Cost-Optimized Warehouse Storage Type Allocations

by

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Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

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Abstract

Amazon's phenomenal sales growth and desire to maintain "Earth's Biggest Selection" have led to an increase in the diversity of product offerings that has resulted in a corresponding increase in complexity of Amazon's warehouse storage management. There is currently limited insight into the trade offs between the capital, fixed and variable costs of Amazon's storage related operational decisions, leading to inefficient warehouse storage type allocations and higher operational costs. The focus of this six-month LGO internship was to develop a cost model that takes into account all relevant costs to develop recommendations on warehouse storage type allocations for both existing and new fulfillment centers in Amazon's North America Fulfillment Center network.

This thesis begins with an overview of Amazon and a description of their fulfillment center network. The overview is followed by a literature review of current warehouse design frameworks and storage optimization research. The following chapter analyzes the current inbound warehouse processes to identify what the relevant storage decisions are, where they are being made, and the current decision making process. Finally, through the development and implementation of a cost model and an analysis of key findings, the thesis provides recommendations for cost-optimized warehouse storage type allocations.

The major recommendations are to replace floor pallet storage within existing fulfillment centers, increasing Non-Sortable product mix in select existing Sortable fulfillment centers, and optimized storage type allocations for new fulfillment centers. The expected scaled annual cost savings associated with these cost optimized warehouse storage type allocations within the existing fulfillment centers is 34% across the entire network and 62% for the select Sortable fulfillment center. The expected scaled annual cost savings associated with the optimized storage type allocations for the new fulfillment centers is 24% per new Sortable building and 11% per new Non-Sortable building. The methodology utilized within the cost model to compare fixed, variable and capital costs can be applied more broadly to assess the cost impact of different storage types in any warehousing design framework.

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Finally, I would like to thank my family and friends, particularly my incredible LGO classmates. Having this outstanding support network has made all the difference in helping to drive my success.

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1 Introduction

The purpose of this thesis is to explore a methodology to assess the total cost impact of stow related decisions utilized to allocate different storage solutions within a warehouse in a retail fulfillment network. Optimization of storage types can be used to reduce both operational costs within the warehouse and the total required warehouse square footage. The research presented was done as a part of an internship completed with Amazon.com, in conjunction with the Leaders of Global Operations program at the Massachusetts Institute of Technology.

1.1 Problem Statement

Amazon's phenomenal sales growth and desire to maintain "Earth's Biggest Selection" have led to an incredible increase in the diversity of product offerings. In addition to the core media products such as books and DVDs, which the Amazon fulfillment center network was built and optimized to process and store, Amazon now offers product lines that range from jewelry to large sporting goods. This diversity has created challenges in understanding how to efficiently store and process items through a fulfillment center. While core media products tend to be uniformly sized and received in standard quantities, the addition of product lines and new service offerings has resulted in Stock Keeping Units (SKUs) that arrive in a wide variety of sizes and quantities, ranging from a single unit to truckloads of a single SKU.

1.2 Project Goals

Currently, there is no cost-optimized network standard policy on where to store an item within an Amazon warehouse, which has led to variation in stow policies throughout the North America fulfillment center network. Stow policies are the decisions governing the location (forward versus reserve) and storage type (see Appendix A: Storage Type Definitions) in which a product is ultimately stored. These decisions drive variable, capital and fixed costs within the fulfillment center making it imperative to develop cost-based standardized stow policies. The necessity of standard stow policies and a framework for understanding the costs driven by these decisions will increase as the fulfillment center network continues to expand to meet growing customer demand.

In order to meet this need, this project seeks to develop standardized, cost minimizing storage allocation recommendations for the fulfillment center network by developing a cost model to evaluate stow decisions. The model will take into account all relevant costs related to these stow decisions. Recommendations will be provided for storage type allocations for both currently existing fulfillment centers and for new fulfillment centers.

1.3 Project Approach

The project approach to achieve these project goals was divided into four phases:

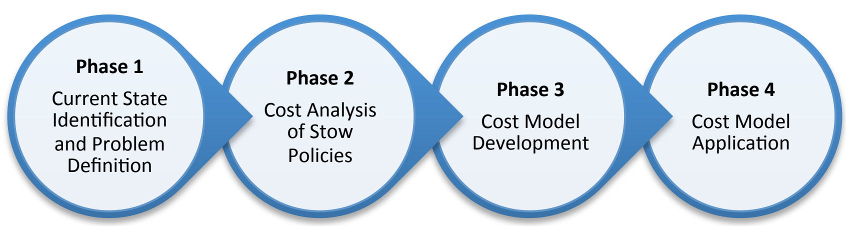

Figure 1. Project approach

Phase 1: Current State Identification and Problem Definition

The goal of this phase was to develop a definition and understanding of current state stow policies in the North America fulfillment center network through analysis of inbound processes at the two primary warehouse types: a Sortable and Non-Sortable fulfillment center. This phase included key stakeholder identification and interviews in addition to process mapping of the inbound processes. Additionally, documentation of what decisions are being made, where these decisions are taking place, and what the drivers of these decisions are was completed.

Phase 2: Cost Analysis of Stow Policies

The goal of second phase of the project was to identify the cost drivers and key metrics for the identified stow decisions from Phase 1. This phase also included an initial analysis of historical inbound process cost data to determine required model inputs.

Phase 3: Cost Model Development

Phase 3 was the development of an analytical framework to evaluate stow decisions. This included identification of appropriate tools, additional data analysis to determine fixed and variable inputs, and formulation of methods to compare the relevant costs. This phase required heavy involvement from key stakeholders from the fulfillment centers, finance organizations, inbound supply chain, and the capacity planning organization.

Phase 4: Cost Model Application

The cost model was utilized in this phase to identify optimized storage type allocations at existing and new fulfillment centers in the North America fulfillment center network. Additional cost savings opportunities were assessed and evaluated for potential implementation.

1.4 Thesis Overview

The thesis begins with an overview of Amazon.com and a description of the Amazon fulfillment center network in Chapter 2. This is followed by a review of relevant published research on warehouse design. Chapters 4 and 5 provides the current state analysis of stow related process flows at the fulfillment center and the subsequent development of the cost model. This cost model is then applied to the current fulfillment center network in Chapter 6 and new fulfillment center development in Chapter 7 to provide cost optimized storage type allocation recommendations. In Chapter 8 the conclusions to the thesis and recommendations are summarized.

2 Amazon.com

2.1 Company Overview

Amazon.com is a global e-commerce retailer founded in 1994 with a mission to be "Earth's most customer-centric company for four primary customer sets: consumers, sellers, enterprises, and content creators."[1] In order to achieve this mission statement, Amazon follows the business model from the customer experience centered growth business model. This model was originally on a napkin by the company's founder and CEO, Jeff Bezos, as shown in Figure 2.[2] In this growth cycle, also known as the "Virtuous Cycle" within the company, the growth flywheel leads to a lower cost structure, which leads to lower prices and an improved customer experience. This improved customer experience leads to increased website traffic and more sellers on the website, thereby increasing selection which feeds back into improving the customer experience.

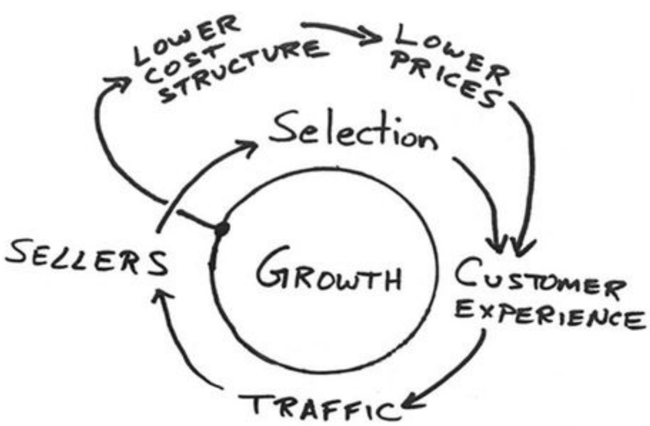

Figure 2. Amazon growth cycle

This business model has proven highly successful for Amazon, which saw a 41% year over year sales growth in 2011 with net sales of $48B, shown in Figure 3.[3] This exponential increase in sales has been mirrored in the growth of the product mix from core media products such as books and music to

[1] http://phx.corporate-ir.net/phoenix.zhtml?c=176060&p=irol-factSheet
[2] http://seekingalpha.com/article/121955-amazon-s-wheel-of-growth
[3] Amazon.com Form 10K, http://phx.corporate-ir.net/phoenix.zhtml?c=97664&p=irol-reportsannual

electronics, grocery, toys, luxury goods, and much more. This expansive product mix along with the introduction of services such as the highly successful Amazon Prime[4] membership program that offers members free two day shipping has greatly increased Amazon's supply chain and logistic complexity.

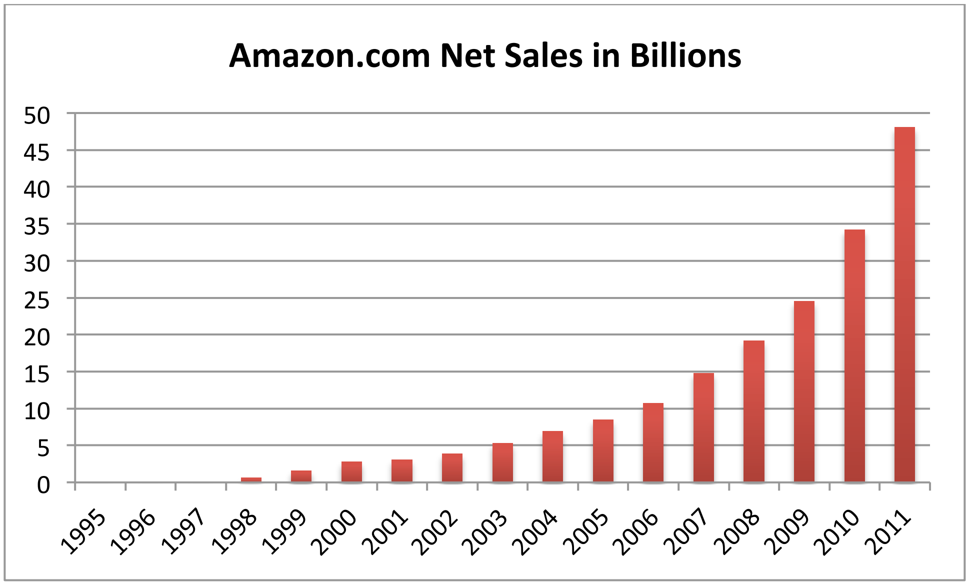

Figure 3. Amazon.com Net Sales Growth

In order to address the increasing customer demand reflected in Figure 3 and the operational challenges created by increased product variety and fast fulfillment requirements, Amazon's fulfillment center network has grown alongside sales. In 1995, Jeff Bezos began shipping customer orders from his garage in Bellevue, WA. Today, Amazon operates dozens of fulfillment centers within North America and dozens more internationally.

2.2 Fulfillment Center Network

The Amazon fulfillment center network is responsible for processing inventory received from suppliers into the warehouse, storing the inventory, and shipping products to the customer. With Amazon's core focus on customer experience, the operational effectiveness of the fulfillment center network is critical in not only ensuring that customers receive shipments before or on their promised receive date but for the

[4] http://www.amazon.com/gp/prime

company's continued growth and success. While the focus of the research in this paper is on the North America fulfillment network, Amazon also maintains operations in Canada, Europe, Japan and China.

2.2.1 Growth in North America Fulfillment Center Network

The Amazon fulfillment center network has been growing rapidly in response to increasing customer demand, with additional fulfillment centers being opened every year. In 2011 alone, Amazon opened up 17 additional fulfillment centers.[5] As the number of fulfillment centers continues to grow, it becomes increasingly important to develop standards to optimize the fulfillment center operations.

2.2.2 Description of Types of Fulfillment Centers

The fulfillment center network consists of Sortable fulfillment centers, Non-Sortable fulfillment centers, Delayed Allocation fulfillment centers, and Specialty fulfillment centers. Maintaining these categories of fulfillment centers allows Amazon to fulfill large varieties of inventory with high efficiency. An overview of these fulfillment centers is provided below in Table 1.

Fulfillment Center Type	Inventory Processed	Fulfills To
Sortable	Small items such as books and DVDs	Customers
Non-Sortable	Larger items such as televisions and rugs	Customers
Delayed Allocation	Small and large inventory	Amazon fulfillment centers
Specialty	Inventory requiring unique storage or processing requirements	Customers
Forward Deploy	Small inventory	Customers

Table 1. Overview of fulfillment center categories

[5] http://www.bloomberg.com/news/2012-03-21/amazon-wrings-profit-from-fulfillment-as-spending-soars-tech.html

Sortable Fulfillment Centers

Sortable fulfillment centers focus on processing items that can be transported on conveyor belts (conveyance), such as books and small media items. These fulfillment centers process the large majority of customer orders and employ the largest labor force in the network. The sortation process used to combine multiple items for a single shipment is done manually in most of the Sortable fulfillment centers with the exception of a few Sortable fulfillment centers that utilize auto-sortation systems.

Non-Sortable Fulfillment Centers

Non-Sortable fulfillment centers process all larger SKUs, such as rugs, kayaks and televisions. Non-Sortable inventory tends to be slower moving than Sortable inventory within the fulfillment center network. The sortation process used to combine multiple items for a single shipment at Non-Sortable fulfillment centers is done manually and there is no conveyance within these fulfillment centers.

Delayed Allocation Fulfillment Centers

Delayed Allocation fulfillment centers process inventory to be distributed across the fulfillment center network, as opposed to being fulfilled directly to the customer. The use of Delayed Allocation fulfillment centers reduce the amount of risk across the network and enables lower safety stock levels at the Sortable fulfillment centers.

Specialty and Forward Deploy Fulfillment Centers

In addition to the Sortable, Non-Sortable and Delayed Allocation fulfillment centers, there are a small number of Specialty and Forward Deploy fulfillment centers. Specialty fulfillment centers hold inventory that require unique storage or processing requirements. Forward Deploy fulfillment centers are small warehouses located near large metropolitan areas in the domestic fulfillment center network. These facilities receive transshipments from the larger fulfillment centers in the network, which they then sort and fulfill to customers in the nearby metropolitan areas. This delayed processing reduces shipping costs by eliminating air shipping costs from orders.

2.2.3 Difference with Brick and Mortar Store Supply Chains

The operation of Amazon's fulfillment center network differs significantly from traditional brick and mortar stores. Inventory in the Amazon supply chain is received from suppliers at all fulfillment centers. Each Amazon fulfillment center will then break down any bulk inventory into individual units to be packaged and sent directly to customers. In contrast, traditional brick and mortar stores typically receive inventory from suppliers directly to stores or to warehouses, which then distributes to retail locations where customers purchase the items in person.

In the Amazon model not all fulfillment centers will maintain the same inventory and it is possible for any fulfillment center to fulfill a customer order, regardless of customer location. This allows Amazon to pool demand variation on a network level, which lowers inventory holding costs throughout the network. The lack of retail storefronts also reduces Amazon's capital costs. These cost savings are then passed on to the customer in the form of lower prices, thus continuing the growth business model shown in Figure 2.

Another large differentiation between Amazon and brick and mortar stores, as well as a source of increasing complexity, is that Amazon fulfillment centers receive inventory from third party vendors as part of the Fulfillment by Amazon (FBA) program. In the FBA program sellers pay to have Amazon store and fulfill their products that are sold on Amazon's website directly from Amazon warehouses. FBA supports the growth model by increasing the selection available to Amazon customers and improving customer experience. The growth of FBA inventory within the fulfillment center network has added complexity to the Amazon fulfillment center inbound operations by increasing the variation of receive quantities and inbound shipments. In general FBA increases the amount of small parcel received at the warehouse and thereby decreases percentage of inbound shipments arriving through vendor freight (in larger pallet quantities.)

3 Literature Review

This chapter provides a review of literature around warehouse design and control relevant to the research presented in this paper.

3.1 Warehouse Design Frameworks

There have been several comprehensive reviews done of warehouse operations that provide frameworks for the warehouse design issues discussed in this paper. Rouwenhorst, et al. (2000) provides a reference framework and classification of warehouse design and control problems through a review of warehousing systems.

The warehouse processes in Rouwenhorst's review are categorized into receiving, storage, order picking and shipping which correlates to the Amazon fulfillment center processes discussed in the current state analysis in Chapter 4. Warehouse resources are distinguished into the storage unit, storage system, pick equipment, order pick auxiliaries, computer system and personnel. Warehouse organization issues are divided into the process flow, assignment policies determining the allocation of trucks to docks, storage policies, order picking zoning policies, sorting policies of picked order, dock assignment policies, and operator and equipment assignment policies. This thesis is focused on the receiving and storage processes, the storage unit and storage system resources, and the process flow and storage policies utilized within the warehouse.

Gu, Goetschalackx and McGinnis (2007) published another comprehensive review of warehouse operations, classifying warehouse operational planning problems into the warehouse functions of receiving, storage, order picking, and shipping. Similarly warehouse design problems are organized into overall structure, sizing and dimensioning, department layout, equipment selection and operation strategy. As discussed within the parallel framework provided by Rowenhorst, the focus in this paper is on storage, which is described as having the goal "to achieve high space utilization and facilitate efficient material handling." These two goals are encompassed within the fixed and variable cost optimization done within the cost model. Gu's review also provides insight into new planning models and methods currently available for warehouse operations including dynamic storage location assignment problems.

Bartholdi and Hackman (2011) provide a comprehensive review of warehouse science including a categorization of warehouse operations, equipment, and issues similar to framework discussed in Rouwenhorst's review. Additionally, the authors also present a method for conducting warehouse activity profiling to provide measurement and statistical analysis of warehouse activity. Bartholdi discusses how three main types of data are required to support profiling: SKU Data, Order History, and Warehouse Layout. Basic warehouse activity profiling was completed during cost model development and all three types of data were collected utilizing existing databases, stakeholder interviews, and on site visits to Amazon fulfillment centers as discussed in Section 4.4.

3.2 Required Flexibility in Warehouse Design

The challenges Amazon faces in handling the large increase in customer demand and diversity of SKUs can be described as a need for flexibility. Brockmann and Godin (1997) discuss warehouse flexibility and the requirement for warehouses to handle an increase in the variety and number of SKUs. Based on the flexibility benefits rating used in this paper, Amazon utilizes bulk storage, single deep pallet rack, and shelving storage that is rated as highly flexible. The authors discuss how "in general, the tighter the warehouse layout, the less productive the warehouse." This is a tradeoff being made at the Amazon warehouses that is analyzed in the cost model; maintaining a tighter layout means a higher density of products which can lead to shorter picking times and lower total processing costs.

3.3 Warehouse Performance Measurement

Rouwenhorst discusses warehouse performance criteria related to warehouse design and distinguishes two types of warehouses: the distribution warehouse and the production warehouse. He discusses how for the distribution warehouse, such as the fulfillment centers within the Amazon warehouse network, the "prominent design criterion is the maximum throughput, to be reached at minimum investment and operational costs." This thesis seeks to provide recommendations that will reduce the investment and operational costs, while maintaining the current order throughput.

Bartholdi and Hackman discuss the use of performance measurement, typically done as a ratio of units of output achieved to units of input required, to summarize key performance indicators such as operating costs, operating productivity, response time, and order accuracy. Amazon is a highly metric driven company and utilized all of these key performance indicators, as discussed in current state analysis in Section 4.5.

3.4 Warehouse Layout Optimizations

This thesis employs a cost model to provide fulfillment center storage type allocation recommendations to optimize the warehouse layout. Several alternative processes have been developed to optimize warehouse layouts and are described in recent studies. Larson, March and Kusiak (1997) discuss a process to optimize floor space utilization and decrease material handling. The procedure described consists of "(1) determination of aisle layout and storage zone dimensions, (2) assignment of material to a storage medium, and (3) allocation of floor space." The paper focuses on class based storage, as opposed to the randomized storage warehouse operations that Amazon employs. While the authors assert that randomized storage generally has a greater material handling cost because fast moving material is not in the most desirable storage locations (close to the shipping docks), there are congestion concerns with utilizing class based storage at Amazon warehouses.

In a different approach to warehouse layout optimization, Meller and Gue (2006) from the University of Arkansas and Auburn University discuss their fishbone layout concept. The fishbone layout reduces total travel distances of up to 20% compared to traditional parallel picking aisles divided by cross aisles such as those used at Amazon's warehouses. While this thesis focuses on optimizing the current traditional warehouse layout used within the fulfillment center network, the unique fishbone layout provides an area of future opportunity for Amazon.

4 Current State Analysis

The first step of creating the cost model was developing an understanding of the current state of the inbound and outbound process flows to determine the stow decisions taking place that impact the storage location of the received item and the total cost to the fulfillment center. Five geographically diverse Sortable and Non-Sortable fulfillment centers, all with technology and layout similar to expected new fulfillment centers, were analyzed in order to account for variations in processes throughout the network.

4.1 Inbound Process Flows

The primary inbound functions can be broken down into the Receive Dock, Receive, and Stow. A large focus in this section will be placed upon Stow due to its relevance to the cost model and recommendations for this process path.

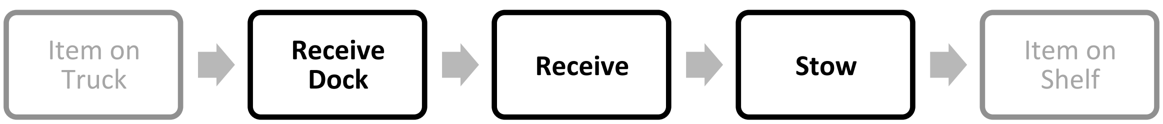

Figure 4. Overview of inbound processes

4.1.1 Receive Dock

The primary goal at the Receive Dock is to inspect shipments to ensure quality, check that the correct quantity and content matches Amazon's information, and to stage the items to be received. At the Receive Dock items can be received as a small parcel shipment, a transshipment from another fulfillment center, or as a large volume shipment through vendor freight.

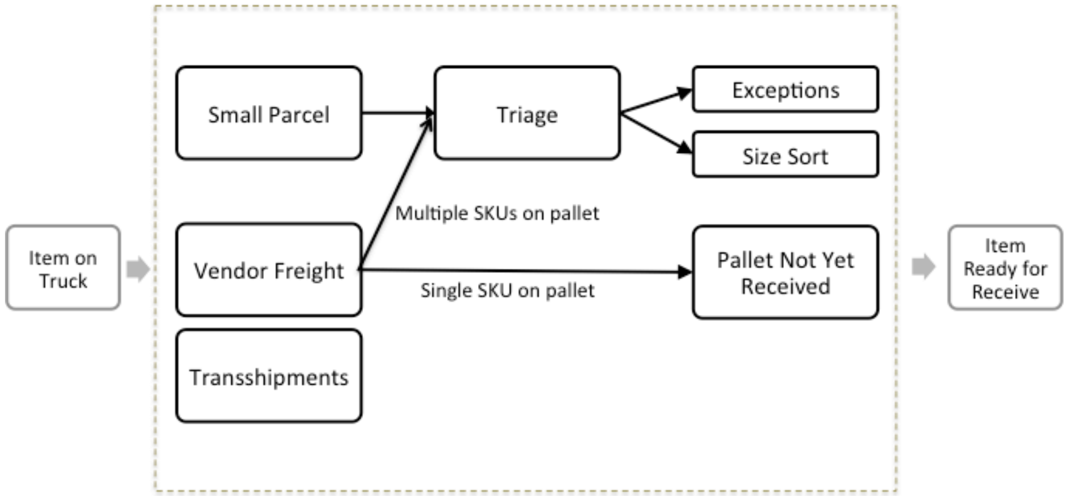

Figure 5. Receive dock process overview

Once unloaded off the truck onto the dock, all items from small parcel are sent to a triage area in which the extra packaging is removed and exception SKUs are pulled out. Exceptions include damaged items, items requiring additional packaging prior to being placed into storage such as liquids, items that require bagging, or items that are eligible to be received through a fast track process. These fast track SKUs are from approved suppliers and bypass the sort process.

All non-exception items are then sorted by size using a sizing template onto carts labeled “Library”, “Mixed”, or “Library Deep” representing different storage types. See the Stow section below for a synopsis of storage types and Appendix A: Storage Type Definitions for more detailed storage type descriptions.

Items from vendor freight with a single SKU on the pallet are sent to the pallet storage area for SKUs that have not have been received into the warehouse. If a pallet at the dock has multiple SKUs on the pallet the pallet will be broken down and the items will be loaded onto a cart and brought to triage to be received as individual units.

Transshipments have already been sorted at another fulfillment center and are sent directly to the receive process.

4.1.2 Receive

The goal of this stage is to virtually receive the items into Amazon's software system to be tracked and then to stage the items to be stowed. Once items are in queue to be received from the Receive Dock, each cart is sent to the appropriate receive line in a First in First Out (FIFO) flow. Library carts are sent through the Library Receive line in which each item is scanned, placed into totes, and put on conveyance. Similarly, Library Deep carts are sent through the Library Deep Receive line where each item is scanned, placed into totes, and put on conveyance.

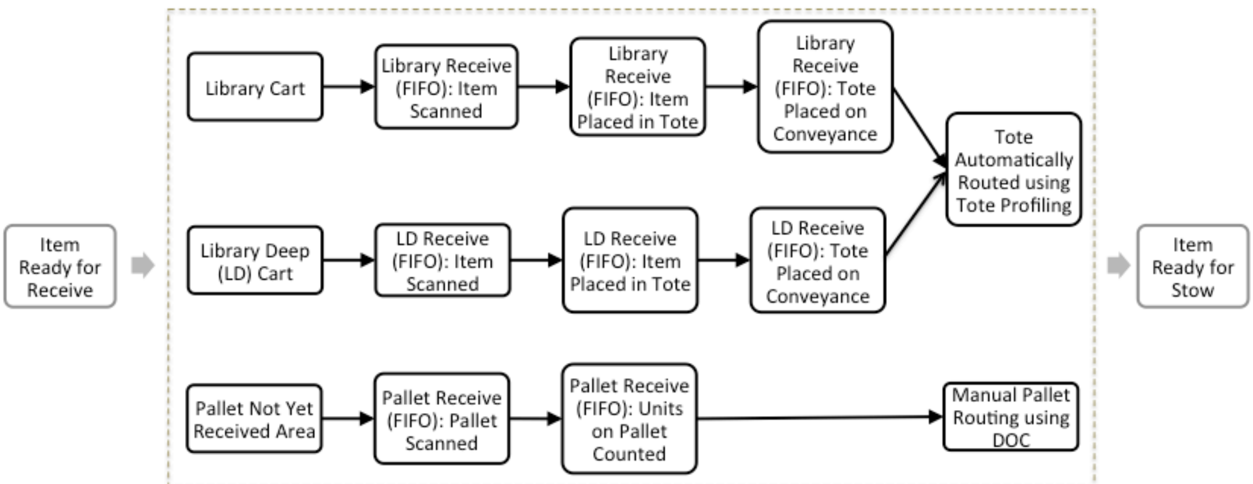

Figure 6. Receive process overview

There are a standard number of items placed in each Library or Library Deep tote, in accordance with standard work defined in the North America fulfillment center network. Once the tote is placed on conveyance, barcodes on the front of the totes are scanned using a tote profiling tool and routed to the appropriate storage area of the fulfillment center. The storage areas utilized are determined by the operations managers for that shift using tools that identify storage areas with the most amount of open space.

Pallets are received into the warehouse by scanning a pallet barcode and manually counting the number of items on the pallet. Based on an inventory level set by each fulfillment center's operation managers, the pallets are either sent to forward pallet storage or reserve pallet storage. This inventory level is called the Days of Cover (DOC) and is the estimated number of days of inventory held in forward pallet storage.

4.1.3 Stow

The goal of the Stow process is to physically store the products so that the product can be retrieved in the outbound pick process for a customer order. Once totes are received in the final storage area, they are placed onto carts based on shelving types and the carts are placed in a queue where they are processed in a FIFO process flow.

Items are physically stowed by associates using a random stow method in which items are placed wherever there is open space for the item. Associates are sent to a particular section of the fulfillment center (identified by management at the start of the shift) and instructed to stow in a certain region. When they find an available storage location the stower uses a RF scanner to scan the item and the storage location so that the physical and virtual location of the item is matched up. This enables the item to be put on a pick list to be retrieved for a customer order.

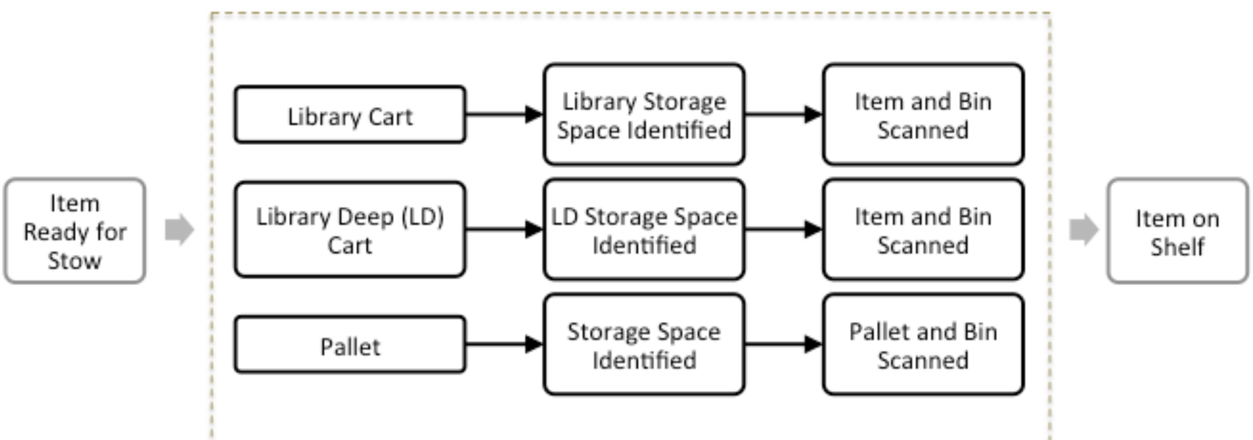

Figure 7. Stow process overview

There is a limited amount of directed stow utilized at the fulfillment centers. An example of this limited use of directed stow is for extremely high demand velocity items. For these types of items the entire pallet of units will be placed in a location close to outbound shipping, as opposed to being broken down and stored as individual units, to reduce the total warehouse transportation time. The velocity threshold for directed stow is set manually by management.

The shelving types used at Amazon are Library, Library Deep, and Pallet storage. An overview of these storage types is included below; a more detailed review of these storage types is contained in Appendix A: Storage Type Definitions.

Library

Library storage consists of shelving similar to what is found at a typical community or school library, sized to hold books and other smaller items. These shelves are divided into bins, individual storage units that can hold multiple small items. Examples of Library-sized items include books, CDs and DVDs. These shelves have the same depth of less than 12” but vary in height from 9” to 12” within each section of shelving. Library shelving is built in the form of single levels (rivitier shelving) or multi-level modules (pick mods).

Library Deep

Library Deep storage is similar to Library storage but with a depth of greater than 12” and shelf heights of 12” to 18”. The larger bin size allows this storage type to hold bulkier items such as kitchen items and electronics. Library Deep shelving is also built in the form of single levels (rivitier shelving) or multi-level modules (pick mods).

Pallet Storage

Pallet storage can be divided into floor and pallet rack storage. Floor pallet storage is considered to be forward storage, to be used for fulfillment of customer orders, while pallet rack storage is considered to primarily be reserve storage. The lower levels of pallet rack may be used as forward storage. Items in reserve storage need to be moved to forward storage before items can be used to fulfill customer orders. Floor pallet storage consists of pallets of SKUs placed directly on the floor, with no additional storage above it. Pallet rack storage consists of large shelving racks that can accommodate multiple levels of pallet storage, similar to what is found in large distribution centers.

4.1.4 Replenishment

An additional inbound process path is replenishment, in which items are retrieved from reserve storage and brought to forward storage. Replenishment can be done on an individual unit, case or pallet level. This occurs when the inventory of a particular SKU is depleted from forward storage. The replenishment process is similar to the pick process described below in combination with the stow process described above.

4.1.5 Non-Sortable Fulfillment Center Inbound Processes

The inbound process flows at a Non-Sortable fulfillment centers are very similar to the Sortable fulfillment centers, with a greater percentage of inbound shipments arriving through vendor freight and no conveyance. In lieu of conveyance, once units are received they are placed directly onto stow carts which are processed in a FIFO flow.

4.2 Outbound Process Flows

The outbound process flows can be broken down into pick, sortation, pack and ship. The only outbound process that is directly impacted by the stow decision made by the inbound supply chain is the picking process.

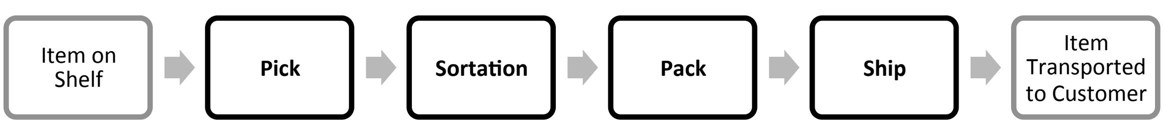

Figure 8. Outbound process flow overview

4.2.1 Pick

Once an order is placed, a computer directed system creates a picking path, or route, for a picker through the fulfillment center storage mods. The picker will go through this picking path and pick units to fulfill a number of orders. A handheld scanner shows the picker the bin location of the next item on the picking list. Once the picker arrives at the bin they inspect the item for damage, scan the item to virtually mark it as removed from the bin, and then place the item into a tote. The totes are then taken to sortation.

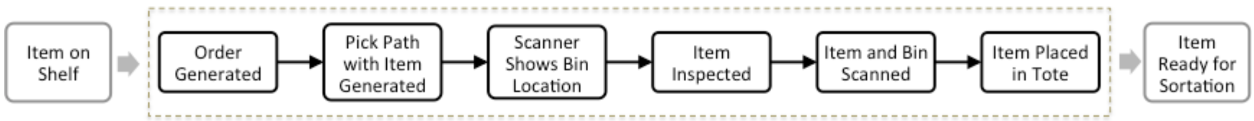

Figure 9. Pick process overview

Missing Items

An important exception case in the pick process occurs when a picker goes to the specified bin and is unable to find the physical item. If the item is not located where the virtual system believes it is located the picker will mark the item as missing on their scanner and move to the next item on their pick list. The system will then locate another unit of the SKU at the same warehouse and place it on another pick list. If there is not another unit of the SKU available it will locate the item at another fulfillment center. This exception process of missing items is extremely important as it can lead to missed customer shipments and increased labor costs, all which negatively impact the growth cycle.

4.2.2 Sortation

In sortation, units from an order that are dispersed amongst different totes are assembled into a single order. As mentioned earlier, Amazon fulfillment centers utilize both automated and manual sortation. Automated sortation consists of mechanical systems in which all items are processed through an induct station and are directed through conveyance to a single chute where the rest of the items in the order will be placed. Once the order is completed it will move on to pack and ship. In manual sortation, which occurs in the majority of fulfillment centers, the items will be scanned and manually placed in a temporary shelving bin along with the rest of the items in the order.

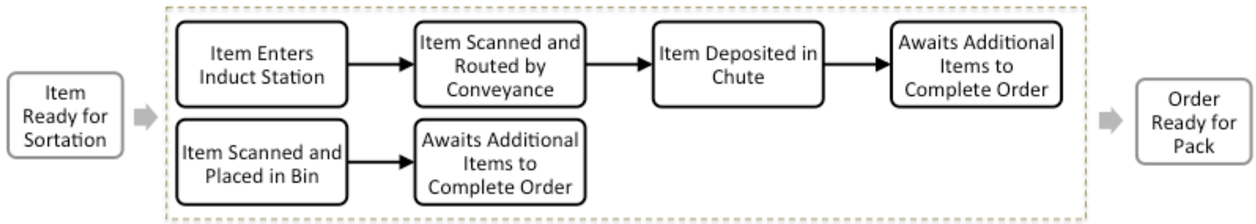

Figure 10. Sortation process overview

4.2.3 Pack and Ship

Completed customer orders are placed into appropriately sized packaging, labeled with a shipping label, and then directed either manually or using conveyance to the correct outbound dock. At the dock it will be loaded onto trucks for customer delivery.

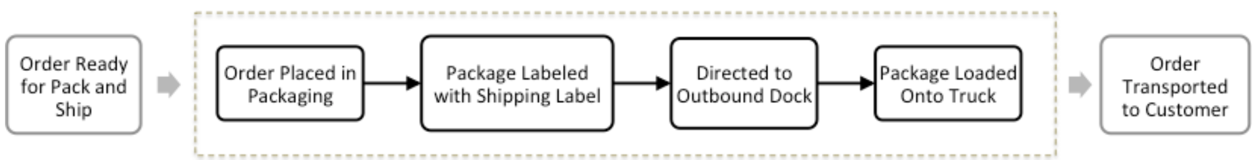

Figure 11. Pack and ship process overview

4.3 Stakeholder Interviews

Key stakeholders interviews were initiated throughout the first two phases of the project to understand the required scope of the project, existing related work, current accounting methods, and how various organizations may utilize the results of the model as well as the model itself for future business case development and opportunity assessment. Meetings with these key stakeholders continued throughout the remainder of the project to validate data and analysis as well as to provide stakeholders with results of the cost model development.

The organizations interviewed include capacity planning, supply chain finance, fulfillment center finance, fulfillment center financial controllers, engineering and operation managers. These interviews resulted in more clear project scoping, access to financial and cost data, as well as insight into potential areas of cost improvement, constraints related to stow within the fulfillment centers, and current priorities of the organizations.

In addition to the stakeholder interviews, a weekly stow call was organized in order to bring together stow subject matter experts who were dealing with similar problems throughout the North America network. This weekly call provided an additional opportunity to identify cost savings opportunities, required input requirements for stow decisions for the model, and to review the current status of the project.

4.4 Analytical Data Collection and Analysis

Historical data was collected to determine the average time it took for a unit to go through each process path for units of different inventory sizes (Library or Library Deep). This data was collected from databases containing detailed process path data for the major processes described above. Amazon associates use scanners to scan a SKU at every major process step in the inbound supply chain, in which all data associated with the SKU including physical dimensions is captured, so detailed information can be obtained on the exact processing time for different inventory types.

Two fulfillment centers (one Sortable and one Non-Sortable) were selected for analysis based on similarities to other large buildings in the network and expected similarities to capabilities (automation and layout) to new fulfillment centers planned to be built. Process path rate analysis from additional fulfillment centers was used for validation of key findings and for sensitivity analysis. The time scale of data analyzed was the most recent one-month of data from time of analysis in 2012, selected in order to take into account recent continuous improvement projects done at the two sites.

4.5 Key Performance Metrics

The key performance metrics tracked by fulfillment centers are the rates in units per hour (UPH) for each process path, broken down by product size specified by final storage bin type. These rates are tracked at an individual associate level and are aggregated up to a fulfillment center level for time periods beginning with each shift. Target UPH rates are provided by leadership teams and are communicated down to an individual worker level. These rates are primarily based upon the specific fulfillment center's historical performance and comparison to fulfillment centers with similar inventories and technologies.

Another metric pertinent in the model is the bin utilization at each fulfillment center. The bin utilization is the target level of volume occupied by inventory in a bin compared to total bin volume. This level is based upon increasing the utilization of storage capacity while maintaining other performance metrics such as pick and stow rates. If bins are too full, items may fall out of bins or not be clearly visible to be picked.

Additional performance metrics measured at the fulfillment centers include Defects Per Million Opportunities (DPMO), safety incidents, missed customer shipments, adherence to stow etiquette, and lost, broken or damaged inventory. These metrics are reviewed at regular intervals by fulfillment center leadership teams and corporate organizations including finance and capacity planning.

4.6 Current State Problem Statement

There are many storage decisions that are being made without a clear understanding of total cost ramifications. These decisions include initial warehouse design and current process decisions occurring throughout the processes described in this chapter, from the sizing template used to determine if an item goes to Library or Library Deep shelving in the Receive process to how many unique items can go into a storage unit in the Stow process. Bartholdi (2011) discusses how "storage locations are expensive because they represent space, with consequent costs of rent, heating an/or air conditioning, security and so on. In addition, storage locations are typically within specialized equipment, such as shelving or flow rack, which are a capital cost." In the current state storage decisions are being made without consideration of the capital and fixed costs of storage locations. This project seeks to address the lack of insight into the capital and fixed costs while taking into account the current performance metrics utilized in the current state in order to enable total cost conscious storage recommendations.

5 Cost Model

5.1 Overview

The cost model was developed utilizing data analysis, stakeholder interviews, and process path analysis from the first two phases of the project. The cost model analysis supplies insight into the impact of process path rates, hourly labor costs, bin storage configuration and the final bin storage type decision on the variable, fixed and capital costs for a SKU with a specified cubic volume and received quantity. This model does so by assessing the total lifecycle costs (comprised of variable, fixed and capital costs) of an order processed through a fulfillment center assuming no maximum capacity constraints of storage type. The framework used to evaluate each cost category is summarized below.

5.2 Model Inputs and Outputs

5.2.1 Model Inputs

The model is designed to be used within the capacity planning organization to gain insights into the cost tradeoffs in addition to provide awareness to fulfillment center management into understanding their particular cost structure and the impact of changing their stow decisions. The model inputs are specified for an order given a single SKU's dimensions, a fulfillment center's labor costs, and stow decisions. These stow decisions include the minimum and maximum pallet heights allowed, bin utilization targets, percent of units eligible for fast track receive, cost of capital, and maximum number of unique SKUs allowed per bin of a storage type. Through the course of stakeholder interviews and process mapping, it was found that these stow decisions vary throughout the fulfillment center network. A representation of the cost model inputs and how they feed into different cost calculations is shown in Figure 12 on the following page.

The model contains drop down menus, which enable the model to be input with average or typical values of the input variables from selected fulfillment centers, by fulfillment center type, where available. This allows for more general analysis on a network level or if a specific fulfillment center's information is not known. The available pre-populated data was chosen from selected fulfillment centers based on the similarity of these buildings to expected future fulfillment centers technologies and layouts. For example, average dimensions per SKU for different storage types were calculated for a network level through data analysis of past actual history of units and their storage types.

The model then utilizes historic fixed, capital and variable cost data associated with processing a SKU with the input dimensions through all inbound and outbound process paths impacted by final storage type, as discussed in the current state analysis in Chapter 4. The assumptions used to calculate these costs are discussed below with the assumptions in Section 5.3.

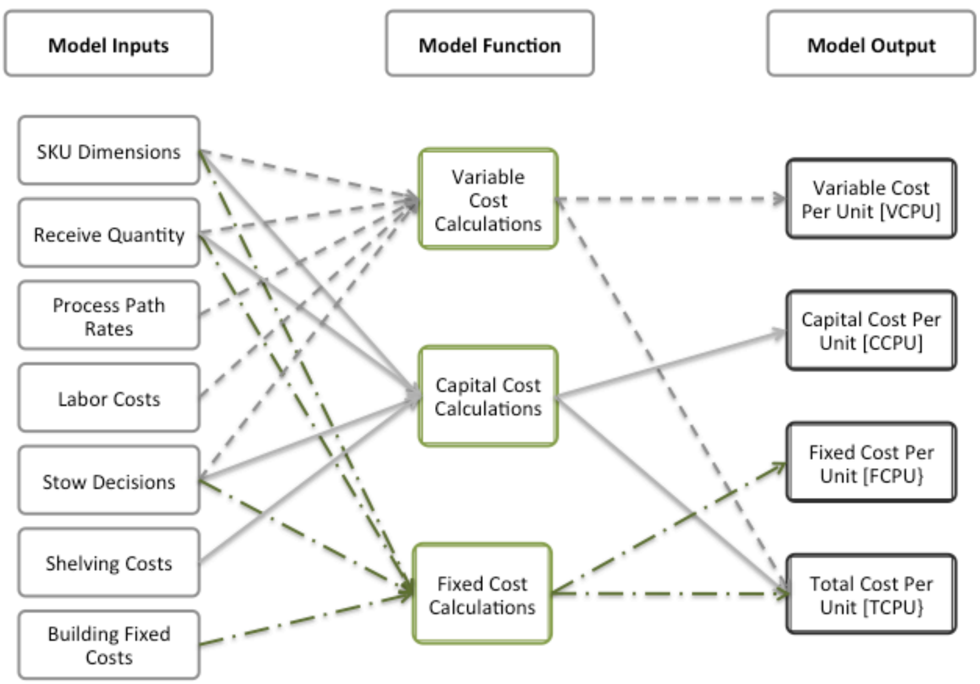

Figure 12. Model input and output map

5.2.2 Model Outputs

The final output of the model are the total fixed, capital, variable, and lifecycle costs of the order for each storage type, given a range of receive quantities. Receive quantity and SKU size were determined to be a primary drivers of storage type and stow decisions, and this output provides insight into the tradeoffs of these two variables directly. This output also allowed sensitivity analysis over the input variables to understand the impact of these variables on the total lifecycle cost and cost-optimized storage type decision for a given SKU over a range of receive quantities.

5.3 Cost Assessment Framework and Assumptions

The model is based upon a framework of analyzing fixed, capital and variable costs on a per order basis. The assumptions utilized to enable this comparison are critical to the analysis and key findings of this thesis.

5.3.1 Fixed Cost Framework and Assumptions

Fixed costs in warehousing are traditionally considered to be the business costs of running the warehouse that are independent of the number of units processed through the building. In order to compare fixed costs of different storage types, fixed costs are segregated into fixed costs related to the building footprint (referred to as indirect fixed costs) and fixed costs related to the throughput of inventory through the building (referred to as direct fixed costs). Examples of indirect fixed costs are the building rent costs and property taxes. Examples of direct fixed costs are utilities and costs related to conveyance and electronics.

Direct fixed costs are assumed to remain constant on a building and network level, and do not depend on storage utilization. These costs are not included in the model fixed cost allocations. The remaining indirect fixed costs assessed were translated into an annualized $\$/ft^3$ cost for each storage type using the warehouse's square footage, annual indirect fixed costs, and ft^3/ft^2 storage capacity of each storage type. This $\$/ft^3$ cost is used with the calculated cubic volume utilized for each storage type. The calculated cubic volume utilized for each order was determined based on the receive quantity and stow rules such as the maximum number of items and unique SKUs allowed in each bin.

5.3.2 Capital Cost Framework and Assumptions

Capital costs in warehousing are the costs of the physical storage units, such as shelving and pallet racks. Based on current fulfillment center network growth shown in Figure 3, it is assumed that incremental volume of any given storage type assessed in the model this year would need to be built next year. Therefore the capital cost in the model is considered to be only the cost of capital of the shelving structure costs ($\$/ft^3$) applied to the calculated cubic volume utilized for each storage type for one year.

5.3.3 Variable Cost Framework and Assumptions

The variable costs in the fulfillment centers are the labor costs related to processing the order through the warehouse. The cost model considers fulfillment center labor costs of process paths directly impacted by stow decisions as discussed in Chapter 4: receive dock, receive, stow, replenishment in inbound process paths and pick in outbound process paths. Support process paths (such as problem solve for exception items) are not included due to the low percentage of units processed through them. This process path rate data can be manually inputted or pre-populated into the model with historical rate data for an example Sortable or Non-Sortable building. Rates are translated into stow related Variable Cost per Unit (VCPU) for each storage type using the input hourly labor cost.

5.3.4 Example Total Cost Calculation

An application of this framework is shown below for a small item such as a book being processed through a fictitious warehouse. The numbers utilized are for example only and are not representative of actual Amazon data or relative capital, fixed, and variable costs in Amazon warehouses.

Fixed Cost Calculation

In order to calculate the fixed cost contribution of this book, the first step is to calculate the $\$/ft^2$ for the fixed costs for the warehouse. Using an annual indirect fixed cost value of $2M and total warehouse space of 1M ft^2 results in a $\$/ft^2$ of $2 of indirect fixed cost per ft^2 of the warehouse.

The next step is to calculate the ft^3/ft^2 storage capacity of the shelf the book will be stored on. If the shelving structure has a footprint of 5 ft^2 and total storage capacity under expected utilization of 40 ft^3, the shelving structure has a storage capacity of 8 ft^3/ft^2.

This results in a cost of \$4 per ft^3 of the book for this warehouse. Using a total utilized storage volume of 0.5 ft^3, the total fixed cost of storing the book comes to \$2 for the book.

Capital Cost Calculation

The capital cost of the shelving is assumed to be \$500 with the same calculated capacity of 40 ft^3. Assuming a cost of capital of 5%, the capital cost is \$0.63 per ft^3 used. Using the same total utilized storage volume of 0.5 ft^3, the total capital cost of storing the book comes to \$0.31.

Variable Cost Calculation

Process Path	Rate (UPH)	VCPU (\$20/hr labor rate)
Receive Dock	800	\$0.03
Receive	400	\$0.05
Stow	200	\$0.10
Pick	100	\$0.20

Table 2. Example variable cost data

Assuming the above rates in units per hour for each process path this book will move through and a \$20/hour labor rate, the total variable cost for the book is \$0.38.

Total Cost

The total cost for this example book and warehouse is \$2 of fixed cost, \$0.31 of capital cost, and \$0.38 of variable cost for a total cost of \$2.69.

5.4 Model Validation and Scenario Testing

5.4.1 Model Validation

The model was validated through comparison of scenarios run for example buildings with actual annual labor and fixed costs provided by the finance organization. Validation was first done for both a Sortable and Non-Sortable building using historic received inventory data, building process path rates and labor costs for inputs and stow decisions currently in use in each building. This model validation and initial test run provided the key findings of the trade offs between the different costs which the recommendations in Chapters 6 and 7 are based upon.

5.4.2 Scenario Testing

Sensitivity analysis was done by varying the values of identified key input variables over a range of expected values to identify the input cost drivers in a series of scenario testing. Through this methodology the total cost impact of changing stow decisions such as maximum unique items per bin and target bin utilizations on the variable, fixed and capital costs was quantified.

Scenarios were run with different average unit types over a range of receive quantities at both Sortable and Non-Sortable fulfillment centers as well to provide insight into lowest cost storage types.

5.5 Example Model Results

The key findings from the model test scenarios are presented for an example Sortable building and are representative of key findings from the Non-Sortable building. These results are the foundation of the recommendations to be made and provide significant insight into the cost tradeoffs between variable, fixed and capital costs for each storage type and between storage types.

5.5.1 Sortable Fulfillment Center Stow Related Lifecycle Cost Per Unit

The model was run for an example Sortable building using an order with an average Sortable Library volume and utilizing current stow policy decisions from the example building. The example building's historic process path rates were used in addition to representative labor costs.

The following total fulfillment center (FC) costs of processing an order composed of one SKU over a range of receive quantities per bin type per unit are shown below:

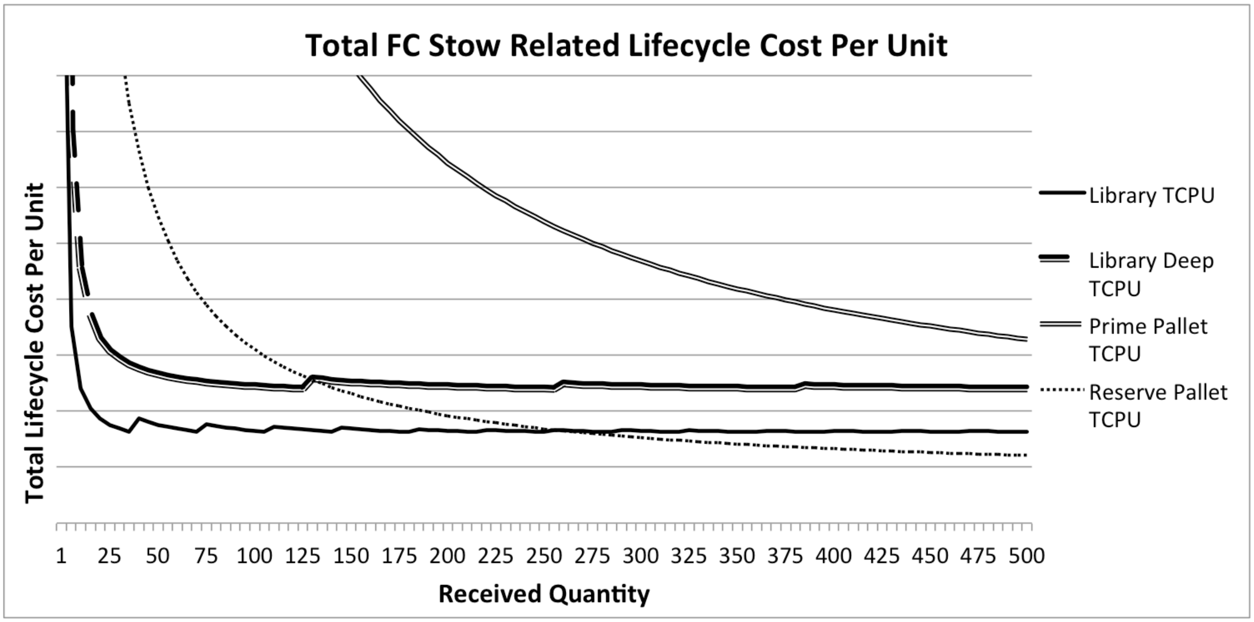

Figure 13. Total fulfillment center stow related lifecycle cost per unit by storage type

Figure 13 demonstrates that in this example scenario for receive quantities up to 260 units stowing in Library storage provides the lowest total cost per unit, with Library Deep storage total cost per unit (TCPU) remaining slightly higher due to higher variable rates. For receive quantities higher than 260 units Pallet Rack becomes the most cost effective, due to the higher storage capacity and lower variable costs for processing through pallet storage.

A key finding from the results in Figure 13 is that Floor Pallet storage always has the highest TCPU. The drivers for these cost differences are seen below in the breakdown between variable, capital and fixed costs in Figures 14, 15, 16 and 17.

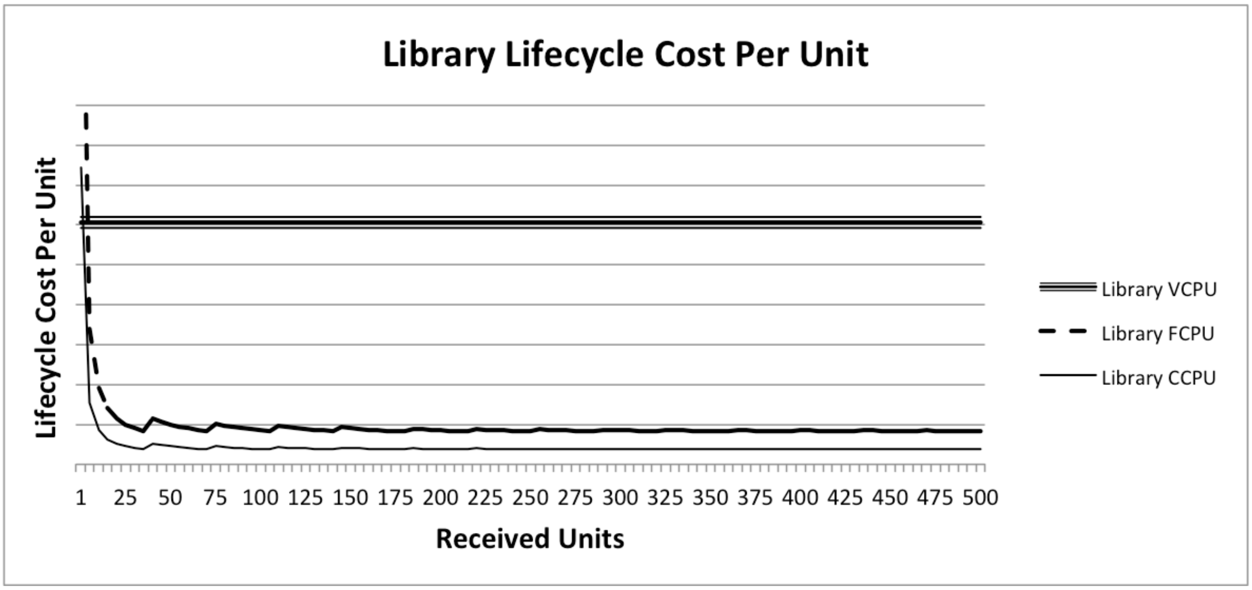

Figure 14. Breakdown of Library TCPU into VCPU, FCPU, and CCPU

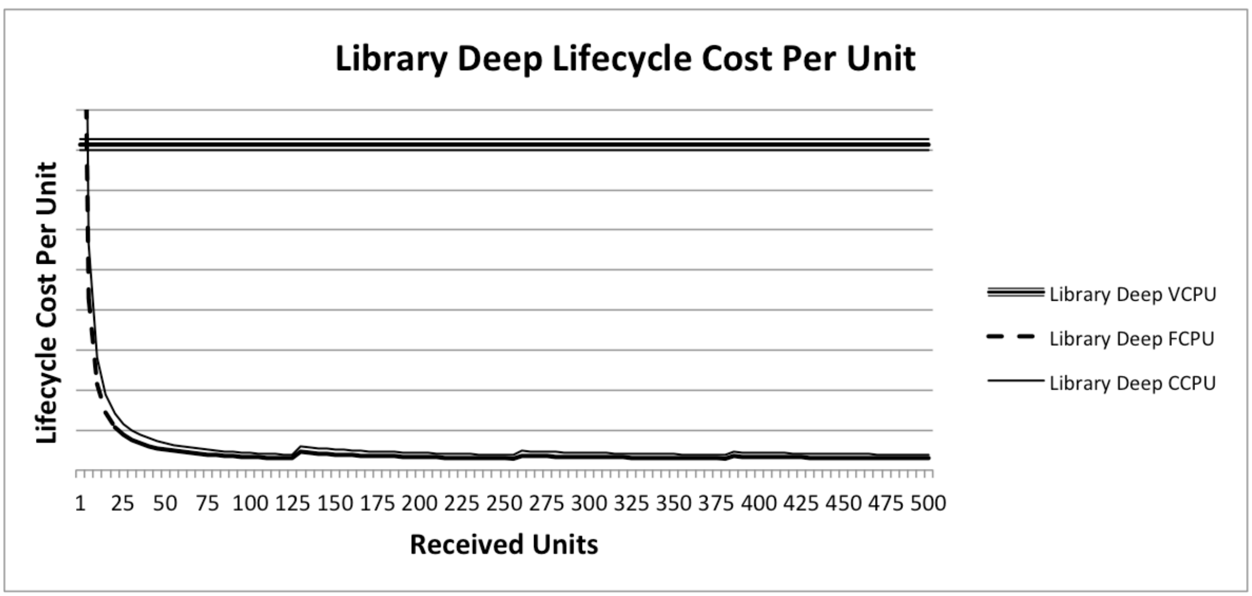

Figure 15. Breakdown of Library Deep TCPU into VCPU, FCPU, and CCPU

The breakdown of the total cost in Figure 14 and Figure 15 into the relevant cost components illuminate that variable costs are the primary cost driver for the Library and Library Deep bins.

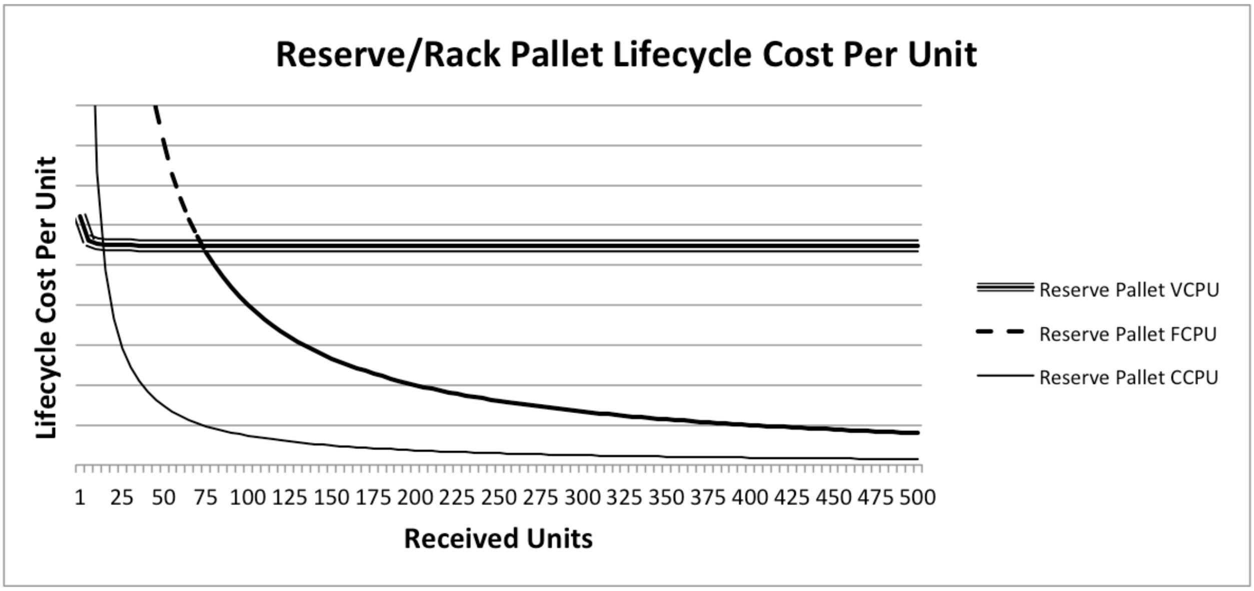

Figure 16. Breakdown of Reserve Pallet TCPU into VCPU, FCPU, and CCPU

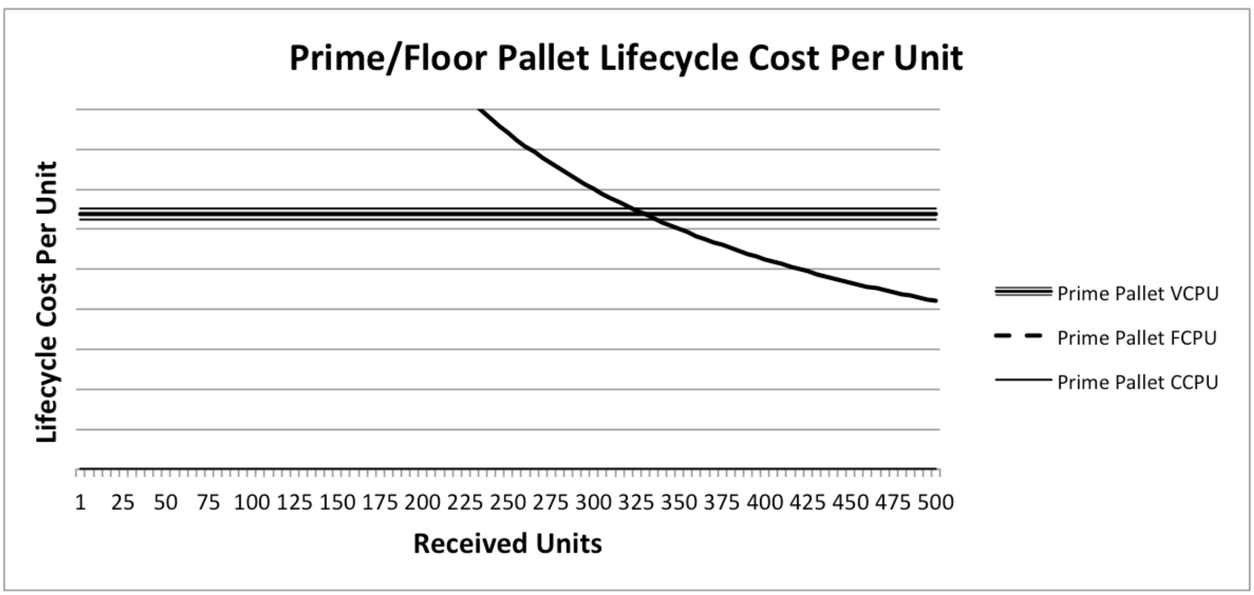

Figure 17. Breakdown of Prime Pallet TCPU into VCPU, FCPU, and CCPU

From Figures 16 and 16 it can be seen that for both pallet storage types the fixed costs are the intiial cost driver, due to the one max unique SKU limit per pallet. The low ft^3/ft^2 for floor pallet causes fixed costs to remain the cost driver for receive quantities up through 325 for floor pallet storage, with pallet rack storage total costs becoming driven by variable costs at receive quantities of 80.

5.5.2 Implications of Lifecycle Cost Per Unit Analysis

The model provided the expected initial results for storage type based on order receive quantity: for low receive quantities of a Library sized unit a Library bin would have the lowest lifecycle cost per unit and as the receive quantity increased the order should be processed through Pallet Rack storage. For this example scenario Library Deep never has the lowest total cost due to the higher variable rates. Similarly Floor Pallet storage never has the lowest total cost due to the very high fixed costs. It is important to note here that the model does not take into account fringe cases in which floor pallet storage would be required, such as extremely high velocity items such as new releases.

There are additional implications on the focus on cost reduction activities within individual fulfillment centers. Currently fulfillment centers are solely focused upon reducing the variable costs in the network by increasing their process path rates. Based upon the model results, it is clear that this variable cost component is the cost driver for the Library and Library Deep storage types and focusing on reducing these process path times will have the largest impact on reducing TCPU. However, it is clear from the model results that it is also necessary to begin focusing on reducing the FCPU associated with the pallet storage to reduce total storage related costs at the fulfillment center.

6 Current Fulfillment Center Optimizations

Two opportunities were analyzed for current fulfillment center optimization, based upon the key findings discussed in Section 5.4, in addition to an opportunity identified by the capacity planning organization. The first opportunity assessed was replacing floor pallet storage due to the high fixed cost that makes this storage type highly cost inefficient. The second opportunity assessed was to introduce Non-Sortable inventory into Sortable buildings to reduce transportation costs in the network.

Both opportunities were evaluated using the proposed cost model to quantify annual cost savings. These assessments are summarized in recommendations for the capacity planning team, focused on the cost savings of implementing these recommendations. Finally, additional areas of opportunity implementation challenges for each opportunity are discussed.

6.1 Replacing Floor Pallet Storage

6.1.1 Motivation

Results in Section 5.4 demonstrate that floor pallet storage was not cost competitive compared to other storage types, due to floor pallet's low ft^3/ft^2 storage capacity (about five times lower ft^3/ft^2 capacity than pallet rack storage.) Based on this finding, the total cost of replacing floor pallet storage was assessed by replacement storage type (Library and Library Deep pick mod shelving, Library rivitier shelving, Library Deep rivitier shelving, a mix of Library and Library Deep rivitier shelving, and pallet rack shelving.) Pallet rack shelving for the Sortable network was analyzed in two scenarios: use as reserve (assuming replenishment to floor pallet/Library/Library Deep storage bin) and use as prime (pick for customer orders directly from pallet rack.)

6.1.2 Assumptions

This analysis assumes that additional storage capacity will be fully utilized by the network. With the current incoming receive quantities in the Sortable network this may require relaxing the one SKU per pallet constraint to increase the amount of product sent to pallet rack shelving. Additionally, the model does not take into account extremely fast moving SKUs in the Sortable network and bulky items in the Non-Sortable network, which requires that some floor pallet storage be maintained.

6.1.3 Cost and Opportunity Analysis

Variable Costs

The variable cost is considered to be the VCPU difference between floor pallet and replacement storage types process paths for the total annual units currently in floor pallet. This analysis was based on historic utilization of floor pallet storage, average unit volume of items in floor pallet storage and the lost storage capacity in the building from removing floor pallet storage. The process paths considered in the variable cost analysis are receive, stow, pick and case/pallet replenishment for reserve pallet. The pick rate used for reserve pallets was based on historic Non-Sortable pallet rack pick rates. In calculating the total amount of annual inventory currently held in floor pallet storage, historic inventory turns were calculated based on total shipped units and average inventory units from 2011 data.

Fixed Costs

The fixed costs savings are based on the gained volume of replacement storage by replacement storage type. These volume are used in conjunction with the $\$/ft^3$ indirect fixed cost storage type allocations to calculate fixed cost savings.

Capital Costs

Capital costs are calculated by applying the cost of capital by replacement storage type capital expenditure of one year, using the base model assumption that any non-optimized storage allocation built out this year would need to be built out next year due to the current rate of growth in the fulfillment center network.

6.1.4 Results

An example of the output of the annual scaled cost savings of replacing floor pallet storage for a building in the Sortable network is shown below. While exact numbers are not available for this paper, the bars represent relative scales between all change types. Net gained volume accounts for the lost floor pallet storage capacity. The capital cost for lost volume is the capital cost for rebuilding out the lost floor pallet storage capacity in the replacement storage type being assessed. The annual fixed cost savings is based upon the net gained volume. The total variable and fixed cost savings are assessed in addition to the payback period for the capital cost for lost volume.

Change Type	Net Gained Volume	Capital Cost for Lost Volume	Variable Cost Increase (Decrease)	Annual Fixed Cost Savings (Cost)	Total Variable and Fixed Savings (Cost)	Payback Period (Years)
Library Pick Mod					14%	17.6
Library Rivitier					-5%	N/A
Library Deep Pick Mod					0%	2883.6
Library Deep Rivitier					-10%	N/A
Mixed L/LD Rivitier					-8%	N/A
Pallet Rack: Use as Reserve					**21%**	**0.5**
Pallet Rack: Use as Prime					-23%	N/A

Table 3. Example cost analysis of replacing floor pallet storage

Table 3 demonstrates that the cost optimized savings for a building in the Sortable network is a savings of 21% with a payback period of 0.5 years by replacing floor pallet storage with pallet rack storage used as reserve storage. Similar analysis done for a Non-Sortable building identified that the optimal cost opportunity is a cost savings of 17% with a payback period of 1.4 years by replacing floor pallet storage with pallet rack storage.

These cost savings are primarily driven from the fixed cost savings derived by increasing the ft^3/ft^2 storage capacity, as expected from the key findings of the test scenarios. The additional variable cost, and lost capacity in the Library rivitier storage type, however, negates the fixed cost savings for all storage types except Library pick mod and pallet rack used as reserve storage. The long payback period for the Library pick mod makes it an unreasonable replacement storage type.

6.1.5 Recommendations and Challenges

Based upon the cost opportunities identified, it is recommended for floor pallet storage to be replaced with pallet rack shelving used as reserve shelving in the Sortable network for an annual cost savings of

21% per building with a payback period of 0.5 years. The lower two levels of pallet rack shelving should be utilized as prime pallet storage. For the existing Non-Sortable network the floor pallet storage is recommended to be replaced pallet rack storage for an annual cost savings of 17% per building with a payback period of 1.4 years.

An area of further exploration is to assess the safety, equipment and aisle width requirements of a modified pallet rack configuration that could accommodate larger Non-Sortable SKUs. One potential modification that would accommodate these bulky SKUs would be changing current pallet rack configurations of 5 levels of 3-5ft rack positions to 2 levels of 11ft rack positions.

6.2 Increasing Non-Sortable Product Mix in Sortable Network

6.2.1 Motivation

The model was utilized to estimate the net impact of storing Non-Sortable product mix in specified Sortable fulfillment centers. The hypothesis was that there would be a net cost savings driven by the transportation cost savings from shipping Non-Sortable items from Sortable buildings that are closer to the end customers. There are expected cost increases in the Sortable buildings from managing the additional inventory.

These transportation savings are understood to be temporary as the network continues to grow, and therefore will need to be re-evaluated as additional Non-Sortable and Sortable buildings are opened. The cost saving analysis in this project focused on the cost assessment of fulfilling Non-Sortable SKUs from two specific pairings of Sortable and Non-Sortable buildings. The following analysis will examine shipping SKUs from SBuilding1 instead of NSBuilding1 and SBuilding2 instead of NSBuilding2.

6.2.2 Cost Analysis

Transportation Cost

In order to assess the transportation savings, the metropolitan regions with cost saving opportunities for shipping from SBuilding1 over NSBuilding1 were identified. The regions were identified through the comparison of year-to-date ship costs per unit for SBuilding1 and the closest Sortable building to NSBuilding1 to different regions, and applying this shipping cost factor to NSBuilding1's year-to-date ship costs by region.

Capital Cost

The capital cost was assessed for replacing floor prime pallet storage with pallet rack storage specifically for use for Non-Sortable SKUs as prime storage. The capital costs assessed were the cost of capital applied to the gained pallet racking for one year.

Fixed Cost

The fixed cost benefit was assessed by calculating the gained ft^3/ft^2 capacity of pallet racking over floor pallet storage, similar to the analysis done in 6.1.

Variable Cost

The variable cost impact for the Sortable buildings was calculated using an estimate by SBuilding1 that included additional processing time for handling larger items through each process path as well as additional manual processing that is now required, as the new inventory cannot be put on conveyance. This increased VCPU was applied to the expected number of units that would be processed through NSBuilding1. Similar analysis was done for SBuilding2 and NSBuilding2.

Validation

The total cost impact to the network were validated by comparing the results to an estimate done by a supply chain optimization organization through simulations.

6.2.3 Results and Implementation Challenges

Total scaled annual savings is estimated to be 13%, summarized in Table 4.

	Transportation Savings (Cost)	Variable Cost Savings (Cost)	Net Annual Savings
SBuilding1	12.5%	-4.5%	8.0%
SBuilding2	8.0%	-3.0%	5.0%
Total Savings	20.5%	-7.5%	13.0%

Table 4. Total cost opportunity for increasing Non-Sortable product mix in two Sortable buildings

Due to the significant transportation savings of stowing Non-Sortable SKUs in SBuilding1 and SBuilding2, it is recommended that floor pallet storage at these sites are replaced with forward pallet rack storage specifically for Non-Sortable SKUs.

The barriers to implementing this recommendation are focused around challenges in process changes in utilizing pallet rack storage as forward pallet rack storage. These challenges were identified through a pilot program utilizing powered equipment to pick items from the elevated pallet rack shelves. Some of the identified barriers to success include the increased use of powered equipment, safety concerns, and the necessity of additional support process paths. An example of an additional support process path is consolidation of pallet inventory as inventory levels drop.

7 Cost Optimized New Fulfillment Center Storage Type Allocation

7.1 Motivation

The layout of the fulfillment centers including the allocations of quantity and types of storage are currently based upon historical allocation of product category to storage types. The model was leveraged to optimize the storage type allocation utilizing expected annual demand to optimize the lowest cost storage types based on this demand.

7.2 Methodology

Demand data for the 2013 peak retail day was obtained for an example Sortable and Non-Sortable building from the Sales and Operational Planning (S&OP) organization. This data is the same data that current capacity planning analysis is based upon. The demand data provided a breakdown of the expected number of units based on retail type (for example, household versus books), which was utilized to estimate a break down of volumes. The average SKU volumes were based upon an analysis of items received in those product lines from the full 2011 retail year.

To determine incoming receive quantities, historic peak retail day inventories from 2011 were used for the same example Sortable and Non-Sortable building. Using the most recent peak data available assists in taking into account the trends of increasing FBA inventory coming into the fulfillment centers.

7.3 Storage Type Allocations For Sortable Network

The model was first run utilizing the variables from the example Sortable building, such as labor rates, process path rates, fixed costs and capital costs. The resultant output of the model allocated each SKU size into a lowest cost storage type based on receive quantity, shown in Table 5.

SKU Size	Model Lowest Cost Storage Type	Receive Quantity	% Units of SKU size
Library	Library	1-430	98.90%
	Reserve Pallet	430+	1.10%
Library Deep	Library Deep	1-160	98.76%
	Reserve Pallet	160+	1.24%

Table 5. Sortable fulfillment center lowest cost storage allocation

This data from Table 5 was applied to the demand data that had been broken down into SKU size and expected receive volume to provide optimized allocation of storage types based on the expected demand. This was compared to the current allocation of storage types shown in Table 6 with scaled representative data below.

Sortable Fulfillment Center Storage Type	Optimized Allocation (% total)	Current Allocation (% total)
Library	30.43%	22.68%
Library Deep	60.32%	44.52%
Pallet Rack	9.25%	19.17%
Floor Pallet	--	13.63%

Table 6. Sortable fulfillment center optimized storage type allocations (scaled representative data)

As demonstrated with the representative data in Table 6, the optimized allocation of storage eliminates floor pallet storage, reduces pallet rack storage from 19% to 9%, increases Library Deep shelving from 45% to 60% and increases Library shelving from 23% to 30%. These changes are in line with the key findings observed, with no floor pallet storage due to the high fixed costs associated with that storage type and reduced pallet rack storage due to the higher labor costs associated with that process path rate. The large increase in Library Deep shelving is primarily attributed to the decrease in the amount of pallet storage. The cost benefits of the optimized allocations are discussed in Section 7.5.

7.4 Storage Type Allocations For Non-Sortable Network

The same analysis was done for an example Non-Sortable building, again utilizing outputs from the cost model for allocation based on original receive quantity and SKU volume when the labor costs, capital costs, and fixed costs of the example building were input into the model. The output of the Non-Sortable building model based on SKU volume and receive quantity is shown below in Table 7.

SKU Size	Model Lowest Cost Storage Type	Receive Quantity	% Units of SKU size
Library Deep	Library Deep	1-15	89.0%
	Reserve Pallet	16+	11.0%
Pallet	Prime Pallet	--	0%
	Reserve Pallet	1+	100%

Table 7. Non-Sortable model output for storage type allocation

These results were applied against the demand data for the example Non-Sortable building to derive low cost optimized storage type allocations, shown below in Table 8 with scaled representative data. The cost benefits of the optimized allocations are discussed in Section 7.5.

Non-Sortable Storage Type	Optimized Allocation (% total)	Current Allocation (% total)
Library Deep	15.24%	18.50%
Floor Pallet	0.00%	18.06%
Pallet Rack	84.76%	63.43%

Table 8. Non-Sortable fulfillment center optimized storage type allocations (scaled representative data)

Table 8 shows with scaled representative data that an optimized Non-Sortable building eliminates floor pallet storage, decreases Library Deep shelving from 18.5% to 15.2% and increases rack pallet storage from 63% to 84%. Similar to the Sortable building optimized allocations, these optimized allocations are in line with the results of the cost model showing elimination of floor pallet storage due to the high fixed costs associated with floor pallet storage. There is a slight decrease in Library Deep shelving based on the current expected receive quantities of expected demand and the expected pallet rack storage increase driven primarily by the elimination of floor pallet storage. Limitations and challenges are discussed below in Section 7.6.

7.5 Cost Benefit Analysis of Optimized Storage Type Allocations

The cost benefits of utilizing the optimized storage type allocations were calculated through analysis of variable, fixed and capital costs.

Variable Costs

The variable cost savings were calculated using the total estimated demand of units by storage type in combination with the total stow related variable costs. The total stow related variable costs were derived using the cost model applied with the process path rates for the example Sortable and Non-Sortable building used in the storage type allocation analysis.

Fixed Costs

Similar to the original model, only indirect fixed costs (fixed costs associated with the square footage of the building) were utilized. The indirect fixed costs savings were calculated using the ft^2 of storage space required by the current and optimized storage type as shown in Table 6 and Table 8 and then applying a calculated $\$/ft^2$ fixed cost calculated for each building type.

Capital Costs

The capital costs were calculated utilizing the $\$/ft^3$ cost for each shelving type with Amazon's cost of capital rate.

While actual cost data is not available to be shown, the total scaled savings derived from the changes to storage type allocations for both a Sortable and Non-Sortable fulfillment center is shown in Table 9.

	Sortable Fulfillment Center	Non-Sortable Fulfillment Center
	Savings (Cost)	Savings (Cost)
Variable Cost	14.5%	0.5%
Fixed Cost	12.0%	12.0%
Capital Cost	-3.5%	-1.0%
Total Cost	**23.5%**	**11.0%**

Table 9. Total cost analysis for optimized Sortable and Non-Sortable storage type allocation

Table 9 shows a total scaled annual cost opportunity of 23.5% for optimizing a Sortable building with a payback period of 1.2 years and a 11% cost opportunity for optimizing a Non-Sortable building with a payback period of 0.9 years. The payback period represents the additional capital expenditure required for the additional shelving to accommodate units currently stored in floor pallet locations.

These highly significant annual cost savings are driven by the variable and fixed cost savings for an optimized Sortable building and fixed cost savings for a Non-Sortable building. The variable cost savings in the Sortable building are driven by the fact that for an optimized building the majority of storage is in the more densely populated Library and Library Deep shelving storage areas. More dense product storage leads to faster picking times due to reduced walking times between individual picks on a picker's pick list.

The fixed cost savings in both a Sortable and Non-Sortable building is driven by the elimination of floor pallet storage, which had a significantly higher fixed cost per cubic foot of storage available. There is a capital cost in both building types due to the required additional shelving required to hold inventory that was in floor pallet storage.

7.6 Limitations of Analysis and Implementation

It is important to note that these optimized allocations do not take into account fringe cases where floor pallet storage will need to be maintained in Sortable buildings for extremely high velocity SKUs such as new releases. Additionally, since average volumes were used from the demand data obtained, the optimized allocations do not address required bulk stock storage in Non-Sortable buildings for SKUs that are too bulky for pallet racking.

Based on discussions with operations managers in the fulfillment centers, in order to be able to implement these optimized storage type allocations there will need to be further investigation to assess the requirements for powered equipment for the bulk stock that are currently in the pallet racking. It is possible to change existing pallet configurations to have pallet racking with a smaller amount of levels to accommodate this inventory.

8 Conclusions

8.1 Project Conclusions

The development of a framework for assessing the trade offs between variable, fixed and capital costs related to storage related decisions has provided insight into storage cost drivers and several significant cost saving opportunities for both existing and new fulfillment centers. This framework can be applied for future cost savings opportunities as well as automated to pull in information for specific new warehouses to be built to optimize layout.

This model quantified the impact of the fixed costs related to storage type allocations of floor pallet storage. While some floor pallet storage will be required for fringe cases, replacing floor pallet storage or removing floor pallet storage represents a significant annual cost savings in gained capacity for Amazon.

With the expected growth of the fulfillment center network it becomes more important to ensure that the storage type allocations are optimized for the growing diversity of inventory, receive quantities, and that all costs are taken into account.

8.2 Areas for Future Investigation

There are several related areas for future research to be explored by Amazon or for future LGO internships. The next steps for the model would be to automate the model to input detailed historical inventory data, expected retail demand and fulfillment center rates so that fulfillment center costs can be compared quickly. This automated model can be applied to provide detailed storage allocation recommendation for the next wave of fulfillment center plans.

The model can also be automated to include transportation costs and simulations to optimize costs on a network level and not a building level.

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Appendix A: Storage Type Definitions

The primary storage types at an Amazon fulfillment center are Library shelving, Library Deep shelving, pallet floor shelving and pallet rack storage. The variety of shelving allows the fulfillment center to more effectively store and process a wide variety of inventory.

Library and Library Deep Storage

Library shelving has a depth of less than 12” deep with shelf heights ranging from 9” to 12”. Each shelf is further divided into bins for inventory to be stored in. Library shelving is utilized to accommodate small items ranging from key chains to books.

Figure 18. Library rivitier shelving in a Sortable fulfillment center[6]

Library Deep shelving has a depth of greater than 12” with shelf heights ranging from 12” to 18”. Library Deep shelving is utilized to accommodate larger items.

Both Library and Library Deep shelving are used at Sortable and Non-Sortable fulfillment centers, with a greater percentage of current storage allocated to Library shelving at Sortable fulfillment centers and a greater percentage of current storage allocated to Library Deep shelving within Non-Sortable fulfillment centers.

[6] http://imgur.com/a/q1WIO

Within Sortable fulfillment centers there are two types of Library and Library Deep storage: rivitier and pick mod shelving. Rivitier shelving consists of a single floor level of storage, shown in Figure 18, while a pick mod contains several levels of shelving.

Figure 19. Library and Library Deep pick mod shelving at a Sortable fulfillment center[7]

A typical pick mod may contain 3 or 4 levels of a combination of Library and Library Deep shelving, as shown in Figure 19.

Pallet Storage

Pallet storage is used for the storage of high receive volumes of a single SKU and is divided into floor pallet storage and pallet rack storage, shown in Figure 20.

Both floor pallet storage and pallet rack storage are found at Sortable and Non-Sortable fulfillment centers, with a greater percentage of total storage allocation at Non-Sortable fulfillment centers consisting of pallet storage. Pallet storage locations are typically 42" by 48" and are stored in a single level. Pallet rack shelving consists of large rack structures in which pallets are placed up to five levels up.

[7] http://imgur.com/a/q1WIO

Figure 20. Pallet rack storage in a Sortable fulfillment center[8]

Special Storage Types

There are several variations of specialty storage types and modifications made to existing storage types, in order to accommodate specific products. An example of a modification made to existing storage is the application of flexible netting on the outside of Library shelving to prevent plastic packages stacked on top of each other to stay within the shelves. Due to the low portion of total storage that is comprised of specialty storage types they are not included in the cost model.

[8] http://imgur.com/a/q1WIO

Appendix B: Select Definitions

Term	Definition
Capital Costs	Costs related to expenditures incurred for fixed assets
Delayed Allocation Fulfillment Center	Fulfillment centers which receive inventory from suppliers to be distributed amongst fulfillment centers
Direct Fixed Costs	Costs that are independent to the level of inventory processed and are related to the throughput of inventory processed through a fulfillment center
Directed Stow	Storage methodology in which a SKU is assigned to a specific storage location. This storage location is often tied to the SKU's demand velocity.
FIFO	First In First Out
Forward Deploy Fulfillment Center	Fulfillment centers located near large metropolitan areas that receive transshipments from larger fulfillment centers in the network, which they then sort and fulfill to customers in the nearby metropolitan areas.
Forward Storage	Storage from which inventory can be directly fulfilled to customers
Indirect Fixed Costs	Costs that are independent to the level of inventory processed and are related to building footprint of a fulfillment center
Non-Sortable Fulfillment Center	Fulfillment centers which process non-conveyable inventory such as televisions
Replenishment	The process path of moving inventory from reserve storage to forward storage
Reserve Storage	Storage from which inventory is replenished to forward storage, which it then can be picked from to fulfill customer orders
SKU	Stock Keeping Unit
Small Parcel	Transportation/shipping of small package through parcel carriers such as UPS or FedEx
Sortable Fulfillment Center	Fulfillment centers which processes conveyable inventory such as books
Specialty Fulfillment Center	Fulfillment centers designed to store inventory with specialized storage requirements
Stow Policies	Policies that impact the final storage location of inventory within the warehouse. This may include rules related to which inventory is directed to a storage type or location, how much inventory can be

	stored in a storage type, and in what method the inventory is stored.
Transshipments	Transportation of inventory done between two Amazon fulfillment centers
Variable Costs	Costs dependent on the number of units processed through the fulfillment center
Vendor Freight	Transportation/shipping of large volume shipments such as pallets