An Optimization Model for the Vehicle Routing Problem in Multi-product Frozen Food Delivery

Y. Zhang * and X. D. Chen

School of Economics and Management,
Beijing Jiaotong University,
Beijing 100044, China.
*12120675@bjtu.edu.cn, xdchen@bjtu.edu.cn

ABSTRACT
This paper addresses a vehicle scheduling problem encountered in the cold chain logistics of the frozen food delivery industry. Unlike the single product delivery scenario, we propose an optimization model that manages the delivery of a variety of products. In this scenario, a set of customers make requests for a variety of frozen foods which are being loaded together. The objective is to find the routes that represent the minimum delivery cost for a fleet of identical vehicles that, departing from a depot, visiting all customers only once and returning to the depot. The delivery cost includes the transportation cost, the cost of refrigeration, the penalty cost and cargo damage cost based on the characteristics of different frozen food products. Apart from the usual constraints of time windows and loading weight, the study also takes into account the constraints of loading volume related to the unit volume of different frozen foods. We then propose a Genetic Algorithm (GA) method for the model. Computational tests with real data from a case validate the feasibility and rationality of the model and show the efficient combinations of parameter values of the GA method.

Keywords: Vehicle Routing Problem, Genetic Algorithm, Frozen Foods Delivery.

1. Introduction

The need for fresh, refrigerated and frozen food has grown continuously in recent years due to high demand for healthy and convenient diets in urban fast-paced daily living. Correspondingly, the market for low-temperature logistics is expanding due to demand for low-temperature food [1]. This paper considers a specific vehicle routing problem in the cold chain distribution industry for a variety of frozen food products. Compared to normal temperature distribution, cold chain distribution requires strict temperature and time control to preserve food quality. Frozen food products with low thermal inertia (such as ice cream) are more vulnerable to any disruption in the cold chain distribution process. As frozen food distribution companies tend to serve rather large numbers of customers in dispersed locations, it is crucial for them to design the routes for vehicles in an efficient way so as to minimize the delivery cost while maintaining or even improving food and service quality for customers.

In the past, most studies on the vehicle routing problem (VRP) have focused on the expansion of the network and algorithms [2,7,10-13,16-18]. Little attention has been paid to the improvement of the vehicle routing model [3]. The optimization models used for vehicle routing problems in current cold chain distribution studies often aim to minimize the total delivery cost, comprising the transportation cost, energy cost and deterioration cost [4-7]. Also, until now, vehicle routing models have been built for a single product only and the constraints considered in the model and its variants have always been the loading weight and time windows [4-9]. However, as is widely recognized, the reality is that customer orders are not limited to a single frozen food product and different frozen food products ordered by one customer are often loaded together in one vehicle.

The factors considered in this scenario include unit volume, price, the punishment degree and perishable coefficient of different frozen food products.

In addition to the usual constraints of time windows and the loading weight, the volume capacity of the vehicle is also taken into consideration.

This paper proposes a solution to the VRP in multi-product frozen food distribution taking into account the multiple factors discussed above.

The reminder of this paper is organized as follows. Section 2 describes in detail the model development process. In Section 3, the GA approach for the distribution model is proposed. Section 4 applies the GA in a case study. Finally, conclusions and future research are presented in Section 5.

2. The routing model for frozen food distribution

2.1 Assumptions and constraints

Assuming a fleet of identical vehicles with given internal and external dimensions of length, width and height, the objective is to find a set of minimum cost vehicle routes, starting from and terminating at the depot, such that:

1) The depot centre houses a fleet of identical vehicles with a fixed rate υ.

2) The loading weight and volume of the vehicle are known and there is no midway assignment.

3) The geographic locations and time windows of customers are known.

4) Information concerning the mass and loading volume of per unit frozen food products is given.

5) Each customer's orders are delivered by exactly one vehicle during distribution, but each vehicle can serve different customers.

6) The vehicle maintains a constant temperature inside and outside during distribution.

7) The cumulate weight and volume of a vehicle κ (κ = 1,2…K) does not exceed its capacity M and N at any point on the route.

2.2.Distribution cost analysis

1) The cargo damage cost of frozen food

The main damage cost in the process of distribution consists of two parts: a) damage cost accumulated due to transit time, b) damage cost caused by a break in the cold chain during a series of links including the arrival of food, code inspection and shelving. We assume that the quality of the frozen food in the transportation process and customer service process is inversely proportional to the time and the demand of customers, respectively. Hence, considering different damage rates and the price of frozen food products, the cargo damage cost Θ can be expressed by Eq. 1 [4].

$$\Theta = \sum_{\kappa=1}^{K}\sum_{\nu=1}^{H}\sum_{\gamma=1}^{E}(\theta_\gamma \tau_{\mu\nu\kappa} + \lambda_\gamma \beta_{\gamma\nu})\chi_{\mu\nu\kappa}\rho_\gamma \tag{1}$$

where θ_γ denotes the cargo damage rate of the frozen food γ (γ = 1,2…E) during the process of transportation, λ_γ is the cargo damage rate of the frozen food γ during customer service, ρ_γ represents the unit price of the frozen food γ, $\tau_{\mu\nu\kappa}$ indicates the time of vehicle κ from customer μ to customer ν, $\beta_{\gamma\nu}$ is the order of food γ from customer ν. The (routing) decision variable $\chi_{\mu\nu\kappa}$ is defined as

$$\chi_{\mu\nu\kappa} = \begin{cases} 1, \text{vehicle } \kappa \text{ starts from customer } \mu \text{ to customer } \nu \\ 0, \text{otherwise} \end{cases}$$

2) The vehicle transportation cost

The transportation cost includes fuel consumption, vehicle maintenance, etc. And the cost is generally proportional to the distance [7]. The transportation cost is given by:

$$X = \sum_{\kappa=1}^{K}\sum_{\mu=1}^{H}\sum_{\nu=1}^{H}\varpi_{\mu\nu\kappa} \tag{2}$$

where $\varpi_{\mu\nu\kappa}$ denotes the transportation cost of vehicle κ between customer μ and ν.

3) The refrigeration cost

The refrigeration cost relates mainly to two aspects. One is heat transfer inside and outside the refrigerator caused by the temperature difference during transportation. On the other hand, heat will exchange during loading/unloading process because of air convection. The refrigeration