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A milk collection problem with blending

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ABSTRACT

A milk collection problem with blending is introduced. A firm collects milk from farms, and each farm produces one out of three possible qualities of milk. The revenue increases with quality, and there is a minimum requirement at the plant for each quality. Different qualities of milk can be blended in the trucks, reducing revenues, but also transportation costs, resulting in higher profit. A mixed integer-programming model, a new cut, and a branch-and-cut algorithm are proposed to solve medium-sized instances. A three-stage heuristic is designed for large instances. Computational experience for test instances and a large-sized real case is presented.

1. Introduction

The cost of collecting milk from producers in the milk production supply chain has a significant impact on profit (Rojas and Lusa, 2005; Lahrichi et al., 2013). Milk producers are frequently scattered over extended rural areas, sometimes far from processing plants, making transportation cost a relevant component of total cost. It is also common for small producers to organize themselves into cooperatives, able to obtain better commercial terms with, usually, a single buyer (FAO, 2012). Each cooperative sells the milk produced by its members to the buyer, or firm, who performs the collection process (Palsule-Desai, 2015). This arrangement is convenient for the cooperative members, but poses some challenges to the buyer, who must collect milk from all farms in the cooperative, although some may be located far from the plant. Moreover, milk produced by different farms can have different qualities or grades, used for different final products. Currently, firms address the differences in quality by either using separate trucks for collecting different qualities, or using tanks with separate compartments for different qualities. Both solutions are expensive, and particularly if some farms produce small quantities of milk, as in the real case in this study.

A different approach, consisting of mixing or blending different qualities of milk in some of the trucks, is also possible. Blending degrades the quality of part of the collected milk, as the blended product is classified as its lowest quality component, which reduces the firm's revenue. However, the savings in transportation cost exceed the reduction in revenue and ultimately increase profit.

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Blending is a common practice. GLH Incorporated (2014), in a report for the United States' Food and Drug Administration (FDA), explicitly declares that "It is a common practice in some states, including two large milk production states, that bulk milk pickup tankers pick up milk from both Grade 'A' and non-Grade 'A' milk producers on the same tanker. Then, these loads are delivered to non-Grade 'A' processing facilities." New York regulations allow commingled milk in trucks (New York SDAM, 2003). A plant in the south of Chile, which is this paper's case study, also uses blending. The common use of blending makes this a relevant practice that, to the best of the authors' knowledge, has never been analyzed in the literature.

Note that blending does not violate any regulations, as long as the resulting milk is correctly classified at the processing facility. Therefore, this procedure could be extended to wherever the grading of milk or dairy products is performed by bacterial limits and somatic cell count, or by fat content. Examples of countries with such regulations, among others, are the United States (Chite, 1991; U.S. DHHS, 2009), Canada (CDIC, 2005), Bolivia (UNIA, 2011), Mexico (INIFAP, 2011), Panama (Pinzón, 2015), and India (MHFW, 2015). This procedure also applies when the industry imposes such a classification, as in the case of the Murray Goulburn Co-operative in New South Wales and Sydney, Australia (Devondale Murray Goulburn, 2014).

The blending of different products or product qualities in the same vehicle also applies to other industries. Bing et al. (2014) solve a waste collection problem, in which collection is either performed after separating some recyclables at collection points, or by loading different classes of waste in the same truck and classifying them at the processing site. These are also possible applications for this study's approach.

Finally, yet importantly, Sethanan and Pitakaso (2016) state that the mixing of raw milk from different collection centers in the same compartment would be a valuable extension of their research, as they do not use blending, and this would "add to the ability of (their) technique to model real world problems."

An optimization of the blending procedure is proposed, as this is of practical relevance, and has not been previously addressed. This study's contributions are several. First, the Milk Collection Problem with Blending (MB) is introduced which, rather than an algorithmic contribution, describes and solves an innovative milk collection method. For each truck in a heterogeneous fleet, the MB solution indicates what farms each truck must visit, and the route it must follow, to deliver all produced milk to the plant. This also specifies whether it is more convenient to perform blending in the trucks or at the plant. The objective is to maximize the firm's profits. Second, a mixed integer formulation for the problem is proposed, as well as a branch-and-cut algorithm, using a new cut and known cuts to solve medium-sized instances optimally. Third, a heuristic procedure is designed to solve large instances, which partitions the set of farms into clusters or areas, each with a fewer number of farms. Solving the problem by clustering is non-trivial, as there are milk quotas to be fulfilled and a given truck fleet; therefore, trucks and milk quotas must be efficiently assigned to clusters. Finally, the problem is solved for each cluster using the branch-and-cut algorithm.

Test instances of up to 100 nodes are solved, and a real instance is solved that includes 500 farms. The solutions obtained using this new approach are then compared to the solutions currently implemented by the firm, and with the solutions obtained by collecting each quality of milk separately, using the vehicle routing problem (VRP) for each. Managerial insight is provided. Finally, solutions for trucks with and without compartments, and with and without blending are compared, which demonstrates that blending dominates all solutions.

Note that the problem is NP-Hard, as for one quality of milk, it reduces the VRP, which is NP-Hard (Irnich et al., 2014; Toth and Vigo, 2001).

The remainder of the paper is organized as follows: Section 2 presents the literature review. Section 3 describes the milk collection problem with blending. Section 4 details the development of the mixed integer programming (MIP) model, the valid cuts, and their separation algorithms. Section 5 illustrates a procedure for solving large instances. Section 6 is devoted to numerical experience, with the test instances, the actual case, and the full heuristic. Different alternative approaches are compared in this section, including the use of compartments. Section 7 concludes.

2. Literature review

The literature provides a large number of articles studying the VRP, considering different variants, applications and solution methods (Golden et al., 2008; Toth and Vigo, 2001, 2014). A relevant variant of the VRP is the Multi-Product Vehicle Routing Problem (MPVRP). The MPVRP allows to reduce costs, by consolidating different products in a same vehicle (Liu et al., 2008). This variant has been addressed in different ways. Some authors consider as the main concern the inventory management over a time horizon (Coelho et al., 2012; Huang and Lin, 2010; Moin et al., 2011; Zhalechian et al., 2016; Zhang et al., 2014) or dimension constraints for products with different weight and volume, e.g., boxes, furniture, etc. (Junqueira et al., 2013; Russell et al., 2008; Viswanathan and Mathur, 1997). Other studies solve the MPVRP using trucks with compartments for liquids, avoiding product blending in a same compartment (Caramia and Guerriero, 2010; El Fallahi et al., 2008; Henke et al., 2015; Lahyani et al., 2015; Lai et al., 2013; Mendoza et al., 2010; Reed et al., 2014; Sethanan and Pitakaso, 2016). In all those cases, the products are loaded on a same vehicle but remain separable, so they can also be unloaded separately.

Product collection, specifically, has also been profusely addressed in a broad range of fields, going from blood collection from donors (Gunpinar and Centeno, 2016) to waste collection from islands (Miranda et al., 2015), to cite extreme examples. None has used different product blending. In terms of milk collection, there are different variants, as well as a number of