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Dynamic vehicle routing for online B2C delivery

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Abstract

Electronic commerce (EC) is increasingly popular in today's businesses. The business-to-consumer EC environment has voluminous, unpredictable, and dynamically changing customer orders. A major part of the delivery system of this environment is the dynamic vehicle routing (DVR) system. This study investigates several algorithms suitable for solving the DVR problem in business-to-consumer (B2C) EC environment. It designs the solution process into three phases: initial-routes formation, inter-routes improvement, and intra-route improvement. A computer program is created to demonstrate a system simulating vehicle routing process under the online B2C environment. The simulated system collects data for system performance indexes such as simulation time, travel distance, delivery time, and delay time. The results show that when orders are placed through the Internet in an online B2C environment, the Nearest algorithms can be used to find satisfactory routes during the first phase of a DVR delivery system. The three-phase solution process is proven to be significantly better in travel distance and delivery time than the conventional single-phase solution process.

Keywords: Vehicle routing; Transportation; Algorithm; Route formation; System simulation; Electronic commerce; B2C; JIT delivery

1. Introduction

Delivering goods to customers is a critical activity in any business. On-time delivery relies heavily on effective vehicle routing once the merchandise is out the supplier's door and on its way to the customer. The problem of vehicle routing is much more complicated in an electronic commerce (EC) environment where the process of buying, selling, or exchanging products, services, and information is done through the Internet. In business-to-business (B2B) EC environment, the buyers and sellers are all business units. The main concern is how to maintain the efficiency of the supply chain partnership, which coordinates the order generation, the order taking, and the order fulfilment and distribution. In this environment, the buyers purchase products and services from the sellers with or without an intermediary. The two business partners integrate Just-in-Time (JIT) manufacturing and JIT inventory policy with JIT delivery. In fact, a JIT delivery service could be provided by either a buyer's, a seller's, or a third-party's deliverer (such as FedEx, UPS, or DHL). It is a coordinated effort of the deliverer and the seller or the suppliers of the seller. It is normal that these business partners have long-term relationships. The orders are normally planned, repeated, and reliable.

Contrary to B2B environment, the delivery policy of business-to-consumer (B2C) EC environment is different. The orders in online B2C environment are small in size, instantaneous, ever changing, and placed by numerous consumers. These customers are normally bargain seekers and care less about loyalty to the sellers. The coordination between the buyers and the sellers for JIT delivery is extremely difficult, if not impossible. When a customer places an order through the Internet, the best practice for the seller

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is to ship the goods from an adjacent distribution center or partnering supplier. However, the availability of on-hand inventory (or safety stock) is very limited under JIT production setting and the goods will very likely be shipped from a distance depot. Therefore, in the B2C environment the need of having a quick-response vehicle dispatching system that handles dynamic demands of consumers is much greater than that in the B2B. This calls for an effective routing of delivery vehicles in order to minimize the travel distance and the delivery time.

There are various vehicle routing algorithms in the literature. However, none of them alone is useful in the online B2C environment. These algorithms work best only when customer orders are planned and can be predicted by the delivery system. This study adopts the heuristic approach of the existing dynamic vehicle routing technique to solve the delivery problem in the online B2C environment. The solution process is divided into three phases. The purposes of this study are: (1) to demonstrate a system simulating vehicle routing process under the online B2C environment, (2) to verify that the three-phase solution process performs significantly better than the single-phase solution process, and (3) to identify the optimal algorithms and improvement strategies for vehicle routing in the online B2C environment. The remaining paper is organized as follows. Section 2 reviews the existing literature on vehicle routing. Section 3 describes a three-stage dynamic vehicle routing process. Section 4 presents the architecture of the prototype of a dynamic vehicle routing system. Section 5 demonstrates the prototype system by running a simulation experiment. During the simulation, several route improvement strategies are tested using combinations of different existing algorithms. The performance indexes such as travel distance, service time, system time, and delay time are collected to analyze the simulation scenarios. Based on the simulation results, conclusions and recommendations about the delivery performance of these route improvement strategies are presented in Section 6.

2. Literature review

A review of literature reveals that the existing research into vehicle routing [1] or traveling salesman [2] problem focuses invariably on the JIT delivery in the B2B environment where orders are normally planned. There is a lacking of research for the online B2C environment because the coordination between buyers (i.e., consumers) and sellers for JIT delivery has been deemed neither feasible nor possible in the online B2C environment. Although we agree that the JIT inventory strategy popular in the online B2B environment is infeasible for the online B2C environment, it is our contention that the delivery performance could be improved in the online B2C environment by means of combining different vehicle routing algorithms available today. A review of relevant literature on vehicle routing problem and algorithms is presented in Sections 2 and 3.

2.1. Vehicle routing system

The solutions of vehicle routing problem (VRP) find the vehicle routes with the lowest cost given a known route map $G=(V,A)$, where $V=\{1,\dots,n\}$ are the nodes of customers and the depot, and $A=\{(n_i,n_j): n_i,n_j\in N, i\neq j\}$ are the links between the nodes [3]. Normally, there are three restrictions on solving the VRP: (1) each node, except the depot, can only be served once by only one vehicle; (2) all vehicles return to the depot after completing the service; and (3) all constraints have to be met. The examples of common constraints are vehicle capacity, the maximum visiting allowance, the total travel time, and the delivery time window. Using a formal mathematical expression, the VRP may be defined as [4]

$$\text{Minimize} \sum_{ijk} c_{ij}x_{ijk} \tag{1}$$

Subject to

$$\sum_i y_{ik} = \begin{cases} 1, & i=2,\dots,n, \\ m, & i=1, \end{cases} \tag{2}$$

$$\sum_{i,k} q_i y_{ik} \leqslant Q_k, \quad i=1,\dots,n,\ k=1,\dots,m, \tag{3}$$

$$\sum_i x_{ijk} = \sum_i x_{jik} = y_{ik}, \quad i=1,\dots,n,\ k=1,\dots,m, \tag{4}$$

$$\sum_{i,j\in S} x_{ijk} \leqslant |S|-1, \quad \forall S\subseteq\{2,\dots,n\}, \quad k=1,\dots,m, \tag{5}$$

$$y_{ik}\in\{0,1\}, \quad i=1,\dots,n,\ k=1,\dots,m, \tag{6}$$

$$x_{ijk}\in\{0,1\}, \quad i,j=1,\dots,n,\ k=1,\dots,m, \tag{7}$$

where y_{ik} stands for node i served by vehicle k; c_{ij} is the delivery cost from nodes i to j; q_i is the ordering quantity of node i; Q_k is the capacity of vehicle k; $x_{ijk}=1$ means vehicle k drives from nodes i to j, m is the number of vehicles, and n is the number of nodes. Eq. (1) is the objective function to minimize the total traveling cost. The constraints of Eqs. (2)–(7) place a limit on the vehicle capacity and the travel flow.

Generally speaking, there are seven kinds of approaches to solving the VRP [5,6]:

(1) *Cluster-first route-second* approach divides the orders into several clusters and finds the most economic routes to ensure that the order deliveries are not assigned to inefficient routes. An example of this approach is the Sweep algorithm [7].
(2) *Route-first cluster-second* approach generates a vehicle route through all customers, and then divides the