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A SIMULATION TOOL TO DETERMINE WAREHOUSE EFFICIENCIES AND STORAGE ALLOCATIONS

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ABSTRACT

Using ProModel simulation language, a universal warehouse storage simulation model has been developed. Applications of the model have been executed with success to analyze the storage capacity and rack efficiency of a medium volume, low stock-keeping unit (SKU) warehouse and a medium volume, large SKU warehouse. The model is scaleable and can be modified to simulate any warehouse configuration, including selective racks, bulk floor storage, push-back, flow-through, drive-in and drive-through racks.

1 INTRODUCTION

Due to the realization that the overhead for inventory may be as large as 50% of the purchase cost (Hodson 1992), many companies are more attentive to the amounts of material in their warehouse and the methods of their storage. Reducing this overhead has become a significant piece of many corporate near-term strategies. This endeavor is the motivation for our subject in this paper.

Unlike popular belief, every warehouse is not the same. With new warehousing technologies (especially high-density storage racks) becoming available for less, it is important to understand the effect of product mix, SKUs, batch sizing, order sizing, etc. on the layout and rack storage type of a warehouse. A ProModel-based simulation tool has been developed that can be used to assist an engineer in determining the number of pallet positions, pick faces and rack types required to store inventory. With this data, the combination of rack types, layout and operational standards can be determined that will allow a client to store more for less.

Specifically, the model was used to determine the type, amount and layout of pallet storage that was required for two industrial warehouses. Each warehouse was experiencing an overcapacity situation and the owners were looking for solutions to their storage needs without having to resort to brick and mortar.

Warehouse #1 was a manufacturer with medium volumes (~250 pallets a day throughput) and with a low number of SKUs (88) to store. They were anticipating a moderate production growth of 30% over a five-year period. However, they anticipated a much larger (50%) case count increase due to a change in packaging. At the start of the project, their existing rack system, which included bulk floor storage, selective racks, drive-through racks and flow-through racks, was fully utilized and they were required to use an overflow warehouse adjacent to the existing building.

Warehouse #2 was a manufacturer with a medium production volume (~300 pallet loads/day) with a large number of SKUs (~3000) to be stored. They were anticipating a minimal production growth over the next five years. Their existing rack system, which included selective racks and a minimum amount of bulk floor stacks, was also fully utilized and a second warehouse was being leased to accommodate the overflow.

Previous articles regarding the use of simulation as a tool in warehouse design have been written (Senko and Suskind 1990). More specific examples of articles that discuss models of order picking systems (Daniels et al. 1998, Kim et al. 2002), cost models for inventory and inventory sizing models (Cormier and Gunn 1996), models for warehouse capacity expansion (Cormier and Gunn 1999) have been written. We have dedicated our research to develop a simulation model to quantify rack utilization and capacity of different configurations of pallet racks in a warehouse. Currently, rack manufacturers and warehouse designers provide rules-of-thumb (Advanced Storage Products 2002) to determine rack utilization for high-density rack systems.

2 WAREHOUSE SIMULATION MODEL

The simulation model was developed using the ProModel software tool. A design criteria document was developed to guide the simulation model development. This document includes the model objectives, data required, model design, general logic flow, and experimentation and analysis. The following is a brief synopsis of that design criteria document.

2.1 Model Objectives

The simulation model is being utilized as a tool to analyze existing warehouse systems, as well as a method to experiment with different storage and process options. More specifically, the simulation model was developed so that it can be used to answer the following concerns:

- Determine the following effects on warehouse size:
  - Production run size
  - Age of warehouse stock
  - Incoming material transfer from other plants
  - Shipping lead-time
  - Outsourced items
  - Poor inventory control
  - Different rack/storage types
- Equipment/resource limitations
- Storage method efficiency
- Order picking method performance
- Layout efficiency.

2.2 Required Data

The model and analysis requires a significant amount of data to be collected. The acquisition of the necessary data will require both observational data and ERP system database queries.

Observational data

- Duration of pallet storage
- Distribution of trailer arrivals
- Duration to load trailer
- Duration to pick an order
- Duration of picked orders staged.

ERP system data

- Customer orders
- Current warehouse inventory by pallet location
- Physical inventory data
- Current warehouse inventory by item
- Production order
- Inter-warehouse transactions
- Outsourced finished goods receipts
- Production orders.

2.3 Model Design

A ProModel simulation model consists of several modules that when brought together create a dynamic system that can be used to emulate a real system. The modules of a simulation model are entities, locations, and resources. The entities control the flow of action or the tasks in a system. The locations define objects where these tasks occur and the resources are the items required to execute a given task. The following sections will describe the basic elements of each module that were developed for the warehouse simulation.

2.3.1 Entities

Production Order This entity represents the orders completed by the production machines on a daily basis. It also dictates the product numbers and their quantities produced by each of the lines.

Case This entity represents a single case of packaged goods. These cases are loaded onto a pallet for eventual delivery to the warehouse.

Pallet This entity begins as an empty pallet. The empty pallet is placed in a loading area adjacent to a machine, which is then loaded with cases. Once full, this entity represents a pallet of finished goods ready for storage in the warehouse.

Customer Order This entity is generated and orders the start of the case picking process. This entity remains in the system until the completed pallets are loaded into the trailer.

Replenishment This entity controls the replenishment operation for picking bins. Once created, this entity will be assigned a product number and then will release the stored pallets to be retrieved by the stacker driver crew.

Customer Pallet This entity is unique than the previous pallet entities discussed, since it represents the pallets that are loaded with cases during the picking process.

2.3.2 Locations

Workcenter Locations for the manufacturing machines. The model is currently designed to have up to 50 production lines running at a given time.

Put-Away Staging The staging area for transfer of pallets between production and the warehouse.

Pallet Storage A large number of general locations are used to define the warehouse storage system. Each location can be modified by changing its parameters to define the different types of storage including: bulk floor storage, selective racks, drive-in, drive-through racks, flow-through racks and pushback racks. The number and type will vary as different storage scenarios are developed.

“A” Bin The pallet positions available for pallets to be picked from (picking bins).

Customer Staging There is a specific area that will be used to stage completed pallets from the picking area.

2.3.3 Resources

Production Material Handlers This crew transports the completed pallets from the production workcenter, through stretch wrapping and to the putaway staging area in the warehouse

Stacker Drivers This team is responsible for putaway of pallets and retrieval of pallets for the “A” bins, as necessary. Another duty will be to unload full pallets from the storage locations for shipping.

Picking Crew This crew is responsible for picking cases for the customer orders. This includes stretch-wrapping the completed pallets.

Reach Trucks These trucks are used for storage and retrieval of pallets from the pallet racks. This resource will have an associated downtime for battery changes.

Walk-Behind Trucks These pallet trucks are used during the case picking process of order picking. This resource will have an associated downtime for battery changes.

Lift Trucks Generally, these trucks are used to load trailers, but may serve other miscellaneous tasks also.

Trailer Loaders These resources are responsible for loading the trailers with completed pallets.

2.4 General Logic

The general flow logic was broken down into several process flow diagrams. These diagrams were the road maps used to ensure that the model reflected the actual warehouses that were being modeled.

Auto-Palletize This part of the model is available for warehouse operations that contain an auto-palletizer. This diagram contains the logic flow of cases from the production, through an incoming conveyor, through the gantry operations and onto the pallet.

Manufacturing Describes the operations of the production of items from setup, through production and case palletization to the delivery of completed pallet to the warehouse.

Storage & Retrieval Contains the logic flow of completed pallets from the output of manufacturing, to pallet storage and pallet retrieval by the picking operation. Figure 1 is an example of the put-away logic flow.

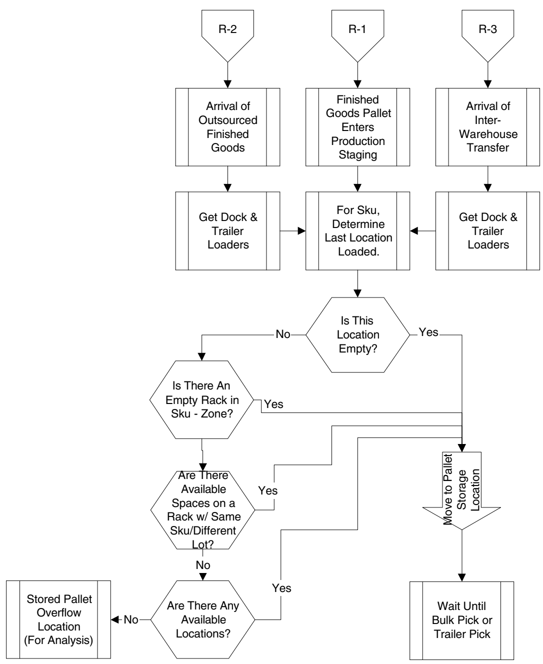

Figure 1: Put-Away Logic Flow

Order Fulfillment This logic flow describes the case picking operation through shipping.

There are several tables used in the model to store and retrieve data required. These are defined as:

SKU	This table will keep track of the characteristics of each case code (SKU).
Storage	This table will provide for each SKU its multiple locations and quantities.
Storage Racks	This table will define the characteristic of the racks used in the warehouse, including type, capacity, and loading rules.
Bulk Retrieval Report	This table will list each SKU and the quantity of cases required.
Customer Tally	For each customer, this table will list each required product number and its quantity for each daily customer set.

The simulation model can be run for any length of time depending on the amount of data that is available. Typically, the model was run for a period of one month in order to adequately warm-up the system and to collect statistically sound data. The user also has the ability to turn the randomness on or off using a user-defined parameter and to change the distribution parameters of the time delays.

2.5 Experimentation and Analysis

The simulation model can be used to answer the following concerns:

- Warehouse capacity due to company growth
- Storage method efficiency
- Equipment/resource limitations
- Order picking method performance
- Effect of the production run size.

These concerns affect the overall performance of a warehouse system. Therefore, these items can be considered as controllable factors of this system. For each of these factors, there exists a set of different options that in some manner change the system (e.g., number of pallet racks). The simulation model can be configured for each of these options. In order to compare and evaluate the options, a performance metric (e.g., operator utilization) must be calculated during each simulation run. Each controllable factor will have a set of metrics that best quantifies the system performance for analysis and that have the most potential to change due to different options within the factor. The controllable factors of the model and their performance metrics and extraneous factors are defined in Table 1.

Table 1: Controllable Factors and Metrics of the Model

1. Storage Methods/Warehouse Management	
Metrics	**Extraneous Factors**
• Storage equipment utilization (%) • Average warehouse inventory • Maximum warehouse inventory	• Increase in production volume • Changes in production cycles

2. Warehouse Crew Size	
Metrics	**Extraneous Factors**
• Operator utilization (%) • Hours to satisfy demand	• Increase in production volume

3. Case Picking Methods	
Metrics	**Extraneous Factors**
• Picking duration • Picking crew utilization (%) • Picking throughput (pallets/hr)	• Increase in production volume

4. Customer Order Staging Capacity	
Metrics	**Extraneous Factors**
• Picking duration • Staging utilization (%) • Picking throughput (pallets/hr)	• Increase in production volume

5. Production Cycles	
Metrics	**Extraneous Factors**
• Production line utilization (%)	• Increase in production volume

3 MODEL APPLICATIONS

The model has been utilized successfully in two separate applications. In each case, the results of the model were validated against the observed systems. In each of these applications, the system is a finished goods warehouse where the storage and retrieval of pallets was performed manually. The first application was performed at a medium volume, low SKU warehouse with automated palletization of finished goods cases. The second application was performed at a medium volume, high SKU warehouse. In each of these cases, the different conceptual warehouse designs that included different rack type configurations were represented by the model. For each model, three significant output metrics were calculated. These metrics can be defined as the rack utilization by rack type and the average and maximum number of pallets in storage.

It is important to note that the inputs to the model, such as production orders and customer orders, are existent historical data that has been converted into a format the model could efficiently read. Although these inputs are not probabilistic, the model has untested stochastic capabilities.

3.1 Medium Volume, Low SKU Warehouse

In this section, we describe the background and results of the first application, a finished goods warehouse that received from an adjacent production facility and shipped 250 pallets daily (Figure 2). The motive for our study was the evident current limited capacity (3331 pallet positions) of the warehouse coupled with expected growth of demand over the next five years. Anticipating the eventual overcapacity of the warehouse, the necessity to develop alternative warehousing solutions was critical to continued plant operations. Although our emphasis in this study was the utilization of the warehouse, our model integrated the following processes; palletization of cases from production, pallet putaway, order fulfillment and trailer loading.

The current warehouse configuration comprised of 48% flow-through rack, 31% bulk storage (floor), 14% drive-through rack and 7% selective rack. Another characteristic of this warehouse includes the accommodation of only 88 different product types (SKUs). The size of this warehouse is 70,000 square feet. The model would quantify the increase in warehouse capacity through conversion of bulk storage and drive-through rack that historically have low rack utilization in certain applications, to flow-through racks.

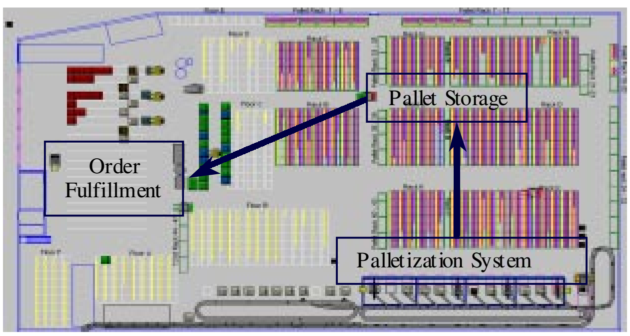

Figure 2: Graphical Representation of Warehouse Model

3.1.1 Model Validation

The observed system contains various rack types from simple bulk storage to more complex types, such as flow-through racks. This mixture is an advantage in the validation of model results. It permits the comparison of the rack utilizations of the observed system to the model calculations. Multiple samples were collected to calculate the observed rack utilization values for each rack type. The model was run for a period of four weeks, 24 hours/day.

Table 2 delineates both the observed and model rack utilizations. It is important to note that the inputs to the model are from a period that was earlier than when the observed samples were collected. This notion is the reason for the subtle differences in rack utilization between the model results and observed values. The production and shipment rates vary throughout the course of the year. Therefore, the inventory levels are dynamic, as well as, the rack utilizations.

Another point to discuss, is that the simulated rack utilizations were developed with an input set that did not maximize the warehouse capacity. Therefore, the shown utilization levels are not an indication of the maximum utilization of the racks. To investigate the maximum capabilities of the warehouse, the model was run until a point where the racks achieved capacity based on the put-away rules as designed by the owner and the inventory size of the various products. These rules restricted the rack utilization that would be greater in value if a conventional warehouse management system was employed. Table 3 provides the model results for the warehouse operating at a maximum capacity level.

Table 2: Rack Utilization of Observed and Model Results

	Rack Utilizations (%)	
Rack Type	**Model Result**	**Observed**
Flow-Through	79%	78%
Drive-Through	56%	61%
Bulk Storage	58%	61%
Selective	88%	88%
Overall	**70%**	**71%**

Table 3: Maximum Rack Utilization

Rack Type	**Rack Utilization (%)**
Flow-Through	84%
Drive-Through	58%
Bulk Storage	67%
Selective	100%
Overall	**76%**

3.1.2 Model Results

A summary of the warehouse model results is best illustrated as the chart in Figure 3. Each vertical bar on the chart represents the average number of required pallet positions in the warehouse during the selected 4-week period for a particular year. For each year, the production and shipment quantities were increased by a general growth factor that was defined by the owner. The increase in required warehouse capacity was commensurate with the increase in demand.

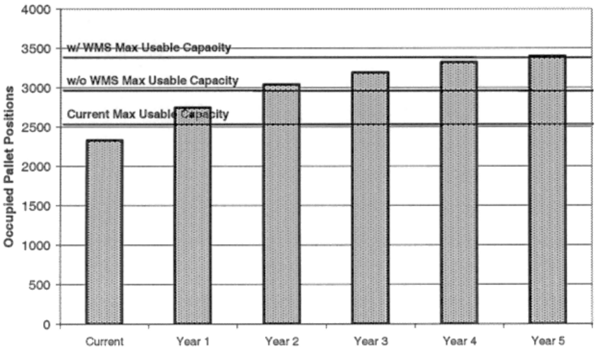

Figure 3: Warehouse Storage Requirements

The horizontal lines denote the capacity of the different warehouse concepts as developed during the study. The values of these lines are calculated as

$$C_{max} = \sum_{i=0}^{N} \left(\mu_{max_i} x_i \right) \quad (1)$$

where C_{max} is the maximum capacity of the warehouse under consideration. μ_{max} is the maximum utilization as calculated by the model for the rack type, i, and x is the number of pallet positions of the particular rack type in the warehouse design.

The lowest horizontal line represents the current maximum capacity of the warehouse at 2,544 pallet positions. The best warehouse rack concept converted all of the drive-through racks and a majority of bulk storage to flow-through rack types, which is represented by the next higher horizontal limit. For this concept, the maximum overall rack utilization is 85%, thus resulting in a maximum usable capacity of 2,971 pallet positions. The topmost line is the maximum usable capacity of the rack concept integrated with a warehouse management system that allows more complex putaway rules thus increasing the rack efficiency to 96%. The capacity for this warehouse system is 3,372. As illustrated by Figure 3, the warehouse system including an advanced warehouse management system is the only developed concept that would meet the future operational requirements for the next five years.

3.2 Medium Volume, High SKU Warehouse

The second application of the model was utilized in a study of a finished goods warehouse that was already at overcapacity that would only experience further problems due to an anticipated growth in demand. The objective of this application was to quantify the utilization and capacity of reasonable, cost-effective warehouse designs. To rectify this overcapacity, an additional warehouse that supplemented the main warehouse was leased at an approximate cost of $450,000/year. Approximately 40% of the finished goods inventory was stored at this warehouse that was five miles from the production facility. Additional operational costs were realized through additional space, equipment, and manpower.

Current warehouse operations can be quantified in terms of daily receipt from an adjacent production area and shipment of 300 pallets. Another characteristic of this warehouse is that it was required to store 3,000 different SKUs. The composition of the current warehouse design can be described as 70% selective pallet racks and 30% bulk storage (floor) of pallets. One outcome of this study demonstrated the inefficiency of the current storage methodology.

3.2.1 Model Validation

For this application the owner only used selective pallet rack and bulk storage. Therefore, validation of alternative racks systems rack utilizations were not performed in this case. However, a validation of the inventory size of the observed warehouse and that of the model was performed with satisfactory results.

3.2.2 Model Results

In this study, four warehouse design concepts were developed to provide the owner with varying options of warehouse capacity, complexity and cost. The warehouse concepts are described as follows:

1. Selective Rack Concept
2. Flow-Through Rack Concept
3. Pushback Rack Concept
4. Maximum Rack Concept.

Each concept had utilized the current warehouse space while using additional facility space through removal of under-utilized production equipment and removal of office space. The main difference between each design is in the rack type used in the newly available space. The exception was concept four which included the maximum amount of high-density storage possible for the given facility footprint. Table 4 delineates the composition and performance of each concept.

Similar to the first application, the model calculated the utilization of each rack type based on the putaway logic and inventory levels of each SKU. Table 5 provides the results of these calculations. Using the aforementioned formula (1), the average usable rack positions were calculated as

$$C_{avg} = \sum_{i=0}^{N} \left(\mu_{avg_i} x_i \right) \quad (2)$$

where C_{avg} is the average capacity of the warehouse under consideration. μ_{avg} is the average utilization as calculated

Table 4: Warehouse Concepts Capacities

	Warehouse Concepts (Pallet Positions)			
Rack Types	**#1**	**#2**	**#3**	**#4**
Selective	4,044	3,248	3,196	880
2-Deep Pushback	368	368	376	352
3-Deep Pushback	228	228	1,464	5,064
4-Deep Pushback	144	144	144	*
5-Deep Flow-Thru	*	240	*	*
6-Deep Flow-Thru	*	936	*	*
Total	4,784	5,164	5,180	6,296
Avg Usable Rack	**4,741**	**4,922**	**5,065**	**5,095**
Avg Utilization	**99.1%**	**95.3%**	**97.8%**	**80.9%**
Estimated Cost	**$132K**	**$380K**	**$251K**	**$730K**

Table 5: Average Rack Utilization of Each Type

	Rack Utilizations (%)	
Rack Type	**Concepts 1-3**	**Concept 4**
Selective	100%	100%
2-Deep Pushback	95.7%	95.7%
3-Deep Pushback	94.3%	76.6%
4-Deep Pushback	90.5%	90.5%
5-Deep Flow-Thru	84.3%	84.3%
6-Deep Flow-Thru	82.8%	82.8%

by the model for the rack type, i, and x is the number of pallet positions of the particular rack type in the warehouse design.

The three-deep pushback rack utilization is shown to be significantly reduced from its value of warehouse concepts 1 through 3 to its value of concept 4. The reduction is a result of significantly increasing the ratio of multi-depth pallet rack to selective rack. For this particular application, there does not exist an adequate amount of products with inventory levels that efficiently fit in a high number of high-density racks. Many of these products have less than five pallets in inventory. Therefore, the ratio of multi-depth to selective rack used in warehouse concepts 1, 2 and 3 is efficient for this example.

Figure 4 illustrates the comparison of the various warehouse concepts and the warehouse capacity requirements for the years as indicated. The inventory requirement values are shown as the vertical bar for each year. These values were calculated by the warehouse model where the inputs to the model were changed each year to reflect growth and inventory reductions.

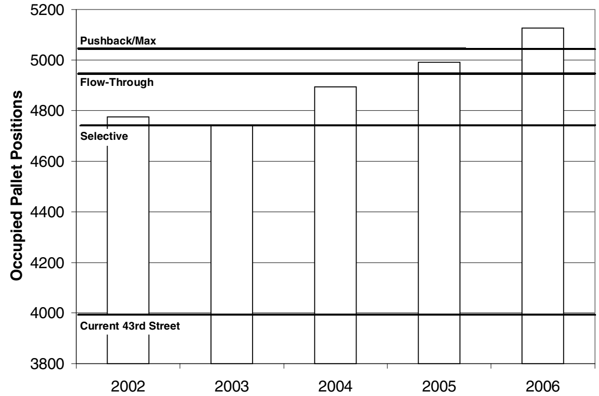

Figure 4: Comparison of Warehouse Concept Designs

For this example, there are three chief considerations in selecting the appropriate warehouse layout; cost, production/scheduling capabilities, and capabilities to meet future warehouse demands. Immediately, the maximum pallet position layout concept can be eliminated as a candidate due to its expense, particularly since it does not significantly outperform the less expensive pushback layout option. The selective rack concept is the least expensive, but more aggressive production schedules are required to reduce inventory levels and to meet future inventory growth. The pushback layout option performs well through 2006 through a modest change to production schedules. The flow-through layout is feasible but more expensive than the pushback concept. Unless strict first-in/first-out must be maintained, this layout concept can be removed from consideration.

4 CONCLUSION

Successful studies that have assisted in the efficient design of warehouses have proven the usefulness of the work defined in this paper. In both studies described herein, the quantitative analysis that the warehouse model provided assisted the design team in the development and selection of the best warehouse design for the given application. Also, previous perceptions of the capabilities of the current warehouse systems were in some cases disproved. The ability to foresee the effects of growth on the system was also beneficial in determining the appropriate investments in the warehouse. Certain warehouse concepts were demonstrated to work well in the current conditions, however, due to growth were quickly outgrown.

Future work of this endeavor will include further validation in other systems particularly in high volume applications. While the code is universal for any model, the user interface and input can be improved to enable fast calculations of any warehouse size requirements. Thereby enabling warehouse design teams to quickly develop warehouse concepts that are more accurate than the current rule-of-thumb or heuristic methods.

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