Hybrid Make-to-Stock, Make-to-Order (MTS-MTO) Production Optimization and Predictive Manufacturing Plan

By

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B.S. Systems Engineering, United States Military Academy, 2009

Submitted to the MIT Sloan School of Management and the Institute for Data, Systems, and Society on May 6th, 2016 in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration and
Master of Science in Engineering Systems

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Abstract

The rapid growth of the Print on Demand (POD) business has necessitated a capacity expansion plan that spans the next five years. After analyzing sales data it was determined that more titles are selling in larger quantities. For these titles, the current make-to-order model does not represent the optimal manufacturing and fulfillment strategy. This preliminary insight led to the realization that an inventory model that uses demand forecasts and a cost analysis for each title should be used to determine the optimal ordering quantity for qualifying titles, in an initiative called high volume pre-builds. Additionally, an initiative called predictive manufacturing should be used concurrently to provide customer experience improvements to titles that sell in large quantities but do not qualify for high volume pre-builds.

The development of a hybrid make-to-stock, make-to-order (MTS-MTO) production optimization model will lead to pre-building between 1.1M and 2.1M retail units per year, but could be scaled upward. Pre-building allows for cost savings through economies of scale in manufacturing and through transportation savings based on inventory placement and network topology. An additional 300K+ annual retail titles will be eligible for predictive manufacturing, which will also benefit from transportation savings. The customer experience improvements alone would make these initiatives worth pursuing even if they were NPV neutral or slightly negative. However, they are a clear win when also considering overall integration and cost savings. These initiatives will drive a lower cost structure for book manufacturing that benefits all stakeholders (Amazon, authors, and customers), which will lead to the continued, rapid growth of POD.

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Table of Contents

Table of Figures

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1. Introduction

This document provides the framework for how Amazon can scale effectively as demand continues to increase rapidly year over year. To do so, Amazon must violate the assumption that all books should be make-to-order except for pre-builds during peak demand at the end of the year. *Print on Demand (POD) cannot treat all books as POD.* Instead, demand forecasts and a cost analysis for each title should determine the optimal manufacturing and fulfillment strategy. For example, the high number of retail titles that sold only one or two units should be treated differently from the lower number of retail titles that sold more than 500 units in 2014.[1] The higher volume titles can be manufactured at a lower cost and stowed. Representative of Amazon's virtuous cycle, the lower cost structure for book manufacturing paired with Amazon's fulfillment capabilities leads to better royalty rates for authors and better customer experience, which leads to continued, rapid POD growth. POD will be able to support the growth with reduced capital investments due to the two proposed initiatives: *high volume pre-builds* (external) and *predictive manufacturing* (internal).

To capture the benefits from high volume pre-builds, POD should use a hybrid MTS-MTO production optimization model, which would lead to pre-building ~1.1M-2.1M retail units/year on ~800-1000 titles. Pre-building allows for cost savings through economies of scale in manufacturing (using offset or digital printing) and through transportation savings based on inventory placement and network topology. Total variable and transportation cost savings has an estimated NPV between $600K and $3.9M over the next five years.

[1] The model determines the ordering decision, not based solely on "more than 500" criteria

To provide customer experience improvements to titles that sell in large quantities but do not qualify for external pre-builds, POD should integrate predictive manufacturing with the high volume pre-builds, where internal capacity is used to manufacture books that have the highest probability of sale over a short time horizon. Based on 2014 data, this opportunity will allow for potentially predictively manufacturing up to 330K retail titles annually.[2] While the internal costs for the book remain the same, network topology benefits will lead to transportation savings of ~$.20/unit.

The customer experience improvements make these initiatives worth pursuing even if they were NPV neutral or slightly negative. They are a clear win when also considering overall integration and cost savings. Optimally placed inventory shortens SLAs (5-9 hour reduction for retail demand), increases fast track (the button on the Amazon.com website that guarantees delivery on a certain date if the order is placed "within X hrs YY mins") availability, reduces fast track misses, reduces missed multis (reduced transportation costs from being able to combine shipments), increases multi opportunities while reducing splits, reduces inventory from cancelled or modified orders and allows for consumer in-stock value (CIV) benefits (lift from fast track in-stock glance views). Additionally, POD will be less reliant on outsourcing as a safety valve for when the network is unable to accommodate demand, which incurs a higher cost. Both of the initiatives can be scaled up for peak demand, where pre-building saved $1M+ in capital and the hybrid model would have saved an additional ~$700K in variable costs for Q414. Lastly, there is potential to

[2] Initial screening criteria is titles that sold at least 3 or more units in 2014

offer one day, same day, or Prime Now delivery for qualifying titles, which would likely experience a sales lift from these features.

1.1 Project Motivation

Analyzing trends in retail sales for POD shows that the number of titles selling in larger quantities per quarter is increasing (~60% YoY growth between Q114 and Q115 for titles that sold in excess of 1000 units). More people are self-publishing, and these titles are becoming more successful. In Q1 2015, only one title sold more than 10K units, whereas in Q2 2015, seven titles surpassed 10K units. Unfortunately, toner-based printing is unable to capture economies of scale for large print runs of the same title, and the total fulfilled cost per unit (TFCPU) at the four POD sites is roughly ~60% higher than the TFCPU from high volume pre-builds using the hybrid model.[3] There are two inherent problems with internal manufacturing processes: (1) POD does not mirror a book on a shelf in terms of customer experience and (2) POD does not have a mechanism to optimize manufacturing based on demand and costs (offset/inkjet for high volume titles and toner-based printing for the long tail). This project proposes a solution.

1.2 Problem Statement

To more explicitly understand the problem that POD is facing, it is important to realize that every POD book that is ordered is manufactured in the same manner, except for pre-builds which are conducted before peak demand season. Pre-builds represent the current make to stock component of POD, where the retail team chooses certain titles and

[3] The TFCPU is the total cost to manufacture a book and deliver it to the customer. The TFCPU for the four POD sites is based on the June 2015 Monthly Business Review.

order quantities of these titles to outsource manufacturing and to stock. This has been done once a year before the Christmas holiday buying season as members of the retail team will use heuristics that they have developed to make these decisions. Other than these pre-builds, POD does not analyze demand forecasts for high volume titles over a certain time horizon and is thereby missing out on opportunities to take advantage of economies of scale in manufacturing. Economies of scale for the print industry has to do with the printing technology that is used. POD uses toner based printing, where each page of the book is printed on an individual sheet of paper. However, with larger print runs, inkjet printing can be more economical, and for the largest print runs, off-set printing is the most economical. These technologies will be explained in more detail in a later section. Ultimately, these factors leads to the following problem statement for the project:

What is the most effective way for the POD business to expand capacity over the next five years to meet growing demand and to offer a differentiated, unique product to customers that optimizes operational efficiency through TFCPU analysis and network topology while remaining flexible to demand fluctuations caused by industry trends, technological innovations, and other sources of uncertainty?

1.3 Steps Taken

The approach to this problem involved first conducting sufficient background research, data collection and analysis. The initial insights from this research and analysis lead to the development of hypotheses that were explored in further detail. Additional insights came from visits to the POD manufacturing facilities to conduct contextual inquiries with the workers onsite and also to conduct informal interviews with POD

management located in Seattle and in Ontario, California. Observing the manufacturing process showed the limitations of the toner based printing for a title that sold in large quantities. There was no mechanism to batch these orders and reduce costs or cycle time. Every book was printed and manufactured the same way once the order was received. With this insight, it became clear that POD should have inventory tolerance and that an inventory model would help the business determine which titles and how many units of these titles should be converted to make-to-stock. This determination would be based on demand forecasts for the titles as well as a comparison of the different cost components that are involved in the make-to-stock vs. make-to-order decision (whether a book is manufactured externally or internally using POD processes).

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2. Background

2.1 Industry Overview

There are multiple relevant industries that will be discussed for this thesis. The first is the online retail sector, where Amazon.com is a prominent player. A second relevant industry is the book publishing industry, looking at both the traditional publishers such as the big four which consists of Simon & Schuster, HarperCollins, Penguin Random House, and Hachette, and the self-publishing companies, with competitors such as lulu, blurb, and lightning source. These industries are further discussed in the next few sections.

2.2 Types of Printing Technology

The two main types of printing technology that should be understood for this project are digital printing and offset printing. Offset printing technology is a large scale operation that requires large equipment and plates (usually made from aluminum). The plates are used to transfer an image onto a rubber "blanket" and then rolling that image onto a sheet of paper [1]. This type of printing is called offset because the ink is not transferred directly onto the paper. Digital printing is different because it eliminates many of the mechanical steps required for offset printing and uses options such as toner or liquid ink instead of aluminum plates to print a digital-based image. The large equipment that are required for offset printing require capital expenditures that can exceed $10M and the mechanical steps lead to increased labor costs as well. However, once the equipment is installed, the process is set in place, and the plates are produced, the unit cost can go down considerably as the quantity goes up (quoted prices from contract manufacturer had a

reduction of up to 60% based on run length). This pricing structure is different for digital printing where every print job has the same cost regardless of the job run length. Additional advantages of each type of printing technology are shown in Table 1 [1].

Table 1. Digital vs Offset Printing

Advantages of Digital Printing	Advantages of Offset Printing
Setup costs are lower for short runs	Larger quantities can be printed cost effectively
Print only the amount needed, when it's needed	The more that's printed, the cheaper the price per piece
Lower minimum quantities (as low as 1, 20, or 50 pieces)	A large variety of paper types with custom finishes can be used
Inexpensive black and white digital printing	Special custom inks such as metallic and Pantone colors are available
Variable data capability	Highest possible printing quality, with greater detail and color fidelity

2.3 Amazon.com

While Amazon's first slogan as "Earth's Biggest Bookstore" describes the business they were initially in, it did not describe the vision of the business that they have become in the many years since the founding in 1994 [2]. However, it does emphasize the symbolic importance of Amazon's book business, both when it comes to selling books and their own expansion as a book publisher. Amazon has been able to singlehandedly change consumer behavior, where "running an errand" has been replaced by "going online" and instantaneous price-shopping from one location [2]. Amazon has even expanded beyond the "Everything store" concept by introducing a wide variety of products and services that

includes the kindle reading device and tablet computers, Amazon web services, Amazon studios, and many other innovations across sectors.

The 1997 Letter to Shareholders provides some insight into how Jeff Bezos views what the company should focus on in the future. Bezos saw tremendous opportunity in the internet and in the development of online commerce in particular. He believed that the company needed to move quickly to solidify and extend their current position while continuing to pursue the online commerce opportunities in other areas. While he realized that this was a risky strategy, he believed that serious investment and crisp execution would help the company compete against established franchise leaders [3]. Additionally, he believed that a fundamental measure of success for the company would be the shareholder value that they created over the long term. He believed that this value would be a direct result of their ability to extend and solidify their current market leadership position. Market leadership translates directly to higher revenue, higher profitability, greater capital velocity, and correspondingly stronger returns on invested capital [3]. This mentality demonstrates why Amazon would be willing to invest in resources that better position the Print on Demand business for long term growth and profitability.

2.4 Print on Demand

While the global printing industry is generally thought to be in decline due to the growing popularity of e-books, online newspapers, and magazines, the industry is actually forecast to reach $980 billion by 2018, driven primarily by the growth in packaging and labels [4]. The printing industry in the US had revenues of $83.4B in 2015, and is facing an annual rate of decline of 1.2% from 2010-2015 and is forecasted to continue to decline at

an average rate of 0.5% from 2015-2020 [5]. Book printing generates an estimated 5.8% (or $4.84B) of the industry's revenue, where general books account for 29.4% of this product line, while textbooks and reference books generate a respective 18.0% and 9.8% of the product segment's revenue [5].

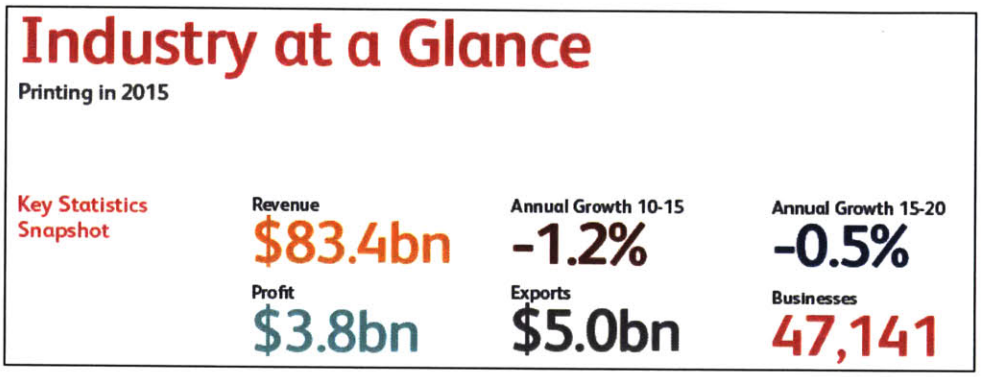

Figure 1. US Print Industry [5]

The printing industry has shown key features of a declining industry such as the fact that the industry is declining as a share of the overall economy, the market is generally saturated (contributing to industry consolidation), the lack of technology and process change, and the declining per capita consumption of goods [5]. However, while the printing industry as a whole has been in decline, POD has experienced rapid growth and is forecasted to continue to grow rapidly over the next five years. To support the growth, POD has had to open new manufacturing facilities. There are currently four facilities, three are embedded within fulfillment centers and the fourth is a stand-alone site. Each new facility helps the network topology and drives down transportation costs. Figure 2 shows the layout of a POD manufacturing facility. The manufacturing flow through the plant is relatively simple:

(1) The pages of the book are printed from either black and white or color printers

(2) The pages are appropriately cut with trimmers

(3) The covers for the book are printed and laminated

(4) The laminated covers are placed with the bins that have the corresponding inner pages of the book (book blocks)

(5) Machines bind the book blocks with the laminated covers and ensure the edges are appropriately cut

(6) The completed books are inspected and either sent to wholesale order storage or prepared for shipment by the fulfillment center

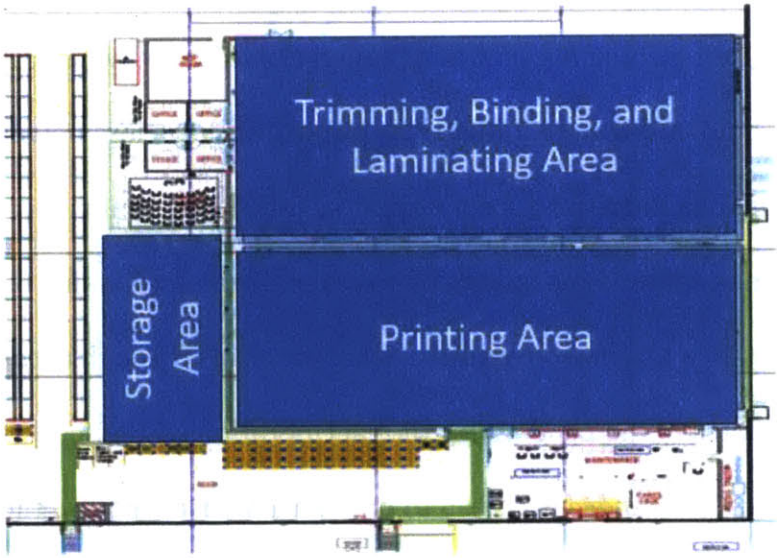

Figure 2. POD facility layout

The growth of POD can be partly attributed to two sources: increasing the size of the catalog and the growing popularity of self-publishing. The main value proposition for Amazon, and one of the main reasons why Amazon manufactures books in the first place is to offer the largest selection of books possible to customers. By eliminating the need to

hold inventory for the long tail of retail demand, Amazon can offer an unlimited quantity of titles (currently 1 million+). In 2014, approximately 90% of the catalogue did not sell a single unit, but were available to customers, who are still very interested in purchasing books. Even with the decline in the overall print industry, over 20M customers have purchased books on Amazon from February through August 2015. Additionally, online retail sales of books is expected to continue to grow rapidly over the next few years.[4] Adding titles into the POD network that sell fewer than 50 units per year and that sell between 50-1000 units per year is expected to represent a potential 100M+ positive NPV opportunity for the business.

Besides holding the long tail of retail demand, POD also receives demand from an Amazon-owned self-publishing platform, called *Createspace*, which can potentially disrupt the traditional book publishing industry as publishers have less power and as the barrier to entry for authors has decreased. To paraphrase Jeff Wilke, Senior Vice President of Consumer business at Amazon, giving people a platform for making creative content is of strategic importance to Amazon's future, whether that's through *Createspace* or other channels. Graduates of the Leaders for Global Operations (LGO) program recently took advantage of the *Createspace* platform to publish a book called "Do the Right Thing: Real Life Stories of Leaders Facing Tough Choices." Ultimately, the vision for self-publishing is that anyone with an internet connection will be able to easily and instantly publish their work in any language or format. Improving operational efficiency, which this project aims

[4] Based on data from Amazon Insights, which is an Amazon internal source of data and statistics

to do, will help ensure that authors using Amazon's platform are able to earn more for their work than they could using other channels.

2.5 What makes POD unique?

The ability to manufacture books provides strategic advantages to Amazon in addition to the reasons that were already mentioned. Since POD books are digitized as PDFs, they allow for greater customization, which is something that customers may really value now or in the future. This ability to customize products can be extended from books to magazines to posters and have a wide array of applications. Additionally, since Amazon owns *Createspace* they can offer loyalty programs to help with author retention and recruitment, and provide incentives or value added services for authors who gain popularity or are already popular. Interestingly, Amazon has even opened its first physical bookstore in Seattle, called Amazon Books. This store provides a unique customer experience as Amazon uses its vast troves of data that it collects from its online customers to stock the shelves and showcase books that have amassed the most pre-orders online. The books also come with Amazon's trademark low price tags, due to the fact that Amazon Books is as much a bookstore as it is a billboard [6]. The fact that Amazon chose a bookstore as its first physical retail location shows that books continue to be of strategic importance to the company, and emphasizes the potential growing importance of POD's capacity expansion plan.

Amazon's continually growing customer data will allow for advanced data analytics capabilities. Similar to how Amazon Studies is able to launch a pilot season and get real time customer feedback to determine which shows to actually produce, the print industry

has the opportunity to use this same model with new book series. One example is with a service that allows for instant reader feedback and crowdsourcing of ideas for new content for stories. Ultimately, even in an established industry such as the print industry, there lies tremendous opportunities for growth through innovation and technological improvements.

2.6 Competitive Landscape

The relationship between Amazon, publishers, and the print industry in general has been a rocky one. By the time that Borders went bankrupt, in 2011, and closed all its stores, Amazon was selling more print books than anyone; was beginning to have success with unknown authors publishing directly in the electronic format; and, most important of all, was the go-to site for book-buying research and recommendations [7]. Amazon was the publishers' biggest customer but also, increasingly, a competitor. One of the focal points of the hostilities between Amazon and the publishers has been the tough negotiation between Amazon and the publisher Hachette, with some public sniping between the companies' executives. All of the publishers feel bullied by Amazon, and Amazon, in turn, feels misunderstood [7]. One of the main points of the conflict has to do with both margin and price, as Amazon aims to charge $9.99 for all e-books, which publishers believe is too low. However, from the author's perspective, they typically make the same amount from royalties for a $9.99 e-book that they could make on a paperback that costs as much as $34.95 [8]. This is a win for both the producer and the consumer; only the middleman suffers, who in this case is the publisher.

Other start-up companies, such as Scribd and Oyster, have become surprising competitors to Amazon, and have made a serious push into the book-subscription market,

using a Netflix type business model. Customers can pay about $10 a month and read all the books that they want on the digital device of their choice, and the publishers are paid a similar amount as if the person bought the e-book [7]. The new paradigm for the book industry was recently explained by Amazon's senior vice president for Kindle, Russell Grandinetti who claimed that "Books don't just compete against books. Books compete against Candy Crush, Twitter, Facebook, streaming movies, newspapers you can read for free. It's a new world. [8]" This is the main reason why the kindle is so important for the company, because it offers a platform for digital content to customers while at the same time is tied into Amazon's ecosystem, collecting data on customers and providing them with the opportunity to buy e-books or actual books.

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3. Literature Review

This next section will explore some topics that are relevant to this thesis, and includes understanding dual sourcing policies and why firms make this decision, make-to-order and make-to-stock production planning, and the role of customer value proposition in operations strategy.

3.1 Dual Sourcing Policies

Firms want to develop supply chains that reduce costs while also maintaining a high level of customer service and do so by incorporating alternatives with respect to sourcing. This can be done either by using different suppliers or with different modes of delivery with a single supplier. Typically, having a supplier deliver materials or a product faster is associated with a higher cost, thus making it a non-optimal and expensive strategy to procure solely from this premium agent. For this reason, many companies prefer to use dual sourcing, where they get the bulk of their materials from a cheaper regular supplier at a lower cost (and longer lead time) but turn to premium expedited channels when needed [9].

However, there are many other reasons to use dual sourcing policies, with some strategic ones being to safeguard against predatory monopolistic practices, hedging against uncertainties in international markets, avoiding supply disruptions, and limiting the effect of exchange rate shifts [9]. While POD has four internal manufacturing sites, which provides flexibility for internal manufacturing, they also currently have a relationship with a manufacturer to pre-build books. This manufacturer has a tremendous amount of

experience and expertise when it comes to book manufacturing as they have been in the print industry since the late 1800s, and had revenues of $11.6B in 2014 [10]. They currently have 8.9% market share of the U.S. print industry. Even still, if Amazon plans on conducting additional high volume pre-builds it is important for POD to establish relationships with multiple suppliers for a wide variety of reasons, but primarily to weaken the bargaining power of the suppliers. However, grooming additional sourcing option has been difficult due to the fact that the print industry has been struggling, which has led to consolidation amongst the key players. While having an outsourcing relationship with this company has provided them with a great amount of bargaining power, at the same time, the company anticipates having excess capacity and may be willing to compromise and concede on price in order to win the volume that this new initiative could bring to their business.

3.2 Make-to-Order, Make-to-Stock Production Planning

An assemble-to-order (or make-to-order) manufacturer offers a family of products that can be assembled rapidly, in response to a customer's order, from an inventory of a relatively small number of modular components [11]. Dynamic control of an assemble-to-order system is challenging because the state space (outstanding orders and their due dates, and the inventory and production status for each component) is very large, and thus the decision of when and how much to produce of one component cannot be made without knowledge of the inventory levels of other components. POD's system is much less complex because manufacturing books is a relatively easy and simple process, especially since at the moment they only have the capability to manufacture soft cover books. In this case, the

primary raw materials for manufacturing only consist of such low cost materials as laminate, paper, and glue.

In many circumstances, increasing cost pressures have led supply chain managers to focus on running increasingly lean and efficient supply chains, which typically means having minimal inventory as firms rely on pull or make-to-order supply chains to minimize cost and waste. However, increasing competitive pressures have led to greater emphasis on customer service, which requires having inventory of make-to-stock items, and delivering make-to-order products quickly and by the promised due date [12]. More specifically, Amazon has prided themselves in customer obsession and often makes significant investment decisions to improve customer experience.

Minimizing inventory holding costs and quoting reliable and short lead times to customers are clearly conflicting objectives in supply chains with stochastic demand and processing times. While ideally, companies would like to initiate production every time a customer order arrives in order to avoid inventory holding costs, this strategy is likely to lead to long waiting times for order delivery. These long lead times lead to customer dissatisfaction, lost sales, and decreased profits [12]. For POD, delays in manufacturing due to equipment breakdowns or other reasons will often result in the ability for fast track to be turned off. The importance of fast track is demonstrated by the sales lift that it provides to products that have this option, although the specific sales lift is different depending on the product. Lastly, POD has the capability to outsource manufacturing at a higher cost as a safety valve when the network is unable to accommodate demand.

The decision on using either an MTO strategy or an MTS strategy at a facility depends heavily on the characteristics of the systems. In supply chains using a combined system, holding inventory at some of the stages of the chain and using a MTO strategy at other facilities might decrease the costs dramatically without increasing the lead times. Because of this, companies are starting to employ a hybrid approach, a "push-pull" strategy (a combined MTO-MTS system), and are holding inventory at some of the facilities in their supply chain and producing to order in others [12]. For POD, the majority of the MTS strategy will be executed with external manufacturers while the MTO strategy will continue to be conducted using internal capacity.

One way to approach these types of problems is with the concept of the decoupling point (DP), which has to do with the concept for integral control. In this context, integral control means planning and management of the goods flow from purchased materials to delivery takes place, based on the characteristics of the product-market combination, within a suited organizational and control structure. Integral control is designed by finding a balance in the costs of procurement, production, distribution, and storage against the customer service to be offered. In essence, the decoupling point is the point that indicates how deeply the customer order penetrates into the goods flow [13]. The decoupling point is also important for the following reasons:

- It separates the order-driven activities from the forecast-driven activities
- It is the main stock point from which delivery to customers are made and the amount of stock should be sufficient to satisfy demand in a certain period

- The upstream activities can be optimized in some ways, as they are based on forecasts and are more or less independent from irregular demands in the market

Figure 3 shows the main determinants of the decoupling point and are split into two categories: (1) product and market characteristics and (2) process and stock characteristics.

Product and market characteristics	Process and stock characteristics
Required delivery reliability	Lead times and costs of steps in the (primary) process
Required delivery time	Controllability of manufacturing and procurement
Predictability of demand	Costs of stock-holding and value added between stock points
Specificity of demand	Risk of obsolescence

Figure 3. Determinants of the decoupling point [13]

For each of the terms mentioned in Figure 4, the influence on the location of the DP is shown. For example, irregular market demand will (if everything else remains stable) have an upstream effect on the location of the DP, while short delivery times will force the DP more downstream, towards the make-to-stock position [13]. These factors are important to consider and should be applied to POD to determine the DP that makes the most sense for the business.

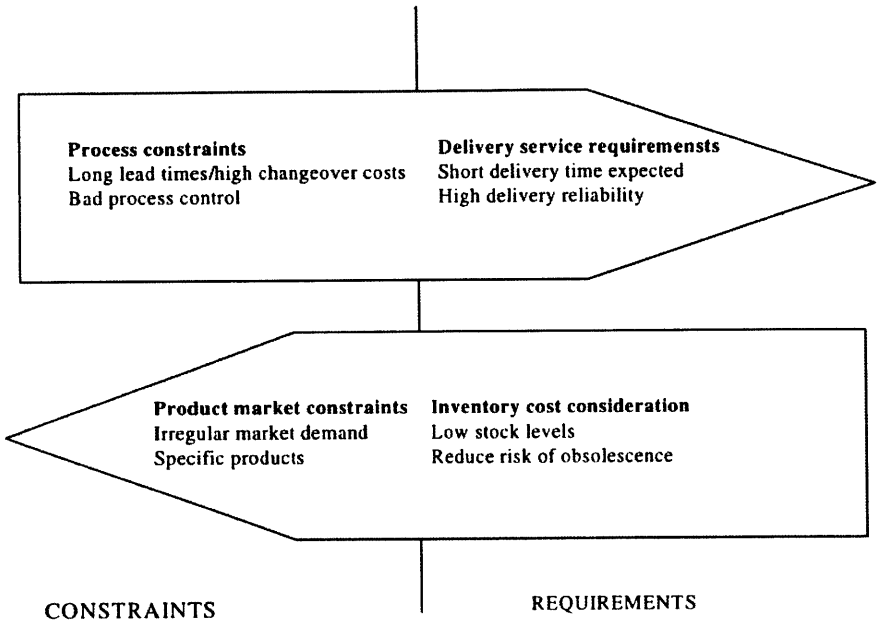

Figure 4. Business characteristic and influence on the DP [13]

3.3 Operations Strategy and Customer Value Proposition

Since firms struggle to compete on all dimensions of customer value (i.e. highest quality, fastest fulfillment, and lowest cost), the manufacturing and supply chain strategy of the business should be directly tied to its value proposition to customers [14]. For POD, the different sales channels (*Createspace* and Amazon.com) seem to have different value propositions, implying that they should have uniquely tailored supply chain strategies.

The retail business, particularly the books that are sold on Amazon.com, has a similar value proposition to that of the rest of Amazon marketplace, focusing on product selection and availability, which implies an operations strategy focused on efficient and reliable order fulfillment. When customers make a purchase on Amazon.com they expect the item to have a low cost and to have the item delivered to them as quickly as possible. To meet this objective, holding inventory of books that can be picked from a shelf and shipped

to a customer is optimal. The manufactured quality of the book, such as measured by the quality of paper used, is likely not a major factor that a customer would consider when making a purchase of a softcover book on Amazon.com.

Createspace customers, on the contrary, understand that the speed of delivery for wholesale orders may take longer, but would prefer to have a higher quality product as self-publishing has given them a platform for their creative endeavors. For these customers, POD internal manufacturing makes the most sense because toner-based printing is typically higher quality than inkjet printing and allows for better quality control. Additionally, these authors will want to have flexibility to quickly ramp up production if the books become popular and will conversely not want to have to place a big bet and hold inventory before analyzing demand signals from their customer base. The fact that the authors can trust POD to manage the supply chain for their books with no minimum production quantity and optimally fulfill demand is a great benefit to the authors. An even greater benefit occurs when POD can pass the savings from efficient manufacturing to the authors by way of increased revenue and royalty rates. Figure 5 highlights the main differences in value proposition for a customer that is shopping for a book on the Amazon.com website and a *Createspace* self-publishing author, which ultimately defines the uniquely tailored supply chain strategy. For the purpose of this diagram, the further the point is away from the origin the more important is the factor (the four factors are flexibility, cost, quality, and speed).

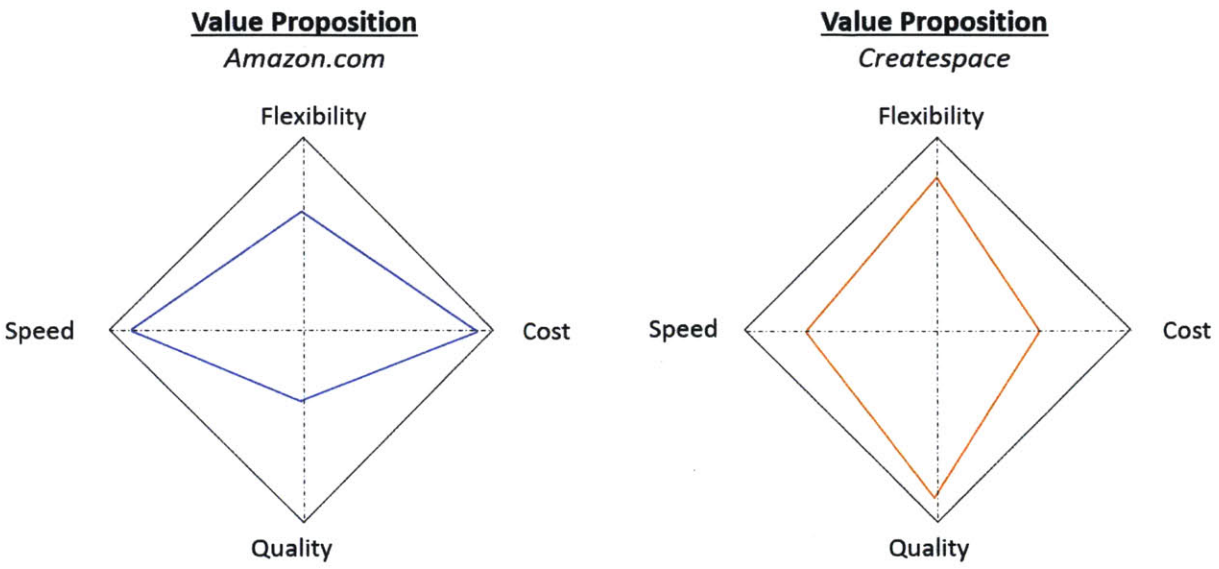

Figure 5. Value Proposition Diagrams

These different value propositions lead to the insight that the retail business would benefit from a push based make-to-stock system for certain titles. However, other factors that drive this decision are economies of scale and demand uncertainty. As mentioned previously, economies of scale exist in book manufacturing and forecasts tend to be more accurate with retail demand that sells in larger quantities. Conversely, the long tail of retail demand's high uncertainty makes a pull system most logical. The recommendation for a hybrid MTS-MTO production optimization model maintains both capabilities and helps manage the inherent trade-offs when deciding upon these approaches, such as efficiency and responsiveness, flexibility and cost, and quality and price.[5]

[5] Flexibility specifically refers to the ability to adjust volume levers, having manufacturing customization, etc.

4. Initial Hypothesis

The hypothesis for the project is that there are enough titles that sell in large quantities and sales volume for these titles, and that demand forecasts are accurate enough that they can be used to make inventory decisions to achieve cost savings and customer experience improvements for POD. While holding inventory, capacity in the internal POD network will be reserved primarily for the long tail of retail demand, wholesale books, and additional units of fast moving titles once the inventory position has been depleted, but without the future demand forecasts to justify re-orders.

The current state of the system is depicted in Figure 6, and shows that the manufacturing process for a book within POD does not begin until an order has been received. The orders can come from purchases on the Amazon.com website (retail orders) or through the *Createspace* self-publishing platform (wholesale orders). At this point, the majority of orders will be fulfilled internally through the POD manufacturing process, while there is the capability to do dropship and external manufacturing on a very limited basis. External manufacturing is more expensive and is typically only used as a safety valve for when internal capacity is unable to meet demand, for reasons that include demand spikes or equipment break downs. Additionally, there was a pre-build before the holiday season in 2014 to ensure that the network would have the capacity to fulfill demand during the holiday sales spike. These orders were determined using very simple heuristics looking at past sales and high probability of future sales. These orders were not placed based on cost analyses and optimal ordering levels.

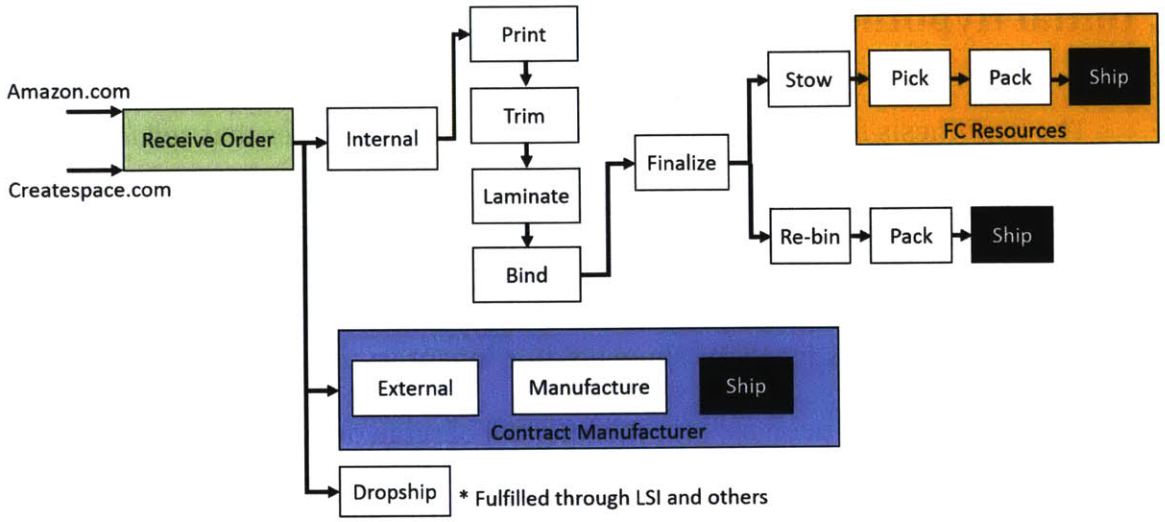

Figure 6. Current State

To complete the conversion from a make-to-order to a hybrid system, POD needs a tool that uses demand forecasts to determine which ASINs (Amazon specific terminology that refers to a specific title or book) to hold inventory for along with the optimal order quantity. The hybrid system decreases the risks that these systems, when used individually, often face. For example, POD does not need to worry about excessive inventory due to safety stock, because POD can manufacture units internally once the inventory has depleted. The inventory position serves as a baseline from which flexible capacity in the network can accommodate demand variability (illustrated by the red line in the Figure 7). Figure 7 proposes this future hybrid state for the business, and shows how both internal and external capacity can be used for both the make to order and make to stock production systems.

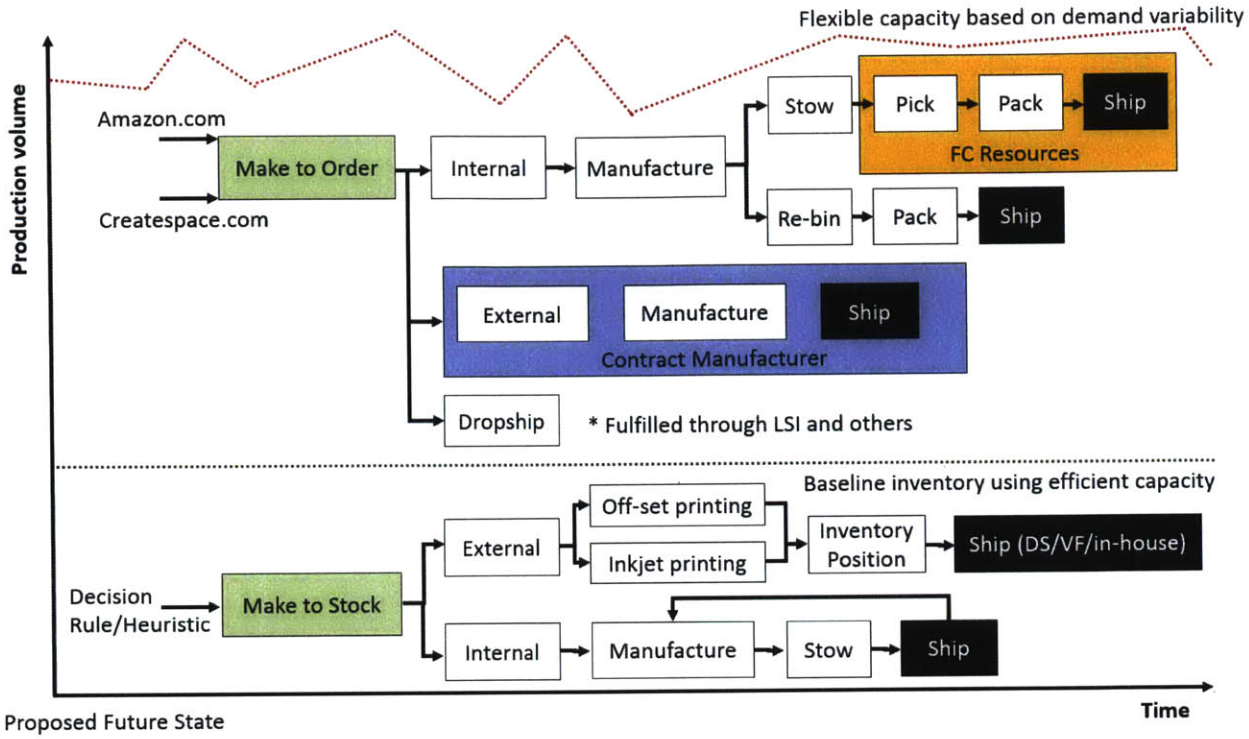

Figure 7. Proposed Future State

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5. Data Collection and Analysis

Collecting and analyzing sales data for POD was a critical first step to better understand the problem that the business was facing and to ultimately develop the initial hypothesis. After looking at a wide array of historical data, the data from the first quarter of 2015 was very representative of the overall sales data. The Pareto chart below shows that approximately 45% of the titles sold during Q1 2015 only sold one unit, and that 60% of the titles sold only one or two units. Lastly, this chart highlights the value of POD and the fact that the business is able to provide the long tail to customers at a low cost for the business, since they are not required to hold inventory.

Figure 8. Pareto Chart #1

A second Pareto chart was used to gain insights on how the titles with certain sales volumes make up the overall sales volume for the business. Figure 9 shows that the 60% of

the titles that sold only one or two units make up a very small percentage of the total sales volume (<5%). The majority of the volume came from titles that sold 10 or more units. More specifically, titles that sold between 11-50 units and 201-1000 units make up the greatest sales volume. This finding helps to support the hypothesis that there is sufficient volume from the fast movers to achieve cost savings for POD. Due to economies of scale in manufacturing the initial thought process was to screen for titles that sold in quantities greater than 1000 units in a quarter, since this is the volume where off-set printing is most cost effective. However, after further analysis, it was determined to target titles with projected volume greater than 500 units. In the future, this screening can also be reduced as long as POD can get reliable cost estimates for external manufacturing for a wide variety of run lengths. This will be further discussed in a later section.

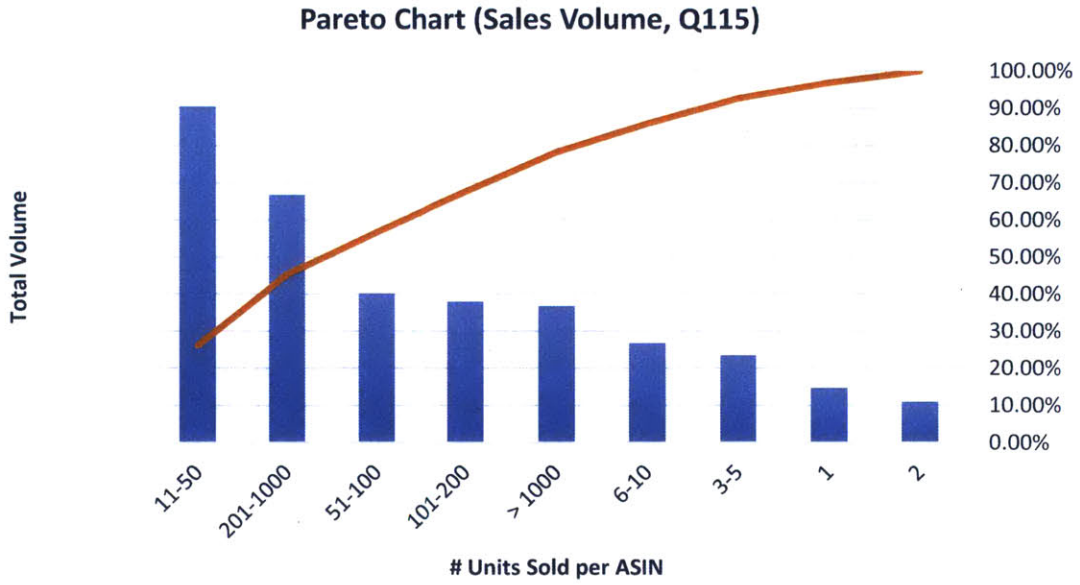

Figure 9. Pareto Chart #2

5.1 Outsourcing Opportunity Model & Forecasts

After gaining these insights, it was important to roughly understand the size of the pre-build and outsourcing opportunity to determine if the development of a model to determine how much inventory to hold would even be necessary. Using a few years of historical sales data and accounting for various factors, such as seasonality, a regression model was developed to determine the growth in the number of pre-build opportunities over the next five years. To qualify for pre-builds, the assumption was made that titles would need to sell in excess of 1250 units per quarter. However, this assumption would need to be re-addressed once more specific pricing information was received from the manufacturer.

One problem with this model is that it did not take economic factors into consideration, as each title has a unique variable cost and purchase cost that will factor into the ordering decision. Demand forecasts are also very important and are not being considered. However, the model did show from a volume perspective, that more and more titles are selling in larger quantities, where Q1 2015 showed ~60% YoY growth. Figure 10 shows the model estimates for the number of off-set pre-build opportunities per week and the percentage of these opportunities against the forecasted retail demand (% Retail). While ~850K units would have been eligible for pre-building in 2013, the number of units eligible would increase by approximately three to five fold by 2019. The pre-build opportunities (volume that could have been make-to-stock) hovers consistently around ~11% of the overall retail demand, and indicates a sizeable and growing opportunity.

Offset Opportunities	Per Week	% Retail
2013	15K	N/A
2014	25K	N/A
2015	35K	9.0%
2016	55K	11.0%
2017	65K	11.0%
2018	75K	11.0%
2019	90K	11.0%

Figure 10. Pre-build Opportunities Forecast Table

Figure 11 shows how the pre-build opportunities change based on the review period that is used. Additionally, this figure indicates that a quarterly review period seems to be the most appropriate for POD, since anything less than quarterly would not show titles with the forecasted demand to justify pre-building. While having a review period longer than quarterly was considered, this seemed like too much of a risk, particularly due to the volatility of demand when dealing with long tail items and self-published books. Additionally, this figure shows the tremendous year over year growth, which is projected to be around 60%. The reason for the decline over the last period is because of the spike during the time period leading up to Christmas.

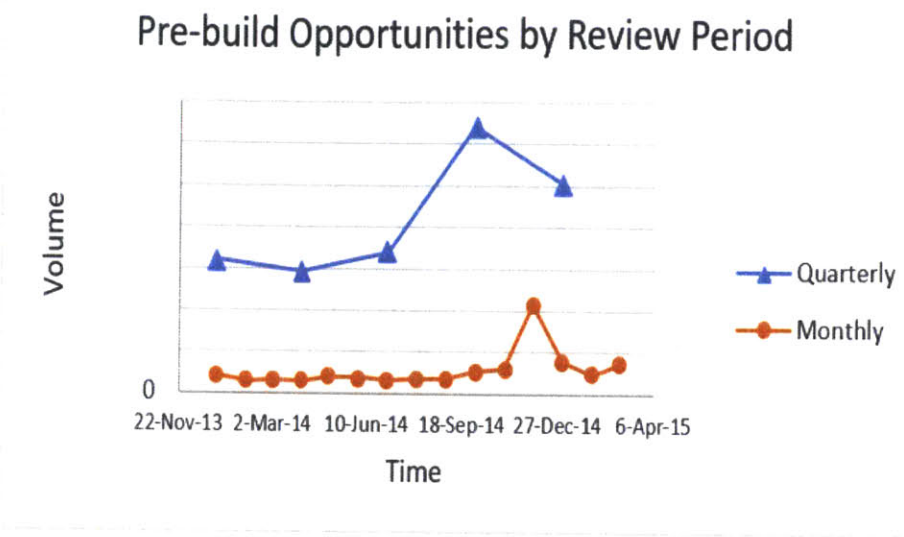

Figure 11. Pre-build Opportunities by Review Period

Figure 12 depicts the number of titles that would be eligible for pre-building based on the same two reference review periods, quarterly and monthly. Even using quarterly review periods, based on the screening criteria, POD would only be pre-building 485 titles out of the more than one million titles that are in the POD catalogue, with 207 of these selling between 1000 and 2000 units. This table also shows that some of these titles should very obviously be manufactured using off-set printing, especially given that some sell in quantities over 35,000 a quarter. These are likely self-published books that have exploded in popularity, and the fact that so many were manufactured internally represents unrealized cost savings. More importantly, since they were only manufactured once an order was placed, the customer did not have the option for optimal expedited order fulfillment, even though these titles had exploded in popularity. The risk with these titles is that their popularity can plummet as quickly as they have risen.

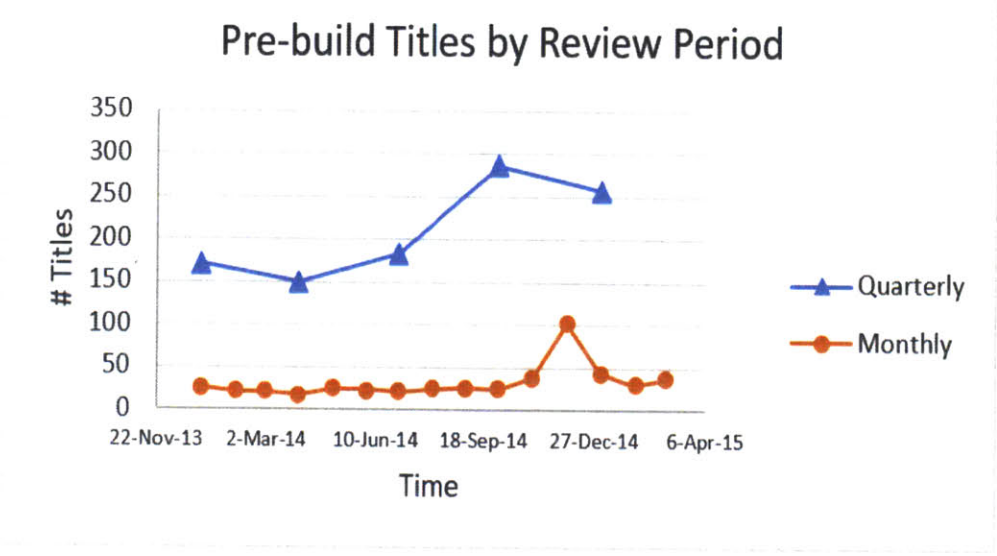

Figure 12. Pre-build Titles by Review Period

Being able to accurately model the number of pre-build opportunities allows for the opportunity to assess how this would affect the opening of new MOD sites, where the cost to open a new site can be exceedingly high. Not having to open a new MOD site would lead to an increase in free cash flow, since the money would not have to be spent, or there would at least be a delay in spending the money.

5.2 Total Fulfilled Cost Per Unit (TFCPU) Analysis

The Pareto analysis and pre-build opportunities model provides justification to implement a make to stock component of the system and to develop a model to determine optimal order quantities for high volume titles. In order to start developing the model, it was important to fully understand the cost components and other considerations that are involved when doing internal and external manufacturing and order fulfillment. The table below defines the variables that will be included in the model.

p	D	y	C_{MTO}	C_{MTS}	T_{MTO}	T_{MTS}	r	s	T
Price	Demand	Order quantity	Cost (MTO)	Cost (MTS)	Trans Cost (MTO)	Trans Cost (MTS)	Discount rate	Salvage value	Cycle time
C	I	T_{RD}	VPC	C_{Inb}	T_{TR}	P_{FRF}	S_{Multi}	$\bar{y}$	h
Capital Cost	Inventory Cost	Trans Cost (RRD to RC)	Variable Purchase Cost	Inbound Cost at RC	Trans Ship Cost	Forecast Risk Factor Probability	Savings (Multi)	Order quantity (upper bound)	Holding cost

Figure 13. Model Parameters

For internal manufacturing, the TFCPU includes the make-to-order cost (C_{MTO}), which can essentially be thought of as the variable cost, and the transportation cost (T_{MTS}). The costs associated with external manufacturing are a bit more complicated. The make-to-stock cost (C_{MTS}) is not just the cost to pay for the manufacturing, also referred to as the variable purchase cost. The transportation from the contract manufacturer to the Amazon receive center (T_{RD}), the inbound cost once it arrives at the center, and the transshipment cost to place the inventory in Amazon's fulfillment center network needs to be included here as well. Essentially, these different variables represent all of the costs associated with placing the book on the shelf. This equation is shown below and the variables are explained in more detail in the model assumptions.

$$C_{MTS} = VPC + T_{RD} + C_{Inb} + T_{TR} \qquad (1)$$

The transportation cost for this inventory once it's in the Amazon fulfillment center network (T_{MTS}) can interestingly be less than the make-to-order transportation cost. This is because Amazon fulfillment can optimally place inventory based on regional demand, whereas make-to-order manufacturing is constrained to a four node network (POD sites). The four sites are represented by the icons in Figure 14.

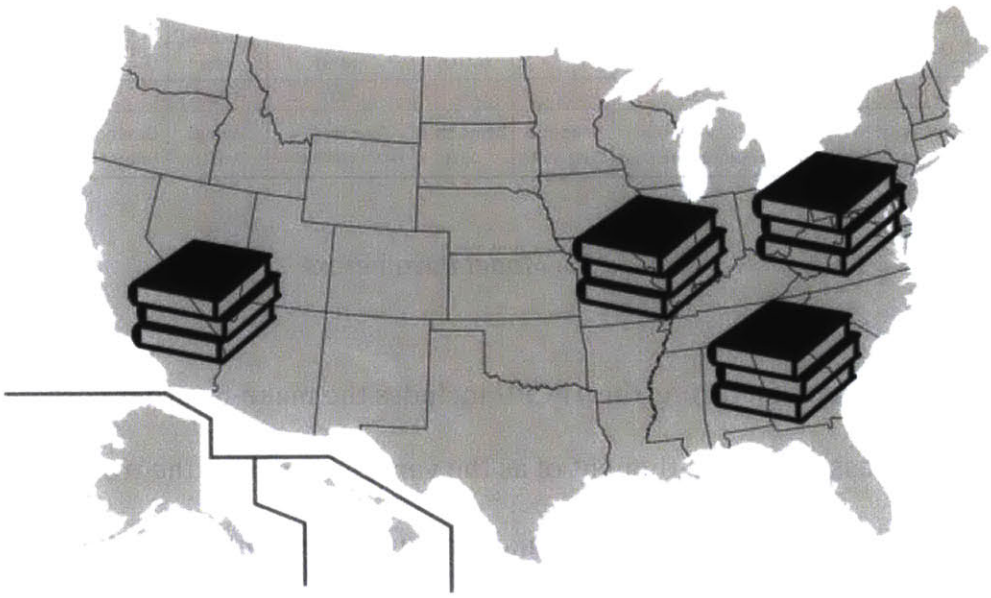

Figure 14. POD Network

Additionally, the benefits from having less missed multi's would be accounted for as a fixed amount in the make-to-stock transportation cost, as shown below (S_{Multi}) .

$$T_{MTS} = T_{Ship} - S_{Multi} \qquad (2)$$

Additional variables that need to be described in further detail include:

Table 2. Variable Descriptions

Symbol	Variable	Description
T	Cycle Time	Length of time (13 weeks)
C	Cost of Capital	Opportunity cost of making the investment, includes C_{MTS} and the discount rate
I	Inventory Cost	Cost to store items at fulfillment centers, based on the volume of the book and storage cost per day
VPC	Variable Purchase Cost	The cost per book based on the run length
h	Holding cost	Inventory Cost + Cost of Capital

6. Hybrid MTS-MTO Production Optimization

The first decision that had to be made was whether to use a single period or a multi period model for this project. Demand uncertainty over longer time horizons for POD books and the menu pricing format with quantity discounts leads to a preference for a single period model (aiming to deplete the inventory by the end of each period) over a multi period model.

The main contention with using a multi-period model is that there would no longer be a closed form solution of the optimal order-up-to level, which is advantageous for evaluating multiple entries in the menu of prices based on the offered batch sizes (or run lengths). Also, defining the optimal multi-period is challenging as Amazon only generates distributional forecasts over a 32 week time period. The increased model complexity combined with lacking good quality inputs for the multi-period formulation and being generally less flexible to the somewhat erratic nature of retail demand makes the single period approach more appealing and realistic.

6.1 Model Formulation & Inputs

MTS-MTO Single Period Production Optimization (High Volume Pre-build) Model

Figure 15 is the same table as depicted earlier, which shows the model parameters to be used as a reference when explaining the model.

p	D	y	C_{MTO}	C_{MTS}	T_{MTO}	T_{MTS}	r	s	T
Price	Demand	Order quantity	Cost (MTO)	Cost (MTS)	Trans Cost (MTO)	Trans Cost (MTS)	Discount rate	Salvage value	Cycle time
C	I	T_{RD}	VPC	C_{Inb}	T_{TR}	P_{FRF}	S_{Multi}	$\bar{y}$	h
Capital Cost	Inventory Cost	Trans Cost (RRD to RC)	Variable Purchase Cost	Inbound Cost at RC	Trans Ship Cost	Forecast Risk Factor Probability	Savings (Multi)	Order quantity (upper bound)	Holding cost

Figure 15. Model Parameters

The purpose of the model is to optimize the external order quantity (y*) based primarily on the relationship between internal and external costs. The starting point for the model is the equation for the expected profit with the order quantity as the independent variable:

$$g(y) = E\{p * D - (C_{MTS} * y) - (C_{MTO} * max(0, D - y)) - (T_{MTS} * min(D, y)) - (T_{MTO} * max(0, D - y)) + (s * max(0, y - D)) - (hT * max(0, y - D))\} \quad (3)$$

This equation takes into consideration the internal variable cost, C_{MTO}, the external variable purchase cost, C_{MTS}, the different transportation costs for make-to-order and make-to-stock, as well as salvage value and holding cost, which consists of the cost of capital and inventory costs.

Since: $T * \min(D, y) = T * (D - \max(D - y, 0))$ *or* $TD - T * \max(D - y, 0))$ then the objective function for the model can be simplified to the following.

Objective Function:

$$g(y) = (p - T_{MTS}) * E(D) - C_{MTS} * y - \left(C_{MTO} - (T_{MTS} - T_{MTO})\right) * E(max(0, D - y)) + (s - hT) * E(max(0, y - D)) \quad (4)$$

If the salvage value is less than C_{MTS} than the maximum profit is attained at the ordering quantity (y) that solves the following equation, where F(y) represents the

cumulative distribution function of the forecasts for the ASIN and $\tilde{c}$ is a variable that was defined to aid in simplification.

$$\tilde{c} = C_{MTO} - (T_{MTS} - T_{MTO}) \quad (5)$$

$$g'(y) = -C_{MTS} + \tilde{c}\big(1 - F(y)\big) + (s - hT) * F(y) \quad (6)$$

$$g'(y) = 0 \quad (7)$$

Then:

$$0 = -C_{MTS} + \tilde{c} * \big(1 - F(y)\big) + (s - hT) * F(y) \quad (8)$$

This leads to the critical ratio, depicted in equation 9. The critical ratio is used to maximize expected profit by minimizing the expected total cost of underage and overage. The order quantity that is chosen is equal to the probability that there will not be lost sales.

$$\boxed{F(y) = \frac{\tilde{c} - C_{MTS}}{\tilde{c} - (s - hT)}} \quad (9)$$

Dimensional analysis was used to further break down the holding costs and to match up units. The equation for the holding cost is shown in equation 10, and includes the inventory cost and the cost of capital. The inventory cost was based on the cost that Amazon charges third party vendors to store products at fulfillment centers. Additionally, to better understand the inventory cost the volume of each book was calculated based on

the trim size and the page count of the book. The trim sizes and page counts were rounded up to the reference prices when necessary.

$$hT = (I + C) * T \qquad (10)$$

The profit maximizing equation for this model serves a similar purpose as it does in a traditional newsvendor model, where the y* is chosen such that the probability of the last unit not being sold is equal to the ratio on the right side of the equation. Complexities to this model include the quantity discounts for 68 different run lengths and the unique prices per ASIN based on trim size, page count, and finish (gloss or matte). Further complexities include incorporating the benefits of being able to reduce missed multis (multis are reduced transportation costs by being able to ship multiple items together), the gain in multis from holding inventory, the costs to transport and stow the books in Receive Centers, and the appropriate way to account for the salvage value, which is explained in more detail in a later section. All of these complexities are currently being accounted for (except for the gain in multis from holding inventory), and the accuracy of the methods to account for these factors can be improved after a pilot implementation. A pilot program would also give insight into what the gain in multis would be.

6.2 Model Demonstration

The model can be demonstrated using the ASIN with the highest demand forecast for Q1 2015. After estimating all the price inputs based on unique characteristics of the book, the next step is to pull the demand forecasts at the six available service levels (from P50 to P90) and build the demand distribution by minimizing the sum square error to

estimate the parameters of the Gamma distribution (used by the forecast team). After using the formulas to calculate the profit maximizing ratio, the optimal order quantity, 18687 units, is determined using the forecast distribution (shown below in Figure 16).

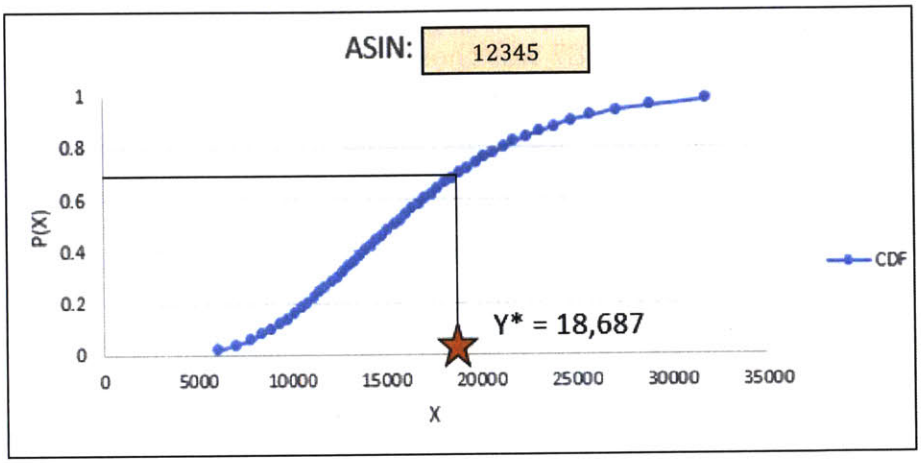

Figure 16. Sample Feasible Solution

The vendor for the external manufacturing provided 68 distinct prices for print run lengths starting at 100 units and ending at 20K units. This meant that each title will have a distinct critical ratio, salvage value, C_{MTS} and order quantity depending on the run length that is being analyzed. The order quantity needs to be greater than or equal to the run length that gives the specific price point used to make it a feasible solution. For example, if the order quantity was 300 using a run length price of 500, then this would not be a feasible solution, since an order of 500 would need to be placed to actually receive this price. For the purposes of maximizing the pre-build opportunities, the highest order quantity within the appropriate price range from the group of feasible solutions is chosen (i.e. 18687 is between 18K and 19K). To get a sample of the differing critical ratios by run length, the table below shows 11 of the 68 price ranges and the critical ratios for the ASIN at each price range.

ASIN	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000
12345	0.72	0.71	0.72	0.71	0.72	0.71	0.70	0.69	0.68	0.67	0.66

Figure 17. Sample Critical Ratios Table

These critical ratios correspond to the order quantities below, where the y* at 18K is a feasible solution. In this case, 18687 was chosen as the order quantity.

ASIN	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000
12345	19485.98	19485.98	19485.98	19485.98	19485.98	19485.98	19485.98	19078.27	18686.54	18686.54	18308.73

Figure 18. Sample Order Quantities Table

While explained in more detail in a later section, a preliminary explanation is that the model should run after receiving new forecasts every Sunday to monitor inventory depletion, to determine if future forecasts justify a re-order, and to capture new titles that qualify for pre-building. The quantity discounts make it more advantageous to allow the inventory to deplete, ignoring lead time, in order to best take advantage of quantity discounts.

6.3 Model Assumptions

The hybrid model is based on the following assumptions, which were developed in close coordination with finance, transportation, and other subject matter experts at Amazon, some of them being on the POD team and some from external teams.

Hybrid MTS-MTO Production Model Assumptions

- Discount rate is 8%
- The transportation cost to the Receive Centers is based on previous negotiations and can likely be reduced; transshipment and inbound costs are based past data
- The make to stock prices are being overestimated in regards to trim size, due to the fact that the manufacturing company only provided prices for two sizes: 5x8 and 6x9; the 5x8 price was used for all trim sizes smaller than 5x8 and the 6x9 price was used for all trim sizes between the two
- The make to stock prices are also overestimated in regards to page count; the manufacturing company had prices in increments of 16 pages starting with a minimum of 96 pages. 96 pages was used as a minimum and round up to the nearest 16 page increment
- Only applying the holding cost and cost of capital to the remaining inventory at the end of the period
- Did not consider lead time, although it will realistically be ~12 days. This is not a major concern since there is no threat of lost sales due to stock outs. In the future would need to adjust how the forecasts are pulled to adjust for lead time during implementation
- The inventory items will be transshipped to locations where they will have a similar transportation cost per unit as the average transportation costs for books
- Used the price that Amazon charges 3PP for inventory cost, although if the network is not capacity constrained, the true cost is actually zero. Amazon is only capacity constrained during the 4^{th} quarter of the year

6.4 Salvage Value Heuristic

One challenge for the single period model was to come up with a method to deal with the salvage value. The challenge is trying to determine how to apply a salvage value for one period, when in reality, the book may sell in future periods. For this reason, assuming no salvage value seemed unrealistic and needed a heuristic to account for it. The heuristic looks at the probability of selling more than the quantity ordered ($\bar{y}$) for a certain title over two periods, or 26 weeks. The make-to-stock cost was then multiplied by this probability, meaning that if the title was very likely to sell over this 26 week period then it was very likely to completely regain the make-to-stock cost for the book.

$$s = C_{MTS} * P\left(D_{[0,26]} > \bar{y}\right) * (1 - P_{FRF}) \qquad (11)$$

The fact that the hybrid model has difficulty adjusting for the risk that a title will have a precipitous drop off in sales led to the development of a Forecast Risk Factor (FRF).[6] Moving forward, each title could have a unique FRF based on a combination of the most relevant factors, with the ultimate goal of hedging against the risk of the precipitous sales decline. One example of a relevant factor would be the release date of the book. A newer book would have a higher risk of volatile demand than a book that has been selling a consistent volume over a significant period of time. However, at this time, the FRF is being used as a sensitivity analysis lever that can be adjusted based partly on risk and flexibility.

[6] A second risk is that the author changes the content of the book. To prevent this, authors need to be given an opportunity to make final changes to a version of their book before the high volume pre-builds.

Part of the reason for the risk is the inherent inaccuracy of forecasting over a long period of time. Figure 19 below shows the probability that the title will sell the volume for each price range over the 26 week time period. The columns represent the run length (which has a certain price associated with it) and the rows represent the different books. The first ASIN (12345) has a 98% probability of selling at least every run length depicted (from 100 to 1000 units). The last ASIN (22123) has a 78% probability of selling at least 100 units and a 36% probability of selling at least 1000 units. These probabilities were determined by looking at forecasts for the next two quarters (or 26 weeks).

ASIN	100	200	300	400	500	600	700	800	900	1000
12345	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
23456	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
34567	0.98	0.98	0.96	0.94	0.94	0.92	0.90	0.88	0.88	0.86
45678	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
56789	0.98	0.98	0.98	0.98	0.98	0.96	0.96	0.94	0.92	0.88
67890	0.84	0.76	0.72	0.68	0.64	0.62	0.58	0.56	0.54	0.52
21345	0.84	0.76	0.70	0.64	0.60	0.56	0.52	0.48	0.46	0.42
31234	0.98	0.98	0.98	0.98	0.98	0.98	0.96	0.96	0.94	0.94
41234	0.98	0.98	0.98	0.96	0.94	0.90	0.88	0.84	0.80	0.76
51234	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.96	0.96	0.94
61234	0.92	0.84	0.78	0.72	0.66	0.62	0.56	0.52	0.48	0.44
71234	0.88	0.80	0.74	0.68	0.64	0.60	0.56	0.52	0.48	0.46
81234	0.98	0.98	0.98	0.96	0.94	0.92	0.90	0.86	0.82	0.78
91234	0.98	0.98	0.98	0.98	0.96	0.94	0.92	0.88	0.84	0.80
01234	0.98	0.94	0.90	0.86	0.82	0.76	0.72	0.66	0.62	0.56
11234	0.78	0.70	0.64	0.58	0.52	0.48	0.46	0.42	0.38	0.36
22123										

Figure 19. Salvage Value - Probability of Sale

6.5 Programmatic Solution and Outputs

The first iteration of the hybrid model with estimated gamma distribution parameters for the forecasts and with no salvage value led to a total pre-build volume of 93,601 units, which would have achieved an 81.93% sell-through rate. Additionally, ~85%

of the 124 eligible titles would have completely depleted their inventory by the end of the period. Most notably, the remaining inventory from two ASINs accounted for 75% of the total remaining inventory due to an inexplicably dramatic sales decline. This sales decline will be further explored in a later section.

The second iteration of the model improved by using the actual demand distributions and by using the salvage value heuristic that was explained previously. Figure 20 is a quick illustration of the critical ratios for 10 of the 68 price ranges for each title and the complexity that this adds to the problem. Each of the run lengths, depicted in the columns, also has a corresponding price, which is part of the critical ratio calculation (#9).

ASIN	100	200	300	400	500	600	700	800	900	1000
12345	-0.10	-0.12	-0.14	-0.15	0.23	0.22	0.34	0.33	0.33	0.33
23456	0.16	0.15	0.14	0.13	0.42	0.42	0.43	0.45	0.45	0.45
34567	-0.32	-0.33	-0.33	-0.34	0.05	0.04	0.16	0.16	0.15	0.15
45678	-0.37	-0.41	-0.44	-0.44	0.06	0.05	0.20	0.20	0.20	0.20
56789	-0.94	-1.01	-1.05	-1.09	-0.27	-0.28	-0.04	-0.05	-0.05	-0.05
67890	0.32	0.31	0.30	0.30	0.51	0.51	0.52	0.53	0.53	0.53
21345	-0.86	-0.92	-0.96	-0.99	-0.23	-0.24	-0.03	-0.03	-0.03	-0.03
31234	0.09	0.08	0.06	0.05	0.25	0.25	0.35	0.39	0.38	0.38
41234	0.14	0.12	0.11	0.10	0.22	0.22	0.30	0.31	0.31	0.30
51234	0.21	0.20	0.19	0.18	0.36	0.36	0.47	0.49	0.49	0.49
61234	0.19	0.17	0.15	0.15	0.31	0.31	0.31	0.32	0.32	0.31
71234	-0.14	-0.17	-0.19	-0.20	0.19	0.19	0.31	0.31	0.31	0.31
81234	0.12	0.10	0.10	0.08	0.29	0.29	0.40	0.44	0.44	0.44
91234	0.00	-0.02	-0.04	-0.05	0.29	0.29	0.39	0.39	0.39	0.39
01234	-0.31	-0.34	-0.37	-0.38	0.09	0.08	0.23	0.23	0.23	0.23
11234	0.16	0.15	0.14	0.13	0.42	0.42	0.43	0.45	0.45	0.45
22123										

Figure 20. Sample Critical Ratios

Figure 21 highlights the titles that have feasible solutions based on the critical ratios, meaning that these books should be make-to-stock with POD holding an inventory position. Some of these books have multiple feasible solutions, and as mentioned previously, the highest order quantity is the one chosen. This figure also shows how the shape of the

demand distribution plays a big role in determining whether or not POD should be holding inventory.

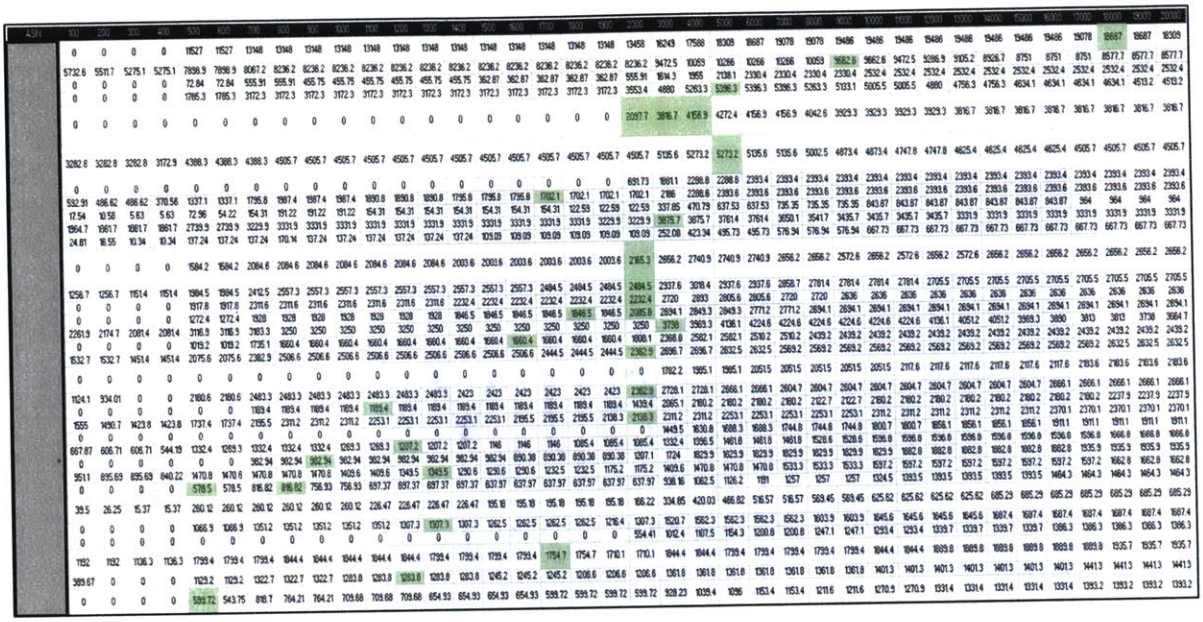

Figure 21. Sample Feasible Solutions Table

Figure 22 is a table of the sample output for the model, showing the Y* (optimal order quantity) for the top 20 titles based on P90 forecasts (90 percent probability of selling less than this amount), with an FRF of 25%. In the event that POD is capacity constrained and wants to maximize pre-builds, even at a slight VC loss, POD can order a minimum quantity of these top titles (i.e. 1000) that currently have an order quantity of zero. The fact that the model recommended not ordering four of the top 20 titles with the highest P90 forecasts required further investigation. One of the main reasons for this discrepancy is the shape of the gamma distribution for these forecasts. While *Title B* had more stable demand, based on the fact that it had a P50 forecast of 8751 units and a P90 forecast of 14002 units, in contrast, *Title K* had a P50 forecast of 769 units and a P90 of

9004 units. This huge variability in demand forecasts is the main driver in the decision not to order the book. This decision can also be illustrated by a cost analysis using *Title K*, which shows that the make-to-stock cost for 700 units is $1.20/unit, while the internal variable cost is $1.19.

Title	ASIN	P90	Y*
Title A		26948.6	18687
Title B		13329.2	9663
Title C		10310	0
Title D		9666.44	5396
Title E		8826.45	4157
Title F		8795.25	5273
Title G		8513.03	0
Title H		7407.25	1702
Title I		7101	0
Title J		7053.37	3876
Title K		6956	0
Title L		6269.88	2165
Title M		6102.12	2485
Title N		6018.84	2232
Title O		6018.02	2086
Title P		5782.53	3738
Title Q		5539.78	1660
Title R		5430.89	2383
Title S		5290.53	0
Title T		5268.39	2363

Figure 22. Top Titles Optimal Order Quantity

The left and right limits of the pre-build opportunity is determined by analyzing the results when there is no salvage value and when there is full salvage value with no forecast risk factor. This model recommends ordering between 127K-236K units, depending on the FRF, with excess between 17K-55K units. Comparing these results to a scenario of ordering

the forecasted units at specific service levels (i.e. P50, P60, P70, etc.) shows that the hybrid model has less eligible titles, but has much better sell through after one and two periods. Additionally, since the forecast ordering scenarios do not take economics into consideration, they have large variable cost losses (i.e. -$215K for P50 forecasts and -$295K for P60 forecasts).[7]

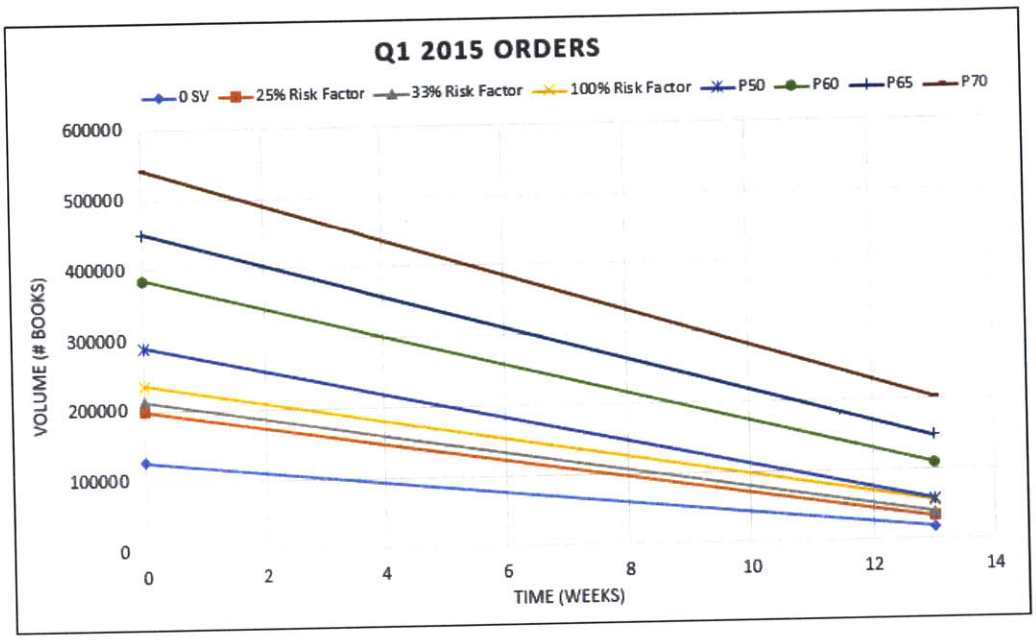

Figure 23. Q1 2015 Model Results

Another data point to look at is the number of eligible titles based on the screening criteria. While the number of titles increases considerably from using the P50-P90 forecasts, these ordering decisions results in variable cost losses as mentioned previously. Additionally, even when using more relaxed screening criteria, less than 1000 titles out of the entire catalog would be eligible for make-to-stock, which is less than .02% of the POD catalog.

[7] The graph assumes linear inventory depletion, although this would not be the case in reality

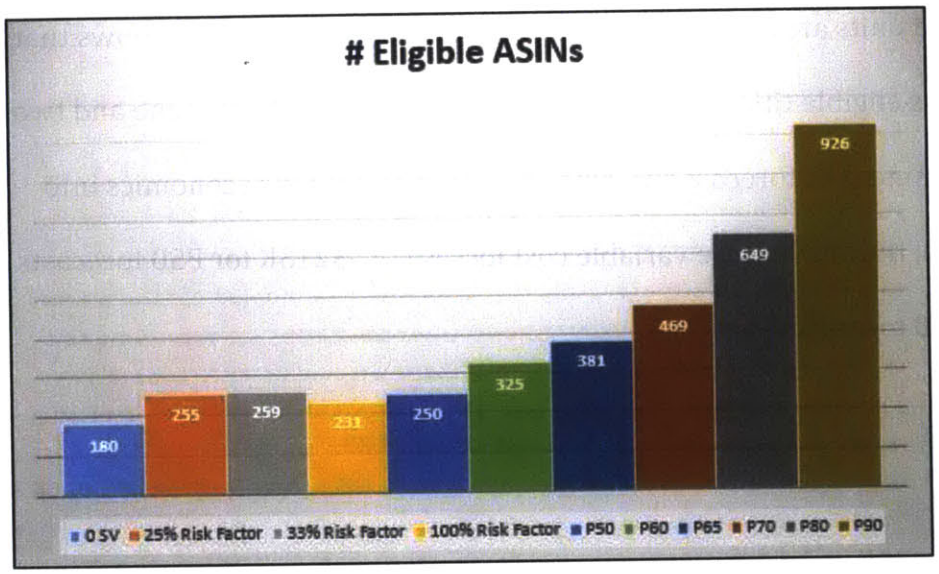

Figure 24. Eligible Titles for Pre-building

The economic data below shows the sell through rates and variable and transportation cost savings from the hybrid model with different forecast risk factors. With a 25% risk factor, the model achieved a 91.8% sell-through after two quarters for a total savings of $73.9K. As units continue to sell past the 2nd quarter, each unit will realize marginal variable and transportation cost savings until the inventory fully depletes. The range in cost benefits after two quarters was between $47K and $82K with sell through between ~91%-94%.

Model	Order	Excess (1Q)	Sell through	Excess (2Q)	Sell through	VC (1Q)	VC (2Q)	TC (1Q)	TC (2Q)	Holding	Total (1Q)	Total (2Q)
100% (No SV)	127088	17977	85.85%	8128	93.60%	$ 5,448	$ 4,128	$35,134	$ 3,171	$ 355	$ 40,227	$ 47,526
33% Risk Factor	199353	32944	83.47%	14497	92.73%	$ 5,446	$ 5,055	$53,584	$ 5,940	$ 848	$ 58,182	$ 69,178
25% Risk Factor	213128	39439	81.50%	17484	91.80%	$ 6,322	$ 5,248	$55,928	$ 7,070	$ 698	$ 61,551	$ 73,869
0% (Full SV)	236024	55785	76.36%	20636	91.26%	$ 8,783	$ 5,928	$58,037	$ 11,318	$1,231	$ 65,588	$ 82,834

Figure 25. Model Economic Data Table

Changing the internal transportation cost from the number provided from the five year plan to the actual cost from December, with 25% FRF showed the ordering quantity increase to 409K, with sell-through at 90.22% after two quarters. The total savings in this

instance was ~$285K, all from transportation, while variable cost was slightly negative. This sensitivity analysis shows how using real transportation cost inputs can affect the model, and is a mechanism to drive up the pre-build quantity along with assuming full salvage value and removing holding costs.

6.6 Discussion of Results

The use of the hybrid model to conduct high volume external pre-builds is tremendously promising. Not only does this model improve customer experience but it also leads to a projected five year NPV of savings between $600K and $3.9M (using conservative growth estimates). Additionally, one further implication of the variable cost savings is that there will be a break-even point for each title, where even throwing away deadwood of a particular title would still have achieved cost savings. Figure 26 below provides a sample for how the NPV of savings was calculated, and is based on cost savings over 20 periods (or five years), which are represented in the eight columns shown. Additional factors taken into consideration for the model includes estimates for the growth rates of the pre-build opportunities over time and conservative and aggressive pre-build cost savings.

		Total	0	1	2	16	17	18	19	20
62,500	5%	593,639	$ 62,500.00	$ 62,040.44	$ 60,376.73	$ 5,159.14	$ 3,790.52	$ 2,644.61	$ 1,838.03	$ 1,252.40
62,500	10%	694,733	$ 62,500.00	$ 62,806.37	$ 61,876.71	$ 6,278.25	$ 4,595.78	$ 3,298.22	$ 2,320.60	$ 1,600.74
62,500	15%	680,091	$ 62,500.00	$ 63,572.90	$ 63,995.10	$ 7,621.95	$ 5,647.44	$ 4,102.99	$ 2,921.60	$ 2,099.89
62,500	20%	730,044	$ 62,500.00	$ 64,338.24	$ 64,931.90	$ 9,231.78	$ 6,922.64	$ 5,089.30	$ 3,668.12	$ 2,591.97
62,500	25%	785,355	$ 62,500.00	$ 65,104.17	$ 66,487.10	$ 11,156.29	$ 8,465.37	$ 6,297.55	$ 4,593.01	$ 3,284.15
62,500	30%	846,622	$ 62,500.00	$ 65,870.10	$ 68,060.70	$ 13,452.16	$ 10,327.56	$ 7,773.26	$ 5,735.99	$ 4,149.67

		Total	0	1	2	16	17	18	19	20
284,910	5%	2,706,138	$284,909.88	$282,814.95	$ 275,230.81	$ 23,518.23	$ 17,005.79	$ 12,055.60	$ 8,378.77	$ 5,709.16
284,910	10%	2,893,469	$284,909.88	$286,906.49	$ 282,068.58	$ 28,619.76	$ 20,950.14	$ 15,085.15	$ 10,578.60	$ 7,297.07
284,910	15%	3,099,960	$284,909.88	$289,798.04	$ 288,990.26	$ 34,745.12	$ 25,744.18	$ 18,700.97	$ 13,318.30	$ 9,298.94
284,910	20%	3,327,948	$284,909.88	$293,289.58	$ 295,995.83	$ 42,083.60	$ 31,557.26	$ 23,199.87	$ 16,721.36	$ 11,815.64
284,910	25%	3,580,085	$284,909.88	$296,781.12	$ 303,085.29	$ 50,856.58	$ 38,589.86	$ 28,707.74	$ 20,937.49	$ 14,970.98
284,910	30%	3,859,375	$284,909.88	$300,272.66	$ 310,258.66	$ 61,322.46	$ 47,078.77	$ 35,434.84	$ 26,147.83	$ 18,916.50

Figure 26. NPV for Savings

Another area of savings is when the high volume pre-builds are used to cover peak demand. By doing so, and when implemented alongside predictive manufacturing (discussed in a later section) POD would have capital avoidance benefits and would have saved almost $700K. This is because POD had to pay approximately $1.70 per unit more to outsource the pre-builds at a higher cost than the average cost per unit using the hybrid model (based on data from the Q4 2014 pre-build).

Peak 2014 Volume	Savings per unit	Total Savings
402,400	$ 1.70	$ 684,080

Figure 27. Capital Avoidance during Peak Demand - 2014

Figure 28 below shows a sample for how the inventory from the high volume pre-builds can deplete over the 13 week time period, or longer. There is little concern in having the inventory completely deplete before placing a re-order since POD has internal capacity in the network to cover the gap. Ultimately, a depleting inventory position is not a primary concern, as the model will recommend re-ordering when the demand forecasts and current inventory level justifies one. Quantity discounts in the pricing structure also incentivizes larger orders over numerous smaller orders.

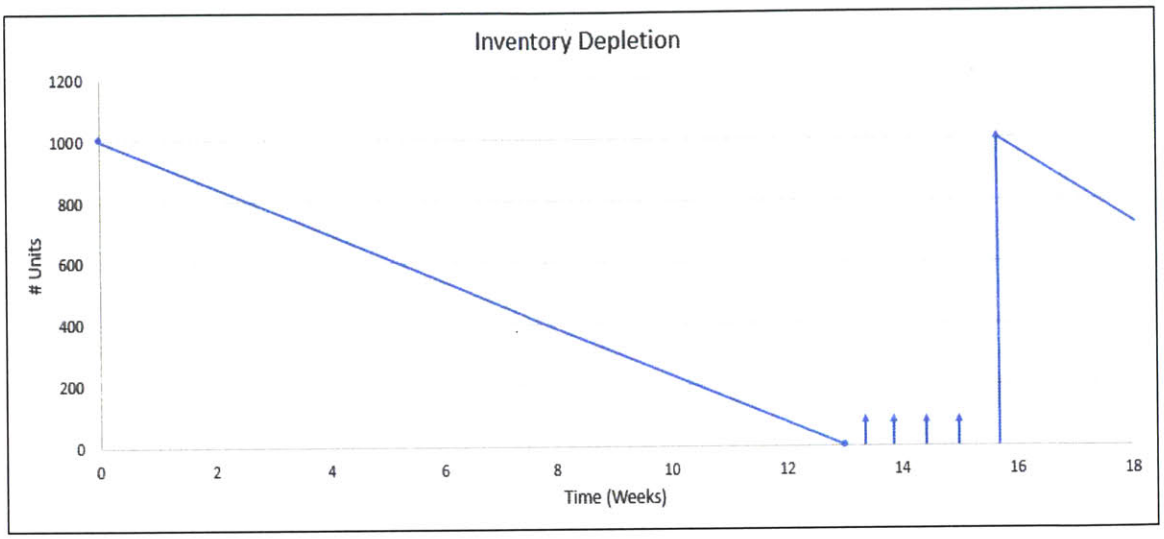

Figure 28. Sample Inventory Depletion over Time

One last important area to investigate was the source of the excess inventory when running the model for Q1 2015. The discovery was that two books contributed the vast majority to the excess inventory as the actual orders during the quarter were in the 3.84 and 0.01 percentiles of their respective forecast distributions. In other words, highly improbable events occurred. These results are shown in Figure 28 below.

Title	ASIN	P50	P60	P65	P70	P80	P90	Actual Sales	Forecast Percentile
Diet Book A		16838	18593	19554	20601	23126	26949	7596	3.84%
Diet Book B		5783	6386	6717	7077	7945	9260	882	0.01%

Figure 29. Error Investigation

This result confirms how difficult it can be to forecast these POD books, where even books with high sales volumes can experience precipitous declines. Analyzing and gathering further data during a pilot program can help determine how to further refine the FRF model to mitigate this risk. Looking at the forecast birth date and categorizing the books (i.e. in this case they both were fad diet books) might be a good first place to start.

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7. Predictive Manufacturing Strategy

7.1 Model Formulation & Inputs

Predictive manufacturing is a complementary plan to the high volume pre-builds that uses internal capacity at the four POD sites to pre-build books that have the highest probability of sale over a short time horizon. This plan is meant to fill the gap between the true long tail books and those eligible to pre-build, improving customer experience through shorter lead times and increased fast track capability. The predictive manufacturing model should run after the hybrid model on a weekly basis to determine the predictive queue for the week. The theoretical basis for predictive manufacturing is to first create the queue by analyzing the differences in the P02 forecast (98% probability of sale) over two weeks and the current inventory position (to include items on order from the pre-build model, shown as I(t) in the model below) and to prioritize based on this gap, while pushing those ASINs with depleted inventory to the top of the list. The second iteration of this model analyzes the difference between the P05 forecast, the items already in the queue from the P02 forecast (shown as Q(t) in the model below), and the current inventory position to determine additional manufacturing quantities when capacity is available.

First Iteration: $$P_{02} - I(t) \geq 1 \qquad (12)$$

Second Iteration: $$P_{05} - I(t) - Q(t) \geq 1 \qquad (13)$$

Further analysis can be done to determine if there is an asymptotically optimal predictive manufacturing quantity. For example, it might be optimal to manufacture only one unit on the east coast and one on the west coast, and then to replenish these units once

they are sold and shipped to customers. However, if there are cost savings by being able to optimally place the inventory and reduce the cost gap between the internal shipping cost and the optimal shipping cost then units that are predictively manufactured will have a lower total fulfilled cost per unit than those that are made to order. In this scenario, manufacturing all of the units in the queue would be optimal (unless inventory tolerance becomes a factor due to capacity constraints).[8]

Figure 30 below shows a sample dashboard to illustrate the type of information that should be monitored, as it would be important to understand the remaining levels of inventory that are on hand.

ASIN	Forecast T+13	Inventory Position	Inventory On Hand	Inventory on Order	Order Quantity

Figure 30. Sample Monitoring Dashboard

Figure 31 shows a sample scenario that illustrates how to determine the predictive manufacturing queue based on the P02 and P05 forecasts of a list of seven hypothetical titles (A-G).

[8] The transportation cost gap between the make-to-stock and make-to-order costs was $.32/unit.

ASIN	Inventory Position	P02 Forecast (T+2)	Build Quantity	P05 Forecast (T+2)	Build Quantity
A	30	25	0	38	8
B	20	25	5	31	6
C	15	18	3	22	4
D	15	30	15	35	5
E	10	10	0	13	3
F	5	3	0	6	1
G	0	10	10	15	5

ASIN	Queue	
G	10	From P02 Forecast
D	15	
B	5	
C	3	
A	8	From P05 Forecast
B	6	
D	5	
G	5	
C	4	
E	3	
F	1	

Figure 31. Predictive Manufacturing Sample

Demand forecasts from May 2015 were used to gauge the size of the predictive manufacturing opportunity with a forecast timeframe of two weeks and four weeks. While this analysis likely includes units that would be in inventory from high volume pre-builds, it provides insight into the predictive manufacturing volume. With a 98% probability of sale over two weeks, 8,158 titles were forecast to sell at least one unit and the total volume was ~115K. Over a four week timeframe, 12,190 titles were forecast to sell at least one unit and the total volume was ~240K. In the event that POD wants to build up to the P06 level, this would lead to volume of ~152K and ~309K respectively for the two and four week timeframes. Interestingly, after two weeks, the P02 plan would have achieved 91.21% sell-through, with 98% of the ASINs selling at least one unit. Based on this analysis, it seems very likely that POD would have the capability of covering peak demand through high volume pre-builds and predictive manufacturing.

Start Date	Time Period	P02	ASINs >=1	P04 (+)	Total	P06 (+)	Total
31-May-15	2 weeks	114,095	8,158	21,728	135,823	15,958	151,781
31-May-15	4 weeks	239,005	12,190	40,459	279,464	29,146	308,610

Figure 32. Predictive Manufacturing Opportunity

7.2 Discussion of Results

Ultimately, these results show that predictive manufacturing is a clear win for a variety of reasons. However, in order to determine exactly how to implement this initiative, there needs to be a pilot program that can help determine the optimal predictive manufacturing service level (i.e. building up to the P02 vs P04 vs P06 service level). Additionally, regarding prioritization, it might be optimal to favor retail orders to wholesale orders, which have a longer SLA of five days. In the future, economic factors such as customer in-stock value (CIV) or other criteria such as glance views, Fast Track, or Prime Now eligibility could be used as inputs for prioritization. An example of CIV relevancy is that students might only choose to buy a textbook if they could get it a day or two before classes start, meaning that this title should be prioritized over a title with a lower CIV in the relevant timeframe.

8. Implementation and Effect on Operations Strategy

The hybrid model and the predictive manufacturing plan should work in concert to achieve the most effective results. The hybrid model would run first to determine if demand forecasts and current inventory positions require new orders for high volume pre-builds. The predictive manufacturing model would run second to determine based on demand forecasts and current inventory positions which titles and how many should be manufactured and stowed using internal capacity at the four POD sites, based on having the highest probability of sale over a shorter time horizon. These two plans are ensuring efficient manufacturing and are separating those books that are eligible for pre-build from the true long tail books; accomplishing the goal of tailoring the supply chain based on the value proposition to the customers.

8.1 Process Implementation & Requirements

Figure 33 shows in more detail how POD operations could run with the new systems in place. The make-to-stock component is primarily through external high volume pre-builds, the predictive manufacturing component uses available internal capacity through a running queue of books to manufacture, and there is still the daily operations and the make-to-order component for retail and wholesale orders. Even wholesale orders of larger quantities will be fulfilled using make-to-order internal capacity since the customer base of self-publishing authors care more about quality, which is a focus for POD. Lastly, there will be some books that are brand new and will be initially fulfilled using make-to-order internal capacity. However, "runners" (books that explode in popularity) will be identified once there is enough data to get more accurate time series forecasts. The

hybrid model will be the basis for determining which books will switch to make-to-stock and what the order quantity will be. However, these book can easily switch back to make-to-order once the inventory depletes and if future demand forecasts do not justify a re-order.

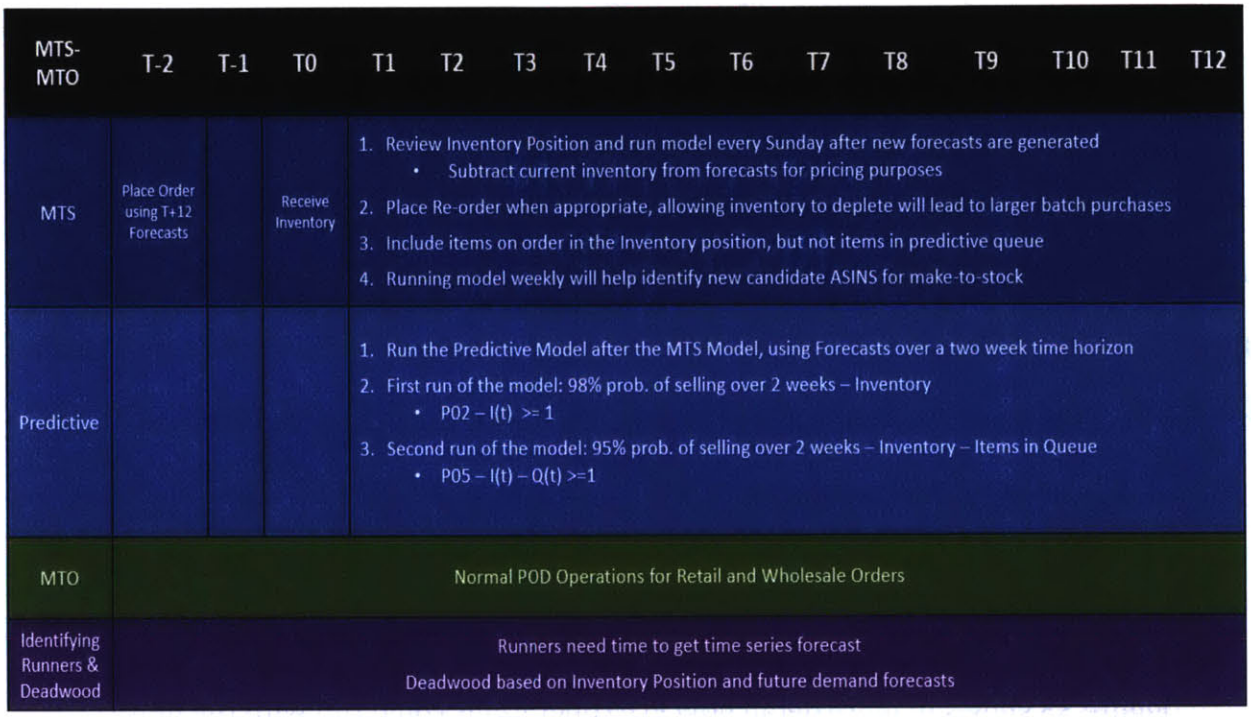

Figure 33. System Implementation

Launching a pilot in an upcoming quarter should be the first step towards implementation and can be used to help refine the model even more before wider scale implementation. POD will need developer support to build the model in ruby or another programming language and ensure that there are appropriate dashboards that track the qualifying ASINs, current inventory level, and other categories as depicted in the sample dashboards from section 7.1. As mentioned previously, the hybrid model should run every

Sunday, followed by the predictive model, which then determines the queue of items to build on a weekly basis.

Due to the nature of the hybrid model, many of the traditional inventory performance metrics are less relevant, such as the cost per stock out event and item fill rate. For the purposes of the pilot, metrics such as the sell through rate of the inventory, inventory turns, excess inventory at the end of the period, and deadwood conversion percentage are more relevant. This data should be collected and analyzed for model improvements.

8.2 Management Considerations

Typically, decisions in a business setting are made based on NPV calculations and other metrics. However, Amazon makes many investments that may be harder to justify on an NPV basis, but are clear wins for the consumer. An interesting aspect of this project was understanding the balance between making decisions that may be neutral from an NPV perspective but lead to these customer experience improvements. One way to reconcile this difficulty in assessment is to continue to develop metrics and key performance indicators (KPIs) that are not currently tracked. Amazon puts a great deal of effort into these initiatives that aim to identify new KPIs, such as with the development of the customer in-stock value metric, which represents how valuable it is to customers when an item is in stock and whether there is an associated sales lift. Additionally, there may be sales lifts from the availability of other expedited shipping options, such as fast track or prime eligibility. This lead to the realization that managers do not have to be constrained by the data or analysis that is current available to them. They have the ability to develop

new KPIs when making investments in new technology or process improvements that may help justify further investments or the expansion of programs in the future.

Another important consideration as Amazon continues to expand POD is the fact that this expansion may continue to cause frustration and tension from the major publishers. While Amazon may be helping the publishers by enabling long tail books to be POD capable and no longer require inventory, the truth of the matter is that they realize that Amazon is becoming an increasingly powerful competitor in this market. Amazon's massive fulfillment network and infrastructure directly feeds into their virtuous cycle, shown in Figure 34, which allows them to provide a lower cost structure and lower prices, resulting in higher royalty rates for authors. Other major publishers are unable to compete, and have already shown their frustration from low prices for e-books when Jeff Bezos announced that new releases and best-sellers would be priced at $9.99. Publishers believed that Amazon would eventually go even lower, putting intolerable price pressure on print books and the places that sold them [7]. Ultimately, Amazon needs to find a way to reconcile this tension with the major publishers in a mutually beneficial arrangement in order to be able to continue to do business with them in the future.

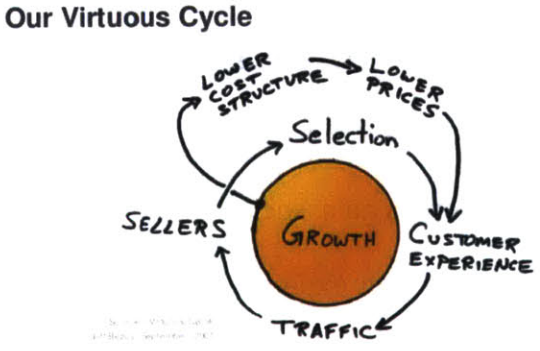

Figure 34. Amazon's Virtuous Cycle [15]

9. Conclusion & Recommendations

9.1 Conclusion for Production Optimization for Print on Demand

The *high volume pre-builds* using the hybrid model and *predictive manufacturing* initiatives have economic and customer experience benefits that directly tie into the business's value proposition. A summary of the benefits can be found in Figure 34 below. To further expand customer selection and availability, the hybrid model can be used to negotiate with authors and publishers who have titles that sell in any quantity. By making titles POD capable, Amazon will be taking the inventory risk from the publisher and can use the variable cost savings from the pre-builds to offer a higher share of the royalties, thus driving customer experience and growth.

VC & Trans Savings	Reduce SLA	Increase FT/CIV	Reduce FT Miss	Reduce Missed Multi	Increase Multis	Reduce "Inventory Defects"	CIV (1 day, 2 day, PrimeNow)	Capital Avoidance	VC Savings from Peak 2014	Reduce Outsourcing
$600K $3.9M	5-9 hour reduction for retail	Lift from FT in-stock glance views	Inventory reduces FT misses	Multi Million in savings	Inventory in more FCs increases opportunities	Unplanned inventory due to modified or cancelled orders	Sales lift from offering 1 day, 2 day, or Prime Now for qualifying ASINs	Savings from not having to open a new facility	~$700K savings for Q414	Less outsourcing as a safety valve

Figure 35. Production Optimization Benefits

Lastly, the capability for high volume pre-builds and predictive manufacturing will allow POD to pursue future initiatives that continue to expand the catalog and improve customer experience while maintaining a supply chain that is tailored to what the customer values most from the retail and wholesale channels. This strategy demonstrates a true

commitment to the customer's needs and provides a flexible production model to grow the business.

9.1 Recommendations for Future Initiatives

An important question to answer in the future is how big the POD network should be. While the business currently has four sites that does manufacturing, with three of those sites embedded within fulfillment centers, there is an argument that further expansion in the current format may not be in Amazon's best interest. The topology benefits resulting in reduced transportation costs have largely been achieved from the four sites and the question going forward may be whether or not they should continue with the embedded manufacturing site model or should instead open one large manufacturing facility. These expansion plans require significant investment and it may be worthwhile to explore in the future the possibility of working with capacity planning teams to send more volume externally to reduce the investment in new manufacturing facilities and to drive customer experience improvements. After a certain point, the increased external volume may even be negative from an NPV standpoint, but still in the best interest of the business. Further work can be done to quantify the utility of various customer experience improvements. Lastly, the hybrid model itself is particularly interesting for other "on demand" industries that do make-to-order manufacturing and could be extended to 3D printing initiatives or other similar ones.

When looking to implement a new initiative or feature or product, one reason that Amazon has been so successful is because they are willing to take risks and make mistakes along the way, knowing that "with a bit of good fortune – there will also be a few

[investments] that open up into broad avenues" [16]. This customer-driven focus and innovative mindset will continue to lead the company to new and exciting breakthroughs that both surprise and delight customers.

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