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Differential evolution algorithms for scheduling raw milk transportation

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ABSTRACT

This paper focuses on determining routes for raw milk collection from collection centers to dairy factories with the objective of minimizing the total costs, considering fuel costs and costs of cleaning and sanitizing raw milk tanks on vehicles. This problem is considered to be a special case of the vehicle routing problem (VRP) but it is complex compared to the general VRP, especially since each vehicle contains more than one tank with heterogeneous capacity to collect raw milk and raw milk from different collection centers cannot be transferred into the same compartment. In this paper, a DE metaheuristic was used to solve the problem. In order to improve the solution quality, five modified DE algorithms with two additional steps, reincarnation and survival processes, were proposed. In addition, the skipped customer and multi-route attributes are also developed in the decoding process in order to obtain a shorter traveling distance and lower truck usage in the system, especially if they are used together with the reincarnation and survival processes. The computational results reveal that the modified DE algorithms yield higher relative improvement (*RI*) on the total costs and also the *RI* on the number of vehicles used.

1. Introduction

This paper considers a special vehicle routing problem (VRP) with pickup and delivery services (PDP). It is found in various practical operations of real-world industries, especially in the agricultural food industry, such as the poultry and dairy factories. This research focuses on designing the routes for raw milk collection in the dairy factory as a case study application. In the process of milk production, raw milk management is one of the crucial activities in the supply chain of milk production, since raw milk is perishable product. The most commonly used method to retard the deterioration of milk on its way from farms to a dairy factory is cooling (Lambert, 2001). Raw milk is delivered to the dairy using temperature-controlled vehicles. These vehicles have standard cold storage equipment and are usually more expensive, have many compartments, and consume more fuel than regular vehicles. In addition, raw milk usually has a short shelf life; thus its timely delivery not only significantly affects the delivery dairy factory's costs, but also the continuous production of the dairy factory. Furthermore, the requirement to serve the dairy factory within the allowable maximum duration of delivery time can increase the complexity of vehicle routing and the scheduling problem for planners. Due to the high energy price for retardation of milk deterioration on its way from farm to dairy factory, the collection center, which is the place that farmers transport their milk to before transporting it to the dairy factory, plays an important role in cooling raw milk, since farms at which raw milk is collected are quite small and are often inaccessible by temperature-controlled vehicles. The raw milk collection problem is considered to be a special case of the vehicle routing problem (VRP).

In this problem, a fleet of heterogeneous temperature-controlled vehicles located at a depot must be routed to pick up raw milk from the collection centers scattered geographically. The amount of raw milk at each collection center may be different, depending on the amount supplied from the farmers in that area. Once the temperature-controlled vehicles finish picking up raw milk from the collection center of their route, they must deliver the raw milk to the dairy factory within the maximum time specified by the dairy factory planner. Fig. 1 illustrates a tour which represents a solution of the raw milk collection problem (with the constraints mentioned earlier). The vehicle starts from the depot (i.e., the dairy factory) and picks up raw milk from the collection centers at its maximum capacity. Then the vehicle goes back to deliver raw milk to the depot. When the collected raw milk is transported to the dairy factory, it must be inspected to check if it is in good condition. If so, the vehicle is weighed and then cleaned and sanitized in order to prevent deterioration of the incoming raw milk lots, while the raw milk is transferred into the raw milk tank for further processing. However, the raw milk

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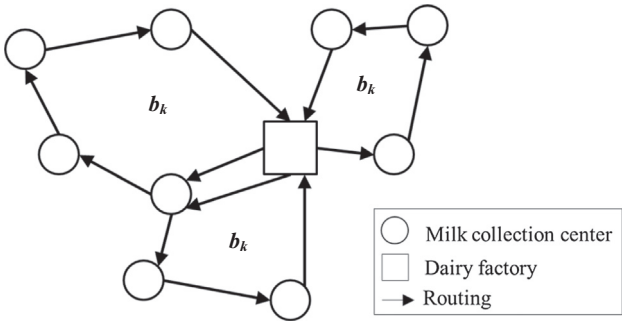

Fig. 1. Illustration of the tour representing a solution of the problem.

collection problem is complex compared to the general VRP in five ways:

1. Unlike the general VRP problem studied in the literature, each vehicle contains more than one tank with heterogeneous capacity to collect raw milk. However, generally, each vehicle usually has three individual compartments (see Fig. 2).
2. In order to maintain traceability of milk product, raw milk from different collection centers cannot be transferred in the same compartment. This means that when raw milk from a particular collection center has been transferred into a compartment, that compartment cannot be used to contain raw milk from other collection centers, until the compartment has been cleaned and sanitized at the dairy factory when the vehicle arrives. Hence, separate milk collection, either independent runs for different milk types, or storage of distinct milk types in the vehicle compartments, may increase the length and number of runs required.
3. Each collection center has a known demand and may be visited more than once by more than one vehicle, and each vehicle may visit more than one collection center depending on the amount of raw milk at that collection center and also the capacity of the vehicle itself.
4. Each vehicle could be used to collect milk on more than one round (route).
5. Both traveling costs and cleaning costs of vehicles are considered as the objective function. That means minimizing not only the travel distance, but also the number of vehicles by fully utilizing the vehicles' capacity.

Due to its complexity, it is therefore difficult to effectively manage cold chain distribution, especially managing vehicle routings and retarding raw milk deterioration. Inefficient transportation may often lead to deterioration of raw milk due to extended travel times and frequent stops during the collection process. Therefore, the dairy factory must cope with (1) high transportation cost especially if the amount of raw milk is much smaller than the compartment capacity, (2) high cleaning cost of tanks on the vehicle (i.e., electricity bill, water supply bill and chemical expenses) due to the temperature-controlled vehicles used in transporting the raw milk not being full-loaded. Therefore, a lot of temperature-controlled vehicles are required to be cleaned before loading the incoming raw milk lots, and (3) raw milk quality concerns due to high travel distance and high frequency of cleanings of temperature-controlled vehicles. Most importantly, due to the sanitization constraint, raw milk from different collection centers cannot be transferred into the same compartment. This restriction causes a significant impact to high production costs of milk production. In order to make higher volumes attractive and possibly produce economies of scale in milk collection, while maintaining the same marginal profit, optimizing transportation and vehicle cleaning costs may allow the dairy factory to pay higher milk prices to farmers with the balancing of a reduction in the milk collection costs (Butler et al., 2005). This paper therefore focuses on determining routes for picking up raw milk from collection centers to the milk factory with the objective to minimize the total costs, with consideration of capacity restriction of heterogeneous fleets, multiple tank compartments in a vehicle, and allowing maximum duration of a route. The total cost consists of two cost components: fuel cost and cost of cleaning and sanitizing tanks on vehicles. The fuel cost can be minimized by reducing the traveling distance while the cleaning cost of temperature-controlled vehicles can be reduced by minimizing the number of vehicles by fully utilizing the vehicles' capacities. To solve the problem, an efficient mixed integer programming model was developed for small-size problems. Since the problem considered is an NP-hard problem, the computational effort, in general, required to find an optimal solution grows exponentially with the size of the problem. In an effort to find a near optimal solution for problems with larger, more practical problems, a meta-heuristic was developed. An efficient algorithm is developed based on Differential Evolution (DE), a well-known metaheuristic. In order to improve the solution quality in terms of traveling cost and cleaning raw milk tank cost, in this paper, the modified DE algorithms were proposed in which two additional steps were included in the traditional DE: (1) reincarnation process and (2) survival process. Additionally, in this paper, the skipped customer and multi-route process were also developed in the decoding process in order to obtain highest utilization of vehicles used. The skipped customer attribute allows the next possible collection center to be a candidate in the route if the current collection center cannot fit in the route if the completion traveling time of the current collection center exceeds the maximum duration of a route. Hence, instead of creating a new route, this attribute allows the new client to be in a route as long as the ending time of a route does not exceed the maximum route duration. For the multi-route attribute, it allows each truck to pick up the raw milk from more than one round (for which each round may be a different route) as long as the maximum route duration is not exceeded.

To illustrate the proposed method effectiveness, numerical experimental results were compared with the mathematical model

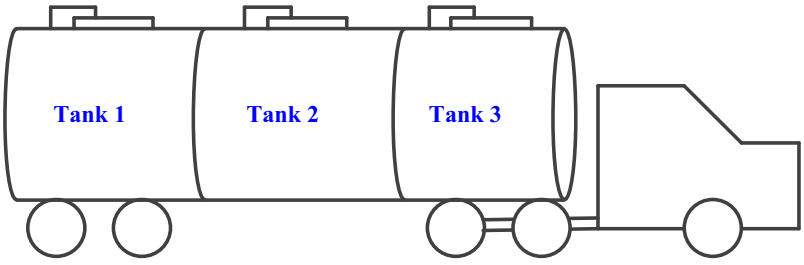

Fig. 2. Milk vehicle with multi-compartments.