An efficient order-picking route planning based on a fuzzy set method with a multiple-aisle in a distribution center

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Abstract

In this paper, we propose a methodology based on the fuzzy set theory to solve the order-picking route planning problem with a multiple-aisle in a distribution center. Unlike traditional route planning strategies that only cope with quantitative data, fuzzy set-based methods provide proper mechanism for expressing planners’ linguistic terms to determine the level of factors that affect the order-picking route planning. A proposed order-picking route planning procedure that applies the fuzzy logic and the fuzzy clustering algorithm is presented here. The objective aimed to achieve is to reduce the traveling distance and time of order picking on the dynamic and elaborate order fulfillment operations. An example is given to illustrate the proposed route planning procedure. It is our hope that the proposed fuzzy approaches from this study can assist order pickers to deal with both quantitative and linguistic factors in improving the overall performance of their order-picking operations.

Keywords: order-picking; route planning; clustering algorithm; fuzzy set theory; distribution center

1. Introduction

In the past few years, the implementation of the Internet of Things (IoT) and the installation of related devices and platforms in a distribution center (DC) has risen widely. In order to be successful in IoT for DC, an efficient
order fulfillment more relies on an intelligent order-picking route planning. Therefore, it enable the DC become the key role in the logistic. According to Coyle et al. [1], order-picking operations can account for roughly 65% of the total operating cost of a warehouse. The study of Tompkins et al. [2] shows that the travel time accounts for about 50% of all order-picking operations. Towards inner operations in DC, order picking is often a labor massive but necessary process, which may consume as much as 60% of all labor activities in a warehouse [3]. However, an order-picking route planning is affected easily by planner’s subjective decisions and linguistic terms to evaluate the performance of the creation, travel or move, pick, sort and accumulate. As result, one may be difficult to justify which route path can be allocated precisely within the period of order-picking operations.

In order to solve this problem, in this paper, an order-picking route planning procedure that applies the fuzzy logic and the fuzzy clustering algorithm is presented. Unlike traditional route planning strategies that only cope with quantitative data, fuzzy set-based methods provide proper mechanism for expressing planners’ linguistic terms to determine the level of factors that affect the order-picking route planning. Fig. 1 shows the layout of a distribution warehouse which contains racks and aisles and pick-up and drop-off (P/D) location proposed by Roodbergen and De Koster [4].

The remainder of this paper is organized as follows. In section 2, a review of the literature pertinent to this design problem is conducted. In section 3, the design methodology we proposed is explained. An example is given in section 4 to illustrate the proposed design method. Finally, section 5 concludes and summarizes the results of this study.

2. Literature review

Since the aspect of few quantities and intensive types is a trend for distributor, many methods of order picking become elements to minimize the order-picking travel distance in DCs. Research has shown that optimization of order-picking route can accomplish the purpose. For example, Hall [5] developed distance approximation methods for five order-picking route strategies, i.e. traversal, midpoint, largest-gap, optimal routing, and minimal, in a
warehouses with two cross aisles. Petersen [6] evaluated the performance of six heuristic routing strategies and compared them to the optimal strategy. Caron et al. [7] compared the expected travel distance for different routing strategies, i.e. traversal and return policies. They developed a cube-per-order index (COI) based stock location assignment strategy to determine the major parameter related to the expected travel distance. Roodbergen and De Koster [4] investigated route-planning problems in a warehouse with multiple cross aisles. They considered several heuristics to determine order-picking routes. To analyze the performance of their heuristics, a branch-and-bound algorithm that generates shortest order-picking routes was used. For presenting the linguistic expression of knowledge in DCs’ operations, to the best knowledge of authors, order-picking studies that consider the fuzzy set theory are still in the minority. Lam et al. [8] proposed an order-picking operations system (OPOS) to assist the formulation of an order-picking plan and batch-handling sequence. They integrated a mathematical model and fuzzy logic technique to divide the receiving orders into batches and prioritized the batch-handling sequence for picking. In order to solve the problem in the order-picking route planning by using fuzzy set theory, a new solution procedure must be developed.

3. The proposed methodology

The aim of this study is to propose a methodology that the route planning based on fuzzy set in a multiple-aisle DC for order-picking operations was implemented under various criteria. Due to the numerical aspects of picking segments between aisles, lots of route paths will be chosen by pickers during the period of order-picking operations. Given the reason to avoid the efficiency reduction from the operation conflict, a well-prepared plan becomes more substantial. Fig. 2 gives an overview of the proposed route planning method.

As shown in Fig. 2, the proposed order-picking route planning method has two phases – fuzzy set-based order clustering algorithm and intelligent picking segment formation. The purpose of the order clustering algorithm is to provide a mechanism that can determine which orders can be picked up together at the same time per trip. To achieve this purpose, the route planner is required to identify various order content of pick operations in the creation, travel or move, pick, sort and accumulate. However, these appearances, i.e., variables, may not be described precisely due to uncertainty on them. It is important to determine these variables as factors, define the membership function, and rate the linguistic values for these variables via a fuzzification module in the fuzzy decision-making system (FDMS) shown in Fig. 3.
After conducting the clustering algorithm for the order grouping, each picking list can be recorded as the picking commend that will be an input to intelligent picking segment formation. The purpose of the intelligent picking segment formation is to develop an order fulfillment heuristic algorithm by generating the number of picking segment over the distribution warehouse respectively. We will explain each of them as follows.

3.1. The fuzzy set-based clustering algorithm

In this section, the problem we deal with is to assign $n$ order types in racks to $c$ entity units (i.e. clusters) in which pickers operated. In tradition, one needs to define a finite data set $X$, $X=\{x_1, x_2, \ldots, x_n\}$, and let $x_k=\{x_{k1}, x_{k2}, \ldots, x_{kq}\}$, where $x_k$ is a vector represented by $q$ features of characteristics such as order type operating with the picking group $x_k$. For gathering creation, travel or move, pick, sort and accumulate, one aim to determine the similarity rating between these order-picking objects. In our study, we replace the characteristics with how similar $x_k$ to others is.

In order to form the similarity rating matrix, five variables determined by planners between order-picking objects in a DC are: creation volume (CV), travel or move flow (TMF), picking size (PS), sort and accumulate degree (SAD), and similarity rating (SR). The set of membership functions used for them can be illustrated in Fig. 4. An example of the fuzzy logic between a pair of objects is reasoned as follows:

\[ \text{IF (CV) is (very large) AND (TME) is (very high) AND (PS) is (medium) AND (SAD) is (easy) THEN (SR) is (A)} \]

All the input variables are considered as trapezoidal membership functions while output variable is considered as triangular membership function. The number of rules in decision-making module can be calculated by Eq. (1).

\[ N = \sum_{j=1}^{m} \left( \prod_{i=1}^{n} L_i \right) \]  

where

- $N$ = the total number of rules,
- $L_i$ = the number of membership function in $i$th input variable,
- $m$ = the number of the sets of rules, and
- $n$ = the number of input variables used in a set of rules.
As indicated in Lee [9], the three commonly used strategies may be described as the max criteria, the mean of maximum, and the center of area (COA). In addition, Braae and Rutherford [10] concluded that COA strategy yields superior results. In this study, we adopt COA as the defuzzification strategy to calculate the final crisp value of each similarity rating. Among objects, the FDMS is repeated with the number of combination of each pair of objects. After all crisp values of similarity rating obtained, the similarity rating matrix can be formed as a kind of characteristics to follow up a clustering algorithms.

### 3.2. Intelligent picking segment formation

As the clustering of picking groups is completed, the next phase is to approach a segment formation problem. The segment formation we defined is how many blocks that one trip is required to be covered and what orders will be assigned into the segments according to picking list in final picking groups. However, the segment formation is distinguished from the picking groups in a problem that the number of clusters is not specified. In our study, a method based on fuzzy equivalence relations is adopted since the relations can induce a crisp partition in each of its $\alpha$-cut without a specified number of clusters. Let $R_s$ be a similarity relation, then each $\alpha$-cut $^\alpha R_s$ is a crisp equivalence relation that represents the presence of similarity between the picking groups to the membership degree $\alpha$. That is, the similarity classes among picking groups are defined in terms of a specified membership degree $\alpha$. A three-type segment formation example in a corner of distribution warehouse can be found by a determination of similarity degree in a partition tree’s level set $R_T$ shown in Fig. 5 (a), (b), and (c).
4. Experimental result

In this section, an experimental result will be presented to help readers understand the proposed methodology for order-picking route planning problem in a multiple-aisle distribution warehouse. As shown in Fig. 6, one can easily understand five picking segments are formed to generate the route planning respectively.

Fig. 6. The illustration of order-picking route for each picking segment.
5. Conclusion

In this paper, a method applying the fuzzy logic and the fuzzy clustering algorithm that takes all appearances of the order-picking operations into consideration to make order-picking route planning more efficient and precise to reduce the traveling and order fulfillment period of time is proposed. The proposed method is capable of justifying order-picking route planning more objectively in the early planning phase.

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References