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Simulation Analysis of Warehouses Utilizing Bulk and Rack Storage Systems

Rukshar A. Bhisti and Michael E. Kuhl
Industrial and Systems Engineering Department
Rochester Institute of Technology
Rochester, NY, USA

Abstract

With the growth of supply chain and increase in customer demand, efficient warehouse operations have become very important. One of the key aspects of warehouse design is to have an effective warehouse configuration such that the day to day operations enable the delivery of orders on time. Poor warehouse design can lead to ineffective utilization of warehouse space and costs associated inefficient operations. The purpose of this study is to develop an analysis tool that enables companies to identify the appropriate mix of bulk and rack storage locations to effectively utilize warehouse space. A simulation-based methodology is used to determine the optimal mix of the number of racks and bulk lanes for a warehouse layout considering both inventory quantities and inventory turnover rates. Evaluation parameters include the number of racks storage locations, the number of bulk lanes and lane depth, and the velocity mapping of products based on demand. The experimental results demonstrate the trade-offs of key performance metrics for various system configurations.

Keywords
Warehouse Systems; Simulation; Bulk Storage; Rack Storage

1. Introduction

Supply chain systems have evolved to address the global marketplace and the demand by customers for quick and reliable delivery of products. Responsiveness of supply chains depends heavily on the operational aspects of warehouses and logistics systems. In particular, warehouse operations contribute significantly to the success, performance, and cost of supply chain systems [1]. A study of warehouse systems concludes that capital investment and operational costs of a warehouse can account for 22-25 percent of a company’s overall expenses [2].

Warehouse operations include receiving, storing, retrieving, sorting, picking, and shipping. One of the major tasks is determining the appropriate method for storing and retrieving materials. When designing a new warehouse or revising an existing warehouse layout, there are a number of factors that contribute to the performance of a warehouse including how to make best use of available space to store materials. Storing inventories appropriately and proper inventory management can lead to effective space utilization.

Two common types of warehouse storage systems are rack storage and bulk storage. In a typical rack storage system, pallets of material are stored on racks that are arranged in long aisles with multiple levels (as many as 10 or more levels high). Some of the advantages associated with rack storage systems include: the flexibility of storage locations; the ease of inspecting and accounting for material; the low likelihood of material damage; the high density of material storage (vertical storage); and the suitability for picking less than pallet size orders. The disadvantages associated with rack storage include: the heavy investment in terms of buying and constructing racks; special equipment may be needed for high rack storage systems; and storing and retrieval can be higher cost in terms of time/skill required.

Bulk storage is mostly suitable for storing materials in pallets. Pallets (typically of the same material) are stored in rows (bulk lanes) on the warehouse floor and may be stacked directly on one another. The number of pallet that can be stacked will depend on the type of material and palletizing methods. The advantages associated with bulk storage include: the low capital cost; the effective use of space; specialized material handling equipment is not needed; and the suitability for storing material with large batch sizes and high picking frequency. The disadvantages associated with bulk storage include: the higher likelihood of damage as compared with rack storage; limited use of building vertical space; and limitations on access to particular pallets of material.

Given a particular inventory strategy (ordering frequency, holding quantities, demand rates, etc.) a company needs to determine the type of warehouse system that will meet their needs. The company may consider a rack storage warehouse, a bulk storage warehouse, or perhaps a mixed rack/bulk storage warehouse. The purpose of this study is to develop an analysis tool that enables companies to identify the appropriate mix of rack and bulk storage locations to effectively utilize warehouse space. A simulation-based methodology is used to determine the best mix of number of racks and bulk lanes for a warehouse layout considering both inventory quantities and inventory turnover rates. The methodology enables the evaluation of parameters including the number of racks storage locations, the number of bulk lanes and lane depth, and the velocity mapping of products based on demand. The methodology enables experimentation to evaluate the trade-offs of key performance metrics for various system configurations.

The remainder of the paper is organized as follows. Related work is discussed in section 2. In section 3, an overview of the warehouse system is described. The simulation-based methodology is described in section 4. An example that illustrates the experimental capabilities of the methodology is presented in section 5. Finally, conclusions and future work are presented in section 6.

2. Related Work

There has been a wide variety of research conducted on warehousing and supply chain systems. In this section, we highlight only a few papers directly related to the problem at hand. Sharma and Shah [3] present a mathematical model with a novel layout, zoning, and hybrid storage assignment policy that results in improvement in picking and reduced unwanted package movement, travel distance, and travel time. Derhami, Smith, and Gue [4] use a simulation-based algorithm to find the optimal number of aisles, cross aisles, and bay depth for block stacking (bulk) warehouses with the objective of maximizing space utilization and minimizing material handling cost. Clements et al. [5] develop a simulation-based method to determine the depth of bulk lanes and the allocation of warehouse space considering frequency zones in warehouse design. The methods considered in this research build on these methods to maximize space utilization and efficiency of the storage/retrieval process using simulation for material stored in bulk lanes and storage racks considering the inherent variability and dynamic behavior of the system.

3. Warehouse System Description

In the warehouse systems under consideration, unit loads (pallets) of material arrive to the warehouse at the receiving area. Figure 1 illustrates the layout of an example warehouse. As pallets arrive, often via tractor trailer, they are removed from the trailer and checked in. Some pallets may be required to go through a quality check. Pallets are then placed in a staging area to be moved to a storage location. The storage location of each unit load is often determined and tracked by a Warehouse Management System (WMS). The methodology assumes that the following warehouse information and data are known: the number of SKUs (Stock Keeping Units); average number of unit loads of each SKU on hand; and the demand rate for each SKU.

The layout in Figure 1 shows a warehouse with one aisle of bulk storage lanes with depths of three and four pallets as well as a two aisles of single depth rack storage locations. The unit loads placed in bulk storage lanes are only accessible from the bulk aisle on a last in first out basis. Furthermore, pallets in the bulk storage lanes may be stacked multiple units high. For example, a four-deep bulk lane stacked two high could hold a total of up to eight pallets of the same SKU. The unit loads placed in rack storage are accessible from the rack aisles. The racks may be multiple levels high. The number of levels is limited by the ceiling height of the facility and the vertical storage and retrieval capability of the material handling equipment.

In addition, the layout contains three frequency zones (A, B, and C). SKUs are assigned to a zone based on their demand frequency. Class A items include SKUs that are ordered and picked most frequently, hence they are stored closest to shipping and receiving area to minimize the travel distance. Class B and class C items have moderate and low demand rates, respectively. The number of storage locations allocated to each frequency zone is important. If too few locations are allocated to high frequency SKUs, the SKUs will need to be stored in zone that is farther away. On the other hand, if too many locations are allocated to high frequency SKU, forklifts will bypass empty locations to store lower frequency items. Both situations result in additional travel distance. When the demand for an SKU occurs, the pallet is removed from the storage location and is taken to the shipping area.

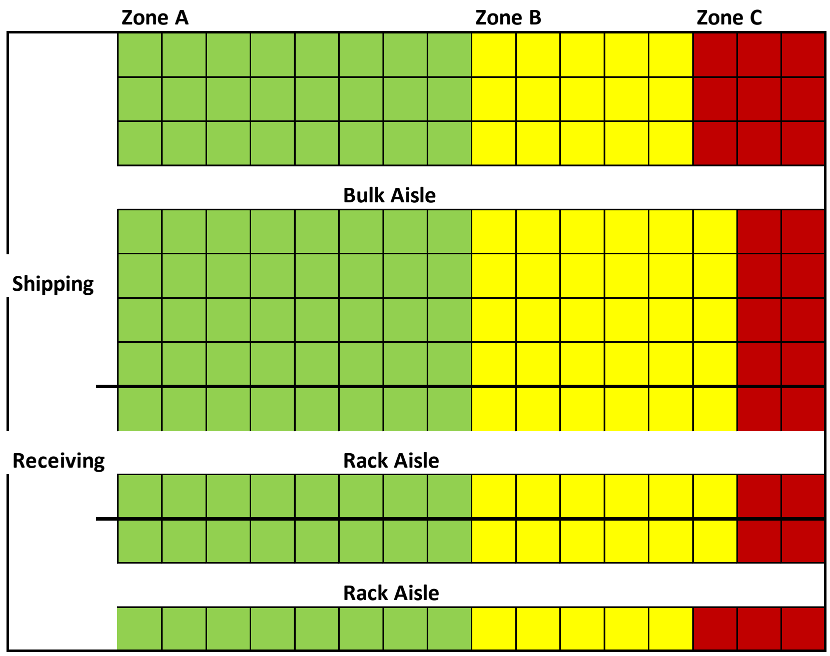

Figure 1: Warehouse layout with bulk and rack storage locations and frequency zone classifications.

4. Modeling Methodology

To determine the best mix of the number of racks and bulk lanes for a warehouse layout considering both inventory quantities and inventory turnover rates, we propose a simulation-based methodology. The simulation model consists of the arrival of material, inspection, storage assignments, zone classifications, storage processes, retrieval processes and shipping. The simulation model is designed to be a completely data driven model. To illustrate the simulation-based approach, the simulation methodology is implemented using Simio simulation software [6].

The input data required for the simulation model includes a list of SKUs, the average inventory level for each SKU, the inventory turnover ratio for each SKU (expressed as a demand rate), the likelihood of a quality inspection for each SKU, the distributions of pallet arrival and demand events, the number forklifts and their velocity, and the number, type (rack or bulk), capacity, zone designation, and coordinates of storage locations. This information is provided by the user to the simulation in a tabular format.

The facility layout is containing bulk lanes and storage racks are represented by objects with multiple capacity. Each storage location is assumed to be flexible (as opposed to dedicated) to allow any SKU to be stored. Each storage location is tracked with the current SKU number and quantity. Bulk lanes and multiple depth storage rack locations are restricted to a single SKU number.

Each unit load is represented by an entity in the model. The entity is assigned an SKU number upon arrival. The pallet samples from a distribution to determine if it will go through the quality check and then proceeds to a staging location. At the staging location, the storage location is determined and a forklift is requested to perform the storage process. Once placed in the storage location, the pallet will remain there until it is retrieved to fulfill a demand request. Demand requests are generated via a demand distribution. A demand entity is created and assigned an SKU number. A search is conducted to identify the particular SKU pallet in the warehouse to be retrieved. A forklift is then dispatched to retrieve the pallet. The pallet is then moved to the shipping location and leaves the system.

To make the storage location assignment for the arriving pallet and the pallet selection for the demand, we utilize the following strategy (based on the strategy found in [5]). The storage and retrieval strategies are summarized in Figure 2.

For the storage process,

1. Determine if the SKU already has a partially full storage location assigned among all available storage locations. If so, assign the pallet to that storage location. Otherwise, continue to step 2.
2. Search for an available storage location based on preferred storage type (rack or bulk storage) and the zone classification (A, B, or C). If found, assign the pallet to that storage location. Otherwise continue to step 3.
3. Search for an available storage location based on the preferred storage type and less frequent zone classifications. If found, assign the pallet to that storage location. Otherwise continue to step 4.
4. If no available storage location is found, assign the pallet to a temporary *overflow* storage location.

The retrieval process is follows a similar pattern,

1. Search for the SKU in a partially full storage location.
2. Search for the SKU in a less frequent zone classification.
3. Search for the SKU in the preferred zone classification.

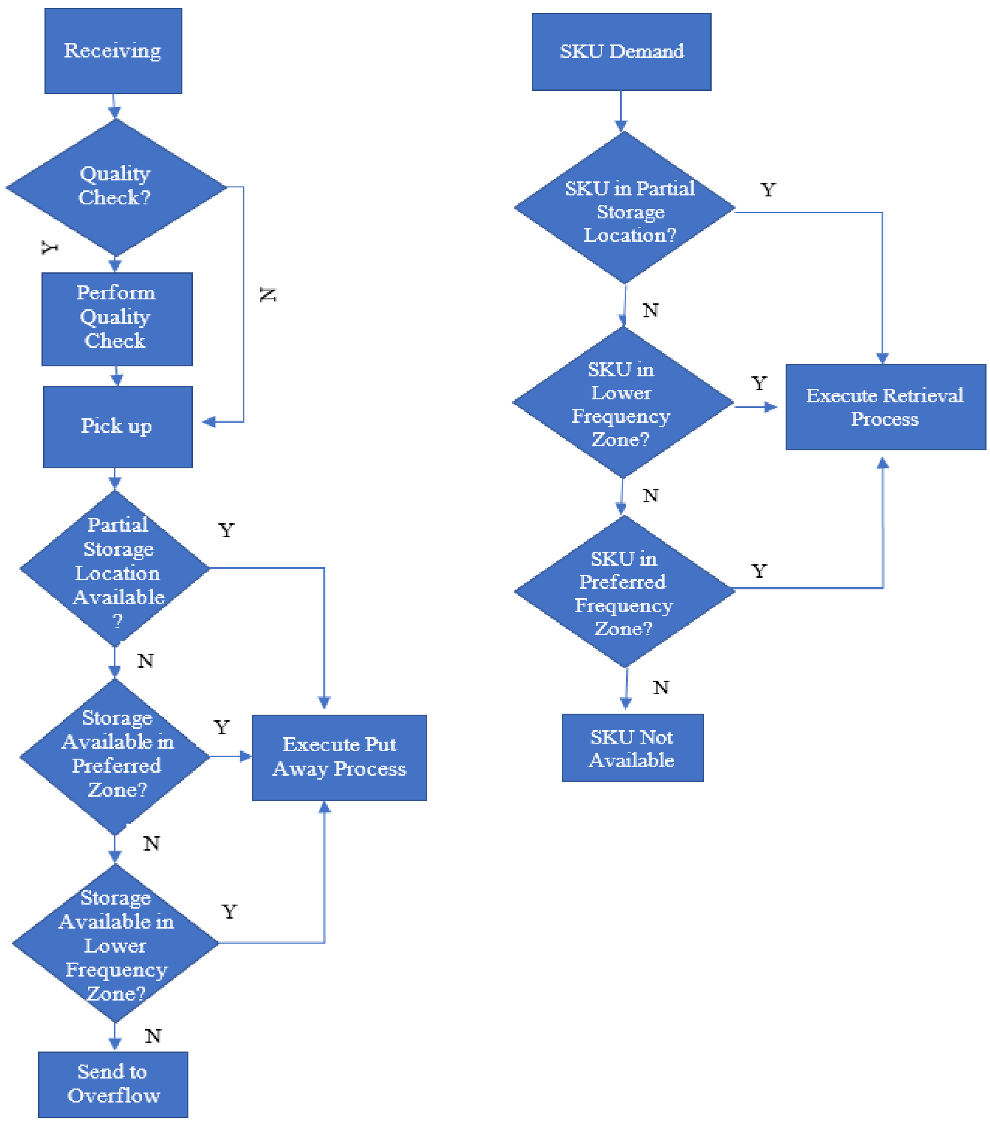

Figure 2: Process flow for an arriving pallet and assignment of a storage location; and the process flow for the demand process and pallet selection to meet the demand.

To initialize the system, the warehouse is loaded with a random sample of SKUs according to the expected mix of SKU inventory quantities. The storage process described in Figure 2 is used to determine the pallet storage locations for the initial warehouse inventory. The simulation is then run for multiple replications to collect performance metrics for the system configuration.

5. Rack/Bulk Warehouse Example and Experiment

To illustrate the capabilities and functionality of the simulation-based methodology, we present an experiment for an example warehouse.

In this example, we assume the warehouse needs to accommodate 115 SKUs. The SKUs are classified by their demand frequency where 50% of the SKUs are class A, 35% of SKUs are class B, and 15% of SKUs are class C. The initial conditions of the warehouse are such that the expected utilization of the storage locations is 80%. The probability of each SKU requiring inspection is set to 20%.

Three different configurations of the warehouse are considered including:

1. 55% Bulk lanes and 45% Rack storage;
2. 75% Bulk lanes and 25% Rack storage; and
3. 100% Bulk lanes.

The layout of each of the warehouses is similar to that shown in Figure 1. The details of each configuration are shown in Table 1. Each storage rack location can hold one pallet. At each bulk lane storage location, pallet can be double stacked.

Table 1: Description of warehouse configurations.

Warehouse Configuration	3 Deep Bulk Lanes	4 Deep Bulk Lanes	3 High Rack Rows	Area (m^2)
55% Bulk and 45% Rack	16	16	4	898
75% Bulk and 25% Rack	32	16	2	1087
100% Bulk	48	32	0	1638

Three forklifts are used in each system for the storage and retrieval operations. The pallet arrival and demand events each have an interarrival time that is uniformly distributed between 5 and 10 minutes. Each systems configuration is set up to run for 250, ten-hour work days (total of 2,500 hours) per replication. A total of 100 replications are run for each configuration.

The simulation is set up to collect a wide variety of performance measures. To illustrate the comparison of alternative configurations, we present a subset of the measures in Table 2.

Table 2: Performance measures of alternative system configurations: mean (standard deviation).

Warehouse Configuration	Bulk Overflow Instances	Rack Overflow Instances	Pallets Not Stored in Preferred Zone	Forklift Utilization	Distance Traveled (Km)
55% Bulk and 45% Rack	4.85 (5.37)	150.41 (23.50)	1,028.12 (460.50)	22.25%	3,944.49
75% Bulk and 25% Rack	5.31 (5.28)	179.37 (25.08)	973.45 (305.47)	28.82%	4,986.84
100% Bulk	0.99 (3.43)	- -	12.63 (16.40)	26.51%	4,492.67

The bulk and rack overflow instances indicate the number of times an arriving pallet was not able to be placed in a storage location due to unavailability. The overflow instances are relatively small for each configuration. The number of pallets not stored in preferred zone indicates the number of times a class A SKU was placed in Zone B or C or a class B SKU was placed in Zone C. Although these two performance measures are lowest for the 100% Bulk storage configuration, the forklift utilization and distance traveled by the forklifts is much higher. This is primarily due to the larger number of bulk storage lanes need to accommodate the product mix and the much larger warehouse footprint. Of these three configurations, the 55% Bulk and 45% Rack system configuration seems to perform the best overall, as the number of overflow and non-preferred storage instances are acceptable, the forklift utilization, travel distance, and warehouse area are minimized.

6. Conclusions and Future Work

In this paper, we introduce a simulation-based methodology for the comparison of alternative warehouse system configurations. The methodology can enable companies to identify the appropriate mix of bulk and rack storage locations to effectively utilize warehouse space. The simulation methodology is based on a data driven modeling approach that allows the user to supply the input data for the existing system. With this, alternative configurations can be evaluated to study the trade-offs of system parameters including the number of bulk storage lanes, rack storage locations, and frequency zone allocation.

The future work for this research includes a more extensive experimental performance evaluation to quantify the capabilities and limitations of the methodology. In addition, we plan to investigate animation features that will enable the automatic creation of a realistic 3D visualization of the system configurations. Finally, we would like to investigate the use of AI methods for the selection of storage locations for arriving SKUs.

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