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Review

Route optimization in mechanized sugarcane harvesting

E. Santoro [a], E.M. Soler [b], A.C. Cherri [b,*]

[a] Universidade Estadual Paulista (UNESP), Faculdade de Engenharia, Bauru, Av. Eng. Luiz Edmundo C. Coube, 14-01, 17033-360 SP, Brazil
[b] Universidade Estadual Paulista (UNESP), Faculdade de Ciências, Bauru, Av. Eng. Luiz Edmundo C. Coube, 14-01, 17033-360 SP, Brazil

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ABSTRACT

Sugarcane cultivation is important for the economy of many countries, particularly for Brazil. This plant has been used to produce sugar, ethanol, second generation ethanol, fertilizers, as well as bioelectricity. Due to production growth and the establishment of mechanized sugarcane harvesting, this process needs to be optimized. High costs are linked to mechanized harvesting, which affect the total cost of production. One of the costs of harvesting is related to the long time the sugarcane harvesting machine takes to change the crop row to be cut. To help reduce costs, this work proposes a mathematical model to the Route Planning Problem for Mechanized Harvesting. This mathematical model minimizes the time of maneuvering the harvesting machine and, consequently, reduces fuel and labor costs, among others. Computer tests were performed using data supplied by a company from the sugarcane energy sector located in the state of São Paulo, Brazil. The results were compared to the traditional routes used by the company and proved the efficiency of the mathematical model in supplying solutions that minimize the time of harvesting machine maneuvers. Not only are there economic benefits, but also environmental ones that can be obtained.

Contents

1. Introduction

Sugarcane has a major importance in the Brazilian economy. The country is the biggest producer of sugarcane in the world, followed by India and China, and is the largest producer of sugar and ethanol. Brazil is responsible for approximately 20% of sugar production and 40% of the sugar exported in the world. Sugarcane is also hugely important in terms of the environment as ethanol is one of the best alternatives for reducing gas pollutant emissions, which are the fundamental cause of the greenhouse effect. According to data from the Companhia Nacional de Abastecimento (CONAB, 2015), changing gasoline to ethanol could reduce up to 70% of gas pollutant emissions.

Until 2014, sugarcane harvesting in Brazil was predominantly manual. In this harvesting strategy, the sugarcane had to be burned so it could be cut by workers, and then transported to the plant. Although ethanol is beneficial to the environment, this strategy had many negative impacts on the environment and human health because of sugarcane burning. However, due to an Agro Environmental Protocol proposed by the Sugarcane Industry Association

* Corresponding author at: Universidade Estadual Paulista (UNESP), Faculdade de Ciências, Bauru, Av. Eng. Luiz Edmundo C. Coube, 14-01, 17033-360, Bauru, SP, Brazil.

E-mail addresses: eversantoro@gmail.com (E. Santoro), edilaine@fc.unesp.br (E.M. Soler), adriana@fc.unesp.br (A.C. Cherri).

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(UNICA – União da Indústria de Cana-de-Açúcar) and the government of the state of São Paulo, a legislation was introduced imposing that from 2017 the harvesting should only be mechanized. Mechanized harvesting totally eliminates sugarcane burning and also increases profits because the straw remaining from the sugarcane can be used. This byproduct has been used to produce energy and second generation ethanol.

With the advent of mechanized harvesting, new technologies emerged and improvements were made in all planting and harvesting processes. In order to have more economic benefits in mechanized harvesting, quality control related to sugarcane planting has become priority, as well as the need for efficient techniques for mechanized harvesting. Benedini and Conde (2008) affirm that planning of harvesting machine routes is needed because the machines take about 1.5–2.0 min to be maneuvered and change the sugarcane crop row. Although optimization techniques have been proposed in various agricultural sectors, strategies to help sugarcane harvesting machine routes to try and reduce the number of maneuvers is a study that still needs to be developed.

Concerning routes, some papers in the literature have proposed approaches to reduce the distances that vehicles have to travel to carry out tasks and, by and large, do not consider minimizing costs on fuel, labor, reducing time, among others as optimization criteria. Oksanen and Visala (2009) proposed two approaches to solve the coverage path planning problem in fields performed by agricultural machines. The approaches are applicable to both robots and human-driven machines. Whole fields should be covered and the objective was to find as an efficient route as possible. Advantages and disadvantages were found in both approaches and neither of them solved this problem optimally. Zhou et al. (2014) developed a planning method that generates feasible areas for agricultural machines to perform operations in fields with obstacles where machine traffic is not possible. However, according to the authors, this method cannot be applied to harvesting. In a paper by Bochtis et al. (2015), a route planning approach for orchard operations was developed and tested using a deterministic behavior robot. The core of the planning method was to generate optimal route planning based on adapting the B-pattern area coverage, an approach developed for arable farming operations.

Conesa-Munoz et al. (2016) proposed a general approach to optimize the route planning problems with more than one vehicle with the same or different features (different speeds or different turning radii), variability of the field and the possibility of refilling the tank. Criteria such as travelled distance, the time required to perform the task and the input costs should be optimized. The proposed approach was solved using a simulated annealing algorithm and has special relevance for route planning in site-specific herbicide applications. Tests using illustrative problems were carried out to validate the strategy. Seyyedhasani and Dvorak (2017) proposed the allocation and ordering of field paths among a number of available machines using the vehicle routing problem, thus minimizing the time to complete a task in the field. A heuristic algorithm and a meta-heuristic algorithm were used to solve the problem. Both techniques were evaluated using computer simulations in a hypothetical basic rectangular field and in a real-world field.

Due to the importance of the Brazilian sugarcane sector, many optimization mathematical models have been proposed to reduce sugar and ethanol production costs. Grisotto (1995) presented a model to represent the activities that include loading, transporting and unloading sugarcane. To solve the problem, a heuristic that uses interior points method was proposed. Yoshizaki et al. (1996) proposed a mathematical model to optimize the ethanol distribution in Southeast Brazil. Colin et al. (1999) proposed a linear programming model to optimize the logistics system for sugar distribution and storage considering a central deposit and a number of secondary deposits. Solutions were obtained using linear programming software.

Iannoni and Morabito (2006) presented a study on the processes related to sugarcane arriving at a mill making use of discrete simulation to analyze the performance of the system and investigate alternative configurations and policies for its operations. Simulations were performed using Arena software. Kawamura et al. (2006) presented a multiperiod linear programming model, which considers decisions regarding transportation and storage of a cooperative of sugar and ethanol producers. The model was implemented using the "What's Best!" software package, industrial version 5.0. Tests were performed using real data. Florentino et al. (2013) proposed an integer nonlinear mathematical model to help plantation planning, as well as sugarcane harvesting aiming to increase productivity in a five-year period. To solve the problem, a genetic algorithm was proposed and tests were performed with random generated instances.

Although the costs entailed with mechanized harvesting are highly representative in the total production cost, to the best of our knowledge, there is no study which addresses this problem. In order to improve the efficiency of the harvest process, routes which will be covered by the harvesting machine need to be planned taking into account the time spent by the machine to execute the maneuvers. Due to the lack of studies in the literature that optimize the sugarcane harvesting process and the need to reduce these costs, this paper contributes to the literature by proposing an integer programming model for the Route Planning Problem for Mechanized Harvesting (RPPMH) aiming to minimize the time the harvest machine takes to maneuver and, consequently, reduce the fuel and labor costs, among others.

The mathematical model proposed is based on the Rural Postman Problem (Orloff, 1974; Eiselt et al., 1995; Pearn and Wu, 1995; Corberan et al., 2006), which is a widely studied problem in the literature and one of the most important optimization problems, applicable in many real situations (Mullaseril et al., 1997; Archetti et al., 2014; Arbib et al., 2014). Computational tests were performed using data supplied by a company from the sugarcane energy sector from the state of Sã Paulo, Brazil. The obtained results were compared with the traditional harvest routes used by the company and confirmed the efficiency of the model in providing solutions that minimize the number of harvesting machine maneuvers, generating economics benefits and other advantages.

The paper is organized as follows: in Section 2, the mathematical model proposed for RPPMH is described; in Section 3, computational tests performed using real data are shown; Section 4 presents the analysis and discussions of the results; and finally in Section 5, the conclusions of this study are drawn.

2. Mathematical model for the route planning problem for mechanized harvesting

In Rodrigues and Abi Saab (2007), the authors highlight that the change in the process of sugarcane harvesting is not only a matter of replacing the technique. This change means adapting aspects such as: soil preparation in agriculture, the equipment in the field, maintenance and support teams, training people involved, as well as transport changes and the arrival of the sugarcane at the mill. Even with all the preparation and planning for the sugarcane crops, the sector is also attempting to improve the harvesting process.

The proposed mathematical model for the Route Planning Problem for Mechanized Harvesting (RPPMH) aims to minimize the time that the harvesting machine takes to perform maneuvers given that the layout of the plantation area to be harvested is known. Furthermore, the model ensures that all sugarcane rows are covered by the harvest machine.