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Intelligent algorithms for a new joint replenishment and synthetical delivery problem in a warehouse centralized supply chain

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ABSTRACT

In this paper, a novel joint replenishment and synthetical delivery (JRD) model is proposed to improve the coordination of replenishment and delivery processes. Traditional, in a warehouse centralized supply chain, orders from online customers are usually delivered independently after multiple items have been jointly replenished. To decrease the outbound delivery cost, a new delivery strategy considering synthetical dispatched orders, orders and customers matching, and customer visiting sequence is proposed. Three new beta-heuristic algorithms, namely, quantum evolution algorithm (QEA), differential evolution algorithm (DE) and quantum differential evolution algorithm (QDE), are utilized to solve the proposed JRD. The most important parts of each algorithm (initialization, reproduction and mutation, and selection) are redesigned according to the structure of the decision variables. Numerical experiments are conducted to find the best parameter settings and potential searching abilities of each algorithm. Finally, experimental results show the superiorities of the proposed DE and QDE in terms of searching speed, accuracy, and robustness.

1. Introduction

Joint replenishment is one of the most favored considerations in the replenishment process under multi-product environments. Especially, it is very critical to multinational corporations that aim to establish stable worldwide supply/procurement systems. In recent years, joint replenishment strategy and the delivery strategy are considered simultaneously [1,2], but the delivery process is assumed with a consolidated one-to-one service mode, which loses some generality comparing that in real delivery practices. Therefore, it leaves us spaces to make improvements in delivery process of JRDs. To begin with, before unfolding the model constructing process, the development of JRD researches are reviewed in the following contents.

Initially, JRPs are the problems that pertain to coordinating the replenishment of a group of items that may be jointly ordered from a single supplier [3,4]. The main feature of these classic JRPs is that they assume constant demand [5]. Other JRPs are mainly extensions of the classic JRPs [6], such as JRP under dynamic demand [5], and JRP under stochastic demand [7], which shows that JRPs consistently attract the attention of numerous researchers, although JRP has been discussed for several years.

The savings from group replenishment are so significant that practitioners are motivated to adjust their replenishment strategies regularly to save cost. For example, for a higher ratio of major to minor setup cost, the savings in the replenishment scheme of Chan et al. [4] range from 36% to 70% in different routes. According to the estimation of Porras and Dekker [8], for a 20-item problem with the major setup cost in the range of 25–75 units, approximately 5.4–13.2% savings can be achieved with respect to independent ordering compared with the cost obtained through the economic order quantity (EOQ) approach. It has been reported that 2.3% extra savings are obtained using joint replenishment strategy supported by a novel differential evolution algorithm (DE) comparing with the cost obtained through the EOQ strategy [9].

Typically speaking, of all the new JRP models, two extensions of JRP should be noted if the warehouse is assumed as the center of a supply chain. One extension is in the supply end, and the other is in the selling end. For both extensions, delivery considerations are taken into account, such considerations are called the joint replenishment-delivery problem, given that inventory and scheduling decisions are integrated in JRDs [10–12]. For the former type of JRD, the original JRPs with one supplier are usually extended to multi-supplier problems. After that, the delivery process is included after the orders are placed. Hsu [13] investigated a joint replenishment decision for a

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central factory and its satellite factories. In his model, raw materials are grouped together from different satellite factories to form a large shipment and then delivered to the central factory. For the latter type of JRD, Chan et al. [14] focused on a new multi-buyer situation of a firm who owns multi-branches. The firm prepares the ordered items and schedules the deliveries to his branches. A joint economic procurement-production-delivery policy was proposed to find the production sequences of multi-items, the common production cycle length, and the delivery frequencies [15]. Another JRD provided by Cha et al. [1] linked joint replenishment and delivery for a one-warehouse, n-retailer system. Both replenishment frequency and outbound frequency are decision variables. Based on the work of Cha et al., [1], Qu et al. [2] proposed JRD with a grouping constraint.

For current JRDs, the delivery assumptions are sometimes too strong such that generality is lost. For example, all the outbound deliveries are assumed as one-to-one delivery in Moon et al. [16]. Sometimes, delivery assumptions are complex to implement, such as in Kim et al. [15]. In reality, the outbound delivery strategy largely depends on the number of customers who order items. For example, if several customers order a specific product, the conventional one-to-one delivery strategy in Çetinkaya and Lee[11], Çetinkaya et al. [17] and Moon et al. [16] show higher distribution cost. Therefore, based on the work of Moon et al. [16], Qu et al. [2] and Cui et al. [18], we improve the delivery end of JRD under stationary policy and construct a new joint replenishment and delivery model with a varying number of customers who order multiple items.

Another great challenge in the study of JRDs is finding effective and efficient approaches for researchers [9]. JRPs [8] and JRDs [1] have been proven as NP-hard problems. Current approaches for JRPs can be classified as heuristics and meta-heuristics [6]. Available approaches to JRPs include an iterative algorithm, RAND algorithm [19], power-of-two policy [20], genetic algorithm (GA) [1], and DE [21]. The most well-known heuristic procedure for JRP is *RAND* for an equally divided search space. Other heuristics are mainly developed by using the RAND approach, such as the *QD-RAND* [22], *SP-RAND* [16]. In *RAND*, a continuous solution space must be searched so that small spaces can be equally split to find global optimal solutions, which constrains its ability to find solutions distributed in discrete spaces.

Current solving methods for JRDs originated from JRPs. Certain researchers opt to find proper meta-heuristic algorithms to solve different JRDs, such as the heuristic and evolutionary algorithm. Some approaches obtain close or even better results compared with those obtained by heuristic approaches. For example, GAs [1] and DEs [23] show good comprehensive performance in handling this NP-hard problem. However, finding a proper algorithm to solve a specific JRD is different because many candidate algorithms are available. *A more promising approach is to take advantage of the superior settings of currently adopted evolution algorithms and develop a new high performance algorithm.*

This study aims to contribute to literature in JRD research by providing an improved JRD model and effective intelligent algorithms. Our research differs from previous research and the main contributions are given in the following aspects:

(1) A new JRD model is constructed, in which the outbound schedule/scheme is improved from a fixed one-to-one service mode to a touring mode that dynamically changes according to a specific number of served customers.
(2) Three beta-heuristic algorithms named QEA, DE and QDE are specifically designed and utilized to solve the new JRD model. The evolutionary processes of these algorithms are redesigned according to the structure of the decision variables.
(3) Parameter sensitivities, most effective parameter settings, and the robustness of threes algorithms in solving small scale JRP, benchmark functions, and JRDs are vigorously compared and analyzed.
(4) Two supplement experiments are conducted to explore the performance of DE and QDE in solving the large-scale JRD and JRD with resource limitations.

The remainder of this paper is organized as follows. Section 2 presents the notations and the model formulation. Most importantly, the improvements to the conventional JRD and the steps for processing delivery strategy are introduced. Section 3 discusses the detail designed three algorithms, QEA, DE and QDE for solving the new JRD. Parameter sensitivities and robustness of three algorithms are tested and the computational results are intensively discussed in Section 4. The conclusions and future research are given in Section 5.

2. Improved JRD model

We reconsider the situation in Moon et al. [16], and a third party warehouse is considered in the center of a worldwide supply chain. Specifically, the warehouse replenishes multiple items from suppliers abroad, and then sells the items to the customers who sent the orders through the e-market. We also assume that the warehouse is located in the center of the local area and that the customers are randomly scattered over this area and around the warehouse. Therefore, the warehouse should decide the inbound schedule and delivery schemes considering the replenishment schedule of multi-item. The *objective* is to determine the *replenishment frequencies of multi-item*, the *basic cycle time*, and the *customer visiting sequence*, simultaneously. A sketch map of the improved JRD problem is illustrated in Fig. 1.

The basic notations below are employed in the following contents:

Basic notations	
i	the index of ith items, i =1,2,...,n.
TC	the total cost of the consolidated JRD per unit time
D_i	annual demand of item i
S	major ordering cost of each order
s_i	minor ordering cost of each item
s_i^c	fixed outbound transportation cost of each item
h_i	holding cost of item i per unit, per time
w_i	customer waiting cost of item i per unit, per time
Q_i	order quantity of item i
T	basic cycle time (*decision variable*)
k_i	replenishment schedule of item i (*decision variable, positive integer*)
K	$n \times 1$ vector that consists of k_i
f_i	outbound delivery schedule of item i (*decision variable, positive integer*)
F	$n \times 1$ vector that consists of f_i

2.1. JRD with the stationary policy

JRD with the stationary policy has two typical features, one is that intervals between successive deliveries must remain the same throughout the planning horizon. The other is that the consolidated freight order quantity also remains unchanged. The specific process is as follows: First, the warehouse replenishes item i at each integer multiple k_i of the basic cycle time T. Then, the warehouse delivers the ordered items to the customers according to the order information, inventory level and outbound schedule f_i of item i. Fig. 2 provides a good understanding of JRD with the stationary policy.

The total cost per unit time (or *total cost* for short) is given by

$$TC(T,K,F) = \frac{1}{T}\left(S + \sum_{i=1}^{n}\frac{s_i}{k_i}\right) + \sum_{i=1}^{n}\frac{(f_i-1)k_iTD_ih_i}{2f_i} + \sum_{i=1}^{n}\frac{f_is_i^c}{k_iT} + \sum_{i=1}^{n}\frac{k_iTD_iw_i}{2f_i} \tag{1}$$

The total cost is the summation of four terms: major and minor ordering cost, inventory holding cost, outbound delivery cost and customer waiting cost. T, K and F are the decision variables that minimize