Prime Pantry Optimization: A Cost Analysis and Deep-Dive in Process Improvement

by

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Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering in partial fulfillment of the requirements for the degrees of

Master of Business Administration
and
Master of Science in Mechanical Engineering

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ABSTRACT

Amazon's Prime Pantry is a specialty business that focuses on selling household goods such as toilet paper or bottled water. The business is a part of the consumables portfolio that has consistently met or exceeded forecasts. However as the business grows and lower Average Sales Price (ASP) items are introduced, optimizing the current fulfillment solution is critical to ensure profitability through growth. In 2016, there was a $662B market opportunity to fulfill consumables between the $0-5 ASP range. As a relatively high velocity consumables business, the Pantry platform is well situated to help address this opportunity as well as address fulfillment of items below a $5 ASP.

This thesis analyzes two primary initiatives: 1) The first is to determine the ideal characteristics (inbound profile, cubic velocity, demand) of Stock Keeping Units (SKUs) that will determine how new SKUs can be added to Amazon Pantry while maintaining a positive profit through an in depth analysis of inventory management strategies, 2) The second is to design a low cost fulfillment solution for this chosen product profile while maximizing throughput and capacity through process flow changes and automation where necessary.

Part I analysis determined general tenets for inventory management correlating item characteristics with cost. Key recommendations included palletizing larger items and storing smaller items in smaller quantities to decrease obsolescence costs. The study showed it was necessary to make strategic decisions at a SKU level. Therefore, a dynamic model was created to change the inputs based on characteristics for new or existing SKUs to output the operational cost implications on the network.

Part II analysis showed that splitting process paths significantly improved throughput and capacity for Pantry operations. The thesis shows that with a large scale operation, consolidation of process paths is not necessarily cost efficient or operationally beneficial. This is shown through an in depth analysis of a new picking process, pick to rebin. An additional design analysis of an automated sortation system investigates further operational improvements.

Each of the initiatives outlined above will provide additional savings to the Pantry business. Though the Low ASP analysis generated savings of $2.27M, only a fraction of the SKUs were analyzed. If case replenishment is automated or more pallets are used in the field, these savings will increase since the Variable Cost Per Unit (VCPU) of handling these items will decrease. The pick to rebin initiative can save the company an additional $432,000 annually with a VCPU improvement of $0.018. Lastly, an automated sortation machine would save $312,000 annually since the improvement over manual pick to rebin is a VCPU improvement of $0.013. In total, these savings amount to $3.02M annually.

Though the cost improvements are fairly significant, these improvements could prevent the business from needing to open new sites at the current frequency required and will improve the business's current operations immensely. Additionally, it will enable the business to introduce even lower ASP items profitably while improving the customer experience.

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I would be remised if I did not acknowledge my fellow Amazon Associate Experience Week (AEW) coworkers, Josephine Douglas, Saurabh Shetty, and Jessica Forman, who repeatedly assured me that I'd complete my thesis and helped me explore Amazon and Seattle from Day 1.

Last but most certainly not least, I received immense support from the MIT community. I'd like to especially thank my advisors Donald Rosenfield, Julie Shah and Sanjay Sarma. Their deep expertise in their respective fields has allowed me to approach the problems discussed in this thesis with a wider lens while digging into details. I very much appreciated being able to learn from them and am lucky to have had their full support.

Dedication

I'd like to take this opportunity to dedicate this work to my family – Satchit, Rajashree, Aditi, Vishaal and Tahoe Dokras. Thanks for pushing me forward to do more than I ever thought I'd be able to do.

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Table of Contents

Table of Tables

Table of Figures

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I. Introduction

This thesis analyzes the efficiency of operations in a high volume, limited selection, low margin business. The analysis focuses on analyzing current operations at Prime Pantry, Amazon's specialty business for household consumables. It will specifically study how SKU selection affects day to day operations and how costs can be decreased through more efficient velocity based inventory management. This thesis also evaluates the operations for process improvement through a process path analysis in order to alleviate network capacity issues.

The approach taken for the first part of the study evaluates the benefit of ordering in larger quantities to create single SKU pallets to improve operational labor costs, and compares this option with ordering smaller quantities of a SKU to decrease obsolescence costs. This analysis further explores the effect of these ordering strategies on fixed costs and holding inventory costs. For the process improvement recommendations, the benefits of splitting process paths and automation in such a high-SKU, velocity-driven environment were evaluated.

The purpose of this chapter is to provide the context for the studies presented in this thesis. An overview of the company and its core will provide background for the company's competitive strategy and how it makes its business decisions. Prime Pantry, a specialty business in Amazon, has an even more niche value proposition. An overview of this business will target why the SKU selection and velocity based issues in this thesis are worth evaluating and addressing.

A. Industry and Company Overview

Retail E-Commerce

Though the internet as we know it today was created in 1991, online retail was said to be born in 1994 as security concerns were addressed, making the internet more accessible to the general public.[1] Since then, the e-commerce industry has become a dominant player in the retail industry. In fact, 62% of retail growth came from e-commerce in 2015.[2] Within the online

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[1] Kenneth C. Laudon and Carol G. Traver, E-Commerce: Business, Technology, Society, Second Edition (US: Pearson/Addison Wesley, 2008).

[2] Adam Levy, "Amazon's U.S. Online Sales Growth Last Year Was More Than Everyone Else's Combined," *The Motley Fool*. Feb 10, 2017.

market, two basic types of commerce have emerged, business-to-business (B2B) and business-to-customer (B2C)[3]. B2B commerce includes sales or services provided from one business to another however this section will focus on B2C which provides services from a company directly to the public.

Amazon and E-Commerce

Founded in 1995 by Jeff Bezos, Amazon.com started as the first major online book retailer, allowing customers to order books from the comfort of their homes and have their purchases delivered within a few days. This business model had such a profound impact on the market that within one year of its inception Amazon "became a multimillion dollar business with a database of 1.1 million books searchable by title, author, subject, or keyword, and [was] favored by both publishers and customers".[4] Since 1995, the tech giant has expanded its services as an online retailer to sell almost any item imaginable including clothes, food, and household items.

E-Commerce of Consumables

Today, the e-commerce industry has expanded past digitizing the sales of traditional brick-and-mortar stores in the retail industry. E-commerce now includes the sales of products in a variety of industries including automotive, services, and groceries.

The online grocery market has grown to $7B of sales in 2016.[5] Major grocery companies such as Walmart and Safeway are investing in online services, but other companies such as Amazon Fresh, Peapod, and Instacart are strong competitors. Though margins in this business tend to be rather low due to the high potential for product obsolescence from shorter shelf lives and more complex distribution logistics, sales of consumables are an attractive business for these companies due to their resistance to cyclical demands and economic downturns. The product offerings in a consumables business are also generally essentials or items which customers will have to buy more frequently.

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[3] Yan Tian, "History of E-Commerce," *E-Commerce Land*. 2004.
[4] Yan Tian, "History of E-Commerce," *E-Commerce Land*. 2004.
[5] Joshua Bender,"Statistics and facts on consumers' online grocery shopping in the U.S.," *Statista.*

Recognizing these benefits and leveraging its brand name and infrastructure, Amazon has created three specialty businesses that offer customers these consumable products: 1) Prime Now, which offers two hour delivery of specific consumable items with a Prime membership (Amazon's loyalty program), 2) Fresh, which offers produce and dry goods for an annual membership fee, and 3) Pantry, which offers dry goods for a flat shipping fee. With these offerings, the company has grown to be worth over $290 billion.[6] The following content of this thesis focuses on an analysis of the Pantry business.

B. Company Core

Prior to discussing additional background for the Pantry business, it is important to understand Amazon's core values as it defines how the company makes critical decisions for the business. Since its inception, Amazon has made a name for itself as the world's most customer centric company. Its growth plan is centered on improving the customer experience as it allows the company to gain customer loyalty and trust, and drive additional sales.

As seen in Figure 1, Amazon's core is based on multiple reinforcing loops, in which the customer experience is a critical factor driving the company's growth. If the customer experience is positive, there will be more traffic on the site. This attracts additional vendors and sellers which adds to the selection of items Amazon can offer to its customers, reinforcing additional sales through a better customer experience. The additional scale also allows the company to lower prices further improving the customer experience, through a second reinforcing loop. Though this flywheel is rather simplified, the positive feedback it depicts is the core of the company and drives its business decisions. This philosophy is not only applied in Amazon's traditional e-commerce business but is also used internally to create additional sustainable business platforms including Amazon Businesses and Amazon Web Services, in which the customers are other businesses.

[6] "The World's Most Innovative Companies," *Forbes*. Feb 7, 2017.

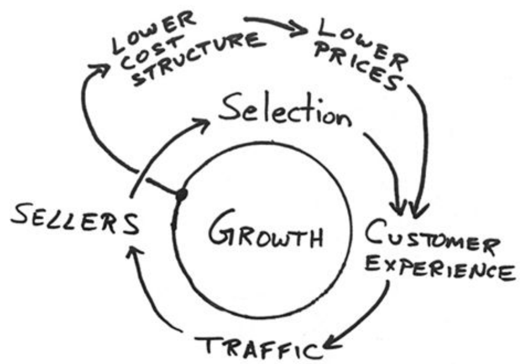

Figure 1: The Amazon Flywheel is a reinforcing system dynamics loop that drives growth for the company [7]

Though Figure 1 does not depict the negative feedback loops that could hinder its growth, Amazon has appropriately allocated a large portion of its resources to developing strong logistics and operations. Without having an expertise in these key areas, it would be difficult for the company to maintain rapid growth rates and continue to fulfill customer orders at high quality thresholds, ensuring packages contained the correct content and were delivered quickly. With a strong IT team, the company has been able to develop a platform that aggregates customer requests with on hand inventory. The value proposition of such speedy delivery could not be possible without their clear organization of software driven warehouse logistics for ordering inventory, storing inventory, and processing inventory for customer orders. Acquiring Kiva Robotics, now known as Amazon Robotics (for more information see Chapter II), has enabled the company to integrate automation software into their operations and customize it to their needs.[8]

C. Prime Pantry Business Model and Background

As mentioned above, Prime Pantry is a specialty business that is part of the consumables portfolio. The service offers customers the ability to purchase household goods for a $5.99 shipping cost. It is only available to Prime members who pay a $99 annual fee for Prime benefits including free shipping on selected items on Amazon.com. These membership and shipping fees enable Amazon to "offer a wider range of items including heavy and bulky items such as

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[7] Benedict Evans, "Why Amazon Has No Profits (And Why It Works)." Sept 5, 2014.
[8] S. Kirshner, "Amazon buys warehouse robotics start-up Kiva Systems for $775," *Boston Globe.* 19 March 2012.

popular soft drinks, bottled water, a new range of paper and laundry products…that are cost prohibitive to ship for free." [9] The product selection rounds out Amazon's offerings to be competitive with Costco, Walmart, and Target.

The initial intent for Prime Pantry was to leverage economies of scale. The product selection was limited to around 11,000 Stock Keeping Units (SKUs)[10], compared to Walmart's 125,000 SKUs.[11] By curating the items offered through this business and leveraging fast moving items, inventory from vendors could be bought as wholesale items. This would allow shipments of goods to be received as full pallets, allowing the business to process these items more efficiently (the details of pallet processing will be further discussed in the following section) and at a lower cost. These cost savings could then be passed on to the customer, following the principles of the Amazon flywheel discussed above.

When a customer selects an item they wish to purchase from Prime Pantry, a virtual shipping box is created. As the customer adds items to the box, they are notified of how full the box is. Although they can complete an order no matter how full the box is, this indicator incentivizes customers to buy more items to fill the box since they have to pay a flat fee for shipping. Not only does this help the company sell more, but it improves operational efficiency by increasing the units per order (UPO) as will also be discussed in further detail below. Since it was created in 2014, Pantry has consistently met or exceeded sales forecasts. To continue the growth of the business, lower Average Sales Price (ASP) items are being introduced necessitating lower cost fulfillment solutions to maintain profit margins. In 2016, there was a $662B market opportunity to fulfill consumables between the $0-5 ASP range. As a relatively high velocity consumables business, the Pantry platform is well situated to help address this opportunity.

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[9] Abby Callard, "Amazon opens its pantry doors for ordering bulky items," *Internet Retailer.* Apr 24, 2014.
[10] This estimate was generated by searching the item catalog on https://www.Amazon.com/Prime-Pantry.
[11] Sarah Nassauer, "Wal-Mart Shrinks the Big Box, Vexing Vendors," *Wall Street Journal*. Oct 25, 2015.

II. Prime Pantry Operations

The first chapter provided a background of the company, the industry, and the Prime Pantry business. The following chapter will delve into the details of the operations of Prime Pantry which are critical to understanding the core issues and analysis presented in this thesis. Specifically, this chapter will discuss the details of Amazon Robotics and its role in warehouse operations, the overall size and capacity of the Pantry network, the various processes involved in completing a customer order, and current inventory management practices.

A. Amazon Robotics

As mentioned in Chapter I, Kiva Robotics was acquired by Amazon to improve warehouse operations, enabling faster delivery to the customer. Now known as Amazon Robotics (AR), it has become an industry leader in goods-to-person inventory automation and physically moves inventory within the fulfillment center.[12] In the AR system, inventory is stored on shelving units or pods. Their automated drives use RFID to follow a designated path to move inventory to the appropriate stations determined with a sophisticated order processing algorithm.

In fulfillment centers that can be as large as 1M ft^2, AR provides a major benefit for associates and prevents them from having to walk through inventory storage racks to store or pick items for completing orders. By automatically bringing associates the required storage racks called pods, AR eliminates the portion of the fulfillment process that contributes to the most non-value added labor and decreases associate fatigue. The RFID technology also allows inventory location to be tracked and accounted for at any period of time.

The Amazon Robotics (AR) Field

The Amazon Robotics field is the designated area in which the inventory pods are stored and the Amazon Robotics drives are allowed to move. The perimeter of the field is set up with stowing stations where inventory is placed into the field, and picking stations where inventory is removed from the field for customer orders. The center of the field is primarily used for

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12 Brigitte Brozenec, "Deliver the Goods: How Automated Picking Solutions Help DCs Meet Consumer Demand," *Material Handling & Logistics* 70.10 (2015): 24-25. Jan. 2, 2017.

storing inventory. Because people or carts do not need to be able to go between different storage pods to retrieve inventory, the pods can be very densely organized in stationary positions, significantly increasing the storage capacity per square foot. As a safety precaution, no humans are allowed to walk inside the AR field.

Inventory stored in the AR field is critical to Amazon's operations because unless an item is in the AR field it will not appear on the website for a customer to buy. Therefore, although Amazon may have certain items elsewhere in their warehouse or fulfillment network, this inventory will not be considered 'buyable' until it is moved into the AR field. This allows Amazon to decrease their 'click to deliver' time, or the time from when the customer places their order to when the completed order is delivered to the customer.

Reserve Racking

The AR field is not the only place where inventory is stored in the fulfillment center. Items that are not stored in the AR field, can be stored in fixed shelves called reserve or reserve racking. In order to store inventory in these shelves, inventory must be placed on single ASIN pallets and moved to the shelving on high-lows.

B. Pantry Operations Overview

Prime Pantry currently has four fulfillment centers located in Newark, CA; Cincinnati, OH; Dallas, TX; and Newark, NJ. Though the design and size of each site is different, they all use Amazon Robotics and similar inventory management strategies to store and move items through the fulfillment center (FC). With current processes and capabilities, these sites can fulfill a total of 1M units weekly.

FC processes are split up by inbound and outbound processes. Inbound processes include receiving and stowing which track inventory in the FC and store the inventory in the appropriate locations. Outbound processes refer to aggregating customer orders through picking, packing and shipping. These processes are described in more detail below.

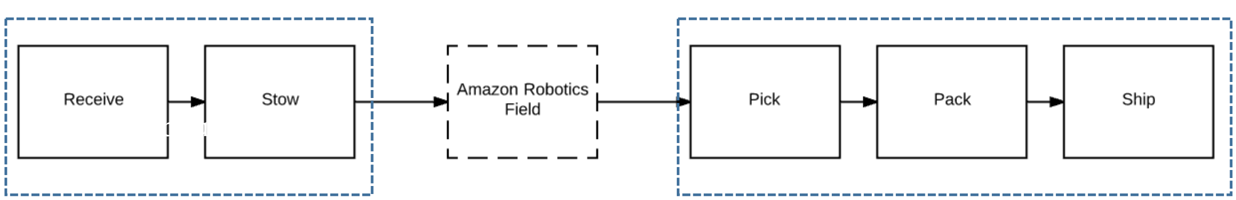

Figure 2: Inbound and outbound process flow for inventory

Receiving

Receiving processes in Pantry are classified by two types, pallet receive and each receive. All inventory from various vendors are delivered to the FC on pallets. Based on the quantity of items that are being delivered from the vendor, these pallets could contain only one Amazon Standard Index Number (ASIN)[13] or multiple ASINs. Single ASIN pallets are generally made up of high velocity products or high cubic volume products such as paper towels, water bottles, napkins etc. If the quantity ordered of a particular ASIN is not large enough to create a full pallet (full pallets at Amazon are considered to be 70 cubic feet on average[14]), vendors will usually place other ASINs on the same pallet to decrease delivery costs. Single ASIN pallets and mutli-ASIN pallets have separate receive processes.

Pallet Receive

The pallet receive process is more efficient than the each receive process. To fully process a pallet, associates scan an item on the pallet and enter the quantity delivered. If the height of the delivered pallet is too large, associates will down stack a pallet and split the inventory across two pallets to ensure it fits within the FC racking. After scanning the items, a tracking sticker is applied and the pallet will be ready to stow. Associates do not need to open and count every item on single ASIN pallets to receive them, making the process very time efficient.

Each Receive

Multi-ASIN pallets are processed with each receive. The each receive process is much more cumbersome than the pallet receive process. First, associates cut plastic shrink wrap off of the pallet. This shrink wrap is used to keep items from falling off of the pallet during transportation but needs to be removed in order to account for the inventory delivered by vendors. If items come in a case, the case is pulled off the pallet to a receive station. The case is scanned, and each of the items in the case are inspected for damage. The quantity of sellable units is then entered

[13] ASINs are Amazon's internal Stock Keeping Units (SKUs). There is an individual SKU number or ASIN associated with each unique item of inventory in the FC.

[14] While this is not the exact value used by Amazon, this value will be used for the purposes of this paper.

into the system and the damaged items are accounted for donation. If the pallet has multiple cases of the same ASIN, associates do not need to scan all of the items but can instead open the cases to check the units are not damaged and then enter their quantity directly into the system after scanning only the first case on the pallet with the same ASIN. Therefore, the more cases on a pallet with the same ASIN, the faster and more efficient the each receive process.

Stowing

Once items are received they are stowed into storage. Inventory can be stored in either reserve racking or the Amazon Robotics (AR) field. Where inventory is stored after it is received is dependent on the current inventory on hand in the AR field. Because items do not appear as sellable to customers unless they are stored in the AR field, ensuring at least one unit of every ASIN in the FC is in the AR field at all times is critical.

Figure 3: Reserve Racking

Figure 4: AR field Racking

The Details of the Stowing Strategy

When items are delivered to the FC, they are classified as either single ASIN pallets or multi-ASIN pallets. Multi-ASIN pallets are either down-stacked into single ASIN pallets if enough inventory exists to take up more than around $40ft^3$ or they are received as eaches. If items are received as eaches, they are placed directly into the AR field. Even if the days of cover[15] (DOC) of these units in the AR field exceeds the required threshold, not enough units of this ASIN have been received to be palletized and placed in reserve racking if they are each received. Since reserve racking is only for pallets, placing these items directly in the AR field is more efficient than storing inventory outside the AR field manually since they cannot be palletized. However, each stowing this inventory into the AR field in spite of this ASIN being above the DOC threshold in the AR field can lead to overcrowding the AR field and higher holding costs. Single ASIN pallets are scanned to see how many units of that SKU are in the AR field at that point in time. If that number of units is below the minimum DOC threshold, the pallet is directly stowed into the AR field after being received. If the minimum DOC threshold has not been reached, the pallet is stored in the reserve racking until the inventory in the AR field falls below the DOC threshold. At this time, the earliest received items are pulled into the AR field to ensure first-in-first-out (FIFO) inventory management. These process flows and decisions for inventory storage are mapped out in Figure 5.

Each fulfillment center can specify the minimum days of cover (DOC) required within the AR field. If this is too low and not enough inventory for a specific SKU is stored in the AR field, increased stock-outs can occur. A stock-out is when no units of a specific SKU are left in the AR field, meaning customers can no longer order that SKU. If the DOC minimum is too high, this can lead to congestion in the AR field since more units of each SKU are required in the AR field and this can lead to decreased picking and stowing efficiency. At most FCs, this minimum is specified to be 1DOC for all SKUs.

[15] Days of Cover (DOC) is the number of days demand for an item can be met with the inventory on hand. It is a function of customer demand and the number of units of inventory. The equation for DOC can be found in the appendix.

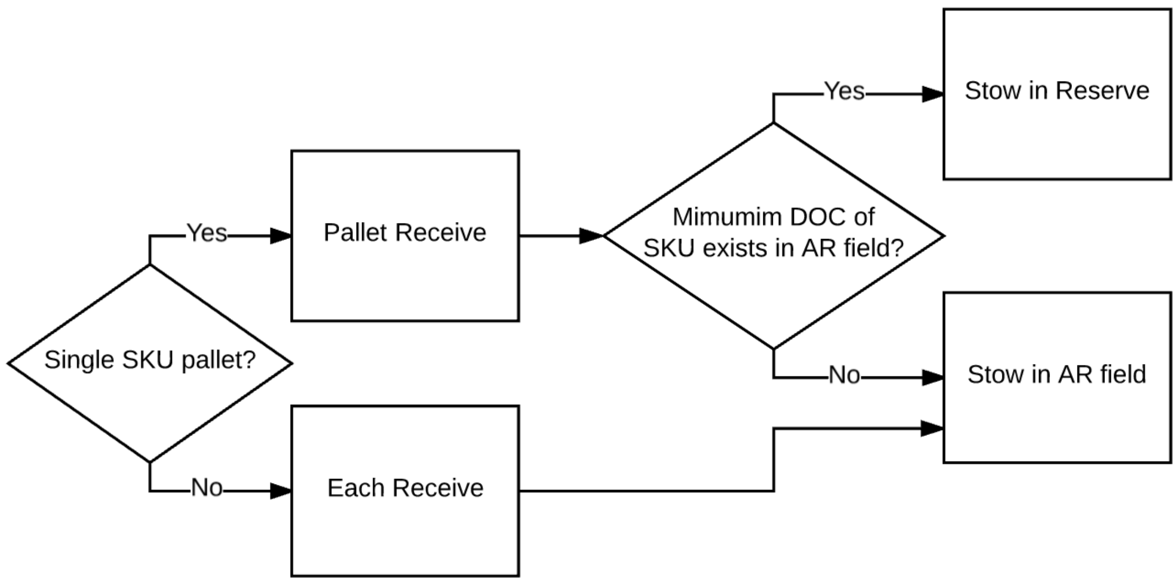

Figure 5: Process flow for inbound strategy

Picking

Although there are many way to pick items at Amazon, within Pantry pick to carton or pick to tote are primarily used. Though they are very similar, pick to carton refers to placing picked items into the corrugate box that the final items will be shipped in. Pick to tote refers to picking items into a yellow plastic tote which will be conveyed to the packing stations. In this process, the corrugate boxes are made at the packing stations.

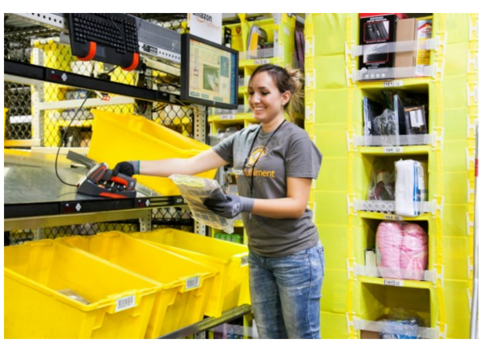

Figure 6: Pick to Tote

In either case, the Amazon Robotics pods of inventory move from stowing stations to picking stations. At the picking stations, the pods are presented to a picker. Each picker has a set of open orders in their stations. A computer will notify the picker to find an item in a specific bin on the pod and designate which order it belongs to. Once the picker places the given item in the appropriate bin, a new pod is presented to the picker.

Packing

Packing operations are fairly standardized across all Pantry sites. During this process, associates weigh the box and its contents, add protective stuffing or inserts to the box, seal it, add a shipping label, and then push the box onto the conveyor to outbound docking stations. If the pick to tote process is used, associates in pack stations will also build the box and transfer each item from the plastic tote into the box.

Shipping

Outbound shipping processes include sorting the boxes according to outbound carriers such as FedEx, UPS, USPS and the sort facilities. Pallets are created and shrink-wrapped for each of these outbound paths and loaded onto outbound trucks a few times a day depending on demand.

C. Prime Pantry's Current Inventory Storage Strategy and Its Challenges

Although Pantry was founded on providing a curated number of fast-moving SKUs to customers, in keeping with Amazon's core, the business is looking to expand SKU selection for customers. Therefore over the last few years Retail has made certain slower moving SKUs available on Prime Pantry based on customer data that shows many customers might buy these items when completing their orders.

Since the cubic volume of available storage space is limited in the AR field and customers can only buy inventory in the AR field, inventory management within the FCs is critical. Overpopulating the AR field with slow moving items means that the opportunity cost for selling another item is high – that is, other items that are faster moving cannot be stored in the AR field and sold if the slower moving items take up too much cubic volume in the AR field.

However slow moving items cannot simply be moved to the reserve racking. Reserve racking only accommodates pallets of inventory with the current software and reserve stowing processes. Placing incomplete pallets in reserve hinders the ability to store full pallets of inventory in the limited storage area. Additionally, retrieving cases instead of pallets from reserve is not currently supported due to physical restrictions; oftentimes pallets are stacked vertically which can make it difficult to reach certain inventory without the support of a fork-lift. Using fork-lifts for case replenishment would increase variable costs of retrieving and stowing inventory in the AR field since fork drivers would have to retrieve the pallet, remove the number of cases required and then place the remaining pallet inventory in the shelving again.

Of course not all pallets in the reserve racking are completely full. Amazon considers pallets that are 70ft[3] as full pallets, however if received pallets have inventory that is more than half the height of a reserve rack and there is more than two days of cover of that ASIN in the AR field, the pallet is sometimes stowed in reserve. These thresholds for minimum days of cover in the AR field and minimum pallet height required for reserve storage are left to the discretion of each site based on the storage capacity available at a given period of time and are often manually set by the site leads and inbound area managers.

This strategy creates a complex problem for inventory strategy that must be addressed. If slow moving items that do not fill up a full pallet are moved into reserve racking they would prevent other full pallets from being stored in that racking. If they take up too much space in the AR field and take too long to sell, faster moving items cannot be moved into the AR field and sold. Although additional items of that SKU could be ordered to complete a full pallet, this can increase holding costs and obsolescence costs. It is this tradeoff between costs for holding inventory in reserve verses in the AR field that this thesis aims to optimize through an analytical model discussed in the following chapters.

III. Basics of Inventory Management

To better understand Amazon's inventory strategies, it is imperative to first understand the basics of inventory theory. This section will aim to discuss inventory theory for demand and variability as well as holding costs. Additionally, the fundamentals of ordering policies will be reviewed. These concepts will help analyze if the WOC thresholds seen in the Pantry business are optimal for efficient FC performance in the following chapters.

A. Inventory Demand and Variability

Inventory theory has shown that product volume is directly dependent on forecast error and the lead time for the products being considered. Typically, inventory can be modeled as such: [16]

$$Inventory = z * \varepsilon \qquad \text{Equation 1}$$

where z is a service level multiplier (a z value of 1 represents 84.1% of a normally distributed population) and ε is forecast error. In practice, standard deviation of demand, σ, can be used although forecast error can be different from standard deviation. For Amazon, the question becomes how does σ and inventory vary with demand and how might this affect field policy. For this, the theory of demand, forecast error, and standard deviation are necessary to look at. Inventory theory states the following:

$$D = \tau \cdot D_t \qquad \text{Equation 2}$$

where D is the mean demand during the lead time, τ is the lead time for that SKU, and D_t is the demand during a specified time period. The standard deviation of total demand during the lead time can be calculated by the following equation: [17]

$$\sigma_D = \sqrt{\tau \cdot var(D_t) + {D_t}^2 \cdot var(\tau)} \qquad \text{Equation 3}$$

Therefore, as the lead time increases, so does the standard deviation of the demand of that particular SKU. As the variance of demand decreases, so does the standard deviation of demand. As seen from Equation 1, a higher standard deviation of demand leads to less inventory required to meet expected demand. Therefore, if the variations of demand or lead time decrease, the overall inventory required to meet demand can decrease.

For order cycles one through time *t*, the standard deviation of demand can be represented as:

$$\sigma_D = \sqrt{\text{var } D_t} = \sqrt{t}\ \sigma_i \qquad \text{Equation 4}$$

[16] Donald B. Rosenfield, "Innovation and Onshoring: The Case for Product Variety", *Production in the Innovation Economy* (2014): 225.
[17] Edward A. Silver, Inventory Management and Production Planning and Scheduling (John Wiley & Sons, 1998) 283.

where σ_i is the standard deviation of demand in any period i.[18] Higher demand items tend to have lower coefficients of variance (for theoretical treatment see Donald B. Rosenfield's "Production in the Innovation Economy"). This results in lower inventory levels or safety stock on a percentage basis that is needed to support the given demand.

B. Reorder Inventory Models for Stochastic Demand

As mentioned above, lead times and demand values are random variables that can be described through probability distributions. Amazon accounts for this variability in its supply chain by utilizing an Order-Up-to inventory reordering process. In this order policy, order frequencies are predetermined though agreements with various vendors. These vendors are scheduled to deliver products on a consistent weekly or bi-weekly basis. This means that the buying period is fixed for every SKU, and Amazon can only place an order every T time periods. The inventory ordered at every reorder point, Q changes to meet an inventory level, R. This desired inventory level is determined according to demand predictions, D, which are based on historical demand. The Order-Up-to model does not constantly track inventory levels but only checks inventory status at a reorder period, therefore the reordering quantities must account for variabilities in demand over period T and variabilities in an item's lead time.

In this model, one can think of the order up to level as the sum of the safety stock and lot quantity or cycle stock. The lot quantity is $D \cdot T$, where T is the time between orders or the buying period. For higher demand items, T is lower and hence the cycle stock is lower on a percentage basis. An item with a lead time of τ and a buying period of T will have an average inventory level of:

$$I = R - D \cdot \tau - \frac{D \cdot T}{2} \qquad \textit{Equation 5}$$

Inventory theory states that the optimal Order-Up-to quantity has an optimal fractile of:

$$F(R^*) = \frac{\pi - h \cdot T}{\pi} \qquad \textit{Equation 6}$$

[18] Donald B. Rosenfield, "Innovation and Onshoring: The Case for Product Variety", *Production in the Innovation Economy* (2014): 225.

where $h \cdot T$ is the cost to carry one unit of inventory and π is the shortage cost of that item. Assuming a normal distribution of demand, the optimal fractile can be correlated to a z-value through statistical tables. With this, the optimal R value can be determined as

$$R^* = D + z\sqrt{\sigma} \qquad \text{Equation 7}$$

Since shortages are unacceptable at Amazon because they can severely degrade the customer experience, π is significantly higher than $h \cdot T$ and R^* values should be set high.[19]

C. Dual-Inventory Replenishment

For fast moving items, it is important to monitor the inventory frequently. Failure to have these items available for customers has a significant impact on the business since fast moving items tend to be box-starters, or items which draw customers to the site. Not having these items in inventory can make the company not only lose the sale of that missing item, but any other items that might have been purchased subsequently in that same order.

Though Amazon uses an Order-Up-to policy for ordering new inventory, it manages high-velocity, palletized SKUs through a two-bin system. Inventory levels in the AR field are continuously monitored and if the number of units for a particular SKU dips below the safety stock, replenishment from the reserve racking is triggered. Therefore, the replenishment of fast moving items from reserve to the AR field can be modeled through a continuously monitored (Q,r) policy in which an order of Q units is placed when inventory levels reach r units.

Because reserve racking only holds pallets, an order to replenish Q units of inventory from reserve racking to the AR field could result in moving more than Q units into the AR field since a pallet could contain more than Q units. Additionally, SKUs that are to be replenished from reserve racking already have units within the fulfillment center, so the maximum lead time used for replenishment, τ, is 1 day. When the inventory level drops below this set threshold of *r* units, a replenishment of Q units on a pallet from reserve to the AR field is placed.[20]

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[19] Ronald G Askin. and Jeffrey B. Goldberg. Design and Analysis of Lean Production Systems (John Wiley & Sons, 2002) 193-195.

[20] Ronald G Askin. and Jeffrey B. Goldberg. Design and Analysis of Lean Production Systems (John Wiley & Sons, 2002) 186-189.

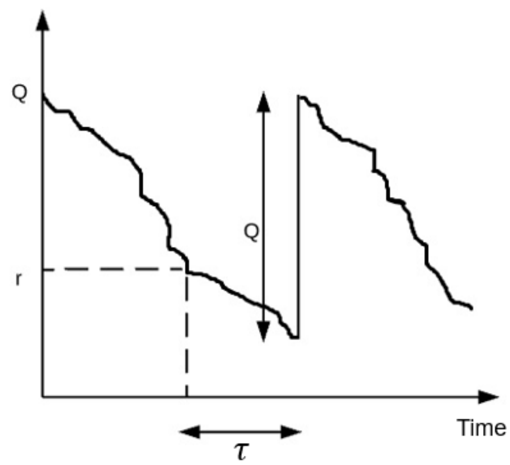

Figure 7: Inventory levels in the Prime field with continuous inventory monitoring and replenishment

Though Amazon does not use a strict two bin inventory management approach, this analogy conveys the interdependent relationship between reserve and the AR field.

D. Fixed Costs and Holding Costs

As discussed above, variance has a direct effect on costs. When an item has less variation, a lower safety stock or amount of inventory can be held to still meet customer demand and shipping requirements. With a smaller safety stock, the length of time that items are sitting on the shelves is lower. Fixed costs can be represented as

$$Fixed\ Cost\ Per\ Unit\ (FCPU) = Cost\ Per\ Day\ in\ Reserve(CPD_R) * t_R + Cost\ Per\ Day\ in\ Field(CPD_F) * t_F \qquad \text{Equation 8}$$

where t_R is the number of days an item is stored in reserve racking, and t_F is the number of days the item is stored in the Amazon Robotics field.

FCPU is less for faster moving items than slower moving items since t_R and t_F are dependent on item velocity. Therefore there is a strategic advantage to curtailing products to only the faster moving items as these items have lower variability in demand and delivery, shorter time periods in the fulfillment center, and therefore a lower fixed cost.

E. Summary of Key Principles of Inventory Theory

Understanding the basics of inventory theory is critical to analyze current inventory strategies. In summary, the equations above demonstrate the following key principles of inventory management:

1. Items with higher demand have lower percentage variation and therefore require lower levels of inventory on a percentage basis
2. Items with high variation in lead times or items that have longer lead times will result in high variations in demand, requiring higher levels of inventory
3. Items that are ordered more frequently and have higher demand can have lower cycle stocks

IV. Low ASP Historical Data Analysis

With the context provided for the complications of inventory management in Pantry and the theory behind optimal ordering and inventory on hand, this section discusses the analysis and approach conducted to quantify costs and develop an inventory strategy for Pantry. In order to understand the causes for the current inventory storage issues discussed above, a study was conducted to determine if there was any correlation between certain ASIN characteristics and operational costs. This study used Excel-based regression modelling to identify these relationships in order to highlight some key inventory tenets that could be utilized to decrease costs. Historical data for Pantry SKUs was used for this study. This chapter discusses the details of the key characteristics or factors analyzed, the findings for their correlation to cost, and the conclusions that were drawn to shape future inventory strategy.

A. Background

As the business grows, Retail has determined that additional items must be added to Pantry selection to improve the customer experience. Most box starters, items that bring customers to the Prime Pantry site, have already been added. These tend to be the fastest moving items within the fulfillment center (i.e. cases of water bottles, toilet paper, etc[21]). Items that Retail would like to add are supplemental items that can be used to fill a box. Although they are not box starters, they are additional items customers look for once they get to the site. These items are not as fast moving as box starters, and are therefore often ordered in smaller quantities.

[21] This data was gathered by reviewing Prime Pantry's Best Sellers on their homepage on Jan 5, 2017.

Adding more ASINs has significant operational impacts. As more of these slower moving items are added to the product mix, fewer and fewer items can be bought in full pallets decreasing the processing efficiencies that can be gained from the current fulfillment process. If more than one ASIN is on a pallet, it is each received and all of its contents are placed directly into the Prime field, regardless of demand or cubic velocity. Though more inventory would need to be ordered in order to palletize certain ASINs and the FC would have to carry higher days of cover, the fixed costs associated with items that are in reserve is less than those same items in the Prime field due to the high capital investment of implementing Amazon Robotics (see Appendix A). The cost implications of these decisions are critical since Pantry is a low margin business.[22] Therefore, the purpose of this study is to understand if there are any underlying relationships or trends among different types of ASINs that could drive processing changes to decrease cost.

B. Key Factors

The following are all factors that are believed to have a significant impact on the cost and efficiency of inventory storage. Through the analysis, it will be critical to quantify their effects on cost to generate general tenets or guidelines for inventory management. Key factors that were studied on a per ASIN basis for cost correlation in the current state model include inbound (IB) profile, average sales price, cubic velocity, turns and size.

IB profile indicates whether or not the units are processed as eaches or pallets. Because the actual operational rates of processing goods differs based off of these characteristics as discussed above, the variable costs and key Retail metric, Contributed Profit Less Fixed Cost (CPLF) is greatly affected.

Average Sales Price (ASP) is a metric used to determine what an ASIN sells for on average. This is useful because offering low ASP items ($0-3) improves customer satisfaction. The tighter margins on low ASP items however makes it critical to minimize the costs associated with

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[22] Chih-Chin Liang, "Smart Inventory Management System Of Food-Processing-And- Distribution Industry." *Procedia Computer Science* 17 (2013) 373-378.

offering and processing these goods. In order for the business to succeed and become profitable, the appropriate balance between these must be achieved.

Cubic velocity and inventory turns are additional key metrics utilized to determine how quickly an item is sold. The less time an item spends on a shelf, the more cost efficient it is because this space can be utilized for other inventory. Therefore, the higher the turns the better the cost efficiency. Cubic velocity is a unique metric but potentially one of the most critical because it combines how long an item is in the warehouse with how much volume it occupies directly impacting fixed costs.

Size categories are necessary to help correlate labor processing restrictions and capabilities which directly affects VCPU and FCPU. Additionally, size can play a large role in affecting fixed costs since FCPU is determined on a per cube basis. Item size was defined as Small, Medium, or Large according to the Amazon's Global Size Definition for the initial parts of the study.

	Dimensions	Max Cube	Max Weight
Small	<18x14x8in	80 cubic in	< 5lbs
Medium	<18x14x8in	All other	< 20lbs
Large	>18x14x8in	18,000 cubic in	< 50lbs

Table 1: ASIN Original Size Definitions

However, upon further investigation through physical time trials at a Pantry site, it was determined that these size definitions were not granular enough to understand impacts on VCPU and FCPU. Items that were particularly easy to grab or that had one dimension that was rather small could easily be stowed quickly since more items could be carried in a single trip from the conveyor to the stowing pod.

Additionally, the physical cube of the items played a large role in receive times due to the fact that most items came in packages with plastic. In order to prepare the items for stowing, receivers peel back the plastic which adds close to 30% more time to their receiving cycle time. The smaller the items, the more units were usually bundled in a single plastic enclosure, increasing the number of units that could be received within the amount of time needed to open a plastic enclosure.

To incorporate the learnings from the size trial, more granular size definitions were used in the analysis as seen below. Items with any dimension less than 2" were considered highly grabable items. These included seasoning packets, chips, make-up items, etc. Based off of the findings from the size trials, a 10% decrease was applied to the VCPU of these items. Additional scaling to the VCPU of receiving and stowing was also incorporated to factor in the effect of size to the receiving and stowing rates for eaches.

	Dimensions	Max Cube	Max Weight	Percentage of Total Units Sold
Tiny	<18x14x8in	<40 cubic in	< 5lbs	15.70%
Small	<18x14x8in	<80 cubic in	< 5lbs	22.18%
Medium1	<18x14x8in	<200 cubic in	< 20lbs	32.00%
Medium2	<18x14x8in	<400 cubic in	< 20lbs	15.00%
Medium3	<18x14x8in	<600 cubic in	< 20lbs	8.56%
Medium4	<18x14x8in	All else	< 20lbs	6.57%

Table 2: ASIN Newly Defined Size Definitions

C. Analysis and Results

The results of the costs were aggregated based off of size and inbound profile. Current ordering processes were used to categorize SKUs, therefore each row or subset of ASINs as seen in Table 2 and Table 3 are unique – that is no SKU has been included in more than one category. The results of the study validated the following key guidelines for inventory management:

1. High Cube items should be processed as pallets

Table 3 shows the VCPU associated with all sizes of inventory for both inbound profiles through each of the steps in the fulfillment of an order (Note: all costs shown are scaled by a randomized constant to maintain confidentiality of actual costs). Overall, the picking process is the most costly step of fulfilling an order contributing to $0.133 in variable cost on average, close to 22% of the total $0.60 variable cost of fulfilling shipment. Focusing on inbound processes, the inbound profile has the largest effect on the VCPU of stowing. For example, a tiny item stowed as an each has a VCPU around fifteen times the cost a tiny item stowed as a pallet ($0.072 compared to $0.005); whereas a tiny item received as an each has a VCPU around seven times the cost of receiving a tiny item as a pallet ($0.036 compared to $0.005). In order to be able to stow more items as pallets, they must also be received as pallets which also lowers VCPUs. Although there is some degradation in picking VCPU by stowing pallets since additional plastic and cardboard needs to be cut and thrown out, this degradation is only 19% of the improvement that can be achieved in VCPU by receiving and stowing as pallets.

Size	IB Profile	VCPU IB Receive	VCPU IB Stow	VCPU OB Pick	VCPU OB Pack	Total VCPU	% Units	Unique ASINs
Tiny	Each	$0.036	$0.072	$0.137	$0.025	$0.44	17%	28.5%
Tiny	Pallet	$0.005	$0.005	$0.165	$0.025	$0.35	1%	0.2%
Small	Each	$0.035	$0.073	$0.137	$0.025	$0.45	16%	21.9%
Small	Pallet	$0.005	$0.005	$0.168	$0.025	$0.36	6%	0.8%
Medium1	Each	$0.067	$0.158	$0.162	$0.026	$0.64	15%	24.6%
Medium1	Pallet	$0.012	$0.015	$0.194	$0.026	$0.43	16%	2.0%
Medium2	Each	$0.069	$0.163	$0.162	$0.027	$0.65	5%	10.1%
Medium2	Pallet	$0.012	$0.015	$0.195	$0.027	$0.44	9%	2.0%
Medium3	Each	$0.070	$0.167	$0.162	$0.027	$0.65	1%	2.9%
Medium3	Pallet	$0.012	$0.015	$0.195	$0.027	$0.44	6%	1.2%
Medium4	Each	$0.134	$0.292	$0.181	$0.028	$0.89	1%	4.1%
Medium4	Pallet	$0.020	$0.026	$0.214	$0.028	$0.49	6%	1.5%
Weighted Averages		$.001	$.052	$0.133	$0.020	0.6	100%	100%

Table 3: VCPU for various process paths and inbound profiles (indirect labor not broken out but accounted for in total costs).

2. *Low cube items with at least medium velocity and high cube items with high velocity should be prioritized for storage in the AR field over slower items*

Despite the fact that small items can be cheaper to process as pallets, they are only delivered to the FC as full pallets 5% of the time as determined from historical data. Therefore, most of these smaller units are directly placed in the AR field as eaches. This is validated in Table 4 which shows that the majority of the units in the AR field are sizes Tiny, Small, or Medium 1 in the column titled Units to Prime. Note all costs shown are scaled by a randomized constant to maintain confidentiality of actual costs.

Size	Weekly Cubic Vel (ft3/wk)	FCPU Prime	Units in Prime	WOC in Prime	FCPU Reserve	Units in Reserve	WOC in Reserve
Tiny	0.24	$0.110	23.92%	3.92	$0.042	2.58%	0.24
Small	1.11	$0.187	27.23%	3.09	$0.027	9.59%	0.62
Medium1	2.68	$0.481	29.11%	2.44	$0.171	33.89%	1.60
Medium2	6.25	$0.725	11.82%	1.96	$0.676	21.31%	2.00
Medium3	16.67	$0.939	4.39%	1.39	$0.283	17.18%	3.08
Medium4	18.79	$1.260	3.53%	1.31	$0.675	15.43%	3.23
Total	3.71	$0.389	100.00%	2.58	$0.359	100.00%	1.46

Table 4: FCPU for items' average WOC in Prime (the AR field) and reserve based off of various sizes

The fixed costs per cubic foot per day for storing a unit in reserve is 17% the cost of storing it in the AR field; yet there are high weeks of cover for smaller sized items in the AR field compared to reserve as seen in Table 4.[23] Larger items incur higher fixed costs due to their larger cube (for example, Medium 4 items incur an FCPU of $1.260 in Prime while Tiny items incur an FCPU of $0.110), therefore the current strategy of placing most of the larger items in reserve racking is appropriate especially if they are relatively slower moving ASINs.

However, it is also important to note that if the cubic velocity of a smaller item is not high enough, the total fixed cost of the item being stored in the AR field could be better utilized for a higher velocity, larger sized ASIN. As seen in Figure 8, a Medium 3 item which is stored in the field for 4 days prior to selling has the same fixed cost ($0.20) as a Medium 1 item that is held in the AR field for 15 days.

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[23] Note: Costs shown are scaled by a randomized constant to maintain confidentiality of actual costs

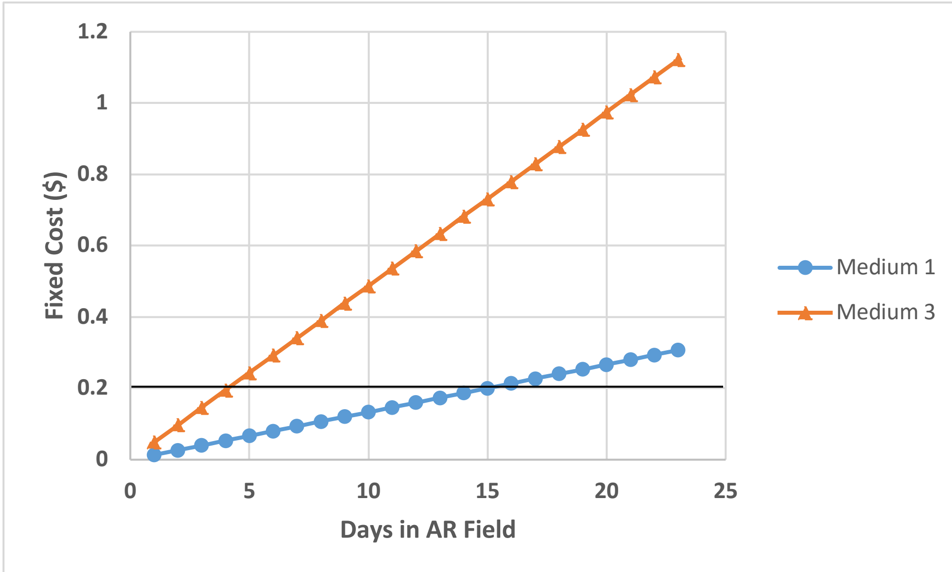

Figure 8: Fixed Cost comparison of various sized items as the number of storage days increases

3. Weeks of Cover (WOC) guidelines vary based on item velocity

Analysis of the Weeks of Cover (WOC) for the current inventory in the AR fields of Pantry FCs was conducted as seen in Figure 9. The results show that majority of the ASINs are stocked well over two WOC. Generally, the plot shows that the higher the cubic velocity of an item, the lower the WOC held in inventory, which follows the guidelines of inventory theory seen through Chapter III.

However, an overwhelmingly large portion of the inventory is held in the FC for more than two WOC. Though the AR field has limited storage space, it is holding more slow moving inventory than optimal as a result of each processing. This can drive more obsolescence costs, capital costs, and opportunity costs since only items in the AR field can be bought by a customer. Therefore, having lower WOC or shorter inventory cycles on a per ASIN basis is desirable and necessary to decrease costs.[24]

[24] Anna Bieniasz and Zbigniew Golas, "Empirical Analysis Of The Influence Of Inventory Management On Financial Performance In The Food Industry In Poland," *Engineering Economics* 27.3 (2016) 264-275.

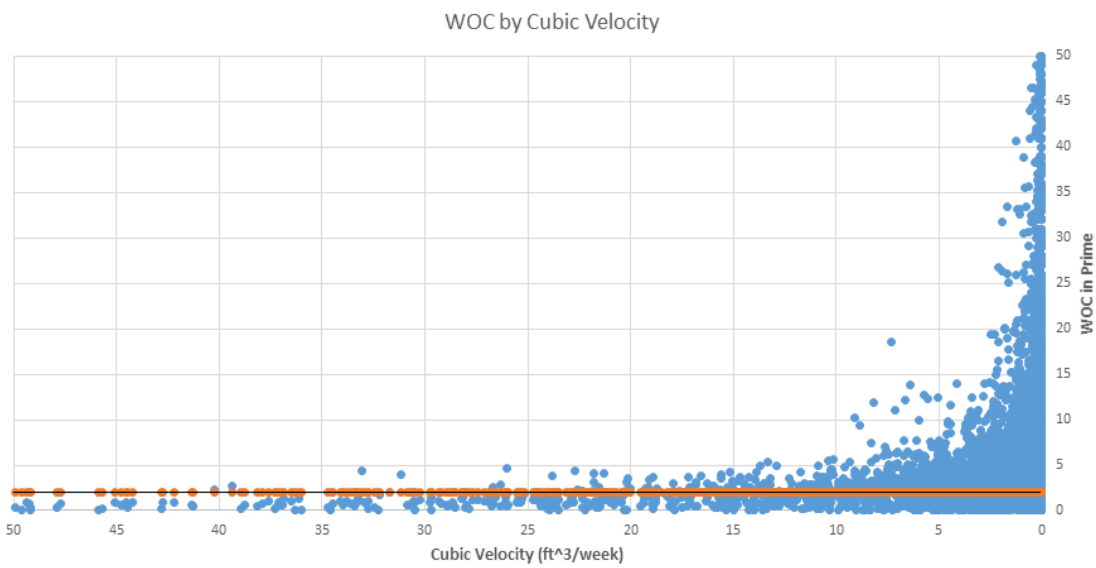

Figure 9: Weeks of Cover in the Prime field by Cubic Velocity

Using a theoretical target of 2 weeks of cover within the Prime field, or 26 turns, the volume of the inventory in the Prime field that is over two weeks of cover is more than 7,000ft^3 of inventory. Since the holding cost of an item in reserve is close to 17% the cost of storing an item in the AR field, moving these slower moving items to reserve as partially filled pallets can improve costs by $380,000 per week given 1M outbound units are shipped. These recommendations show, as expected from the inventory theory discussed in the previous chapter, that WOC thresholds should be set on a per ASIN basis and should vary based on velocity.

D. Conclusion

The analysis validates Amazon's general inventory management strategies – 1) larger items should be processed as pallets to decrease variable costs, 2) faster moving items should be stored in the AR field over slower moving items, and 3) faster moving items do not need higher weeks of cover. However, the data revealed that more granular recommendations for handling inventory are required to decrease the high WOC and fixed costs of most ASINs. A huge opportunity exists to improve the current operations within Pantry. Due to the wide range in velocities of different ASINs, an FC wide target for WOC would not suffice and could produce other problems, such as shortages for faster moving ASINs.

This analysis compares the variable and fixed costs of pallets and eaches for items, however the results have limitations. The recommendations are based on how current ASINs are processed. This analysis also studies each of the scenarios independently of effects of ordering processes. If items are to be stored in reserve, they must be palletized hence the number of units ordered would have to be large enough to create a full pallet. The consequences of these actions could result in high product obsolescence if items are ordered as pallets but not sold quickly. Ordering in pallets could also create additional storage capacity issues. Additionally, a detailed study on appropriate WOC targets is also necessary to decrease costs. These are critical considerations that must be accounted for in resolving the inventory management issues and will be discussed in the analysis in the following section.

V. Low ASP Bottom Up ASIN Analysis Model

Though the top down analysis for the current state provided some key insights, it showed that more granular recommendations were needed. The purpose of this bottom up study is to quantify the benefits that can be gained through single ASIN palletization and determine which types of ASINs would be more likely to provide that benefit. This will not only help Retail understand the cost implications of adding a specific ASIN when expanding Pantry selection, but will also allow the FCs to set WOC targets for decreasing the amount of slow moving inventory in the AR field.

Using the historic data for the velocity of items sold, variable and fixed costs could be calculated based on current ordering inputs that are manually determined by the vendor team. This model weighs the cost of processing these units as eaches with ordering more units to create a full pallet, and completes the analysis for every ASIN. This analysis is more granular than the first approach taken in part one of the analysis because it considers the theoretical costs the business can expect if the current ordering processes were not used. This section will also delve into the details for this approach, the key inputs and factors considered for the model, and the conclusions that can be drawn from the results of the model.

A. Model Details

To complete this analysis, the core of this study aims at understanding the effects of palletizing ASINs on the fixed cost per unit (FCPU) and variable cost per unit (VCPU).

Key Inputs and Assumptions:

Key inputs that were studied included inventory size profiles, velocity or weekly demand, vendor minimum order quantities, delivery frequency, vendor lead time and product shelf lives or pad times.

This study analyzed the 30 fastest ASINs within each size category. Only items that have been introduced to the network prior to 2016 and received through June 2016 were utilized to ensure they were mature ASINs; ASINs see volatile changes in customer demand during the first six months that they are offered to customers. The ASINs studied are also replenishable[25] and buyable[26] in the inventory management system.

Although operationally a pallet is on average $70ft^3$, in the study the pallet sizes were defined by each vendor. The fixed minimum quantities that must be bought from vendors to qualify as a pallet were utilized for the study to ensure more accuracy. The model also considered average vendor lead times (VLT) and buying periods to calculate frequencies of deliveries. This in turn affects the quantities that must be ordered, obsolescence costs[27], liquidation costs[28] and capital costs[29]. Based on Retail input, a 30 day payment to the vendor was assumed for capital costs of inventory calculations. VLTs ranged from 5-17 days and buying periods were either on a one week or two week period. Capital costs were assumed to be 15% of inventory costs.

Since many of the Pantry items are grocery items, their pad times are less than one year. Though many of the beauty items have longer pad times, these were also modeled with a maximum pad time of 1 year. This is primarily because though those the products don't physically spoil, customer preferences change as new scents or colors of beauty products are released, making beauty products over a year old less desirable.

[25] Replenishable items are in reserve and can be pulled into the AR field to be made available to a customer to buy
[26] Buyable ASINs are items that Retail can buy from a vendor and items that the business intends to continue offering
[27] Obsolescence cost is the amount of money lost by liquidating items that could not be sold before their pad times were reached. Higher vendor costs lead to higher obsolescence costs since liquidation costs are directly related to vendor costs.
[28] A 10% recovery at liquidation was used to determine the amount of money lost from unsold items
[29] A 15% cost of capital was used to determine capital costs of inventory

Critical inputs for this analysis are the Fixed Cost Per Day (FCPD) which are calculated values for the fixed cost per cube per day of items in reserve or in the AR field. These inputs were calculated by determining the capital costs and depreciation associated with items in reserve and items in AR (additional details can be found in Appendix A).

Model Calculations:

In order to determine if SKUs should be ordered as pallets, two scenarios are analyzed: 1) the costs of fulfillment if full pallets were ordered and 2) the costs of fulfillment if only the minimum amount were ordered and placed in the AR field.

Scenario 1: Pallet Ordering

To start, the average order quantity is calculated based off of the vender defined minimum pallet quantities (P), vendor lead times (VLT), and average weekly demand (D) that is calculated from historical data. The following equation can be used to calculate the order quantity:

$$Q = roundup\left(\frac{D*VLT}{P}\right) * P \qquad \textit{Equation 9}$$

This equation assumes there is enough on hand inventory for this SKU and the order quantity only accounts for the quantity that will be required during the amount of time required for delivery after the order is placed (D∗VLT). Since the order quantity must be rounded up to the next full pallet, the larger the minimum pallet quantity, the more excess units need to be purchased to palletize a SKU. For example, if the minimum pallet quantity is 100 units and the expected D∗VLT value is 101 units, two full pallets will be purchased to meet the demand, and 99 additional units are ordered.

Using the newly determined order quantity and Equation 5, the average inventory, I, can be calculated. This in turn can be used to calculate the inventory weeks of cover ($\frac{I}{D}$) and fixed cost of holding the inventory ($FCPU_s$) in reserve according to the following equation:

$$FCPU_s = \frac{I}{D} * FCPD_{Reserve} \qquad \textit{Equation 10}$$

Though this accounts for the storage cost for the inventory, capital costs of inventory must also be accounted for. If the inventory was being sold enough to need monthly deliveries (WOC<4), the capital costs were assumed to be zero since vendors were also paid on a monthly cycle. If the inventory was slower moving and had to be delivered less than once a month in pallet quantities, the capital cost of inventory was assumed to be 15% of the vendor cost (V), the amount paid to the vendor for one unit of that SKU.

$$FCPU_C = I * V * .15 \qquad \text{Equation 11}$$

Another major cost that must be accounted for when analyzing if pallet ordering should be implemented for a SKU is obsolescence cost, $FCPU_O$. If inventory is stored in the fulfillment center longer than the pad time, those units of inventory will be considered obsolete and will not be sellable. Liquation costs, L, are 10% of vendor costs per unit. Therefore the fixed costs for obsolescence amount to:

$$FCPU_O = (WOC * 7 - pad\ time) * D * L \qquad \text{Equation 12}$$

The total fixed cost incurred from palletization is then calculated as the sum of each of these costs:

$$FCPU = FCPU_S + FCPU_C + FCPU_O \qquad \text{Equation 13}$$

<u>Scenario 2: Each ordering for the AR field</u>

Similar to scenario 1, the total order quantity is calculated using current demand; however instead of using minimum pallet quantities to define the number of units ordered, the order quantity is driven by case quantities. Case quantities refer to the minimum number of units you can purchase from a vendor.

The calculations cost of capital are the same as in scenario 1, but the calculation for average inventory in the AR field must also capture the current inventory on hand (IOH). Current IOH is utilized in scenario 2 because this analysis is strictly studying SKUs that are each received which means they are not currently palletized and therefore have no inventory on hand in reserve. Since the FCPD is different for reserve than for the AR field, the FCPD equation used changes to:

$$FCPU_s = \frac{I}{D} * FCPD_{AR\ field} \qquad \text{Equation 14}$$

Additionally, since smaller quantities are ordered in cases in scenario 2, there are no obsolescence costs for inventory in the AR field. Therefore the overall fixed costs amount to:

$$FCPU = FCPU_s + FCPU_C \qquad \text{Equation 15}$$

Criteria for Palletization:

The calculations in scenario 1 and scenario 2 determine the fixed costs associated with ordering and storing inventory in reserve or the AR field. In order to determine if items should be palletized the variable costs must also be considered. To palletize an ASIN, the FCPU of an item in AR must be larger than the sum of the FCPU of that same item in reserve plus the VCPU associated with stowing and replenishing the pallets to and from reserve.

$$FCPU_{AR} = FCPU_{Reserve} + VCPU_{Replenishment} \qquad \textit{Equation 16}$$

Though there are also some cost savings in the receiving process if items are received as eaches verses pallets, these savings are insignificant compared to the VCPU and FCPU costs discussed above. Therefore the stowing and storing costs analyzed can be utilized to drive inventory strategy.

B. Velocity Results

The first part of this model determines the velocity required for palletization. The model gradually increases the weekly demand to determine how many units per week are required to sell for each SKU before Equation 16 is solved.

To show the results of the model, the performance of select ASINs in each size category can be seen in Table 5 (Note: Costs shown are scaled by a randomized constant to maintain confidentiality of actual costs). The Current Weekly Velocity per Site values are the D values utilized in the equations above. The Weekly Velocity Needed values denotes D*, the number of units that must be sold every week in order to satisfy Equation 16 and palletize that SKU.

Table 5 shows that for the Medium1, Medium2, and Medium3 ASINs studied, palletization can provide cost savings since the current velocity of these ASINs is higher than the velocity needed to palletize. For example, for the Medium 1 item only 20 units must be sold per week for there to be a cost benefit to palletizing and since the current weekly velocity of the item is 29 units, this item should be palletized, resulting in $0.24 in savings per unit. As can be seen in Table 5, larger items generally require lower weekly velocities to palletize because ASINs with a higher cube require fewer units to meet minimum pallet quantity thresholds. This is important because buying too many units to create a full pallet increases capital costs of inventory as well as increases the likelihood of high obsolescence costs.

Description	Size	Current Weekly velocity per site	Minimum pallet quantity	Weekly velocity needed to palletize	Vendor Cost per unit [30]	Palletize?	Cost savings per unit from palletization	Cost savings per year
Can of Tomato Sauce	Tiny	62	2112	83	$1.19	N	-	-
Fabric Softener	Small	27	864	43	$4.45	N	-	-
Juice Carton	Medium 1	29	480	20	$3.74	Y	$0.24	$1,447
Laundry Detergent	Medium 2	13	336	9	$5.94	Y	$0.39	$1,054
Soup Pack	Medium 3	14	144	4	$17.27	Y	$2.00	$5,824
Potato Chips	Medium 4	4	110	4	$5.76	Y	$0.00	$0.00

Table 5: Velocity requirements for palletization; note that Tiny, Small and Medium 4 items will not currently provide cost savings from palletization since their current weekly velocity is not higher than the velocity needed to palletize.

C. Inventory Management WOC Results

The second part of this model uses the equations from Section A to track the amount of inventory that should be kept on hand assuming the current demand is held constant. Varying the IOH until Equation 16 is satisfied, identifies the maximum amount of inventory that can be supported in the field before it becomes more cost efficient to order larger quantities and palletize items. Therefore, if the value for Inventory on Hand to Palletize is lower than the current Inventory on Hand (IOH) value in Table 6, the SKU should be palletized. Additionally, the maximum Weeks of Cover (WOC) threshold can be set by dividing the Inventory on Hand to Palletize by the current Weekly Velocity Per Site.

Table 6 shows that if smaller ASINs are fast moving, they require very high weeks of cover before needing to be palletized. In these cases (as can be seen from the Small item in Table 6 which has a Max WOC in AR of 176), though the analysis shows the field could support more WOC in the AR field and still be cost efficient, the maximum WOC in AR should be set to 52 to prevent adding items to the field that would expire. Larger items generally have lower WOC

[30] Note: Costs shown are scaled by a randomized constant to maintain confidentiality of actual costs

since their larger cube accrue more FCPU in the AR field than smaller items. The Medium 3 item indicates that there is WOC sensitivity to vendor cost. Palletizing an item with higher vendor costs accrues more capital costs since much more inventory must be ordered to palletize. The benefits are far outweighed by the capital costs of inventory when palletized, therefore a higher WOC threshold is acceptable in the field.

Description	Size	Weekly velocity per site	Minimum pallet quantity	Inventory on Hand (IOH)	Inventory on hand to palletize	Vendor Cost [31]	Max WOC in AR	Palletize?	Weekly cost savings per unit from palletization
Diced Tomatoes	Tiny	35	2304	293	-	$1.49	-	N	-
Allergy Tablets	Small	1	1440	128	176	$15.25	176	N	-
Juice Carton	Medium 1	37	480	162	116	$3.74	3.1	Y	$1.36
Laundry Detergent	Medium 2	13	336	156	38	$5.94	2.9	Y	$12.45
Hair Dryer	Medium 3	2	480	19	21	$14.49	10.5	N	-
Potato Chips	Medium 4	4	110	35	24	$5.76	6	Y	$39.49

Table 6: Maximum weeks of cover thresholds for AR field

Tiny and Small items require very high inventories on hand to overcome the additional obsolescence costs, capital costs, and variable cost of moving items from reserve to the AR field with palletization. Therefore, these ASINs should not be palletized. Faster moving, larger ASINs however, such as the Medium 1, Medium 2 and Medium 4 items cited should be palletized and lower WOC thresholds in the field can be utilized. Identifying these WOC thresholds not only decreases the costs of fulfillment, but also makes additional storage space available in the AR field. Since items can only be sold if they are stored in the AR field, this is critical to improving inventory management and can enable the company to sell more of their faster moving items.

Though inventory theory suggests faster moving items require less on hand inventory, the results of this analysis show that the size of the items and minimum pallet quantities have a large bearing on the optimal inventory that should be kept on hand. In a dual inventory storage

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[31] Note: Costs shown are scaled by a randomized constant to maintain confidentiality of actual costs

scenario such as Amazon's, it may be optimal to order more than the lower levels inventory theory recommends in order to decrease costs.

D. Model Usage, Recommendations, and Next Steps

The model can be used to determine two key thresholds: 1) what velocity is required to palletize an ASIN given current inventory metrics and 2) what is the maximum weeks of cover allowed in the AR field for an ASIN given its current velocity.

Since results for palletization are heavily dependent on item obsolescence, order WOC, ASIN velocity and minimum pallet order quantities specified by each vendor, general guidelines or tenets are not easily applicable. However, this model was specifically designed with an interactive frontend (see Appendix C) to analyze each ASIN based on its unique characteristics. This allows varying Retail inputs (velocity, VLT, delivery frequency, WOC at the reorder point, vendor costs, and minimum pallet quantities) to determine the effect on operational variables (inventory on hand, order WOC) and financial outputs (VCPU and FCPU).

The output of this model can be used in two distinct ways for the Retail teams: 1) Retail can run the model on existing ASINs and with historical velocity data to determine if any changes should be made to an items palletization and 2) Retail can use this model to determine the characteristics that would be required for new ASINs that they would like to bring into Pantry selection in order to be profitable. For the Operations teams, the model can be used to define WOC thresholds on a per unit basis, decreasing AR field congestion. Though the velocity analysis could only be completed for 30 ASINs due to lack of data for vendor pallet minimum quantities, these ASINs yielded $62,000 in annual savings network wide for those 30 ASINs. Projecting these savings for the 150 additional fast moving ASINs that fall within the same velocity range yields a total of $373,000 in annual savings. Additionally, decreasing the inventory on hand in the AR field by palletizing ASINs and storing them in reserve yields $319,000 in annual savings for the 30 ASINs. Projecting these savings for the other 150 fast moving ASINs would suggest total savings of $1.9M can be achieved network wide. These savings do not include majority of the 11k ASINs within the Pantry business and warrant an analysis on all ASINs in the future.

To understand the total benefit of palletizing more ASINs, this study must be conducted on all 11k Pantry ASINs. Retail will need to assign a data analyst to aggregate this data from Pantry's 1500 vendors. Though the current state analysis of whether or not an ASIN should be palletized has been automated through the model, the sensitivity analysis of varying velocity and IOH to determine tipping points needs to be automated by the new owners of the low ASP initiative to ensure a thorough vetting of all 11k ASINs in Pantry is completed.

Moving forward, Retail will use this tool to determine which ASINs should be bought as full pallets from vendors. This can be changed in the ordering strategy within a day. In order to see the results of palletization on storage in the AR field, VCPU and FCPU, the daily metrics should be monitored over the course of implementation before the strategy is re-evaluated. As Retail looks to add more selection to the Pantry business, the custom input option will allow the Retail team to specify the new ASIN characteristics to determine if it should be palletized. They will also be able to determine the velocity required for this new ASIN for it to be palletized and how much additional cost it will accrue if its velocity is too low to palletize.

Similarly, the sites and the Operations teams will be able to use the tool to determine inventory management strategy. This will set their guidelines for the maximum WOC in the AR field on a per ASIN basis. When an item is received at the inbound docks, the software will automatically check to ensure the maximum WOC has not already been achieved within the AR field prior to designating if the items will be stowed to the AR field or reserve. Bi-weekly meetings will need to occur with the sites to monitor the effectiveness of these WOC settings on decreasing storage issues in the AR field.

Though the team has identified ASINs to palletize, the automated version of the file will provide a complete list. In order to test palletizing these ASINs however, case reserve replenishment is necessary otherwise the items would need to be pallet stowed into the field, significantly increasing the WOC of the item in the field and further increasing the FCPU. Manual case replenishment is currently expected to launch in the next Pantry site which could be a pilot for this trial.

Automating case reserve replenishment could decrease VCPU since reserve stowing and replenishment costs on a case level are $0.10. By not having to necessarily store items as full pallets in reserve, the processing of tiny and small items will primarily be impacted. This would mean full pallets would not need to be ordered as a reason to store items in reserve. Therefore obsolescence costs would not play a significant factor in the analysis. As a result, the maximum WOC of tiny and small items in the AR field would decrease. Two options for automating case reserve replenishment are 1) a shuttle system and 2) a crane system. Using a crane system would enable better cube utilization as separate conveyors and vertical lifts would not be required. The vertical capabilities of a crane system surpass that of a shuttle system. Since the crane system requires fewer conveyors, the square footage and costs of the system are also smaller than a shuttle system.

Conversations with Dematic to design and implement a shuttle or crane system only began recently. The team will use the outputs from the model created to determine velocity and volume inputs for the study. The design for both options needs to be completed to determine which system is optimal from a cost, square footage, and volume perspective.

VI. Pick to Rebin

The previous chapters of this thesis focused on analyzing the inbound processes of Prime Pantry fulfillment. With a steady increase in demand and capacity restrictions limiting potential growth, it is also crucial to analyze outbound processes. This chapter will focus on outbound process path analysis and answer the question of whether or not it is always beneficial to pool processes or separate processes based off of specific order characteristics. This section of the thesis will first provide background to various picking processes and their benefits, complete a process path analysis to compare the options of pooling or order separation, and provide the strategy for a launch plan to address the capacity issues moving forward.

A. Pick to Order vs. Flow Picking Process Comparison

The pick to order methodology used in Prime Pantry enables lower variable cost per unit by eliminating post pick sorting. In traditional FCs, flow picking is used; any items on the presented pod required for any open orders in the FC are picked from the pod. These items are then sent to a sortation center in the FC where they are aggregated on a per order basis. In this process, pod movement in the AR field can also be minimized since the station where the inventory is picked is irrelevant. In this scenario, pods can go to the closest picking station for the inventory to be picked and sent to the sortation center for order aggregation, reducing pod congestion in the field.

In pick to order, pickers can only pick the items from a pod that can fulfill the open orders at their station. If an item off of that pod is also needed for another open order within the FC, the pod needs to make its way to the picking station that had the order with that particular item. Though this can make the logistics internal to the AR field more complex, it decreases the overall order retrieval time, the time required for picking and aggregating a complete order, which is important to enable flexibility in late changes to orders.[32]

Pick to order wins in efficiency from reduced touches since it eliminates the resorting step all together, but in an AR environment, this methodology reduces picking productivity and throughput since it limits the picking to the open orders in a station. Although more open orders can be placed per station at Pantry sites to improve pile on[33] for picking to order, this has proved to increase pod congestion in the AR field, making it more difficult for pods to get from one station to another quickly.

B. Pick to Rebin Process

The pick to rebin methodology is a combination of pick to order and flow picking. When items are picked off of an AR pod, the picker places the item directly into a wall of individual slots behind the picking station. Each of these slots represents a different open order. When all the items for an order are placed into the allocated bin and an order is completed, a light indicator tells packers on the other side of the wall to take the items and pack the orders for shipment.

Although the software for pod allocation in pick to rebin runs similarly to pick to order, since more orders are open at any given station, pod pile on can increase. Initially, the process was only utilized in sortable facilities where smaller items were fulfilled and orders averaged two units per order (UPO). This inventory profile was used because it would be easier for the picker to move the items into the bins, and smaller bins could be used enabling more bins per wall for the same square footage and hence more open orders per station. Additionally, with lower UPO the dwell time[34] of a given order in the wall decreases because the picker would not need to wait for one particular item to arrive at the station in order to complete the order for it to be processed by the packer.

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[32] Wenrong Lu et al, 2.

[33] Pod pile on refers to when more items can be picked off of the same pod when presented to a picker. This increases processing efficiency because pods would spend less time moving from station to station, a non-value added step, in order to fulfill orders. It also decreases the number of drives needed per picker to ensure enough work is presented to them and they do not have dead time.

[34] Dwell time is the amount of time an order is open in a given portion of the process. For the picking process of pick to rebin, the dwell time refers to the time in which the bin started to be used for a given order with the placement of the first item in the order, to the time at which the last item of that order is placed in the bin and the light switches to indicate that packing should commence.

C. Theoretical Improvement and Implementation Strategy

As mentioned above, Pantry sites utilize the pick to order methodology. If, for example, there were x open orders per station and an average of y UPO in this part of the business, each station would have around $x*y$ possible items to pick off of a pod at any given period in time. When lower UPO orders are opened in a given station, there are fewer possible items that can be brought to the station to complete an open order. This means that there is a lower probability of a needed item for the station's open orders being on a pod close to the picking station, increasing the dwell time per unit for the orders.

Regardless of the UPO, each order in Pantry currently requires the picker to pick up a yellow tote and place it in racking to prepare for picking. Once the picker completes picking all items for the order, they also push out the yellow tote on the conveyors that take the item to the packing stations. As seen in the Table 7 below, this is the most laborious portion of the picking process, increasing VCPU.

Pick to rebin is a picking process has only been implemented at Site X, a sortable facility. All Pantry sites pick to order, however Pantry can achieve a decrease in VCPU if orders with lower UPO are processed through pick to rebin. As seen in Figure 10, there is a distinct cost benefit to using pick to rebin for orders less than 5 UPO. This is primarily because pick to rebin would eliminate the need to induct totes, the most laborious part of the picking process. As more units are added to an order, the variable cost of handling the totes is distributed across the units, decreasing the overall cost of tote handling on a per unit basis. Not only will items processed through pick to rebin provide VCPU savings of $0.018 ($432,000 annually assuming 2M units per month), but all pick to carton stations will also see a benefit since operators would have to induct totes fewer times for the same number of picks if the UPO is increased at these stations.

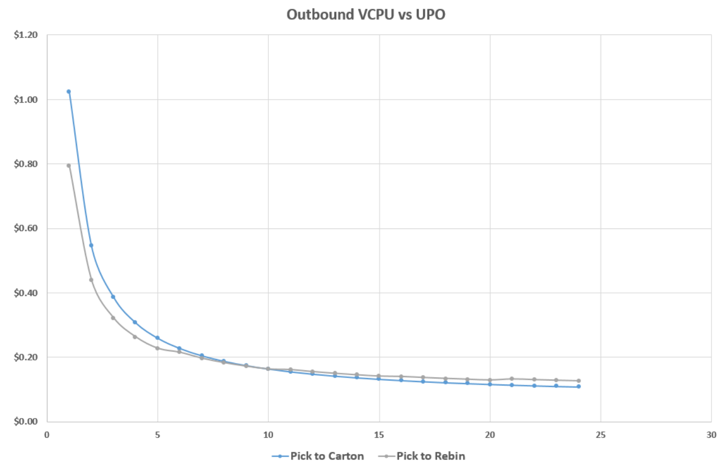


Figure 10: VCPU of Pick to rebin and pick to order processes as UPO varies

If orders of 5 UPO or less are processed through pick to rebin, 36% of outbound shipments and 10% of outbound units will be affected. Though an argument can be made for processing UPOs of 10 and lower as pick to rebin, the effects of grabability or moving more items from the AFE wall has not been tested and could potentially dilute the benefits. Separating orders of 5 UPO or lower and the box suite 2B5 and lower will increase the average UPO of pick to carton orders from 9.6 to 13.5.

To better quantify the actual VCPU improvements that can be gained pick rate or units per hour (UPH) was analyzed at each site as seen in Table 7 . Since the UPO of pick to carton orders will increase from 9.6 to 13.5, pick rates will increase by 19 UPH on average since for every tote induct more units can be picked. Pick to rebin will also increase the pick rate by 9% network wide, and decrease VCPU by $0.018.

	SiteA	Site B	Site C	Site D	Network
Pick to carton/tote current rates at 9 UPO	224	297	191	226	234
Theoretical pick to carton rates after pick to rebin at 13 UPO	242	312	205	242	250
Theoretical pick to rebin rates	332	320	312	360	331
Theoretical total rates after pick to rebin	248	310	210	235	251

Theoretical total VCPU improvement	$0.019	$0.008	$0.022	$0.024	$0.018

Table 7: Pick to rebin effects on overall operation; Table includes scaled rates used for analysis and improvement expected from implementation

D. System Design

Being a new system for the Pantry business, certain design considerations needed to be vetted to implement pick to rebin as a fulfillment solution. The wall itself needed to be redesigned to meet Pantry specifications and box sizes and the stations at current sites needed to be redesigned to accommodate a different picking strategy.

The Wall Design

The pick to rebin wall, otherwise known as the Amazon Fulfillment Engine (AFE) wall, was designed to accommodate box suites 2B5 and ensure low dwell times. Picking orders with lower UPO would be faster and therefore more orders would need to be open to ensure pickers have enough available work. This buffer was a key criteria in the wall design. Additionally, the design was created with flexibility in mind for future changes due to the dynamic nature of the company and incoming orders. If it is not being used to full capacity or if there is a lot more demand for lower UPO orders, the max UPO and box suite settings for routing orders through the AFE wall can be changed electronically. Additionally, the bins of the AFE wall are reconfigurable making it easier to adjust if needed in the future. Each of the smaller bins were designs to be half the size of the larger bins so that the partitions can simply be removed or added to allow for creating bins of the appropriate size as necessary. If pick to rebin does not produce the intended results for Pantry, the wall dimensions were sized to match other AFE walls in the Amazon network making them easy to use at other sites.

A new lighting system was also utilized in the design to allow for quick changes in the number and size of bins. Lights were mounted on each shelving level and could be activated by simply scanning the bar code next to them to add or delete it from the order sortation algorithms. If bin configurations change, hardware changes are minimized, decreasing the time required.

Station Design

Given the theoretical picking rates at a pick to rebin station and the wall design, two picking stations could feed one AFE wall. The opposite side of the AFE wall would then have six packing stations. Since packing requires building the box it can sometimes require more time per order than the picking process. To ensure that it does not become a bottleneck for the pick to rebin process, each picking station with the AFE wall would be paired with three packing stations. Although not all three will need to be utilized at once, designing three allows for additional staffing during peak demand.

E. Site Specific Design

Since implementing pick to rebin in Pantry sites is an expansion project, the designs are site specific, accounting for differences in existing building features. Key considerations for site design included minimizing the addition or alteration of existing Material Handling Equipment (MHE), ensuring proximity to dock doors, and ensuring ample physical space for the wall and surrounding processes. Additionally, due to the fact that picking rates would increase, the system could be particularly sensitive to pod congestion; therefore location of the stations in relation to the AR field was critical in ensuring high pod congestion would not negatively impact rates. From an implementation point of view, stations that were unused or required less time to retrofit were targeted if possible to ensure less down time of current operations while setting up the new process.

F. Operator Utilization Study

As discussed above, pick to rebin stations would have higher pick rates than pick to order stations. To quantify the actual benefit of pick to rebin, it is necessary to understand the effect of operator utilization (OU) on UPH; if the pick rates increase but not enough pods are presented to the pickers, OU will decrease since the picker will spend more time waiting for work. UPH is calculated with the following equation:

$$UPH = \frac{3600 * OU}{pick\ seconds * UPO + induct\ seconds} \quad \text{Equation 17}$$

Pick to rebin will not require inducting totes and the UPO of the network should remain unchanged with this implementation, so pick seconds and OU are the two main factors that would affect UPH as seen in the equation above. Figure 11 depicts how the variation in pick seconds has more of an impact on UPH than OU (Note: Costs shown are scaled by a randomized constant to maintain confidentiality of actual costs). For example, when a picker can pick at six seconds per unit, they require only 72% OU to achieve a rate of 432 UPH, whereas when a picker picks at 7 seconds, they require an OU of 84% to achieve the same rate.

Therefore, even a one second difference in pick seconds affects the overall picking rate as much as a 10% difference in OU.

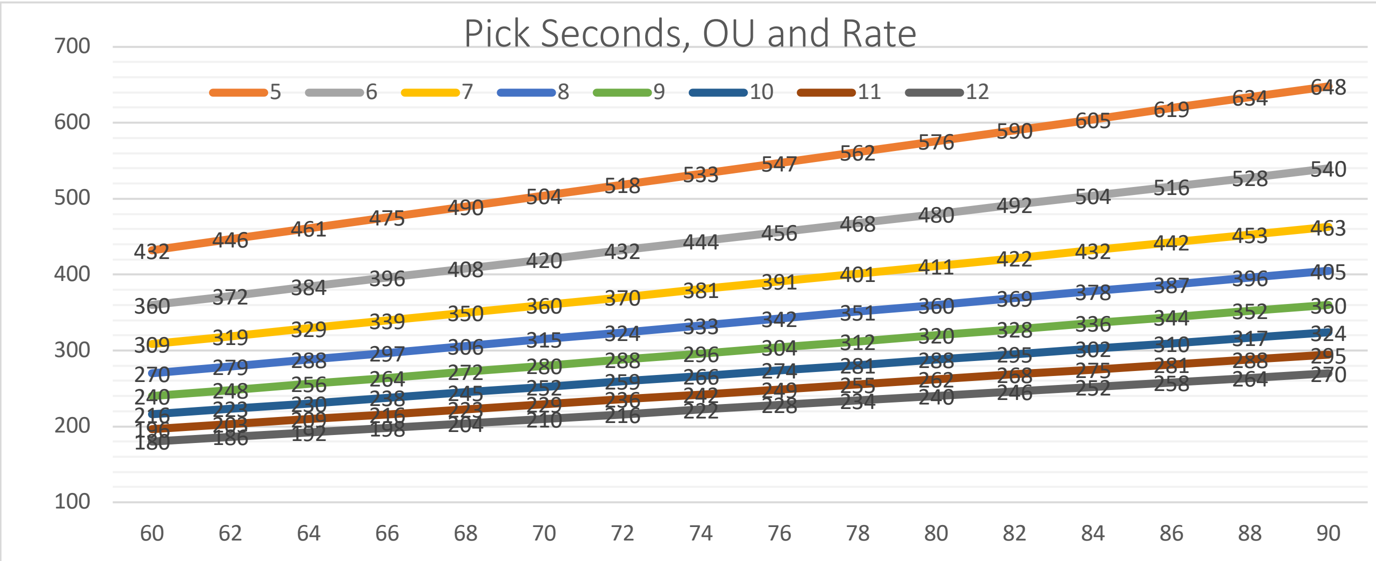


Figure 11: Effect of OU on pick rate for various pick seconds

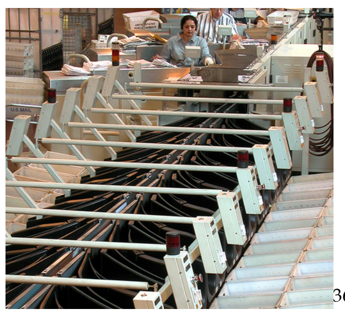
Current data across Pantry sites show the variation in OU is between 6-10% on the busiest days, which oftentimes experience more pod congestion. However this analysis shows that as long as the pick seconds are maintained at each site or improved, even if the OU decreases by the maximum 10% previously experienced in sites, the UPH should only be minimally affected and expected UPH targets can feasibly be achieved.

VII. **Sortation Automation**

The previous chapter showed that process path splitting can provide benefits for operational efficiency. With the massive growth in demand however, changing the process paths will not be sufficient for enabling the network to sustain growth. The following section will evaluate an automated sortation solution to determine if automation has a place in the Prime Pantry business and if it can significantly alleviate the operational constraints the network is currently seeing. This section will first highlight the basics of a sortation machine and how it works in other applications. Then, a process analysis will compare using a sortation machine with the processes discussed above. Critical design considerations for this automation solution will be highlighted in more detail. Lastly, conclusions from the study will help develop the next steps and recommendations for the Pantry business as they scale.

A. Background

As Pantry looks to further decrease VCPU, applications from sortable buildings can be used. Though generated for sortable sites due to the smaller average item size (sortable sites have an average cube size of $0.058m^3$ whereas Pantry has an average cube size of $0.18m^3$), the machine can be used to automate aggregating orders. The system consists of an induct module and sortation modules for units to be sorted based off of outbound orders. Many sortation devices are currently being used in mail or package sortation applications. Machines currently on the market include tilt trays, flat mail conveyors, or cross belt sorters with various output destinations, square footage and processing capabilities.


[35]

[36]

[37]

Figure 12: From left to right, current sortation machines such as tilt trays, flat mail sorters and cross belts are seen.

B. Process Analysis

When picking to rebin, pickers need to pick an item, scan the item, walk to the wall, place the item in the appropriate chute, press the confirmation light indicator, and walk back to their stations to begin a new pick. With a sortation machine, operators currently pick to tote through batch picking, the totes are manually moved to the machine, and an inductor inducts each item from the tote into the sortation machine where the items are sorted by order. In the proposed solution for Pantry operations, the operator would pick an item from the pod and place the item

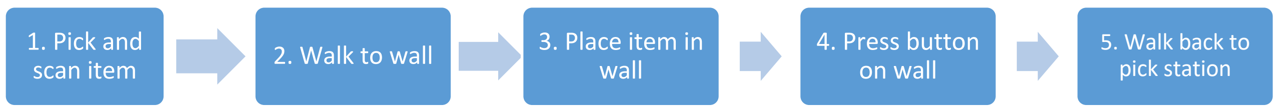
[35] "High-speed sortation system with over 28,000+ shipments per hour" Oct 2017. https://www.falconautoonline.com/ecommerce-logistics-automation/

[36] "The Mailing Industry and the United States Postal Service: An Enduring Partnership" Smithsonian Postal Museum. Jan 2017.

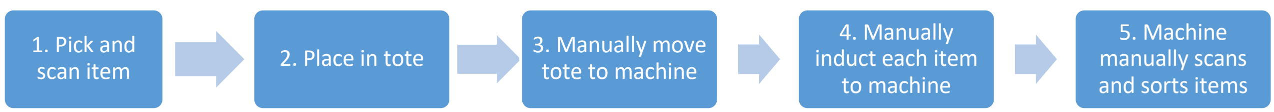
[37] United States Postal Service Photo Gallery. Jan 2017.

on a conveyor with the barcode up or in a visible orientation. The conveyor would take the item through a scanner and then induct the item onto a carrier which would deliver the item to a designated chute.

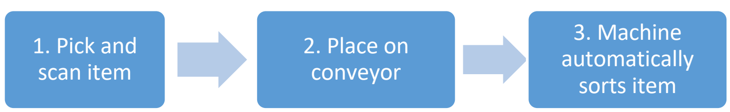
Pick to Rebin:



Current Machine Operations:



Machine Pantry Operations Proposal:



The sortation machine would be required to manage at least 97% of Pantry ASIN dimensions such that at least 80% of outbound shipments could be sorted. The machine should be capable of processing hundreds of open orders at any period of time to ensure that there is a significant improvement to current operations, and not consume significant floor space due to lay-out restrictions.

Induct:

The limiting factor to any sortation machine is the manual induct rate which can range from 1500-1800 UPH. With the theoretical estimates for pick to rebin rates, five pick stations could feed into one sortation machine to meet full capacity (Note: rates are scaled by a randomized constant to maintain confidentiality). In order to fully utilize the machine, one option is to use batch picking to merge products from the five designated pick stations allocated for a single machine. In this scenario, items are picked into a tote and when the tote is completed, it is placed on a conveyor that directs it to a specific sortation machine. There, an associate would induct each of the items into the sortation machine.

Another option, would be to use flow picking for all the sortation machine pick stations and use conveyors to sort the items to the appropriate machine (this would mean one machine is not paired with five pick stations but the sortation would occur FC-wide). This would eliminate the need for an additional induct step since the items are individually placed on the conveyors. It would ensure that only one induct module is required per sortation machine decreasing the required hardware and complexity of the system. The conveyors in the sortation process could inherently provide a buffer for the induction process if needed, similar to the buffer systems at sort centers.

Packout:

On the output side of the machine, tote removal or pack processing will be required. To decrease the number of times a completed order is handled and decrease variable costs, it would be ideal to directly pack items from the sortation machine rather than removing totes and packing them further downstream, however pack stations must accommodate large containers and box suites which can take up significant floor space. The closer these stations can be located to the sortation machine, the less conveyance would be required or the less walking an associate would have to do. Larger orders in Pantry would be rather heavy so this would be a critical consideration to ensure ergonomic standards were met.

C. Other Considerations

One of the biggest concerns with automating this process would be the impact on damaging goods since chips and soda packs could be in the same order. When sorted into the same bins in the machine, it is critical the soda packs are not dropped on top of the bags, damaging the items. In order to address this issue, the orders could be split into two output chutes located next to one another. This would allow heavy items to be in one chute and lighter items to be in another. Splitting the order into two adjacent chutes would ensure that the packer would not have to do too much walking to combine the final order. Another option would be to route orders with heavy items through the pick to carton stations since there will need to be a few pick to carton stations to accommodate the 3% of ASINs that do not currently fit well in any industry sortation solution. As seen in Table 8 : Percent of orders and ASINs that can be processed by the machine if various ASIN level weight restrictions were applied to prevent damageability, for a majority of orders to be processed by industry sortation solutions the lowest ASIN level weight restriction that can be applied is 5lbs.

Weight limit per ASIN for machine to minimize damage	**2lb**	**5lb**	**10lb**	**15lb**	**20lb**
% of ASINs below weight limit	70%	88%	93%	96%	97%
% of outbound orders through machine that have all items below weight limit	27%	50%	67%	80%	80%

Table 8 : Percent of orders and ASINs that can be processed by the machine if various ASIN level weight restrictions were applied to prevent damageability

Assuming the 20lb weight restriction and that two pick stations would be running at pick to carton, the overall network volume could increase to 3.1M per week at maximum capacity. The VCPU benefits using current state assumptions are $0.031. Implementing this automation solution will provide a $0.013 improvement from manual pick to rebin changes discussed above (Note: Costs and rates shown are scaled by a randomized constant to maintain confidentiality of actual costs).

	Site A	**Site B**	**Site C**	**Site D**	**Average**
Flow pick rate for machine	332	320	312	360	332
Pick to carton rate at 9 UPO	224	297	191	210	231
Flow pick stations	16	16	14	20	
Pick to carton pick stations	2	2	2	2	
Theoretical total volume throughput per week	766,156	759,937	631,755	1,013,523	
Theoretical total volume throughput network wide	3,171,372				
Theoretical Flow VCPU	$ 0.069	$ 0.072	$ 0.074	$ 0.064	
Theoretical pick to carton VCPU	$ 0.103	$ 0.077	$ 0.120	$ 0.109	
Theoretical VCPU Improvement	$ 0.033	$ 0.006	$ 0.047	$ 0.046	
Theoretical overall VCPU Improvement (4% of units processed through pick to carton)	$ 0.032	$ 0.005	$ 0.045	$ 0.044	$ 0.031

Table 9: Sortation Machine rates, VCPU, and volumes

In addition to the cost benefits, face pile on would increase significantly with flow picking since pickers could now pick to all open orders for the sortation machine process path. This in turn would decrease the number of pod transitions required, and decrease traverse paths of drives since inventory sortation for orders would happen outside the field through the conveyor sortation system. With less traverse paths, pod travel times could also decrease. The effects of this on the number of drives required can be found in Appendix H.

D. Recommendation and Next Steps

Moving forward, majority of pick stations in Pantry should utilize this automation solution. The analysis above scoped the potential for this solution but the details of a potential design should be analyzed by the Worldwide Engineering team.

Overall trends in the company's performance and growth further strengthen the argument to pursue more automated solutions. A large number of Amazon's fulfillment centers are located in small towns where land and building costs are cheaper and there are less restrictions for the building's square footage. Like many companies that have a large workforce in manual labor, Amazon is very susceptible to employee turnover in fulfillment centers. Fulfillment centers located in smaller towns however run the risk of exhausting their pool of potential labor with employee attrition. As the company struggles to find laborers in these small towns and the demand for increased output continues to climb, automated solutions such as automated sorters will have a more significant role in the company.

VIII. Conclusion

Previous chapters in this thesis have discussed the e-commerce industry, the rapid growth of Amazon and its businesses, and how to improve inbound and outbound operations through an analysis of inventory strategy and picking efficiency. This chapter provides a short summary of the findings in this thesis, the cost benefits and implications, and final thoughts.

A. Summary of Findings

This thesis highlights these main findings in improving the operations at Prime Pantry:

1) Inventory analysis and strategy must be set on a per ASIN basis. Though general tenets could be generated, a per ASIN bottom-up approach revealed strategy guided by the tenets left a lot of room for operational improvement. The analysis revealed that factors such as product obsolescence, delivery variability in vendor lead times, minimum pallet quantities, and cubic velocity are critical in determining inventory strategy. With the variability of these factors among different ASINs, the analysis demonstrated per ASIN strategies are required.

2) With large economies of scale, separation of process paths is more efficient and beneficial. Though the current process path is efficient for most of Pantry since it eliminates the step of order aggregation and sortation for all orders, the pick to order methodology is not optimal for orders with fewer units. A split process path will improve operator utilization and the efficiency of processing orders with higher number of units as well as orders with lower number of units.

3) Automation of outbound process paths is a viable solution for scaling the business. Though the current Pantry infrastructure stands to benefit from utilizing automation solutions like a sortation machine, as the business scales automation will have more of a significant impact on improving the efficiency of outbound operations and catering to the increasing demand of the network.

B. Cost Benefits and Implications

Each of the initiatives outlined above will provide additional savings to the Pantry business. Though the Low ASP analysis generated savings of $2.27M, only a fraction of the ASINs were analyzed. If case replenishment is automated or more pallets are used in the field, these savings will increase since the VCPU of handling these items will decrease. The pick to rebin initiative saved the company an additional $432,000 annually with a VCPU improvement of $0.018. Lastly, a sortation machine would save $312,000 annually since the improvement over manual pick to rebin is a VCPU improvement of $0.013. In total, these savings amount to $3.02M annually as seen in Table 10.

Project	Cost Savings
Low ASP - Velocity	$373,000
Low ASP - WOC	$1,900,000

Pick to Rebin	$432,000
Sortation Machine	$312,000
Total	**$3,017,000**

Table 10: Cost Savings from Pantry Improvement Proposals

These initiatives will also increase throughput and capacity, which could prevent the business from needing to open new sites at the current frequency required. Though the financial benefits are quite significant, these changes more importantly streamline the business's current operations, enabling a sustainable path towards expanding the business. Implementing these initiatives will require more training for associates and investment in setting up the appropriate infrastructure. Additionally, more active monitoring of these processes will be required until the algorithms are fully automated, and DOC thresholds for inventory management and UPO thresholds for the pick to rebin wall are tested in the FCs and optimized.

C. Final Thoughts

With such a complex operation and high diversity of orders, it can be very tempting to search for a general solution that can standardize operations. Though standardization has benefits, in this high-velocity, highly-variable environment, customized thresholds for inventory management and processes provide significant operational and financial benefits. The findings from this analysis are applicable not only to the other businesses within Amazon, but to many other high volume applications. As e-commerce continues to grow, warehouse operations must continue to focus on current improvements and future expansion. The findings regarding inventory strategies, process paths, and automation improvements become ever more prevalent as the demand of the market strains the capacity of the entire network.

IX. Appendix

A. Fixed Cost Per Day (FCPD) Calculations

The FCPD calculations were based off of field and reserve allocations from OAK7. The percent of total square footage was used to generate cost breakdowns for the field and reserve.

	Cube	Sqft	Percent
Reserve	100,000	20,000	16%
Prime field	103,000	103,000	84%
Total	203,000	123,000	100%

		Quarterly costs at OAK7	Allocated Costs for reserve	Allocated Costs for prime field
Salaries & Bonuses		260.6	42.4	218.3
Relocation		54.6	8.9	45.7
Other Employee Benefits		27.4	4.5	22.9
Travel & Entertainment		19.2	3.1	16.1
Depreciation Expense		435.4	35.4	400.0
Building Rent & Opex		142.6	23.2	119.4
Janitorial		0.0	0.0	0.0
Infrastructure Expenses		74.6	12.1	62.5
Parts, Repairs, Maintenance		9.5	1.5	8.0
Taxes & Licenses		7.5	1.2	6.2
Telecom & Data Charges		0.2	0.0	0.2
Outside Services		873.8	142.1	731.7
Other Administrative Expenses		0.5	0.1	0.4
Total Fixed Costs	quarterly	1,905.8	274.5	1,631.3
	daily		3.0	18.1

Using the daily costs calculated above and the volume of storage space, the costs per day of storing inventory in reserve and the AR field were calculated as seen below:

	Cube	Daily Cost	Cost per cube per day
Reserve	100,000	3.0	0.03
Prime field	103,000	18.1	0.18

B. Equations and Assumptions for Low ASP Palletization Model

Equation for total fixed cost of placing items in reserve on a case level:

$$Avg\ Inventory * (Order\ WOC - \frac{\frac{CaseQty}{WeeklyDemand}}{2}) * 7 * cube * FCPD_{Reserve} + Avg\ Inventory * \frac{\frac{CaseQty}{WeeklyDemand}}{2} * 7 * cube * FCPD_{AR}$$

Equation for total fixed cost of placing items in AR directly:

$$Avg\ Inventory * (Order\ WOC) * 7 * cube * FCPD_{AR}$$

Below are the estimated case replenishment rates used in the model. The VCPU of case stow to reserve and case pick were utilized for cost comparisons for the fixed costs in reserve to the fixed costs in the field.

Case Rates		
	Rate	Cost Per Unit
Case Receive	550	0.0398
Case Stow to Reserve	28	0.06509
Case Pick	42	0.04339
Case Stow to Prime	370	0.0591

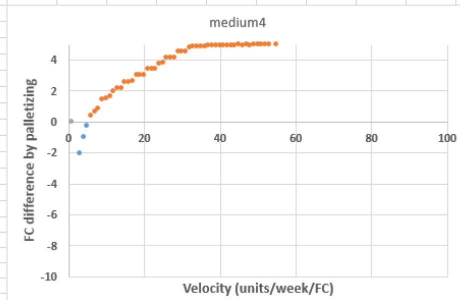
C. Low ASP Dynamic Model Frontend

Below is the frontend for the velocity sensitivity for palletization. The ASIN can be selected from a dropdown which would update all the ASIN specific characteristics and inputs in the rows below it. If a new ASIN needs to be tested or the characteristics of a current ASIN changes, the dropdown includes a custom option allowing the user to change the default settings. The columns on the right show the velocity change and its effect on the cost of palletization.

ASIN		
ASIN description		
cube (in^3)	652.08	[redacted]
pad time	365	
T90/90*7	9	
Vendor Cost	24.95	
WOC at tip	6.841339156	
avgVLT	7.9425	
buying period	7	
TIP	61.5720524	
current inventory on hand	42.5	
case quantity	4	
minimum pallet quantity for vendor	150	
new size class	medium4	
asp	22.19436321	

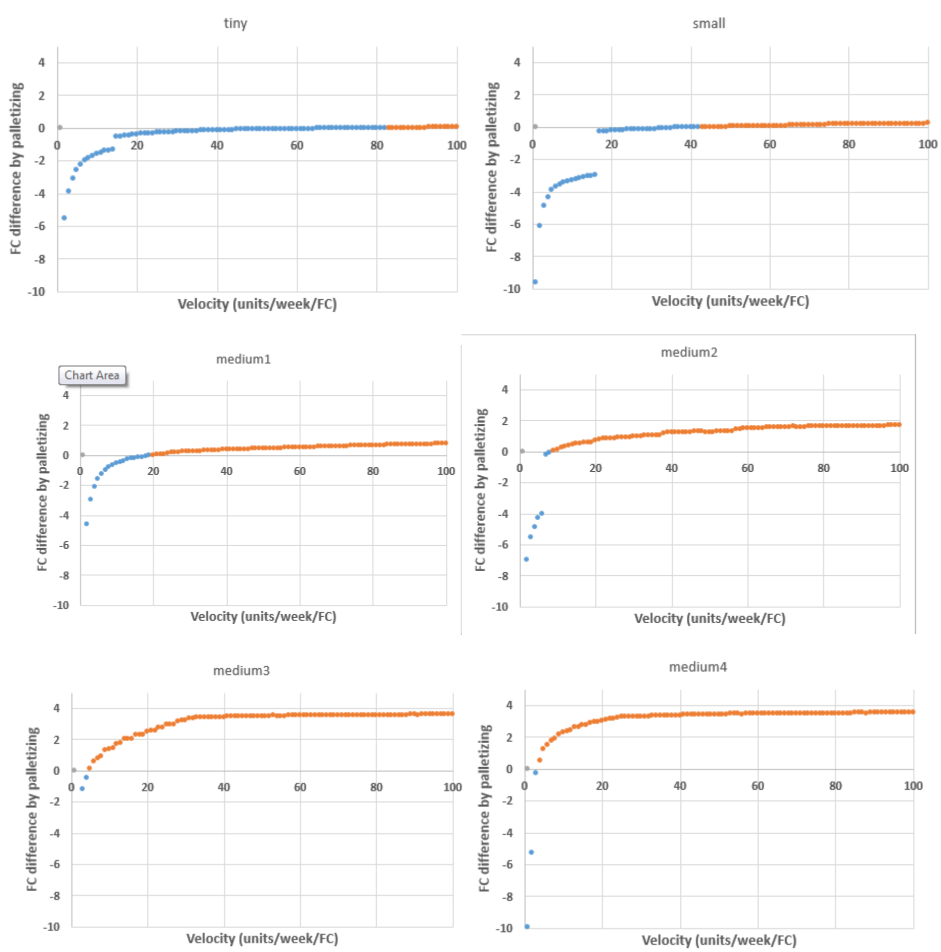
[redacted]

T90/90*7	Should be	DNP	P
1	-29.409	-29.409	999
2	-22.907	-22.907	999
3	-2.05	-2.05	999
4	-1.0176	-1.0176	999
5	-0.3052	-0.3052	999
6	0.40415	999	0.40415
7	0.62164	999	0.62164
8	0.84286	999	0.84286
9	1.43011	999	1.43011
10	1.51094	999	1.51094
11	1.61934	999	1.61934
12	1.98281	999	1.98281
13	2.13374	999	2.13374
14	2.1635	999	2.1635
15	2.53215	999	2.53215
16	2.55278	999	2.55278
17	2.65302	999	2.65302
18	3.00234	999	3.00234
19	3.01138	999	3.01138
20	3.04276	999	3.04276
21	3.40516	999	3.40516
22	3.42996	999	3.42996



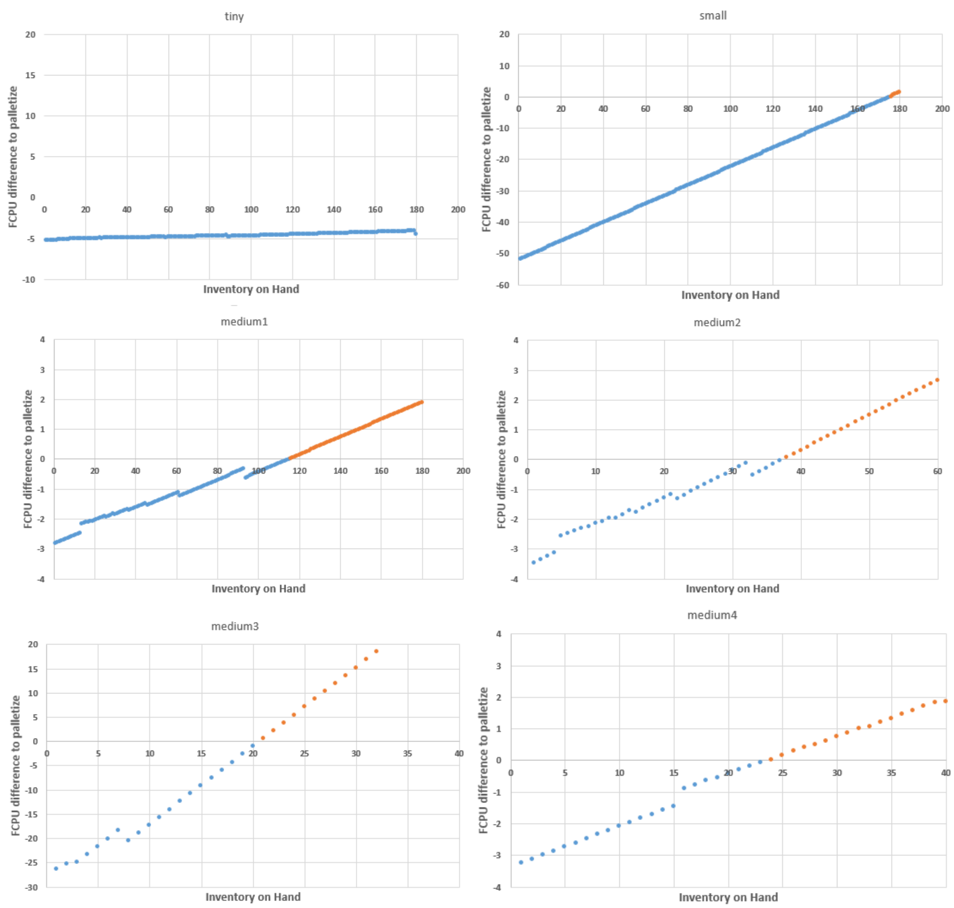
D. Low ASP Velocity Thresholds

The plots below correspond to Table 5: Velocity requirements for palletization; note that Tiny, Small and Medium 4 items will not currently provide cost savings from palletization since their current weekly velocity is not higher than the velocity needed to palletize. and show the cost difference between palletization and storage in AR (orange on the right of plot) verses storing items directly in the AR field (blue on the left of plot). As can be seen in step differentials in the plots, obsolescence costs are significant to overall costs. Once the velocities are high enough to eliminate obsolescence costs, the capital costs and fixed costs play a larger factor in determining palletization. Vendor costs for the Small and Medium 2 items are relatively high which explains why the obsolescence cost has a larger effect on the overall velocity needed to palletize.



E. Low ASP WOC Thresholds

The charts below are reference to Table 6: Maximum weeks of cover thresholds for AR field. Smaller items require higher WOC before it becomes beneficial to palletize.



F. Pallet to Each Receive Breakdown across FCs and Network Wide

The rates of eaches verses pallets are very similar at each of the FCs within the network. With a majority of items being processed as eaches, it is clear the operational business strategy has shifted from the inception of Pantry in which the initial idea was to provide only high velocity items that would be received solely as pallets.

	Site A	Site B	Site C	Whole Network
EACH	59.30%	57.23%	58.30%	58.32%
PALLET	40.70%	42.77%	41.70%	41.68%
Grand Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**

G. Effect of UPO on VCPU

UPO primarily affects the VCPU of the pick and pack processes. Among the pick processes, UPO mainly affects the amount of time allocated for pick seconds. As the number of UPOs increases, these costs are divided among additional units, while the costs only increase by a percentage of the total cost. (Values have been skewed to ensure confidentiality).

Pick sec	10.2
Induct sec	28
Push out sec	8.4
Pack Seconds	110

Unit Per order	Seconds	Seconds per unit	Rate (UPH)	VCPU	% Decrease in VCPU
1	156.6	156.6	22.98851	0.9570	0%
2	166.8	83.40	43.17	0.5097	21%
3	177	59.00	61.02	0.3606	14%
4	187.2	46.80	76.92	0.2860	9%
5	197.4	39.48	91.19	0.2413	7%
6	207.6	34.60	104.05	0.2114	5%
7	217.8	31.11	115.70	0.1901	4%
8	228	28.50	126.32	0.1742	3%
9	238.2	26.47	136.02	0.1617	3%
10	248.4	24.84	144.93	0.1518	2%

H. Drives per site calculations

$$Drive\ Units\ per\ Station = Calculated\ Mission\ Time\ per\ Face\ Presented \times Faces\ Presented\ per\ Hour\ per\ Station$$

$$Faces\ Presented\ per\ Hour\ per\ Station = \frac{Raw\ Rate}{Face\ PileOn}$$

$$Raw\ Rate = \frac{Station\ Rate}{Operator\ Utilization}$$

$$Stations = \frac{Throughput\ Units\ per\ Hour}{Station\ Rate}$$

$$Drive\ Units = Drive\ Units\ per\ Station \times Stations$$

Though the pod pile on improvements have yet to be quantified, other sortable facilities such as have face pile on of 1.6. This is similar to Pantry which currently has a pod pile on of 1.5 because the field size in sortable facilities is larger and area of responsibility per pick station is higher. Assuming the pick seconds for a sortation machine should be close to pick seconds for pick to rebin stations and that pile on should increase given the size of the field is constant, additional drives may not be needed.

X. Bibliography and References

"A History of E-Commerce." *Concordia University, St. Paul Online*, July 28, 2016.

"Amazon to Hire 120k Seasonal Workers in U.S. — a New Peak That Could Signal a Big Holiday Ahead." *GeekWire*. Oct. 13, 2016.

Askin, Ronald G. and Jeffrey B. Goldberg. *Design and Analysis of Lean Production Systems.* John Wiley & Sons, 2002.

Bender, Joshua. "Statistics and facts on consumers' online grocery shopping in the U.S.," *Statista,* 2016.

Brozenec, Brigitte. "Deliver the Goods: How Automated Picking Solutions Help Dcs Meet Consumer Demand," *Material Handling & Logistics* 70.10, Jan. 2, 2017.

Callard, Abby. "Amazon Opens Its Pantry Doors for Ordering Bulky Items," *Internet Retailer*, Apr. 24, 2014.

Calzavara, Martina, et al. "Analysis Of Economic And Ergonomic Performance Measures Of Different Rack Layouts In An Order Picking Warehouse." *Computers & Industrial Engineering* (2016): *ScienceDirect*, Jan. 2, 2017.

Durham, Christopher. "Amazon Primed for Growth." *My Private Brand*, Mar. 3, 2017.

Evans, Benedict. "Why Amazon Has No Profits (And Why It Works)." *Benedict Evans*, Sept. 5, 2014.

Golas, Zbigniew, and Anna Bieniasz. "Empirical Analysis Of The Influence Of Inventory Management On Financial Performance In The Food Industry In Poland." *Engineering Economics* 27.3 (2016): 264-275. *Business Source Complete*, Jan. 2, 2017.

Gorman, M. F. and M. Stoblein. "Dynamic Planned Safety Stocks in Supply Networks." *International Journal of Production Research* Vol 48. 11 Dec 2009.

Grosse, Eric H., Christoph H. Glock, and W. Patrick Neumann. "Human Factors In Order Picking System Design: A Content Analysis." *IFAC Papersonline* 48.15th IFAC Symposium on Information Control Problems in Manufacturing (2015): 320-325. *ScienceDirect*. Jan. 2, 2017.

"High-speed sortation system with over 28,000+ shipments per hour" Oct 2017. https://www.falconautoonline.com/ecommerce-logistics-automation.

Kirshner, S. "Amazon buys warehouse robotics start-up Kiva Systems for $775," *Boston Globe,* March 19, 2012.

Lamballais, T., D. Roy, and M.B.M. De Koster. "Innovative Applications Of O.R.: Estimating Performance In A Robotic Mobile Fulfillment System." *European Journal Of Operational Research* 256.(2017): 976-990. *ScienceDirect*. Jan. 2, 2017.

Laudon, Kenneth C and Carol G. Traver. *E-Commerce: Business, Technology, Society, Second Edition*. Pearson/Addison Wesley, 2008.

Le-Duc, Tho. *Design And Control Of Efficient Order Picking Processes*. n.p.: Delft, The Netherlands : Netherlands TRAIL Research School, 2005., 2005. *MIT Barton Catalog*. Jan. 2, 2017.

Levy, Adam. “Amazon’s U.S. Online Sales Growth Last Year Was More Than Everyone Else’s Combined,” *The Motley Fool*, Mar. 1, 2017.

Liang, Chih-Chin. "Smart Inventory Management System Of Food-Processing-And-Distribution Industry." *Procedia Computer Science* 17.First International Conference on Information Technology and Quantitative Management (2013): 373-378. *ScienceDirect*. Jan. 2, 2017.

Nassauer, Sarah. “Wal-Mart Shrinks the Big Box, Vexing Vendors,” *Wall Street Journal,* Oct. 25, 2015.

Pauls-Worm, Karin G.J., et al. "Order Quantities For Perishable Inventory Control With Non-Stationary Demand And A Fill Rate Constraint." *International Journal Of Production Economics* 181.Part A (2016): 238-246. *ScienceDirect*. Jan. 2, 2017.

Rakesh, Venkitasubramony, and Gajendra. K Adil. "Layout Optimization Of A Three Dimensional Order Picking Warehouse." *IFAC Papersonline* 48.15th IFAC Symposium on Information Control Problems in Manufacturing (2015): 1155-1160. *ScienceDirect*. Jan. 2, 2017.

Rosenfield, Donald B. “Innovation and Onshoring: The Case for Product Variety.” *Production in the Innovation Economy*. Ed. Richard M. Locke, Ed. Rachel L. Wellhausen. Cambridge: MIT Press, 2014. 211-234. Print.

Stowe, James DeWitt. “Throughput Optimization Of Multi-Agent Robotic Automated Warehouses.” *MIT Barton Catalog*. Jan. 2, 2017.

Silver, Edward A. *Inventory Management and Production Planning and Scheduling*. John Wiley & Sons, 1998.

Tian, Yan, and Concetta Steward. “History of E-Commerce,” E-Commerce Land, IGI Global, 2008.

“The Mailing Industry and the United States Postal Service: An Enduring Partnership” Smithsonian Postal Museum. https://postalmuseum.si.edu/americasmailingindustry/United-States-Postal-Service.html

“The World’s Most Innovative Companies.” *Forbes,* Feb 7, 2017.

Torkul, O., et al. "A Real-Time Inventory Model To Manage Variance Of Demand For Decreasing Inventory Holding Cost." *Computers & Industrial Engineering* 102.(2016): 435-439.

United States Postal Service. Jan 2017. https://about.usps.com/news/photos/equipment-gallery.html.Webster, Karen. “Could Amazon Do To Groceries What It Did to Books?” *PYMNTS.com*. Apr. 6, 2015.

Wenrong Lu et al. "An Algorithm For Dynamic Order-Picking In Warehouse Operations." *European Journal Of Operational Research* 248.1 (2016): 107-122.

Won, Jaeyeon. “Order Batching and Picking Optimization in Terms of Supply Chain Management (SCM),” *Iowa State University,* 2004. Print.

Yu, Mengfei, & De Koster, René B.M. "Enhancing performance in order picking processes by Dynamic Storage Systems," *International Journal of Production Research*, May 12, 2009.