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O.R. Applications

A clustering algorithm for item assignment in a synchronized zone order picking system

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Abstract

In a synchronized zone order picking system, all the zones process the same order simultaneously. There may be some idle time when the zone pickers wait until all the pickers complete the current order. This paper develops a heuristic algorithm to balance the workload among all pickers so that the utilization of the order picking system is improved and to reduce the time needed for fulfilling each requested order. A similarity measurement, using customer orders, of any two items is first presented for measuring the co-appearance of both items in the same order. With this similarity measurement, a natural cluster model, which is a relaxation of the well-studied NP-hard homogeneous cluster model, is constructed. The heuristic algorithm is then proposed to solve the model for locating all the items into distinct zones. Finally, empirical data and simulation experiments verify that the objectives of the item cluster model are achieved.

Keywords: Warehousing; Item cluster; Synchronized zoning; Utilization improvement; Heuristic

1. Introduction

Order picking is defined as the process by which appropriate amounts of products are retrieved from specified storage locations to fulfill customer orders. The total pick area may be divided into picking zones so that each picker is dedicated to picking the items only in his/her zone. Depending on the process sequence, zoning is further classified into progressive zoning and synchronized zoning. Under progressive zoning, each order is processed by one zone picker at a time. Under synchronized zoning, all the zones are processing the same order at the same time.

In general, the order picking process is one of the most laborious processes of all warehouse operations. Coyle et al. (1996) estimate that on average 65% of the total operating costs of a common warehouse are spent on order picking activities. According to Delaney's (2000) annual studies of transportation and logistics cost, in 1999 the overall logistics cost is estimated to be 10.9% of

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the Gross National Product, and 8% of this logistics cost is used for warehousing. In a survey conducted by the Warehousing Education and Research Council (1986), order picking activity has been identified as the number one area for improvement in warehousing. In today's competitive environment, the increasing emphasis on better delivery time and accuracy standards cause the order picking system to play an increasingly important role in a distribution center.

To improve the order picking process, most of the researches focus on travel time reduction as well as storage location assignment in a general warehouse. Amirhosseini and Sharp (1996) present a generalized correlation measure that examines the degree to which two or more products together fill warehouse or customer orders to reduce the overall distance during order picking. Petersen (1997) evaluates various routing policies in a random storage environment, and the impact of warehouse shape and pick-up/drop-off location. On the basis of the ratio of the required space to order frequency, Caron et al. (1998) evaluate the expected travel distance for traversal policy and return policy in low-level picker-to-part systems in which items are assigned to storage locations. In simultaneous analysis of products and orders in storage assignment, Hall (1993) evaluates and compares strategies for routing a manual picker through a simple warehouse. Several rules of thumb are derived for selection of order pick strategies and optimization of warehouse shape. Chew and Tang (1999) present a travel time model in a rectangular warehouse, give the exact probability mass functions that characterize the tour of an order picker, and derive the first and second moments associated with the tour. Guenov and Raeside (1992) investigate the effect of zone shape in a class-based storage on the optimal picking tour of the S/R machine. As to person-on-board AS/RS systems, in which recurrent orders are to be retrieved, Oudheusden and Zhu (1992) solve the storage layout problem by making use of the traveling salesman problem in order to minimize the routing distance. To save the travel distance of the picker in a general warehouse, the homogeneous cluster (HC) model for locating items is proposed by Rosenwein (1994). In the HC model, items are grouped into a specified number of p clusters by means of selecting p items as the medians such that the sum of distance from all items to their respective median is minimized. One famous storage location rule is the cube-per-order index rule proposed by Heskett (1963). This index is defined as the ratio of the space requirement (cube) of an item to its turnover rate. The rule ranks the items in an ascending order of the index, and then assigns them in that order to the locations nearest to the I/O point.

Brynzer and Johansson (1996) propose a storage location assignment strategy using product structure, which results in a reduction in picking information. For environments where items may be stored in multiple locations, a model for determining simultaneously the assignment and sequencing decisions is formulated and is compared with previous models for order picking (Daniels et al., 1998). The so-called pattern graph proposed by Suzuki (1988) enables planners to identify the relationships between orders, items and retrieved quantities. For manual pickers, a computer-aided system can be used for order picking to simplify the tasks of human pickers (Frazelle, 1989), and a light-directed pick system with automated data entry can reduce human errors by 95% as well as increase productivity by 10% (Tolliver, 1989). The analytical design algorithm by Bozer and White (1996) which uses an approximate analytical model is presented to estimate the expected picker utilization for general system configurations with two or more pick positions per aisle and/or two or more aisles per picker. All the above studies focus on general warehouses. However, zone picking systems are rarely discussed. For a progressive zone picking system, heuristic algorithms proposed by Jane (2000) are to balance the workloads among the pickers and to adjust the zone size for order volume fluctuation.

This paper deals with the synchronized zone manual order picking system, in which all the zone pickers are working on the same order simultaneously. To improve the utilization of the order picking system and to reduce the time needed for fulfilling each order, this paper first proposes a similarity measurement for any two items, and then builds a natural cluster (NC) model. The NC model, which groups all items into clusters directly from the viewpoint of global optimization and does not select any item as the median of each cluster, is a relaxation of the NP-hard homogeneous cluster (HC) model. A heuristic algorithm is then proposed to solve the NC model. Finally, empirical data collected from a case company and simulation experiments conducted show that the proposed NC model does achieve the objectives.

2. The synchronized zoning system

Zoning an order picking system is to separate the entire picking area into individual zones so that each picker is dedicated to picking the items only in his/her zone. Due to the smaller area coverage by each picker, the advantages of such zoning are the familiarity of each picker with his/her zone, and the travel time reduction. The traveling time can thus be excluded from the total picking time. That is, for each zone picker, with respect to an order, the workload is measured by the time of picking operations rather than by the time of traveling. In a progressive zone picking system, each order is completed only after it has sequentially visited all the zones containing its items. In a synchronized zone picking system, there may be some idle time when the zone pickers wait until all the zone pickers finish the current order. The synchronized zone picking system usually gives a shorter response time at the expense of order integrity than does the progress zone picking system. The *utilization* of such a synchronized zoning system with respect to an order is defined by the average utilization of all zone pickers with respect to the order. The utilization of a zone picker with respect to a specified order is the ratio of the total picking time the zone picker spends on the order to the time the order occupies the zone system.

A pick-to-light system uses rack mounted lights to direct zone pickers to specific stock locations. Each item has an individual numeric display with a light, an acknowledgement button, and a digital readout for indicating quantity. The displays tell the picker which and how many items to pick. The picker confirms the picks via the acknowledgement buttons. To secure accuracy, the picker is requested to pick one kind of item at a time. Before picking the next item, the picker presses the acknowledgement button and the picked items in hand must be put into the container specified for the picking order. Beside high accuracy and search time reduction, the paperless pick-to-light system also allows for a flexible workforce, as training time is virtually nonexistent. Fig. 1 shows an illustration of the hybrid system.

This paper considers a synchronized zone manual order picking system, using gravity flow racks, together with the pick-to-light system. Since the advantages of the zoning system and the pick-to-light system are the travel time and search time reduction, respectively, it is assumed that the travel time and search time are negligible and are thus excluded from the picker's total picking time. In addition to the exclusion of travel time and search time, the following assumptions are made under the hybrid system: (1) each order requires a variety of items, and only a small number of each item is demanded; (2) this small amount of each demanded item is picked up at one time; (3) each item is allocated in one flow rack only; (4) stock outs never happen; (5) the pick operation of each picker is standard, that is, each picking takes the same amount of time.

According to the above assumptions, the total picking time of picker j with respect to order i equals to the picking time that picker j spends on order i; moreover the picking time that picker j

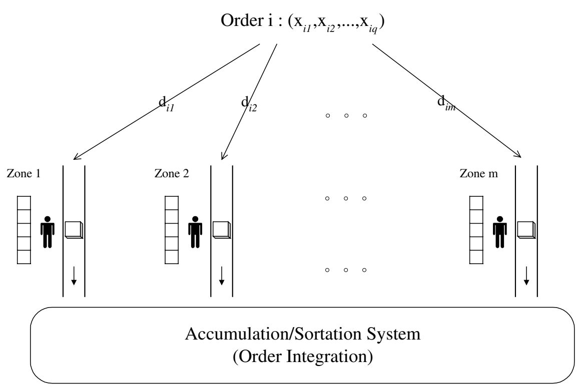

Fig. 1. The synchronized zone manual order picking system.

spends on order i is proportional to the kinds of items that are asked by order i and stored in zone j. On the other hand, the disadvantage of the considered hybrid system is that there may be idle time for some pickers. This implies the workloads among all pickers are not evenly allotted and the order picking system is not completely utilized. Under the paperless pick-to-light system, as the workforce is flexible, such workload unfairness can be avoided by adjusting all the pickers among the zones. Since, for each zone, the kinds of items asked by each order is not changed, such adjustment neither minimizes the idle time of the picking system nor reduces the completion time of each order. In fact, if all the items are located into disjoint zones so that each order requires almost the same number of kinds of items at each zone, the workload can be made even and the fulfill time of each order can be reduced. As a result, the idle time of the zone pickers can be reduced and the utilization of the picking system can be improved. This is the main objective of this paper.

3. The natural cluster model

To improve the utilization of the zone picking system, the following similarity measurement is proposed, based on empirical orders, between any two items for measuring the co-appearance of both items in the same order. Say, there are n orders, m zones, and q items. First of all, each order i can be represented by a q-tuple $(x_{i1}, x_{i2}, \ldots, x_{iq})$ where $x_{ij} = 1$ if item j for $1 \leqslant j \leqslant q$ is asked by order i, and $x_{ij} = 0$ if otherwise. The *similarity* measurement N_{ab} between different items a and b is defined as $N_{ab} = N_{ba} = \sum_{1 \leqslant i \leqslant n} x_{ia}x_{ib}$ where $x_{ia}x_{ib}$ is 1 if and only if $x_{ia} = x_{ib} = 1$. That is, both items a and b are asked by order i. Thus, N_{ab} is the times that both items a and b are requested by the same order among the total n orders. To minimize the idle time of the synchronized zone system in which all the zone pickers are working on the same order simultaneously, items frequently asked together should be located into different zones. That is, the larger N_{ab} is, the less items a and b are stored in the same zone. To achieve this goal, the following natural cluster (NC) model is constructed:

$$\min \quad Z = \sum_{1 \leqslant a < q} \sum_{a < b \leqslant q} \sum_{1 \leqslant k \leqslant m} N_{ab} C_{ak} C_{bk}, \tag{1}$$

$$\text{s.t.} \quad \sum_{1 \leqslant k \leqslant m} C_{ak} = 1 \quad \text{for } 1 \leqslant a \leqslant q, \tag{2}$$

$$C_{ak} = 1 \text{ or } 0 \quad \text{for } 1 \leqslant a \leqslant q, \; 1 \leqslant k \leqslant m, \tag{3}$$

where $C_{ak} = 1$ or 0 represents that item a is located into zone k or not, respectively. The constraint $\sum_{1 \leqslant k \leqslant m} C_{ak} = 1$ restricts each item such that it must and can only be located into one zone. The term $N_{ab}C_{ak}C_{bk}$ equals N_{ab} if and only if items a and b are placed into the same zone k (i.e., $C_{ak} = C_{bk} = 1$), and is 0 otherwise. The objective "The larger N_{ab} is, the less items a and b are stored in the same zone" can then be achieved in terms of the objective function (1).

The NC model is a relaxation of the NP-hard p-median homogenous cluster problem. In the following, we propose a heuristic to solve the NC model efficiently.

4. The heuristic algorithm

To solve the NC model, all the $q' = q(q-1)/2$ N_{ab}'s similarity values are first computed according to the empirical orders and sorted in an ascending manner. Without loss of generality, the sorted sequence is denoted as

$$N_{a_1 b_1} \leqslant N_{a_2 b_2} \leqslant \cdots \leqslant N_{a_{q'} b_{q'}}. \tag{4}$$

The following steps are then employed to locate all the items into disjoint zones.

Step 1. Initially, items a_1 and b_1 are placed into zone 1. Then repeat the following sub-steps $m-1$ times. Say, it is the ith time now for $1 \leqslant i \leqslant m-1$.

- Step 1.1. Find the first $N_{a_{i'} b_{i'}}$, according to the sorted sequence (4) so that both items $a_{i'}$ and $b_{i'}$ are not assigned to any zone yet.
- Step 1.2. Both items $a_{i'}$ and $b_{i'}$ are assigned into zone $i+1$.

Step 2. Repeat the following sub-steps until each item is assigned to a proper zone.

- Step 2.1. Find the first $N_{a_i b_i}$ according to the sorted sequence (4) so that at least one of the items a_i and b_i are not assigned to a zone yet.

Step 2.2. Let Z_j be the set of items that are already assigned into zone j for $1 \leqslant j \leqslant m$.

Case 1. One, say b_i, is assigned and the other, say a_i, is not assigned yet.

(a) Let $S_{j^*} = \min_{1 \leqslant j \leqslant m} S_j$ where $S_j = \sum_{e \in Z_j} N_{ea_i}$ for $1 \leqslant j \leqslant m$ is the sum of similarities between each item e of Z_j and a_i.

(b) Item a_i is assigned into zone j^*.

Case 2. Both a_i and b_i are not assigned yet.

(a) Let $S_j = \sum_{e \in Z_j} N_{ea_i}$ for $1 \leqslant j \leqslant m$ and $S_{j^*} = \min_{1 \leqslant j \leqslant m} S_j$.

(b) Let $T_j = \sum_{e \in Z_j} N_{eb_i}$ for $1 \leqslant j \leqslant m$ and $T_{j'} = \min_{1 \leqslant j \leqslant m} T_j$.

Case 2.1. $S_{j^*} \leqslant T_{j'}$.

(a) Item a_i is assigned into zone j^*.

(b) Update $T_{j^*} = \sum_{e \in Z_{j^*}} N_{eb_i}$ and let $T_{j'} = \min_{1 \leqslant j \leqslant m} T_j$. Item b_i is assigned into zone j'.

Case 2.2. $S_{j^*} > T_{j'}$.

(a) Item b_i is assigned into zone j'.

(b) Update $S_{j'} = \sum_{e \in Z_{j'}} N_{ea_i}$ and let $S_{j^*} = \min_{1 \leqslant j \leqslant m} S_j$. Item a_i is assigned into zone j^*.

Remark. When two or more zones have the same minimum S_{j^*} and/or $T_{j'}$ value, item a_i and/or b_i is assigned to the zone that has the fewest items already assigned into it. If these zones also have the same number of items stored in them, then choose any one zone arbitrarily. When an item is assigned to a specified zone, due to the advantages of the hybrid system (i.e., the travel time and search time reduction), it is randomly allocated in the zone.

As Z_j is the set of items stored in zone j, $d_{ij} = \sum_{e \in Z_j} x_{ie}$ represents the kinds of items asked by order i and stored in zone j. Since all the zones process the same order simultaneously, according to the underlying assumptions, the time picker j spends on order i is $d_{ij} \cdot t$ and the time order i stays at zone j is $d_i \cdot t$ for all $1 \leqslant j \leqslant m$ where t is the standard time each picker picks one kind of item and $d_i = \max_{1 \leqslant j \leqslant m} \{d_{ij}\}$. As a result, the utilization of picker j with respect to order i is $u_{ij} = d_{ij} \cdot t / d_i \cdot t = d_{ij}/d_i$. The utilization index U_i of the system with respect to order i is $U_i = \sum_{1 \leqslant j \leqslant m} u_{ij}/m = \sum_{1 \leqslant j \leqslant m} d_{ij}/(m \cdot d_i)$. As $u_{ij} = d_{ij}/d_i$, u_{ij} and U_i are not greater than 1. The closer U_i is to 1, the less idle time the system wastes on order i. When order i is being fulfilled, let d_i^{P} and d_i^{E} be the maximal number of kinds of items among the m zones induced from the proposed storage heuristic and from the existing storage policy, respectively. The fulfill time for order i is thus $d_i^{\mathrm{P}} \cdot t$ and $d_i^{\mathrm{E}} \cdot t$, respectively. The percentage of completion time improvement with respect to order i is defined as $I_i = \{1 - (d_i^{\mathrm{P}} \cdot t)/(d_i^{\mathrm{E}} \cdot t)\} \times 100\% = (d_i^{\mathrm{E}} - d_i^{\mathrm{P}})/d_i^{\mathrm{E}} \times 100\%$.

It is noted that the underlying assumptions, which are reasonable and acceptable, dominate the evaluation of the system utilization. Any violation of the assumptions complicates the analyses of the total picking time a picker spends on an order and the fulfill time of the order in the hybrid system.

5. Case study

To evaluate the performance of the proposed storage heuristic, we collect empirical data of the case company: the X-mart distribution center, including 22,538 lists of customer orders of the first quarter of 2001 and the existing location record of each item in the picking area. The mean, range and standard deviation of the kinds of items ordered on these 22,538 orders are 18.16, 20, and 3.11, respectively. The X-mart uses the synchronized zoning and the pick-to-light manual order picking system. There are 680 items supplied by the X-mart and the picking area is divided into eight zones. Under the existing storage policy, the average utilization indexes $\sum_{1 \leqslant i \leqslant n} U_i/n$ over the order lists of January, February, March, and the first quarter of 2001 are 0.4784, 0.4926, 0.4806, and 0.4837, respectively. None has a value greater than 0.5, refer to Table 1. If all the 680 items are re-located into the eight zones by the proposed heuristic, after all the similarities N_{ab} are derived from the 22,568 order lists, the average utilization indexes $\sum_{1 \leqslant i \leqslant n} U_i/n$ over the order lists

Table 1
Comparisons of utilization made among different storage policies

Periods	January	February	March	First quarter
Number of order lists n	7485	7035	8018	22,538
Utilization				
Existing policy				
Average	0.4784	0.4926	0.4806	0.4837
Range	0.5627	0.5732	0.5681	0.5833
Standard deviation	0.1062	0.1057	0.1031	0.1038
Proposed heuristic				
Average	0.6215	0.6368	0.6197	0.6257
Range	0.5249	0.5192	0.5208	0.5286
Standard deviation	0.0953	0.0975	0.0987	0.0962
Random location				
Average	0.4884	0.4976	0.4928	0.4929
Range	0.5723	0.5667	0.5825	0.5825
Standard deviation	0.1094	0.1045	0.1027	0.1066
Average percentage of order completion time improvement ($\sum_{1\leqslant i\leqslant n} I_i/n$)	0.1704	0.1785	0.1884	0.1793

of January, February, March, and the first quarter of 2001 are 0.6215, 0.6368, 0.6197, and 0.6257, respectively. It is observed that the utilization of the order picking system, on average, is significantly improved by 29.89%, 29.27%, 28.94%, and 29.36% with respect to January, February, March, and the first quarter of 2001, respectively. The range and standard deviation of the utilization are also analyzed and recorded in Table 1. It is noted here that the proposed heuristic has smaller range and standard deviation than the existing policy has in January, February, March, and the first quarter of 2001. To further discover the utilization of the order picking system, since random storage is a common practice in many warehouses, we randomly assign all the 680 items into the eight zones, and try to fulfill the 22,538 orders of the first quarter of 2001. The average, range and standard deviation of utilization are also listed in Table 1. As can be seen, the existing storage policy is not superior to the random storage policy.

As to the improvement in order completion time made by the proposed NC model, the average percentage of completion time improvement $\sum_{1\leqslant i\leqslant n} I_i/n$ are 17.04%, 17.85%, 18.84%, and 17.93%, as shown in Table 1, for January, February, March, and the first quarter of 2001, respectively. This verifies that the completion time of the order can be significantly reduced whenever the proposed heuristic is employed for locating the items.

In the following we generate order lists of six months (8000 orders per month) according to the cumulated density function of each item using the 22,538 orders of the first quarter of 2001. In the circumstance that all items are stored into a proper zone by the proposed storage heuristic, these simulated orders are then fulfilled by the order picking system. The average, range and standard deviation of the utilization of the order picking system are listed in Table 2. As can be seen, all the average utilizations are greater than 0.6257, the average utilization of the first quarter of 2001. It is thus concluded that the picking system will have a stable average utilization value greater than 0.6257, if the customer demand is stationary in the forthcoming future.

The proposed item cluster model can be employed to analyze the zone size of the order picking system. For example, see Table 3, in six different zone size cases (ranging from 5 to 10) when all the 680 items are located according to the proposed heurist and the 22,538 orders of the first quarter of 2001 are fulfilled, the average utilization of the

Table 2
Utilization of the picking system for simulated order lists

Periods	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6
Number of order lists n	8000	8000	8000	8000	8000	8000
Utilization						
Average	0.6308	0.6295	0.6353	0.6262	0.6336	0.6279
Range	0.5228	0.5309	0.5273	0.5316	0.5288	0.5327
Standard deviation	0.0958	0.0965	0.0982	0.09622	0.0948	0.0979

Table 3
Utilization of the picking system for different zone number

Number of zones m	5 zones	6 zones	7 zones	8 zones	9 zones	10 zones
Number of order lists n	22,538	22,538	22,538	22,538	22,538	22,538
Utilization						
Average	0.7265	0.6853	0.6502	0.6257	0.5974	0.5781
Range	0.5299	0.5306	0.5328	0.5286	0.5314	0.5292
Standard deviation	0.0977	0.0986	0.0933	0.0962	0.0969	0.0943

system ranges from 0.5781 to 0.7265. More specifically, the average utilization of the system increases when the number of zones decreases. However, though one of the objectives of the cluster model is to balance the workload among all the pickers so that the utilization of the system is improved, it is noted that the workload of each picker is also increased when the number of zones decreases since the total workload (22,538 orders) is assigned to a fewer number of pickers. In conclusion, reducing the zone size results in a higher system average utilization but a heavier picker workload. A proper zone size should be decided by trading-off between the system utilization and the picker workload, which is worth further research.

6. Conclusion

In this paper, the synchronized zone manual order picking system is explored. To improve the utilization of the system as well as to reduce the completion time of each order, we present the similarity measurement, construct a natural cluster model, and give a solution to the model by the proposed heuristic. The percentage of completion time improvement is also presented as a measure of the improvement of the completion time of each order made by the proposed heuristic. According to the data from the case company, the average utilization of the picking system over the first quarter of 2001 is significantly improved from 0.4837 to 0.6257, an increase of 29.36%. Regarding the completion time of each order, the proposed heuristic obtains an average 17.9% of shorter order completion time over the first quarter of 2001. It is also discovered that the system utilization of the existing storage policy is not superior to randomly assigning all items into the zones. So long as the customer demand for items is stationary in the forthcoming future, the simulated experiment verifies that the proposed item location heuristic can result in the order picking system having a stable average utilization of value greater than 0.6257. Meanwhile, it is shown that under the proposed item location heuristic, a picking system of smaller zone size has a higher system average utilization but a heavier picker workload. Trading off picker workload for system utilization is worth further research.

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