Layout Design of Multiple Blocks Class-Based Storage Strategy Warehouses

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Abstract

Manual order-picking warehouses are highly influenced by its' layout design. In fact, layout parameters play the most important role in determining the route length which is responsible for the largest share in a warehouse operating costs. Conventional simulation techniques are not capable to capture the complexities in dynamic systems. Therefore, this paper develops an agent-based model to simultaneously investigate the effects of order size in parallel with different layout parameters such as number of cross aisles, aisle length and number of aisles on the order-picking distance. Statistical analysis is performed on the results to specify which decision factors are critical to be considered in layout design. Sensitivity analysis is conducted among different layout configurations to determine which conditions give the maximum savings in route length. The results show that with class-based storage policy, adding an extra cross aisle to the one-block layout warehouse would result in a decrease in route length. However, having too many cross aisles could turn the balance. It also was found that the order-picking density is a significant factor that could lead to changes in layout preferences. The novel aspect of this research is the utilization of agent-based simulation in designing manual order-picking warehouses.

Keywords
Manual order-picking Warehouse, agent-based simulation, Layout design, Class-based storage

1. Introduction
Warehouses are key components of modern supply chains where products are temporarily stored to fulfill customer orders. They are essential in facilitating the coordination between production and demand. Although many companies try to adopt various strategies, such as just-in-time strategy, in order to synchronize direct supply to customers, warehouses will continue to play a vital role in logistics management. Order picking is considered to be the most labor-intensive and hence most costly activity in manual order-picking warehouse's operations. The order picking consumes about 55% of the total warehouse operating expenses (Tompkins et al., 2003). In addition, the travel time between locations represents 50% of the total picking time (Tompkins et al., 2003). Hence, the reduction in travel distance will have a significant effect on increasing warehouses productivity, decreasing its throughput time, and operating cost.

Layout design concerns itself with the aisle configuration in the order picking system. The general objective of layout optimization is to find the best layout that would result in the lowest material handling cost which is a function of the travelled distance. The factors that should be determined at layout design level are: the number of blocks, the depot location; and the number, length and width of aisles.

Class-based storage is a storage assignment policy in which products are divided into classes. Each class is then allocated to a dedicated storage area in the warehouse. Products of each class are stored within their dedicated area randomly. Classes are determined by demand frequency of products measured by different rules such as the cube-per-order index (COI). The COI of an item is defined as the ratio of the item's total required storage space to the number of trips needed to satisfy its demand in a certain period (Malmborg, 1995).

Agent-based simulation is relatively a new technology within the simulation domain. It has only been studied since about 1980, and the field has only gained widespread recognition since the mid-1990s (Wooldridge, 2002). It emerged as an expansion for Cellular Automata and it was focused on the simulation of primitive insect colonies. Today, agent-based models (ABMs) have been used in a variety of applications including modeling of nations, economic and business. In recent years, there has been an increased interest in agent-based modeling since it is capable of solving complicated problems that conventional models cannot.

There is no universal agreement on the precise definition of ABM. But in their most basic form, agents can be defined as autonomous objects that perceive their environment and act on that environment to achieve certain objectives. Agents have the ability to sense their environment, communicate with other agents, build perceptions, make decisions, and take actions in an attempt to simultaneously satisfy their objectives. One important feature of ABM is its ability to represent the interaction between agents which gives the model flexibility in handling the dynamic nature of real-world systems. The major distinction between ABM and other conventional techniques is the concept of reproduction and inheritance which can be defined as the agent ability to generate a new agent (called a child) that inherits all the characteristics of the parent (Law and Kelton, 2000). Moreover, ABM gives the user the ability to schedule agents' behavior synchronously and asynchronously. In the former case, agents perform their duties in discrete time steps while, in the later situation, agents actions are dependent on other agents actions or with reference to a clock (Devillers et al., 2010).

Using agent-based simulation approach, this paper investigates the effects of number of storage blocks, aisle length, number of aisles and order size on the travelled distance by order pickers for warehouses using class-based storage policy. All the previous parameters are analyzed simultaneously with their interactions to determine their significance on the order picking distance. Sensitivity analysis is conducted among different layout configurations to determine which conditions give the maximum savings in route length.

Section two briefly reviews the related literature. Section three depicts the considered warehouse layout and the experimental design. Section four describes the simulation model. The results are presented and analyzed in section five. Finally, section six comprises conclusions and future work.

2. Literature Review

Bassan et al. (1980) proposed an analytical optimization approach for unit load warehouses, in which the stock keeping units (SKUs) arrive and leave on pallets, considering aisle configuration, doors location and zone configuration of storage area to minimize the construction and maintenance cost as well as the material handling cost. Rosenblatt and Roll (1984) used both analytical and simulation methods to study the effects of warehouse storage capacity and storage policy on the total cost which includes the construction, shortage and storage policy costs.

Hall (1993) studied the effect of warehouse's length to width ratio on the expected route length. He concluded that for a fixed warehouse area, increasing the length to width ratio would result in a decrease in the route length. Caron et al. (1998), (2000a) and (2000b) investigated the effect of the COI storage policy on the expected travel distance via simulation and analytical approaches. They also considered factors such as number of aisles, total aisles length, number of locations to be visited per tour and routing policy. Petersen (2002) proposed a simulation model to investigate the relationship between the order-picking travel distance and warehouse configuration represented by the number of aisles and length of each aisle. Petersen and Aase (2004) introduced a simulation model to examine the effect of picking, storage and routing policies on order picker travel time.

For manually operated warehouses using class-based storage strategy, Le-Duc and De Koster (2005) proposed a probabilistic model to estimate the average travel distance of picking tour in warehouses consisting of two blocks of parallel aisles. They proposed a mathematical formulation for finding the optimal storage boundaries or zones of classes using the average travel distance as the objective function. They also proposed a heuristic technique to solve the problem since the analytical model is limited to warehouses with small storage capacity.

Using random storage policy, Roodbergen and Vis (2006) proposed an analytical model that expresses the average travel distance as a function of internal layout parameters such as number of aisles, depot location and length of each aisle. However, their model is only applicable for warehouses consisting of one block of parallel aisles. Roodbergen et al. (2008) improved the model proposed by Roodbergen and Vis (2006) to handle warehouses consisting of multiple blocks of parallel aisles.

Recently, researchers tried to arrange the picking aisles in a non-traditional way in order to increase the order picking efficiency. Gue and Meller (2009) introduced the fishbone and flying-V designs for single-command unit-load warehouses using random storage policy. Ducik et al. (2010) studied the effect of different warehouse layouts, including the fishbone design, via simulation. He found that The fishbone layout will give less travel distance than the one-block layout while the traditional layout with one cross aisle results in much less travel time than a traditional layout without a cross aisle. Pohl et al., (2011) investigated the effects of the fishbone and flying-V layouts in unit-load warehouses using turnover-based storage policy with single and dual-command operations.

Rao and Adil (2013) proposed an analytical procedure for estimating travel distance in a two-block warehouse using return routing policy and multi-item picks. They also developed an iterative hierarchical framework to simultaneously obtain pick list size, number of aisles, and class storage boundaries.

As could be seen in the previous literature review, most researches concentrate on the basic layout design that only have two cross aisles (one at the front of the warehouse and one at the back) although having extra cross aisles in a warehouse could increase the number of routing options and hence may result in lower travel distances (Vaughan and Petersen, 1999). Moreover, Up to the researcher knowledge, agent-based simulation approach has not been utilized in warehouse design previously. Hence, this research would be a novel agent-based modeling approach in designing manual order-picking warehouses.

3. Warehouse Layout and Experimental Design

Figure 1 shows layout decisions in order picking system design. The layout structure is divided to several pick aisles which have racks to store products on both sides. The location where the order picker starts and finishes his picking route is known as the depot. Cross aisles are the aisles used by the order picker to move from one pick aisle to another. Cross aisles are perpendicular to the pick aisles and they have no pick locations. The minimum number of cross aisles in an order picking warehouse is two, one at the front of the warehouse and one at the back. All sub-aisles between two cross aisles are called a storage block.

The simulation experiments were classified according to four key factors: Number of aisles, aisle length, number of storage blocks and order size. Table 1 shows these design factors with their various levels which are based on observations of many actual manual operating warehouses (Caron et al., 2000b) (Roodbergen and De Koster, 2001). As a result of the previous combinations, 81 experiments have been performed.

For each simulation experiment, it is necessary to determine the number of replications such that the estimate for mean travel distance has a percent error smaller than some $100\gamma\%$ where γ is the relative error. An approximate equation to calculate the necessary number of replications such that the relative error is smaller than γ with a probability of $1-\alpha$, is given in Law and Kelton (1991). For all experiments considered in this research, a replication size of 2000 orders has appeared to be sufficient to guarantee a percent error of at most 1% with a probability of 95%. The routing technique used in order picking process is S-shape heuristic because it is simple and widely used in manually-operated warehouses.

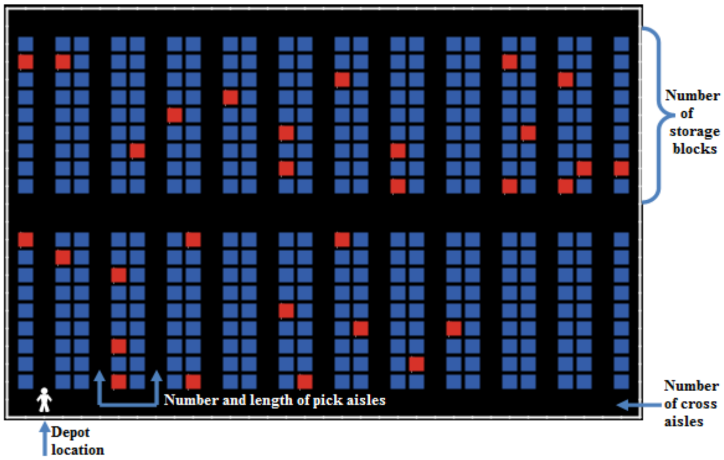

Figure1: Layout decisions in order picking warehouse system

Table 1: Layout design factors with their levels

Factors	Levels
Number of aisles	7, 11, 15
Aisle length	12, 18, 24
Number of storage blocks	1, 2, 3
Order size	20, 30, 40

4. Model Building, Verification and Validation

NetLogo software was used to build a model that simulates the order picking process in warehouses under different design parameters. Several agents (turtles) are involved in the model and are described as follows:

- Agents '*storage cells*' where the SKUs are stored. The number and configuration of these cells determine the warehouse storage capacity and layout.
- Agents '*picks*' represent the specified storage cells that the order picker has to visit in order to pick the items in the order list.
- Agents '*order pickers*' who are individuals responsible for the order picking process. These agents considered to be the perceptive entities in the model that have the ability to perceive, think, take decisions and react according to predefined objectives.

The simulation algorithm is described briefly as follows:

- A set of agents (storage cells) are created and arranged according to the specified warehouse storage capacity and layout parameters.
- A set of agents (picks) are created according to the specified order size. 50% of picks are allocated in class A region, 30% in class B region and 20% in class C region. The picks are allocated randomly inside each dedicated area.
- An agent (order picker) is created and located at the depot.
- While the items in the order list are not completely picked, the order picker applies the S-shape routeing heuristic to pick items.
- After picking all the items in the order list, the order picker returns to the depot. Then, the model gives a user massage indicating the travelled distance by the order picker.

In order to perform the verification process easily, the computer program was divided in to modules. The simulation model's main program and the key subprograms were written and debugged first. Then, additional subprograms with different levels of details were added and debugged successively until the whole model was developed. After developing the model, it was run under a variety of settings of input parameters to check outputs reasonability. A simple measure of performance (order picking distance) was computed manually and used for comparison purposes. It also was helpful to observe the animation of the simulation output to verify the simulation model.

A major obstacle arising in validating agent-based models is the lack of suitable benchmark problems whose results are comparable with those provided by ABM. Predominantly, ABM is used to solve complex problems for which no analytical solutions are available. For this reason, validating ABMs is not as simple as it might appear. According to Barbati et al., (2012), around 9% of researchers who applied ABM for optimization problems did not present any validation, while about 22% utilized instances from literature in order to test their proposed models. Less than 2% used exact algorithms for comparison purposes and 51% compared the results to the ones coming from other heuristic techniques. In situations where the model is concerning with real-world system, the result of the approach was compared to a real-life scenario. Since it is not possible to validate the model developed in this paper via real experiments, the model was validated qualitatively using experst judgment.

5. Results and Discussion

The results of the simulation experiments are presented in Table 2 which presents the order picking distance for different layout configurations. In order to determine the design parameters that have the most significant effect on the picking travel distance, analysis of variance (ANOVA) with full factorial design was performed using Minitab software. Table 3 is the resultant ANOVA table for order picking distance. The ANOVA results indicate that all of the main, the two-way interaction and the three-way interaction effects are significant at an alpha of 0.05. Since the result of each level combination is treated as a single replicate, the number of parameters in the ANOVA model equals the number of observations. As a result, the four-way interaction effect is neglected and its mean square is used as an estimate of the error mean square.

In order to examine the factors effects more deeply, the main and the two-way interaction effects are illustrated in Figures 2 and 3, respectively. It could be noticed easily in these figures that increasing the number of aisles, aisle length or order size would result in an increase in order picking distance. This fact is axiomatic since any increment in these factors levels will lengthen the picking route regardless of other design factors. An interesting remark about the number of blocks is that increasing the number of blocks would decrease the order picking distance until it reaches its minimum value (at number of blocks = 2). However, any further increment in the number of blocks would have a negative effect on the travel distance. This can be explained by the fact that adding an extra cross aisle would give the order picker the opportunity to move freely between picking aisles and hence decreasing the route length. On the other hand, having too many cross aisles could result in a substantial increase in the travelling distance. This result coincides with Roodbergen and De Koster, (2001) and Ducik et al., (2010) who obtained similar outcomes in warehouses using random storage policy.

It is worth mentioning that when picking density is law (20 picks per order), the three-block configuration is much better (around 18%) than the traditional one-block configuration. However, when the picking density is increased the superiority almost vanishes. This observation is institutively clear; the main advantage of adding cross aisles is to increase routing possibilities. However, if the order picker has to visit many pick locations, the extra cross aisles would not add a significant benefit since the order picker will almost traverse all picking aisles. Another intelligible remark in Figure 3 is that small warehouses are less sensitive to variations in number of cross aisles or order size than large warehouses. It is possible to employ this result effectively in designing and operating warehouses; If the throughput rate of a warehouse is predicted to be variable (e.g. seasonable demand) it would be beneficial to divide the warehouse total storage area into several picking zones which makes the order picking distance less sensitive to variation in demand intensity.

Table 2: The results of the simulation experiments (order picking distance in meters)

		1-block			2-blocks			3-blocks		
Order size	aisle length	No. of aisles			No. of aisles			No. of aisles		
		7	11	15	7	11	15	7	11	15
20	12	124.2	182.7	230.4	108.6	149.3	183.3	122.2	172	215.2
	18	164	239	297.1	136.9	185	223.7	145	199.6	247.7
	24	204.6	293.9	364.3	165.3	220	263.3	169.9	229.8	278.6
30	12	129	196.9	257.1	118.8	167.7	209.9	140.8	203.6	256.7
	18	171.3	259.1	335.7	152.5	211.8	260.6	169.6	238.6	297.8
	24	215.2	320.9	413.6	186.3	255.5	311.7	198.8	275.7	339
40	12	131.1	202.9	269.8	125.5	180.1	228.3	151.6	222.4	284.4
	18	175	267.9	353.7	162.6	229.9	287.4	183.8	263.6	332.3
	24	219.1	333	437	199.8	378.2	346.1	216.5	305.2	381.3

Table 3: Full factorial ANOVA for order picking distance

Term	DOF	SS	MS	F	P
no. of aisles	2	229668.6	114834.3	201583.68	0.000
aisle length	2	111900.1	5595.1	98216.47	0.000
no. of blocks	2	28621.6	14310.8	25121.65	0.000
order size	2	29648.6	14824.3	26023.02	0.000
no. of aisles * aisle length	4	3948.0	987.0	1732.62	0.000
no. of aisles * no. of blocks	4	6182.0	1545.5	2713.02	0.000
no. of aisles * order size	4	4346.2	1086.5	1907.35	0.000
aisle length * no. of blocks	4	6013.3	1503.3	2638.99	0.000
aisle length * order size	4	1348.8	337.2	591.94	0.000
no. of blocks * order size	4	2090.1	522.5	917.28	0.000
no. of aisles * aisle length * no. of blocks	8	792.0	99.0	173.78	0.000
no. of aisles * aisle length * order size	8	69.0	8.6	15.14	0.000
no. of aisles * no. of blocks * order size	8	163.3	20.4	35.84	0.000
aisle length * no. of blocks * order size	8	25.4	3.2	5.58	0.002
Error	16	9.1	0.6		
Total	80	424826.3			

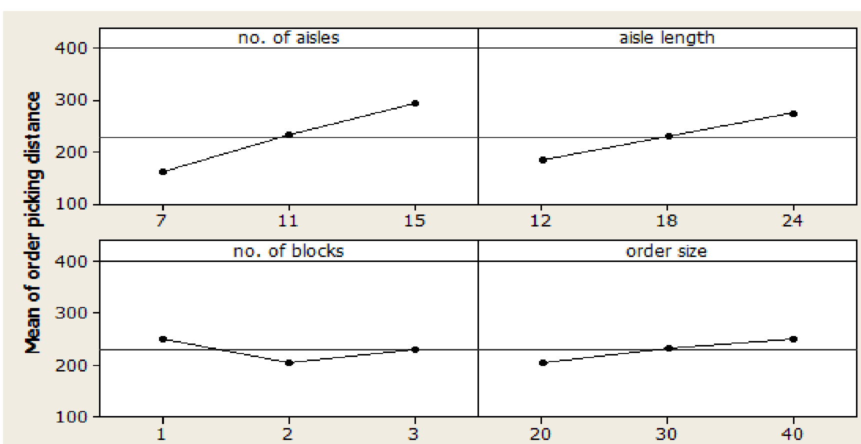

Figure 2: Main effects plot for order picking distance.

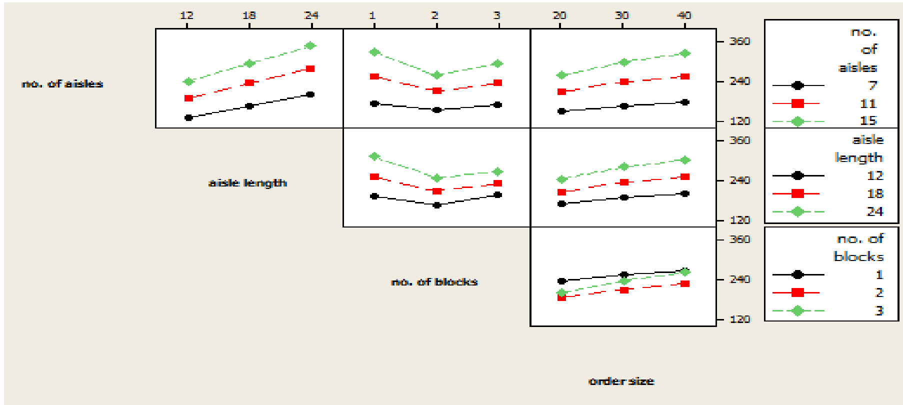

Figure 3: Two-way interaction effects plot for order picking distance.

Sensitivity analysis is conducted on the results to determine which conditions give the maximum savings in route length. Tables 4-6 demonstrate % increase in route length for different layout configurations compared to a base line. The two-block configuration is considered to be the base line for comparison purposes since it gives the minimum travel distance regardless of other factors levels. The sensitivity analysis shows that in one-block warehouses, increasing the aisle length would result in a significant %increase in route length. Nevertheless, the opposite is true for warehouses that consist of three-blocks of parallel aisles. This outcome is not surprising since increasing the aisle length without adding a cross aisle to allow the order picker to change pick aisles will force him to traverse considerable distances to reach picking locations and hence, the travel distance would be much more than the case where a cross aisle is present. The situation will differ when the number of blocks is three; if a warehouse has short pick aisles, the traveled distance in the cross aisles represents a relatively large percentage of the total travel distance. Consequently, the longer picking aisles require more cross aisles in order to optimize travel distance.

Another notable point is that increasing the number of picks per tour could result in changes in layout preferences. For example when the order size equals 20 picks, the three-block configuration is preferable than the one-block configuration regardless of other design factors levels. However, when the number of picks is increased up to 30, this rule applies with two exceptions. The exceptions occur for warehouse layouts that consist of 7 or 11 aisles with 12 meter's aisle length. Further increment in number of picks per tour to 40 will lead to extra two exceptions in the previous rule. Accordingly, it is expected that increasing the order size to a certain point will make the one-block configuration preferable over the three-block configuration regardless of other design factors.

Table 4: % Increase in route length for different layout configurations at order size = 20 picks

aisle length	1-block			2-blocks			3-blocks		
	No. of aisles			No. of aisles			No. of aisles		
	7	11	15	7	11	15	7	11	15
12	14.3	22.4	25.7	0	0	0	11.1	13.2	14.8
18	19.8	29.2	32.8	0	0	0	5.6	7.3	9.7
24	23.8	33.6	38.4	0	0	0	2.7	4.3	5.5

Table 5: % Increase in route length for different layout configurations at order size = 30 picks

aisle length	1-block			2-blocks			3-blocks		
	No. of aisles			No. of aisles			No. of aisles		
	7	11	15	7	11	15	7	11	15
12	8.6	17.4	22.5	0	0	0	18.5	21.4	22.3
18	12.3	22.3	28.8	0	0	0	11.2	12.7	14.3
24	15.5	25.6	32.7	0	0	0	6.7	7.9	8.8

Table 6: % Increase in route length for different layout configurations at order size = 40 picks

aisle length	1-block			2-blocks			3-blocks		
	No. of aisles			No. of aisles			No. of aisles		
	7	11	15	7	11	15	7	11	15
12	4.5	12.7	18.2	0	0	0	20.8	23.5	24.6
18	7.6	16.5	23.1	0	0	0	13.0	14.7	15.6
24	9.7	19.7	26.3	0	0	0	8.4	9.7	10.2

6. Conclusions and Future Work

This paper develops a novel agent-based simulation model in order to investigate the effect of different warehouse design parameters on order picking distance. The model is applied for manual order-picking warehouses that adopt the class-based storage policy. Order size and layout design parameters represented by number of aisles, aisle length and number of blocks were analyzed and found to have considerable effects on order picking distance. In particular, the number of picks per tour seems to be important and could result in changes in layout preferences. It was found that adding an extra cross aisle to the traditional one-block warehouse layout would decrease the route length. However, adding too many cross aisles could increase the route length because the space occupied by the cross aisles is considered to be a non-storage area that has to be traversed by the order picker as well. It was concluded that the small warehouses could be less sensitive to variations in number of cross aisles or order size than large warehouses. As a result, warehouses with wavering demand patterns could take advantage of this by dividing the warehouse storage area into picking zones and assigning workers to specific areas of the warehouse and portions of the orders are assigned to appropriate zones. However, the cost reductions resulting from zone picking have to be weighed against increased costs for the sorting process.

For future research extensions, the positioning of the cross aisle is an interesting area to be investigated especially with class-based storage policy since there will be many picks located in the frequently requested items area. It is also worthwhile to apply the same methodology using within aisle class-based storage instead of the traditional cross aisle pattern. Another extension to this research could be investigating the effects of other design factors such as storage and routing policies.

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Biography

Maram I. Shqair is a MSc. student with an emphasis in operations management and simulation. She received a bachelor's degree in chemical engineering from the University of Jordan. Maram finished her MSc. courses with 4/4 GPA and she now works on her thesis under Dr. Safwan Altarazi conducting research related to warehouse design and control.

Safwan A. Altarazi: A professor, trainer, researcher, and consultant with a strong record of achievements in the fields of quality management and supply chain management. Have long experience in academia-industry bridging projects with rigid problem solving capability across different fields in very systematic manner. As a primer and participant researcher, have raised more than $250,000 as research funds during the last four years and is currently participating in two EU-Tempus projects for developing master programs in various engineering fields. Served in various administrative positions including head of industrial engineering department-Germany Jordanian University, head of maintenance engineering and management department-Germany Jordanian University, elected member of mechanical engineering assembly-Jordanian Engineers Association, and chair of scientific committee-Seventh Jordanian International Mechanical Engineering Conference.