QUICK RESPONSE PRACTICES AT THE WAREHOUSE OF ANKOR

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Quick response practices at the warehouse of Ankor

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Abstract:

In the warehouse of Ankor, a wholesaler of tools and garden equipment, various problems concerning the storage and retrieval of products arise. For example, heavy products have to be retrieved prior to light products to prevent damage. Furthermore, the layout of the warehouse differs from the layout generally assumed in literature. The goal of this research was to determine storage locations for the products and a routing method to obtain sequences in which products are to be retrieved from their locations. It is shown that despite deviations from the "normal" case, similar savings in route length can be obtained by adapting existing solution techniques. Total labor savings are far less than expected on basis of assumptions made in literature. With a minimum of adaptations to the current situation the average route length can be decreased by 30 %. There is no need for complex techniques.

Introduction

Order picking concerns the retrieval of products from the warehouse to satisfy customer orders. It is one of the most time consuming activities amounting to about 55% of the operational costs in a warehouse [Tompkins et al. 1996]. Nowadays customers tend to order late and expect a quick delivery of their ordered products. This trend, which is inherent to the widely spread Just-In-Time principle, in combination with the high amount of labor involved, makes warehouses want to improve their efficiency on order picking. Factors influencing order picking efficiency are the routing policy, the storage strategy, the demand patterns of the products and the layout of the warehouse. Important candidates to increase the speed of order picking in an existing warehouse are the routing policy and the storage strategy, because these can be changed without altering racks or equipment.

A routing policy determines the sequence in which products are retrieved from the warehouse. It is generally assumed that the time needed to travel between locations takes about 50% of the total time spent on picking orders [Tompkins et al. 1996]. The remainder of the time is spent on, for example, identifying locations, extracting products and packaging. Decreasing the length of the route therefore can decrease the total time involved with order picking significantly. Finding a shortest route in a rectangular warehouse can be solved in running time linear in the number of aisles and the number of products to be picked [Ratliff and Rosenthal 1983].

1

As an alternative to optimal routing, heuristics can be used. Heuristics create a sequence in which products are retrieved according to a standard pattern. The pattern can vary from fairly easy to more complex and dynamic. Several types of heuristics are discussed in Petersen [1997], Petersen and Schmenner [1999] and Roodbergen [2001].

The use of heuristics has several advantages compared to optimal routing. The first advantage is that heuristics are easier to work with and to implement in software. Secondly, heuristics can be created for those situations for which no efficient optimal routing method is known. Heuristics can also easily be adjusted to changes in layout and for predetermined picking priorities (breakable products last). Therefore, heuristics are generally preferred over optimal routing in practice.

The reduction in route length when implementing a heuristic varies between 9% and 40%, compared to standard methods used in practice [De Koster et al. 1998, De Koster and Van der Poort, 1998]. The average length of routes created by a suitable heuristic is between 5% and 10% longer than the average length of routes created by an optimal routing method [Petersen 1999]. These results are strongly dependent on the number of aisles, the number of products to be picked and the complexity of the heuristic.

A storage strategy assigns each product to a storage location in the warehouse. Three commonly used alternatives to assign products to locations are random storage, dedicated storage and grouped storage [Hausman et al.1976]. Random storage assigns each product to an arbitrarily selected empty storage location in the warehouse. With dedicated storage each product is assigned to a fixed location. The criterion in grouped assignment can either be based on product type, physical volume, number of picks or any combination of these three characteristics. A well-known example of grouped assignment is called ABC- storage. Products are classified as A, B or C product based on their pick frequency and each product group of product is assigned to a certain area of the warehouse, see Malmborg [1995] and Petersen [1999]. Some additional constraints involved with storage are different product groups that have to be stored separately, weight restrictions for the locations, family grouping and capacity restrictions for the locations.

Extensive research has been performed on both subjects. However, most of this research is restricted to either routing policies or storage policies. Daniels et al. [1998] deal with the combination of routing and storage assignment. They consider a warehouse with multiple locations for each product. Petersen [1999] uses simulation to determine good combinations from a set of predetermined storage assignment rules and routing methods.

We have done research on the case of Ankor. We investigated combinations of routing and storage policies such that a good storage is determined for a given routing policy. The situation at Ankor differs from the warehouse layouts and general assumptions made in literature. In the layout we can distinguish multiple cross aisles, two floors, non-coinciding start and end points (top floor) and some dead-end aisles. For such situations, no efficient optimal routing methods are known. Also, different product groups are distinguished, that may not be mixed in the packing process (leading to sequencing in the pick process). Every product group contains breakable products which must be picked last in the route. In fact, such restrictions and non-standard layouts are fairly common in practice, but combinations of storage strategy, routing strategy and pick sequencing have not been addressed in

2

literature. No optimal methods are known. We will show that for the case of Ankor, using modified standard methods known from literature, we can address all these problems and can achieve substantial improvements in travel time (about 30%). The storage and routing methods to achieve this appear to be relatively easy to understand and implement. We believe that the methods applied for Ankor can be applied at other non-standard order picking situations as well, potentially leading to similar improvements.

First we will give a description of the current situation within the company. Thereafter we discuss alternative routing heuristics. Based on characteristics of these routing heuristics we define storage strategies. The last step of the research is the execution of a local improvement procedure. We will end this paper with an overview of the implementation.

The Company

Ankor is a wholesaler in Leidschendam, The Netherlands, specialized in tools, hardware and gardening equipment. In their warehouse they store over 18,000 products with a great diversity in characteristics. On basis of these characteristics three groups are being distinguished. First we have the fast movers; this group consists of the 384 best selling products. The second group is distinguished by size; products of which the longest edge is over 80 centimeters require special handling and are therefore treated separately. These products are called *non-conveyables* (Nocos). The third and last group consists of the regular products; this group contains all products that do not belong to one of the other two groups. The layout of the picking area is adjusted to facilitate storage locations for all types of products. Figure 1 shows the layout of the warehouse. The storage area for fast selling products is marked with 1, the area for Nocos with 2 and the areas for regular products with 3.
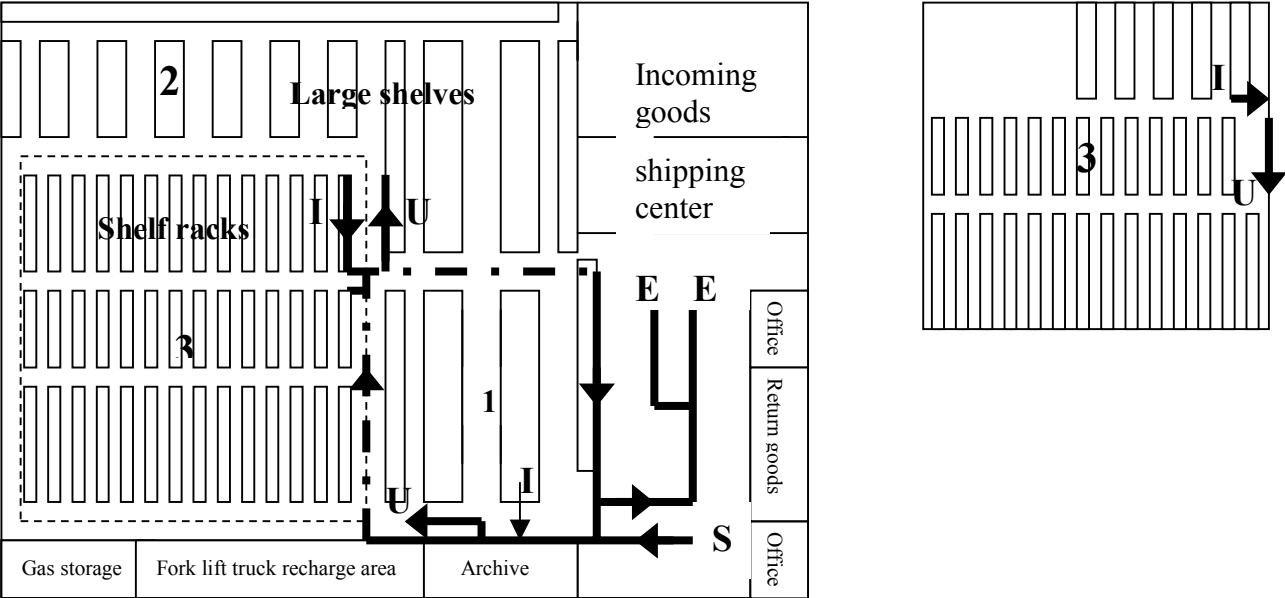
Figure 1: Layout of the warehouse. The storage locations of the different groups are marked with numbers. The right image represents the mezzanine.

The image on the right represents the mezzanine. The dashed line in the left image indicates where the mezzanine is located. The aisles in both outer storage blocks with racks on the mezzanine can only be entered from one side,

the middle of the floor. The other side of the aisles is fenced.

In 2001 Ankor introduced a Warehouse Management System (WMS) that uses the principle of paperless warehousing. The order pickers use a hand terminal with an integrated scanner to verify the products retrieved from the storage locations. The WMS also controls the internal transport of the boxes, which are used to pack products. For this transport a conveyor is constructed throughout the warehouse. The conveyor is represented by the thick line in figure 1. A bold dashed line indicates an overhead conveyor. At the starting point of the conveyor (indicated with "S") boxes belonging to an order are placed on the conveyor. From this point every box goes to one of the three starting points for order picking (indicated with "U"). There are two starting points on the ground floor and one at the mezzanine. From these starting points an order picker collects one or more boxes from the conveyor, scans them and puts them on a cart. He now starts retrieving the products from the storage locations. On his screen he sees from which location, which product and which amount of this product he has to retrieve next. He retrieves and scans it and then he puts it in the box and scans the box. This continues until all products of an order are retrieved. When this is done, the box is put on the conveyor at an input point (indicated with "I"). There are two input points on the ground floor and one at the mezzanine. The boxes are transported to one of the endpoints of the conveyor (indicated with "E"), where they are prepared for shipment. Later we will discuss the route that is used to retrieve the products in more detail.

Nocos are collected and packed separately by order pickers with a special cart. Because of their size Nocos cannot be put in boxes and therefore they cannot be transported with the conveyor. This fact makes the packing process time consuming. Every product receives a special treatment to prevent damage during transport.

Each of the three product groups has its own area where products can be stored. The largest of these groups is the group of regular products, containing 17,000 of the total of 18,000 products. In earlier days storage of this group was based on an ABC-classification. The head and the tail of each aisle at the ground floor were used for the storage of A-products. The middle of the aisles on the ground floor was used for the storage of B-products. The storage locations at the mezzanine were used for the storage of C-products. The customers, however, want the products to be delivered separated according to product type, i.e. tools, hardware and gardening equipment. In order to fulfil this need, a new storage strategy was developed in which regular products were stored based on product type. Each type of products is now located at its own specified area. A further separation is made on breakable and unbreakable products. By retrieving the breakable products after the unbreakable less damage to products will occur. Within the unbreakable products no further classification is made although there are still remainders of the former ABC-storage method to be found.

We now take a closer look at the regular products and the subdivisions into groups. Table 1 shows for each product type the total number of products, the number of breakable products, the number of picks generated in a year and the percentage of storage locations needed.

Regular products	Total number of products	Number of breakable products	Number of picks generated in a year	Percentage of storage locations needed
Tools	8538	338	653,966	38.0 %
Hardware	8150	529	231,520	47.1 %
Gardening equipment	859	325	71,481	14.9 %
Total	17547	1192	956,967	100 %

Table 1: Subdivisions of the regular products.

In table 1 we see that tools generate by far the most picks. It has to be noted that the group of fast selling products is not included here since we are discussing regular products only. All fast selling products are tools as well. A remarkable fact is the percentage of storage locations needed for the hardware. With fewer products than the tools, the hardware requires more storage locations. The gardening equipment has only been introduced three years ago at Ankor; therefore it only generates a small part of the total picks. We also see that each product type has breakable products. These breakable products have to be stored together in order to be able to retrieve these products at the end of a route.

The need to separate the products by type, leads to a change in storage strategy to a strategy which, in combination with the current routing policy, made it possible that the main groups could be retrieved separately from the warehouse in one route. The used routing strategy however leads to many questions about its performance. As we shall see the pattern used to create these routes contains an illogical element. Another problem that arose is the fact that the new storage strategy of the regular products does not take into account the number of picks generated of each product. The aim of this research therefore is to find a combination of a routing and a storage strategy, which leads to a decrease of the average route length needed to retrieve an order from the warehouse. This is done under the condition that products from the three main groups are not mixed in the route and that breakable goods are picked last. These problems particularly arise for the regular products so from now on we will focus on this part of the warehouse only.

Routing heuristics

Now the problem has been stated, the next step is the comparison of the current routing policy with four heuristics and the optimal routing. To be able to make this comparison we wrote a simulation model in Visual-C++. This model generates picking locations to an order and calculates the length of the route created by all

mentioned routing policies. The input is based on real data, that is real orders and real picking frequencies of the products. The 1098 orders, collected in weeks 6 and 7 in the year 2001, vary from 1 to 325 lines with an average order-size of 25.31 order-lines. In each replication one random order from this set is chosen with equal probability. For each line of the chosen order, a pick location is generated. To generate a location we look at two aspects. First, the main group involved with the order line and second, the pick frequency of the products within this main group. The generated location must be situated in the area of the involved main group and the probability by which a location is selected depends only on the pick frequency of the stored product in that location. The used pick frequencies are based on the second half of 1999 and the first half of 2000. Because of the huge number of locations in the storage area of regular products, 17,000, a simplification is made in the simulation model. Instead of the real location we used 376 clustered locations. This means that each clustered location consists of four metres of shelf racks, two on the left and two on the right side of an aisle (two-side picking is done). The minimum number of locations clustered is 24 and the average is 45. To obtain pick frequencies for the clustered locations we summed the pick frequencies of the products stored in the original locations of each clustered location. To finally estimate the average time needed to retrieve an order, information about working speed was collected. We estimate that every order picker is productive for 7 hours and 10 minutes a day, which contains 8 working hours. The average measured walking speed is 1 metre/second, the measured start up time 130 seconds per order and picking time 47 seconds per order-line. In these 47 seconds an order picker reads the screen of his terminal, retrieves the product from its location, scans the product, packs the product and scans the box in which the product is packed.

The four heuristics we used in this research are the S-shape (or Transversal), Midpoint, Largest Gap and the Combined heuristic. Besides these heuristics we also determine the optimal route. Before we take a closer look at these heuristics and the optimal route we first give a detailed description of the current routing policy.

On the ground floor there are two start-points (indicated with U in figure 1). Both start-points are linked to one, the closest, endpoint, I, which makes that the start-point and endpoint approximately coincide for a route. The start-point near the archive is used when at least one product is a tool, the other is used when all products are hardware. Figure 2 shows an example of an order picking route, marked with thin lines, in the regular products storage area (the shelf racks marked with a 3 in figure 1). From the starting point at the ground floor an order picker walks through the first cross aisle. If he passes an aisle with a pick location, before the middle of the aisle, he enters this aisle without his cart, retrieves the product from its location and returns to his cart in the cross aisle. The order picker continues his way through the cross aisle until he reaches the end of a block of shelf racks. At this point he walks around the block and continues his way in the next cross aisle. From the cross aisles an order picker can enter both aisles, if any, on the left- as on the right side of the cross aisle. When all pick locations are visited the order picker returns to the endpoint.

At the mezzanine, where there are only two cross aisles, the order picker enters the first cross aisle from the start-point and walks along the first block with shelf racks. If he passes an aisle with a pick location, he enters the aisle and collects the product no matter how far from the cross aisle the location is. After all products from the first block are retrieved he returns to the start-point now retrieving products, from the second block, up to the middle

6

of the aisles. He walks around the second block and starts retrieving the remaining products from this block. When he has finished the second block the order picker returns to the endpoint, retrieving products from the third block.

The current routing policy has two characteristics, which distinguish it from the heuristics. At first, an aisle is at most entered up to the middle unless the aisle can be entered from only one side, which is the case at the mezzanine. The second characteristic is that the current routing policy never travels through an aisle completely, so that the blocks with shelf racks have to be rounded. The Midpoint heuristic differs only at the second characteristics from the current routing policy. The other heuristics differ on both characteristics from the current routing policy.

In figure 3 the Midpoint heuristic [Hall 1993] is shown for the order of figure 2. In figure 3 we see that most of the aisles are entered no further than the middle. There are however also aisles that are traveled completely. This is done either to go to the next cross aisle or to return to the endpoint of the route. The fact that aisles are traveled entirely makes it possible, in contrast with the current policy, to retrieve items from two blocks at a time at the mezzanine.

The Largest gap heuristic resembles the Midpoint heuristic, but an aisle is now entered up to the largest gap instead of entering up to the middle. Hereby a gap is defined as the distance between any two adjacent pick locations, or between a pick location and a cross aisle. After retrieving the product, the order picker returns to his cart in the cross aisle where he came from. For the same reasons as with the Midpoint heuristic, some aisles are traveled completely. It is known that the Largest gap heuristic always performs better than the Midpoint heuristic [Hall 1993].

With the S-shape, or Transversal, heuristic [Hall 1993] the order picker always travels through an aisle entirely if it contains any pick locations. This is probably the simplest and most used heuristic in practice. In contrast to the Midpoint -, Largest gap - and the current heuristic an order picker only visits locations of one block at the time. Only when an order picker is totally finished with a block he moves on to the next block.

The route constructed by the Combined heuristic [Roodbergen 2001] is based on a dynamic programming algorithm. This algorithm decides for each aisle whether it should be travelled entirely or that it is better for the order picker to return to the cross aisle from which he entered the aisle. In this way it tries to improve upon the S-shape and Midpoint heuristics. To make the choice the algorithm takes into account the next pick location to be visited. For the Combined heuristic an order picker also visits locations of one block at the time. Figure 4 shows an example route created with the combined heuristic.

The optimal route, based on the travelling salesman branch and bound solution procedure of Little et al. [1963], typically makes use of the same dynamics as the Combined heuristic does. Aisles can be traveled entirely or one can enter and leave an aisle from the same cross aisle. In contrast to the Combined heuristic however the optimal

route is not restricted to pick all items from a certain block before going on to the next block. Because of the different start- and endpoint at the mezzanine, an imaginary location with zero distance to both start- and endpoint and infinite distance to every other point on the mezzanine has to be created in order to be able to calculate the length of the optimal route. This imaginary point forces the route to travel from start point to endpoint via the imaginary point. In this way the route starts and ends at the original start point but the length of the route between the original endpoint and the original start point is zero.
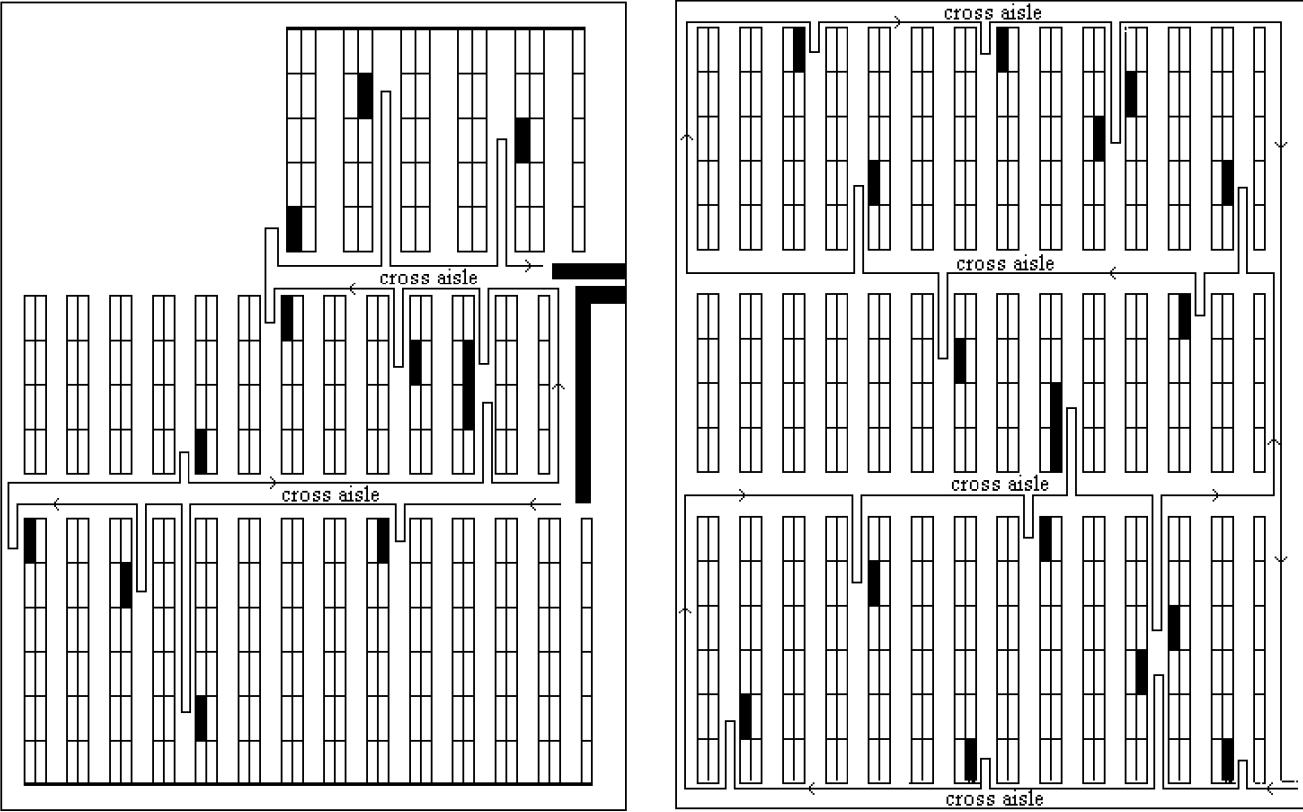
Figure 2:An example of the current routing policy, on the mezzanine (left) and ground floor (right). S is the starting point and pick locations are bold.

8
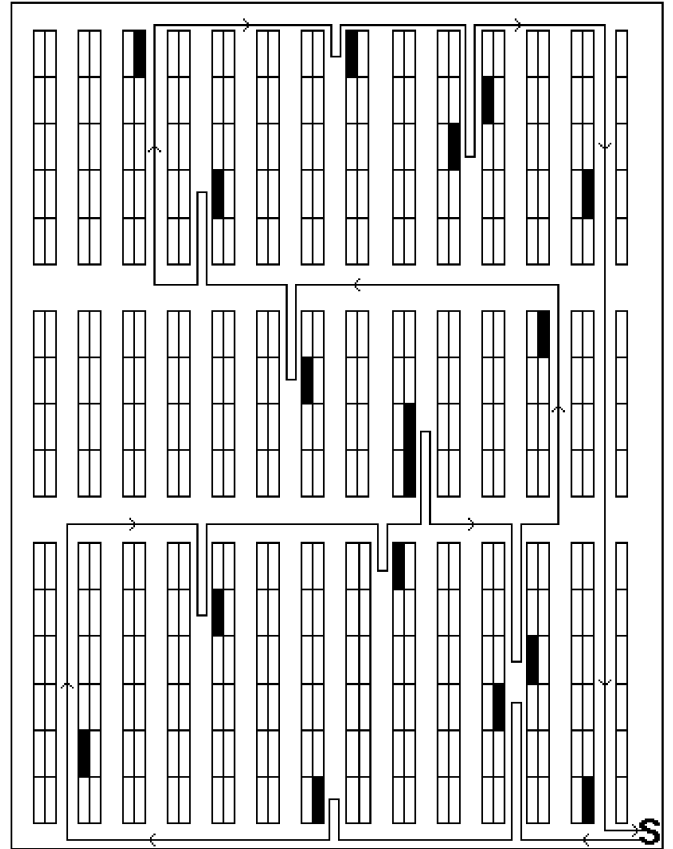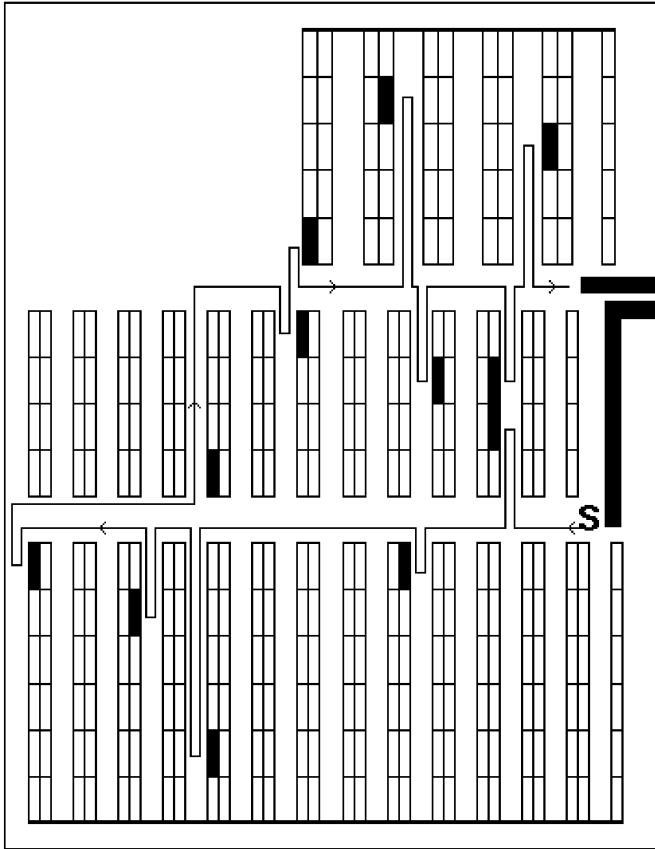
Figure 3:An example of the Midpoint routing heuristic
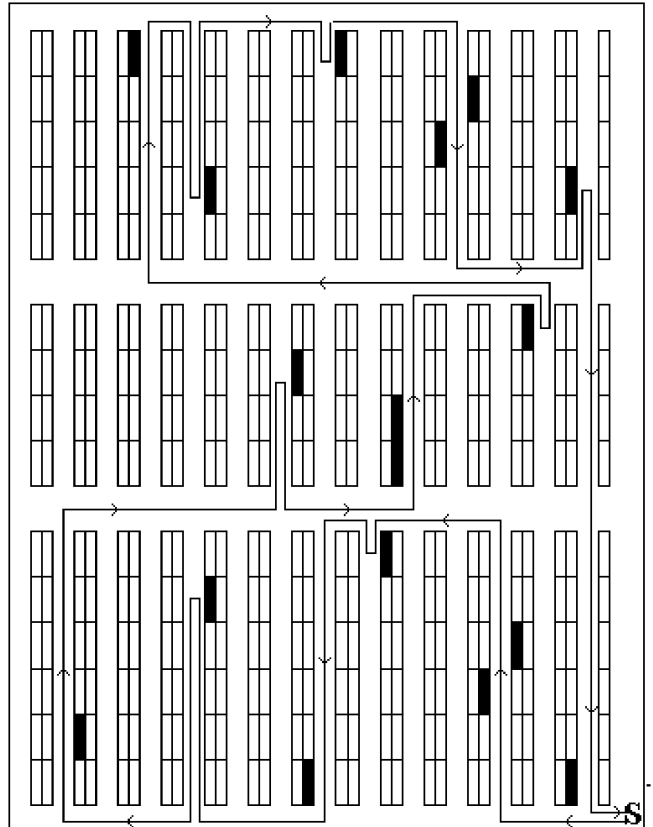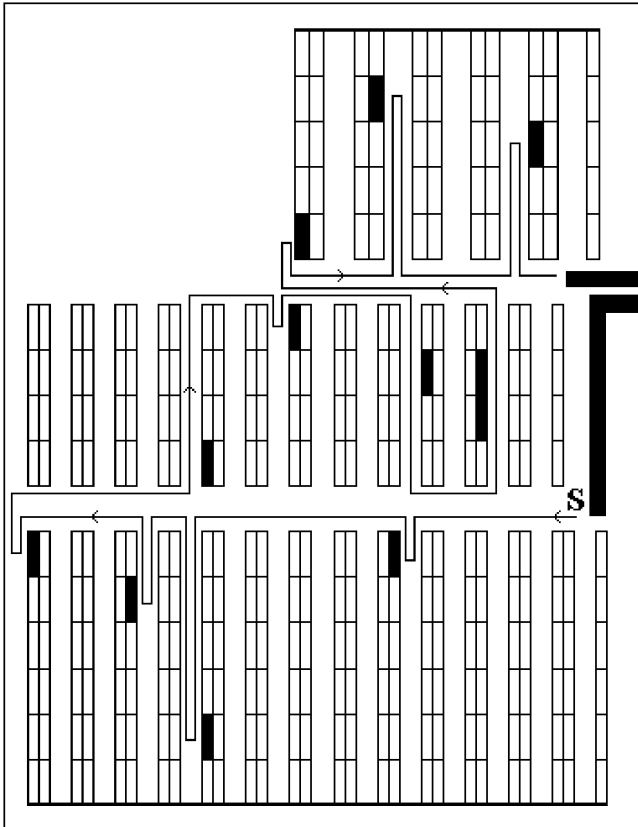
Figure 4:An example of the Combined heuristic

To obtain average route lengths we generated 10,000 orders with the model described above. This number of replications leads to small standard deviations in travel distance, implicating small confidence intervals, so that the obtained results are useful to make comparisons. In table 2, for all routing policies the average length of the route on the ground floor, the average length of the route on the mezzanine, the average total length and the standard deviation of the total are listed, all expressed in meters.

Routing policy	Average length on the ground floor (m)	Average length on the mezzanine (m)	Average total length per order (m)	Standard deviation of average route length (m)
Current	157.05	37.24	194.29	1.53
Midpoint	129.41	34.85	164.26	1.34
Largest gap	128.59	34.85	163.43	1.33
S-shape	147.01	36.92	183.93	1.49
Combined	134.64	35.16	169.80	1.35
Optimal	119.36	31.18	150.54	1.47

Table 2: Average lengths of the six used routing policies including their standard deviation.

In this table we see that the average length of the route in the current situation, 194.29 metres, decreases to 150.54 metres, using the optimal routing. The use of any of the heuristics leads to various results. The S-shape heuristic performs slightly better than the current routing. The savings that can be achieved, using one of the other heuristics, vary between 12 and 15 % and are only a little less than the savings achieved using the optimal routing. Especially the result of the Midpoint heuristic is remarkable because of all used heuristics, this heuristic has the greatest resemblance to the current routing policy. Contributing to this result is the former storage strategy, which used to be based both on an A/B/C-classification and the current routing policy. Because of the resemblance of the Midpoint to the current routing, the former storage strategy is also appropriate for the Midpoint heuristic.

Storage strategies:

In a previous section we mentioned the impact of storage strategies. The fact that there still are remains of the former A/B/C-storage method, with A-locations at the end of the aisles, is one of the reasons of the good performance of the Midpoint- and Largest gap heuristics. In order to further improve the effect of routing heuristics we define different A/B/C-storage strategies, dependent on the various routing heuristics used in this research. In doing so we have to take several constraints into account:

1   Main groups have to be retrieved separately.

2   Breakable products have to be retrieved after all unbreakable products.

3   There must be some empty buffer locations in all zones (A/B/C, breakables) in which, for example, new products can be stored.

The first constraint leads to separate areas for each of the three main groups. As we saw in table 1 each main group consists of both unbreakable and breakable products. To retrieve these products separately, within the area of the main groups a specified area should be reserved for the storage of breakable products. The order picker must visit this area at the end of his route. Future changes in the demand will lead to changes in the structure of the different classes. Buffer locations should therefore be situated at the borders of the areas of the different classes.

To make an A/B/C-storage classification we have to take a closer look at the regular, unbreakable products, shown in table 1. Each group of unbreakable products generates a typical Pareto pick-frequency curve, which is used to make a subdivision in classes. The pick-frequency curve for the unbreakable tools is shown in figure 5.
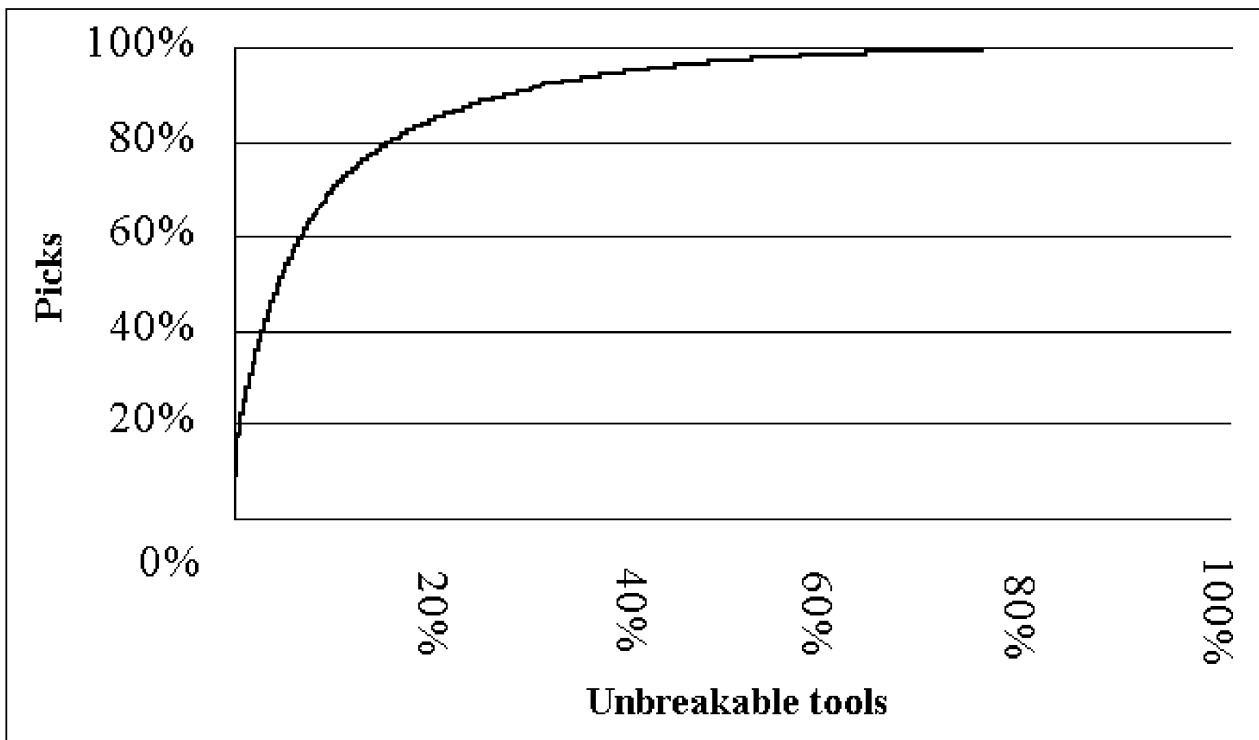
Figure 5: Distribution by picks curve for the unbreakable tools

We decided to subdivide each main group into three classes. Because no hard rules can be found in literature about this subdivision we decided to use the following rules:

class A contains up to 70% of the total picks or 15% of the total number of products.
classes A+B contain up to 90% of the total picks or 50% of the total number of products.
class C contains the remaining products.

To establish the number of clustered storage locations needed for each class we measured the current number of locations that are occupied by the products contained in the classes. On basis of this space occupation the size of the class storage area can be determined. In table 3 we see the subdivision of the main groups on basis of the rules described above. In this table for each class the percentage of picks, the percentage of products and the number of clustered locations needed to store these products, if available, is stated.

| Class	Tools			Hardware			Gardening		
	% prod	% picks	# loca tions	% prod	% picks.	# loca tions	% prod	% picks.	# loca tions
A	10	70	23	15	65	31	15	62	7
B	17.5	20	25	26	25	43	27	28	9
C	72.5	10	82	59	10	81	58	10	18
Breakable	N/A	N/A	7	N/A	N/A	13	N/A	N/A	16
buffer	N/A	N/A	6	N/A.	N/A	9	N/A	N/A	6
total	100	100	143	100	100	177	100	100	56

Table 3: Subdivision of the main groups of the regular products in classes and an overview of the locations needed to store each class.

We can distinguish two groups of routing heuristics to which potential storage strategies have to be adapted. On the one hand we have the S-shape- and the Combined heuristic, which never enter an aisle twice. On the other hand we have the Midpoint - and Largest gap heuristic by which an aisle can be entered twice. On basis of this difference we decided to define two new storage strategies. For both these strategies, first the areas of the main groups must be specified. Secondly for each storage class, locations must be specified.

The areas for the main groups of the storage strategy belonging to the S-shape- and Combined heuristic, called the "Combined storage" strategy, must be specified in a way that each aisle only contains products from one main group. The reason for this is the fact that an aisle is entered only once. When two main groups are stored in one aisle, products no longer can be retrieved separately.

Next we can assign locations to each of the five classes, class A, B, C, breakable products and buffer locations, shown in table 3. At the end of every route an order pickers travels through the first aisles, of the blocks, from which products are to be retrieved. Therefore the first aisle(s) of each block with shelf racks is/are used for the

storage of breakable products. Products from the A/B/C classes are stored such that the closer an aisle is to a starting-point, the faster moving the stored class in that aisle is. Class C products are stored in aisles farthest away from the starting-points. The buffer locations are proportionally assigned at the borders between the A/B/C classes. Figure 6 shows the exact areas assigned to each main group and to each class within these main groups for the Combined storage strategy.
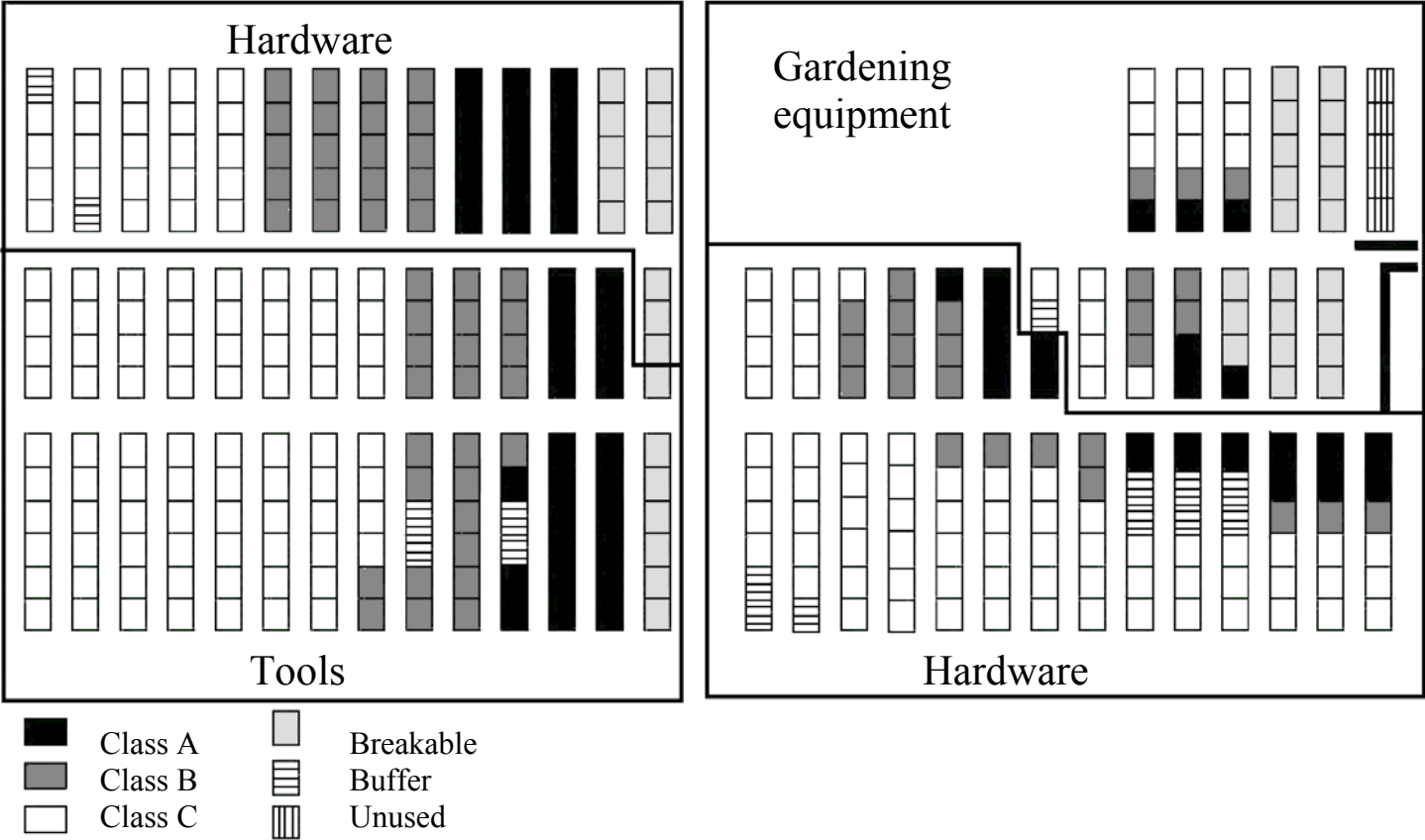
Figure 6 Combined storage strategy

For the storage strategy belonging to the Midpoint- and Largest gap heuristic, the "Midpoint storage" strategy, the areas for the main groups are defined per half aisle. This is done because an order picker, hardly, ever passes the midpoint of an aisle. The same area division for the main groups is used by the current storage strategy. Breakable products and buffer locations are assigned to the same locations as with the Combined strategy. Besides the aisles closest to the starting-points, the locations at the head and tail of an aisle are preferred above the ones in the middle of an aisle. The reason for this is that with these routing heuristics an order picker returns to the cross aisle he came from. It is therefore more time consuming to visit a location in the middle of an aisle than to visit a location at the head or tail of an aisle. Thus a trade-off has to be made between locations at the head and tail of an aisle and the locations in the middle of an aisle closer to the depot. Figure 7 shows the exact areas assigned to each main group and to each class within these main groups for the Midpoint storage strategy.

Class A
Class B
Class C
Breakable
Buffer
Unused
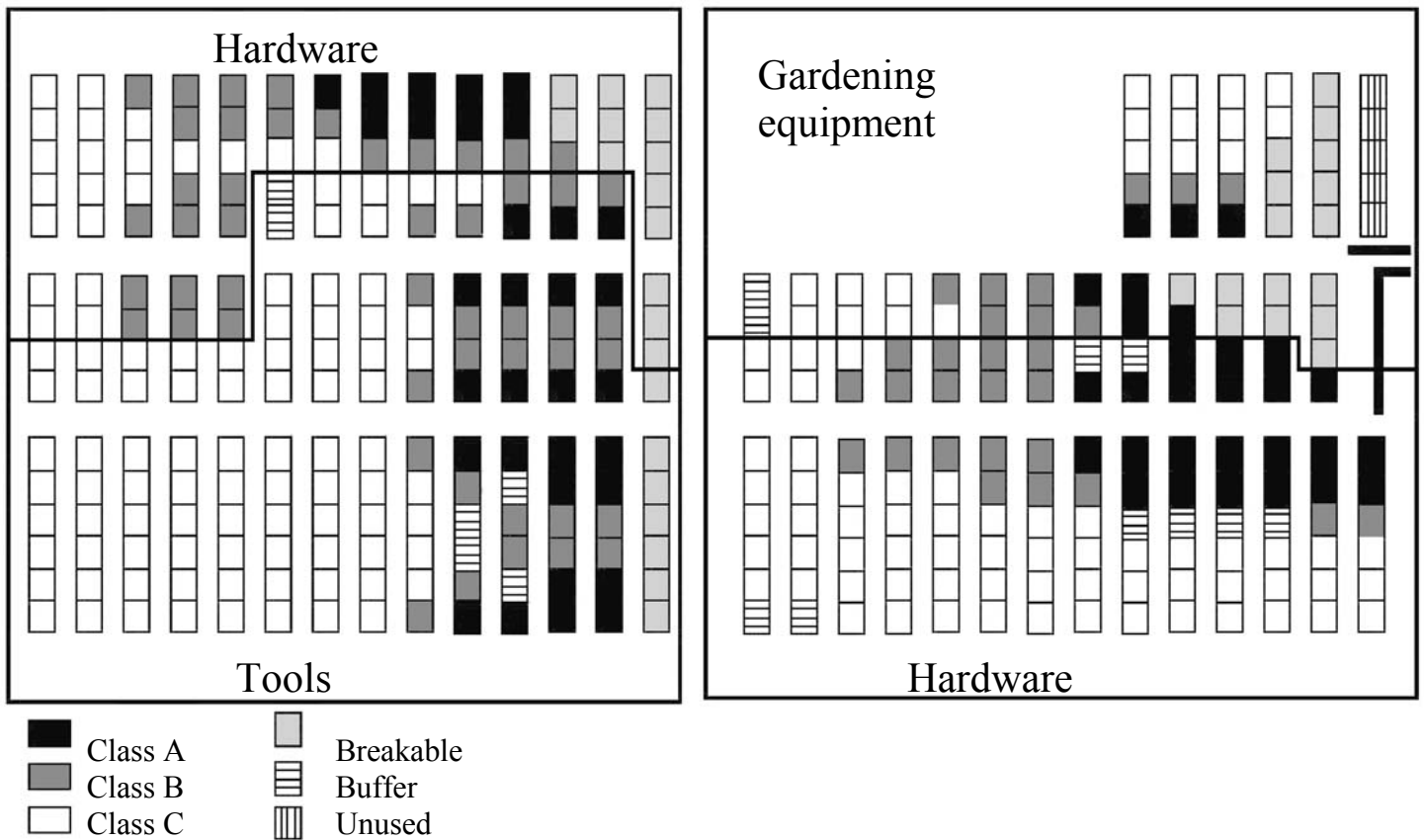
Figure 7 Midpoint storage strategy

With both storage strategies the same 10,000 orders as mentioned previously are executed. The average length of each routing policy is determined under the new storage strategies. Table 4 shows these results, for both the current and the new strategies, in metres.

Routing policy	Current storage strategy	Combined storage strategy	Midpoint storage strategy
Current	194.29	179.06	169.10
Midpoint	164.26	138.02	138.20
Largest gap	163.43	136.25	137.55
S-shape	183.93	140.36	153.96
Combined	169.80	134.73	141.42
Optimal	150.54	122.40	125.43

Table 4: Average lengths of the routing policies under three different storage strategies.

14

From these results we can conclude that using an alternative storage strategy in combination with a routing heuristic leads to a decrease of the average route length of nearly 30 %. The decrease in average length, after applying alternative storage strategies, is not the same for all routing policies. The decrease for the Midpoint – and Largest gap heuristics is smallest. Remains of the former storage strategy already influenced the results of these heuristics under the current storage strategy so the additional effect of a dedicated storage, for those heuristics, is partly incorporated in the results under the current storage. The S-shape heuristic has the greatest advantage of a dedicated storage strategy. The average length for this heuristic decreases with more than 40 metres, that is more than 20%.

Except for the current routing policy the Combined storage strategy leads to the best results for all routing policies. It is possible that the different areas for the main groups are partly debt to these results. Still it is a remarkable result because we adapted the Midpoint storage strategy to the characteristics of the Midpoint- and Largest gap heuristics. Even though there is only a small difference between both strategies we can question the assumptions made defining the Midpoint storage strategy.

These reductions in travel time lead to an increase of productivity. As said, many studies suggest that travel time is 50 % of the total order picking time. This would mean that a reduction in the travel time of 30 %, leads to a reduction of 15 % on the average time needed to retrieve an order. We already mentioned the working speed we measured at Ankor. Under the current circumstances it takes an order picker at Ankor 1513.86 seconds to retrieve an average order of 25,31 lines; 25.31*47 (picking time) +130 (start up time) +194.29*1 (travel time). Using the best possible alternative, Optimal routing in combination with the Combined storage strategy, this time reduces to 1445.35 seconds. That is a decrease of only 4.53%. It is obvious that at Ankor the standard assumption does not hold. De Koster, Roodbergen and Van Voorden (1999) found a similar result during a case study at the Bijenkorf. There can be two reasons for this result, either the standard assumption does not hold in general or the picking process at Ankor can be improved. Most probably the answer lies somewhere in between.

Local improvement

On basis of the results shown in the previous section we questioned the assumptions made to define the Midpoint storage strategy. Because of the given restrictions, the assumptions about the breakable products and the buffer locations however have to remain in tact. Therefore further research to find the best locations for the products from the A, B and C classes is needed. The optimal storage strategy for these three classes, given the restrictions, is found when a 3-opt procedure is executed. An approximation is found using a 2-opt procedure. The number of iterations needed to execute this procedure is far less than the number of iterations needed to execute the 3-opt procedure. For example within the tool area the three opt procedure uses about 650 times as much iterations as the 2-opt procedure. The time needed to execute the 2-opt procedure on the total areas is already 50 to 60 hours on a Pentium II PC. In practice the use of a 2-opt procedure is therefore preferred above the use of the 3-opt procedureeven though this procedure may end in a local minimum. The 2-opt procedure has therefore been executed for both the Combined storage strategy and the Midpoint storage strategy. Each iteration of the 2-opt procedure starts with a systematic selection of two clustered storage locations. These locations must satisfy the

15

following criteria:

1 They must belong to the same main group area
2 They must be used for the storage of different classes
3 They are not used as buffer or as storage for breakable products

If the selected locations fit these criteria they are interchanged where after 10,000 orders are executed. Only if the average length of the route has decreased the interchange is accepted. The selection criterion is the average length of the route generated by one of the heuristics. For the Combined storage strategy we decided to use the Combined heuristic as criterion. For the Midpoint storage strategy we used the results of the Midpoint heuristic. The procedure stops when no new pairs can be found. The resulting two storage strategies are now compared for all other routing strategies as well, in table 5. The results before and after applying the two-opt procedure on both storage strategies can be found in this table.

Routing policy	Storage policy			
	Midpoint before 2-opt	Midpoint after 2-opt	Combined before 2-opt	Combined after 2-opt
Current	169.10	170.37	179.06	176.74
Midpoint	138.20	137.60	138.02	136.59
Largest gap	137.55	136.05	136.25	134.79
S-shape	153.96	146.97	140.36	140.51
Combined	141.42	136.41	134.73	133.71
Optimal	125.43	125.44	122.40	121.76

Table 5: Average route lengths before and after applying the 2-opt procedure. The shaded cells indicate the routing strategies used to determine the 2-opt storage strategy.

In general only a small decrease in the average route length is achieved. Only the changes of the S-shape- and the Combined heuristic after applying the 2-opt procedure on the Midpoint storage strategy are worth mentioning. Therefore it seems, on basis of the route length, that the defined storage strategies are not far from optimal. When we look in detail at the storage strategies after applying the 2-opt procedure, we see that no major changes have occurred to the Combined strategy. The Midpoint storage strategy, however, has changed a lot and in fact resembles the Combined strategy, see figure 8. The only differences remaining between the two strategies are the different areas in which the main groups are stored. This difference leads to the small differences in the average length of a route between both strategies.
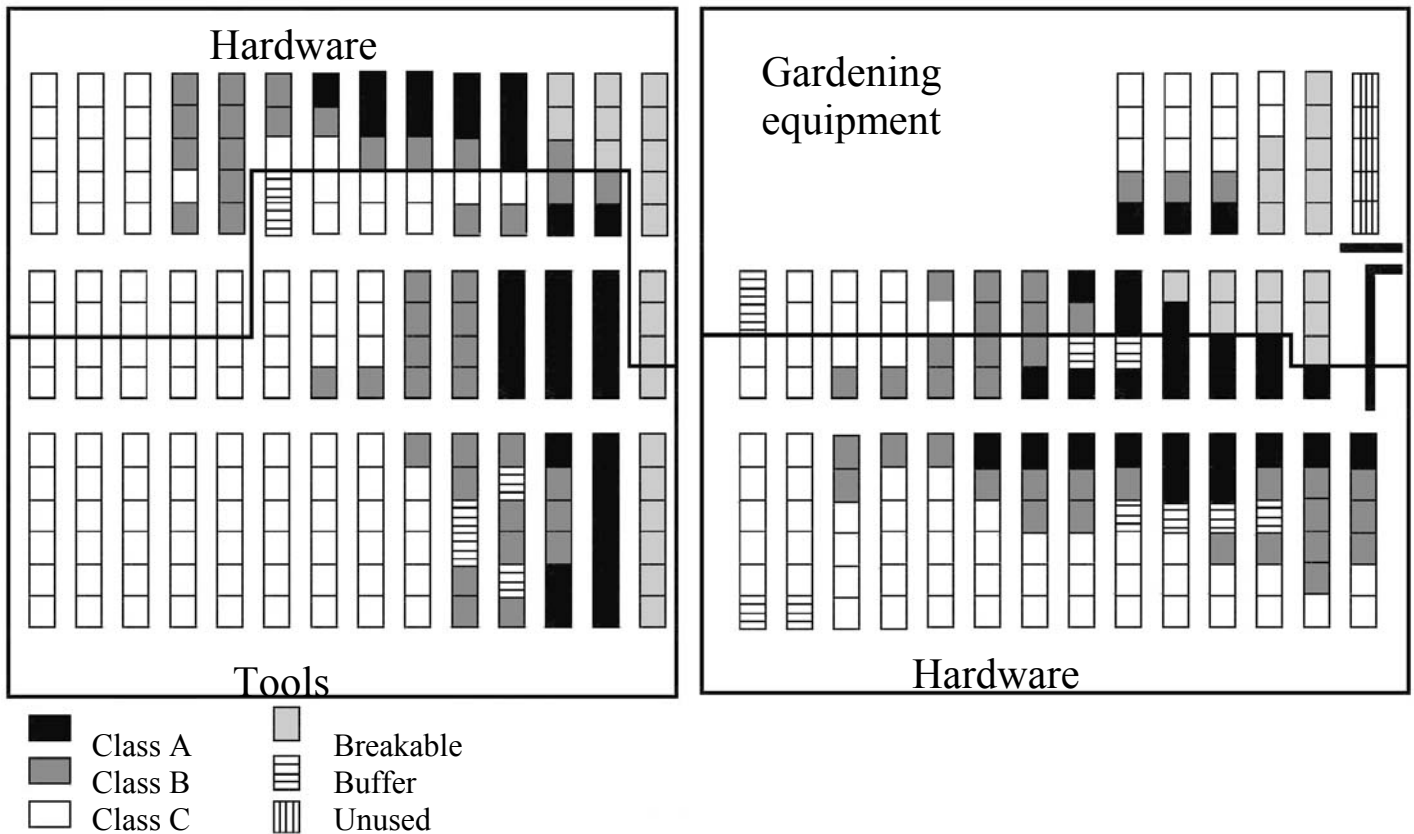
Figure 8 Midpoint storage strategy after applying the 2-opt procedure

Apparently, the routing policy chosen hardly affects the optimal allocation of products divided in A/B/C-storage classes. For Ankor this implies that aisles that are closest to a starting-point must completely be used for storage of products from the highest class, A. The aisles farthest away from a starting-point are used for products from the lowest class, C.

Implementation:

As a result of this study Ankor decided to change their routing policy as well as their storage strategy. Because of the restriction, that all products from the main groups have to be retrieved separately, a number of routing heuristics can not be used at all or can not be used in combination with a certain storage strategy. These are the optimal and the Largest gap heuristic, furthermore the Midpoint heuristic in combination with the Combined storage strategy and finally the S-shape and Combined heuristic in combination with the Midpoint storage strategy. These exclusions left the company with three options: Midpoint heuristic with the Midpoint strategy, the S-shape heuristic with the Combined strategy and the Combined heuristic with the Combined strategy. The results, of the three options left, vary between 134.73 and 140.36 metres and in reduction on the average time needed to retrieve an order only between 3.93 and 3.56 %. Because of these small differences the company decided to stay as close to the old situation as possible and therefore to implement the Midpoint heuristic with the Midpoint storage strategy. The average route length will decrease to 137.60 meters. This is a reduction of 28.87

%. The average time needed to retrieve an order reduces with 3.74 %

Besides this implementation further research is started on the picking time. It can be calculated that in the current situation picking time consumes 76 % of the total time. Reduction of the travel time leads to an even higher relative percentage of the picking time. Research on picking time also focuses on start up problems of the WMS.

Before the storage strategy can be implemented it has to be worked out in detail. Within each class the products have to be assigned to a specific location. Problems such as weight restrictions and demand correlation between products can be taken into account doing so. Heavy or difficult to handle products, such as hammers and saws, can be stored in such a way that these products are retrieved first. When this is done there will be less problems packing the products. Products with a high demand correlation can be stored close to one another, which leads to a further decrease of the average route length. The time needed to finally change the storage allocation in the warehouse is estimated at two days. Besides this extra work this change does not influence the jobs of the order pickers.

For the implementation of the routing policy, mainly software changes within the WMS are needed. The time needed to change and test the software is, because of the great resemblance with the current routing, estimated at three working days. The main problem with the implementation is to find a way to indicate whether an order picker must return to the cross aisle where he came from or that the order picker must travel through the entire aisle with his cart. This requires an indication on the screen of the hand terminals. A practical problem arises within the aisles, which are used to return to the endpoint. These aisles have become congested. To reduce the congestion some order pickers leave their carts and enter these aisles without their cart to collect it later. This leads to a slight increase in route length but also to a more workable situation.

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