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OPTIMAL SELECTION OF MOVABLE SHELVES UNDER *CARGO-TO-PERSON* PICKING MODE

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Abstract
In recent years, some e-commerce companies such as Amazon have adopted the *cargo-to-person* picking mode to improve their pickup efficiency. Under this mode, a shelf can store several types of goods and a type of goods can be placed on some shelves. When orders arrive, the warehouse robots move one shelf or more containing the ordered items to a fixed platform, and the pickers select the items from the shelves. It is very important to decide which shelves should be moved to increase picking efficiency. This paper addresses the problem of optimal movable-shelf selection for the *cargo-to-person* picking mode. The goal of this study is to minimize the total time (costs) of moving the selected shelves to finish a batch of orders. We model this problem using 0-1 linear programming and show that the problem is NP-hard. Furthermore, we propose a three-stage hybrid heuristic algorithm with polynomial complexity to solve it. We conduct numerical experiments to show the efficiency of this algorithm.
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Key Words: *Cargo-to-Person* Mode; Warehousing; 0-1 Linear Programming; Heuristic Algorithm

1. INTRODUCTION

In recent years, e-commerce has developed rapidly, and online sales have greatly increased, requiring the support of fast and efficient logistics. Different from traditional offline logistics, e-commerce logistics are characterized by variety [1], high frequency and small batches. To enhance the efficiency of order-picking, the designers of the Kiva system proposed a new picking mode: *cargo-to-person*. Based on this mode, they developed a new warehouse management system – Kiva. This system uses storage shelves which is movable and can be moved by robots. Moving the shelves containing products in a batch of orders to the pickers has increased warehousing efficiency greatly and improved flexibility and accountability simultaneously [2]. In March 2012, Amazon spent $775 million to buy the Kiva system, which it used in its warehouse management. Picking efficiency has greatly increased since then, and picking costs have been shown to help save $458 million to $916 million annually.

The layout of warehouses that use a *cargo-to-person* picking mode is depicted in Fig. 1. The movable shelves, on which goods are stored according to predetermined rules, are arranged in the upper part of Fig. 1. Each shelf can store several types of goods, and every type of goods can be stored on multiple shelves [3]. The working platform is located in the lower left corner, and the robots' parking and charging area is in the lower right corner. When orders arrive, they are partitioned into several batches according to predetermined rules. For each batch of orders, one shelf or more is selected and moved to the working platform by robots. After the workers pick items from these shelves, the shelves are returned to their original place. In the *cargo-to-person* picking mode, consumer goods that sell quickly might be placed on multiple shelves [4, 5] to increase picking efficiency and reduce the moving time needed for selected shelves. Shelf selection for a given batch of orders is a key issue for the *cargo-to-person* picking mode. This paper addresses this problem.