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Improving product location and order picking activities in a distribution centre

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This article examines the effect of different product location strategies on the distance that order pickers must cover to do their job. This distance is an important cost component in warehousing activities. Our empirical study is based on a real industrial setting, in which the products are located on both sides of a conveyor belt. We show that choosing the right product location strategy allows the current picking distance to be reduced more than 10%. We also propose a post-optimization procedure that can further reduce picking distances—up to 20% of the current distances. Through a study of the routing strategy used to dispatch pickers, we demonstrate that solving a simple travelling salesman problem can further reduce distances up to 13%, compared with the distances incurred using a predetermined route. We show that reductions of up to 27% compared to current picking distances are possible if our product location and routing methods are combined.

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Introduction

Both distribution centres (DCs) and warehousing operations are key elements in supply chain efficiency. In most cases, DC efficiency and throughput have an impact on the capacity of the entire supply chain. From a strategic point of view, DC efficiency and throughput are the result of technological and design choices, such as the selection of storage and order picking systems (van den Berg, 1999; Rouwenhorst *et al*, 2000). Although modern supply chain management strategies focus on reducing inventory, product diversification and customization require handling additional stock keeping units (SKUs). This necessity has pushed companies to review their distribution networks, moving the emphasis from storage to flowthrough. For example, the *Société des alcools du Québec* (SAQ), a state-owned corporation responsible for the trade of alcoholic beverages in Québec (Canada), has doubled the number of products commercialized in the last 10 years, passing from 3851 in 1996 to 7633 in 2005. The distribution network has also grown from 494 point-of-sales in 1996 to 806 in 2005, and company sales have increased from CAN$ 1.31 billion in 1996 to 2.54 billion in 2005 (SAQs annual report is available at http://www.saq.com). In order to handle this increased volume, and the consequent network expansion, most DCs, including SAQs, must improve their order fulfillment operations through better storage, picking and routing strategies (Petersen and Aase, 2004).

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Storage strategies assign SKUs to storage locations. Classic storage strategies include *dedicated storage*, in which products are allocated to fixed locations; *random storage*, in which products are allocated to various locations according to the available storage space; and *classed-based storage*, in which products are allocated to specific zones or areas in the warehouse. These basic strategies may be combined to better respond to specific requirements.

Order picking strategies determine how the ordered SKUs are grouped into picking lists, and subsequently retrieved from their storage locations by one or many pickers. There are four basic procedures for picking orders: discrete; zone; batch; and wave. In *discrete picking*, one person picks one order, one line at a time. This strategy is often preferred because it is easily implemented and order integrity is always maintained. In *zone picking*, the warehouse is divided into distinct zones, with one picker assigned to each zone. This means that the items in an order are divided into several picking lists. In *batch picking*, one person may pick many orders at the same time. In *wave picking*, orders are picked to satisfy the required shipping schedule. All other picking practices are a combination of these basic procedures. For a more detailed description of these basic procedures, please consult Tompkins *et al* (1996), Tompkins and Smith (1998) and Petersen (2000).

Routing strategies determine the sequence in which the SKUs on a given picking list are collected, the objective being to minimize the distance covered by the picker. Heuristics or optimal procedures can be used to determine these sequences; however, as optimal routes may change from one order to another, requiring the pickers' constant attention, warehouses often use predetermined routes in order to simplify the pickers' work.

Operating DCs or warehouses requires much more than choosing storage and picking strategies. In fact, even given a basic storage model—dedicated storage, for example—many decisions must be made: what type of equipment should be chosen (eg, racking), whether certain equipment (eg, handling devices like conveyors) should be used, and which products should assigned to which storage locations.

The goal of these decisions is to allow warehousing systems to respond rapidly to customer demands, and the choices made play an important role in the success of a supply chain. In this paper, we report on our efforts to optimize the product location and order picking activities of a high throughput DC. In this real-life DC, products are located in both sides of a conveyor belt according to a dedicated storage model. Orders are picked one at the time (discrete order picking), and pickers follow a predetermined route. To the best of our knowledge, such a system has never been studied before. Our empirical study is based on real data provided by our industrial partner. We first concentrate on product location strategies (ie, the assignment of products to the storage locations), showing their impact on the order picking distances. Then, we study the routing strategies (ie, the way in which items are collected), proposing a procedure that further reduces the total distance covered when picking the requested orders.

The rest of this paper is organized as follows. First, the literature relevant to both order picker routing problems and product location problems is reviewed. Then, the context of the studied company's warehousing operations is presented, and our new product location and routing strategies are introduced. Finally, our computational results are reported, followed by a brief conclusion summarizing the advances made by this study.

Literature review

Order picker routing has received considerable attention in operational research literature. It is well-known that determining the minimum distance picker route within a warehouse is a variant of the classic *Traveling Salesman Problem* (TSP), which is NP-hard (see Lawler *et al*, 1985; Laporte, 1992). Briefly, the TSP consists of determining a minimum distance cycle that passes through each vertex once and only once. In the case of order picker routing, each product to be picked corresponds to a vertex, and the distance between two vertices is set to be the shortest distance between the corresponding locations in the warehouse. Usually, since the distances are symmetrical, the problem of finding the shortest picking route corresponds to a symmetrical TSP. However, in warehouses with unidirectional aisles, the distance matrix is asymmetrical, and thus, so is the corresponding TSP. Numerous efficient TSP algorithms exist that can be used to optimize the picker routes.

Even though the general order picker routing problem has been proved to be NP-hard, special warehouse configurations can be used to allow the problem to be solved simply. For example, Ratliff and Rosenthal (1983) showed that if the order picking is done in a rectangular warehouse that contains crossovers only at the ends of aisles, the routing problem is a special solvable case of the TSP. Goetschalckx and Ratliff (1988) studied a case in which pickers had to walk down a single aisle, picking items from both sides of the aisle, but were not able to reach items on both sides without changing position. They showed that the optimal route can be found by solving a shortest path problem. De Koster and Van Der Poort (1998) generalized Ratliff and Rosenthal's (1983) algorithm to warehouses in which orders can be picked up and deposited at the head of every aisle. In this case, only the starting point of the next order-picking route is known beforehand. Vaughan and Petersen (1999) studied the impact of adding cross aisles on order-picking efficiency, and Roodbergen and de Koster (2001) studied the case in which aisle changing is possible at the front, rear and middle of the warehouse (a warehouse with three cross aisles). Petersen and Aase (2004) recently examined the effect of picking, storage and routing decisions on picking distances in a warehouse with only a front and a back aisle.

On the other hand, product location strategies (ie where to store products in order to facilitate order picking) has received considerably less attention. Theoretical contributions are scarce, given that product location is highly dependent on warehouse configuration and on the order-picking strategy and technology in place, and thus most of the research in the literature deals with specific practical cases. In his classic work, Heskett (1963) developed the *cube-per-order* index, in which the most popular products are located closest to the base location. This index minimizes the routing distance for cases in which one product is picked on each route (*pallet picking*). Jarvis and McDowell (1991) developed a model for locating products in a warehouse in such a way that the average order-picking time is minimized. Vickson and Fujimoto (1996) examined the problem of optimal product location in a single bi-directional carousel storage and retrieval system, where the objective was to minimize the average picking distance between successive picks over the long run, and Petersen and Schmenner (1999) studied volume-based storage in which high-volume items are located close to the pick-up/drop-off point in order to minimize picking distances. Litvak and Adan (2002) analysed a carousel system used to store and retrieve small- and medium-sized goods to determine the time needed to pick several items. Recently, Jewkes *et al* (2004) took a closer look at product location along a picking line. In their study, each order was filled by moving a container past the various product storage locations, with the appropriate quantity of each product being transferred from its respective storage location to the container. To the best of our knowledge, the problem of product location involving a conveyor belt, like the one studied in this paper, has never been addressed before.

Warehouse design and operations

The company studied in this paper is the largest snack selling company in the United States (potato chips, corn chips, hardy pretzels, savory cookies, etc). The distribution centre under study is attached to the second largest production plant in Canada, producing annually more than 40 millions kilograms of products. The distribution centre handles more than 12 millions of cases annually and uses two different storage policies in their warehousing system depending on the type of customer to be served. The first type of customer includes local DCs and/or internal customers. These customers order large quantities of products that are shipped on pallets by truckloads. Orders are assembled using a *pallet picking* strategy, with forklifts moving back and forth between the warehouse, where the pallets are stored on standard racks, and the shipping area, where the trucks wait to be loaded. This section of the warehouse has adopted a random storage policy.

The second type of customer comprises external retailers, who may order any quantity of any product. These customers generate the greatest part of the orders. Products for these customers are assigned to storage locations (slots) in a mezzanine shelving system on both sides of a conveyor belt, according to a dedicated storage policy. A *wave discrete order picking* policy is used. The orders that have to be loaded in a given truck are released (*waving*) following the shipping schedule. Thus, the picker works on a single order (*discrete picking*) walking along the shelves, gathering the required quantities of the products from the various locations along the route (*case picking*), and putting them on the conveyor belt. The conveyor belt is connected to a roller conveyor that automatically moves products to trucks in the shipping area. As orders are picked one by one, there is no need to sort the collected products. The average throughput of this picking system is around 600 cases per hour and it works 24 h a day.

This conveyor belt system has many advantages. After a few training hours, any picker can achieve a high picking productivity. Since a dedicated storage policy is used, the system can predetermine the picking routes by sorting the requested products, which simplifies the work of the pickers. This belt system, which can be viewed as a fast pick area reduces the distances travelled by the pickers. Handling activities are also minimized as cases are only moved from their location to the belt (see Figure 1). Finally, order accuracy reaches 99%. The main limitation of this belt system is that its configuration can hardly be modified without major investments. This situation may happen if, for example, the number of products helds by the company increases. Finally, in case of a conveyor breakdown, the entire picking system is stopped. Fortunately, this occurs rarely.

In this paper, we focus exclusively on the mezzanine system used to service the latter category of customer, with the objective of improving both the storage and order-picking operations by (1) optimizing the allocation of products to storage locations, and (2) reviewing the picking strategy. In the following sections, the conveyor belt layout, the product categories, the order picking procedure, the modelling of the conveyor operations, and the company's present product location strategy are described in detail.

Conveyor belt layout

Figure 1 presents the layout of the storage system and the conveyor belt (black arrows correspond to a picker's route that will be discussed later). In the common language used in the company, this storage system is simply called the *belt*. Each rectangle in the figure represents a location where one or many different products may be stored. A total of 240 storage locations, or slots, are distributed on either side of the belt. Each of these contains a wooden board full of the products. When a board is empty, a replenishment activity is called, and another board is brought to the belt. Once a day, the empty boards are moved to predefined locations, whose location names end in B (eg, A311-B, A319-B, A327-B) (represented as grey boxes in Figure 1). The conveyor belt (represented by the continuous solid grey line between the storage locations) always moves in the same direction, as indicated by the white arrows.

The belt is divided into six sections: A, B, C, D, E and F. Each storage slot bears a number and the letter of the section in which it is located. For example, in section A, the storage locations are numbered from A303 to A350. The physical structure of slots D352 to D358 (represented as squares in the figure) has been reinforced to allow them to bear the weight of the company's heaviest products. Doors are located at various points along the belt (the black squares marked with a *D* in Figure 1). When a door is opened, the belt stops, and a picker can cross it safely. Footbridges join the different sections of the belt (represented as grey cells in the figure), making it possible to go from section to section. For instance, using the footbridge located between slots B322 and B324, a picker can move from section B to section C.

Product categories and storage

For commercial reasons, company products are separated into two categories: regular products and vending products, or simply *vendings*. Regular products are products that can be ordered by any DC or any retailer in the province of Québec. Vending products are products that are shipped only to the province of New Brunswick, where they are not manufactured. According to this classification, orders may contain either regular products or vending products, but not both. Since vending products represent only a small part of the demand—around 20%—the company has placed these products in section F, the farthest section of the belt.

Order picking procedure

The special structure of this belt imposes certain restrictions with regard to the path that pickers take to gather the items on

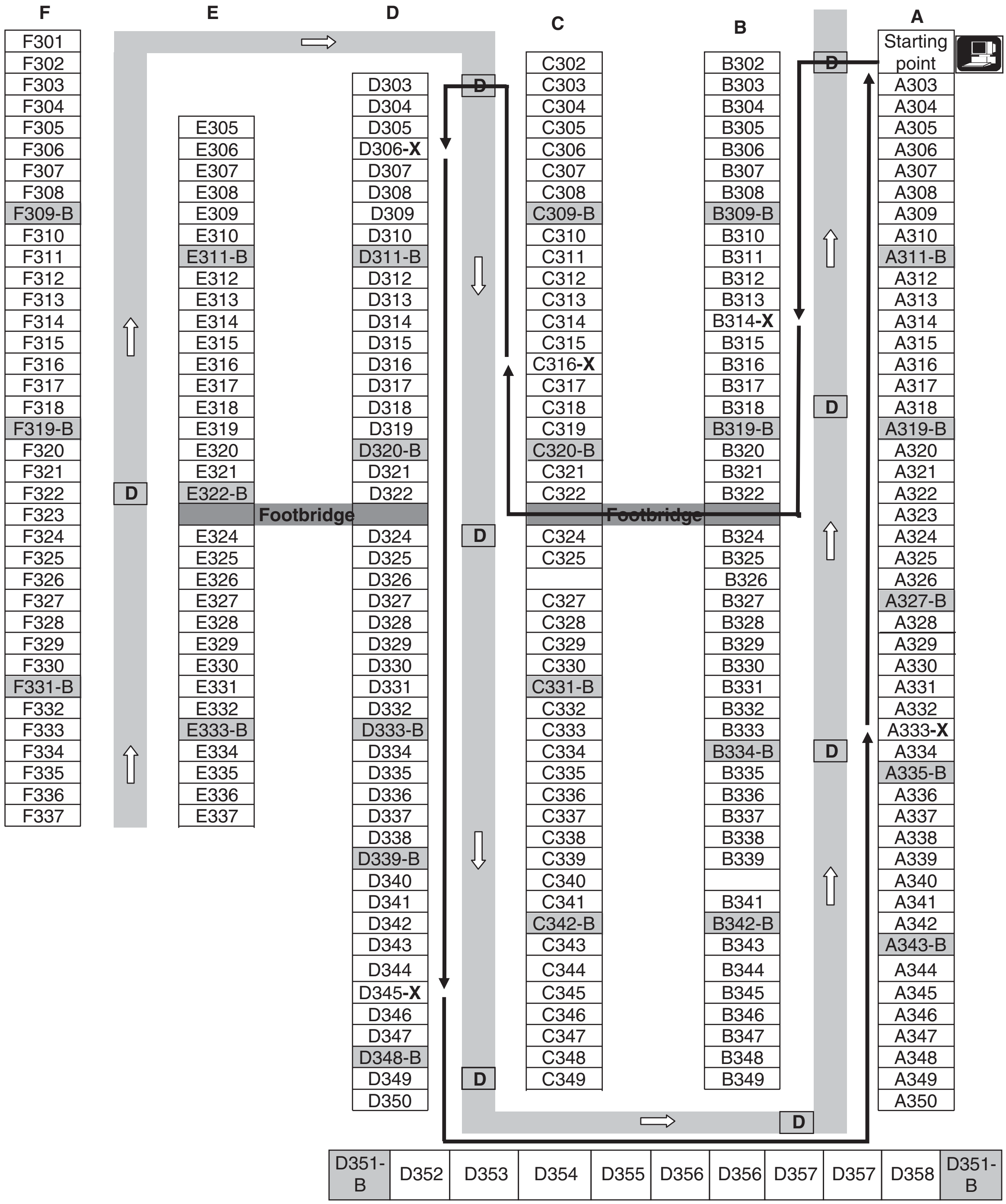

Figure 1 The conveyor belt system.

the orders. Currently, the company uses the following picking strategy:

> A picker starts the tour at location A303, where a computer prints the picking list. S/he visit sections B, C, F, E, D and A in that order before returning to location A303. According to this sequence, the picker crosses the belt-door at slot A303 and begins gathering items in section B, working from slot B302 to slot B349. Then s/he walks along section C, picking items stored in slots C349 to C302. Taking the aisle between the belt and the wall, s/he proceeds to section F, picking products from F301 to F337, and then reversing direction, follows section E, from slot E337 to slot E305. Continuing along section D of the belt, s/he picks products from D303 down to D350 and

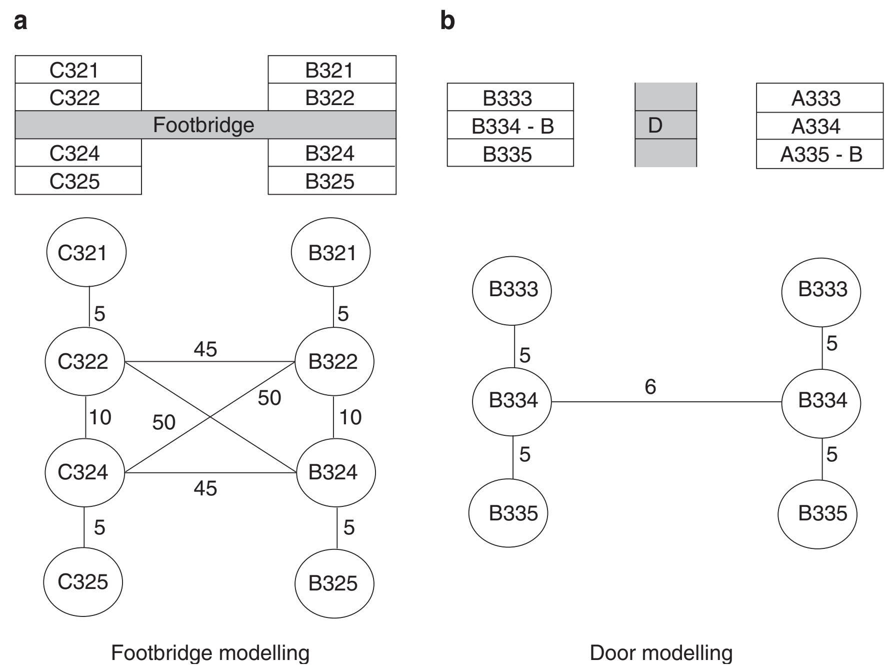

Figure 2 Network modelling of the belt.

then heads to the heavy products section (slots D352 to D358) before turning to follow the belt in section A, picking products up to slot A303. To facilitate the picker's task, computer sorts the items in the picking list to match the picker's route.

Clearly, it is not efficient to follow the entire path when only a few storage locations need to be visited. In such cases, the picker simply follows the predetermined route, skipping the sections of the belt that are not relevant to the order at hand. The picker may also use the doors and the footbridges in order to reduce the distance walked. Figure 1 presents an example in which a five-product order is picked. The products are located in slots A333, B314, C3016, D306 and D345 (identified in the figure by an X). These storage locations are sorted automatically and appear on the picking list in the following sequence: B314, C316, D306, D345 and A333. The picker's route is represented by the black arrows; in order to minimize the distance walked, the picker uses doors and footbridges to skip the inappropriate sections.

Conveyor modelling

We modelled the belt as an undirected connected graph, in which each storage location corresponds to a node and in which an edge (undirected arc) exists between each pair of adjacent nodes. Distances were carefully measured in the warehouse and validated by the company's logistics manager. Figure 2(a) shows the 5-foot edge between slots C321 and C322 (represented by nodes C321 and C322). However, storage locations can also be connected by doors and footbridges. For example, the slots on either side of the door shown in Figure 2(b) are connected by a 6-foot edge; Figure 2(a) shows that slot C322 is not only connected to slot C324, but is also connected to slots B322 and B324 via a footbridge. In addition to these, several other distances also needed to be specified explicitly in order to adequately model the picker routes:

- the distance from the route starting point to the first storage locations on each aisle (from the starting point to A303, B302, C302, D303, E305 and F301 equals 12, 13, 64, 80, 130 and 120 feet, respectively);
- the distance between the storage locations at the beginning and the end of the aisles (between B302 and C302, C302 and F301, F337 and E337, B349 and C349, D303 and E305 equals 45, 56, 6, 45 and 60 feet respectively); and
- the distance from the regular slots to the heavy product slots (from D350 to D351 and from D359 to A350 are 20 and 14 feet, respectively).

This network representation is simple and very flexible. Any physical modification of the belt can be modelled by adjusting the set of connected nodes. The shortest distances between all the storage location pairs are obtained by solving a shortest path problem for each pair of nodes using a standard algorithm. In the section that follows, we assume that the pickers always use the shortest available path when moving from one location to another. This is a realistic hypothesis as the number of feasible paths is quite small, and experienced pickers would see the advantage of reducing the distance they must walk and act accordingly.

Product location strategy

At present, products are assigned to locations based solely on the experience and knowledge of the logistics manager. There is neither a specific location strategy nor a computer system to help the manager accomplish this important task. The product location assignments are revised every 3 or 4 months, at which time, the logistics manager refers to each product's sales forecast to determine the product's new location assignment. The rule-of-thumb generally used by the logistics manager is that products with the highest sales forecast are placed as near as possible to the starting point, filling sections A and B first followed by C, D and E. Vending products are systematically placed in section F, and the heavy products are restricted to slots D352 to D358, which are equipped with special lift tables to prevent work-related injuries, such as back injuries.

Up to this point, it has been assumed that each storage location can hold only one product. However, some strategically located slots are equipped to receive two or three different products. The first and last slot in each aisle (A350, B302, B349, C302, C349, D303, D350) can hold two products, and since pickers cross the footbridges frequently, all slots adjacent to the footbridges (B322, B324, C322, C324, D322, D324 and E324) are equipped to hold three products, except for E322 which is reserved for storing empty wooden boards. The next section proposes some new strategies to improve product location.

New product location strategies

The product location strategies proposed in this section are based on the same sales forecast used by the logistics manager, but incorporate new sorting rules to streamline the process. In order to assign products to locations, we first created a list of all the products. This list was sorted in decreasing order according to the product's relevance with respect to a given criterion or rule. The list of storage locations, or slots, was also sorted according to a specific criterion. To determine the location allocation, the first non-assigned product in the list was selected and assigned to the first available position in the location list. This procedure was repeated until all the products had been assigned. Needless to say, the result of this assignment depends on the rules chosen for sorting the products and locations. These sorting rules—two for products and three for locations—are presented below. They can be combined to produce six different product allocation procedures. Owing to their specific nature, vending products do not follow the procedures described below: they are immediately assigned to the first available location in section F.

Product sorting rules

The product sorting rule determines the order in which products appear on the sorted list. The first rule, *Quantity*, simply sorts the products in decreasing order according to their forecast demand. To this, we added a second rule, *Frequency*, that sorts the products in decreasing order of their ordering frequency (the number of times that a product is ordered by customers, independent of the requested quantity).

Location sorting rules

The first rule, *Shortest distance*, simply sorts the locations according to their distance from the starting point. The second rule, *ABCDEF*, first sorts the locations by section, following the order *A-B-C-D-E-F*; then it sorts the locations within a section according to their distance from the starting point, with those closest to the starting point coming first. The third rule, *BCFEDA*, is similar to the second, but its sorting order is different. It first sorts the locations in the order that they would be visited by a picker walking a complete tour around the conveyor; within a section, locations are sorted according to their distance from the starting point, as in both rule 1 and rule 2.

Improving the product location assignment

The objective of the above procedure is to assign products to storage locations so as to minimize the distance walked by the pickers. The optimization procedure that we propose aims to further reduce that distance by using a local search procedure based on a two-product exchange neighbourhood. Given an initial solution and a number of picking lists, the heuristic evaluates, for each possible pair of products, the decrease in the distance walked if their storage locations were exchanged. After all the possible exchanges have been evaluated, the one that offers the most improvement is selected and implemented. This procedure continues until no improvement can be obtained.

Computational results

This section first presents the data obtained from the company. Then, the computational results of our experiments are reported in order to evaluate the performance of our product location strategies in terms of the current location strategies that are based exclusively on the manager's judgement. Finally, the gain in productivity that can be achieved by routing pickers optimally instead of using the present predetermined route strategy is evaluated.

The data

All our simulations and tests were executed on real data provided by our industrial partner. Specifically, we were given access to all the orders (including customer names, products and requested quantities) received between 21 March and 15 May of 2004. The product storage location used by the company during this period was also provided.

During this period, 372 customers ordered 256 different products. Given that the company bases its product location assignments on sales forecasts, and given that the demand during this period of the year is stationary, we decided to split

Table 1 Number of lines in the orders

Orders	*Forecast data*				*Evaluation data*			
	1	2	3	4	5	6	7	8
1	6	39	30	69	75	72	104	58
2	72	56	47	18	11	67	34	17
3	16	67	55	59	59	55	33	56
4	34	82	25	64	14	29	76	25
5	71	48	22	86	75	75	44	66
6	43	55	12	48	28	5	91	16
7	28	69	82	52	65	9	72	73
8	3	93	25	68	80	64	43	48
9	54	4	23	51	47	73	74	72
10	39	74	31	41	87	67	58	55
11	56	51	69	46	51	69	79	64
12	90	9	74	69	53	35	29	66
13	6	17	7	1	89	41	55	52
14	30	73	86	65	49	40	10	77
15	16	44	91	27	60	45	43	52
16	85	11	54	48	73	79	46	46
17	44	10	57	58	53	55	32	31
18	52	13	72	54	39	60	46	41
19	64	46	38	77	46	86	67	79
20	54	60	94	58	54	81	48	58
Average	43.15	46.05	49.70	52.95	55.40	55.35	54.20	52.60

our data set into two subsets. The first subset, containing the first 4 weeks of data, was used in the place of the manager's sales forecasts to assign the products to specific storage locations. The second subset, containing data from weeks 5–8, was used to evaluate the quality of the assignments produced by our methods.

We sampled the company's data to randomly generate 20 orders from each week, producing eight sets of 20 orders. Table 1, which shows the number of lines in each order, provides an idea of the order size. As the number of items to be picked remained constant for any proposed product storage location, the total gathering time also remained constant, independent of product location. Thus, picking operations did not need to be specifically taken into account.

Simulation results

This section takes a look at the performance of the 12 proposed product location strategies in terms of picking distance. These 12 strategies were obtained by combining the two product sorting rules (*Quantity* and *Frequency*) and the three location sorting rules (*Shortest*, *ABCDEF* and *BCFEDA*), with or without product category (*Vending* and *Regular*). To make this text more readable, these strategies are denoted: [*Product sorting rule*; *Location sorting rule*; *Vending/Regular*].

The results of the simulations of the total picking distance for the 20 orders in the evaluation data sets (5, 6, 7 and 8) are presented in Tables 1 and 2 according to the product sorting rules. Table 2 presents the distances when the products are sorted according to the *Quantity* criterion, and Table 3 presents the same results for the *Frequency* product sorting rule. Specifically, the first three columns report the results for the Shortest distance (*Shortest*), *ABCDEF* and *BCFEDA* location sorting rules, respectively, when no product category is taken into consideration. Columns 4–6 report the results for the same rules when vending and regular products are handled separately. The last column reports the total distance calculated with the product storage location currently used by the company. The line *Global* reports the total distance for the four data sets (80 orders). The line % presents the percentage of improvement compared to the company's present results; a negative value means an increase in the distance walked while a positive value means a decrease in the distance walked, thus reflecting an improvement.

First of all, both Tables 2 and 3 indicate that when vending products are not handled separately, the distances generated are from 1.03 to 27.79%, greater than the company's current distances. In light of this information, in the following discussion, we will concentrate on the rules that consider vending and regular products separately.

When vending and regular products are handled separately, all of our sorting rules improve the company's results from 6.75 to 11.25%. The best results are consistently obtained with the shortest distance sorting rule. The overall best result is obtained using the [Frequency; Shortest; Vending] strategy, which reduces the picking distance by 9779 feet, an improvement of 11.25%. In other words, if this product location strategy were used, the picker would walk 9779 feet less than with the company's present product location.

Table 2 Total picking distances obtained with the quantity product sorting rule

Data set	*Without any product category*			*With vending/regular products handled separately*			*Current location*
	Shortest	*ABCDEF*	*BCFEDA*	*Shortest*	*ABCDEF*	*BCFEDA*	
5	25 118	24 108	28 256	19 545	20 453	20 437	21 446
6	25 473	22 315	27 815	20 057	20 913	21 161	21 617
7	25 082	23 122	27 881	18 571	19 401	19 423	21 713
8	25 504	23 325	27 140	19 706	20 119	20 044	22 159
Global	101 177	92 870	111 092	77 879	80 886	81 065	86 935
%	−16.38	−6.83	−27.79	10.42	6.96	6.75	

Table 3 Total picking distances obtained with the frequency product sorting rule

Data set	*Without any product category*			*With vending/regular products handled separately*			*Current location*
	Shortest	*ABCDEF*	*BCFEDA*	*Shortest*	*ABCDEF*	*BCFEDA*	
5	23 743	21 880	25 439	19 575	19 929	19 833	21 446
6	23 951	21 642	26 163	20 307	20 558	20 968	21 617
7	22 739	22 341	24 722	18 094	19 744	19 183	21 713
8	23 583	21 970	25 514	19 180	20 389	19 749	22 159
Global	94 016	87 833	101 838	77 156	80 620	79 733	86 935
%	−8.15	−1.03	−17.14	11.25	7.26	8.28	

Table 4 Improvement obtained by the optimization procedure

Data set	[*Quantity*; *; *Vending*]			[*Frequency*; *; *Vending*]			*Company's improved location*
	Shortest	*ABCDEF*	*BCFEDA*	*Shortest*	*ABCDEF*	*BCFEDA*	
5	17 975	17 609	18 383	18 306	17 859	18 433	17 941
6	18 485	18 228	19 354	18 546	18 503	19 205	18 786
7	16 672	16 791	16 878	17 299	16 339	17 162	17 578
8	18 208	17 734	17 759	17 855	17 448	17 824	18 207
Global	71 340	70 362	72 374	72 006	70 149	72 624	72 512
%	8.40	13.01	10.72	6.67	12.99	8.92	16.59
%	17.94	19.06	16.75	17.17	19.31	16.46	16.59

We decided to evaluate the ability of the proposed optimization procedure to improve the quality of the results shown in Tables 2 and 3. To insure a fair assessment of its performance, we proceeded as follows. Based on the storage locations obtained with each of the previous strategies, we ran the optimization procedure in order to reduce the total distance walked for the orders in the 'forecast' data subset. Then, we evaluated the quality of the optimized storage locations against the results for the orders in the 'evaluation' data subset.

Table 4 presents the results of the optimization procedure for each product location strategy and the company's present storage location. In this table, the line % shows the percentage of reduction of the picking distance produced by the optimization procedure. The line %%, which gives the percentage of reduction of the picking distance compared to the current company's location (86 935 feet), shows that the picking distance has been reduced from 86 935 feet to 72 512 feet. The line % shows that, for all cases, the optimization procedure was able to reduce the picking distances, obtaining reductions that range from 6.67% up to 13.01%. In addition, the optimization procedure appears to be quite robust as it reduces the gap between the distances associated with different strategies. As shown in line %%, the most improvement with respect to the company's present storage location—19.31%—was achieved using the [*Frequency*; *ABCDEF*; *Vending*] strategy, which produced a total picking distance of 70 149 feet, for a total reduction of 16 786 feet. These results clearly show that significant productivity gains can be obtained by using a better product location strategy.

Improving the routing of order pickers

We have already described the order picking procedure used in the company. This procedure follows a predetermined route through all the sections. When no product in a given section is

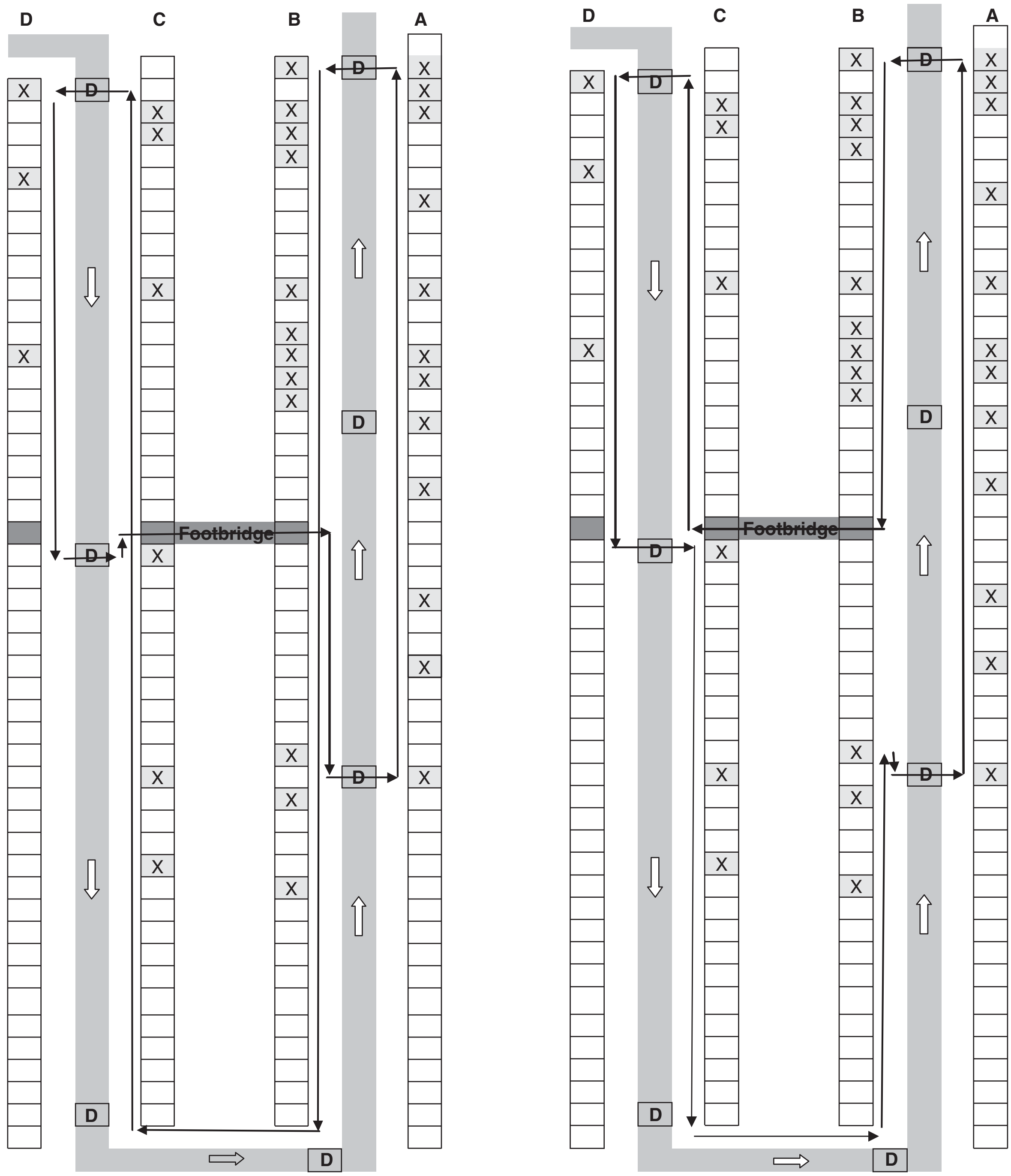

Figure 3 Using the TSP to improve the order-picking sequence.

on the picking list, the picker simply skips this section of the belt and proceeds to the next section. As stated in the Introduction, this routing problem is a classic symmetrical TSP for which many efficient algorithms already exist (see Helsgaun, 2000, for example). In a fairly recent study, Makris and Giakoumakis (2003) used a *k*-interchange procedure to reduce the route distance. In this study, we chose the more powerful classic 3-opt TSP algorithm (Lin, 1965), which produces good results and is easy to implement.

Figure 3 displays the second order of data set 7, which contains 34 lines (see Table 1). For this order, two products share the same location, meaning that only 33 slots must be visited. The company's picking sequence (left side of Figure 3) results in a 908-foot picking distance. The pickers

Table 5 Percentage of improvement obtained by scheduling order-picking operations by solving a travelling salesman problem

Data set	*[Quantity; * ; Vending]*			*[Frequency; * ; Vending]*			*Company's improved location*
	Shortest	*ABCDEF*	*BCFEDA*	*Shortest*	*ABCDEF*	*BCFEDA*	
5	17 025	16 368	15 446	16 829	16 585	16 281	16 830
6	17 926	16 758	16 897	17 902	17 401	16 794	17 231
7	16 068	15 819	14 913	16 136	15 479	15 901	15 881
8	17 046	17 734	15 392	16 837	15 942	15 921	17 111
Global	68 065	66 679	62 668	67 704	65 407	64 897	67 053
%	4.59	5.23	13.41	5.97	6.76	10.64	7.53
%%	21.71	23.30	27.91	22.12	24.76	25.35	22.86

cannot make choices to improve this route since they are restricted to the printed picking list, which forces them to walk through section B. The solution displayed on the right side of Figure 3 was obtained by solving a TSP over 34 nodes (33 slots plus the starting point). This solution has a total length of 798 feet, a direct savings of 110 feet or 12.1%. This means that if the company's information system were able to solve such a TSP prior to printing the picking list, important savings could be obtained.

In order to estimate the percentage of improvement that can be achieved by using the TSP to sequence order picking, we applied the TSP to each order in the data sets 5–8, starting with the product location strategy shown in Table 4, which handles vending products separately. The results are reported in Table 5, where the % line reports the percentage of improvement in terms of the total distance obtained by solving the TSP. This table shows that distances can be reduced from 4.59 to 13.41%, depending on the initial product location methods.

This improvement can be easily implemented within the warehouse management system of the company by sorting products on the picking list based on the TSP solution. Remember that the current system already sorts the picking lists, but in the order they appear in sections B, C, F, E, D, and A. For such small problems, solving the associated TSP would require only a fraction of a second.

Line %% shows the percentage that the picking distance has been reduced by applying our optimization procedure, compared to the company's present storage location (86 935 feet), assuming that pickers follow the sequence obtained by the TSP solution. The highest percentage of improvement compared to the company's current location is 27.91%. These results clearly show that, regardless of which product location strategy is used, the solutions are consistently improved by more than 20%. These reductions represent important potential gains in productivity, which could lead to reduced costs and/or a higher throughput using the same pickers.

We also applied the TSP to the initial company product location (last column of Table 2), but a better routing is only able to reduce the picking distance to 2.29% (1991 feet). This improvement is lower that those reported in Table 5 and can be explained by the fact that the company location strategy distributes the products around the belt in such a way that all the sections must be visited, therefore minimizing the possibility of a TSP improvement.

Conclusion

This article proposes and analyses different product location and routing procedures to optimize order-picking activities in a belt-based warehousing system. Using real data provided by our partner company, we simulated the company's operations and evaluated the productivity gains that could be achieved by using a better product location strategy. Our results suggest that improvements of up to 11.25% can be achieved if product location is done using a shortest distance rule. An optimization procedure designed to improve product location made further reductions of up to 16 786 feet possible, which corresponds to a 19% reduction in the total picking distance. We also analysed the company's present routing strategy, which is based on predetermined routes. We were able to show that important reductions in the picking distance, ranging from 5 to 13%, can be obtained by using a simple travelling salesman problem algorithm. Overall, these new procedures are able to reduce the total picking distance from 21.71 to 27.91%, which will significantly increase warehouse productivity by reducing order-picking time, thus allowing more orders to be picked by the same number of workers.

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