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An algorithm for dynamic order-picking in warehouse operations

Wenrong Lu[a,*], Duncan McFarlane[a], Vaggelis Giannikas[a], Quan Zhang[b]

[a] Institute for Manufacturing, University of Cambridge, 17 Charles Babbage Road, Cambridge, CB3 0FS, UK
[b] YH Global Logistics Ltd, 1201, Central Commerce Building, 88 Fuhua First Road, Fu Tian Qu, Shenzhen, 518048, PR China

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ABSTRACT

Warehousing has been traditionally viewed as a non-value-adding activity but in recent years a number of new developments have meant that supply chain logistics have become critical to profitability. This paper focuses specifically on order-picking which is a key factor affecting warehouse performance. Order picking is the operation of retrieving goods from specified storage locations based on customer orders. Today's warehouses face challenges for greater responsiveness to customer orders that require more flexibility than conventional strategies can offer. Hence, dynamic order-picking strategies that allow for changes of pick-lists during a pick cycle have attracted attention recently. In this paper we introduce an interventionist routing algorithm for optimising the dynamic order-picking routes. The algorithm is tested using a set of simulations based on an industrial case example. The results indicate that under a range of conditions, the proposed interventionist routing algorithm can outperform both static and heuristic dynamic order-picking routing algorithms.

1. Introduction

Warehouse management is a long established area—both in terms of industrial practice and academic literature. The attention paid to warehouse performance (and logistics performance generally) has increased in recent years as a result of factors such as (a) leaner supply chain separation requiring reduced inventory and faster warehouse response time (Agarwal, Shankar, & Tiwari, 2006; Naim & Gosling, 2011); (b) greater number of 3PL providers managing larger, more complex warehouses with multiple customers with widely varying requirements (Selviaridis & Spring, 2007; Tian, Ellinger, & Chen, 2010); (c) the rapid rise in the number of on-line retailer transactions, in which orders to the end customer are managed directly by the warehouse (Davarzani & Norrman, 2015; Gong & De Koster, 2008).

Across the various operations in a warehouse, order-picking is the most time consuming operation in general (Roodbergen & Koster, 2001) and accounts for around 55–75 percent of total warehousing costs (Chiang, Lin, & Chen, 2011). Therefore, order-picking has the highest priority for productivity improvement (De Koster, Le-Duc, & Roodbergen, 2007). The order-picking operation is particularly important in manual picker-to-parts picking systems,[1] which are the most common ones (Gong & De Koster, 2008) and account for over 80 percent of all order-picking systems in Western Europe (De Koster et al., 2007). In a picker-to-parts system, orders are firstly batched to form a pick-list. The list then guides the order-picker to travel along the aisles with a picking device (e.g. picking cart or fork-lifter) and collect requested items from designated storage locations (storage racks or bins) (De Koster et al., 2007).

Although many studies have been conducted on improving the order-picking operation, managing it efficiently remains complex (Gong & De Koster, 2008). On the demand side, the complexity arises from the introduction of new sales channels such as on-line shopping; and on the supply side, it arises from new operating programs, e.g. JIT, cycle-time reduction (Davarzani & Norrman, 2015; Tompkins, 2010). In such novel business models, customers can place an order by a click of the mouse in their computer, expecting inexpensive, rapid and accurate delivery (De Koster, 2003), i.e. they tend to order more frequently but in smaller quantities asking for more customised service. In response, more companies are inclined to accept late orders which leads to tighter windows for timely deliveries (Gong & De Koster, 2008). Moreover, many logistics companies are replacing small warehouses by fewer but larger warehouses to realise the economies of scale (De Koster et al., 2007). Consequently, the time available for order picking is increasingly shorter. Hence, a fast response is critical for warehouses to operate in such a complex environment (Otto & Chung, 2000).

Conventional, Static Order-Picking (SOP) requires batch formation to generate static pick-lists, which is time-consuming and insufficient

* Corresponding author. Tel.: +44 01223 765910.
E-mail address: wl296@cam.ac.uk (W. Lu).

[1] The reader is referred to De Koster et al. (2007); Tompkins (2010) for detailed reviews on order-picking systems.

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to cope with the rising number of daily orders and the decreasing lead time (Gong & De Koster, 2008). In order to shorten the response time, Dynamic Order-Picking (DOP) systems that allow for changes of a pick-list during a pick-cycle have been introduced. Such systems can also be useful for managing disruptions occurring in a warehouse. For example, disruptions occurring from the arrival of an urgent order or by noticing inaccuracies between items requested and items actually picked. These systems use constantly and selectively updated pick information of newly arrived orders as well as information regarding the status of the warehouse operations. A DOP system capable of updating pick-lists during execution has been previously proposed by Gong and De Koster (2008) which, however, constrains the picker to travel on a heuristic (non optimal) route and limits the assignment of new orders depending on a picker's current location. As a result, it has been suggested that the performance of such a system can be significantly improved by determining the new picking route in an optimal way (Gong & De Koster, 2008).

Motivated by this, in this paper we present an Interventionist Routing Algorithm (IRA) to address the problem of dynamic picking route optimisation. The algorithm calculates the route of minimised distance an order-picker should follow, upon receiving updated information on the requested items of new orders during the picking operation. Moreover, we investigate potential benefits of using such an algorithm in comparison to a conventional static optimal algorithm and dynamic heuristic algorithm, in terms of the average order completion time and average travel distance per order. The algorithm forms a fundamental part of a DOP, the authors have introduced in previous papers (Giannikas, Lu, McFarlane, & Hyde, 2013; Lu, Giannikas, McFarlane, & Hyde, 2014) and treats new orders as external disruptions and incorporates distributed intelligence to manage them.

The paper is organised as follows: Section 2 provides a background to order-picking operations. Section 3 introduces the routing problems for both conventional and interventional order-picking, clarifies the terminology, and introduces the notations and important definitions for supporting the dynamic extension of a static optimal algorithm originally proposed by Ratliff and Rosenthal (1983). Section 4 proposes the interventionist routing algorithm and provides an illustrative example. Section 5 presents and discusses the results of applying the algorithm in an industrial scenario. Finally, the paper concludes with a summary and an outlook on further research topics.

2. Background

In this section, we provide the necessary background on warehouse order picking. We begin by introducing the order-picking problem in warehouse operations and then focus on routing methods as one of the methods that reduce picking travel-time. Finally, we discuss approaches that can be used in order picking in non-static settings.

2.1. Order picking

An order-picking operation is the operation of retrieving goods from specified storage locations on the basis of customer orders (Roodbergen & Koster, 2001). The most common objective of any order-picking system is to maximise the service level (i.e. factors like the average and variation of order delivery time, order integrity and accuracy) subject to resource constraints such as labour, machines and capital (Gu, Goetschalckx, & McGinnis, 2010). In fact, order-picking is arguably a crucial link to other services in warehousing since it can significantly affect the point of time an order is available to be shipped to the customer (De Koster et al., 2007). If an order is late for its outbound transportation due time, it may have to wait for the next transportation service, thus affecting the whole transportation schedule (Goetschalckx, 1989). Hence, De Koster et al. (2007) emphasise that *"minimising the order retrieval time is a need for any order-picking system"* highlighting the fact that the shorter the *order retrieval time,*[2] the higher the flexibility in handling late changes in orders.

Many activities contribute to the order retrieval time, including travelling between storage locations, item searching, item picking, equipment setting-up, etc. (Dekker, De Koster, Roodbergen, & Van Kalleveen, 2004). Among them, *travelling* is the dominant component which accounts for more than 50 percent of the total retrieval time (Tompkins, 2010). Furthermore, travel time is considered a waste since it costs labour hours and adds no value (Bartholdi & Hackman, 2010). Therefore, in order to improve the performance of order-picking, reducing travel time is critical. Since the travel distance is proportional to travel time for picker-to-parts system (Petersen & Aase, 2004), minimising the travel distance (total or average) of a picking tour is often considered as imperative factor to reduce travel time and consequently improve warehouse operation efficiency (De Koster et al., 2007).

There are four methods to reduce the travel distance of an order-picker (De Koster et al., 2007; Petersen II, 1999):

(i) storage location assignment,
(ii) warehouse zoning,
(iii) order batching and
(iv) pick-routing methods.

This paper will focus on the pick-routing methods with an in-depth review in the next sub-section.

2.2. Routing methods in order-picking

This well-researched problem consists of the determination of the optimal sequence and route to pick up a set of requested items, subject to the layout of the warehouse and working methods (Van Nieuwenhuyse & De Koster, 2009). Optimisation is often achieved by minimising the total travel distance or time of the picker(s) or minimising the total material handling costs.

In practice, heuristic procedures are widely applied for the their simplicity and flexibility (De Koster et al., 2007). Several heuristics procedures for single-block warehouses exist (for a detailed review, see De Koster et al. (2007); Petersen II (1997)). Among them, the *largest gap* heuristic procedure outperforms the others when the number of products in a pick-list is small (Petersen II, 1997). However, despite the simplicity and flexibility of the heuristics procedures to most order-pickers, optimisation algorithms are still the centre of routing studies since they result in less travel distance (Petersen II, 1999).

To pursue the optimal or near-optimal order-picking route in a typical rectangular, multi-parallel-aisle warehouse, the order-picking routing problem is classified as the Steiner Travelling Salesman Problem (STSP) (De Koster et al., 2007; Theys, Bräysy, Dullaert, & Raa, 2010). There are two general methods to solve the STSP (Theys et al., 2010): the first one is to reformulate a STSP into the classic TSP by computing the shortest paths between every pair of required nodes, by which many well-studied TSP heuristics can be applied to STSP, e.g. Makris and Giakoumakis (2003); Renaud and Ruiz (2007); The second method for the solution of a STSP is by using exact (dedicated) algorithms.

The latter method is preferred to the former although it can only be applied to a rectangular warehouse layout with less than three blocks, for the following reasons:

- The original graph, which represents the warehouse layout and pick locations, may be easier to solve than the TSP on a complete graph (Cornuéjols, Fonlupt, & Naddef, 1985), especially

[2] The time needed for the items of an order to be picked from the designated storage locations.