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Integrating a multiple crop year routing design for sugarcane harvesters to plant a new crop

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ABSTRACT

This paper discusses the integration of a multiple crop year routing design for a sugarcane harvester and planning of the planting of a new crop. A multiple crop year routing design (i.e., a three year harvesting plan) for a sugarcane crop was formulated and solved by the use of heuristics based on a VRPTW mathematical model (HVRPTW) and a dynamic programming algorithm (HDPA). The three-year harvesting period was determined from the number of years that sugarcane can normally be harvested after a crop is planted in Thailand (one planted crop and two ratoons). The model solution consisted of the harvesting sequence, the harvesters' travelling routes, the harvest starting time and the number of harvesters required. The results of two methods were compared with respect to the maximum profit and computational time. The results showed that solving the problem using HDPA reduced the maximum profit by only 0.28% on average from the solution provided HVRPTW, and the average computational time was also reduced dramatically. The multiple crop year routing design was integrated with the planting of a new crop to ensure that it contained an ideal solution for the 3rd year plan so it would be effective for all three years. We recommend that the growers use a sugarcane cultivar with a similar maturation time in all of the fields that shared the same harvester's route to maintain the ideal routes. Furthermore, the same agricultural practices must be applied to all of the sugarcane crops, such as the planting method, cultivar and fertilization.

1. Introduction

Sugarcane is a perennial agricultural crop that is mainly grown for its expressed juices, which are used to produce raw sugar that is later refined into white sugar (Salassi et al., 2002). It is the world's largest source of sugar, and 160 million tons are used annually as a consumer good (Stray et al., 2012). Researchers have conducted numerous sugarcane-related studies in several countries. For example, Grunow et al. (2007) attempted to develop a method to maintain a constant sugarcane supply while minimizing the associated costs of the entire harvesting plan in Venezuela. They separated the harvesting plan into three parts: cane cultivation, harvesting, and dispatching of the harvesting crews and equipment. In a South African case study, Stray et al. Stray et al. (2012) proposed a decision support system for seasonal sugarcane harvest scheduling for sugarcane growers by formulating optimization models based on a time-dependent travelling salesman problem, which was solved by means of a tabu search. Salassi et al. (2002) attempted to create an optimal harvesting system using a case study in Louisiana, USA. They formulated a prediction model for the sugar yield and a mixed-integer linear programming (MIP) model to maximize the net revenue with respect to farm costs to identify the most economical sugarcane harvesting system in a comparison between a wholestalk harvester and a combine harvester.

In Australia, Higgins et al. (2004) created a framework for combining complex sugarcane harvesting and transportation systems for sugar production to resolve many of the existing inefficiencies resulting from the use of an excessive number of harvesting machines. Higgins et al. (2007) also extensively reviewed the aspects of sugarcane value chain research. They reported that the sugarcane harvesting planning problem has been studied by many researchers, and mathematical models are potential tools for solving the problem. As in other countries, Thai researchers have also produced works dealing with various aspects of sugarcane, such as its cultivation, production, harvesting, and transportation, as exemplified by the studies of Piewthongngam et al. (2009), Pathumnakul et al. (2012), Khamjan et al. (2013), Thuankaewsing et al. (2015), and Kittilertpaisan and Pathumnakul (2015).

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Sugarcane is considered to be one of the most important crops in Thailand and can be grown in almost all regions of the country (Kittilertpaisan and Pathumnakul, 2015). In 2016, there were 50 sugar mills in Thailand: 9 mills in the northern region, 18 mills in the central region, 19 mills in the northeastern region, and 4 mills in the eastern region according to the information from the Office of the Cane and Sugar Board of Thailand (OCSB) (OCSB and PITH, 2016). Thus, northeastern Thailand is an important sugarcane growing region. The characteristic of the sugarcane industry in this region is composed of many family businesses, small-scale independent growers, and rainfed sugarcane farming (Grunow et al., 2007). A major problem in this region is the shortage of harvesting laborers. Thus, the labor force has been replaced by the use of machines such as harvesters (Khon Kaen University, 2006). A harvesting machine can harvest 125 tons/harvester/day, or it can replace 100–125 workers (Khon Kaen University, 2006). Hence, mechanized harvesting is considered to be a promising way to reduce the harvesting cost (Kaewtrakulpong et al., 2008). In particular, mechanized green sugarcane harvesting operations assist farmers to increase their income and also provide environmental advantages (Kaewtrakulpong et al., 2008). However, mechanized harvesting is still considered to be a costly method because of the high investment required for the purchase of harvesters. Moreover, most harvesters are owned by a mill because Thai sugarcane growers normally cannot afford an expensive harvester (Kittilertpaisan and Pathumnakul, 2015). Hence, a mill-owned harvester is shared by several sugarcane growers. In addition to the high cost of purchasing a harvester, the energy cost of operating a harvester is also very high.

There are two different kinds of mechanized harvesting systems available: "whole stalk harvesting" and "chopped cane harvesting" systems (Vorasayan et al., 2014). In Thailand, the chopped cane harvesting system is the most common (Vorasayan et al., 2014). The chopper harvester is widespread use, and this kind of harvester normally operates together with a truck (Kaewtrakulpong et al., 2008), as shown in Fig. 1. Sugarcane stalks are cut into billets with lengths of approximately 12–14 in, and the loading elevator mounted on the chopper is used to load the chopped cane into the truck, which maintains a position alongside and parallel with the chopper harvester (Kaewtrakulpong et al., 2008). There are two types of in-field transportation used with a harvester: trucks and wagons. In Thailand, trucks are used more extensively than wagons. The height of a truck has to be modified from 3.50 m to 3.80 m to allow it to be compatible with a harvester. In addition, two sugarcane loading systems are used with a truck to transport the harvested sugarcane either from the field to a mill or to a loading zone near the harvested field. In the latter case, the loaded sugarcane is transported to a mill by another truck. This second system also increases the availability of the trucks used with the harvester, allowing it to work to its full capacity. In this study, we focused on a chopper harvester that used trucks for in-field transportation and assume that utilized trucks transport and load harvested sugarcane from a field to a loading zone to allow the harvester to operate at its full capacity without idle time.

Fig. 1. Sugarcane chopper harvester in operation.

There are many factors that affect the performance of mechanized harvesting systems. After a mechanized harvesting system replaces a manual harvesting system, successful mechanized harvesting primarily depends on the issues presented by Mayer (1999): (1) field preparation, (2) land slope, (3) land preparation, (4) field layout, (5) row spacing, (6) cane row profile, (7) cane row length, (8) ratoon crop management, (9) agronomic factors (i.e., cane varieties, soil compaction, cane quality, cane losses, and cane deterioration), and (10) economic factors (i.e., field and crop conditions, operator proficiency, machine maintenance, number of loaders, and number of transport units).

Normally, each grower selects an individual cultivation plan, whereas harvesting is scheduled by the mill (Piewthongngam et al., 2009). In other words, sugarcane cultivation is not well-managed using a plan. Important factors concerning appropriate cultivation planning, such as the planting time (with respect to the optimum harvest time), sugarcane cultivar, and maturation time, have traditionally been ignored by growers, causing the sugarcane in individual fields to mature in a random fashion. Furthermore, the mill operator implements a harvester utilization plan for each crop year. The field data are collected by agronomy teams at a particular mill to estimate the growth potential of the sugarcane, but assumptions are made that cause the plan to be based on human judgment and non-representative information (Piewthongngam et al., 2009). In other words, the existing practice of the mill for harvest planning is based on the expertise of the agronomy team. Currently, after they perform evaluations and make decisions about the harvesting time of each field, they manually draw harvesting routes for harvesters. Because of the high cost of mechanical harvesting, they attempt to make the shortest route, while disregarding the best sugarcane yield to avoid unnecessary travel for the harvesters. This reveals that the mills still lack appropriate decision tools for the harvester plan. Consequently, an inefficient harvester routing design may be the result.

Generally, the harvesting period for sugarcane in Thailand is approximately 10–13 months. After sugarcane is planted in the first year, it can be harvested for a 3-year period: once from the initial planting and twice from two ratoonings. The ratooning of sugarcane is the growth of a crop from the stubble of a previous crop. The ages at which the first and second ratoons should be harvested are determined immediately after the respective harvest. Ratooning reduces the material cost of sugarcane planting and tillage for new sugarcane planting. Field capacity, especially in the northeastern region of Thailand, is 11–14 tons/rai (87.50–68.75 tons/ha). Another factor is that different sugarcane cultivars have different maturity ages. Different cultivars ripen at different times depending upon their biological characteristics, which causes the peak yield time for each field to be different from that of the previous year, as shown in Table 1. As a result, the best route cannot be maintained for successive years and designing a sustainable optimal route can be difficult.

Moreover, each sugarcane field has a specific time that is suitable for harvesting, which might be characterized as a time window. The peak yield of each field may also vary within this time window. Thus, in addition to the solution of the harvester routing design problem, how to harvest at the peak yield time must also be determined. This type of problem may be considered to be a vehi-