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Determination of the locations and capacities of sugar cane loading stations in Thailand ☆

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ABSTRACT

In this paper, we address the problem of the location of sugar cane loading stations in Thailand. A loading station is a facility for collecting cane from small farmers; the cane is then transported to a sugar mill by a large truck. An improperly located loading station can result in high investment and transportation costs in the sugar industry. A mathematical model and a heuristic algorithm were developed to determine the suitable capacity of existing loading stations, the locations and capacities of new loading stations and the allocations of cane field harvests to each loading station. The model accounted for variations in the cane yield of each field during the harvesting periods and between crop years. The objective function was the minimization of the associated costs, including the investment costs, the transportation costs and the cost of the cane yield loss if the cane is not harvested at an optimal time. The performance of the developed heuristics was assessed under various scenarios. The results were shown to deviate slightly from the solution to the mathematical model. The sensitivities of the solutions under variations of the transportation cost, yield loss cost and investment costs were studied. The model was also applied to an industrial case study. A relevant and accurate solution was obtained.

1. Introduction

The cost of transporting sugar cane from farms to the mill has been reported to be a major cost in the sugar cane supply chain in many countries, such as Cuba (Milan, Fernandez, & Aragones, 2006), Australia (Martin, Pinkney, & Yu, 2001), South Africa (Bezuidenhout, Lusso, Lyne, & Meyer, 2004) and Thailand (Chetthamrongchai, Auansakul, & Supawan, 2001). In Thailand, the cost of transporting sugar cane from the field to the mill was found to the most expensive component of the total operational cost of sugar production. In the crop year 2007/2008, sugar cane transportation costs accounted for 21.91% of the total operational costs of small growers (Pongwanich-anan, 2009). Most sugar industries, particularly in the northeast region of the country, are characterized by a large number of small independent growers (Grunow, Günther, & Westinner, 2007) that are scattered over a large area surrounding the sugar mills. Some fields are located as far as 80 km from the mill. Delivering the cane supply from the smallholders to the mill is costly and inefficient because their daily production is not sufficient for a full truckload, resulting in a high transportation cost per tonnage of cane (Chetthamrongchai et al., 2001). To reduce the cost of transporting sugar cane from remote small fields to the mill, a sugarcane loading station (LS) strategy has been developed and implemented by many sugar mills in Thailand over the last decade.

Following the loading station strategy, small farmers transport the cane from the fields to a nearby loading station using their available vehicles, which are normally small vehicles (i.e., 5-ton capacity) instead of transporting the cane to the mill directly. The mill then arranges for the transportation from the station to the plant by full trailer trucks (i.e., 39-ton capacity). This strategy has been shown to save approximately 27.8–40.9% in transportation costs over the traditional approach (Chetthamrongchai et al., 2001). The loading station model is shown in Fig. 1.

The loading station strategy also helps to manage the daily truck arrivals at the mill. The number of trucks arriving at the mill can be reduced and scheduled more efficiently. While the loading station strategy is beneficial for the sugar cane procurement system, it also has two major disadvantages. First, the sugar cane quality may be degraded because of double handling due to unloading the cane from the small vehicles and re-loading the cane onto the trailer truck. Second, the establishment of a loading station requires a large investment in land and material handling equipment, such as loading and unloading cranes. This investment cost is the major concern of most sugar mill administrators. The establishment of a loading station is an expensive undertaking. A loading station may need to function for many crop years to

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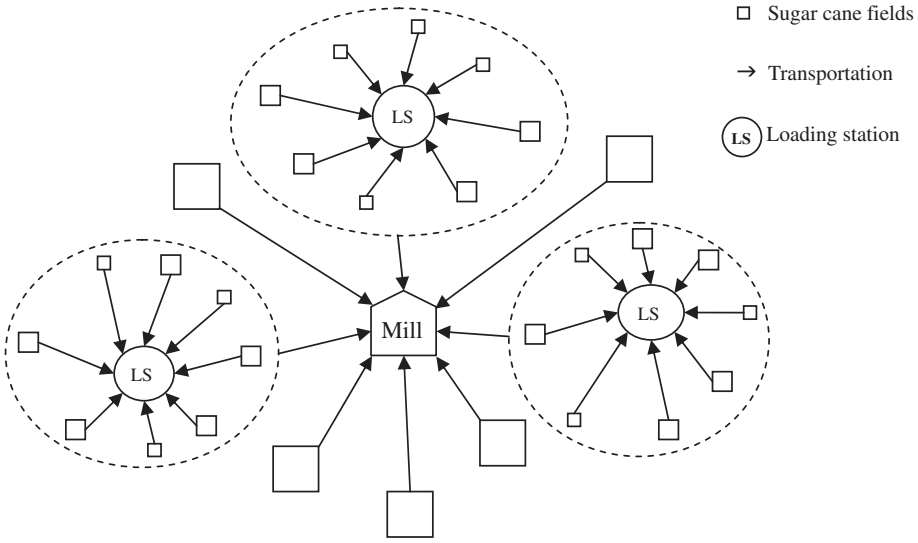

Fig. 1. Transportation system for sugar cane industries in Thailand.

recover the investment costs because of the variation in the cane supply between the harvesting periods in a crop year and between crop years. The variation in the cane supply can be attributed to many factors, such as (1) the interaction between the farmers' field management (e.g., cultivar selection, irrigation, fertilization, tillage operation and residue management) and the surrounding environment (e.g., weather and soil types); (2) the crop-rotation implemented by farmers for breaking pest and disease cycles (Thenail et al., 2009) or growing other economic crops (e.g., rice and cassava) on the plantations; and (3) variation in cane production or cane yield during the periods of a crop year depending on the cultivar selection of the farmers. There is a considerable variation in the cane supply in Thailand, especially in the northeast region. Thus, the cane supply is unevenly distributed throughout the season and over many crop years.

Naturally, each cane field may reach its optimum yield at a different time. For example, some fields reach their maximum yield early, shortly after a harvest season begins, while the yields of other fields may peak in the middle of the season or near the end of the season. If the cane is not harvested in the highest yield period, the mill suffers a yield loss cost. This cost can be avoided by developing an efficient harvesting schedule and procurement system. The decisions on the loading station capacity and the allocation of cane fields to a loading station significantly affect the yield loss costs. If these decisions are poorly made, more cane fields may be harvested outside the peak yield period. For example, if the number and capacity of the loading stations are unable to support all the cane fields at peak yield in a specific harvesting period, some fields must be harvested before or after their peak yield period. This strategy results in unnecessary losses for the sugar industry. Therefore, the cane yield loss cost should be accounted for in determining the location and capacity of the loading stations.

In this paper, the sugar cane loading stations are determined for one of the largest sugar mills in Thailand. The mill case study encompasses more than 5500 small fields, corresponding to approximately 5400 ha of cane. Some fields are located as far as 80 km from the mill. While many loading stations have been set up, they cannot support the increasing quantity of sugar cane and are too far away from some fields. To maximize the efficiency of the sugar mill operations, the mill manager must increase the capacity of the existing loading stations, determine the number of new loading stations required, as well as their locations and capacities, and also allocate fields to each loading station. We assume that the cane supply can be estimated throughout the harvesting season and the crop years in the near future. This assumption is reasonable for the mill under consideration because the mill has typically used statistical data and monthly field surveys to estimate its future cane supply. In this paper, we develop a mathematical model and a heuristic algorithm based on the relaxation of the mathematical model to determine the increased capacity of the existing loading station, the locations of the new loading stations and the allocation of the cane fields to each loading station. The objective function is the minimization of the costs, including the investment costs of enlarging the capacity of the existing loading station(s) and establishing new loading station(s), the transportation costs of delivering cane from the fields to the loading station(s) and from the loading station(s) to the mill and the yield loss cost, if the cane is not harvested at its peak yield.

2. Literature review

There are many studies in the literature on managing operations between the sugar cane fields and the mill. Most of these studies address sugar cane harvesting operations, scheduling (Guan, Nakamura, Shikanai, & Okazaki, 2009; Jiao, Higgins, & Prestwidge, 2005; Le Gal, Lyne, Meyer, & Soler, 2008; Piewthongngam, Pathumnakul, & Setthanan, 2009; Stray, van Vuuren, & Bezuidenhout, 2012) and transportation (Bezuidenhout et al., 2004; Chiadamrong & Kawtummachai, 2008; Higgins, 2006; Milan et al., 2006; Semenzato, 1995). Very few studies have investigated the location of the loading stations (i.e., Pathumnakul, Sanmuang, Eua-anant, & Piewthongngam, 2012).

Obviously, the sugar cane loading station problem under consideration is a type of facility location problem, which has been extensively studied in the literature. Various interesting papers on the facility location problem have been reviewed by Melo, Nickel, and Saldanha-da-Gama (2009) and Farahani, Asgari, Heidari, Hosseininia, and Goh (2012). In general, the facility location problem involves a set of distributed customers and a set of facilities that serve customer demand. Distances, times and costs are common measures of the problem (Melo et al., 2009). In addition to the general problem, there are various types of facility location problems associated with specific application areas. In supply chain management, location decisions are made at the strategic level. Location decisions play an important role in the design of