. Several examples of practical and impractical harvesting patterns are shown in Figs. 1 and 2, respectively.

The current practice does not consider which harvest periods provide the highest sugar productivity. This shortcoming leads to unequal opportunities for growers to harvest: some growers could have opportunities to harvest in periods that provide higher sugar cane yields than those of the others in the same group. In the worst-case scenario, none of the growers have the chance to harvest at the best time. This problem appears to be trivial, and it has been overlooked by the sugar industry in the past. In fact, inefficient harvest scheduling within the groups causes many problems, including conflicts between growers and the unnecessary loss of sugar cane and sugar productivity. These problems significantly affect both the growers and sugar mills, especially when there are many small-scale farms clustered into groups, as in Thailand. Therefore, it is necessary for the sugar industry to manage the harvest schedule within the farm groups. To efficiently schedule the harvests, the sugar cane yield throughout the harvest period of each sugar cane field must be known. The integration of a sugar cane yield estimation method and a harvest scheduling algorithm is required to solve this problem.

In the literature on the sugar cane harvesting problem, several studies have attempted to combine yield estimation and an optimization model or a heuristic algorithm to optimize the sugar cane cultivation or harvest scheduling, such as Salassi et al. (2002), Jiao et al. (2005), Piewthongngam et al. (2009) and Stray et al. (2012). The spatial variation of cane yield is known and is found to be highly effective for harvest productivity (Le Gal et al., 2004). In an attempt to explain cane yield variation, Lawes et al. (2004) employed two multivariate techniques, the 3-way mixture method of clustering and the 3-mode principle component analysis to identify meaningful relationships between farms that performed similarly for both cane yield and CCS for whole mill productivity improvement. Le Gal et al. (2004) compared the recoverable value rate (RV%) in different areas of South Africa. Hence, a number of cane yield estimations have been studied. The estimated yield is usually the forecasted sugar cane yield and/or the sugar yield (expressed as a Commercial cane sugar (CCS) or sucrose), depending on the objective of the optimization problem. For example, Salassi et al. (2002) estimated the sugar cane stalk weight and

Table 1
The traditional harvest schedule of the farmer group.

Transportation round	1	2	3	4	5	6	7	8	9	10	……	99	100
Farmer no.	1	1	1	1	2	1	1	1	1	2	……	1	2