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EVALUATION OF WAREHOUSE BULK STORAGE LANE DEPTH AND ABC SPACE ALLOCATION USING SIMULATION

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ABSTRACT

The principal intention of this paper is to develop an approach for modeling bulk lane storage in a high-volume warehouse environment. Poor layout planning can lead to an ineffective use of space and is a concern of many companies today. A simulation methodology is presented to evaluate alternative bulk storage warehouse configurations. Parameters of interest are the depth of bulk lane rows and the space allotted for various frequency zones. Analysis of representative data shows that there are variations of bulk lane depth and zone size that can reduce travel distance and thus reduce cost. In addition, we present an application of the methodology involving the design of a bulk storage facility for a company.

1 INTRODUCTION

There is a recurrent need for optimized warehouse design in industry for the purposes of production scheduling, inventory management, and minimization of labor costs. Warehouse utilization issues often arise in cases of high inventory variability and uncertain environments (Kofjač, Kljajić, and Rejec 2009). As a result, batching and zoning strategies are very important to the design and productivity of warehouses (Parikh 2006). To deal with these conditions of uncertainty, various types of warehousing designs and strategies are employed to meet the needs of the company. In particular, warehouses are designed with the goal of making the best use of the available storage space while enabling the efficient storage and retrieval of items.

In a typical warehouse, material is stored in standard stock keeping units (SKUs) in the x (length), y (width), and z (vertical) directions throughout the warehouse. Rack storage areas can provide high-density storage of items and often consist of SKUs that are picked in less-than-pallet sizes that are accessed by material handling equipment such as vertical pallet jacks. One disadvantage of the rack picking format is the heightened labor time and cost in traveling in the z direction. Along with this disadvantage, comes the added caution required to safely maneuver pallets off the racks from various elevations. As an alternative, bulk storage lanes (also referred to in the literature as block stacking warehouses) have become popular for storing pallet size SKUs with large batch sizes and high pick frequencies. Bulk storage lanes are typically designed to store pallets or stacks of pallets only on the floor of the warehouse. From a picking perspective, bulk storage lanes primarily involve travel distances in the x and y planes with minimal travel distance in the z direction, which can reduce picking time and permits items with the same SKUs to be stored in the same location, up to the lane's depth.

The purpose of this paper is to create a simulation-based method to model and analyze bulk storage systems. In particular, the method will enable one to determine the depth (in terms of the number of pallets) of bulk lanes within the warehouse as well as the allocation of warehouse space (frequency zones) to fast-moving (A-type) items and slower moving (B-type or C-type) items within a given warehouse space. The bulk lane warehouse configurations are compared based on the utilization of warehouse space, the adherence to SKU zone designations, and travel distance for the storage and retrieval of pallets.

The remainder of the paper is organized as follows. In section 2, we present a review of the relevant literature on warehouse design. The modeling and analysis methodology is discussed in section 3. In section 4, we illustrate the methodology by conducting an experiment to compare alternative configurations for a given bulk lane warehouse. The application of the methodology to the design of a warehousing facility is described in section 6. Finally, our conclusions are discussed in section 7.

2 LITERATURE REVIEW

Striving towards lowered costs within warehouse processes including material storage is not a new concept. The theory behind a cost-based optimization model with variable storage locations has been considered with the intention of reducing space and increasing throughput. Parikh (2006) compiles an in-depth summary of the progress and current research on warehouse design, and presents a simulation model that is implemented using Matlab. Others have pursued floor space configurations, specifically identifying the ideal bulk lane depth, using linear optimization models. Both Barnes (1999) and Larson, March, and Kusiak (1997) discuss similar methods for allocation of material to different zones in a warehouse. Larson, March, and Kusiak (1997) discuss dividing up over 700 SKUs into different regions in order to effectively address the number of aisleways in a distribution center. Derhami, Smith, and Gue (2016) present an analytical method for determining bulk lane storage depths based on production and demand rates with the objective of minimizing wasted space within the warehouse. In addition, unlike many of the prior papers what consider instantaneous arrivals of pallet/lots, Derhami, Smith, and Gue (2016) consider the arrival pallets and demand for pallets over time. The methods we present build on these concepts in attempt to maximize space utilization while minimizing storage and retrieval using simulation for high-volume materials in a bulk lane design taking into consideration variability and the dynamic behavior of the system over time.

3 BULK LANE STORAGE SYSTEMS

In a typical warehouse, pallets enter the system through a receiving dock at a arrival rate that can vary over time. As pallets enter, a warehouse management system indicates to an operator where the pallets need to be stored. If a pallet is received and denoted as a bulk storage item, that pallet is put away in the designated bulk storage area. Within that area, if blocking is to be avoided, the pallet is placed in a bulk lane only if the current contents of that lane share the same SKU. If there are no current bulk lanes with pallets of the same SKU, the pallets will be placed in an empty lane. This concept is shown in Figure 1, where the numbers represent SKUs stored in a pallet location.

A frequency zone layout is often considered for pallet storage locations as well. Within this system, frequency is defined by how often a particular SKU is picked and ordered by a customer where items are designated as high, medium, and low frequency. Figure 1 represents a warehouse with two frequency zones. The higher frequency pallets are stored in the Zone A, and the medium frequency pallets are located in the Zone B farther from shipping and receiving. If a bulk storage system contains slow moving items, a Zone C area could be considered. Figure 1 shows how picking from the bulk lanes is performed vertically and in a last-in-first-out sequence, as the fork truck moves down the aisle. Ultimately, pallets are stored in the warehouse based on their SKUs and their designated frequency zone. Pallets then leave the system based on incoming customer demand orders.

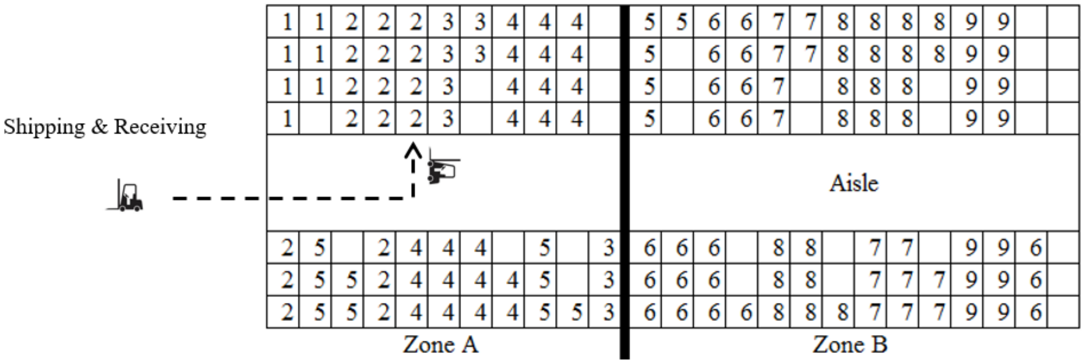


Figure 1: Example bulk lane storage area with two frequency zones, A and B. Each square represents a pallet storage location, and the numbered items represent stored SKUs (pallets) occupying the lane.

4 METHODOLOGY

For determining bulk lane depths and frequency zoning areas in a warehouse setting, we present a simulation-based methodology. In contrast to other approaches such as linear programming models, simulation can effectively represent the dynamic arrival and departure rates of the materials and their inherent variability as well as the dynamic storage and retrieval within the facility.

The simulation models presenting in this paper have been constructed using the Simio® simulation software package (Kelton, Smith, and Sturrock 2013; Joines and Roberts 2015). The simulation entails modeling the facility layout including storage locations, shipping and receiving locations, material handling equipment, demand logic, and storage and retrieval logic. To create the facility layout, bulk lane storage locations are represented as last-in-first-out queues (station objects) having a specified capacity. The station objects are arranged in a pattern representing the layout of the warehouse. The warehouse layout is then partitioned into ABC frequency zones.

Within the model, entities represent the arrivals of pallets to the warehouse. Pallets enter the system at a specified arrival rate. The arrivals can be individually (e.g., representing a pallet coming off the production line) or in batches (e.g., representing the arrival of a truck delivering pallets). Each pallet that enters the system has an SKU assigned with an associated frequency zone. For the purposes of our experimental example and case study, a production rate table is used where the relative likelihood of assigning a particular SKU takes into account the batch size. After being assigned an SKU, the pallet requests a fork truck to place the pallet into a storage location. When the fork truck arrives to the receiving location, the particular bulk lane storage location is selected using the following priorities:

1. Bulk lane within the facility with matching SKU that has remaining storage capacity;
2. Empty bulk lane within the designated frequency zone;
3. Empty bulk lane in lower frequency zone (A → B → C);
4. Empty bulk lane in higher frequency zone (C → B → A); or
5. An "Overflow" destination.

The last alternative, which is to send the pallet to an "overflow", is primarily for the function of the simulation model. The overflow destination is an infinite capacity queue that collects pallets if there is no available pallet location meeting the other criteria. In an actual warehouse, the pallet would be placed in alternative storage location until a storage location becomes available. In our experimentation we will look for configurations that will minimize or eliminate pallets being sent to the overflow destination.

The customer demand is modeled using a second set of entities in the system. Customer trucks arrive to the system with orders that need to be filled. The order consists of the number of each SKU that are required. The fork truck is sent to collect the SKUs from their designated bulk lanes. From there, they are sent to the staging area. If there are multiple bulk lane locations with the same SKU that is needed for the order, the fork truck will pick from the lane with the smallest number of pallets in relation to its depth. Trucks leave the system when their entire order has been retrieved from the warehouse.

Warehouses are inherently in flux based on production and customer demand. Determining the depth of bulk lanes is influenced by the natural variability of a warehouse. Based on the quantities in which SKUs are stored, the depth of the bulk lanes may vary throughout a warehouse. Using the simulation model, various bulk storage layouts can be configured and analyzed. In particular, we would like to determine the depth of the bulk storage lanes as well as the frequency zone designations for the storage lanes within the warehouse. For the purpose of this paper, our goal is to minimize the travel distance (or travel time) of the material handling equipment used for storage and retrieval. Furthermore, we aim to minimize the number of pallets placed in a storage location outside of their designated frequency zone.

5 EXPERIMENTAL EXAMPLE

To demonstrate the simulation-based methodology, we have built an experimental model to represent a bulk storage warehouse. A diagram of the bulk lane warehouse is shown in Figure 2.

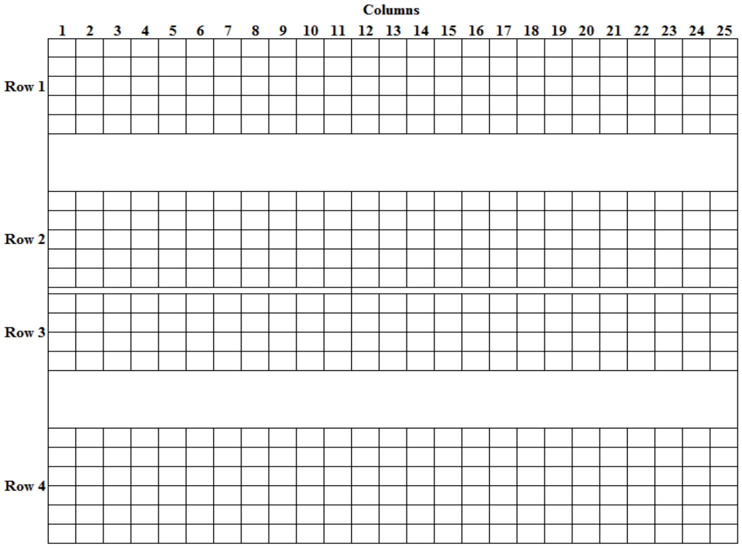


Figure 2: Experimental bulk storage area.

We have made the following assumptions for this experiment in terms of the warehouse configuration and operational controls.

1. Storage Area Dimensions: Storage space is 100 x 100 square feet of the warehouse’s floor.
2. Pallet Size: Pallets occupy a 4x4 square footprint of space.
3. Aisles: Transportation and conveyance space are accounted for in two 10-foot wide aisleways between the pallet storage rows, which span the horizontal length of the space.
4. Pallet Configuration: There are four bulk storage rows that span the storage space. We will assume that each storage lane within a row will have the same depth. Pallets are not stacked.
5. Shipping and Receiving: Pallets will arrive and leave the system from the left (see Figure 2).
6. Arrival and Departure Rates: Pallets enter and leave the system at equal average rates to maintain an inventory balance. Arrivals occur randomly with the distribution of pallets of 30 different SKUs as shown in Table 1.

7. Fork Trucks: To prevent the fork trucks from being the system's limiting factor in system performance, two fork trucks are used. The fork trucks move at a rate of 5 miles per hour (loaded or unloaded). Each fork truck can carry one pallet at a time, and the load/unload times are assumed to be negligible.
8. Frequency Zones: This example will utilize two frequency zones, A and B. SKU zone designations are shown in Table 1.

Table 1: Data used for arrival and demand rates.

SKU	Arrival Probability	Batch Size	Zone	Demand Rate	SKU	Arrival Probability	Batch Size	Zone	Demand Rate
1	0.100	15	A	1.50	16	0.035	7	B	0.27
2	0.080	16	A	1.28	17	0.020	11	B	0.22
3	0.164	7	A	1.15	18	0.020	9	B	0.18
4	0.080	8	A	0.64	19	0.020	9	B	0.18
5	0.040	16	A	0.64	20	0.015	12	B	0.18
6	0.038	16	A	0.61	21	0.010	16	B	0.16
7	0.030	16	B	0.48	22	0.010	13	B	0.13
8	0.025	18	B	0.45	23	0.020	6	B	0.12
9	0.030	13	B	0.39	24	0.010	11	B	0.11
10	0.070	5	B	0.35	25	0.010	10	B	0.10
11	0.020	17	B	0.34	26	0.020	5	B	0.10
12	0.030	11	B	0.33	27	0.010	10	B	0.10
13	0.026	12	B	0.31	28	0.010	9	B	0.09
14	0.020	15	B	0.30	29	0.010	7	B	0.07
15	0.020	15	B	0.30	30	0.001	15	B	0.06

Given the assumed experimental bulk storage area and defined aisles, we determined that there is 80 feet in the vertical direction of the warehouse that can be used for storing materials in bulk lanes. The room is then split up into vertical columns, as shown in Figure 2, where there would be room available for 20 pallets per column. These 20 pallets can be distributed to any of the four bulk lane rows based on the bulk lane depth set for each row.

The following factors are considered in the experiment:

1. Zone A Size: The number of bulk lanes allotted for high-frequency SKUs.
2. Row Lane Depth: The lane depth of each row of bulk lanes subject to the constraint that total number of all pallets in a column is at most 20. In addition, the depth of each row of pallets is constrained to be a minimum of 2 pallets and maximum of 14 pallets.

For the experiment, the simulation model runs for 10 replications, each for a period of 24 hours. Each replication of the model is initialized in a representative steady-state by creating pallet entities representing SKUs randomly sampled based on the product mix and inserting the SKUs into bulk lanes.

To evaluate the performance of the various system configurations, we consider the following:

1. Percent of A SKUs in Zone B
2. Percent of B SKUs in Zone A
3. Total travel distance for storage and retrieval.

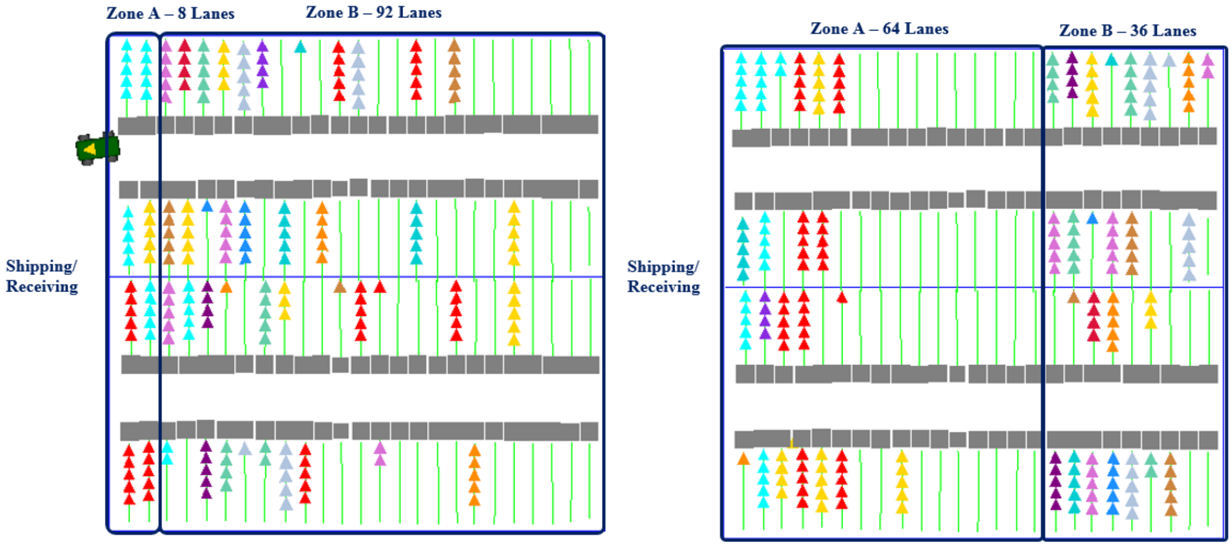
The combination of these experimental results can show how well the bulk storage area is utilized.

5.1 Example Experimental Results

In this section, we illustrate the types of results produced by the model. Various combinations of lane depth and zone size are tested in order to assess layout alternatives. Table 2 contains a subset of the configurations that were tested where the bulk lane depth is varied along with the number of storage lanes designated to Zone A. One observation is that as the number of lanes dedicated to Zone A changes from 8 to 16 to 24, the travel distance decreases and then increases. Figure 3 demonstrates the reason for this non-monotonic behavior. In Figure 3(a) the lane allocation to Zone A is too small, requiring type A items to be stored in Zone B and hence increasing travel distance for these frequently stored items. In Figure 3(b), the lane allocation to Zone A is too large leaving many empty lanes in Zone A that must be bypassed every time an Zone B SKU needs to be stored or retrieved. In addition, the combination of lane depth and zone size has an impact on both the distance traveled and the number of items requiring storage outside of their designated zone. For this example, the scenario with 16 lanes designated to Zone A with a 6/4/6/4 row configuration minimizes travel distance and provides good performance with regard to storing pallets in their designated zone.

Table 2: Experimental results for various Zone A sizes and lane depths.

	Depth of Lanes (# of Pallets)				**Out of Zone**		
Zone A Size (# of lanes)	**Row 1**	**Row 2**	**Row 3**	**Row 4**	**A Items in B**	**B Items in A**	**Distance (Miles)**
8	2	8	6	4	8.09%	0.00%	79.21
16	2	8	6	4	5.49%	0.04%	78.75
24	2	8	6	4	4.04%	0.10%	79.77
8	6	4	6	4	8.03%	0.00%	78.58
16	6	4	6	4	5.74%	0.01%	78.40
24	6	4	6	4	4.10%	0.02%	78.84
8	8	2	2	8	7.56%	0.01%	80.93
16	8	2	2	8	5.68%	0.05%	80.60
24	8	2	2	8	4.13%	0.06%	82.29



(a) (b)

Figure 3: Warehouse configurations (a) Zone A configuration set to 8 lanes; and (b) Zone A configuration set to 64 lanes.

6 CASE STUDY

The methodology presented in this paper was driven by an application of warehouse design conducted by the authors. The company acquired an existing building to use as a warehouse and distribution center. Part of this facility is designated to bulk lane storage. Given the current layout of the facility with existing walls, doors, columns, etc., alternative layouts were evaluated to determine how the overall space could be best utilized. An overview of the layout is shown in Figure 4. The overall storage space will allow for up to 5,400 pallets to be stored in two pallet stacks in each storage location. These bulk storage lanes will hold 353 SKUs. However, a portion of these SKUs require that only pallets produced in the same batch can be stored together to ensure that customers will receive pallets of the same batch when placing an order. For the purpose of storage and retrieval, different batches can be treated similar to different SKUs.

The key decisions in design of the system configuration are the number of bulk storage lanes, bulk lane depth, number of aisles, and how many bulk lanes should are allocated to each zone. The objective of this study is to compare various scenarios using simulation to determine the optimal bulk lane depths as well as the number of bulk lanes per dedicated ABC storage zone. SKU batch size, arrival and demand data, the warehouse layout, and storage constraints are incorporated into the simulation model. This model is developed to minimize distance traveled to ultimately reduce the total labor content required.

6.1 Warehouse Layout

In Figure 4, the numbered blocks within the diagram represent blocks of bulk storage lanes. Due to the constraints of the facility, the bulk lanes in blocks 1-6, 7, 10, 11, 14, 15, 21, 22, and 28 will each have a specified lane depth and will not be part of the experimental factors. However, the remaining bulk lanes will have lane depths that will be determined by our experiment.

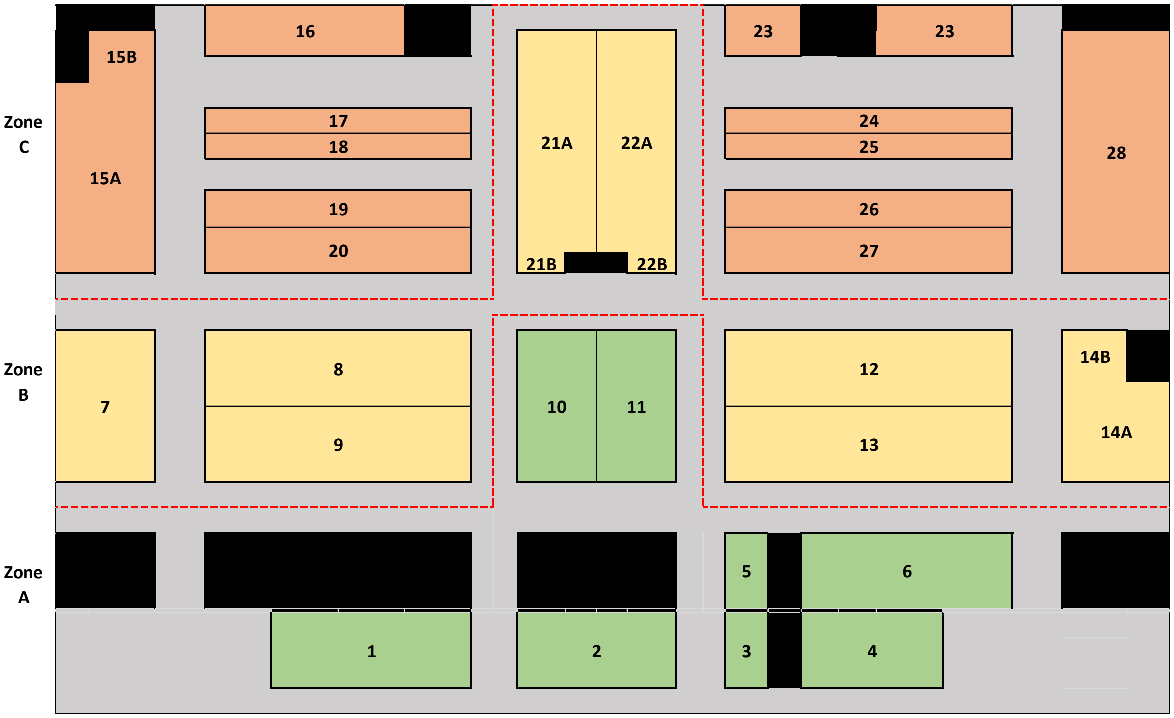


Figure 4: Warehouse bulk storage layout.

The frequency zone is specified for each SKU is based on the number of picks per year. SKUs with 1000 or more picks per year will be designated to Zone A; SKUs having between 200 and 1000 picks per year will be designated to Zone B; and SKUs having fewer than 200 picks per year will be designated to Zone C.

6.2 Arrival and Demand Processes

The newly acquired storage facility is not located adjacent to the production facility; as a result, trucks deliver pallets from the production facility to the warehouse. Trucks arrive to the warehouse to deliver products approximately once per hour and carry approximately 16 pallets of up to three different SKUs that need to be placed in bulk storage. To model the arrival process to include production batches arriving over several days, we generate production batches and place mix of pallets on the delivery truck. Once a full production batch has been delivered, a new production batch of a different SKU is generated. The arrival and demand rates and mix of SKUs are generated as discussed in the methodology.

To begin the simulation, the bulk storage lanes are loaded with SKUs to representative steady-state inventory levels.

6.3 Case Study Experimentation

An experiment is conducted to test various combinations of lane depth and zone size. The designed model records the distance the fork trucks travel to and from the shipping and receiving docks. This metric is the primary response for the experiment. The model also identifies the percentage of pallets that are placed into a zone other than where they belong due to their appropriate zone being filled to capacity. An overflow feature is used as a storage location if the design of the warehouse can no longer accommodate the pallets that arrive. The experiment also records the number of pallets left in overstock because it is an indication that the zones are sized inappropriately. The objective of the experiment is to minimize these responses.

Lane depth configurations are limited by the amount of space available. These restrictions are translated into experimental constraints in the model. Each of the fifteen lane depth variables (x_i) are limited to a specific range based on the available space after aisleways are accounted for, as illustrated in Figure 4. The minimum and maximum number of pallets allowed in a lane are provided in Table 5. The complete list of constraints are as follows:

$$x_{min} \leq x_i \leq x_{max}$$

$$\sum_{i \in S_i} x_i = T_j \quad \forall j$$

$$S_1=\{8,9\}$$

$$S_2=\{12,13\}$$

$$S_3=\{16,17,18,19,20\}$$

$$S_4=\{23,24,25,26,27,28\}$$

where S_i are sets of pallet storage locations, T_j is the maximum total pallet storage lane depth summed over set S_i.

Table 5: Data used to create the constraints.

S_j	T_j	x_i	x_{min}	x_{max}
Set 1	28	Lane Depth 8	10	18
		Lane Depth 9	10	18
Set 2	28	Lane Depth 12	10	18
		Lane Depth 13	10	18
Set 3	30	Lane Depth 16	6	12
		Lane Depth 17	6	8
		Lane Depth 18	6	8
		Lane Depth 19	10	12
		Lane Depth 20	10	12
Set 4	30	Lane Depth 23	6	12
		Lane Depth 24	6	8
		Lane Depth 25	6	8
		Lane Depth 26	10	12
		Lane Depth 27	10	12

6.4 Results

Table 6 below shows a sample of scenarios that were run under the given constraints of the systems as previously discussed. The results of these scenarios, along with their confidence intervals, are reported in Table 7. There are five scenarios of bulk lane depths chosen to be evaluated for the company's bulk storage system. Several characteristics not incorporated into the simulation design, yet important to the company, are that bulk lane depths are relatively even in the similar areas within the defined storage area. Also, the defining areas of the zones should border main aisles and not be in the middle of a bulk lane row. The zone sizes depict how many bulk lanes fit within the zone starting at the far-left most corner of the layout near shipping and receiving. The lane depths depict how many pallets will fit in each bulk lane in the denoted section.

Table 6: Top five scenarios tested.

Scenario	Zone A Size (# of Lanes)	Zone B Size (# of Lanes)	Zone C Size (# of Lanes)	Lane Depth 8	Lane Depth 9	Lane Depth 12	Lane Depth 13	Lane Depth 16	Lane Depth 17	Lane Depth 18	Lane Depth 19	Lane Depth 20	Lane Depth 23	Lane Depth 24	Lane Depth 25	Lane Depth 26	Lane Depth 27
1	98	304	204	14	14	14	14	6	6	6	6	6	6	6	6	6	6
2	98	304	204	16	12	16	12	6	6	6	6	6	6	6	6	6	6
3	98	304	204	10	18	10	18	6	6	6	6	6	6	6	6	6	6
4	98	184	324	12	16	12	16	6	6	6	6	6	6	6	6	6	6
5	98	184	324	14	14	14	14	6	6	6	6	6	6	6	6	6	6

Table 7: 95% confidence intervals on performance measures for the top five scenarios.

	Travel Distance			Percent Stored Out of Zone		
	Lower Limit	Mean	Upper Limit	Lower Limit	Mean	Upper Limit
Scenario 1	54.98	61.63	64.82	0.26%	0.34%	0.36%
Scenario 2	58.06	61.78	65.50	0.25%	0.33%	0.41%
Scenario 3	60.48	62.03	70.52	0.45%	0.47%	0.80%
Scenario 4	62.37	66.81	72.83	3.05%	3.07%	3.76%
Scenario 5	65.77	66.09	72.12	2.89%	2.90%	3.56%

Scenario 1 has the shortest travel distance for all picks completed in one day. It is also beneficial to the system to have only two different lanes depths for consistency. Although achieving the shortest travel distance per day, the zones were placed in areas that are inconvenient for managing the storage/retrieval process.

Next, Scenario 2 allows for the lowest percentage of pallets stored out of their originally defined zone. This factor is important to consider since it shows that the zone definitions are well defined to hold the correct amount of SKUs. Also, this scenario has three different bulk lane depths between sections. This would lead to a difference in visual cues for non-standard lane depths at capacity between sections for the pickers. Similar to Scenario 1, the zone barrier is not defined in a main aisle, therefore this solution may not be the best.

The configuration of Scenario 3 minimizes the objective function for the company's bulk storage area. In analyzing this scenario, neither the Travel Distance nor Percent Stored Out of Zone is the smallest overall. Also, the zone barriers will cut through the side aisles, which is not desired by the company because it would require additional controls for managing the storage/retrieval process.

Scenario 4 is considered, because it fits the zoning layout that best fits the company's needs. The zone barriers are in all of the main aisles and the travel distance is only marginally larger than Scenarios 1, 2, and 3. The Percent Stored Out of Zone is marginally larger than the other scenarios as well, but is not significant given the zone barrier constraints.

Continuing with this idea, Scenario 5 is evaluated since it has the company's same zone barriers as Scenario 4. The Percent Stored Out of Zone is marginally smaller than that of Scenario 4. Also, from the earlier analysis, Scenario 5, only has two lane depth capacities which would be the most straightforward for implementation. Overall, Scenario 5 is the best choice for the company's bulk storage area layout configuration.

All five of the scenarios result in zero pallets in overstock. That is, all pallets that arrived to the warehouse were able to be stored in an available bulk storage lane. The selected bulk storage layout is shown in Figure 4, which displays Scenario 5. Zone barriers are depicted by the dotted lines in the main aisles of the layout.

7 CONCLUSIONS AND FUTURE WORK

The simulation-based methodology presented in this paper is used to analyze bulk storage warehouse configurations with respect to the depth of storage lanes and the number of lanes allocated to frequency zones. The configurations are compared based on utilization of the storage lanes and travel distance. The methodology has been successfully applied to a case study involving a large scale bulk lane storage facility. Future work in this area may involve the generalization of the storage rules and the methodology for establishing guidelines for bulk storage facilities.

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