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The milk collection problem with blending and collection points

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ABSTRACT

A novel problem for the collection of raw milk from a network of farms supplying a dairy is specified and solved. The proposed approach incorporates milk blending and the delivery of production to collection points by small, distant farms. The milk is collected by, and blended in, a homogeneous fleet of trucks and classified according to the lowest quality product included in the blend. Optimization criteria are used to determine where the collection points should be located and which producers are allocated to them for delivery, with all other production picked up directly at the farms. The approach is built around an integer programming model and two implementation strategies, one using a branch-and-cut algorithm for small instances and the other a heuristic procedure combining both exact and approximated methods to handle large instances within a reasonable computation time. A real case study involving 500 farms and 112 possible collection points is solved and the results compared. The impact on the solutions of dividing the real instance into zones is also explored.

1. Introduction

This article presents, models and solves a real-world raw milk collection problem faced by a dairy products company in southern Chile. The company must collect the milk from a set of producer farms distributed across a wide geographical area and transport it to a dairy processing plant. All the milk produced must be collected given that all the farms belong to a cooperative.

Since different farms produce one of three possible qualities of milk, their collection by tanker trucks is normally carried out using either different vehicles for different qualities, or the same vehicles with segregated compartments. In Paredes-Belmar et al. (2016) it is assumed that the various qualities of milk can be mixed in one compartment or a single truck. Upon arriving at the plant, the mixed product is then classified according to the lowest milk quality included in it, thus reducing its commercial value and therefore revenue on the final products. On the other hand, combining different qualities in this way considerably lowers transportation costs, thereby increasing profit.

The simplest method of collecting the milk is for the trucks to visit each producer directly at the farm (door-to-door collection). If the collection routes are long and have multiple stops, transport costs will tend to be high. Direct truck pickup may therefore be inefficient if there are many small producers located far from the dairy processing plant. This is especially so with segregated collection of different milk qualities. In such situations, the collection process would be facilitated by setting up collection points where the output of small producers located far from the plant could be stored in tanks (Anquez and Tiersonnier, 1962; Bylund, 2003). That way, the trucks could collect the total production from a group of such producers, whether of one or more milk qualities, in one single stop, thus reducing the time and cost of transport.

This alternative is addressed in the present article, which generalizes an earlier problem formulated and solved in Paredes-Belmar et al. (2016) by incorporating the task of specifying the location of milk collection points. A model is developed to determine the number and location of these storage centers where farms can deliver their production. The general aim is to cut the tanker trucks' route lengths, which will result in lower transportation costs to the benefit of the dairy company. Our formulation also includes an access cost reflecting the expense incurred by the producer to deliver to a collection point, part of which is refunded by the dairy. This cost is considerably smaller than the transport cost of serving small, distant producers.

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To the best of our knowledge, defining the milk collection problem to include the twin factors of mixed milk qualities and milk collection points, although clearly of significant utility to many agents in the dairy industry, has not previously been studied in the specialized literature. Note that milk from farms can be transported (allocated) directly to the plant or to collection points. Furthermore, these collection points can hold different qualities of milk that could later be mixed on the trucks. Both facts make the problem non-separable in the two aforementioned factors. Furthermore, the problem is neither separable by milk qualities nor divisible in a location and a routing problem. In other words, the embedded allocation problem makes the problem non-separable and more complex than its components. Last but not least, this two-factored problem provides solutions that are more profitable for the operators.

Our first contribution in this paper is therefore to introduce what we call the milk collection problem with blending and collection points (MBCP) and design a mixed integer linear programming model for solving it. We use both new and known cuts with their respective separation algorithms and present a branch-and-cut algorithm to solve small instances of up to 40 nodes (farms or collection points). For each truck serving this network, the model determines the farms and collection points to be visited, the sequence of the visits and the amount of milk delivered to the points by small farms without truck visits.

Our second contribution is to develop an ad hoc three-stage procedure that solves the MBCP for large instances. This algorithm is applied to the real case of a Chilean dairy company collecting milk from 500 producers with a fleet of 80 trucks and 112 candidate collection points. The first of the three stages, optimally solves a covering problem that allocates small producers to collection points. The second stage generates feasible routes using the ant colony metaheuristic. Finally, the third stage chooses the best routes from those generated by the metaheuristic for direct visits to farms and collection points.

The objective of the proposed formulation is to maximize profit from the milk collection operation based on: (i) revenue obtained from the milk delivered to the plant, (ii) truck transport cost, (iii) collection point cost (i.e., operating plus pro-rated installation cost), and (iv) farms' collection point access cost. Since with a single milk quality the MBCP is reduced to the Capacitated m-Ring-Star problem, which is known to be NP-hard (Baldacci et al., 2007), the MBCP must be NP-hard as well.

Note also that although the milk must be collected every day, variations in daily production due to weather, cattle disease, etc. are relatively insignificant (Dayarian et al., 2015a). Collection routes do not therefore have to be rescheduled daily.

The remainder of this article is organized into five sections. Section 2 reviews the related literature, Section 3 formally introduces our proposed problem and sets out its mathematical formulation, Section 4 discusses various solution approaches to the problem, Section 5 reports on a case study, and finally, Section 6 presents our conclusions and some suggestions for future research.

2. Literature review

This survey of the literature is divided into two parts: other milk collection problems and problems having a similar structure to our proposed problem.

2.1. Milk collection problems

Sankaran and Ubgade (1994), Igbaria et al. (1996), Butler et al. (1997), Basnet et al. (1999), Prasertsri and Kilmer (2004), Butler et al. (2005), Hoff and Løkketangen (2007), Claassen and Hendriks (2007), Dayarian et al. (2013, 2015a,b) and Masson et al. (2015) report on real-world milk collection instances with a single quality of milk. Dooley et al. (2005), Lahrichi et al. (2015) and Sethanan and Pitakaso (2016) study cases with more than one milk quality. In none of these cases, mixing different milk qualities in the same truck or truck compartment is permitted.

A similar problem, the Truck and Trailer Routing Problem (TTRP), is dealt with in Caramia and Guerriero (2010). They find best truck routes for collecting three possible qualities of milk, without blending. In their problem, the trucks have compartments holding each one quality of milk. Different qualities cannot be blended. The trucks have trailers. On the route, the trailers are left behind and the truck alone collects the milk in those cases in which the access to the farm is difficult. Once collected, the truck returns back to the site where the trailer awaits, couples with it and continues the trip with the trailer.

Hoff and Løkketangen (2007) also address the TTRP, for one quality of milk, with no compartments or blending, for which they propose a Tabu Search algorithm. The main difference in the problem definition between our problem and the TTRP is that, in the first, the farms delivers the milk to a collection point, while a truck makes a sub-tour to distant/inaccessible farms in the TTRP.

Recently, Paredes-Belmar et al. (2016) presented a milk collection problem for a real instance in Chile with three milk qualities. The dairy allows these to be blended in the same truck provided it has a positive impact on the company profit. The article discusses the benefits of blending and reports increases in profit. The results are compared with the dairy's current collection procedure and with segregated collection by quality (no blending), demonstrating major improvements. As was noted here in the introduction, the present study departs significantly from Paredes-Belmar et al. (2016) in that as well as considering the blending of milk qualities, it addresses the collection point number and location decisions. The resulting formulation thus combines a routing problem with an allocation problem and a location problem, and in this sense both the model and the solution method for different-sized instances are quite novel.

Mumtaz et al. (2014) present a location-routing problem for the collection of a single milk quality. Their model determines the dispatch points that mark the start and end of the routes travelled by the trucks to pick up milk exclusively at collection centers where it must be dropped off by the producers. The model then decides the collection center sequence for each truck collecting milk from these centers. The milk is previously brought to the dispatch points from where it is brought to the dairy plant in larger capacity tankers. The authors develop a heuristic to solve a collection problem for small instances. Unlike the work of Mumtaz et al. (2014) we study the allocation-location-routing simultaneously, with three milk qualities and blending.

For a more complete review of the milk collection literature, see Paredes-Belmar et al. (2016).

2.2. Problems with a similar structure

The milk collection problem with collection points is a particular case of the location-routing problem (LRP) with assignment decisions and multiple product types. Several surveys of the LRP literature have appeared in recent years. Laporte and Rodríguez-Martín (2007) review problems of locating cycles in transport networks. Lopes et al. (2013), Prodhon and Prins (2014) and Drexl and Schneider (2015) give recent and extensive overviews of the LRP. Current and Schilling (1994) introduce the median tour problem (MTP) and the maximal covering tour problem (MCTP).

Two other similar problems, the ring star problem (RSP) and the median cycle problem (MCP), are studied by Labbé et al. (2004, 2005). Moreno Pérez et al. (2003), Renaud et al. (2004), Liefooghe