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Optimizing fleet size and delivery scheduling for multi-temperature food distribution

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ABSTRACT

In light of the demand for high-quality fresh food, transportation requirements for fresh food delivery have been continuously increasing in urban areas. Jointly delivering foods with different temperature-control requirements is an important issue for urban logistic carriers who transport both low temperature-controlled foods and normal merchandise. This study aims to analyze and optimize medium- and short-term operation planning for multi-temperature food transportation. For medium-term planning, this study optimizes fleet size for carriers considering time-dependent multi-temperature food demand. For short-term planning, this study optimizes vehicle loads and departure times from the terminal for each order of multi-temperature food, taking the fleet size decided during medium-term planning into account. The results suggest that carriers determine departure times of multi-temperature food with demand–supply interaction and deliver food of medium temperature ranges with priority because delivering such food yields more profit.

1. Introduction

In light of the demand for high-quality fresh food, transportation requirements for fresh food delivery have been continuously increasing in urban areas. As such, jointly delivering foods with different temperature-control requirements is an important issue for urban logistic carriers who transport both low temperature-controlled foods and normal merchandise. One of the most important problems carriers encounter is determining a departure time from the terminal for each order of food that has delivery time constraints. These decisions, though restricted by the fleet capacity of carriers, affect the cost and quality of shipping services, especially for perishable food.

Compared with normal goods, perishable food needs strict temperature control and less travel time during the shipping process due to product characteristics, such as a short shelf life and quality decay over time and with fluctuating temperatures. The Industrial Technology Research Institute of Taiwan developed a multi-temperature joint delivery (MTJD[1]) system to distribute food of different temperature ranges in the same vehicle, which enables carriers to ship a variety of multi-temperature foods simultaneously. Unlike traditional refrigerated vehicles, which maintain vehicle compartment temperatures using an engine and compressors, the MTJD system maintains temperatures by using replaceable cold accumulators (eutectic plates) in standard cold boxes or cabinets that are loaded into regular vehicles. In this way, the temperatures in the cold boxes are specified for different requirements and are not changed during door openings. In addition, the combination of temperature ranges in the vehicle can also be easily changed. Kuo and Chen [1] pointed out a way of using the MTJD model in which carriers could

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[1] MTJD: multi-temperature joint delivery.

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markedly reduce the logistical costs of handling frequent deliveries in small lots using less than truckload (LTL) transportation, while maintaining customer satisfaction.

This study aims to analyze and optimize medium- and short-term operation planning for multi-temperature food transportation. For medium-term planning, this study optimizes fleet size for carriers considering time-dependent multi-temperature food demand. As for short-term planning, for daily operations, this study optimizes vehicle loads and departure times from the terminal for each order of multi-temperature food, taking the fleet size decided during medium-term planning into account. As mentioned earlier, with the MTJD system, the combination of temperature ranges in the vehicle can be easily changed based on demand. That characteristic allows the MTJD technique to easily deal with the stochastic and dynamic nature of the problem. Furthermore, this study divides the study duration into many small periods. Thus, time-varying demand and delivery volume can be analyzed using a multi-periods approach with high-level accuracy, and the stochastic and dynamic nature of the problem can be considered for multi-temperature food delivery scheduling. Shipping charges are also optimized for jointly delivering multi-temperature food, taking into account dynamic demand patterns and demand–supply interactions between carriers and shippers. In this study, carriers are defined as the logistics contractors who deliver food ordered by general retailers. These carriers have terminals for temporary food storage and own vehicles and temperature controlling equipment that is used to deliver food to retailers. On the other hand, shippers in this study are general retailers in urban areas that sell fresh food to customers in the city, so food delivery times and shipping charges influence their profits and willingness to consign in the future. This study explores demand–supply interaction and constructs a mathematical programming model to determine optimal fleet size and departure times from the terminal for each order, as well as shipping charges for jointly distributing multi-temperature food by maximizing the carrier's profits.

For research related to mathematical modeling for perishable food transportation, Hsu et al. [2] constructed a stochastic vehicle routing problem with time windows (SVRPTW) model to obtain optimal delivery routes, loads, and fleet dispatching and departure times for delivering perishable food from a distribution center. Osvald and Stirn [3] modeled the distribution problem between the distribution centers and the customers (retailers) as a vehicle routing problem with time windows and with time-dependent travel-times (VRPTWTD). Chen et al. [4] proposed a nonlinear mathematical model to consider production scheduling and vehicle routing with time windows for perishable food products in the same framework. Hsu and Liu [5] constructed a binary integer-programming model to determine suitable techniques and the food handling volume required for maximization of cost-efficiency in a hierarchical hub and spoke (H/S) network.

Although many researchers have discussed the importance of food temperature control during the transit process, except for Kuo and Chen [1] and Hsu and Liu [5] there is little research that addresses the application of the MTJD technique. Furthermore, Kuo and Chen [1] did not formulate a mathematical model for analyzing optimal delivery strategies for jointly delivering different temperature range foods using the MTJD system. Hsu and Liu [5] did not discuss dispatching time under time-dependent demand or take into account the demand–supply interaction between the carrier and shippers. To fill the gap, this study focuses on analyzing a joint distribution system operation strategy by considering the costs of carriers, transportation demand, and acceptable shipping charges with a time-dependent demand pattern.

The reminder of this paper is organized as follows. Section 2 describes the model formulation for fleet-size optimization, and Section 3 describes the optimal departure time programming under optimized fleet size and demand–supply interaction. A numerical example is provided in Section 4 to illustrate the application of the model. Finally, conclusions and suggestions are summarized in Section 5.

2. Mathematical programming model for the optimal fleet size

Previous studies have developed fleet-size optimization models to discuss the effects of fleet size on carriers' operating profits. Following the formulation of a fleet-size optimization model by Papier and Thonemann [6], this study constructs an analytical model to determine the optimal fleet size for carriers providing multi-temperature food delivery services. This study focuses on the delivery scheduling of a single distribution center. Therefore, in this study, the whole fleet is used by the same terminal and all orders are distributed from the same place.

Under time-dependent demand, if a carrier owns enough vehicles for peak demand at all times, all orders of food can be delivered in time but many vehicles sit idle during periods with little demand. On the other hand, if the number of vehicles is only sufficient for periods with little demand, even maximizing vehicle capacity would result in loss of revenue due to demand during peak periods. For the sake of simplicity, this study defines the demand time as the middle of a soft time window. For food i ordered by retailer j at time t, with the lower and upper bounds of a soft time window, u_{ijt} and s_{ijt}, respectively, the demand time is $(u_{ijt} + s_{ijt})/2$. To estimate the number of needed vehicles at each period, this study initially assumes that food i ordered by retailer j at time t would leave the terminal at a period that is nearest to (uijt + sijt)/2. After determining fleet size, the departure time would be adjusted through the departure time programming model presented in Section 3.

However, in practice, widths of time windows may be three or four hours. According to Hsu et al. [2], for a soft time window, shippers set the earliest and latest acceptable times for early and late arrival while consigning. Let U_{ijt} and S_{ijt} denote the earliest and latest acceptable times for arrival of food i ordered by retailer j at time t, respectively; the choice set of departure times from the terminal for this order includes several periods and depends on the widths of time slots between U_{ijt} and S_{ijt}. For example, for an order with the earliest and latest acceptable times being 8:00 and 11:00 AM, respectively, if the routing