The impact of routing and storage policies on warehouse efficiency

Abstract Order picking, the activity by which a number of goods are retrieved from a warehousing system to satisfy a number of customer orders, is an essential link in the supply chain and is the major cost component of warehousing. The critical issue is to simultaneously reduce the cost and increase the speed of the order picking activity. The main objectives of this paper are: evaluate various routing heuristics and an optimal routine in a volume-based and random storage environment; compare the performance of volume-based storage to random storage; and examine the impact of travel speed and picking rates on routing and storage policy performance. The experimental results show the solution gap between routing heuristics and optimal routing is highly dependent on the travel speed and picking rate, the storage policy, and the size of the pick list. In addition, volume-based storage produced significant savings over random storage, but again these savings are dependent on the travel speed and picking rate.

Keyword(s): Supply-chain management; Warehousing; Order picking; Heuristics.

Introduction

Order picking, the selection of items from their warehouse storage locations to fill customer orders, is the most costly activity in a typical warehouse. Although order picking appears to be a relatively simple function to perform, there are several factors that greatly affect the performance and efficiency of the pick operation. These factors include the demand pattern of the items, the configuration of the warehouse, the location of the items in the warehouse, the picking method of retrieving the items and consolidating those items into customer orders, and the routing method used by the pickers to determine the sequence of the items to be picked. This paper focuses on the storage of the warehoused items and the routing of the workers to retrieve those items for their respective customer orders.

Storage

Storage policies assign items to warehouse storage locations. Items may be assigned randomly, or similar items may be grouped in the same area of the warehouse, or items may be assigned based on order or picking volume. Volume-based storage places high volume items close to the pick-up/drop-off (p/d) point to minimize picker travel. Volume-based storage is particularly noteworthy as it results in less picker travel (Coyle et al., 1996). It is for this reason that this paper concentrates on volume-based storage. In practice, many warehouses use random storage and use volume-based storage for only a few high volume items.

In volume-based storage, items are assigned storage locations based on the expected volume, usually with high volume items located closest to the p/d point. Because it is rare that demand is known with certainty, items are located in the warehouse based on their expected volume. The advantage of volume-based storage is the reduction in travel time and distance. However, aisle congestion and an unbalanced utilization of the warehouse can result.

Random storage implies that items are randomly assigned to a single location for the entire planning horizon. The advantages of random storage are the uniform utilization of the warehouse and reduced aisle congestion. The disadvantage is the possibility of large travel times from having to traverse the entire warehouse. Random storage is the most common storage policy used in warehouses today even though it results in longer pick routes than volume-based storage.

The research on warehouse storage policies is fairly limited. Schwarz et al. (1978) examined the performance of an automated warehouse with random and volume-based storage. In addition, Gibson and Sharp (1992) and Gray et al. (1992) found that locating high volume items close to the p/d point results in a significant increase in picking efficiency. However, they do not provide information on their implementation of volume-based storage. Jarvis and McDowell (1991) state that the optimal storage strategy is to place the most frequently picked items in the aisle nearest the p/d point and the next most frequently picked items in the next aisle. Their research was limited in that it assumed that the aisles only allowed one-way travel and limited to transversal routing. This paper compares two volume-based storage policies to random storage in a variety of operating conditions.

Routing

Routing policies determine the route of a picker for a picking tour, specifically the sequence in which items are to be picked. These policies range from simple heuristics to optimal procedures. Optimal routing results in less travel time, but heuristic routing benefits from its simplicity and familiarity to most warehouse workers. The majority of order picking operations visited by the author use heuristic routing strategies. Most managers seemed unaware of advanced routing heuristics and optimal routing procedures. Even though heuristics are not as good as optimal routing, they would be a major improvement over current routing. Heuristics are easy to understand and form routes that are fairly consistent in nature.

Such consistency helps to minimize the risk of a missed pick, a much greater sin than having to walk a few extra steps. This advantage of these commonly used heuristics needs to be compared against the distance saved by following optimal routes.

The literature on routing policies includes the development of optimal routing algorithms and the comparison of routing heuristics. Ratliff and Rosenthal (1983) and Goetschalckx and Ratliff (1988a; 1988b) have developed optimal algorithms for routing pickers in a rectangular warehouse. In addition, de Koster and van der Poort (1998) compare optimal and the S-shape heuristic in a decentralized warehouse with no fixed p/d point. However, this paper focuses on heuristics in the more prevalent manual warehouse. Hall (1993) examined routing heuristics in a manual warehouse. In addition, Hall developed distance approximations for several routing heuristics in a random storage warehouse and investigated the impact of warehouse shape. Petersen (1997) extended this by evaluating a new routing heuristic and examining the impact of shape for a fixed-capacity warehouse. Caron et al. (1998) evaluate two simple routing heuristics in a manual single cross-aisle warehouse. This paper compares four routing heuristics to optimal in both random and volume-based storage warehouses.

Objectives

This study’s main objectives are to compare various routing heuristics to optimal routing in a volume-based and random storage environment; compare the performance of volume-based storage and random storage; and examine the impact of travel speed and picking rates on routing and storage policy performance.

The reason this research is important in that it offers managers insights into how to take advantage of the savings that result from using volume-based storage and more sophisticated routing heuristics or optimal routing. The majority of warehouses visited by the author, in industries, such as, mail order, computers, farm equipment, and third-party warehousing used very simple routing heuristics. The order picking process is still primarily a manual proposition at most warehouses. Storage is generally accomplished with random storage, although most firms did make an effort to locate some high volume items close to the pick-up/drop-off point. This is in stark contrast to the literature, which touts the savings of optimal algorithms and the actual use of very simple storage and routing techniques. Tompkins et al. (1996) mention that warehousing and distribution centers operations are historically one of the most frequently overlooked, underfunded, and inadequately planned corporate functions. This paper seeks to help managers gain insights for improvement of warehouse and distribution center operations.

The routing and storage policies in this study are compared in terms of the total time required to complete a given pick list. This time includes not only travel, but also the time for identifying the storage location and product, picking the correct quantity from the pick location, confirming the pick on the pick list and placing the items in the picking cart or vehicle. Tompkins et al. (1996) states that travel time is often only about 50 per cent of an order picker’s time.

The organization of this paper is as follows. The next section describes the warehouse and the assumptions used in this paper. Next, the experimental design is presented. Last, the results are discussed and several conclusions are presented.

Warehouse assumptions

The warehouse that is evaluated in this paper is rectangular with ten picking aisles with front and back access aisles. This is a manual picking environment where over 1, 000 items are stored on either racks or bin shelving. Picking is strict-order/batch picking where a picker retrieves the items on the pick list and transports the items back to the p/d point for order consolidation, packaging, and shipment. The pickers depart from the p/d point and either walk or ride order picking vehicles to all the locations specified on the pick list. The layout is consistent with the warehouse layout literature (Bassan et al., 1980; Ben-Mahmud, 1987; Sims, 1991) and with observations of several order picking operations. The distance a picker travels to complete a picking tour consists of horizontal travel along the front and back aisles and vertical travel in the ten picking aisles. The picking aisles are wide enough to allow two-way travel, but picking can be done from both sides of the aisle. The horizontal distance within picking aisles is not considered. The location of the p/d point is in the middle of the front aisle (Figure 1 shows warehouse layout).

The items are assigned storage locations based on their expected demand. Therefore, high volume items are placed closest to the p/d point and low volume items are located farther away from the p/d point. Typically, a relatively few items account for the vast majority of the sales volume – the Pareto principle.

Pick lists are generated using random numbers to determine the items for the pick list. Once an item has been generated, its storage location, determined from the particular volume storage policy in question and dependent on the rank order volumes of items demanded (i. e. the highest volume items are located closer to the p/d point), is added to the pick list. This process continues until the pick list has reached the desired number of items (pick list size). The routing heuristics and the optimal algorithm form a picking route for each pick list and calculate the travel, picking and total time to complete each pick list.

Routing policies

There are three routing heuristics that are compared to optimal routing in this paper. These routing heuristics are commonly found in many warehouses and have been proposed in prior research.

Transversal strategy

One of the simplest strategies for routing pickers is the transversal strategy where a picker enters only those aisles containing picks from one end of the aisle and exits through the other end of the aisle.

Largest gap strategy

For the largest gap heuristic, a picker enters an aisle only as far as the start of the largest gap within an aisle. The largest gap represents the separation between any two adjacent picks, or between the first pick and the front aisle, or between the last pick and the back aisle. The largest gap within an aisle is therefore the portion of the aisle that the picker does not traverse.

Composite strategy

The composite routing heuristic combines the best features of the return and transversal strategies and seeks to minimize the travel distance between the farthest picks in two adjacent aisles (Petersen, 1997). It will not traverse every aisle if, in fact, a return strategy is preferred for that aisle’s picks.

Optimal routing

Ratliff and Rosenthal (1983) developed an optimal procedure for routing workers in a rectangular warehouse. This procedure is fast and can be run on a personal computer. One may ask why anyone would use a heuristic when a practical optimal algorithm is available. However, as Hall (1993) noted, an optimal route is usually a hybrid of transversal and largest gap strategies. Hall also noted that heuristic strategies may provide near-optimal routes and avoid the confusion inherent in optimal solutions.

Storage policies

The two variations of volume-based storage used in this study are diagonal and within-aisle storage. Figure 2 shows these two volume-based storage policies with a middle p/d point. The dark gray area represents high volume items, the medium gray represents moderate volume items, and the light gray represents low volume items.

Diagonal

Diagonal storage involves having the items stored in the warehouse in a diagonal pattern with the highest volume item in the location closest to the p/d point and the lowest volume item in the farthest location from the p/d point. Tompkins et al. (1996) states that this type of storage strategy is the " optimum".

Within-aisle

Jarvis and McDowell (1991) presented within-aisle storage for a warehouse with one-way aisle travel and using transversal routing. The highest volume items are stored in the aisle closest to the p/d and the lowest volume items are stored in the aisles farthest from the p/d.

Experimental design

The experimental design consists of three factors: routing policies, storage policies, and pick list size. The routing policy factor includes composite (C), largest gap (LG), transversal (T), and optimal (O). The storage policy factor consists of diagonal (D), within-aisle (W), and random (R). The pick list size factor includes pick list sizes from 2 through 50 items. Hall (1993) and Petersen (1997) showed that the number of picks has an effect on the performance of routing strategies. This experiment is a mixed-model with the routing and storage policies as within-subject factors and pick list size as the between-subject factor.

Each routing and storage factor level combination for a given pick list size is tested on the same 500 randomly generated pick lists. There are 588 cells (4 Ã- 3 Ã- 49) and a total of 294, 000 observations which makes statistical significance easy to show. The random numbers used to generate the pick lists were generated using a prime modulus multiplicative linear congruential generator (Law and Kelton, 1991). The performance measure is the total route time for the picker to pick all items on the pick list. This time includes the travel time, time for identifying the storage location and product, picking the correct quantity from the pick location, confirming the pick on the pick list and placing the items in the picking cart or vehicle. For this paper all of the activities listed previously, except travel, are combined into a picking time estimate which includes all non travel related activities. The travel rate is 150 feet per minute and the picking time is 0. 25 minutes per item. The travel rate and picking time are based on information from order picking operations.

Results

The results of the experiment are divided into three sections. The first section examines the performance of the routing policies. The next section examines the volume-based and random storage policies. The last section investigates the effect of travel speed and picking rate on routing and storage policies.

Routing policies

Figure 3 shows the percentage over optimal for the routing heuristics using within-aisle storage. There are several observations to note from Figure 3. It is clear that composite is the better heuristic with an average percentage solution gap of 2. 6 per cent. The largest gap performance is almost identical to the composite until the pick list size is nine items and its solution gap stays at about 4-5 per cent. The transversal does not perform well with small pick list sizes, but its solution gap decreases and is even less than the largest gap after 28 items. As the pick list increases, the percentage solution gap between the routing heuristics and the optimal decreases to 1. 5 per cent for composite and 3-4 per cent for largest gap and transversal. When the number of items to pick per aisle is large (4 to 5), the routing heuristics and optimal algorithm form routes that are nearly identical.

Diagonal storage is used in Figure 4. The composite and largest gap perform very well with a average solution gap of only 1. 5-2 per cent and virtually no difference between them. Again the traversal does not perform well with small pick list sizes, but at 50 items its solution gap is down to 6. 5 per cent.

Figure 5 shows the percentage solution gap for the routing heuristics in a random storage environment. The largest gap is clearly the best overall routing heuristic with a solution gap generally between 2. 5-3. 5 per cent. The composite generally ranges between 1-5 per cent over optimal. In fact for pick lists larger than 35 items, the composite is better than the largest gap. The transversal performance is very striking. After the pick list is above 17 items, the transversal is only 10 per cent over optimal. This gap steadily shrinks to around 1 per cent at 50 items. In fact, the transversal and composite offer almost identical performance between 40 and 50 items.

Storage policies

Figure 6 compares the percentage savings of within-aisle and diagonal storage over random storage for optimal routing. Within-aisle storage is between 30 per cent and 9 per cent better than random storage with an overall saving of 15. 9 per cent. Diagonal storage ranges from 25 per cent to 6 per cent better than random storage with an overall saving of 11. 8 per cent. The difference between within-aisle and diagonal storage varied between 3 per cent to 6 per cent. Figure 6 clearly shows the large savings that are possible from volume-based storage. The savings of volume-based storage used in conjunction was between 12 and 14 per cent for within-aisle storage and around 11 per cent for diagonal storage with composite and largest gap but only 4 per cent for diagonal with transversal.

Travel speed and picking rate effects

To examine the effect of travel speed and picking rate on routing and storage policy performance, several different travel speeds and picking rates are studied. These picking environments include a travel speed of 50 feet per minute with a picking rate of 1. 0 minute per item and a travel speed of 100 feet per minute with a picking rate of 12. 0 minute per item. These are in addition to the previously used travel speed of 150 feet per minute and picking rate of 1. 0 minute per item. Figure 7 shows the effect of picking time on total route time using optimal routing and random storage. It should not be surprising that a picking environment with a larger picking time would have a larger total route time. Also as the pick list size increases, the proportion of travel time decreases as the worker spends more time picking.

Table I shows the mean total route time in minutes for the three picking environments for the routing and storage policies. The average total route time increases from around nine minutes to around 34 minutes to around 56 minutes depending on the travel speed and especially the picking rate. Table II displays the mean percentage solution gap between the routing heuristics and optimal routing for the three picking environments. In addition, Table II also contains the mean percentage solution gap for the heuristics when just considering the total route distance (i. e. where the picking time is not considered). As the picking time increases, the solution gaps between the heuristics and optimal decreases. This implies that for picking environments where the picking time is substantial that heuristic routing gives results within a few percent of optimal. However, when just considering travel distance (or just travel time with no picking time considered) the solution gaps between heuristic and optimal can be significant.

Table III shows the percentage savings of within-aisle and diagonal storage over random storage. Note that when the picking time is substantial the savings between volume-based storage and random storage shrink because the travel component of the total route time is much smaller.

Conclusions and managerial implications

No prior research has evaluated various routing heuristics and an optimal routine in a volume-based and random storage environment; compared the performance of volume-based storage to random storage; and examined the impact of travel speed and picking rates on routing and storage policy performance.

Heuristics are commonly used in practice because they are easy for warehouse workers to understand, they form consistent routes that reduce the risk of missed picks, they offer good solutions, and they have a fast solution time. The biggest drawback to heuristic routing solutions is that the gap between these solutions and the optimal can be significant. This paper has shown that the gap between routing heuristics and optimal routing is highly dependent on the travel speed and picking time. For the three picking environments considered the composite was the best routing heuristic with an average percentage solution gap of 1. 7 per cent. The largest gap had an overall solution gap of 2. 1 per cent and the transversal gap was 6. 8 per cent.

The performance of the routing policies, heuristics and optimal, was also dependent on the storage policy in use. In addition, the advanced heuristics' solutions are sometimes as complex as optimal solutions. Using an optimal routine such as Ratliff and Rosenthal (1983) offers a manager a fast solution time and the shortest distance route. However, optimal routes are often confusing in nature and may not work within the confines of an order picking operation. Managers must analyze the tradeoff between the efficiency of optimal solutions and the ease of implementation and use of heuristic procedures.

This research confirms and extends the results of Jarvis and McDowell (1991) that within-aisle storage is the best overall volume-based storage policy regardless of aisle travel restrictions. In addition, within-aisle storage also works well for all pick list sizes. The performance of diagonal storage was also impressive in comparison to random storage. The managerial implications of these results are that significant cost savings (3-30 per cent) can result from volume-based storage, but these savings are highly dependent on the travel speed, the picking rate, and the number of SKUs on the pick list.

ImageMean total route time in minutes

Table I. Mean total route time in minutes

ImageMean percentage solution gap

Table II. Mean percentage solution gap

ImageMean percentage savings of volume-based storage over random storage

Table III. Mean percentage savings of volume-based storage over random storage

ImageWarehouse layout

Figure 1. Warehouse layout

ImageVolume-based storage policies

Figure 2. Volume-based storage policies

ImagePercent over optimal of the routing heuristics using within-aisle storage

Figure 3. Percent over optimal of the routing heuristics using within-aisle storage

ImagePercent over optimal of the routing heuristics using diagonal storage

Figure 4. Percent over optimal of the routing heuristics using diagonal storage

ImagePercent over optimal of the routing heuristics using random storage

Figure 5. Percent over optimal of the routing heuristics using random storage

ImagePercent savings of within-aisle and diagonal storage over random storage

Figure 6. Percent savings of within-aisle and diagonal storage over random storage

ImageThe effect of pick (handling) time on total route time

Figure 7. The effect of pick (handling) time on total route time

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Order Picking:

Unit load- In this method, nature of the product permits the picker to fill the customers requirement by pulling a full pallet load from stock. An example would be refrigerator distributor who stocks each product one-per-pallet. This method of picking lends itself best to automated forms of picking.

Case lot- often products are pulled to fill orders in full cases only. Case-lot quantities can be stored on a shelf or on a pallet, depending on the order point and replenishment quantities. Although this method can be automated, for the most part it requires manual picking.

Broken case- this method is used by distributors that offer their customers quantities in less than full case lot quantities. Again, this method of picking can be done from a shelf, pallet, or other form of storage unit. This method is very difficult to automate and is almost exclusively a manual operation.

Receiving and Shipping:

Receiving has been defined as that activity concerned with the orderly receipt of all materials coming into the warehouse, the necessary activities to ensure that the quantity and quality of such materials are as ordered, and the disbursement of the materials to the organizational functions requiring them.

In contrast to receiving, shipping can be defined as those activities performed to ensure the accurate and damage free packaging, marking, weighing and loading of finished goods, raw materials and components inn response to customer order requirements in as cost effective and as expeditious a manner as possible.

Further elaboration on page537, Distribution: Planning and Control

Warehouse Automation

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