Computers & Industrial Engineering 95 (2016) 164–174

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Joint order batching and picker Manhattan routing problem

Chun-Cheng Lin [a,*], Jia-Rong Kang [a], Chung-Chih Hou [a], Chen-Yang Cheng [b]

[a] Department of Industrial Engineering and Management, National Chiao Tung University, Hsinchu 300, Taiwan
[b] Department of Industrial Engineering and Management, National Taipei University of Technology, Taipei 106, Taiwan

ARTICLE INFO

Article history:
Received 16 October 2015
Received in revised form 8 February 2016
Accepted 8 March 2016
Available online 15 March 2016

Keywords:
Order picking
Order batching
Particle swarm optimization
Logistics
Warehouse management

ABSTRACT

In picking product items in a warehouse to fulfill customer orders, a practical way is to classify similar orders as the same batch and then to plan the optimal picker routing when picking each batch of items. Different from the previous problems, this work investigates the joint order batching and picker Manhattan routing problem, which simultaneously determines the optimal order batching allocation and the shortest picker Manhattan routing that cannot pass through storage shelves in the warehouse, under some practical constraints. This work further addresses this problem by particle swarm optimization with bad experience to avoid bad solutions, in which a novel solution representation is designed for simultaneously handling both order batching and picker routing. The idea of the design is to transform the warehouse floorplan into a grid, in which virtual *order center* and *batch center* are defined to represent symbolic positions of orders and batches of the solution, respectively. By calculating the distance between the two centers, similar orders are categorized as the same batch. Additionally, theoretical analysis of convergence and stability of the proposed approach is also derived. Performance of this approach is evaluated via comprehensive experimental analysis and a case study.

1. Introduction

Order picking is a core operation of warehouse management, based on needs of customer orders to quickly and accurately pick out the ordered product items from product shelves or other locations and move them with a specific procedure. The order picking process consists of information collection of order picking, traveling or moving and picking, as well as sorting and accumulation. A good planning for order picking can help substantially improve efficiency of warehouse management, and hence, it is of interest and importance to appropriately plan the picker routing distance as short as possible to save picker routing time and further to reduce time cost. In practice, customer orders in some industries (e.g., retailing and customized assembly) are often of great diversity and of small quantity of items. To reduce unnecessary repetitive picker routings, the orders for items with similar picking routing are generally categorized as the same batch to be picked before planning the order picking routes. A suitable *order batching* helps shorten the picker routing distance and reduce the time cost.

In practice, order-picking vehicles are used for picking and moving product items inside a warehouse for higher efficiency, and they are electric in modern warehouses. Design of the routing for order-picking vehicles in warehouses (a.k.a., *order picking routing* or *picker routing*) determines the total picker routing distance, which could be viewed as a vehicle routing problem (VRP). Lots of works on designing metaheuristic algorithms for various VRPs existed, e.g., Kumar et al. (in press), Luo, Li, Chen, and Liu (2015) and Yassen, Ayob, Nazri, and Sabar (2015). For designing particle swarm optimization (PSO) approaches for VRPs, the works in Ai and Kachitvichyanukul (2009a), Ai and Kachitvichyanukul (2009b) and Kachitvichyanukul, Sombuntham, and Kunnapapdeelert (2015) proposed the PSO with novel solution representations to solve various VRPs. The work in Goksal, Karaoglan, and Altiparmak (2013) proposed a hybrid discrete PSO for the VRP with simultaneous pickup and delivery. The work in Marinakis, Marinaki, and Dounias (2010) proposed a hybrid PSO for VRP. The work in Marinakis, Iordanidou, and Marinaki (2013) showed that PSO is the best approach to the order picking routing problem as compared with genetic algorithm (GA) and ant colony optimization (ACO). Therefore, PSO is suitable for the order picking routing problem for order-picking vehicles.

Recent works have considered the *joint order batching and picker routing problem* (Won & Olafsson, 2005), which classifies customer orders into batches and then bases the batching allocation to determine the order picking routing. The work in Kulak, Sahin, and Taner (2011) proposed a two-stage algorithm for the joint problem, which uses a cluster algorithm to allocate order batching

* Corresponding author. Tel.: +886 3 5731758; fax: +886 3 5729101.
E-mail address: cclin321@nctu.edu.tw (C.-C. Lin).

http://dx.doi.org/10.1016/j.cie.2016.03.009
0360-8352/

according to similarity of orders, and then uses tabu search to plan the shortest picker routing. The work in Tsai, Liou, and Huang (2008) proposed a two-stage GA to solve the joint problem; and the previous work in Cheng, Chen, Chen, and Yoo (2015) proposed a two-stage method based on PSO and ACO to solve the joint problem. However, most of the previous methods tended to provide a solution for either the order batching (Hwang & Lee, 1988) or the order picking routing (Marinakis et al., 2013), or used a two-stage approach (Cheng et al., 2015; Kulak et al., 2011; Tsai et al., 2008) to first determine the order batching allocation and then decide the order picking routing. In calculating the picker routing distance, they adopted the Euclidean distance to measure the shortest distance between two locations in a warehouse, and did not consider that some locations in the warehouse cannot be passed through in practice, so that the picker routing distance under this constraint may be different from the actual warehouse environment. To meet practical situations, this work investigates the *joint order batching and picker Manhattan routing problem*, and the major difference from previous problems is to adopt the Manhattan distance (i.e., strictly horizontal or vertical path) that cannot pass through any product storage shelves in the warehouse to measure the shortest picker routing distance between two locations in the warehouse. The objective of this problem is to find the optimal batching of orders with diversified items and the shortest picker Manhattan routing in the warehouse under some practical constraints. Inheriting from the original problem in Kulak et al. (2011), this problem is generally NP-hard, i.e., it cannot be solved deterministically in polynomial time.

This work solves the concerned problem by an improved PSO (ImPSO for short) based on Immanuel Selvakumar and Thanushkodi (2007), which additionally introduces each particle's previous bad experience to accelerate the convergence process of the PSO algorithm. One of the key designs in this work is to propose a novel solution representation for ImPSO, which can simultaneously determine both order batching and picker routing. The idea behind this solution representation is to consider the warehouse floorplan as a grid and to define virtual *order center* and *batch center* as the symbolic positions of orders and batches in the warehouse, respectively. By calculating the distance between the two centers, the orders with a high degree of similarity (in terms of the distance between the two centers) are categorized as the same batch.

The main contributions of this work are given as follows:

- The problem of concern in this work is more general than the previous ones. In calculating the picker routing distance, this work considers the fact that some locations in the warehouse cannot be passed through. Additionally, as compared with the previous work in Kulak et al. (2011) restricted to a fixed warehouse floorplan, this work presents a generalized distance calculation algorithm for different warehouse floorplans, so that the proposed approach can be applied to different warehouse configurations. Another main difference from the previous works is that the picker routing distance in this work is measured precisely by the Manhattan distance that cannot pass through any storage shelves in the warehouse.
- A novel solution representation is designed for determining both the order batching allocation and the picker Manhattan routing simultaneously.
- The proposed approach is applicable to customer orders with diversified items and small quantities, which conform to practical situations in some industries (e.g., retailing and customized assembly).
- This work theoretically analyzes stability and convergence of the proposed ImPSO algorithm. After many experiments under different parameters are conducted, it is discovered that bad experiences of particles in the ImPSO algorithm serve as an indispensable factor in the optimization process in handling the concerned problem.

The remainder of this work is organized as follows. Section 2 introduces the order picking system in warehouses, and gives a detail literature review. Section 3 describes the problem concerned in this work, proposes the algorithm with a novel solution representation for the problem, and derives a theoretical analysis for convergence and stability of the proposed algorithm. Section 4 gives a comprehensive experimental analysis of the proposed algorithm, and then compares the performance of a case study using the proposed approach and the current practice. Section 5 compares the performance of a case study using the proposed approach and the current practice. Lastly, Section 6 gives a conclusion with future work.

2. Preliminaries

This section first introduces the order picking system in warehouses, and then describes the concerned problem.

2.1. The order picking system in warehouses

The purpose of the order picking system is to accurately and efficiently collect the product items ordered by customers in a warehouse (Hwang & Cho, 2006). Some literature surveys can be found in de Koster, Le-Duc, and Roodbergen (2007), Henn, Koch, and Wäscher (2012) and Wäscher (2004). The system process of the whole order picking system can be divided into three stages: *information collection of order picking*, *traveling/moving and picking*, as well as *sorting and accumulation*. First, *information collection of order picking* refers to collection of the information on the customer orders to be handled for each batch, and on what items to be picked and moved for each batch. Second, *traveling/moving and picking* refer to all the activities of how the picker moves inside the warehouse according to the items to be picked to fill orders, confirms types and quantity of the product items to be picked when standing in front of the storage shelf, picks up the items, and moves them to the next storage shelf location or the product-collecting location. The time spent at this stage is the major time consumed for completing the order picking process. Third, *sorting and accumulation* refer to the process of collecting, sorting, and packing items to fill orders after the picker has taken all items of the orders. That is, the time required for the whole order picking system includes: the time for collecting the information for picking, the time for the overall picker routing movement, the time consumed for locating the correct storage shelf after moving close to the storage shelf, the time for picking up and confirming the right type and the right quantity of the item, and the time consumed for sorting and accumulation (Tsai et al., 2008). If the total picker routing distance is minimized, the picker routing time is minimized, and in turn, efficiency of the order picking operation could be increased.

Applying different order picking strategies and methods leads to a different total picker routing distance. Depending on whether each customer order could be split, there are two order picking strategies: *order splitting* and *order batching* (Henn et al., 2012). The *order splitting* strategy splits an order into multiple subsidiary orders that are handed over to different pickers to pick items. After pickers complete picking all items of their own subsidiary orders, the items are sorted and accumulated at the product-collecting location. The *order batching* strategy does not split orders but classifies all customer orders into multiple batches. This strategy is further divided into four categories: the *total batching* strategy