# Reduction of walking time in the distribution center of De Bijenkorf

René de Koster [1], Kees Jan Roodbergen [1] and Ronald van Voorden [2]

[1] Erasmus University Rotterdam, Rotterdam School of Management, P.O. Box 1738,
3000 DR Rotterdam, The Netherlands
[2] Districon B.V., Raadhuisstraat 32-34, 3603 AW Maarssen, The Netherlands

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**Abstract.** In many distribution centers, there is a constant pressure to reduce the order throughput times. One such distribution center is the DC of De Bijenkorf, a retail organization in The Netherlands with 7 subsidiaries and a product assortment of about 300,000 SKUs (stock keeping units). The orders for the subsidiaries are picked manually in this warehouse, which is very labor intensive. Furthermore many shipments have to be finished at about the same time, which leads to peak loads in the picking process. The picking process is therefore a costly operation.

In this study we have investigated the possibilities to pick the orders more efficiently, without altering the storage or material handling equipment used or the storage strategies. It appeared to be possible to obtain a reduction between 17 and 34% in walking time, by simply routing the pickers more efficiently. The amount of walking time reduction depends on the routing algorithm used. The largest saving is obtained by using an optimal routing algorithm that has been developed for De Bijenkorf. The main reason for this substantial reduction in walking time, is the change from one-sided picking to two-sided picking in the narrow aisles.

It is even possible to obtain a further reduction in walking time by clustering the orders. Small orders can be combined on one pick cart and can be picked in a single route. The combined picking of several orders (constrained by the size of the orders and the cart capacity) leads to a total reduction of about 60% in walking time, using a simple order clustering strategy in combination with a newly developed routing strategy. The reduction in total order picking time and hence the reduction in the number of pickers is about 19%.

**Keywords.** warehouse, order picking, routing, batching, case study.

## 1. Introduction

In many warehouses and distribution centers, short order throughput times are of crucial importance. There are several causes for this.

- Suppliers of manufacturing companies are being forced to supply in a just-in-time manner. Their customers have lowered their inventories and demand a rapid and timely supply from their vendors.
- Many internationally operating companies have centralized their European distribution in so-called EDCs, European distribution centers. These EDCs are responsible for the warehousing function and distribution to multiple European countries. The internal process organization often leads to wave picking, in which the pick process is carried out in batch, governed by fixed truck departure times for the different countries or regions. In order for these trucks to leave in time, the orders must be ready before departure, regardless of their number. However, in practice it can often be observed that there is a peak of departures in the afternoon and of receipts in the morning. This leads to order picking processes that are capable of handling peak loads in a timely manner.
- In contrast to the above way of working in EDCs, customer sales does not want any concession in the customer service and simultaneously wants to guarantee short delivery times (overnight for customers in a radius of 500 km of the EDC). This leads to order cut off times that are as late as possible before the truck departure times. Often special procedures are created to be able to handle late emergency orders in time.
- Short delivery times are considered in many branches as a competitive weapon. This puts pressure on the internal throughput times, especially order picking throughput times.
- It becomes more and more difficult to realize short order throughput times because of factors such as a gradual increase in assortment and smaller, yet more frequent, orders. For the increasing assortment an increasing amount of floor space is necessary. This in turn results in increased walking times per order. Smaller orders (less items per line) and an increased frequency of ordering lead to an increase in the work contents of order picking: less full pallets can be picked and more single item picks are necessary.
- The increase of value added logistics (VAL) activities in many warehouses has lead to additional activities that have to be carried out during or after the order picking. These additional activities often lead to the necessity of picking and handling such orders separately, within the short time frame available for handling the orders.
- Especially in the retail business, the increased application of ECR (efficient consumer response) concepts has lead to the direct transmission of order information from scanning cash registers to the distribution centers. These orders are then translated in replenishment instruction from the DC to the stores. This often means more, but smaller orders that have to be supplied.

Most warehouses are gradually confronted with the above mentioned developments. It is important to find an adequate solution to maintain short and well-controlled throughput times. One such option is a radical new design consisting of a new layout, further mechanization and automation of processes.

However, often also by less radical methods the efficiency of the order picking process can be increased.

In this paper, a number of methods are discussed that can help improving the efficiency of the order picking process, without layout change, or a change of storage policies or of material handling equipment. Order picking is, in most companies, a manual job. By a better organization of the process, a more efficient order picking, it is often possible to obtain a substantial reduction of the order throughput time. According to Tompkins et al. (1996) the operation costs in warehouses are determined to a large extent by the order picking process (approximately 55%).

The efficiency of the order picking process depends on factors that are difficult to change, such as the chosen storage systems (racks), the layout, the order picking system (order picking trucks, pick carts, pick-to-belt, pick-to-light, etc.), but also by parts that are more easily changeable, such as the storage strategy (the storage location determination), the sequence by which items are collected from storage locations (routing strategy) and the possible clustering of customer orders in a single order picking route (batching).

In section 2, these relatively simple strategies are considered in more detail. In section 3 it is demonstrated by the case of the distribution center of ‘De Bijenkorf’ in Woerden, The Netherlands, that proper choices for these parts can lead to strong improvements in the efficiency of the order picking process. In this case study the focus is on routing and batching strategies. In section 4 some conclusions are drawn.

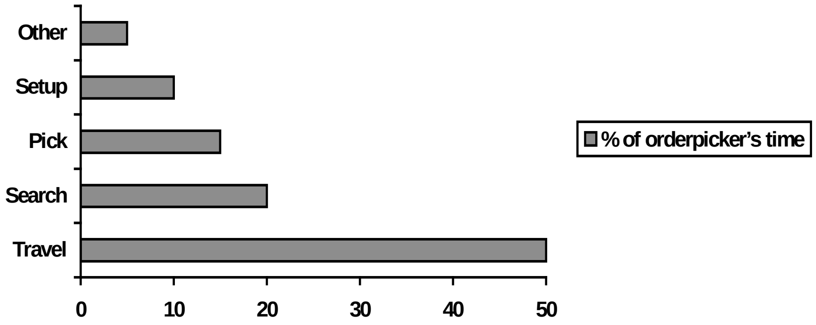
## 2. Reduction of the order pick time in distribution centers

Order picking and shipping customer orders within an agreed time is the core function of a distribution center. In the picking process, customer orders are converted into pick orders.

The time, needed for picking an order can be split in travel time (walking or driving time), pick time and remaining time. The travel time is related to the movement between locations that have to be visited (where the items are stored that have to be picked). The pick time is related to grabbing the items. This includes search for the article, grabbing the units, depositing them on the pick cart, checking the pick, administration of the pick on the pick list (if applicable) and reading the next location to be visited. The remaining time is related to activities such as the acquisition of the pick order, dropping off the full pick cart, waiting time for a next assignment, social contacts etc.

According to Tompkins et al. (1996), the travel time in a warehouse is, in general, responsible for half the total order picking time (see table 1). Hence, reduction of the travel distances and therefore of the travel times has a significant impact on the total order picking time. In a stepwise approach for gradual improvement of the order picking process, walking distance reduction is an important candidate.

Table 1. Typical distribution of an order picker's time (according to Tompkins et al. (1996)).



There are several ways to reduce the travel distances in the order picking process in a warehouse. It is possible to reduce walking distances by system changes, using a higher degree of automation. Examples are the use of A-frames (automatic product dispensers) for automated picking of small articles, AS/RS warehouses, miniloads and carousel systems, in which the items that have to be picked are automatically moved to the picker ('goods-to-man'), or the use of pick-to-belt order picking combined with automatic sortation.

On the other hand it is also possible to reduce walking times by less radical changes. Instead of changing equipment, we can try to improve the operating policies. In sections 2.1 - 2.3, we will restrict ourselves to conventional solutions that are applicable in many warehouses. In specific we will discuss:

- Compact storage. The idea with compact storage is to make the area that has to be traversed by the order pickers as small as possible.
- Routing. Given an order to be retrieved from storage, in which sequence should the order picker visit the pick locations?
- Order batching. Combining two or more orders into one pick route can decrease the total distance to be traveled by the order picker.

## 2.1 Compact storage

This can be reached by applying several principles, such as narrowing pick aisles and densifying storage locations, separation of bulk and pick stock, dividing the pick stock over pickfrequency based storage zones (ABC-storage).

### 2.1.1 Reduction of storage space needed

Aisles in warehouses may have various widths. This depends on the items and product carriers that have to be stored and on the material handling systems used to store and pick them. Since warehouse aisles occupy a considerable percentage of the total storage floor area (costs) and since the average distance to be traveled for order picking or storage increases with the aisle width, it is important to make the aisles as narrow as feasible. In pallet storage areas this may lead to narrow-aisle (semi) high-bay storage with aisle widths varying between 1.2 and 1.7 m. This is a significant reduction when compared to traditional wide-aisle pallet storage with aisles between 2.5 m (reachtrucks) and 3.5 m (forklift trucks). Of course, such a choice has impact on the material handling systems that can be used and on the order picking and storage policies that can be used.

A second way of reducing the storage area is a more efficient use of storage locations. In many warehouses, the average storage location filling rate is low, about 20%. By distinguishing between slot sizes, compacting stored loads as much as possible (for example, storing multiple SKUs per location, or combining multiple small loads of one SKU on one location), it is often possible to achieve great savings in storage space. This can result in a smaller storage area and hence in reduced throughput time and lower costs.

Another option, which may be the most important one, has to do with better cooperation and coordination with suppliers. Storage space reduction can be achieved in various manners. One can think of:

- ordering more frequent smaller quantities, which reduces inventory,
- using drop shipments whenever possible, which avoids handling and storing items first,
- focusing on cross-docking rather than first bringing material to storage,
- reducing standard package quantities, which avoids separate locations for broken packages.

### 2.1.2 Separation of bulk and pick stock

The purpose of separating pick stock in a forward area (from which orders are picked) and bulk stock in a reserve area (used for the replenishment of the pick stock) is to reduce the space in the order picking zone, i.e. the forward area. This can significantly reduce the travel time needed in the order picking process. However, the gain in travel time has to be balanced against the additional time needed to replenish the pick stock from the bulk stock. The main question to be answered is: which quantity per article has to be stored in the forward area. Some methods used in practice to solve this problem are:

- allocate the same space to every article in the forward area (‘equal space method’);
- allocate to every article an amount of space sufficient to meet the demand over a predefined period (‘equal time method’).

Other procedures to allocate products to the forward area, with their performance bounds, can be found in e.g. Hackman and Rosenblatt (1990) and Hackman and Platzman (1990).

In most warehouses all articles have a pick position in the forward area. From recent research by Van den Berg (1996) it appears that considerable savings are possible by picking some articles directly from the reserve area. It has to be noted, however, that order picking from the bulk area needs material handling systems capable of both order picking and storage and retrieval of unit loads.

### 2.1.3 Pickfrequency class-based storage of articles in a warehouse

In general, travel times can be significantly reduced if zoning is used to store the articles. Zoning can be applied in different ways. First, it is possible to create separate storage areas and even separate storage systems, handling systems and separate control for SKUs with different turnovers. For example, in the retail business it is a custom to create a fixed zone for discount articles that move extremely fast. The discount actions are often planned in advance and the storage area is continuously adapted according to the sale action of the coming period.

A second way to apply zoning is subdividing a single physical storage system, for example a pallet warehouse, in multiple logic zones, that contain SKUs belonging to different pickfrequency classes. Fast moving items are stored close to the front end of the racks at easily accessible locations and slow moving items are stored further away. According to Hausman et al. (1976) pickfrequency class-based storage can lead to a reduction of up to 60%, using only three pickfrequency classes. The savings that can be reached, depend on the number of SKUs responsible for a significant part of the picks to be carried out. Van den Berg (1996) suggests that in some situations, five or six pickfrequency classes yield a significant further reduction in travel time. More classes have virtually no additional effect.

Although the above research was carried out in an automatic warehouse environment with aisle-bound trucks or cranes, several authors have reported similar results in other pick-storage layouts. See for example, Caron et al. (1998).

## 2.2 Routing

When the items that have to be picked in a single tour by the picker and their corresponding storage locations have been established, the sequence has to be determined by which these locations have to be visited. This sequence is determined by a routing strategy. The chosen routing strategy has a direct impact on the length and travel time of the tour. Good routing strategies can significantly reduce travel time. De Koster and Van der Poort (1998) report reductions of 30%.

Ratliff and Rosenthal (1983) developed an algorithm to find shortest order picking routes in warehouses with multiple parallel aisles, a central depot and without cross aisles. Their method is based on dynamic programming, where they start in the left most aisle and consider all possibilities to visit the next aisle. This procedure is repeated until all aisles are added. Five different methods (transitions) are distinguished to add an extra aisle and six transitions are distinguished to visit the locations within the aisle. In routes resulting from their method it is possible that an aisle is skipped first, but that it has to be finished later by returning to the aisle. The algorithm of Ratliff and Rosenthal has been extended by De Koster and Van der Poort (1998) for the situation that the picked items can be dropped off at the head of every aisle (decentralized depositing).

In practice, usually simple heuristics are used. To the knowledge of the authors, at the current moment no standard Warehouse Management System (WMS) package exists that contains the Ratliff and Rosenthal algorithm. Methods that are used include the 'S-shape' strategy, the 'Midpoint' return strategy and the 'Largest gap' return strategy (see Hall (1993)). In the S-shape strategy, the aisles containing items are fully traversed in a single direction. This is done in an S-shaped curve fashion. In the application of this algorithm, a distinction has to be made between single-sided picking and two-sided picking. See figure 1. Single-sided picking is only to be preferred in case the aisles are either very wide or when many items have to be visited within the aisles.

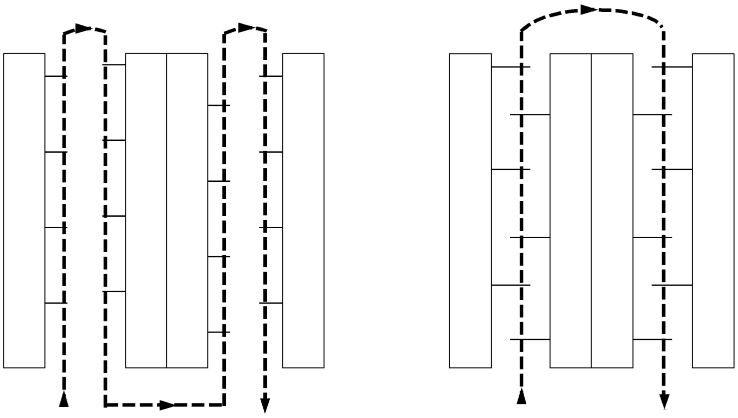
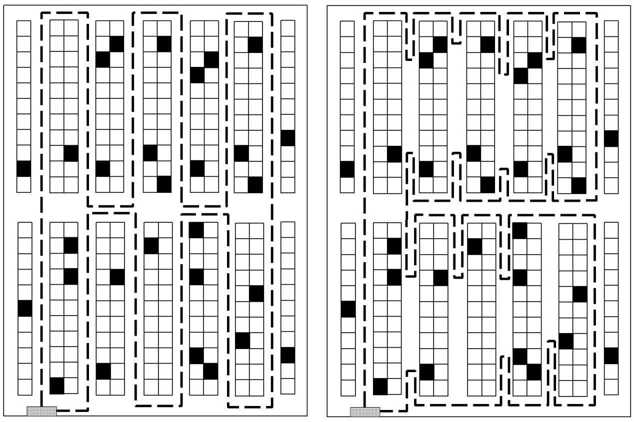


Figure 1. Warehouse (top view) with single-sided picking (left) and two-sided picking (right) using the S-shape algorithm.

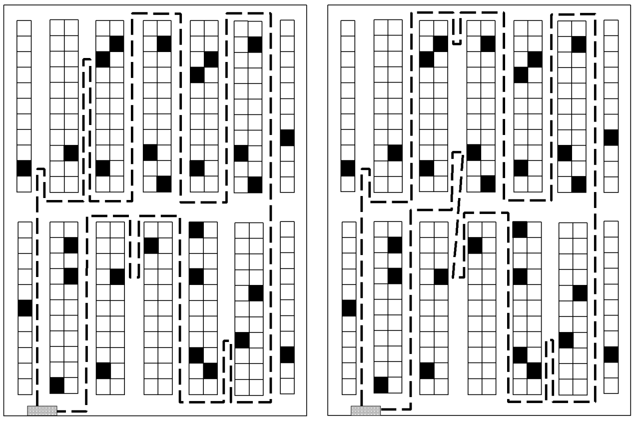
The midpoint return strategy and largest gap return strategy are both routing strategies where the order picker travels in the aisle but always returns to the aisle head where he started. The point of return in the aisle is either determined by the aisle midpoint or by the largest gap between two sequential item locations. The largest gap between such item locations is not traveled. The largest gap strategy is always beneficial over the midpoint return strategy. See for example, Hall (1993). Hall shows that if the number of items to be picked per aisle is small (less than about 3) then the Largest gap strategy is beneficial over the S-shape strategy, with respect to travel time.

For the case that the warehouse has a middle aisle (cross aisle) as in figure 2, an optimal routing algorithm has been developed by Roodbergen and De Koster (1998). A middle aisle divides the warehouse in a front and a rear block. They also developed a Combined heuristic for routing order pickers in a warehouse with any number of cross aisles. The heuristic uses a dynamic programming technique to combine S-shape and an aisle return strategy for traveling within aisles. In traveling to a next aisle, significantly fewer possibilities are allowed than in the optimal algorithm: only two (front or rear end). In the traveling within aisles the best is selected of the S-shape strategy and the 'enter-aisle-and-return' heuristic. A difference with the optimal algorithm is further that picking is done per warehouse block and that no returning to previously skipped aisles can occur.

Examples of the different routing strategies can be found in figure 2.



S-shape Largest gap



Combined Optimal

Figure 2. Examples of four different routing strategies, for a warehouse with a middle aisle.

## 2.3 Order batching

Batch picking is defined in this paper as a method by which multiple orders are picked in one pickroute. The items that are combined in the pickroute in this way have to be sorted per order. Sorting per order can happen during picking ('sort-while-pick') or afterwards ('pick-and-sort'), the latter often via a sortation machine.

The difficulty of batch picking is how to determine which orders can be combined best in order to minimize the total travel time. A boundary condition is that the capacity of the pick device (cart, pallet, roll cage) may not be exceeded.

The problem of finding an optimum is NP-hard (see Gademann et al. (1996)). Gademann et al. (1996) describe a branch-and-bound algorithm for a related problem where the objective is to minimize the maximum pick time of any of the batches formed. Their algorithm is complex and has unpredictable (and often long) calculation times.

However, simple heuristics can be used with very good results, as shown by De Koster et al. (1999). In their paper, the batching heuristics were divided into three groups:

- Simple, straightforward algorithms (like *First Come, First Served*)
- *Seed algorithms*
- Algorithms based on *time savings*.

Each of these groups will be described below in more detail. Other methods could possibly be developed by adjusting solution methods for the Vehicle Routing Problem (see e.g. Fisher (1995)) for the case of order batching.

### 2.3.1 'First Come First Served'

In the 'First Come First Served' batching algorithm, the orders are assigned to pickroutes in sequence of arrival, until the capacity of the pickdevice is reached. Each time that this happens, a new route is started. Only complete orders are assigned. This is a method widely used in practice, because of its simplicity.

### 2.3.2 Seed-algorithms

Seed algorithms consist of two different steps, which are repeated for each new route. First, via a *seed selection rule* an order is selected, that has not yet been included in a route. Next, with an *order addition rule*, orders are added one by one, until the capacity of the pickdevice is reached or no order can be added. the addition may, for instance, be based on the distance (measured with some distance metric) between the existing orders in the route and the order that may be added. The advantage of seed rules is, that they are in general simple to use and fast in calculation.

### 2.3.3 Time savings algorithms

Time savings algorithms are based on the time savings that can be obtained if two orders are combined instead of executed separately (inspired by the time savings algorithm for vehicle routing by Clarke and Wright (1964)).

For each pair of orders the time saving is calculated. The order pair that yields the maximum time saving and that fits on the pickdevice is combined in a route. The order pair with the next greatest time saving is then taken. If one of the orders has already been assigned to a route, the other order is added to that route, if possible. If none of the orders is contained in a route, a new route is formed containing the two orders. This process is repeated for the remaining pairs until all orders have been assigned to a route.

In the calculation of the time savings, a routing algorithm may be used. This may be one of above mentioned heuristics (S-shape, Largest gap, etc.) or an optimal algorithm.

Several types of the above mentioned algorithms are discussed in De Koster et al. (1999). In the next section the impact of efficient routing and batching on travel time are discussed for the case of De Bijenkorf.

# 3. Case: The distribution center of ‘De Bijenkorf’

## 3.1 De Bijenkorf B.V.

De Bijenkorf B.V. is a chain of department stores in the Netherlands with 7 stores in the major cities and over 3600 employees. The assortment is very broad, about 300,000 stock keeping units (SKU) and changes constantly. The assortment contains fashion, consumer electronics, household appliances, books, furniture, personal care products, etc.

All stores are supplied from one DC in Woerden. The arriving articles are checked on quantity, quality and, in many cases, are labeled with the sales price. Next, a part of the arrivals are directly cross-docked to the stores. Another part is stored in one of the four storage areas. One of these storage areas is for hanging fashion. The other three storage areas have conventional storage equipment, like a bin storage area, a pallet area and an open shelf storage area.

In the bin storage area, the products are stored in plastic bins. They are also picked in the same type of bins. In this area the picking is the most labor intensive.

## 3.2 Order picking in the bin storage area

### 3.2.1 The bin storage system

The plastic bins are stored on two different floors in shelf racks. Both floors consist of 12 blocks each having 11 aisles of 18.6 m. length and an aisle width of 90 cm. Every rack has 42 sections offering space for 8 plastic bins, stored on top of each other. Two adjacent blocks form a so-called preferred zone. Every article stored in the bin storage area is assigned to one preferred zone, depending on the cash register from which it is sold in the department stores. Therefore, products sold at a singe cash register are grouped together in one preferred storage zone, a form of *family grouping* of a similar kind as can be observed in food retail warehouses. The most important activities in the bin storage are the *storage* of plastic bins with incoming goods and the *picking* of single units from the plastic bins.

### 3.2.2 Storage

Within the bin storage area, a semi-random storage strategy is applied. This means that if a (group of) bin(s) containing a single SKU has to be stored, the information system (named VIRGO) indicates the preferred storage zone where the bins have to be stored. Within this zone, the warehouse employee may store the bin at any free location. The employee has to keep the bins together (in a vertical stack) as much as possible. Every employee tries to minimize the walking distance when storing a group of bins and stores the bins at the free location closest to the inbound conveyor. After storage, the storage location is confirmed to VIRGO.

### 3.2.3 Order picking

A pickorder consists of those SKUs that have been ordered by the department corresponding to one cash register in a store and is picked by one order picker in one preferred zone (although exceptions occur). Each order picker usually picks one order at a time. The picked items are put in plastic bins on a small pick cart. The sequence in which the orderlines (SKUs) have to be picked is indicated on the pick list. This sequence is based on a simple sortation of the picklocations in increasing order. When the pick order has been finished, the pickorder is confirmed to VIRGO at a central terminal. The pick bins are placed on a conveyor and transported to a sortation system where they are sorted per store and prepared for further transportation.

## 3.3 Problem description

In 1992, a large business process reengineering project ‘Het Distributieproject’ was started at De Bijenkorf in order to make distribution processes more efficient. This process resulted in a number of important changes. First, a new logistic information system, VIRGO, was introduced for support of purchasing, distribution and sales. This system also supports scanning cash registers, where point-of-sales information is matched with the stock in the store and immediately translated into replenishment orders at the warehouse, if necessary (an ECR application). Second, the sales area in the stores was enlarged, so that a larger number of SKUs is now displayed at the stores, rather than stored in the warehouse, in order to increase sales. The stock per SKU has decreased at the stores.

This has put more pressure on the warehouse. All stores are now supplied daily, instead of once every two weeks. In the bin storage area, this has lead to many small orders, instead of few and very large orders. The total walking distance needed to collect the orders has increased significantly. In a study of Van Voorden (1997) it appeared that an order picker in the bin storage area walks on average 7 km on a daily basis to collect the items.

The research project at De Bijenkorf focused on a reduction of these walking distances. In the previous part of this paper several methods of travel time reduction have been discussed, but here we focus only on two, relatively simply implementable methods, namely sequencing the pick locations on the pick lists (routing) and combining multiple orders per pickroute within a preferred zone.

## 3.4 Problem solution approach

The approach that was chosen consists of the following steps:

1. *Order analysis.* A fairly large number of orders in two representative preferred zones of the bin storage area were each analyzed for:
   - articles contained in it,
   - storage location of each article,
   - route taken by the order picker to pick the order (this actually required walking the order together with the picker),
   - time distribution of the picker: time for picking, walking and administration,
   - number of pick bins needed to pick the order (the number of pick bins necessary to pick the order always fits on the pick cart),
   - registration of incidents, such as: location empty registration, search for a new empty pick bin, article not available at indicated location, etc.
2. *Simulation of current situation.* The current order structure and routing method was implemented in a simulation program.

3. *Simulation of alternative routing strategies*. A number of routing strategies were implemented in a simulation program and compared for a large number of orders with the current method.
4. *Simulation of batching strategies*. A number of different batching strategies were defined and investigated on practical feasibility.
5. *Comparison of results*. The batching strategies of the previous step were implemented in a simulation program and compared for a large number of orders with the current method.
6. *Conclusion*. Results were obtained and the best alternative was chosen.
7. *Implementation*. The best solution is currently being implemented.

The above steps are worked out in the sequel.

## 3.5 Order analysis

During two consecutive weeks all orders in the two preferred zones were recorded. Some data of these orders is listed in table 2. Not only averages were obtained, but also full frequency distributions of all quantities listed in table 2. In this table, *units per order* indicates the number of product units (a single product or a set of products in one wrapping) in an order. *Lines per order* stands for the number of product types in an order (multiple units of one product account for one order line).

Table 2. Some data collected for two preferred storage zones.

| | Preferred zone 1 | Preferred zone 2 |
|---|---|---|
| Ave. orders per day | 47 | 29 |
| Ave. lines per order | 17.0 | 31.6 |
| Ave. units per order | 39.3 | 131.2 |
| Ave. pick bins per order | 3.6 | 3.4 |
| Regression: bins/order = | $\lceil 0.994 + 0.156 \text{ lines/order} \rceil$ | $\lceil 1.026 + 0.076 \text{ lines/order} \rceil$ |

From the collected data it was possible to find a pickfrequency distribution for the different storage sections within the preferred storage zones. This was used later on in a simulation program to generate random storage locations of pick items. The storage location distribution is quite skewed, due to the fact that within a preferred storage zone, a worker may freely find a location sufficiently large for the bins to be stored.

The number of pick bins necessary for picking the order depends largely on the size of the order, as can be seen from figure 3. The maximum number of pick bins in one route is 12, in the current situation.

The regression analysis results are also listed in table 2. Due to the upward rounding of the number of bins needed (even 0.1 bin means that 1 bin is needed) in table 2, adding more variables in the regression equation (like the number of units/order) does not yield a significantly better prediction of the number of pick bins necessary. The regression results were used for the simulation.

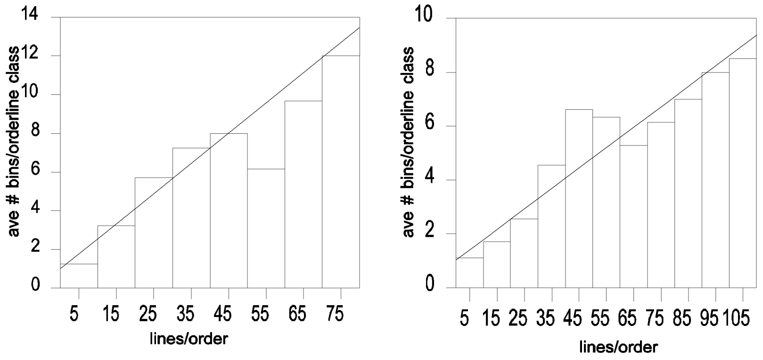


Figure 3. Regression line for the average number of pick bins per group of orderlines. The left figure is for preferred zone 1, the right one for preferred zone 2.

## 3.6 Analysis of the current pick routes

From the analysis of the pick routes it appeared that the large distances that are traveled in the picking process can be attributed mainly to the single-sided orderpicking. It is a well-known fact that two-sided orderpicking greatly outperforms single-sided orderpicking unless the number of pick locations per aisle is very large or the aisles are very wide, see Goetschalckx and Ratliff (1988). The single-sided picking is again due to the location numbering. The location numbers increase as indicated in figure 4. The pick locations are indicated on the pick list, sorted on increasing location section numbers. The layout in figure 4 (and figure 5) has been simplified slightly; the number of locations per rack is only 4 (42 in reality).

In fact, the pickers use two main different traveling strategies. Some pickers work from the middle aisle: they leave their pick cart in the middle aisle when entering an aisle. Other pickers always take their pick cart with them and then consequently travel the full aisle when they have to switch to a neighboring aisle. However, all pickers pick strictly in the sequence indicated on the pick list. After simulation (see next section), it appeared that the last method is slightly better on average than the first one. For the comparison, only this best one was used.

In figure 5 an example is given of this last type of pick routes, in which 17 locations have to be visited. In the righthand storage block of the preferred zone, the picker enters the aisle from the middle aisle and returns to the middle aisle after the furthest pick in the aisle. In the lefthand storage block, the picker traverses the full aisle, starting from the middle aisle, if the next pick location is also in the lefthand storage block and the traveling direction matches with the location numbering sequence (see figure 5).

Two aisles have been marked with an arrow in figure 5, to show that in the top aisle the picker returns to the middle aisle to make sure that in the next pick aisle the travel direction matches the location numbering sequence. On the other hand, in the lower aisle the picker travels the aisle completely also to achieve that the traveling direction matches the location sortation.

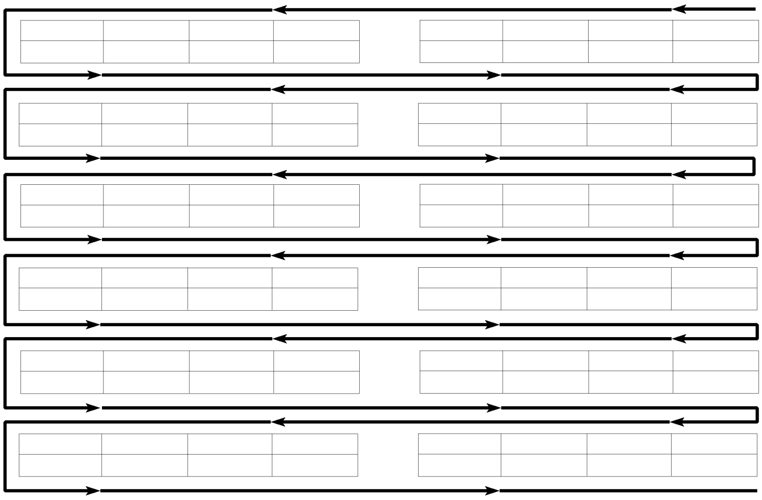


Figure 4. Current location numbering.

Figure 5. Orderpicking route in the current method with full aisle traveling (lefthand block) and return (righthand block).

## 3.7 Order simulation and results

For each of the two preferred storage zones, 10,000 orders have been randomly generated. The travel times needed for these orders were calculated with different routing and batching strategies, including the current one (see figure 5). The number of orderlines of an order, the pick location of each of the articles and the number of pick bins needed for the order, are all drawn from the corresponding probability distributions based on the order analysis.

### 3.7.1 Routing results

In total, 3 different heuristic routing methods and an optimal algorithm have been compared with the current routing method. The heuristic routing methods are S-shape, Largest gap and the Combined heuristic (see Roodbergen and De Koster (1998)). The optimal algorithm (see Roodbergen and De Koster (1998)) is based on dynamic programming and similar to the algorithm of Ratliff and Rosenthal (1983). The results can be found in table 3.

Table 3. Comparison of three heuristics and the optimal routing method with the current routing method.

| Method | Average daily travel distance in bin storage area | Difference with current method (151.352 m.) | Total average daily picktime | Difference with current method (153 hours, 31 min.) |
|---|---|---|---|---|
| S-shape | 125,738 m | 16.9 %<br>(25,614 m) | 145 hrs,<br>37 min. | 5,2 %<br>(7 hours, 54 min.) |
| Largest gap | 116,979 m | 22.7 %<br>(34.373 m) | 142 hours,<br>55 min. | 6,9 %<br>(10 hours, 36 min.) |
| Combined heuristic | 105,091 m | 30.6 %<br>(46,261 m) | 139 hours,<br>15 min. | 9,3 %<br>(14 hours, 16 min.) |
| Optimal | 99,349 m | 34.4 %<br>(52,003 m) | 137 hours,<br>28 min. | 10,5 %<br>(16 hours, 3 min.) |

The results in table 3 have been obtained by extrapolation of the simulation results of 2 preferred storage zones to all 12 preferred storage zones in the bin storage area. It appears that even a simple heuristic such as S-shape or Largest gap yields a significant reduction in traveling distance, namely 16.9% and 22.7%, respectively. This magnitude of the reduction is mainly due to the change to two-sided picking. If the smarter Combined heuristic or an optimal algorithm is used, improvements of even 30.6% or 34.4%, respectively are obtainable.

Even though the reduction in walking distance is significant, the improvement of the total pick time (which includes, besides traveling time, also picking time and administration time) is far less. This is due to the fact that a large part of the nontravel time is spent on removing bins from the racks, waiting for a non-occupied computer terminal to confirm the picks and other administrative tasks. It is clear that further improvements are possible here. The result is that the saving in total pick time varies from 5.2% for S-shape up to 10.5% for the optimal algorithm. Assuming that a productive manday is on average 7 manhours, this leads to a reduction in personnel varying between 1.1 and 2.3 ftes.

It is clear that the optimal algorithm has an advantage over the 3 other heuristics. In practice, there are however also some disadvantages. One such disadvantage is that the algorithm is more complex than the other ones. It has to be implemented in the core part of the Warehouse Management System, which is not an easy task. Also, the optimal algorithm is not very easily adaptable. For example, if the layout of a preferred storage zone would be changed from 2 to 3 adjacent blocks, the algorithm is not usable anymore and not easily adaptable either. Another disadvantage of the optimal algorithm is, that the sequence of the locations on the picklist is not always straightforward to a picker: it does not work block for block and also backtracking to previously skipped aisles is possible. Also, the picker has freedom in deciding via which aisle head he moves to a neighboring aisle. This could lead to longer walking times than expected. The heuristics do not have these disadvantages, or to a less extent.

From the simulation results it appears that the Combined heuristic has very good performance, but that the routing is much less complicated, than that of the optimal algorithm. Therefore, the management of De Bijenkorf decided to implement the Combined heuristic for routing the order pickers.

### 3.7.2 Batching results

In total, 4 different batching strategies have been compared with the current method, in which no batching takes place. Since the batched orders are to be sorted by order during the picking process (‘sort-while-pick’), it was also necessary to investigate how the pick bins could be stacked on the pick cart. The results for three different stack variants have been indicated in table 4.

All stack variants depend on the design of the pick cart. Two pick carts have been sketched in figure 6. Pick cart type A has multiple levels. The pick bins are individually accessible by sliding them off the cart, which offers the possibility of picking a large number of orders at the same time. Pick cart B has only one level on which two bins can be placed next to each other. Other bins can be stacked on top of these two bins.

Stack variants I and II both use a pick cart of type A. The difference is, that the pick cart for variant I has 6 layers with each 2 bins, which makes all bins individually accessible. In variant II only 8 bins are individually accessible from 4 layers. The remaining 6 bins are stacked on top of each other on the top level (5th layer). For stack variant III, pick cart B is used. With this pick cart only 2 bins are directly accessible, since otherwise bins may have to be removed before a particular bin is accessible. Therefore, in stack variant III only two orders can be collected simultaneously. The picker starts with two empty bins, one for each of the two orders. If a bin is full, another empty bin for the same order is stacked on top of it. Empty bins are available everywhere in the bin storage area.

The advantage of batching variants using a pick cart of type A, is that a variable number of orders can be collected, as long as the pick bins needed for these orders fit on the cart. The disadvantage compared to pick cart B, where bins are stacked on top of each other is, that less bins can be picked in one route (assuming a maximum ergonomic stacking height).

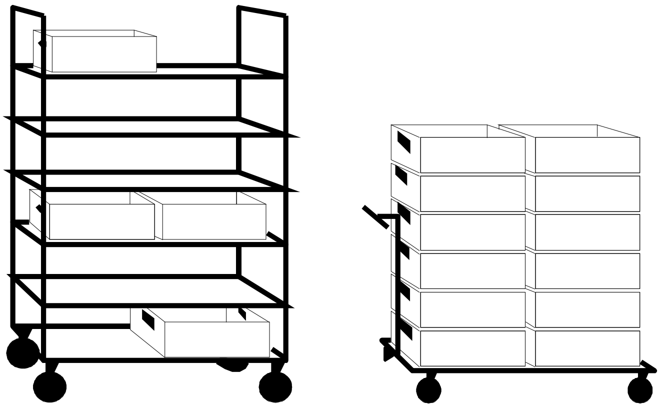


Figure 6. Example of two different pick carts, type A (left) and type B (right).

It should be noted that the extra activities in sorting out the picked items in the proper bin (for all variants) and retrieval of the proper bin from the cart (variants I and II) cost extra pick time compared to the current situation. The extra time per pick location is estimated at 4, 5 and 2 sec. for the three variants, respectively.

From the simulation experiments, it appeared that good results can be obtained with a time-savings-based batching strategy. This strategy can be implemented relatively easy. Also seed algorithms for batching have been implemented, but these did not yield better performance (not even with an extended local 2-OPT optimization procedure). Only the Combined routing heuristic was applied since this was the routing method preferred by the management of the Bijenkorf. The results can be found in table 4.

Although the difference in total average daily walking distance between the three stacking variants is substantial (distance reductions varying between 57 % and 68%), due to the difference in pick time, the difference in the total order pick time is moderate. In practice, variant III, with sortation of only two orders, is the simplest to the order pickers, with the least possibility (of the three) to make mistakes: sorting the picked items for the wrong order. The savings in total pick time mount up to about 19%, which is about 4.2 pickers, based on an effective 7 hours per picker per day.

After the Combined routing algorithm has been implemented, De Bijenkorf will implement the time savings batching heuristic (using the Combined routing algorithm) with stack variant III.

Table 4. Average walking distance and total order pick time with order batching and three different stacking methods in the bin storage area.

| **Stack variant** | **Average daily travel distance in bin storage area** | **Difference with current method (151.352 m.)** | **Total average daily picktime** | **Difference with current method (153 hours, 31 min.)** |
|---|---|---|---|---|
| Variant I (12 bins) | **54,196 m** | **64.2 %<br>(97,156 m)** | **123 hours,<br>58 min.** | **19.2 %** |
| Variant II (14 bins, max. 8 orders) | **48,571 m** | **67.9 %<br>(102,781 m)** | **124 hours,<br>31 min.** | **18.9 %** |
| Variant III (14 bins, max. 2 orders) | **64,825 m** | **57.2 %<br>(86,527 m)** | **124 hours,<br>32 min.** | **18.9 %** |

## 4. Conclusions

In this study, it has been shown that substantial savings in a warehouse can be achieved by making the order pick process more efficient. In the bin storage area of De Bijenkorf the travel distances could be reduced by 30% and the number of pickers by 1.2, by application of a relatively simple routing heuristic. This improvement is to a large extent due to the fact that order pickers currently follow the location numbering, which results in single-sided picking. The introduction of a simple heuristic and corresponding double-sided picking gives a significant improvement. An optimal algorithm for routing was not considered necessary by the management of De Bijenkorf, since travel time improvement was only 3,8% higher than that of the best heuristic. Furthermore, confusion for the order pickers might increase when introducing an optimal routing method. This is due less intuitive routing.

If orders are batched as well, with a time-savings method and the combined routing heuristic, even stronger savings can be achieved, about 68% reduction of travel distance and a saving of 3 to 4 pickers. Better results may even be possible by developing new batching methods based on their analog to the vehicle routing problem.

Besides the above savings, more is probably achievable, by properly looking at reduction of administration time per order. For example, by using barcodes and scanners in the pick process. This would also eliminate the order confirmation process.

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