Comparisons of order picking routing methods for warehouses with multiple cross aisles

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This paper addresses the problem of routing methods in warehouses with multiple cross aisles. Two new heuristics called block-aisle1 and block-aisle2 were developed. Comparisons of well known heuristics for the problem of routing methods for warehouses with multiple cross aisles were performed. To analyze the performance of the heuristics, a computer program is designed and constructed. Performance comparisons between heuristics are given for various warehouse layouts and order sizes. For the majority of the instances, newly developed heuristics appears to perform better than the existing heuristics.

هذه الدراسة تستعرض مشكلة تحديد طرق المسارات لألتقاط الطلبيات داخل المستودعات و المخازن متعددة الممرات العرضية. تم دراسة أربعة طرق استكشافية (heuristic rules) وكذلك تم استحداث طريقتين جديدتين لتحديد أقل مسافة لازمة لألتقاط وتجميع الطلبيات. تم تجربة عدد (٨٠) مسألة مختلفة من حيث شكل المستودعات وحجم و توزيع عناصر الطلبية داخل المستودع. تم استحداث برنامج حاسب ألي لحساب المسارات للطرق الاستكشافية الستة موضوع الدراسة و أجراء المقارنة اللازمة بينها لتحديد الطريقة ذات أقل مسافة ممكنة لألتقاط وتجميع الطلبية. من خلال مقارنة النتائج للمسائل المفروضة يتضح أن الطريقتين الجديدتين تعطيان نتائج أفضل من الطرق الاخري في أغلب المسائل التي تم تجربتها (٦٦ من ٨٠) أي ما يعادل 82% من مجموع المسائل قيد الدراسة. كما تم ملاحظة أن طريقة (Aisle by aisle) أعطت هي الاخري نتائج جيدة (٢٠ من ٨٠).

Keywords: Warehouse, Order picking, Routing methods

1. Introduction and background

Order picking and material handling, in general, have received considerable attention since the 1970's. Order Picking is the process of retrieving items from storage in response to a specific customer request. It is employed in warehouses of every kind, from small, manually served spare-part warehouses of small firms to large, high-bay warehouses which serve as supply depots for a country. Order picking is becoming a more significant operation. As mentioned by De Koster and Van der Poort [1], in warehouses and distribution centers, products have to be picked from specified storage locations on the basis of customer orders. In general, the order picking process is the most laborious of all warehouse processes. It may consume as much as 60% of all labor in the warehouse.

In this article, new routing methods are proposed and a computer program is established to determine appropriate order picking methods which have the minimum travel distance. A proposed algorithm is presented in the aim of reduction of the total consumed time in order picking process for warehouses with multiple cross-aisles.

Bozer and White [2], presented an analytical design algorithm to determine the near minimum number of pickers required in an end-of-aisle order picking operation based on a miniload automated storage/ retrieval system. Ratliff and Rosenthal [3], developed an efficient algorithm to find shortest order picking routes in rectangular warehouse that contains crossovers only at the ends of aisles. Roodbergen and De Koster [4], introduced several methods for routing order pickers in a warehouse with multiple cross aisles. Roodbergen and De Koster [5], presented an algorithm that can find shortest order picking tours in a parallel aisle warehouse, where order pickers can change aisles at the ends of every aisle and also at a cross aisle halfway along the aisles. Tang and Chew [6], considered batching and storage allocation strategies in a manual order picking system of small parts, which processes high volume of orders. The order picking system is modeled by a two-stage queuing system with batching and picking activities.

Yoon and Sharp [7], presented a numerical case study to illustrate a cognitive design procedure for an order pick system (OPS), which has been established through a series of interviews with and presentations to (OPS) experts and literature review. The design procedure and related issues are discussed in the order of input, selection, and evaluation stages along with iterative aspects of top-down decomposition and bottom-up modification. Daniels et al. [8], formulated a model for simultaneously determining the assignment and sequencing decisions, and compare it to previous models for order picking. The complexity of the order-picking problem is discussed, and an upper bound on the number of feasible assignments is established. Lin and Lu [9], proposed a computer based procedure that can determine appropriate order picking strategies in a distribution center. The mechanism of this procedure is two-phase. An analytic method is first employed to classify all orders into five categories. Computer simulation then follows to generate the appropriate picking strategies that correspond to each type of the orders classified. Simpson and Erenguc [10], modeled the order picking function to explore its role with respect to inventory deployment and centralized distribution planning, in the presence of production economies of scale and deterministic demand.

Jarvis and McDowell [11], provided a basis for locating an order picking warehouse such that average order picking time will be minimized. A stochastic model is developed to ensure that optimal, rather than just "good", results are obtained. Chew and Tang [12], presented a travel time model with general item location assignment in a rectangular warehouse system. They give the exact probability mass functions that characterize the tour of an order picker and derive the first and second moments associated with the tour. They apply the model to analyzing order batching and storage allocation strategies in an order picking system. The order picking system is modeled as a queuing model with customer batching. The effects of batching and size on the delay time are discussed with consideration to the picking and sorting times for each batch of orders. Kim et al. [13], considered an actual industrial warehouse order picking problem where goods are stored at multiple locations and the pick location of goods can be selected dynamically in near real time. They solved the problem using an intelligent agent-based model. Van den Berg and Gademann [14], addressed the sequencing of requests in an automated storage/retrieval system with dedicated storage. They considered the block sequencing approach, where a set of storage and retrieval requests is given beforehand and no new requests come in during operation. The objective for this static problem is to find a route of minimal total travel time in which all storage and retrieval requests may be performed.

As it has been exhibited from the comprehensive literature survey by Shouman et al. [15], most researchers focused on minimizing either the number of order pickers (picking strategies, batching and storage allocation and inventory deployment) or total traveling vehicle, and times route distances. Most of the considered talked problems are of static nature of a single aisle or a very limited number of parallel or multiple aisles and of limited cross-over only at the end of aisle(s). Modern warehouse structures have a little bit considerations where the trucks can pick up and deposit pallets at the head of each aisle without return to depot. The influence of moments associated with the tours of order pickers has also a little consideration of research interest. Also the system design profiles such as number of storage aisles, storage rack height and depth, vertical fleet size, number of lifts used and vertical movements of little considerations. Mathematical programming techniques are the most common methodology solvers used for solving the problem under consideration.

Also, a computer-based designed procedure based on performance measuring criteria, such as picking efficiency and accuracy, routes duration times, and system throughputs are of interest concern as solution methodologies. Heuristics and intelligent agent-based methodology solvers are of little concern.

2. Warehouse layouts

Warehouse consists of a number of blocks, each consisting of a number of parallel aisles. The items are stored at both sides of the aisles. With *main aisle* we refer to an aisle between the front and rear end of the warehouse, going through all blocks. The *front aisle* and the *rear aisle* are located entirely at respectively the front and the rear of the warehouse. These two aisles do not contain items, but can be used for changing aisles. Between each pair of blocks, there is a *cross aisle* which can be used to go from one aisle to the next or from one block to the next. Order pickers are assumed to be able to traverse the aisles in both directions and to change direction within the aisles. The aisles are narrow enough to allow picking from both sides of the aisle without changing position. Each order consists of a number of items that are usually spread out over a number of aisles. We assume that the items of an order can be picked in a single route. Aisle changes are possible at the front end, the rear end and in any of the cross aisles. Picked orders have to be deposited at the depot, where the picker also receives the instructions for the next route. The depot is located in the front aisle at the head of the first main aisle. Fig. 1 gives an example of a warehouse layout.

2.1. Objectives of a warehouse layout

Before layout planning can begin, the specific objectives of warehouse layout must be determined. In general, the objectives of a warehouse layout are [16]:

1. To use space efficiently.
2. To allow the most efficient material handling.
3. To provide the most economical storage in relation to costs of equipment, use of space, damage to material, and handling labor.
4. To provide maximum flexibility in order to meet changing storage and handling requirements.
5. To make the warehouse a model of good housekeeping.

3. Order picking strategies

3.1. S-shape heuristic

The simplest way to route order pickers is by using S-shape strategy. Any aisle containing at least one item is traversed through the entire length. Aisles with no picks are skipped. After picking the last item, the order picker returns to the front aisle. This method is likely to be the most frequently used routing strategy. It is especially useful if order picking equipment is used that can not easily change directions within an aisle. Also it is one of the better strategies if equipment is used that requires much time for changing aisles. For an example route see fig. 2.

3.2. Largest gap heuristic

The picker enters the first aisle and traverses this aisle to the back of the warehouse. Each subsequent aisle is entered as far as the 'largest gap' and left from the same side that it was entered. A gap represents the distance between any two

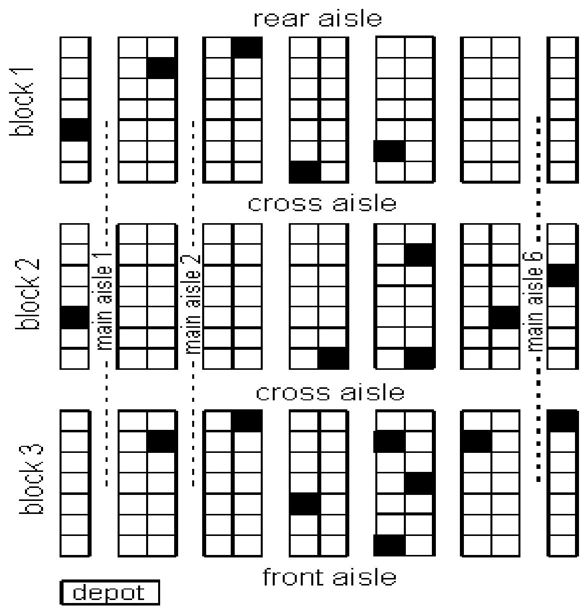

Fig. 1. An example of warehouse layout.

adjacent items, or between a cross aisle and the nearest item. The last aisle is traversed entirely and the picker returns to the depot along the front entering again each aisle up to the largest gap. Thus, the largest gap is the part of the aisle that is not traversed. An example route is given in fig. 3.

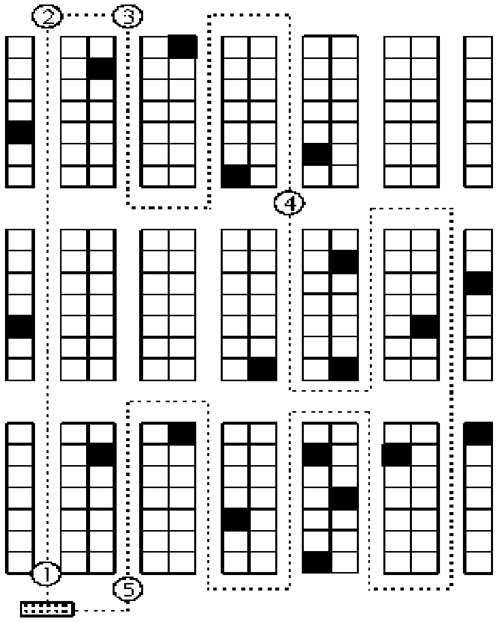

Fig. 2. A route result from S-shape heuristic.

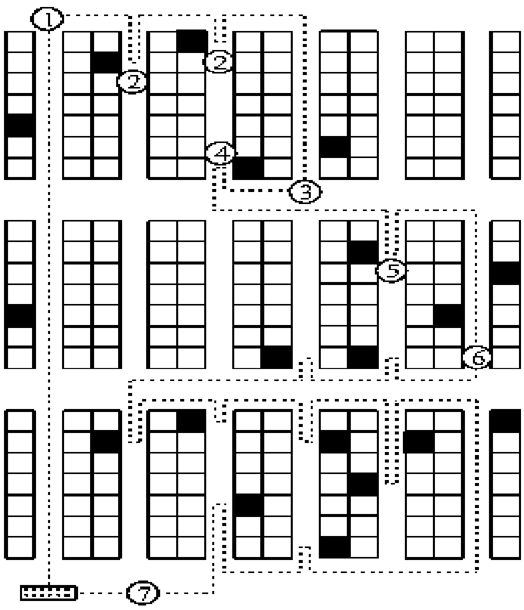

Fig. 3. A route result from largest gap heuristic.

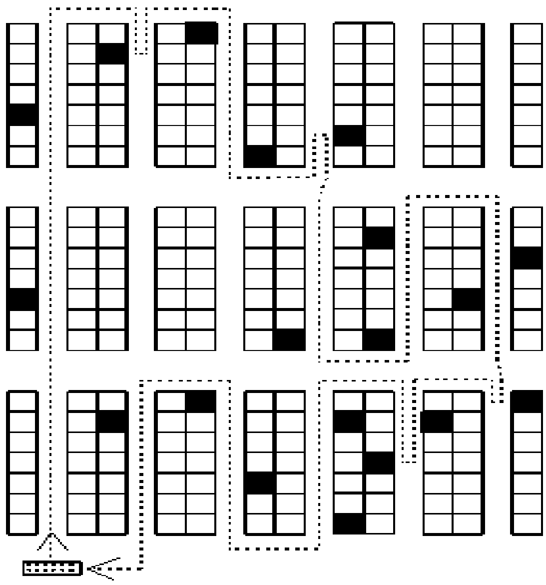

Fig. 4. A route result from combined heuristic.

3.3. Combined heuristic

This heuristic creates order picking routes that visit every aisle that contains items, exactly once. The aisles of each block are visited sequentially, either from left to right or from right to left as shown in fig. 4.

3.4. Aisle-by-aisle heuristic

This heuristic is described by Vaughan and Petersen [17]. Basically, every main aisle is visited once. The order picker starts at the depot and goes to the left most aisle containing items. All items in this main aisle are picked and a cross aisle is chosen to proceed to the next main aisle. Again all items in this main aisle are picked and the order pickers proceed to the next main aisle.

The aisle-by-aisle heuristic determines which cross aisles to use to go from one aisle to the next in such a way that the distances traveled are minimized as shown in fig. 5.

3.5. Block-aisle1 heuristic

Divide each block in to two parts, upper part contains the storage locations that have a distance from the cross aisle less than or equal to half of the block-aisle length and the lower part contains the storage locations that have a distance from the cross aisle more than half of the block-aisle length.

1. Start from depot and go to the most left aisle contains at least one item to be picked.
2. Go to the most upper block contains at least one item to be picked.
3. Enter the first aisle in upper block that contains at least one item to be picked from down to up until the upper cross aisle has been reached then go from left to right picking all the items in the upper part of the block, returning to the upper cross aisle each time until the last aisle contains at least one item to be picked is reached, then go down to the next cross aisle.
4. Start from the most right aisle contains at least one item to be picked in the upper part of the second block or lower part of the first block and then go from right to left in the second cross aisle and picking all the items in the upper part of the second block and lower part of the first block aisle by aisle at the same time and return to the cross aisle. When the last aisle is reached then go down to the next cross aisle.
5. When all the blocks are visited then go to depot. An example route is given in fig. 6.

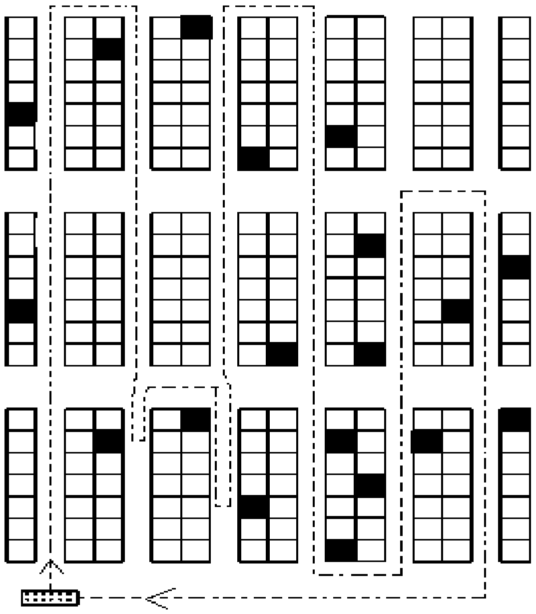

Fig. 5. A route result from Aisle-by heuristic.

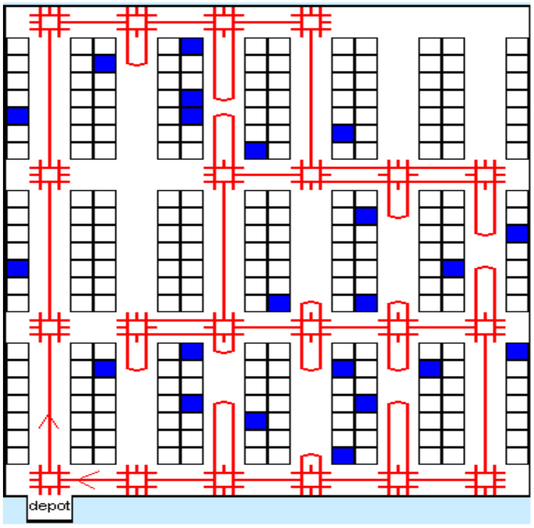

Fig. 6. A route result from block-aisle1 heuristic.

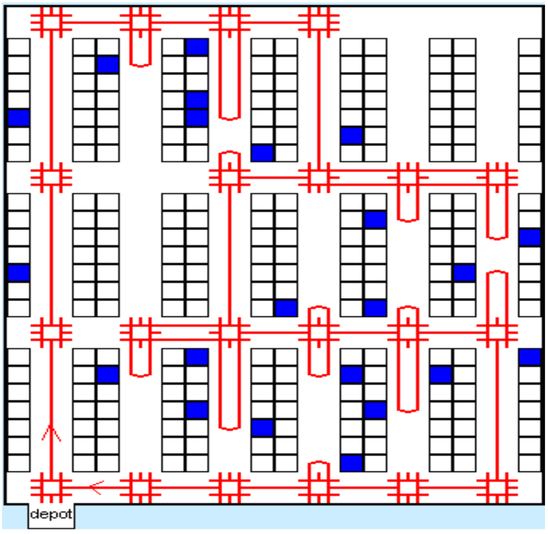

Fig. 7. A route result from block-aisle2 heuristic.

3.6. Block-aisle2 heuristic

Divide each block in to two parts, upper part contains the storage locations that have a distance from the cross aisle less than or equal to half of the block-aisle length (plus next adjacent storage location that contains at least one item to be picked) and the lower part contains the remaining storage locations in that aisle. Flow the same steps in block/aisle method. A route resulting from this heuristic is depicted in the figure below.

To analyze the performance efficiency of the order picking routing methods, an algorithm is designed and constructed. This algorithm is coded in a technical software program written in visual basic language. The end user can enter the problem features and configurations through the software program interface. The proposed order picking routing methods are applied on the problems under consideration. 80 different test problems are considered for the evaluation processes. The measuring performance criterion for evaluation process is the minimum traveled distance. However, fig. 8 shows the proposed algorithm flowchart.

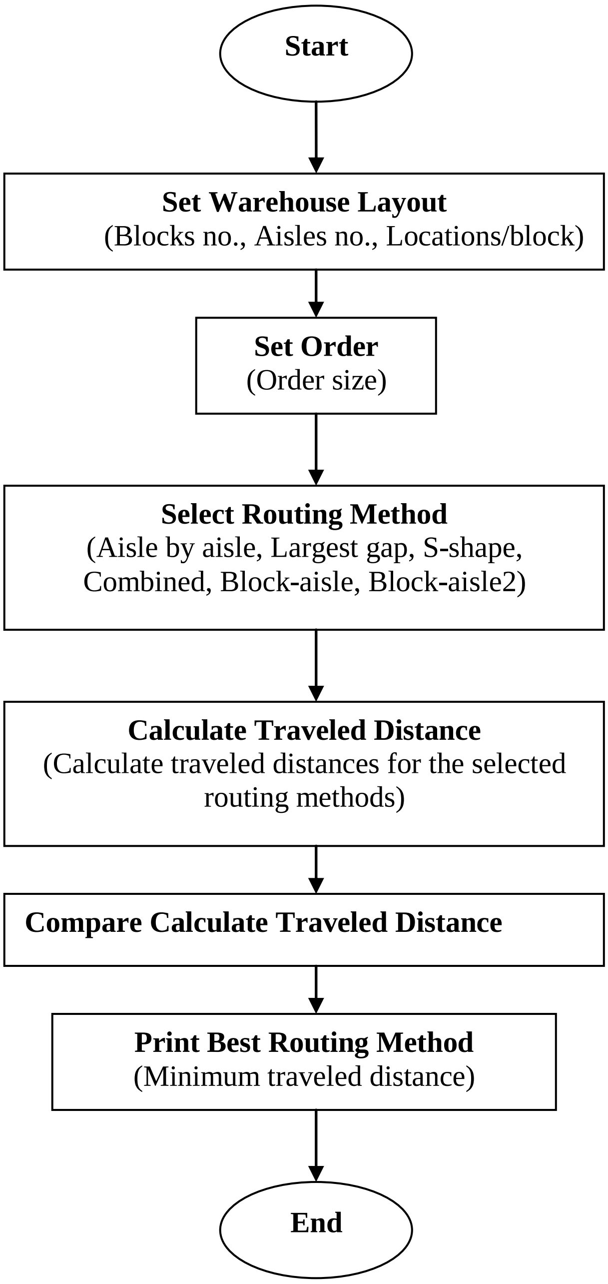

Fig. 8. Proposed algorithm flowchart.

4. Implementation and results

Using the established computer program, eighty different order sizes were picked from different warehouses layouts. According to Roodbergen and De Koster [4], and De Koster and Van der Poort [1], Warehouses dimensions tested by the authors ranged from 3 aisles to 15 and number of visited locations ranged from 10 to 30. We use the extremes of these values for our simulation experimentation. Warehouses layout and orders size presented in appendix (A), number of blocks ranged from 2 to 10 blocks, number of aisles ranged from 3 to 16 aisles, number of visited locations ranged from 14 to 140 and number of storage locations per block ranged from 3 to 30 locations. Orders sizes and locations were randomly selected. Traveled distances using six order picking routing methods for picked orders are presented in appendix (B). Fig. 9 shows the comparisons of total traveled distance for order picking strategies of the tested warehouses layout and order sizes. Appendix (B) exhibits that combined heuristic routing method achieved the best for 10 test problems for the problems under considerations. Aisle by aisle achieved the best for 20 test problems for the problems under considerations. Both the largest gap and S-shape did not achieve the best for any problem for the problems under considerations while Block-aisle1 achieved the best for 22 test problems and Block-aisle2 achieved the best for 44 test problems for the problems under considerations. The simulation test problems exhibited that the best performance is achieved through the proposed order picking routing methods. Fig. 9 exhibits the simulation test experiments for all the considered routing methods. From the results we can conclude that, the block-aisle2 strategy appears to perform better compared with the existing heuristics.

For the majority of the situations (44 of 80) evaluated in this paper, the block aisle2 heuristic had the best performance of the heuristics. The block aisle1 heuristic perform best for (22 of 80). Aisle-by-aisle heuristic was found to be useful for (20 of 80) and combined heuristic appears best for (10 of 80) of the tested warehouses layout and order sizes.

5. Conclusions

The aim objective of the present study is an attempt to introduce order picking routing methods in a warehouse with multiple cross-aisles to find a sequence in which products have to be retrieved from storage locations such that the travel distances are as short as possible. Performances of heuristics in warehouses with two cross aisles have been studied extensively. Several methods for routing order picking in a warehouse with multiple cross aisles are introduced. Two methods named as Block-aisle1 and Block aisle2 heuristics are introduced in this paper. A computer program is designed and constructed to compare and analysis the performance of the routing strategies.

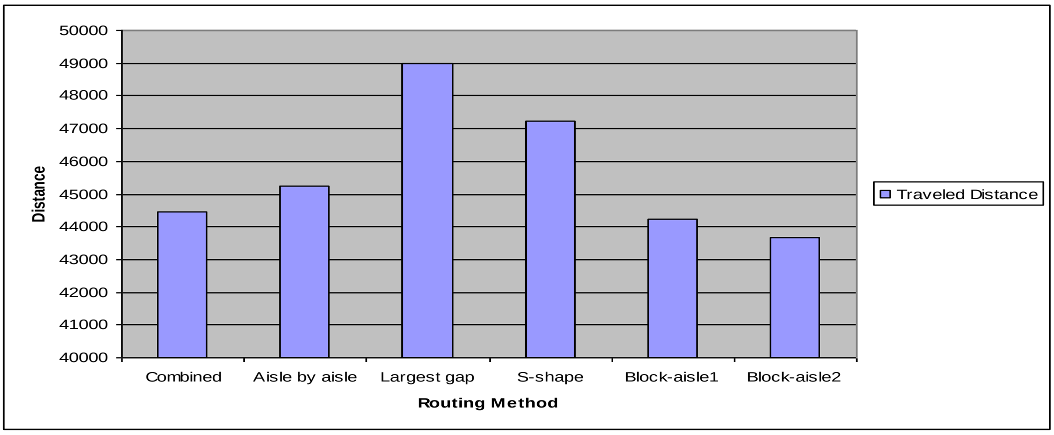

Fig. 9. Comparisons of total traveled distance.

Appendix A
Warehouses layout and orders size

Order no.	Blocks no.	Aisles no.	Locations/ block	Visited locations	Picked items
1	5	5	5	90	90
2	5	5	9	80	80
3	4	11	6	14	30
4	4	13	5	88	175
5	5	9	5	44	119
6	5	10	5	50	142
7	5	11	5	50	159
8	5	12	5	55	111
9	5	12	5	60	145
10	5	13	4	66	169
11	5	5	5	99	192
12	4	5	6	33	33
13	5	6	5	40	77
14	5	7	4	50	126
15	4	8	7	60	169
16	3	9	9	80	164
17	3	9	20	80	142
18	2	9	30	80	144
19	4	9	15	80	159
20	7	11	6	70	193
21	7	12	4	77	211
22	4	12	8	66	145
23	4	8	10	60	90
24	3	15	7	88	186
25	3	14	9	95	195
26	2	14	12	85	170
27	3	14	12	100	194
28	6	6	6	65	123
29	7	7	7	77	146
30	7	17	4	99	196
31	6	12	4	110	203
32	6	12	5	120	120
33	6	5	5	95	170
34	7	9	6	110	207
35	8	8	6	120	234
36	9	9	6	140	262
37	4	9	9	110	170
38	4	10	9	120	166
39	5	10	9	130	190
40	5	11	8	140	201
41	7	11	3	90	134

Appendix A. Cont.

Order no.	Blocks no.	Aisles no.	Locations/ block	Visited locations	Picked items
42	3	15	8	113	158
43	3	15	5	70	70
44	3	16	6	95	140
45	3	12	7	75	109
46	7	4	7	60	90
47	7	7	4	60	83
48	8	8	4	77	116
49	10	8	4	88	132
50	10	10	5	100	141
51	5	5	5	50	90
52	5	7	5	50	101
53	6	8	5	66	66
54	3	3	8	77	77
55	3	4	8	77	77
56	3	6	8	66	66
57	3	7	8	60	60
58	3	8	8	45	45
59	3	9	7	55	55
60	3	10	6	70	70
61	3	11	5	70	70
62	3	12	6	75	75
63	3	13	7	85	85
64	3	14	5	90	90
65	3	15	5	90	90
66	5	5	5	44	44
67	5	5	5	55	55
68	4	8	6	44	44
69	6	8	4	42	42
70	7	8	4	52	84
71	5	9	5	95	95
72	5	7	6	46	85
73	5	7	6	52	78
74	5	6	5	46	67
75	7	7	4	44	87
76	7	7	5	50	93
77	7	9	3	40	81
78	7	9	3	40	88
79	7	11	3	63	119
80	7	11	3	58	110

Appendix B
Traveled distance

	Traveled distance (m)					
Order no.	Combined	Aisle by aisle	Largest gap	S-shape	Block/aisle	Block/aisle2
1	167	165 *	189	177	182	182
2	226 *	272	294	277	255	255
3	159	219	201	169	153 *	153 *
4	309 *	322	349	333	314	314
5	227	258	252	255	225	222 *
6	241	258	262	271	220 *	220 *
7	274	286	285	296	238 *	238 *
8	288	314	329	328	273	269 *
9	306	293	316	328	279 *	279 *
10	275	271	315	299	255	252 *
11	171	161 *	206	171	191	191
12	135	147	135	143	128	125 *
13	161	166	173	173	155 *	155 *
14	176	174	206	186	172 *	172 *
15	242	252	244	248	236	231 *
16	296	303	316	306	293 *	293 *
17	593	629	568	637	568	566 *
18	570 *	613	604	612	671	671
19	495	620	495	517	506	487 *
20	393	495	432	407	347	344 *
21	343	337	410	387	308	305 *
22	349 *	391	389	423	369	361
23	336	332 *	344	356	345	345
24	368	339 *	396	382	355	341
25	424	412 *	452	448	441	430
26	357 *	385	406	379	421	426
27	572	539	566	576	558	558
28	237	231	252	245	226	223 *
29	360	399	350	370	354	349 *
30	489	517	594	539	439 *	440
31	361	331 *	441	371	375	369
32	428	389 *	512	450	454	451
33	196 *	197	233	208	207	207
34	429	434	464	445	431	412 *
35	411 *	411 *	475	431	445	423
36	519	560	585	577	490	478 *
37	379	373 *	441	391	438	421
38	424	396 *	469	428	467	454
39	500	483 *	550	538	504	498
40	510	503 *	582	508	550	534
41	318	283	360	328	279	278 *
42	417	399 *	452	443	424	413
43	283	280	306	297	257	255 *
44	360	337 *	402	388	347	345
45	308	282 *	344	322	333	323
46	220	198 *	243	232	222	217
47	222	238	247	238	210 *	211
48	273	281	320	311	272	266 *
49	346	331 *	414	362	342	338
50	484	518	541	516	452 *	453
51	149 *	169	163	159	150	149 *
52	202	211	227	230	196 *	196 *
53	247 *	257	298	265	289	282
54	103	101	102	103	100	98 *
55	116	108 *	127	111	108 *	110
56	180	184	189	191	182 *	184
57	201 *	213	223	221	209	201 *
58	233	228	227	235	230	226 *
59	206	221	218	216	200	195 *
60	235	216	241	247	220	215 *

Appendix B. Cont.

	Traveled distance (m)					
Order no.	Combined	Aisle by aisle	Largest gap	S-shape	Block/aisle	Block/aisle2
61	224	219	230	238	205 *	207
62	275	251 *	272	287	255	251 *
63	326	331	340	343	313 *	315
64	275	243 *	304	287	253	253
65	282	276	314	300	269	266 *
66	162	155	159	174	142 *	142 *
67	173	165	172	179	161	160 *
68	171	206	201	201	170 *	170 *
69	173	204	205	189	186	186
70	212	244	266	230	213	210 *
71	288	282	322	300	270	269 *
72	200	206	216	202	188 *	188 *
73	242	249	252	270	228	226 *
74	167	160	184	179	166	160 *
75	193	217	220	203	183	177 *
76	246	249	266	264	224 *	224 *
77	191	196	230	203	183 *	184
78	202	205	231	216	198 *	198 *
79	266	276	331	282	265	260 *
80	256	249	298	292	248 *	249
Total traveled distance	23323	23815	25739	24839	23183	22894

(* = minimum distance)

Unfortunately, no order picking routing method has been found to perform well for a wide variety of warehouse dimensions and different order sizes. The basic idea of the proposed system is to integrate the existing and the proposed methods in software to determine the traveling distance for each order using the existing and proposed methods. The best method which provides minimum traveling distance will be chosen.

From the comprehensive test and examination for the performance of the existing and proposed routing heuristics which are compared using the proposed software, we can conclude that, no order picking routing method achieves the best over all the test problems features and configura-tions but the proposed heuristics are relatively have the best performance specially Block-aisle2 that appears to be best in the majority of the tested cases with different warehouses dimensions and different order size.

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