Robotics and Computer-Integrated Manufacturing 43 (2017) 135–147

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim

Full length Article

Joint decisions of shipment consolidation and dynamic pricing of food supply chains

Jing Chen [a], Ming Dong [a,*], F. Frank Chen [b]

[a] Antai College of Economics & Management, Shanghai Jiao Tong University, PR China
[b] Department of Mechanical Engineering, The University of Texas, San Antonio, USA

ARTICLE INFO

Article history:
Received 6 April 2015
Received in revised form
22 September 2015
Accepted 7 October 2015
Available online 3 November 2015

Keywords:
Shipment consolidation
Perishable products
Freshness-keeping cost
Renew reward theory

ABSTRACT

This paper focuses on a perishable product supply chain with a vendor and multiple retailers. These retailers, densely spread in a distribution zone, are sensitive to price, delivery time and product quality. With the aim of optimizing the vendor's expected long-run average profit during a shipment consolidation cycle, an analytical model is proposed for this problem. According to the upper bound expressions of the expected long-run average profit, the approximate optimal time policy and freshness-keeping cost are given based on a certain range of time parameter. Our theoretical findings are verified through a numerical case. Some useful managerial insights are obtained by analyzing the sensitivity of this model from six perspectives, which are market scenarios, types of perishable products, quality requirements of all retailers, cost parameters, line-haul time and vehicle capacity.

1. Introduction

Since transportation cost increasingly accounts for a larger proportion of logistics cost for perishable goods, shipment consolidation is very important for vendors. The practice is to combine small-size shipments into a larger load based on a policy aiming to benefit from economy of scale associated with transportation costs. Currently, three such consolidation shipment policies are commonly seen in practical applications and discussed in the literatures (Higginson and Bookbinder [1], Çetinkaya [2]) which are quantity-based, time-based, and time-and-quantity-based policies, respectively. In addition, due to the perishable characteristics of food products, they often cannot be stored for too long period of time and customers are very sensitive for their price, delivery-time and quality. Thus, in order to obtain economy of transportation scale, the vendor may affect the demand by changing product price.

There exist many literatures focus on the shipment consolidation, which can be mainly divided into two classes: pure shipment consolidation study and integrated shipment consolidation research. The pure shipment consolidation problem only seeks minimization of the inventory cost. Early academic treatments are mostly based on simulation modeling, such as the work of Masters [3], Jackson [4], Cooper [5], Closs and Cook [6], Higginson and Bookbinder [7] and Lieb and Randall [8]. Çetinkaya and Bookbinder [9] propose quantitative approach by applying renewal theory to model the consolidation shipment problem based on both the quantity-based policy and the time-based policy. They also provide the explicit expressions of the policy parameters for the cases of private carriage and common carriage under Poisson demands. Based on this study, Mutlu et al. [10] and Ülkü [11] explore the shipment consolidation problem from cost and perspectives, respectively. Considering the effect of product price on the demand rate, Ülkü and Bookbinder [12] model and maximize a vendor's expected long-run average profit rate when the prices charged depending on the arrival times of orders. The integrated shipment consolidation problem optimizes the total cost of replenishment and inventory. Considering Poisson demand, Çetinkaya et al. [13–15] formulate this problem into three stochastic models by applying quantity-based policy, time-based policy and quantity-and-time-based policy, respectively. Then, Chen et al. [16] also model this problem to compare the operational results based on different shipment consolidation policies. Moreover, a renewal theoretical model with quantity-based policy under the common random order arrivals in random sizes is proposed by Çetinkaya et al. [17]. More recently, many papers analyze the integrated consolidation shipment problem in the perspective of the profit rate. Hong and Lee [18] consider a single-item inventory system and develop a mathematical model with the time-based consolidation policy to obtain the optimal price, replenishment quantity and dispatching cycle for maximizing the total profit. However, these literatures all focus on the regular products. There is a gap on the joint shipment consolidation and pricing decisions for the perishable products in the literature. Thus, considering a single vendor (distributing the

* Corresponding author.
E-mail address: mdong@sjtu.edu.cn (M. Dong).

http://dx.doi.org/10.1016/j.rcim.2015.10.002
0736-5845/

perishable goods to retailers by its own fleet of trucks) and multiple retailers, this paper models this problem based on the price-sensitive, product quality-sensitive and distribution time-sensitive stochastic demand. Exploring the optimal price and consolidation time for the demand is needed. Moreover, how the profit, the optimal consolidation time and the price are affected by model parameters such as cost and capacity factors will be discussed.

The remainder of this paper is organized as follows. In Section 2, details of the problem setting are described and related modeling assumptions are given. Next, the model is developed and solved in Section 3. In Section 4, a numerical example is offered and sensitivity analysis on the optimal solutions is conducted. Finally, concluding remarks and future research are provided in Section 5.

2. Problem definition and modeling assumptions

We consider a pure perishable product's consolidation shipment and pricing problem encountered by a vendor, which is obtained based on a real food company in China. The pictorial explanation of the problem is depicted in Fig. 1. The vendor announces the price, quality and delivery time of perishable products which are sold in standard size. The retailers send their demands to a regional distribution center (RDC) which is owned by the vendor if retailers accept the price, quality and delivery time of the products. Then, the vendor consolidates loads according to the real-time order information from the RDC and dispatches products to the RDC based on the predetermined optimal shipment consolidation cycle. Then, the local delivery to retailers is implemented by the RDC in a predetermined delivery zone. This cycle repeats on a rolling horizon basis. Moreover, we denote the adjacent departure time of the vendor to be a shipment consolidation cycle (SCL-cycle).

In order to facilitate the modeling process, the vendor's transport capacity is assumed to be unlimited. And compared to the distance of local delivery, the distance between the factory and the RDC is significantly long enough so that the local delivery in this model can be neglected. Besides, the quality of perishable products deteriorates as time elapses. But the vendor can utilize some preservation methods to slow down product's deteriorating rate at the expense of high freshness-keeping cost. To ensure the perishable product's quality is acceptable for the retailers, these products must be dispatched before they reach the minimum accepted quality level. The vendor adopts the time-based shipment consolidation policy, so that a particular quoted delivery-time can be guaranteed. The parameters defined in the model are shown in Table 1.

The sequence and timing of events in our model are shown in Fig. 2. We discuss a price-sensitive, delivery time-sensitive and product quality-sensitive demand market, which is similar as the demand market structure in the paper written by Ülkü and Bookbinder [12]. The vendor can optimize its expected long-run average profit per unit time. At the beginning, it decides the cost C_f (per unit product per unit time) for keeping the perishable products fresh and gives the initial price (p_0) and the initial guaranteed delivery time (T_u), which is the sum of the time of shipment consolidation cycle (T) and line-haul time (L). As the time elapses, the vendor updates the price (p_t) and the guaranteed delivery time (T_t), so that $T_t = T + L - t$, at each unit time t ($0 \le t \le T$). As a consequence, demand accumulates at vendor's site according to a non-stationary Poisson process. Then, at time T, vendor dispatches the consolidated load to the RDC.

We need to determine the optimal freshness-keeping cost, C_f^*, the optimal shipment consolidation cycle length, T^*, and the optimal price, p_t^*, in order to enable the vendor obtain the maximal expected long-run average profit.

Table 1
The definitions of parameters in the model.

Parameters	Descriptions
D_{max}	Maximum potential demand
m_t	Perishable products' quality level at time t
M_{min}	The minimum perishable product's quality level acceptable by retailers
δ_p	Demand sensitivity to price (price-sensitive coefficient)
δ_d	Demand sensitivity to delivery-time (deliver-time-sensitive coefficient)
δ_m	Demand sensitivity to products' quality (quality-sensitive coefficient)
V_{max}	Customer's maximum valuation for the perishable product
θ_d	Delivery-time sensitivity of the price (delivery-time-sensitive coefficient)
θ_m	Perishable products' quality sensitivity of the price (quality-sensitive coefficient)
K_w	Fixed order-processing cost for a SCL-cycle (independent of batch size)
K_d	Fixed dispatching cost per vehicle
C_d	Delivery cost per product per unit time
C_w	Handing cost per unit including sorting, loading, unloading, etc. per unit product
C_h	Holding cost per unit product per unit time
μ	Vehicle capacity (number of products)
L	Line-haul time ($L \le \frac{1}{\rho} \ln \frac{m_0}{M_{min}}$)
ρ	Perishable products' quality deteriorating rate
β	Perishable products' quality sensitivity of freshness-keeping cost
T	Length of SCL-cycle
T_t	Delivery-time guaranteed to a customer whose order arrives at vendor at time t
p_t	Price per unit charged to an order arriving at time t
C_f	Freshness-keeping cost per unit product per unit time

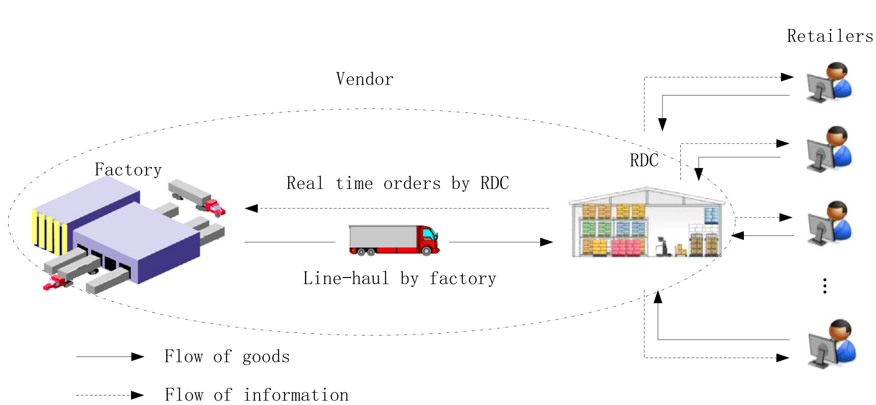

Fig. 1. Flows of products and information in the model.