

ABSTRACT

MICK, CARLY ELIZABETH. The Effects of Digital Printers and Cutters on the Value Stream of United States, Textile Based, Manufacturing. (Under the direction of Dr. West and Dr. Little).

In January 2013, Walmart announced it would buy an additional \$50 billion in U.S. products over the next 10 years in an effort to grow U.S. manufacturing and encourage the creation of U.S. jobs. The focus of this paper is to look at the current manufacturing process of a Walmart supplier who makes a textile-based, mass customizable product in the United States and the ways in which digital cutting and printing technology could influence this process. This research creates an improved understanding of how a supplier could utilize technology to benefit from Walmart's U.S. manufacturing initiative. The use of value stream mapping gives a clear and simple framework by which to consider the viability of converting to a domestic, technology-based manufacturing process. By comparing the value stream of the current production system with that of a hypothetical future state, this research found that employing a digital printing and cutting operation would have a significant effect on the inventory requirements of this manufacturer. The print-on-demand capability of the digital printer would allow for a huge virtual inventory of designs without the need for increased fabric storage and create a more flexible production system. Waste associated with transportation would also decrease significantly; and an opportunity for brand expansion into 'Made in America' markets would be created. Given the size of inventory and associated opportunity costs, the manufacturer observed in this study is a good candidate for the investment.

© Copyright 2015 Carly Elizabeth Mick

All Rights Reserved

The Effects of Digital Printers and Cutters on the Value Stream of United States, Textile
Based, Manufacturing

by
Carly Elizabeth Mick

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Textiles

Raleigh, North Carolina

2015

APPROVED BY:

Dr. Andre West
Co-chair of Advisory Committee

Dr. Trevor Little
Co-chair of Advisory Committee

Dr. Blanton Godfrey

BIOGRAPHY

Carly Mick has a lifelong fascination with fibers, fabrics and soft goods. Her interest in the subject ranges from historic artisanal processes to contemporary automated production technology, and from fiber composition to final product. Her career has followed her interest into areas such as product design, manufacturing management, and designer education. Carly has an undergraduate degree in mathematics from Portland State University and a Masters in Textiles from North Carolina State University. She enjoys exploring the intersection of scientific precision and the more intuitive aspects of fabric.

ACKNOWLEDGMENTS

I would like to acknowledge the following:

- The Walmart U.S. Manufacturing Innovation Fund for funding this project.
- The Integration of Digital Printing with Cut and Sew grant for funding my research.
- The members of my committee for their invaluable assistance.
- The NCSU/Walmart Innovation team for their research and dedication.
- The companies who provided me information and access to their facilities.
- My friends and family for providing support and feedback throughout this process.

TABLE OF CONTENTS

LIST OF TABLES	vi
LIST OF FIGURES	vii
LIST OF ABBREVIATIONS.....	ix
Chapter 1 : Introduction	1
Chapter 2 : Review of Related Literature	3
Argument for Reshoring	5
Ethical issues	5
Communication issues	5
Corruption.....	6
Political and Emotional.....	7
Wage changes	7
Currency fluctuation	8
Tariff and trade avoidance.....	9
Reduces shipping and material handling	10
Arguments Against Reshoring.....	10
Low cost labor	10
Infrastructure.....	11
Rising Chinese market.....	11
Viability and Opportunities of Reshoring.....	11
The Overlap.....	14
Mass Customization.....	15
Lean Manufacturing.....	20

Chapter 3 : Design and Methodology.....	28
Chapter 4 : Results.....	38
Strategy 1: Mass Production.....	38
Strategy 2: Mass Customization	51
Future State Map	54
Information on digital printers.....	59
About CNC cutters	65
Laser cutters.....	66
Knife cutters.....	67
Integrating printers and cutters	67
Chapter 5 : Discussion.....	73
Opportunities for Future Research	86
REFERENCES.....	86
APPENDICES.....	103
Appendix A- <i>Company C Observation Data</i>	104
Appendix B- <i>Cushion Manufacturer’s Most Common Cushions</i>	105
Appendix C- <i>Printer Data</i>	107
Appendix D- <i>Cutting Data</i>	108

LIST OF TABLES

Table 1: Data Sources for the Current VSMS.	36
Table 2: Data Sources for the Future State VSM	41
Table 3: Customer Shipping Options.....	41
Table 4: Manufacturer’s Data on Pieces Shipped One Week, Early in the Production Season	57
Table 5: Future State Inventory Rates	58
Table 6: Total for S1 VSM Timeline.....	78
Table 7: Total for S2 VSM Timeline.....	78
Table 8: Totals for Future State VSM Timeline	79

LIST OF FIGURES

Figure 1: U.S. Manufacturing Employment From 1960-2015 (U.S. Department of Labor, Bureau of Labor Statistics, 2015)	4
Figure 2: Growth in Manufacturing Wages, US vs. China from 2002- 2009 Data Supplied by The Bureau of Labor Statistics, (2013).....	8
Figure 3: Overlapping Management Concepts and Goals	14
Figure 4: Continuum of Strategies (Lampel & Mintzberg, 1996)	17
Figure 5: The Customization Axes (Boër, 2013).....	18
Figure 6: Lean Manufacturing House Diagram (Dennis, 2007).....	23
Figure 7: Tertiary-Education by Country, (National Science Foundation, 2010)	26
Figure 8: Symbols of Value Stream Mapping (Rother, 1999).....	31
Figure 9: Example of VSM Data Box.....	35
Figure 10: Strategy 1, VSM for Cushion Manufacturer	40
Figure 11: MTO Inventory Flow Chart	43
Figure 12: Eastman Fabric Saw (eastmancuts.com, 2015).....	46
Figure 13: Finished Goods Inventory Flow Chart	50
Figure 14: Strategy 2, VSM for cushion manufacturer.....	52
Figure 15: Eastman Chickadee Fabric Cutting Tool, (eastmancuts.com, 2015)	53
Figure 16: Future state, VSM for cushion manufacturer	53
Figure 17: Textile Printing Speeds Compared, (See Appendix C).....	62
Figure 18: Understanding DPI, (Hewlett Packard, 2010).....	63
Figure 19: Common Registration Marks, (Wikipedia, 2014).....	68

Figure 20: Showing Vinyl Decals Before Cutting and After Application for Esko's I-cut
Vision System (Esko, 2015). 69

Figure 21: Aeronaut's Vision System Applying Distortion to the Cut Path Based on the
Repeat of the Print, (Aeronaut, 2014)..... 70

Figure 22: Summa DC4 Print/Cut System (Summa, 2015)..... 71

LIST OF ABBREVIATIONS

ATC	Agreement on Textile and Clothing
Company A	A United States textile mill supplying prepared to print bases cloth.
Company B	A United States textile mill supplying prepared to print bases cloth.
Company B	A United States company supplying digitally printed textiles.
MFA	Multi-fiber Agreement
MTO	Made to Order: the name given to the mass customization department of the manufacturer observed for this paper.
S1	Strategy 1: A manufacturing strategy utilized by the made to order department based on mass production.
S2	Strategy 2: A manufacturing strategy utilized by the made to order department based on mass customization.
TPP	Trans-Pacific Partnership
TPS	Toyota Production System
VSM	Value stream map

Chapter 1: Introduction

Currently the global majority of textile-based manufacturing resides outside of the US. This is due, in part, to the relatively low cost of labor in many developing nations. Textile based manufacturing is a significant manufacturing sector in the United States with more than 230,000 workers, representing 2 percent of the U.S. manufacturing workforce (U.S. Department of Commerce, Select USA, 2014). Since 2009 there has been an increase in manufacturing in the US (U.S. Department of Labor, Bureau of Labor Statistics, 2015) and some companies believe that US manufacturing may be a viable option for their textile-based production (Ellis, 2014). For U.S. production to be competitive with overseas production, manufacturers must create efficiencies that offset the discrepancy in labor prices. The management theories of lean manufacturing and mass customization provide insight to the potential efficiencies of returning manufacturing to the US, also known as reshoring. Lean manufacturing is a management theory that creates efficiency by reducing waste and striving for continuous improvement. Mass customization is a management theory that creates efficiencies by producing a product that exactly suits the customer's needs. Allowing a discreet level of individualization for each product makes mass customization a system whereby manufacturers provide only the product desired by the consumer, eliminating excess or obsolete inventory. These management theories, which have worked in many industries, both rely heavily on technology and reducing supply chain complexity. A broad spectrum of technologies can be useful in implementing both lean manufacturing and mass customization, including information management software, material tracking technology, and automation. Promising forms of automation in the cut and sew industry are digital printing and digital

cutting. This paper will explore how digital printing and cutting could facilitate reshoring for the domestic, 'Made to Order' (MTO) department of a large cushion manufacturer. The MTO department, of this manufacturer makes cushions to satisfy internet-based customer orders. Using value stream mapping, one of the primary tools of lean manufacturing, this paper will explore the current manufacturing practices of the company as well as the changes that would occur were these technologies to be adopted. It will then consider how the automation of digital printing and cutting can be integrated into the company's current systems, and what efficiencies can be utilized while implementing technology, reshoring, mass customization, and lean manufacturing.

Chapter 2: Review of Related Literature

Reshoring

The term reshoring refers specifically to manufacturing conducted outside of the United States relocating to the United States (Moser & Manivannan, 2010). The term was popularized in 2010 through Henry Moser's 'Reshoring Initiative' website and the 'Total Cost Calculator' found there (Reshoring Initiative, 2015). The term replaced an earlier term inshoring, defined as "the relocation of business processes from higher-cost to lower-cost countries, taking the view of the destination country" (Erber & Sayed-Ahmed, 2005). Thus if an American business manufactures in China, it has offshored its manufacturing to China and China has inshored that business' manufacturing.

The manufacturing sector in the US has declined since its peak at the end of the 1970s (see figure 1). This decline in US manufacturing employment is due in part to the outsourcing of manufacturing to other nations. Developed nations have considerably more capital than developing countries, which commonly have more, and thus less expensive, labor (Zhang & Hathcote, 2008). The discrepancy between the abundance of capital and the abundance of labor was a major factor in the US relocating some manufacturing to countries with lower labor cost, especially for those high labor industries such as textiles and apparel production (Free, 2012). As shown in

Figure 1, (U.S. Department of Labor, Bureau of Labor Statistics, 2015) this trend is reversing slightly, and the US is seeing a small increase in manufacturing employment being located or re-located domestically. The change was noticeable even in 2009 when many companies were beginning to have doubts about the profitability of international sourcing (Grant

Thornton LLP, 2010). Many factors influence the selection of a manufacturing site, and companies must consider not just the price of labor but shipping, tariffs, stability, social/environmental factors, and much more. The argument for reshoring a manufacturing facility, company or whole industry will inevitably follow the economic viability of that choice (Au, Wong, & Zeng, 2006).



Figure 1: U.S. Manufacturing Employment From 1960-2015 (U.S. Department of Labor, Bureau of Labor Statistics, 2015)

Argument for Reshoring

Ethical issues

On 24 April 2013, Rana Plaza, a factory facility in the Savar district of Bangladesh, collapsed in what the New York Times called the world's most deadly garment industry disaster (Yardley, 2013). This incident came on the heels of a series of articles highlighting the difficult working conditions and suicides at Foxconn, one of the world's largest manufacturers of consumer electronics (Barboza, 2010). These high profile human rights issues, the latest episodes in the ethically troubled history of American companies utilizing foreign labor, can generate potentially damaging publicity for any brand. Aside from the inherent moral and ethical considerations, these working conditions can create consumer outrage and ultimately damage profits. The clothing found at the Rana Plaza disaster bore the label of a variety of retailers who claimed that no manufacturing was authorized at that facility (Clean Clothes Campaign, 2015). This highlights the difficulties that may arise when manufacturing is based in a distant location with limited oversight. "Across the globe, consumers are now insisting that companies address these issues and make ethics and social responsibility mainstream." (Wankel, 2008).

Communication issues

Handfield (1994), researched which attributes make offshore supply chains viable and found that the top five managerial problems associated with supplying from a low cost country are:

- Differences in culture

- Communication problems
- Different time zones
- Sharing technology
- Obtaining technical support (Handfield, 1994).

Supplying materials and labor from low-cost countries often requires overcoming differences in language, business culture, and informational infrastructure. Aside from the obvious and relatively easy to surmount obstacles related to language, developing nations often have minimal or intermittent communication networks, interruptions in shipping, electricity, and internet access. Differences in business culture in a low cost country can also create obstacle that businesses often perceive as a lack of “trustworthiness” (Handfield, 1994; Ruamsook, Russell, & Thomchick, 2009). This can be difficult to predict and is easy to overlook during offshoring decisions. When working with suppliers in developed nations, timelines and order quantities are often straightforward to negotiate; however, suppliers and manufacturers may need more clarity and time for negotiation in developing nations

Corruption

In addition to general culture and communication-based differences, there are issues common to developing nations such as corruption and political instability that add to the price uncertainty of supply chains. The Corruption Perception Index (2014) has created a scale that rates nations from 1 to 100 with North Korea being an 8 and New Zealand being a 91. Most of South-East Asia, where the top global suppliers to the US are located, rank between twenty-one and thirty eight. This contrasts sharply with Canada, US, and Western

Europe whose rankings are in the range of 60-89 (Transparency International, 2014). Kato & Sato (2014) found that “corruption greatly reduces gross value added per worker and total factor productivity” (Kato & Sato, 2014).

Political and Emotional

There is also a political and emotional component to reshoring. The loss of manufacturing jobs in the United States has changed the composition of the working and middle classes, creating a sense of loss for many people (Autor, 2010). There is debate about the benefits and losses associated with the outsourcing of manufacturing jobs, but there is no doubt that there are many US citizens who feel that reshoring is a step towards regaining a lost era. American political discussions reflect this emotional response to the decline in American manufacturing. In President Obama’s State of the Union Address (2012) he said “we have a huge opportunity, at this moment, to bring manufacturing back. But we have to seize it. Tonight, my message to business leaders is simple: Ask yourselves what you can do to bring jobs back to your country, and your country will do everything we can to help you succeed.” (Obama, 2012). This demonstrates that reshoring is an issue with enough political and emotional support that tariffs, consumer purchasing, and other voter-initiated actions may play a role in increasing the viability of reshoring in the future.

Wage changes

China, the largest exporter of textiles to the US (International Trade Administration, Office of Textile and Apparel (OTEXA), 2014), has experienced a huge increase in manufacturing wages in the last twenty years. This wage growth contrasts sharply with the

relatively stagnant manufacturing wages experienced in the US: see Figure 2. These trends are commonly cited in articles about the business climate and reshoring (Conerly, 2014).

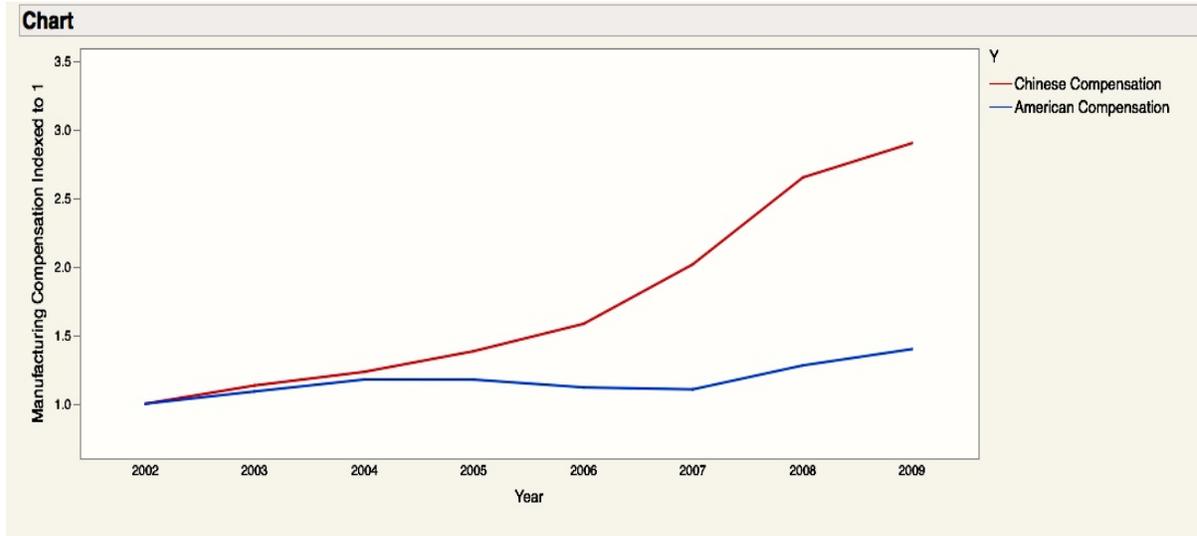


Figure 2: Growth in Manufacturing Wages, US vs. China from 2002- 2009 Data Supplied by The Bureau of Labor Statistics, (2013).

Currency fluctuation

Manufacturing using labor and facilities in other nations increases the risks associated with currency fluctuation. Even in a situation where wages or material prices have not changed, a manufacturer may be paying more or less US dollars for the same commodity or service. Depending on the financial management structure this could also cause uncertainty in supply chain purchasing (Dhanani, 2004). Maintaining a single currency between customer, manufacturers, and supplier minimizes this risk.

Tariff and trade avoidance

The cost of manufacturing overseas must include the cost of importation, which is influenced by tariffs and trade negotiations. These political goals and alliances are continuously shifting and play a role in determining the viability of reshoring (Ellis, 2014). The tariffs and duties associated with importing globally manufactured goods have waxed and waned with protectionist and nationalist trade regulations (Shelton & Wachter, 2005). This continually shifting regulatory environment can add uncertainty to supply chain management. From 1974-1995 the importation of textiles and textile-based product was regulated under the Multifiber Arrangement (MFA) that enforced a set of quotas on the quantity of product that could be imported every year based on the country of origin. In 1995 the Agreement on Textiles and Clothing (ATC) took effect, which allowed for a 10-year transition period to give industry time to adjust to a new regulation that didn't differentiate based on country of origin. Currently the industry is now subject to the General Agreement on Tariff and Trade (WTO, 2015). Although these rules may once again be subject to reform, as the US is in negotiations with eleven other nations to form the Trans-Pacific Partnership (TPP). This partnership aims to open opportunities for the export of American made goods to partnering nations, increase environmental and humanitarian oversight, and reduce corruption. It may also reduce tariffs on imported goods from partner nations (Office of the United States Trade Representative, 2014). Whether or not any of these regulations benefit reshoring initiatives, it is clear that the regulatory environment is often shifting, difficult to predict, and will affect the importing and exporting of goods (Ellis, 2014).

Reduces shipping and material handling

As the price of shipping is directly tied to how far a product must be transported from manufacturer to customer higher shipping price are associated with shipping longer distance. High prices are also associated with those products that are 'high cube', take up a lot of room but have relatively low value (Conerly, 2014). Products such as seat cushions are a perfect example of this. As a cut and sew product they require relatively high labor inputs, but the elevated shipping cost resulting from their bulk offset much of the savings associated with low cost labor production. By manufacturing close to both suppliers and customers substantial saving can be gained by eliminating excess shipping.

Arguments against Reshoring

Low cost labor

Manufacturing facilities off-shored for many reasons that are still in effect today. The developing world can still provide substantially cheaper labor than most developed nations, and with fuel prices dropping, the cost of shipping goods has gone down as well. The average Chinese manufacturing employee's wages in 2009 averaged 1.13 US dollars/hour, whereas the US manufacturing compensation averaged 13.95 US dollars/hour, a little over 20 times as much (Bureau of Labor Statistics, 2014). This discrepancy represents a significant difference in final product cost, especially in a labor-intensive industry such as textile-based manufacturing.

Infrastructure

The investment in manufacturing in South East Asia has led to robust manufacturing infrastructure in that part of the globe. This infrastructure includes the manufacturing of machinery and equipment used in factories, as well as access to raw materials, suppliers, and skilled labor (Curtis, 2014; Conerly, 2014). In some cases, a manufacturing facility was off-shored from the US to another country along with much of the technology and equipment. Although much of this original equipment may be outdated by now, investments in upgrades and additional technology have taken place overseas, creating knowledge and resources in these countries that are not necessarily mirrored domestically (Curtis, 2014).

Rising Chinese market

Proponents of off-shoring point to China and India moving into the developed world and experiencing a rise in consumer demand within their own borders. Relocating a factory that is already in close proximity to its suppliers and customers may not be desirable. American companies with factories in those regions may now have an opportunity to sell to a local market, thus reducing the incentive to reshore. (Conerly, 2014).

Viability and Opportunities of Reshoring

Many of the pressures that encouraged off-shoring in the first place are still in effect. The labor prices of the developing world are still much less expensive (Bureau of Labor Statistics, 2013) and China has a robust manufacturing infrastructure (Curtis, 2014). Recently there been changes in labor prices for the Chinese manufacturing sector as well as

changes in fuel prices, technology, and a new understanding about the costs associated with communicating/managing an overseas supply chain (Ellis, 2014). These changes have encouraged the renewed interest in the viability of reshoring.

Some companies, including those in the textile products industries, are taking the risk of creating new manufacturing facilities in the United States. Bill McRaith (2014), the Chief Supply Chain Officer of PVH Corp. was emphatic: “If anyone in this room still questions Made in the USA as a financially viable option, that's behind you,” he said at the annual American Apparel & Footwear Association's International Sourcing, Customs & Logistics Integration Conference. “It's done. We are doing it. It has happened. I think there are 400 investments going on right now in South Carolina and its way beyond electronics and automotive. It is absolutely in the apparel sector.” (Ellis, 2014).

The higher labor cost associated with manufacturing in the US may be offset in many cases by the shipping and distribution required to produce a product on the other side of the globe from its consumers. The products that are especially expensive to ship and those products that take little labor to produce are among the strongest candidates for effective reshoring (Saporito, 2013).

The introduction of internet-based sales has created the opportunity to develop supply chain based solutions for rapid manufacturing (Kehoe & Boughton, 2001). Short product lifecycles, frequent and rapid, new product introduction makes time-to-market considerations and fast customer response vital for value creation (El Sawy, Malhotra, Gosain, & Young, 1999). Consumers are demanding ever more variety at ever-faster speeds and the companies that can provide that fast paced variety may gain a competitive advantage. “Outsourced and

off-shore manufacturing have introduced several additional steps in the delivery process, including ocean freight and customs clearance. These additional steps introduce variability due to dependence on other companies and governmental agencies, many more hand-offs, additional regulations, and additional paperwork requirements” (Ganesan, 2015). Long shipping time and inventory make this rapid response difficult, resulting in loss of sales; for some manufacturers this complex supply chain may no longer be an option.

The Overlap

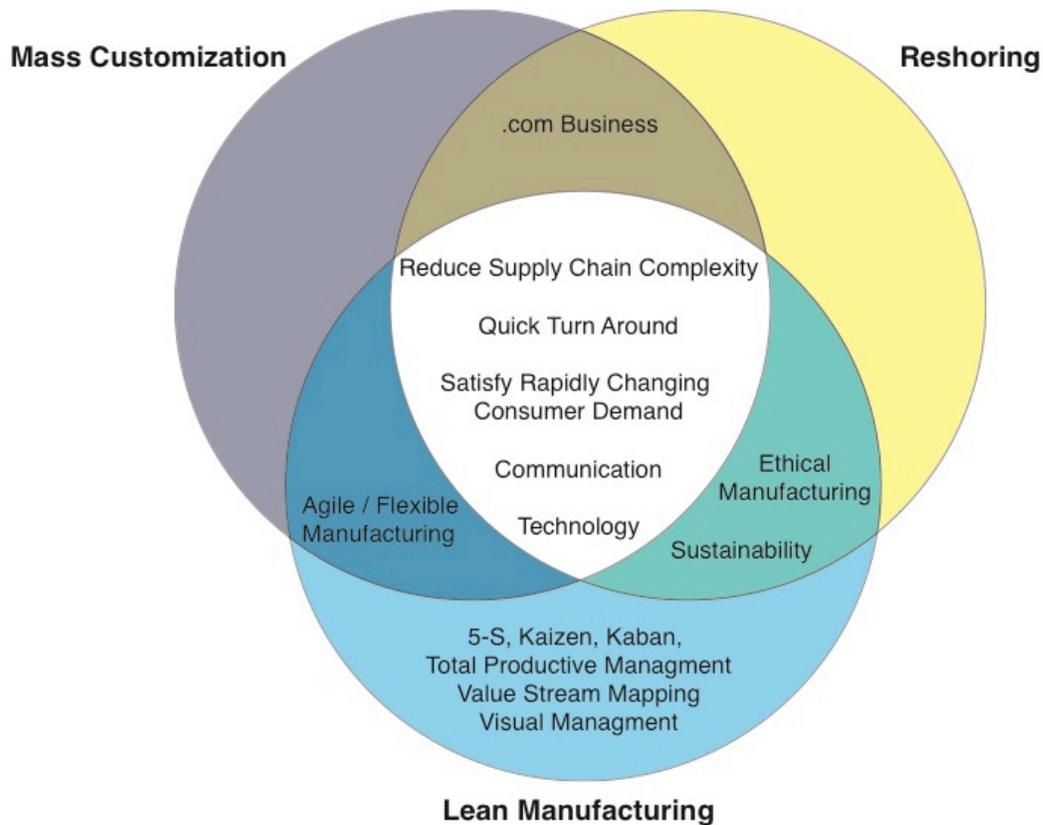


Figure 3: Overlapping Management Concepts and Goals

Reshoring shares many goals with lean manufacturing and mass customization. These manufacturing theories share an interest in reducing waste, reducing supply chain complexity, satisfying rapidly changing consumer demand, and minimizing the time from customer order to delivery. Across all of these philosophies manufacturers have attained these goals through a combination of technology, organizational restructuring, and reconsidering the role of human labor. Observing the processes and tools associated with

these philosophies can provide insight into manufacturing restructuring that could facilitate reshoring.

Mass Customization

Mass customization can be defined as “the capability to produce personalized goods, with near mass production costs and efficiency” (Bellemare, Carrier, & Baptiste, 2013; Boër, 2013; Fralix, 2001; Lim, Istook, & Cassill, 2009; Satam, Liu, & Hoon, 2011; Senanayake, 2004). The very core of mass customization is built around satisfying the customer. It requires a thorough understanding of what each individual customer wants, and requires the manufacturer to effectively deliver it (Boër, 2013). This necessitates the rapid sharing of information, which must be transmitted from the customer to the manufacturer as well as between departments within the manufacture (Boër, 2013).

Davis Stanley originally coined the term mass customization in his book *Future Perfect* (1996). He considered the term to be slightly “tongue in cheek” as it represents the conflicting ideas of mass production, whose focus is standardization, and customization, whose focus is individuality. Mass customization often requires a complete rethinking of the goals of a business. This rethinking is usually discussed in contrast to mass production and in response to changing consumer behavior.

Mass production gains competitive advantage through economies of scale. This means that the production cost per unit generally decreases as the number of units increase. Although effective, the mass production philosophy has a number of issues, including the changing demands of the consumer. In times past, the consumer was limited by the availability of goods; now consumers are responding to fixed or falling prices, ever

increasing variety of product, and rapid delivery times (Bellemare et al., 2013; Dennis, 2007; Fralix, 2001; Goforth, Hodge, & Joines, 2011; F. T. Piller, 2004). Prices can no longer be raised to reflect manufacturing cost; now, manufacturing costs must be lowered to reflect fixed or falling prices.

Mass customization is defined in reference to the spectrum between pure mass production, which aims to maximize productivity through standardization, and pure customization, which is typified by artisans making a specialty product for an individual customer. Mass customization occupies a middle ground on this spectrum, and aims to produce personalized goods at near mass production costs and efficiencies. However, personalized goods is a relative term, and can mean different things to different manufacturers. Figure 4 shows Lampel and Mintzberg's (1996) continuum of strategies. In this figure mass customization could mean any of the three central topics: segmented standardization, customized standardization, and tailored customization.

A Continuum of Strategies

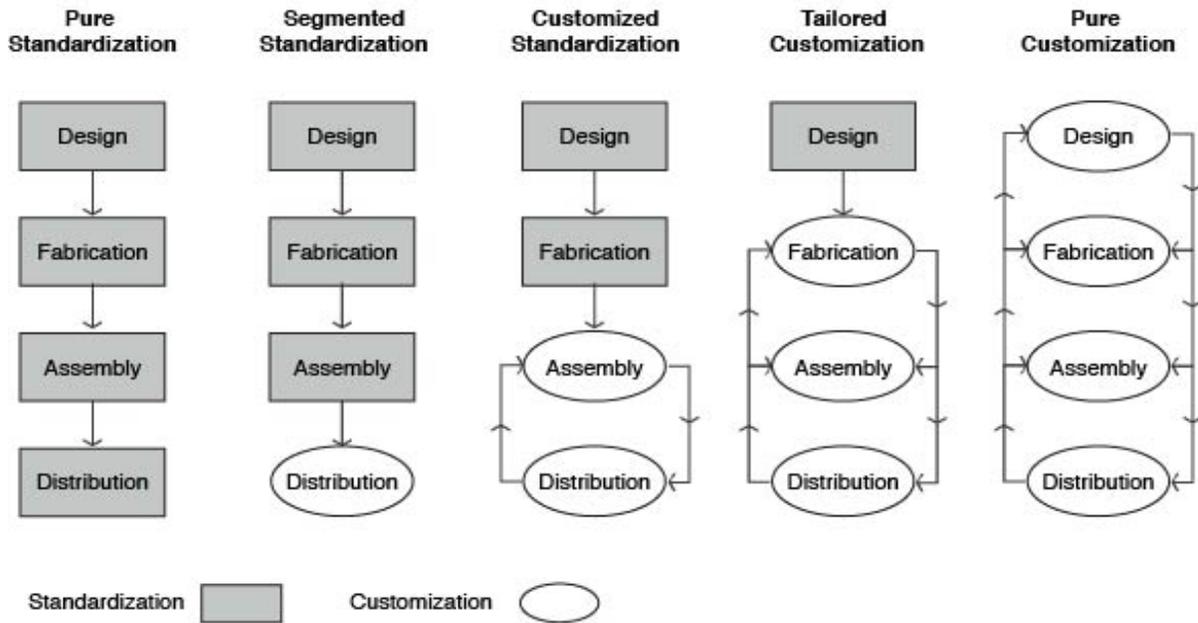


Figure 4: Continuum of Strategies (Lampel & Mintzberg, 1996)

How much customization is offered is dependent on the product and the manufacturer's capacity. As a manufacturer develops more flexibility, the variety of options available to the customer may increase. Regardless of the quantity of customization offered, the options will most likely be defined by three axes (Boër, 2013). In the case of cushions, these axes can be interpreted as; style/ aesthetics, which may include print design, edge treatment, and fabric choice; fit, which may include standard and custom cushion sizes; and functionality, which may include fill density and fabric choices with the addition of extra performance coatings.

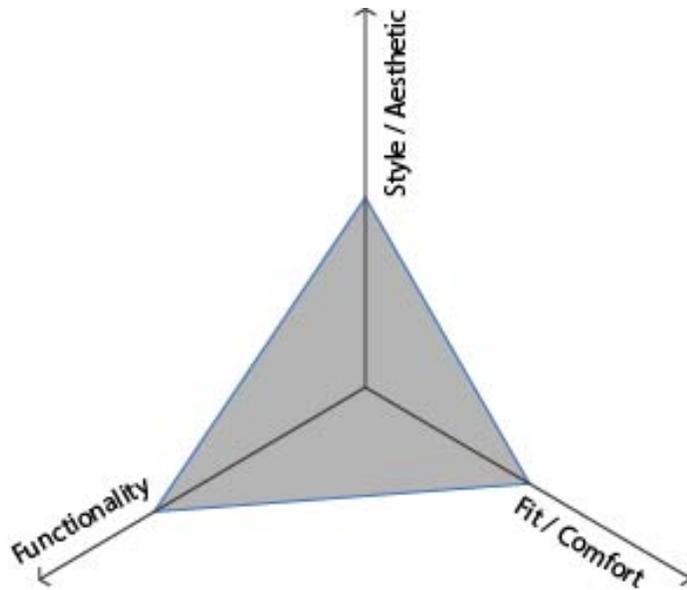


Figure 5: The Customization Axes (Boër, 2013)

There are benefits to offering as much customization as manufacturing can support because, as Pine (1993) wrote, “No one knows exactly what product the company will be creating next. No one knows what market-opportunity windows will open. But everyone does know that the next market opportunity is out there somewhere”. Thus the company that is already capable of providing the customer with his or her ideal product may very well already be selling ‘the next big thing’.

Mass customization has been shown to be effective for companies manufacturing a variety of products. Dell Computer’s has had notable success building computers to their customer’s specifications (Dell, 2015). BMW has also adopted a mass customization operation (BMW, 2015). Even dog food has a new mass customization offering in Purina’s ‘Personalized’ dog food (Purina, 2015). Mass customization has shown itself to be successful

for textile based manufacturing as well, with companies like Brooks Brothers, Nike, and Timbuk2, adopting it (Brooks Brothers, 2015; Nike, 2015; Timbuk2, 2015). With the support of well-known brands and academic literature, it's clear that many people believe mass customization to be a viable and forward-looking production model.

The viability of mass customization is dependent on the efficiencies that it creates. Piller, Moeslein, and Stotko (2004) classified these efficiencies were as 'economies of integration', which arise from three sources:

- Postponing some activities until an order is placed,
- Gaining more precise information about market demands and
- The ability to increase loyalty by directly interacting with each customer (F. T. Piller, Moeslein, & Stotko, 2004).

All of these Economies of Integration mesh with the efficiencies created by reshoring. Near mass production speed and postponement of activities until the order is placed requires that the materials and resources to produce a product must be located close to the customer and the manufacturer. Also, direct interaction with the customer is inherently easier if the manufacturer and the customer share, culture, language, and infrastructure, a by-product of domestic manufacturing (Handfield, 1994). With this in mind, mass customization may be a boon to the reshoring movement.

Lean Manufacturing

In 1950, two young engineers came to the United States to observe the Ford Motor Company at work. Eiji Toyoda and Taiichi Ohno watched the mass production of Ford vehicles and returned to Japan to convey their findings to Eiji's cousin who had recently founded the Toyota motor company. Eiji Toyoda and his companion Taiichi Ohno, decided, on their return, that mass production would not be viable in Japan. There had been massive social and political upheaval in Japan after WW II, which had led Japan's budding auto industry into uncharted waters. Labor unions wouldn't tolerate layoffs, there were no immigrant or migrant populations to employ, and the post war years had left Japan short on capital for large-scale investments. In response to these pressures and others, they created a new management theory. Ohno's ideas in particular would lead to a system that was termed the Toyota Production System (TPS), and would become lean manufacturing (Womack, 1991).

Interest in the theories of lean manufacturing grew, when Womack, Jones, Roos, and Carpenter published *The Machine That Changed The World* (1990). The book follows the research, conducted over five years, comparing the world's largest automakers. The book clearly highlighted the competitive advantages gained by automakers that embraced lean manufacturing. The book is heavily cited in academic, business, and cultural writings and spread the ideas of lean manufacturing.

After years spent studying the effects of lean manufacturing, Womack and Jones wrote *Lean Thinking* (1996), which was intended to be a 'North Star' to help guide managers' actions while implementing the concepts of lean manufacturing. To do this the

authors spent four years observing over fifty businesses in a variety of industries, including manufacturing and service, to analyze the successes and failures of implementing lean manufacturing. Unlike Toyota, which was built from the ground up, this book was intended for businesses that are trying to convert from a previous mass production model.

Lean manufacturing is a system for removing waste from a production process. It involves a collection of organizational tools that can be applied to a system to identify and eliminate waste, with the goals of improving quality, decreasing production costs, shortening cycle times, and satisfying customers (Black, 2008). The waste that lean manufacturing aims to reduce has seven types:

- waste from overproduction
- waste of waiting time
- transportation waste
- inventory waste
- processing waste
- waste of motion
- waste from product defects (Dal, Akçagün, & Yilmaz, 2013; Taj, 2008).

The elimination of these common manufacturing issues can result in a more competitive and streamlined company and the possibility of increased profits (Black, 2008; Dal et al., 2013; Dennis, 2007; Goforth et al., 2011). Applying the lean system has been remarkably successful for Toyota and many other manufacturers. It has also been shown to successfully creating competitive advantage in US textile-based manufacturing (Goforth et al., 2011). There are many arguments that imply that lean manufacturing and overseas suppliers are

fundamentally incompatible (Black, 2008). This makes lean manufacturing a robust, well-documented system that is perfectly positioned to support reshoring.

Although different companies have practiced lean manufacturing in a number of ways, there are some core tenets and tools that have been successfully used to overhaul manufacturing operations. These include Just-in-time and Jidoka, two concepts designed to improve standardization and stability in the manufacturing process, with the goal of increasing customer satisfaction. Just-in-time is a way of setting up material and manufacturing flow wherein every part or material is ordered and assembled only when it is needed, thereby eliminating waste from excess material storage and handling. Jidoka is the idea of stopping manufacturing to address any errors or defects as soon as possible with the goal of fixing the underlying issue before restarting production. This allows for a zero defect policy and a format for making incremental improvements as time goes on (Dennis, 2007).

Neither Just-in-time or Jidoka are possible without a clearly understood outline of the goals and tolerances of a given product or process. Standardization and stability are requirements for outlining goals and tolerances. Stability refers to a system that is self-sustaining; for example, a management team and corporate culture that addresses problems and variations in the system without throwing out the system. Standardization means repeatability, clear beginning and end points for each process, and management techniques that allow defects to be spotted immediately. The principles of lean manufacturing apply all of these ideas in pursuit of customer satisfaction, which is expressed as productivity, quality, delivery time, safety and environment, and morale (Dennis, 2007).

These concepts are often expressed as a “house” diagram.

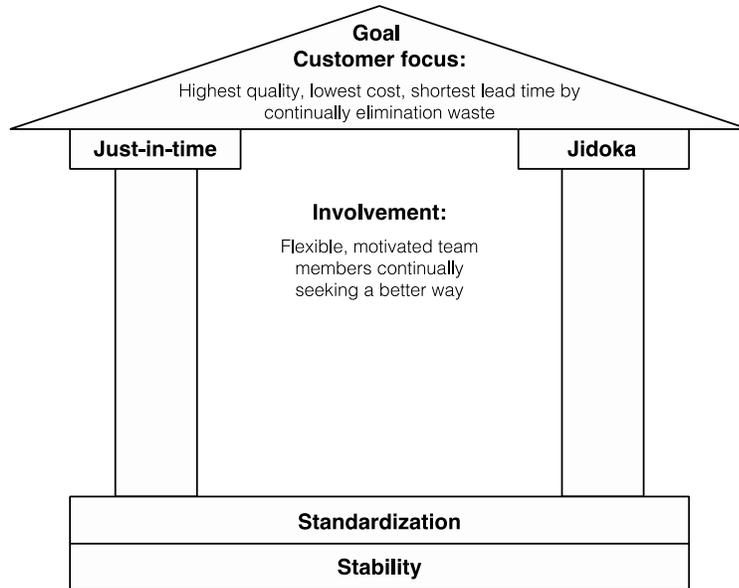


Figure 6: Lean Manufacturing House Diagram (Dennis, 2007)

The common tools that are often cited to facilitate these concepts, especially in the US textile industry (Goforth et al., 2011), include 5-S, Kaizen, Kaban, Total Productive Maintenance, Value Stream Mapping, and Visual Management (Womack, 2003).

5-S stands for sort, set in order, shine, standardize, and sustain. This tool is used to eliminate waste by eliminating excess parts, tool, and trash that clutters the work area causing employees to waste time and money searching for or reordering parts and tools. It also eliminates visual distractions making it visually easier to track processes and find errors.

Kaizen is a tool for getting to heart of where errors and mistakes happen by identifying where errors and defects occur, finding the root cause of the issue, and then considering and implementing solutions to the problem (Womack, 2003).

Kaban is a process for implementing Just-in-time material flow wherein a part or material is labeled either physically or electronically, and once it has been consumed or assembled, the label is used to indicate to the previous operation that more production is required (Womack, 2003).

Total productive maintenance is a process for using and maintaining equipment. It strives to eliminate waste from breakdowns, setup and adjustment delays, machines being run without product being produced, machine speeds that slow production times, defects, and yield reduction. Reducing this waste is accomplished through employee training to fix and report minor issues, find root causes, develop regular maintenance schedules, and to take action before breakdowns occur (Womack, 2003).

Value stream mapping is a sophisticated flow chart that tracks how material and information flow through the manufacturing system. This chart allows the company to identify aspects of a manufacturing process that add no value to the product. Value stream mapping creates an excellent way to identify and focus on areas that need improvement (Womack, 2003).

Visual management is a broad tool that creates visual systems that allow management and staff who interact with a process to be able to tell quickly and easily the production status, inventory levels, machine availability, goals and schedules, rules and objectives, of that process. This can be executed with organization, color-coding, visual signals that call

attention to problems, and visual indicators that explain issues or direct actions (Womack, 2003).

Employee involvement is critical for lean principles to create benefits (Black, 2008). The theory of continuous improvement requires employees to assess and address issues as they arise. To be effective, employees must have an understanding of the overall processes and goals, as well as a detailed knowledge of the steps that come before and after their own (known as cross training). Employees are also much more flexible than machines and capable of problem solving and reconfiguring. As such they are incomparably valuable assets in a flexible, lean manufacturing process. By hiring, training, and retaining high quality employees a company can expect to accomplish their lean goals more effectively (Black, 2008). This can be difficult with a poorly educated workforce that may not share language or culture with the parent company. The reshoring movement embraces this facet of lean manufacturing strategy, as the US has many manufacturing-based parent companies, and a well-educated workforce (National Science Foundation, 2010).

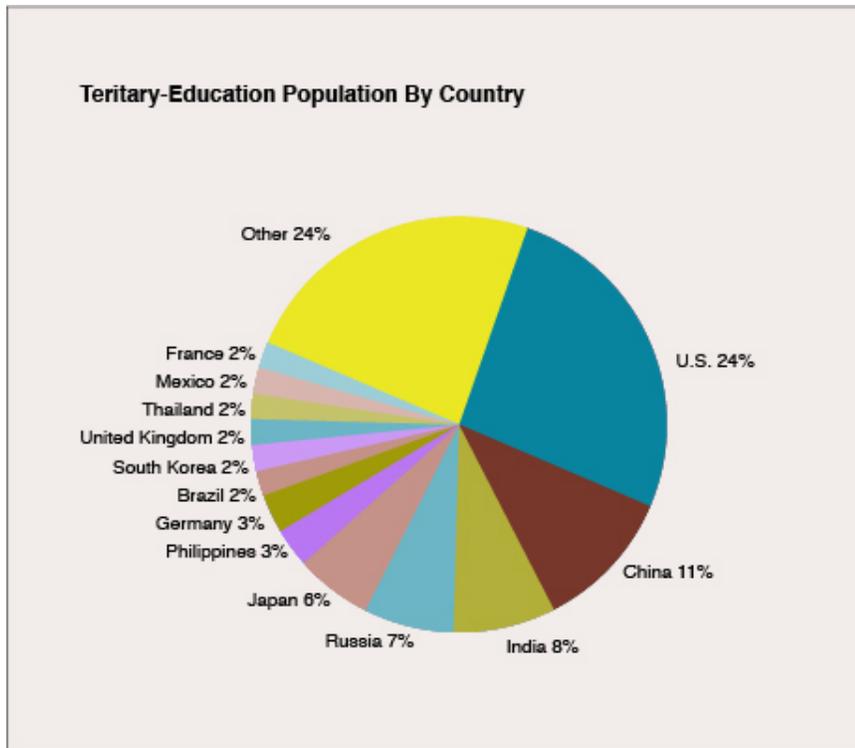


Figure 7: Tertiary-Education by Country, (National Science Foundation, 2010)

As John Black wrote in his book *Lean Production* (2008), “You cannot effectively cultivate and focus the potential of human beings on the far side of the world, or anywhere outside of your own organization, over whom your only influence is economic.” Thus, reshoring and lean manufacturing can go hand in hand, creating efficiencies through simplification, consolidation, and embracing the well-educated (though higher priced) American work force as an efficiency generator.

Lean manufacturing tools have been applied successfully in many industries by companies such as Toyota (J. P. Womack, 1991), Boeing (Black, 2008), and General Motors (Lesser, 2014). Lean principles have even been effective in healthcare (Kenney, 2011) and

government sectors (Bhatia & Drew, 2006). They are currently being applied to US textile based manufacturing in companies such as Alice Manufacturing, Joseph Abboud, Absecon Mills, and National Textiles (Goforth et al., 2011). The efficiencies that lean manufacturing has been shown to create are extremely promising as a means for implementing reshoring. As more and more businesses begin to consider lean manufacturing as option for creating competitive advantage, reshoring may be a natural byproduct.

Chapter 3: Design and Methodology

Value stream mapping (VSM) is one of the tools of lean manufacturing. It was argued by Rother (2009) that the value stream map is one of the best places to start a system based overhaul. It is a tool whose primary purpose is to look at the entire, manufacturing process even as it crosses organizational boundaries. Tracking materials and information across the organizations can highlight systemic issues and opportunities that might be overlooked by overhauling a single department. The visual nature of the tool allows for clear communication between co-workers and departments. This makes improvements easier to discuss and agree on. A value stream map is a living document that anybody in the manufacturing process can use to identify further efficiencies into the future.

VSM is proven tool within lean manufacturing for identifying efficiencies and will be used for this research to identify efficiencies stemming from the introduction of digital technology. To understand VSM it is first important to understand value, and value streams in the context of lean manufacturing.

The five principles of lean manufacturing are summarized in Womack and Jones' book *Lean Thinking* (2003):

1. "Precisely specify *value* by specific product" (Womack and Jones, 2003)
 - In lean manufacturing value "can only be defined by the ultimate customer. And it is only meaningful when expressed in terms of a specific product, which meets the customer's needs at a specific price at a specific time." (Womack, 2003). Thus Value is defined by the customer and cannot exist without a clear understanding of the customer's requirements. In the context of a VSM the value added activities

are those that the customer would be willing to pay for if they knew it was happening.

2. “Identify the *value stream* for each product” (Womack, 2003)

- The value stream is defined as “the set of all the specific actions required to bring a specific product (whether a good, service, or increasingly, a combination of the two) through the critical management tasks of any business.” (Womack, 2003).

The value stream is the collection of all the steps required to manufacture a product; these steps also include transferring information. In a perfect system the value stream includes no steps that do not add value.

3. “Make value *flow* without interruptions” (Womack, 2003)

- Flow can be understood to be the opposite of batch. When a component comes through the value stream, value is added to it at every step. Every time that component becomes part of a batch it is waiting in a group with many other components for the next operator. Thus the ‘flow’ of the component through the value stream has come to a stop (Womack, 2003). In a perfect system materials and information would never wait in inventory or batch, they would flow continuously from source to customer.

4. “Let the customer *pull* value from the producer” (Womack, 2003, p. 10)

- Rother (1999) defined ‘pull’ as the concepts of not producing or supplying anything until it is requested. Nothing is made until the customer orders it, and nothing is supplied until the downstream process requests it from the upstream process. For example, the supplier hands a screw to the person who inserts it in a

toy as oppose to delivering boxes of screws based on forecasted production. Pull eliminates inventory and overproduction.

5. “Pursue *perfection*” (Womack, 2003)

Value Stream Mapping is the act of documenting the value stream. The researcher follows the location of the materials and information through the process of manufacturing, noting the steps that add value, the steps that don't add value, and how long each step takes. It allows the researcher to see how much time is spent on non-value added work, note the interruptions in flow, and see where the system is based on push (overproducing and hoping for customers) or pull (not producing until requested by the customer or downstream process).

VSM relies on a standardized format and standardized symbols. There are many symbols, some of which are more common than others. The symbols that will be used in this paper have been shown below.

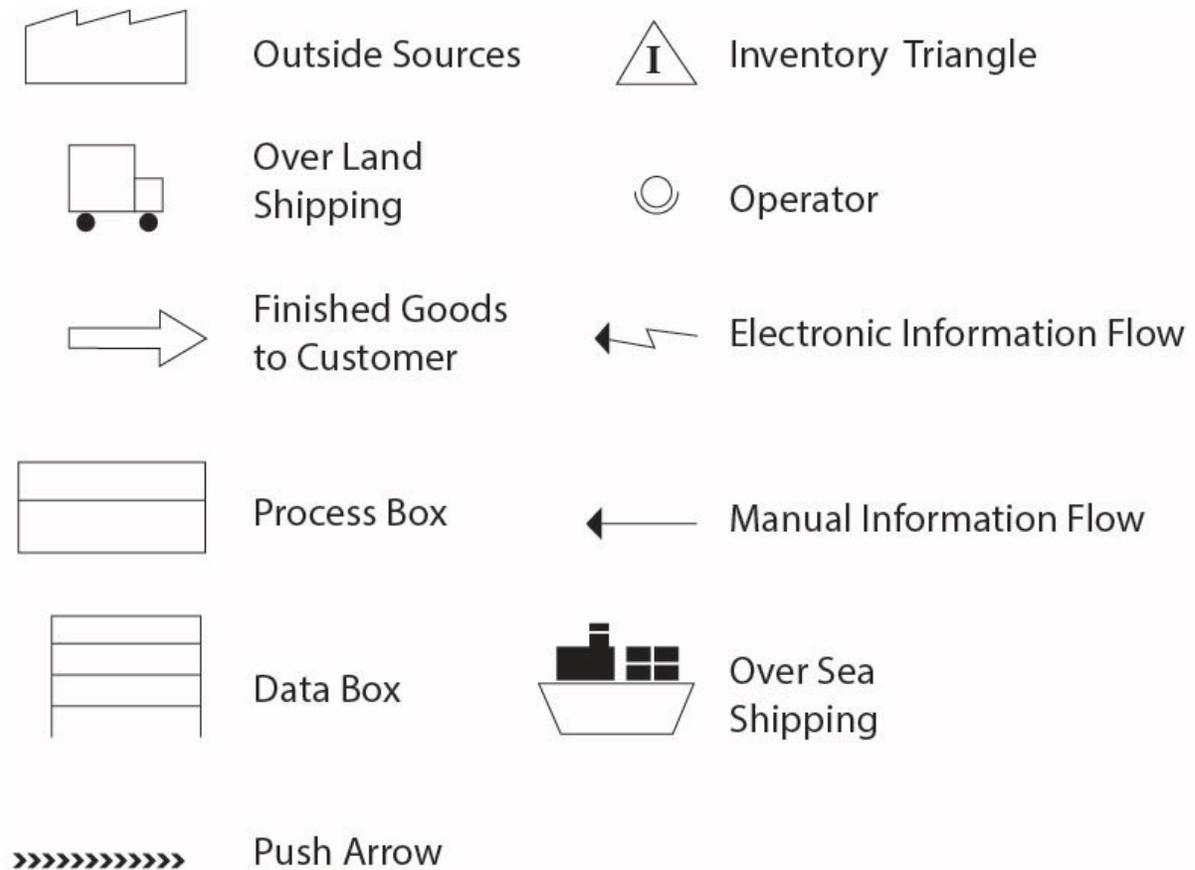


Figure 8: Symbols of Value Stream Mapping (Rother, 1999)

VSM is a tool developed for manufacturers to analyze and improve their production system. Serrano, Ochoa, and Castro (2008) conducted a multiple case study of 12 manufacturers to study the effectiveness of VSM. Their research indicated, “VSM is a useful, efficient and applicable tool for tackling the redesign of production systems” (Serrano, Ochoa, & Castro, 2008). The success of this tool is gaged by the satisfaction and improvement seen on the factory floor and was based on the following factors:

- A common, easily understood language to allow decisions to be discussed by the people involved in the process.
- Efficiency in its use. The results of the process are justified by the time and effort required by the team.
- A graphical and standardized interface language help to make the application process easier.
- The tool focuses on quantitative analysis. The decisions to be taken are based on scientific and objective data analysis.
- A way to emphasize the initial problem situations as well as to provide clear guidelines and innovative concepts to improve the operational performance of the system.
- Reflection of a systemic vision. The study does not lose perspective of the system to be analyzed and improved. The optimization of one point of the process should be evaluated in light of its effect throughout the system.
- Seeing redefinition and redesign as a starting point for production system strategic improvement planning (Serrano et al., 2008).

Although all the companies in Serrano et al.'s (2008) study showed improvement and expressed satisfaction, the results were highly individual, depending on many aspects of the manufacturer.

This paper will explore how digital printing and cutting could facilitate reshoring for the domestic, 'Made to Order' (MTO) department of a large cushion manufacturer. The

MTO department, of this manufacturer makes cushions to satisfy internet-based customer orders. Mapping the current process and developing a hypothetical future state map will show the effects of introducing digital printing and cutting technology. The comparison yields useful information about the viability of these technologies for this manufacturer but will not predict the full scope of effects if the cushion manufacturer being observed adopted these technologies.

The current VSMS for the manufacturers can be seen in figure 10 and figure 14. A VSM is read from the right hand corner at 'Customer', counter-clockwise through the manufacturing process, ending with the product being shipped to the customer. The data is displayed as a data box, timeline, and miscellaneous, along the process. A location where work is being applied to the product is noted as a production station, each station has a data box associated with it.

This data box contains:

- 1) The name of the station where a process is being applied to the unit.
 - a. For example 'Cutting station' where fabric is being cut for the cushion.
- 2) The number of operators working at that station.
 - a. For example the cutting station may have one full time cutter and a secondary cutter who works the cutting station for half of his or her shift and inventory for the other half. This would be expressed as an operator symbol and a number, '☺ x1.5'.
- 3) Cycle time noted as 'c/t'. The cycle time represents the time spent at the station per unit.

- a. For example: If it takes 120 minutes to cut a batch of 60 cushions then the cycle time is $120 \text{ min}/60 \text{ units}=2 \text{ min/unit}$. This is expressed as 'c/t: 2 min'.
- 4) The labor time available per operator, expressed as shifts and shift length.
 - a. For example: If a manufacturer runs 3 shifts/day and each shift is 8 hours, this is expressed as '3x 8 hr shifts'. To determine the total amount of labor available for production these numbers would also be multiplied by the number of operators working each shift.
- 5) The relevant production quantity that this station processed between changeovers.
 - a. For example, the cutting station cut 60 cushions from one stack of fabric. Expressed as 'qty. cut: 60'.
- 6) The time required to changeover to the next production quantity.
 - a. For example, in order to begin cutting a stack of fabric the cutter must determine how many cushions to cut, acquire the fabric to be used, spread plies, and nest the pattern pieces. This time is expressed as 'c/o: 15 min'.
 - b. In some cases the change-over time is expressed as NA. This occurs when the operator treats every unit the same. For example the packing station receives product in boxes. The operator checks, tapes and labels the box. Nothing is changed between boxes. This is expressed as 'c/o: NA'.

Cutting Station
 X 1.5
c/t: 2 min
3x 8 hr shift
qty cut: 60
c/o: 15 min

Figure 9: Example of VSM Data Box

The line, below the data boxes, that jogs up and down is the time line of the product. The lower levels track non-value-added steps such as inventory and batching. The upper levels reflect the cycle time the unit spends at a cutting station. This is the value added time. Thus the total value added time is the sum of the upper level numbers. The times associated for inventory are expressed as a range. This range represents the minimum and maximum times required for a full change of inventory at that location. All other miscellaneous data corresponds with the department or activity it is visually associated with.

Once the current state of manufacturing has been mapped, identification is made of the data that would change with the introduction of digital printing and cutting technology. Data associated with the chosen printer are based on observation of a fabric printing facility that will be referred to here as Company C. Data associated with cutting technology are based on published data, personal communication with manufactures and estimates. The data collected will be applied to the future state map. The researcher then considers the overall flow of materials and information in the current VSM to identify areas of non-value-added work. Any clear means of reducing these actions are also incorporated into the future state

map. Once the future state map has been drawn, comparisons can be made between the current value stream and the future value stream. This will provide insight into how the digital technology will affect the value stream of manufacturer. The data collected should be considered a ‘snapshot’ of the manufacturer during the month that data was collected. Due to the seasonal nature of cushions February (the month observed) is a slower time, with fewer orders being processed. More time would be required to see the effect for other times of the year.

The data contained in the VSMs will be provided by a variety of sources. Table 1 shows origins of current data expressed in the current VSMs for the manufacturer. Table 2 shows the origins of the data expressed in the future state map.

Table 1: Data Sources for the Current VSMs.

Data Name	Origin
<ul style="list-style-type: none"> • Annual forecast • Fabric supplier requirements 	(Engineering manager, personal communication, February 4, 2015).
<ul style="list-style-type: none"> • Fabric supplier lead times • Shipping times 	(Senior Textile Engineer, personal communication, February 26, 2015)
<ul style="list-style-type: none"> • MTO warehouse inventory times 	(Sr. Product Development Engineer, personal communication, February 24, 2015) (MTO supervisor, personal communication, February 11, 2015)
<ul style="list-style-type: none"> • Cutter storage inventory times 	(MTO supervisor, personal communication, February 11, 2015)
<ul style="list-style-type: none"> • Data boxes for all stations 	Direct observation.
<ul style="list-style-type: none"> • Inventory points 	(MTO supervisor, personal communication, February 11, 2015)

Table 2: Data Sources for the Future State VSM.

Data Name	Origin
<ul style="list-style-type: none"> • Annual forecast • Fabric supplier requirements 	(Engineering manager, personal communication, February 4, 2015).
<ul style="list-style-type: none"> • Fabric supplier requirements • Shipping times 	(Company A, textile mill greige goods sales, personal communication, March 2, 2015) (Company B, textile mill greige goods sales, personal communication, February 25, 2015)
<ul style="list-style-type: none"> • Printer 	(Dr. Lisa Chapman, NCSU digital printing specialist, personal communication, February 20, 2015)
<ul style="list-style-type: none"> • Cutter storage inventory times 	Based on calculation, see table 5.
<ul style="list-style-type: none"> • Data boxes for all stations 	Direct observation.
<ul style="list-style-type: none"> • Inventory points 	(MTO supervisor, personal communication, February 11, 2015)

Chapter 4: Results

The mass customization department has two strategies for fulfilling these orders once they have been received. Strategy 1 (S1) is an extension of the mass production strategy it employs for the rest of the products the company manufactures. This involves making and keeping inventory of completed or partially completed cushions that can be pulled and shipped at the time of order. This strategy depends on forecasts, which can be problematic for predicting demand fluctuations. S1 also employs large inventories of fabric and finished goods. Strategy 2 (S2) relies on fabricating and assembling the product at the time of customer order. S2 also relies on large fabric inventories and requires more labor inputs as cushions are often cut individually using single ply, manual cutting instead of simultaneously using multi-ply manual cutting. Digital cutting and printing technology will affect this portion of the value stream most due to the time required to change-over fabric and pattern combinations and the cost of holding fabric inventory.

Strategy 1: Mass Production

The current VSM for the manufacturer's strategy 1 (S1), can be seen in figure 10. The VSM is read from the right hand corner at 'Customer', counter-clockwise through the manufacturing process, ending with the product being shipped to the customer. The analysis of this map is based on observations and conversations conducted at the facility and will follow this path sequentially. At the time of observation the staff was producing a 'Large Cushion' style (see appendix B) that was cut from striped fabric. The alignment of the striped fabric adds some time to the cutter's process.

There are some observations that are not recorded in the VSMS that may be worth noting. First the cushion company displays remarkable flexibility among its employees. Employees demonstrate this by their ability to switch tasks quickly as needed to level the workflow. In addition to being cross-trained within the MTO department many of the employees are also capable of working other departments. This allows the company to transfer employees between departments, as the peak season is different for MTO than their mass production department. Secondly, customers order cushions through the retailer's online '.com' business, such as Walmart.com. This means that the manufacturer does not capture data associated with the customer's decision making. These data could be important for helping the manufacturer identify consumer needs that are currently going unfulfilled as well as current customer satisfaction. This information could facilitate the manufacturer's decision making for future investments.

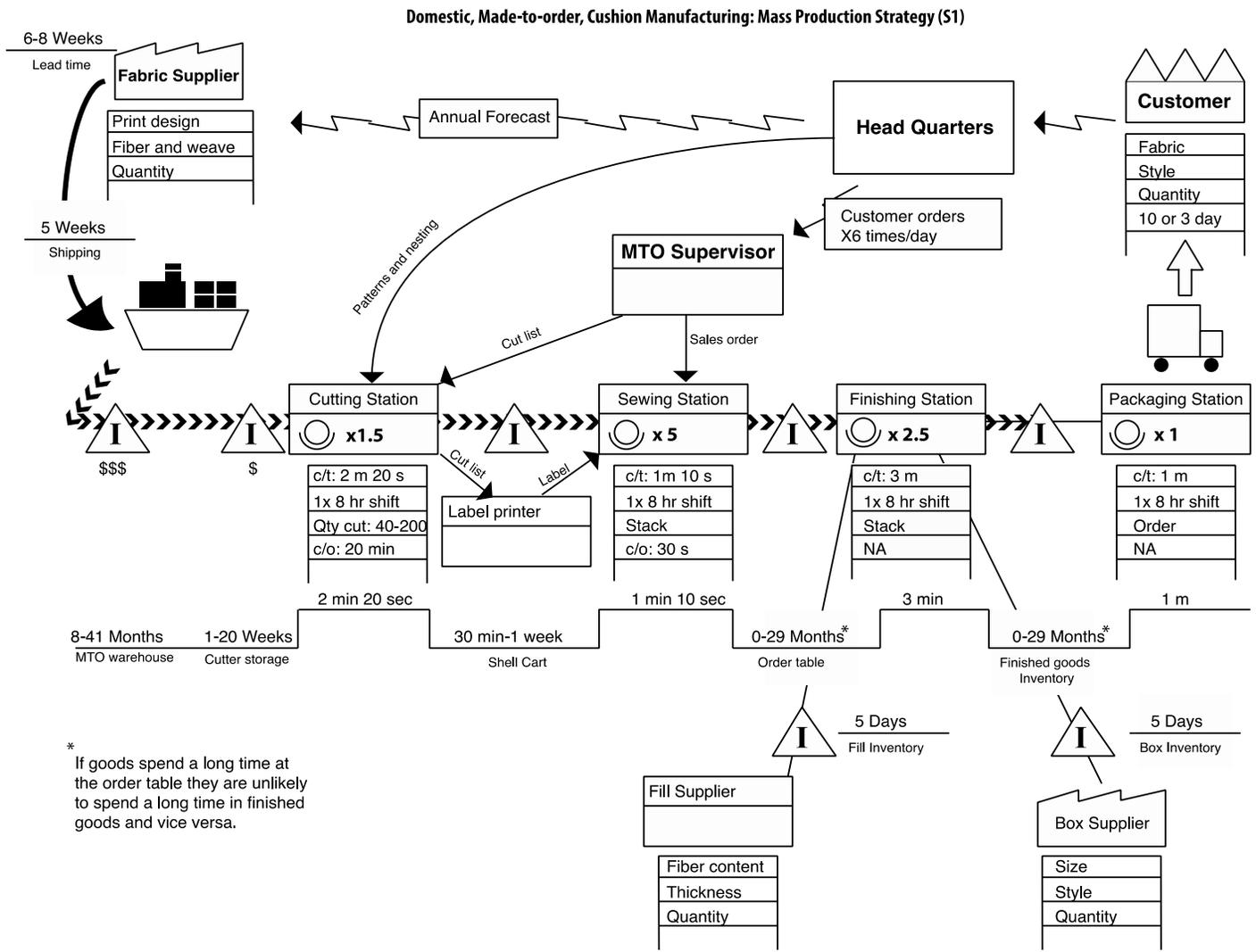


Figure 10: Strategy 1, VSM for Cushion Manufacturer

1) Customer

- a. The customer orders a cushion from Walmart.com.
- b. The information contained in this order notes the fabric, style, quantity, and preferred turnaround of the desired cushion.
- c. The customers specifies in their order when they would like the cushion to arrive.

This is expressed in the following shipping options:

Table 2: Customer Shipping Options

Time to Delivery	Shipping cost
28 days	\$4.97
24 days	\$6.97
22 days	\$7.41
18 days	\$10.25

2) Headquarters

- a. The customer's selection information is conveyed from Walmart.com to the manufacturer's headquarters. The shipping options are converted into two categories; either the product must be manufactured and shipped in 10 days or 3 days.
- b. Based on the orders received, headquarters develops a forecast for next year's fabric requirements. The fabric order is placed annually.

3) Fabric supplier

- a. The fabric supplier is based in South East Asia.

- b. Specification for print/weave design, fiber, and quantity are supplied in the order.
 - c. The turnaround times are 6-8 weeks.
 - d. The fabric then spends 5 weeks 'on the water'.
- 4) MTO warehouse
- a. Delivery is received at the manufacturing facility where it is housed in the MTO warehouse.
 - b. Due to the annual nature of the ordering cycle, a year's supply of fabric is received and housed. As the season progresses some or all of the fabric is utilized.
 - c. Resale to smaller manufacturers, or clearance at a warehouse sale if that fails, is attempted on any unused fabric.
 - d. Some retailers have proprietary clauses associated with the fabric used. This means that no resale to an outside customer of either fabric or finished goods is possible for 3 years.
 - e. Thus a complete inventory turn could theoretically take anywhere from 8-41 months. (See figure 11)

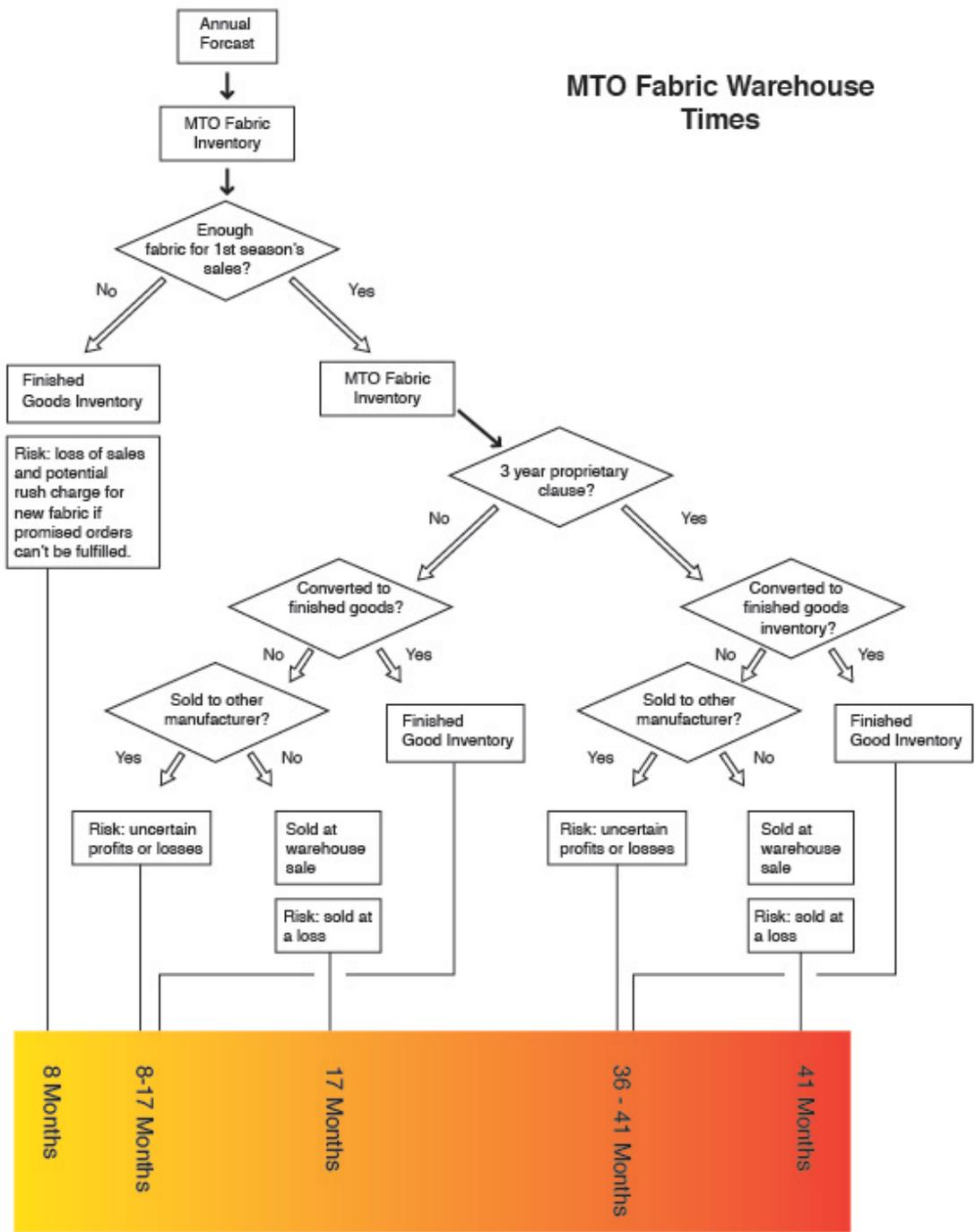


Figure 11: MTO Inventory Flow Chart

5) Cutter Storage

- a. A single roll of a fabric style, that is likely to be used quickly, is pulled from the MTO warehouse and placed on racks close to the cutting station. This fabric roll will be used and replaced in 1-20 weeks.

6) Cutting station

- a. The quantities of product being cut are based on the forecast developed by headquarters and the current incoming orders. 70% of fabric ordered is converted into cushion shells regardless of customer order. The MTO supervisor compiles this information with incoming customer orders into a cut list that is given to the cutter.
- b. Based on the cut list, the appropriate fabric is pulled from the cutter storage, placed on a bar at the end of the cutting table where the fabric is laid out on a table, between 1 – 7 meters in length, and subsequent layers of fabric are stacked on top of each other in a process known as spreading. These fabric stacks can be as much as 15 cm in height. If there are special requirements for how the fabric must be cut due to the print design, the fabric must be aligned very carefully so that the print elements are in a near identical location within each fabric layer. This process can be labor intensive and time consuming as textiles are easily distorted.
- c. Once the fabric has been aligned and stacked, the pattern pieces are arranged on top of the stack. This is accomplished by tracing around templates on a fabric layer and spreading that on top of the fabric stack. To maximize the material

usage pattern pieces are arranged carefully. The process of arranging pattern pieces for maximum material usage is known as nesting. The size and shape of the pattern pieces, as well as their nesting arrangement, is determined by the engineering department who provides the cutting station with a binder of drawings. These drawing specify the arrangement and pattern pieces for every combination of fabric widths and product styles. The retrieval and double-checking of this information contributes significantly to the change-over time.

- d. After the fabric has been spread and aligned, and the pattern pieces have been nested and laid on top of the fabric, the entire stack of fabric is manually cut using a “fabric saw” also known as a “stack knife”. A skilled technician must manually operate stack knives, as any mistakes will affect every layer of fabric simultaneously.
- e. Before cutting the cushion components the tightly woven edges known as ‘selvage’ edges are cut off. This allows for less shifting while the fabric is cut.
- f. The cut cushion components are then arranged with their labels for the sewers to take. The components are placed on the shell carts or the end of the cutting table depending on available space. The labels contain information about the style, retailer, and regulatory requirements.



Figure 12: Eastman Fabric Saw (eastmancuts.com, 2015)

7) Sewing station

- a. The sewers retrieve a stack or stacks of cut components from the shell cart or cutting table. If the sewer is unfamiliar with the cushion style he or she can reference the label and find more information in a reference book kept at the cutting station. Any other questions the sewer might have are usually asked of the cutter.
- b. Some cushion styles require ties to be sewn into a seam in the cushion; these allow the customer to tie the cushion to a chair. If ties are required the sewer either makes ties or retrieves them from a stack of premade ties.

- c. The sewer assembles the cushion shell, leaving one side open for stuffing. The labels have now been sewn into a seam.
 - a. All sewing machines are threaded with a single color of thread that has been shown to harmonize well with the vast majority of fabrics. This reduces the change-over time required. The only change-over operation currently required by the sewer between orders is getting up to retrieve the next set of cushion components.
 - b. The sewer then piles the shells for someone else, known as a “turner”, to invert.
 - c. The turner inverts the shells and stacks them at the order table.
- 8) Order Table.
- a. Shells can stay at this sewn but un-stuffed stage for the entire rest of the season until a customer orders that style/fabric combo.
 - b. If not sold that season they can be finished and transferred to finished goods inventory. They may also be saved at this stage and available for sale in the subsequent season as they take up less space than stuffed cushions.
- 9) Finishing station
- a. The finisher retrieves the stack of shells from the order table. If the cushion style requires a poly-fill insert, the finisher unrolls and cut the appropriate lengths with a stack knife.
 - b. The finisher stuffs the poly-fill into the cushion with the use of a specialty piece of equipment. Then attend to any outstanding stuffing by hand.

- c. If the cushion style requires blow-fill, the fiber mixture is blown into the cushion sections and situated by hand.
 - d. A five day (1 week) inventory of fill is available in the fill inventory area.
 - e. Any scraps generated in the finishing process are saved, and made into more stuffing later.
 - f. The stack of filled cushions is passed to a sewer who closes the side that was left open. He or she will also sew through the entire cushion at designated fold points if the cushion style requires it.
 - g. The cushion is then dropped from the sewing machine into a box. This box will either be placed in finished goods inventory or given to the shipper.
- 10) Finished goods inventory
- a. If the cushions are being made for a specific order then the shipper scans the label, placing them in 'Finished Goods Inventory' and then scans them again to associate the finished product with a customer order. The box containing the customer order is then passed to the shipper. Thus the cushion has passed through the finished goods inventory in a purely electronic sense.
 - b. If however, the finished goods are not associated with a customer order they may be boxed and placed on shelves for the entire rest of the season until a customer orders that style/fabric combo.
 - c. If not sold that season, the cushions may be available for sale to discount retailers, sold the following season, or sold at the manufacturer's clearance sale.

- d. It is important to note that goods are likely to spend time at either the order table or the finished goods inventory but unlikely to spend a long time at both.

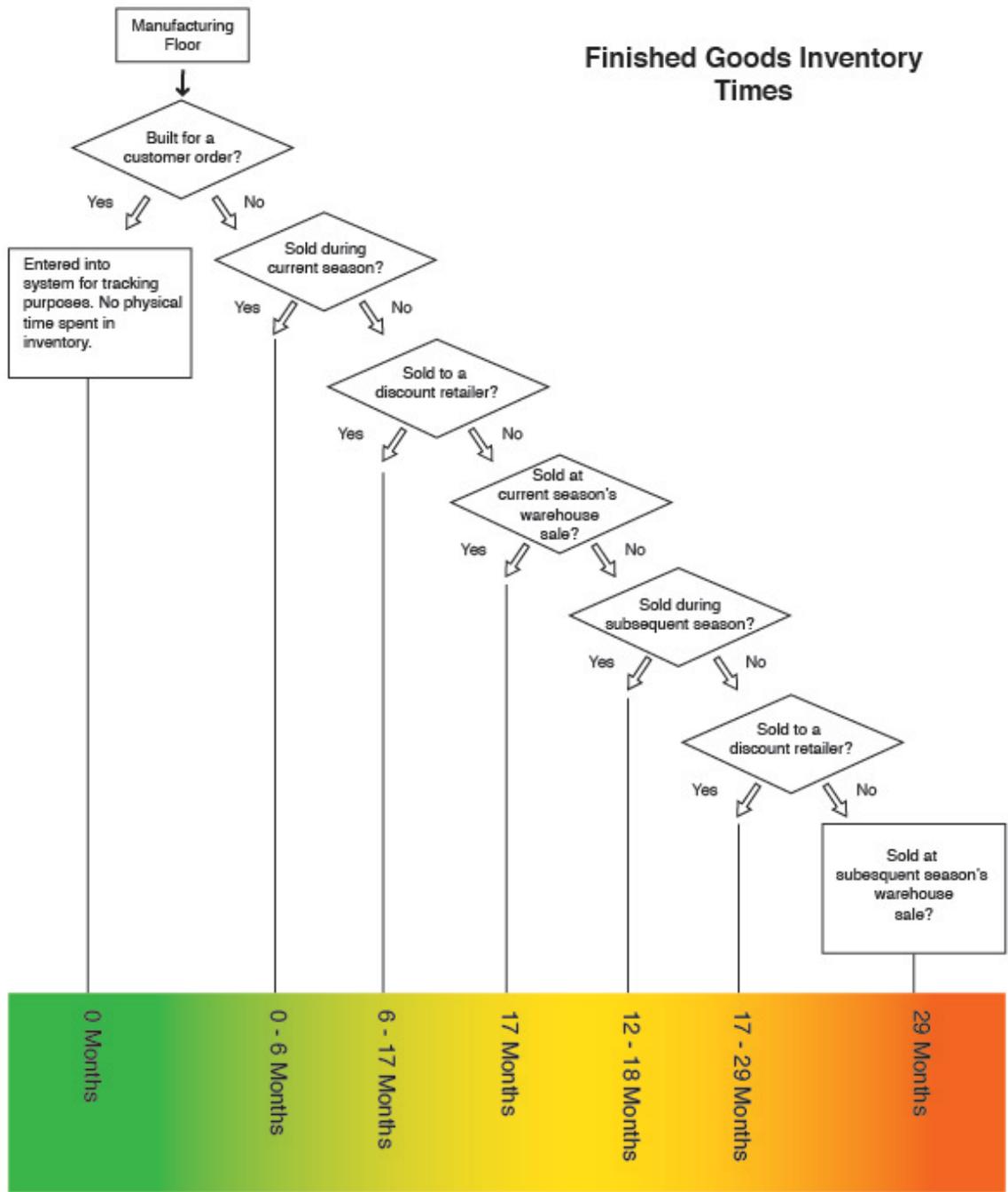


Figure 13: Finished Goods Inventory Flow Chart

11) Shipper

- a. The box is re-checked for accuracy against the customer order.
- b. A shipping label and packing slip are generated and add to the box. The box is then taped, and loaded onto a truck.
- c. The cushions are shipped out once per day, five days per week.

Strategy 2: Mass Customization

The second strategy (S2) employed by the cushion manufacturer uses a mass customization model. In S1 the cushion is not made until the customer orders it. The order quantities range from one to about 40. The current VSM for the manufacturers (S2) can be seen in figure 14. The basic functions of the value stream's components are similar to the S1 model. In fact, the material flow from customer to cutting storage is exactly the same in S1 as S2. What follows is a description of only how the S2 map is different from the S1 map. At the time of observation the production staff was building large 'deck chair' type cushions made from three primary components, a top, bottom, and side panel. More cutting time is needed to cut these multiple pieces. This cushion style is also relatively complicated to sew and therefore takes more sewing time.

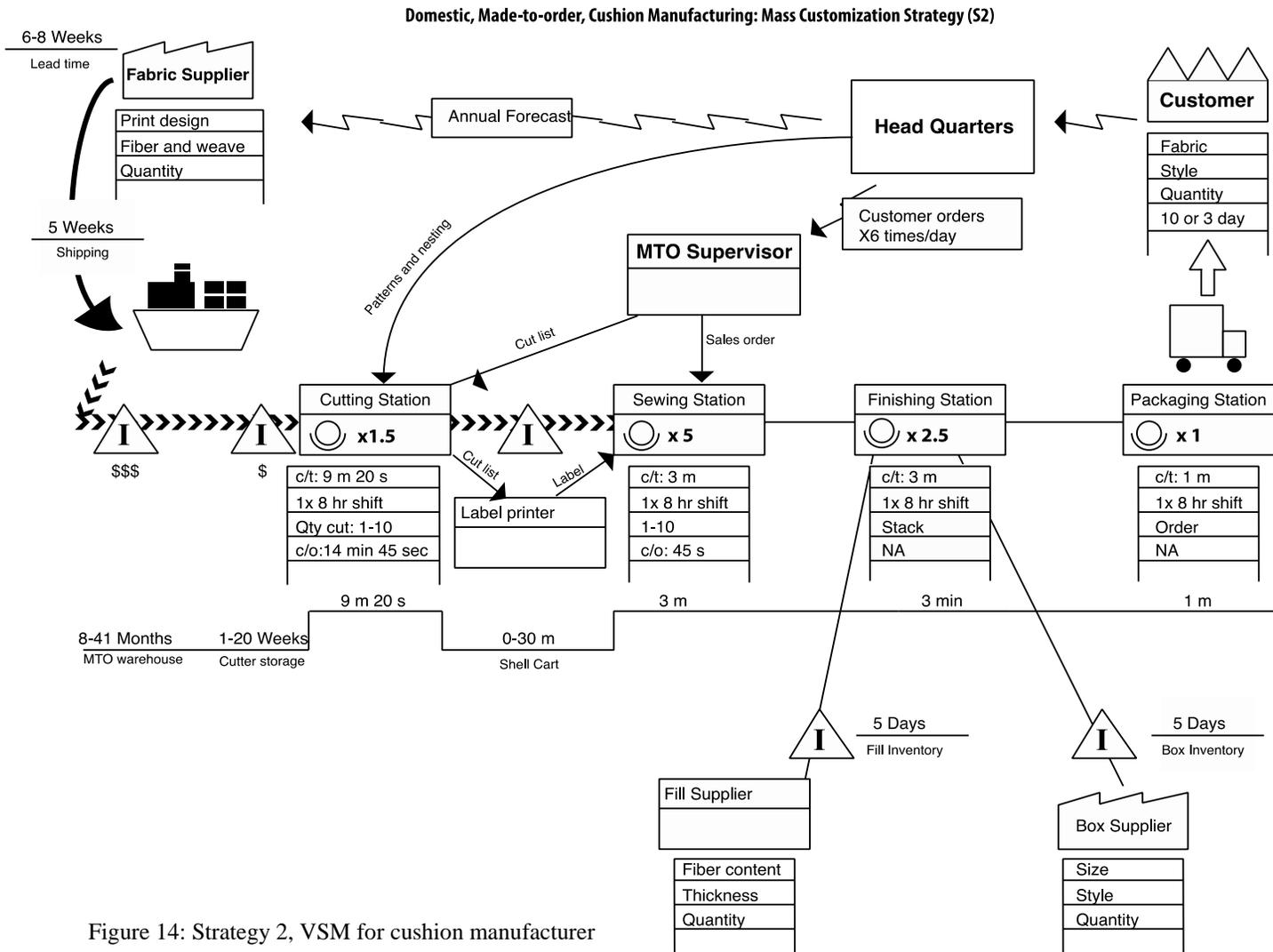


Figure 14: Strategy 2, VSM for cushion manufacturer

1) Cutting station

- a. If only one ply of fabric is to be laid on the table then the cutter sets the roll on the cutting table and unrolls the necessary yardage. This saves changeover time by not mounting the fabric roll to a frame for spreading.
- b. The cutting is achieved by using a smaller hand held rotary knife known as a 'chickadee' that is easier to control. This saves time when cutting the fabric.
- c. Changeover times are associated with each order and thus the cutting process generally takes longer in S2 than S1.



Figure 15: Eastman Chickadee Fabric Cutting Tool, (eastmancuts.com, 2015)

2) Shell cart

- a. Cut components that are associated with an order generally receive priority over un-ordered good. In S2 cut components are retrieved from the shell cart as soon as possible. This is especially true for orders requiring a 3 day turnaround.

3) Sewing station

- a. During observation the sewer requires 15 seconds more to assess the S2 orders. Each order is different and different sewing steps are required. The process of determining what is required for an order is one potential reason for the increase in changeover time.
 - b. In one particularly difficult case, the sewer encountered mechanical difficulties with her sewing machine, and a mechanic had to be called. The order she was sewing did not have a label requiring her to check with the cutter. She received a new label and sewed the cushion on a different machine that seemed to lack the tools for making ties. She was assisted by a coworker. With this complicated set of circumstances the cushion took almost 28 minutes to finish sewing.
- 4) After being turned, the cushion is handed directly to the finisher station and then to the packaging station. This eliminates any batching or inventory that may be associated with the S1 products.

Future State Map

In order to assess how the implementation of digital printing and cutting technology could change the value stream of this domestic, textile based manufacturing process. The overall flow of materials and information was considered to identify areas of non-value-added work. Any clear means of reducing these actions are incorporated into the future state map. Comparisons between the current state and the future state maps will provide insight into how the digital technology will affect the value stream of manufacturer.

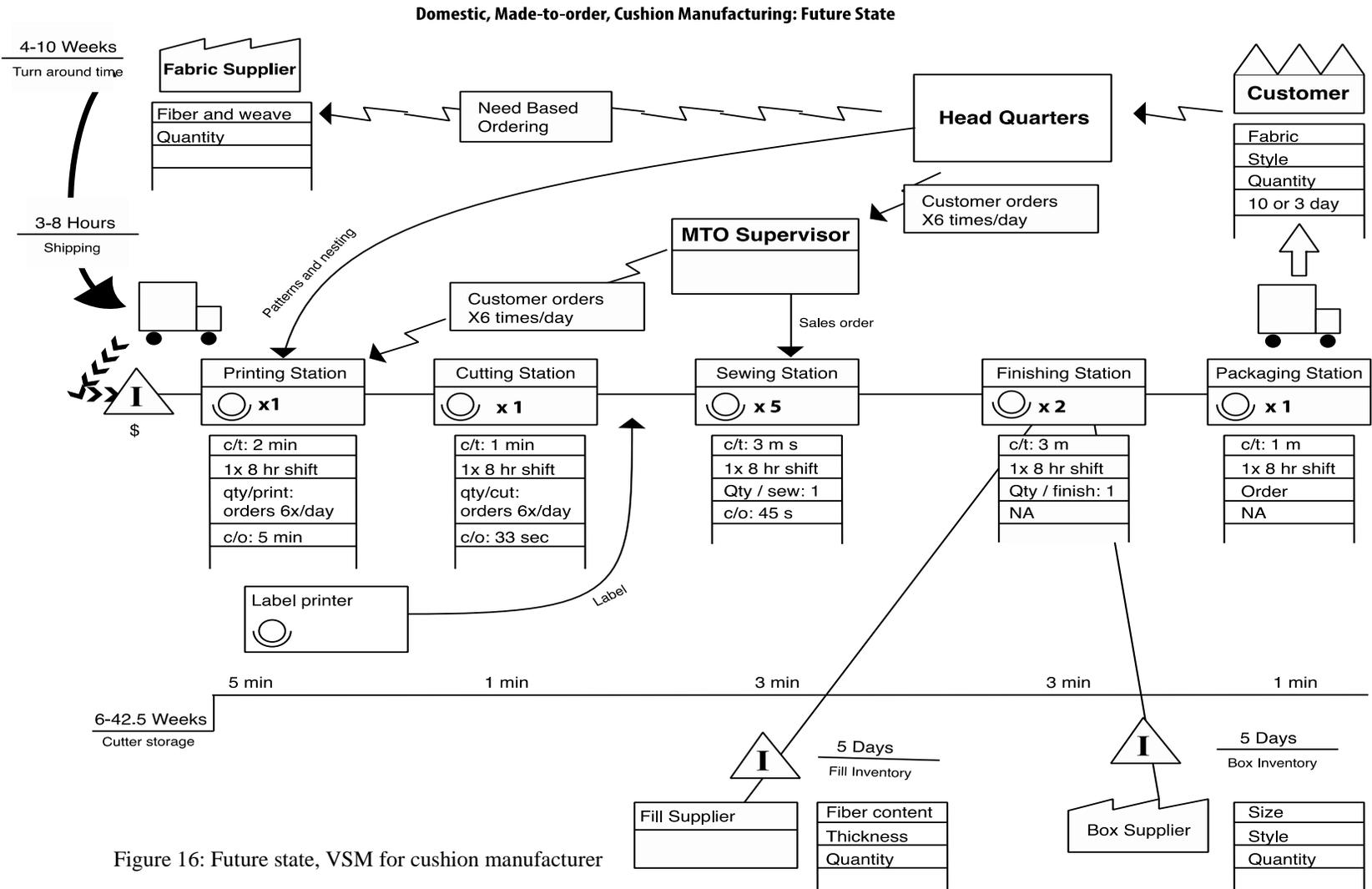


Figure 16: Future state, VSM for cushion manufacturer

1) Need based ordering

- a. The base cloth for digitally printed fabric can be sourced domestically in a ready to print state from a least two different textile mills. If all printed cushions could be made from the same base cloth this would reduce any issues associated with minimum orders. Ordering domestically also reduces the shipping time allowing for ordering to occur whenever it's required to keep materials on hand. This allows a flexible ordering schedule that fluctuates with seasonal demands.

2) Fabric supplier

- a. The domestic mills that were contacted for this research reported turn-around times ranging from 3 to 10 weeks and minimum orders between 30,000 and 50,000 yards (27,432 -45,720 m).
- b. Based on the relative location of the mills to the production facility, shipping times were estimated to be between 3-8 hours.

3) Fabric inventory

- a. The amount of inventory on hand will be based on the fabric mill's minimum order.
- b. If the base cloth being used can share a warp (the long yarns threading onto the looms) with another of the mills customers, the mill may be willing to supply smaller orders at regular intervals. More information about fabric requirements would be needed to determine what efficiencies could be found in conjunction with the mill.

c. Based on the cushion manufacturer’s shipping history for one week early in the production season the following information was provided. All Reference numbers have been rounded for sake of confidentiality. Also, please note that every order may contain different quantities of cushions. Cushions are often sold as a set. Sometimes a set will include a pair or more of cushions. Thus every set contains a certain number of pieces, in this case cushions.

Table 3: Manufacturer’s Data on Pieces Shipped for One Week, Early in the Production Season

Shipped over one week			
Number of Cushion Styles	50	Number of Un-stuffed Styles	5
Number of Cushion Sets	600	Number of Un-stuffed Sets	200
Number of Cushion Pieces	900	Number of Un-stuffed Pieces	200
Total Number of Orders	250		
Total Number of Styles	50	Average Number of Pieces/Order	4.6
Total Number of Sets	800	Percentage of pieces that are cushions	83%
Total Number of Pieces	1000	Average Number of Cushion/Order	3.6

Assumptions:

- The cushion manufacturer makes 900 cushions/week early in the production season.
- One cushion uses on average 1.5 yards (appendix B)

- During peak times there is approximately 5 times as many orders/day as there are early in the season. (MTO supervisor, personal communication, February 11, 2015)
- $(900 \text{ Cushions/week}) / (250 \text{ orders/ week}) = 3.6$ Average number of cushions per order.

Table 4: Future State Inventory Rates

Minimum yardage	Early order rates	Peak order rates
30,000 yds.	25.47 weeks of inventory	5.93 weeks of inventory
50,000 yds.	42.44 weeks of inventory	9.89 weeks of inventory

4) Printer

- The printer chosen for this future state map is the JP5 produced by MS Italy (MS Printing Solutions, 2015a).
- The JP5 is a multi-colorant printer with the following specifications:
 - Max speed 155 sq. meters/hour
 - Up to 8 colors
 - 600 x 600 dpi
 - 16 grey levels
 - Variable drop size

- vi. Open ink system
- vii. Open software system
- viii. Embedded remote diagnostic
- ix. Embedded web serve for cost report
- x. 180 cm max printing width

Information on digital printers

Digital inkjet printing is a relatively recent printing method and one that offers many benefits (The Economist Print Edition, 2002). The majority of textile printing is accomplished using screen-printing wherein inks are spread across a screen that has been treated to allow permeability in the pattern areas. Screen-printing can be executed using flat screens or circular screens that make a continuous repeat. When using a screen-printing method every color must be applied using a different screen and each screen's pattern must be developed individually, resulting in high changeover costs (Ferguson, 2011). Digital printers have very low changeover costs due to the machine's ability to switch from one print graphic to another without pausing. The benefits of low set up costs include the ability to respond rapidly to consumer demand especially in the realm of small and custom orders.

The down sides to digital inkjet printing include the relatively slow speeds and the ink's sensitivity to temperature and humidity, making the nozzles prone to clogging (Ferguson, 2011). Currently the fastest textile inkjet printers utilize a series of inline print heads that can print simultaneously up to seventy-five yards per minute (MS Printing

Solutions, 2015). This is on par with the speeds of a fully automated screen-printing process (Ferguson, 2011).

Inks are a combination of binders, solvents, and colorants that affect color, thickness, flow, drying times and appearance. There are three primary colorant types utilized in textile printing these are acid dyes, reactive dyes, and pigments respectively. The nature of these colorants determines which substrates they can be applied to. Acid dyes are colorants, which form ionic bonds with protein fibers in an acidic environment. In addition to silk and wool, these inks are also a good choice for nylon and acrylic. Reactive dyes are colorants that form covalent bonds with primarily cellulose based fibers. Covalent bonding is one of the strongest chemical bonds and these dyes form a stable wash-fast colorant on cotton, rayon, and even silk and wool if applied in an appropriate solution. Unlike acid and reactive dyes that are soluble, pigments are non-soluble particles suspended in a binder. The pigment particles are bound to the substrate by the binder, which can vary depending on what substrate it's intended for and can be used on a wide variety of fiber types. The size and shape of the pigment particles will determine the intensity and density of the color. The pigment particles must be large enough to create rich color but still small enough to flow through the printer heads without clogging (Ferguson, 2011).

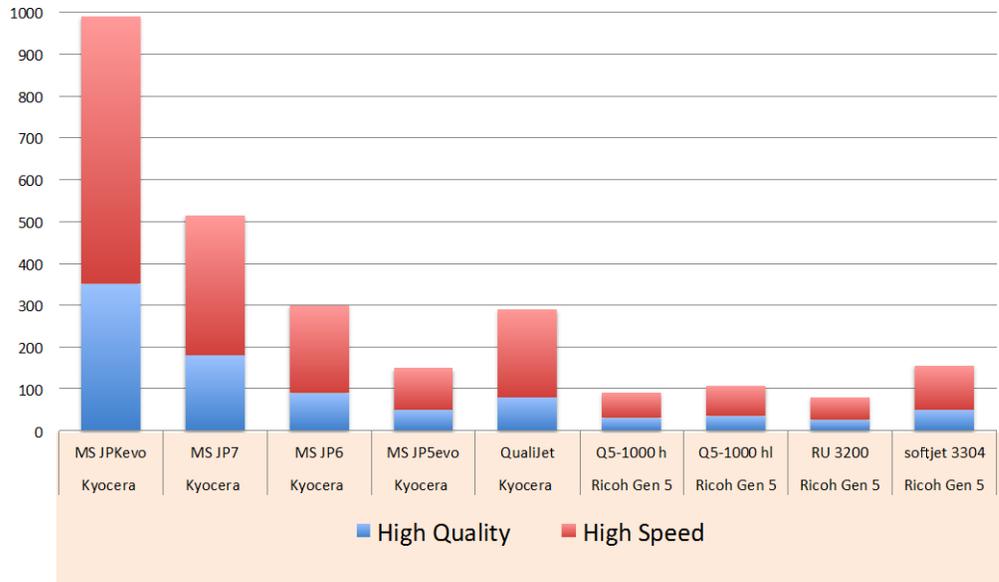
A manufacturer's decision to select a particular printer will depend on the required resolution, speed, price, software, and other aspects. There is not one printer that should be considered. The JP 5 is capable of running at 123 linear yards/hour at its fastest draft-quality speed on 54" wide fabric. At high resolution, the printing speed drops by half to 61.5 linear yard/hour (MS Printing Solutions, 2015). There are many increments of speed/quality

combinations between highest speed and highest resolution. Most printer operators run the machine at one of these 'medium' settings (Print Manager of Company C, personal communication, March 4, 2015). Given this information the following printer requirements can be calculated:

Assuming

- 1 cushion averages 1.5 yard (appendix B)
- $61.5 / 1.32 = 41$ cushions/hour
- The printer selected would not be able to keep up with peak production. This necessitates multiple machines, multiple shifts, or lower resolution in order to satisfy peak production. The following chart shows how the speed of the JP5 compares to other textiles printers.

Digital Printer Speeds Linear m/hr for 1.45m (57") material



All data based on published data specs. not machine trials.

Figure 17: Textile Printing Speeds Compared, (See Appendix C)

Resolution is determined by the size, and density of the colorant that is laid down. It is usually expressed in dots per inch (DPI). Many small dots create a sharper image and fewer, larger dots create a grainier image. There are three aspects that determine the resolution of an image. The first is the dot size, second is the size of the grid that the dots are laid on, and third is the viewing distance.

Typical Viewing Conditions and Recommended Printing Resolutions by Application

Application	Typical Viewing Distance	Minimum Printing Resolution (dpi)	Perceived Printing Resolution (dpi) (at reading distance of 0.5m)
Fine Art	20 in. – 3 ft. 0.5 – 1 m	1,200	1,200 – 2,400
Small format prints, text, documents, technical graphics	20 in. – 3 ft. 0.5 – 1 m	600	600 – 1,200
Point-of-Purchase, Point-of-Display, Event Graphics	3 – 10 ft. 1 – 3 m	300	600 - 900
Directional signage, Vehicle wraps, Billboards, Building Wraps	> 10 ft. > 3 m	150	> 900

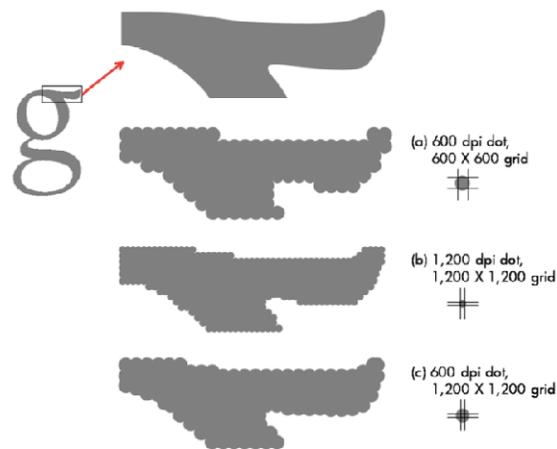


Figure 18: Understanding DPI, (Hewlett Packard, 2010)

The speed is affected by the speed capacity of the printer heads themselves but it is also affected by the time required to load digital images with the software. For the printer to ‘read’ the images they must be converted into a pixel by pixel map. This is known as a Raster file. The software that performs this operation is known as a Raster Image Processor (RIP). Many of the people who work with printers use this as a verb, i.e. they ‘RIP’ a file. This terminology will be used here.

During the observations of company C the print operator utilized a multi-functional process of RIPing, printing, batching, queuing, and machine minding. Minding the machine included checking the colors and addressing any issues, such as wrinkled fabric that occurred. The workflow was not continuous. The operator would begin RIPing a file, start printing a file that had been previously RIPed, queue component files that could be nested together, and eventually start printing the first file (Appendix A). Company C utilizes software developed for their specific workflow needs that helps the operators with many of these components. Not all files take the same amount of time to RIP. The larger the file, due to more complicated images or more yardage, the longer it takes to RIP. On average the files at company C take 4 minutes for every 3 yards (Software Manager of Company C, personal communication, March 04, 2015). The print operator at company C expressed that, with time and training a print operator can become very skilled at batching, queuing, RIPing, and printing in a rhythm that kept production smooth. The RIPing times were included in the observation and are part of the cycle times expressed on the future state map.

5) CNC cutters

- a. The cutter chosen for this future state map is the S3 produced by Zund (Zund Cutting System, 2012)
- b. The S3 is a knife cutter with the following specifications:
 - i. Vacuum hold down
 - ii. Continuous feed
 - iii. Multiple tool option
 - iv. Multiple fabric width options

About CNC cutters

CNC (computer numerically controlled) cutters have been used extensively in the signage industry to create banners, signs, and packaging. The use of digital technology for cutting textiles represents a massive change in textile based manufacturing (Ferguson, 2011); however, it has been growing steadily and is expected to continue to do so (Boer, 2011).

All CNC cutters are based on similar principles. They require a means of cutting, which can be a variety of blades, lasers, ultrasonic tools, and even high-pressure water. This paper focuses on blades and lasers, as they are the most common means of cutting textiles. In addition to cutting, there must also exist a way of moving the cutting device relative to the material. This is often accomplished by means of a head mounted on a movable gantry, set above a bed on which the material is spread. All of the motion and cutting action is Computer Numerically Controlled (CNC) which, means that it converts information from a Computer Aided Design (CAD) program into numerical data, to move the machine head relative to the material. This digital based information can easily be integrated into the resource management software to pair CAD information with customer orders (Glock, 2000).

CNC cutters can be of a high ply or low ply variety. In low ply cutting one layer of fabric is spread across the cutting area of the machine, held in place with vacuum forces, and then cut with the cutting head (Glock, 2000). Cutting equipment intended for production facilities usually has the capacity to advanced the fabric automatically to cut the next section. This advancing, securing, and cutting process can be repeated until the entire roll of fabric has been utilized, at which point a new roll must be load onto the cutting machine. In high ply cutting. Multiple layers are spread across the cutting area to a maximum height of 6 cm.

These layers are held in place with vacuum forces and cut using a cutting head that closely resembles the stack knife. Although multiple layers are cut simultaneously the issues associated with spreading, i.e. manual fabric alignment and waste are still problematic. Also the fabric must be sufficiently air permeable to allow the vacuum to hold the entire stack of material in place. Regardless of the cutting technique used, the fabric must be advanced and/or spread. The time required to set up the next layout of fabric can be a significant portion of the time required to cut and should be taken into account (Glock, 2000).

Laser cutters

There are also two primary differences in cutting heads lasers and knives. Laser cutters are a very precise cutting system that uses focused light to cut fabric. Laser cutting can create a “sealed” edge on many synthetic materials; caused by the material melting and fusing along the cut edge. Sealed edges can add strength to the seam and be especially beneficial for materials that are prone to fraying (Glock, 2000). Lasers are not good for all textile type because some textiles contain material that can create toxic fumes when burned. There is also some smoke and gas produced from all laser cutting processes which can contribute to a poor air quality. This smoke and gas is collected (ideally) by the vacuum system, used to secure the fabric, and by additional vacuum forces located in the cutting head. Laser cutting is also very difficult to utilize to cut multiple layers of fabric due the dispersion of light after the first layer of fabric.

Knife cutters

Knife cutting utilizes a variety of blade types. These can be a simple drag knife (similar to an Exacto brand blade) or roller knife (similar to a very sharp pizza wheel). The knife could also be a “driven” tool such as a tall straight blade or router, which has an additional motor to drive the tool. A driven tool can move with the gantry but also has movement in the vertical direction, as is the case with a tall blade, or rotational movement of the tool, as is the case with a router (Glock, 2000). A simple pressure activated cutting tool such as the drag knife or rotary blade is generally applied to single layer material spreads. A driven blade can, in some cases, be applied to a stack of material as tall as 11cm (Zund, 2015).

Integrating printers and cutters

To cut out a useful product using a digital cutting machine, the cut path must be aligned to the print. This is no minor task given that the printed materials need to be moved between the printer and the cutter, and may be stacked or rolled, or shipped. Even a small misalignment can cause an unacceptable defect resulting in the rejection of the entire product. This alignment process is known as “registration”. The process of registration is very important in the printing industry to align the cut path to the printing; it is also important to aligning the overlapping colors of the print itself. Registration most commonly utilizes marks printed on the material at the same time as the image. These registration marks are noted by either the machine or the operator and used to align the cut path.

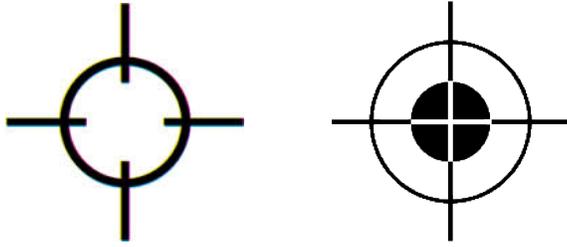


Figure 19: Common Registration Marks, (Wikipedia, 2014)

For accuracy's sake at least three or four registration marks are used for each image that will be cut (Mikkelsen Graphics Engineering, 2014). Once the registration marks on the print have been located, the machine can use the registration marks in the cut file to align the cut path. For stiffer materials where skewing is unlikely, alignment is relatively straightforward. For many textiles and materials such as vinyl sheeting and vehicle film, shifting, skewing, and distortion are possible in the material handling phases. These defects are overcome by adjusting the cut path based on the registration marks (Aeronaut, 2014; Mikkelsen Graphics Engineering, 2014).

There are a few ways to find, align, and adjust the registration marks of the printed material and the cut path. For low production facilities the registration marks can be located manually using a pointer on the cutting table. If these registration marks are shifted, as compared to the marks in the cut file, the software will distort the cut file to match. For higher production facilities where manual selection of registration marks would be unfeasible, a camera system can be installed that locates the registration marks automatically. For example Esko's i-cut vision system locates the registration marks, makes the necessary

adjustments to the cut file, and display's the cut line on an image of the printed material so that the operator can double check the results (Esko, 2015).



Figure 20: Showing Vinyl Decals Before Cutting and After Application for Esko's I-cut Vision System (Esko, 2015).

In the case of Aeronaut's Silicone Eye vision system (Aeronaut, 2014) registration marks can be omitted if the material has a repeating print. In this case a distinct point on the repeat can be used instead. The operator must manually select the same point on four repeats then the software can apply the necessary distortion to the cut path and apply it to all of the cut pieces for that table. This process would then be repeated after advancing the material.

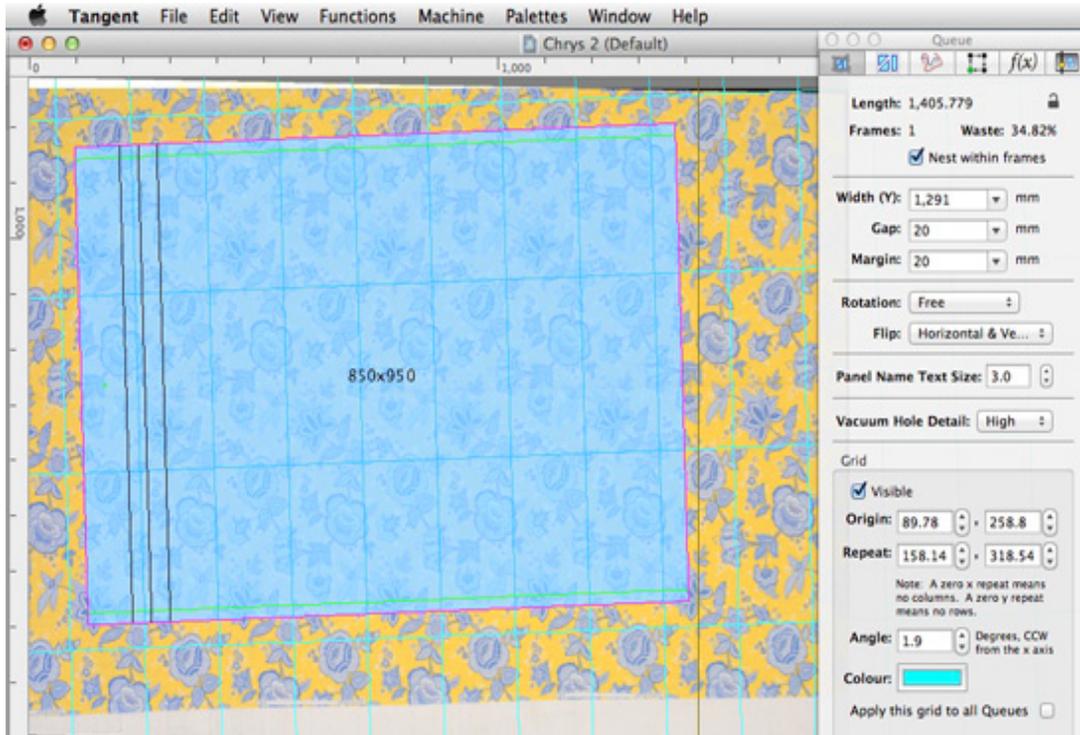


Figure 21: Aeronaut's Vision System Applying Distortion to the Cut Path Based on the Repeat of the Print, (Aeronaut, 2014).

Technology exists which combines both printing and cutting processes into the same equipment (Summa, 2015). In this case, the material is fed off a material roll across a very shallow bed where the image is applied using inkjet technology. The material is advanced as the ink is applied and after a certain distance, either the end of the image or a length determined by the machines capacity, the material is retracted back onto the material roll, the registration marks are aligned automatically, and cutting heads are applied to the previously cut area.



Figure 22: Summa DC4 Print/Cut System (Summa, 2015)

Due to the advancing and retracting of the material, this process can only be used with a stable substrate. It must also retain some level of stability after being cut so that the printing process can resume where it left off. Because of this, the machine is often used for sticker making (Summa, 2015). Stickers require cutting tools that cut through the adhesive vinyl top layer without cutting through the paper backing. The paper backing creates stable and consistent material handling. The benefits of this set up include the very small amount of space required for the equipment and no material handling required from substrate to finished product. The down sides include the fact that material choices are extremely limited and throughput is slower than print-then-cut setups.

- 6) The primary effects of integrating digital printing and cutting are felt in the inventory and cutting phases. The future state map incorporates few changes from the sewing station through to shipping.

Chapter 5: Discussion

In January 2013, Walmart announced it would buy an additional \$50 billion in U.S. products over the next 10 years, in an effort to grow U.S. manufacturing and encourage the creation of U.S. jobs. Walmart stated on their website “We believe we can create more American jobs by supporting more American manufacturing.” (Walmart, 2013). Walmart’s initiative offers the possibility for sales growth for products manufactured in America. The focus of this paper is to discover if digital printing and cutting technology could benefit a manufacturer who makes a textile-based, mass customizable product in the United States. By looking at the current structure of a particular manufacturer, the goal of this research was to understand the effects of this technology in a specific circumstance. Observations were made of a large cushion manufacturer who is currently operating (in addition to their large mass production facility) a small, domestic, mass customization department. By looking at the current manufacturing process of this mass customization department, and how digital cutting and printing technology could influence it, this research creates an improved understanding about how a Walmart supplier could benefit from this opportunity.

The manufacturer being observed produces furniture cushions to supply to Walmart and other large retailers. The vast majority of the cushions they manufacture are produced using a mass production model. The fabric is printed, cut, and sewn into an un-stuffed structure in one of several facilities located in Southeast Asia. The shells are then shipped to a facility in the United States where they are filled with cushioning material, sewn closed, boxed, and trucked to a retailer. This model is currently considered satisfactory by the manufacturer for the majority of their product, but does not allow for the rapid turnaround

required to compete in online retail markets, where quick response to emerging market demand is a critical factor. Cushions manufactured overseas will not qualify for enhanced sales within the framework of Walmart's new initiative.

Each of the large retailers that the manufacturer works with, including Walmart, have an online retail presence. If a customer finds the physical retail location to be out of stock or have limited selection, or would rather purchase online, the customer can order products directly through the retailer's website. These websites also offer a wider selection of fabric types and styles than can be found in a brick and mortar store. Due to the increased variety and rapid turnaround time, the manufacturer found that they needed a faster, more flexible model to fulfill these individual online orders. In response, they created a department that they refer to as the Made to Order (MTO) department. The MTO department fulfills all orders generated by the websites of the manufacturer's retail partners.

The Walmart.com website offers a variety of the manufacture's product, arranged by style. Styles are defined by the product dimensions, construction, and details such as trim, buttons and ties. The customer selects from a menu of options representing combinations of styles and fabric. This relatively modest amount of customization is defined as "customized standardization" in Lampel and Mintzberg's continuum of strategies (Figure 4, Lampel & Mintzberg, 1996).

In order to cater to online markets, the MTO department assembles cushions using two strategies. Strategy 1 (S1) is an extension of the mass production manufacturing that is utilized for the majority of their product figure 10). In S1, the MTO department pre-assembles batches of cushions in anticipation of customer orders. By cutting large quantity of

cushions simultaneously, this strategy minimizes the changeover times associated with manual processes. Using strategy 2 (S2), the MTO department waits until it has an order before assembling the product (figure 13). This minimizes the inventory and overproduction associated with S1. S1 is used to assemble cushions based on an annual forecast of common cushions that are predicted to sell. Any cushions that are not on hand when the customer orders them can be made at that time, employing S2.

The research found that digital printing and cutting create efficiencies along much of the supply chain but does not cause a reduction in assembly labor under all circumstances. The efficiencies that introducing technology created along the supply chain were noted using a future state value stream map (Figure 16). These efficiencies can be categorized as follows: reduction in waste as identified by lean theory, 'Made in America' brand extension, increase in manufacturing flexibility, and efficiencies associated with mass customization and reshoring.

Of the seven kinds of waste first identified in lean manufacturing, primary waste reductions were achieved by reducing overproduction, inventory, and transportation. The overproduction associated with S1 results in significant quantities of fabric and assembled product being stored for long periods of time, or sold at discount prices. Discussions held during observation of the facility often alluded to a need to find buyers for excess inventory. Discount sales of fabric and merchandise can erode margins, and create potential losses associated with selling a product below cost. Employing any system, including a digital printer and cutter based system, that allowed for demand-generated production could reduce the waste from overproduction.

This overproduction inherent to S1 has led to a large inventory system. The MTO department alone utilizes an approximately 9,500 sq ft inventory space. In addition to this space, the production floor is used to store an assortment of materials, as well as assembled and partly assembled goods. This 'production floor inventory' is more difficult to estimate and track. It also creates a visual clutter that may make the utilization of visual management systems nearly impossible

The primary inventory costs associated with the observed facility are carrying costs and opportunity costs. Carrying costs depend on two factors, the cost of capital invested in inventory and the maintenance of that inventory, including taxes, insurance, material degradation, and space occupied. This research has endeavored to exclude monetary figures from all data to maintain the confidentiality of the companies involved. Therefore estimation of the cost of capital, degradation, or the rents associated with inventory space will not be explored, and metrics of evaluation will be based on labor times and warehouse space as opposed to dollar figures.

In addition to occupying space that must be monitored and heated, the inventory itself must be tracked and handled. Cycle counts, which roll and unroll a small percentage of the fabric to ascertain the quantity of inventory on hand, are conducted daily. The labor associated with maintaining inventory was not calculated in this research, however it was not uncommon to see people coming and going, loading and unloading, in the inventory space. The number of the manufacturer's fabric/style combinations carried by retailers is expected to increase in the near future (MTO supervisor, personal communication, February 04, 2015). This may require even more resources to store inventory.

The future state map does not eliminate inventory entirely, due to the need to store base cloth, but substantial reductions can be expected. The lead times and minimum orders dictated by the supplying mills will determine the quantity of base cloth inventory on hand. The 'cutting storage' that appears on all of the VSM maps is a smaller fabric storage area in easy reach of the cutting table that may be able to accommodate the inventory associated with storing base cloth, thus eliminating any printed fabric from the MTO inventory facility.

The cost of inventory also includes opportunity costs. This is the return on capital that could have resulted had the capital been used for some other purpose (Hill, 2000). This cost reflects not only the quantity of capital tied up in inventory, but how long it is held in inventory. The value stream timeline is the sum of time spent at all the stages of the manufacturer's process. The following timetables describe the time spent from the capital investment in fabric until that fabric is converted into a form that can be sold to a customer.

Table 5: Total for S1 VSM Timeline

S1	Min	Max
Fabric supplier	6 weeks	8 weeks
Shipping	5 weeks	5 weeks
MTO warehouse	8 months	41 months
Cutter storage	1 week	20 week
Printing station	NA	NA
Cutting station	2.5 min	2.5 min
Shell cart	30 min	1 week
Sewing station	1.17 min	1.17 min
Order table	*	*
Finishing station	3 min	3 min
Finished Goods Inventory	0 months	29 months
Packing station	1 min	1 min
Total	21 months 37.67 min	78 months 2 week 7.67 min
Total value added time	7.67 min	7.67 min

Table 6: Total for S2 VSM Timeline

S2	Min	Max
Fabric supplier	6 weeks	8 weeks
Shipping	5 weeks	5 weeks
MTO warehouse	8 months	41 months
Cutter storage	1 week	20 week
Printing station	NA	NA
Cutting station	9.5 min	9.5 min
Shell cart	0 min	30 min
Sewing station	3 min	3 min
Order table	0 min	0 min
Finishing station	3 min	3 min
Finished Goods Inventory	0 months	0 months
Packing station	1 min	1 min
Total	11 months 13.5 min	49 months 1 week 46.5 min
Total value added time	16.5 min	16.5 min

Table 7: Totals for Future State VSM Timeline

Future State	Min	Max
Fabric supplier	4 weeks	10 weeks
Shipping	3 hours	8 hours
MTO warehouse	6 weeks	42.5 weeks
Cutter storage	NA	NA
Printing station	5 min	5 min
Cutting station	1 min	1 min
Shell cart	NA	NA
Sewing station	1 min	3 min
Order table	NA	NA
Finishing station	3 min	3 min
Finished Goods Inventory	NA	NA
Packing station	1 min	1 min
Total	10 weeks 3 hrs 11 min	13 months 8 hrs 13 min
Total value added time	11 min	13 min

The maximum amount of time that capital could be tied up in inventory is 78 months, see. This would result from an unlikely, but not impossible, set of circumstances: the manufacturer ordering excess fabric; the retailer having a proprietary clause on fabric usage, which results in the manufacturer needing to store excess outdated fabric that the retailer doesn't reorder; and finally, the manufacturer not finding a secondary retailer to purchase the fabric/finished goods, resulting in liquidation at the subsequent warehouse sale. For more details on this processes see figure 11 and figure 13. A 78-month inventory cycle results in a significant amount of opportunity cost. Although an inventory cycle of that length represents the extreme, sub-optimal inventory cycles and their associated opportunity costs are a common occurrence for the manufacturer.

Employing a digital printing operation would have a significant effect on the inventory for this manufacturer. From observations, the inventory space is used to store primarily fabric and finished goods. The future state map demonstrates a workflow free of finished goods inventory as well as pre-printed fabric. The reduction in inventory can be roughly calculated:

Assuming,

- The inventory facility was approximately 50% finished goods and 50% fabric storage (from observation).
- 70% of the fabric used is printed (MTO supervisor, personal communication, February 11, 2015).

Then utilizing a digital printer could free $.5 + (.5 \times .3) = .85$ or 85% of the inventory space. $0.85 \times 9,500$ is approximately 8,075 sq. ft. of inventory space.

In addition to reduction of waste associated with inventory, waste associated with transportation also decreased significantly. The shipping times from fabric supplier to production facility change from the current state maps to the future state map from 5 weeks to less than 1 day. The reduction of waste associated with transportation is even more remarkable given that the manufacturer is located within two hours of two mills capable of supplying woven fabrics already treated and ready for printing.

An additional efficiency identified in the research is the possibility of 'Made in America' brand expansion. This research was undertaken in part to understanding about how a Walmart supplier could exploit the 'Made in America' initiative in which Walmart has invested. The future state map for the MTO department would create an opportunity for some

of the company's products to qualify for Walmart's initiative, which may increase sales. In addition to the initiative, there have also been numerous articles in trade publications such as *Women's Wear Daily* and *Furniture/Today* citing increased consumer demand for 'Made in America' products. In some cases this demand is specifically for textiles and upholstery (Furniture/Today Staff, 2012; WWD Staff, 2014; Hodnett, 2014; Kennedy, 2012). The relatively small scale of the MTO department may allow the manufacturer to offer a 'Made in America' cushion as a means of gauging customer demand. If demand is high then a viable model will have been developed within the company that may have potential for expansion. If demand is low then the department will still be positioned to address the needs of growing internet-based sales (El Sawy, Malhotra, Gosain, & Young, 1999).

Beyond 'Made in America' brand extension, there are additional benefits associated with manufacturing a product in the United States. When the manufacturing process is paid for in one currency and the product paid for in another, there are risks associated with currency and wage fluctuation (Dhanani, 2004). Domestically produced goods avoid costs associated with tariffs and trade agreements that have an influence on margins (Ellis, 2014). Manufacturing domestically also allows for all aspects of the process to be conducted in a shared language, culture, and infrastructure. This shared business environment will eliminate the five most common difficulties associated with overseas production: differences in culture, communication problems, different time zones, sharing technology, and obtaining technical support (Handfield, 1994). This is in addition to the previously mentioned reduction in shipping costs. Although these aspects are not directly noted in the future state map, they are

potentially beneficial effects stemming from the implementation of the process there outlined.

Another efficiency identified in the future state map is an increase in the flexibility of the system. The seasonal nature of cushion sales along with the trend based demand associated with textiles and housewares can create scheduling uncertainty. Due to the increasing levels of product variety and customization associated with internet sales, the ability to respond to customer orders with variety and short turnaround times can provide a competitive advantage (Reichhart & Holweg, 2007). Addressing demand uncertainty, product variety, and short lead times requires a flexible, responsive manufacturing flow, capable of being customer focused and demand driven (Reichhart & Holweg, 2007). Digital printing and cutting technology would allow the manufacturer to address seasonal variability through smaller orders from local fabric suppliers. The print-on-demand capability of the digital printer would allow for a huge virtual inventory of designs without the need for increased fabric storage. The designs could also be updated mid-season to reflect consumer trends. The flexibility of the printer could eliminate a significant portion of the risk associated with using inventory to address demand fluctuations.

The efficiencies associated with mass customization are also in evidence in the future state map. These ‘economies of integration’ were identified by Piller, Moeslein, and Stotko (2004) and arise from three sources:

- Postponing some activities until an order is placed,
- Gaining more precise information about market demands and

- The ability to increase loyalty by directly interacting with each customer (F. T. Piller, Moeslein, & Stotko, 2004).

Postponing production until the order will allow for partial or complete elimination of the finished goods inventory, freeing space, resources, and capital. The flexibility offered by the printer will allow for efficient response to changing consumer demands. The final economy of integration however, poses difficulty for a manufacturer who relies on a third party to interact with the customer. The use of an external retailer's online marketplace eliminates any customer loyalty or appreciation that may result from the manufacturer's flexibility. Some form of brand extension, either with an 'in house' retail option or a strong partnership with an external retailer may help offset the cost of technology investment.

The implementation of digital printing and cutting technology requires forethought and investment in both equipment and personnel. A manufacturer must have a clear understanding of their production process and the goals they hope to achieve. Digital printing and cutting technology has limitations that may or may not work for a given organization. Using automated processes may require changes in information sharing and tracking. It is also important to consider whether the investment will be cost effective. Ultimately, the decision to reshore will be driven by the economic realities of the manufacturer. However, as this research shows, the benefits are felt along much of the supply chain and are not exclusively labor savings.

Value stream mapping is considered a principle tool of lean manufacturing theory. Its use in this research was effective at highlighting the reductions in shipping, inventory, and cutter changeover time. The visual nature of the tool allows for clear communication between

co-workers and departments. This makes improvements easier to discuss and agree on. A value stream map is a living document that anyone in the manufacturing process can use to identify further efficiencies in the future. The methodology gives a clear and simple framework by which to consider the viability of converting to a domestic, technology-based process. This easy to use framework to determine goals and analyze flow may also encourage reshoring.

There are a wide variety of digital printers and cutters on the market. However, not all features are compatible with all products. The colorant and application method of a printer, and the cutting method of the cutter, must be closely aligned with the base cloth being utilized. Thus, it is important that the purchaser have a clear understanding of the goals and requirements of their product and the facility's capacity to achieve them.

Digital technology also allows for integrated transfers of digital information. There may be opportunities associated with eliminating information handoffs and human error. On the other hand, all machines require maintenance and can be susceptible to break downs. Having rapid, high quality support is essential to the efficient operation of the technology. Finally, as demonstrated during the observations at Company C, a skilled technician is required to operate the machines. These aspects must be considered when deciding on the viability of digital cutting and printing technology.

Based on observations of other facilities and calculations, the projected labor times associated with utilizing digital printing and cutting technology for this manufacturer fell between the labor times of S1 and S2. This does not, however, include the labor times that are required for inventory maintenance. It is also important to note that in S1, unlike the

‘future state’, the labor involved in printing is absorbed by the fabric supplier. The ‘future state’ also satisfies the goals of mass customization: the capability to produce personalized goods, with near mass production costs and efficiency. It does this while creating a flexible, responsive production system that eliminates significant amounts of inventory.

Digital printing and cutting technology may not be viable for all manufacturers considering reshoring. Bellemare, et. al, (2013) found that the difficulties of implementing technologies in textile based manufacturing commonly stem from five issues:

- A lack of technological fluency on the part of both managers and labor,
- A strong resistance to change in a very traditional industry still relying on outdated work habits,
- A lack of proactivity and use/implementation of strategic or technical watches,
- Minimal investment due in part to the difficulty in borrowing and
- The bad press often given to technology and mass customization implementations by some of the important industry actors.” (Bellemare, et. al, p. 5, 2013)

Overcoming these issues requires strategic planning, clear goals, and an easily understood framework for discussing and decision-making. Some manufacturers may find the technology to not be cost effective. However, given the size of inventory and associated opportunity costs, the cushion manufacturer observed in this study is a good candidate for the investment.

Opportunities for Future Research

The research conducted had some limitations that stemmed from not having appropriate digital printers and cutters for time trials. Finding or assembling a similar technology chain as the one described in the future state map could facilitate more effective timing data. This technology chain would allow for the following:

- Time trials that utilize applicable print designs with bar codes and registration marks to determine overall process times.
- Identifying appropriate software for driving machines.
- Determining if software integration could create efficiencies with information flows.
- Determining if nesting software be required. If so, can it be found ‘off the shelf’ or would it need to be developed?

In addition to gaining more precise information there are further efficiencies that may be gained by creating a partnership with a domestic textile mill. In order to determine the relationship and opportunities available, the following would need to be addressed:

- Determine if the ‘‘ready to print’ fabric available at the mill an acceptable option.
- Determine if inventory can be further reduced through an agreement with the mills.

It is also important to note that the Future State Map is intended to be a living document that can be updated by anybody in the system who identifies an improvement. Therefore there are many opportunities for future improvements to the system outlined here that will develop as the system is updated.

REFERENCES

- Aeronaut. (n.d.). Siliconeye. Retrieved from <http://www.aeronaut.org/siliconeye.html>
- André, P. S., & Ferreira, R. A. S. (2014). Colour multiplexing of quick-response (QR) codes. *Electronics Letters*, 50(24), 1828-1829. doi:10.1049/el.2014.2501
- Au, K. F., Wong, W. K., & Zeng, X. H. (2006). Decision model for country site selection of overseas clothing plants. *The International Journal of Advanced Manufacturing Technology*, 29(3-4), 408-417. doi:10.1007/s00170-005-2505-4
- Autor, D. (2010). *The polarization of job opportunities in the U.S. labor market: Implications for employment and earnings*. (). Washington, United States, Washington: Brookings Institution Press. Retrieved from ProQuest Central Retrieved from <http://search.proquest.com.prox.lib.ncsu.edu/docview/845241447?accountid=12725>
- Barboza, D. (2010). After suicides, scrutiny of China's grim factories. Retrieved from <http://www.nytimes.com/2010/06/07/business/global/07suicide.html?pagewanted=all>
- Bellemare, J., Carrier, S., & Baptiste, P. (2013). Mass customisation: Why is the apparel industry so late? *Annals of the University of Oradea. Fascicle of Textiles, Leatherwork*, 14(2), 5-10. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=91671724&site=ehost-live&scope=site>
- Bhatia, N., & Drew, J. (2006). Applying lean production to the public sector. McKinsey and Company Insights & Publications, jan, 19 2015.

Black, J. R. (2008). *Lean production: Implementing a world-class system*. New York, NY:

Industrial Press. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/UNCb5898706>

BMW. Build your own. Retrieved from

<http://www.bmwusa.com/standard/content/byo/default.aspx>

Boër, C. R. (2013). In Bettoni A., Pedrazzoli P. (Eds.), *Mass customization and sustainability an assessment framework and industrial implementation* [electronic resource]. S.l.]:

Springer London. Retrieved from

<http://www2.lib.ncsu.edu/catalog/record/DUKE005916864>; [Get an online version \(Duke only\)](#)

http://proxy.lib.duke.edu/login?url=http://getit.duke.library.duke.edu/?sid=sersol&SS_jc=TC0000904409&title=Mass%20Customization%20and%20Sustainability%20An%20assessment%20framework%20and%20industrial%20implementation; [Get an online version \(NCSU only\)](#)

<http://proxying.lib.ncsu.edu/index.php?url=http://link.springer.com/openurl?genre=book&isbn=978-1-4471-5115-9>

Boer, M. (2011). 2011 wide-format inkjet graphics forecast analysis. *My Print Resource*,

MAY 13, Feb, 22 2015.

Bogue, R. (2014). What future for humans in assembly? *Assembly Automation*, 34(4), 1-13.

Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=100067736&site=bsi-live&scope=site>

Brooks Brothers.Made-to-measure. Retrieved from <http://www.brooksbrothers.com/mtm-about/mtm-about,default,pg.html>

Bureau of Labor Statistics. (2013). International labor comparisons. Retrieved from http://www.bls.gov/ilc/china.htm#data_tables

Clean Clothes Campaign. (2015). Rana plaza. Retrieved from <http://www.cleanclothes.org/ranaplaza>

Conerly, B. (2014).

Reshoring or offshoring: U.S. manufacturing Forecast 2015-2016. Retrieved from <http://www.forbes.com/sites/billconerly/2014/09/02/reshoring-or-offshoring-u-s-manufacturing-forecast-2015-2016/>

Curtis, M. (2014). Reshoring gains momentum Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=95445180&site=ehost-live&scope=site>

Dal, V., Akçagün, E., & Yilmaz, A. (2013). Using lean manufacturing techniques to improve production efficiency in the ready wear industry and a case study. *Fibres & Textiles in Eastern Europe*, 21(4), 16-22. Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=90542851&site=ehost-live&scope=site>

Dell. Dell.com. Retrieved from <http://www.dell.com/>

Dennis, P. (2007). *Lean production simplified: A plain language guide to the world's most powerful production system*. New York: Productivity Press. Retrieved from

<http://www2.lib.ncsu.edu/catalog/record/NCSU1970003>

Dhanani, A. (2004). The management of exchange-rate risk: A case from the manufacturing industry. *Thunderbird International Business Review*, 46(3), 317-338.

doi:10.1002/tie.20011

Diehl, K. (2005). When two rights make a wrong: Searching too much in ordered environments. *Journal of Marketing Research*, 42(3), 313-322. Retrieved from

<http://www.jstor.org/stable/30162375>

eastmancuts.com. (2015). Blue streak II. Retrieved from

<http://www.eastmancuts.com/products/manually-operated-cutting-machines/straight-knives/blue-streak-ii-reg.html>

Ellis, K. (2014). Execs declare made in USA real deal. *WWD: Women's Wear Daily*, 207(86), 6-1. Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=95803848&site=ehost-live&scope=site>

El Sawy, O. A., Malhotra, A., Gosain, S. J., & Young, K. M. (1999). It-intensive value innovation in the electronic economy: Insights from marshall industries. *MIS Quarterly*, 23(3), 305-335. Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=2635124&site=bsi-live&scope=site>

Erber, G., & Sayed-Ahmed, A. (2005). Offshore outsourcing. *Intereconomics*, 40(2), 100-112. doi:10.1007/s10272-005-0141-8

Esko. (2015). i-cut vision pro. Retrieved from <http://www.esko.com/en/products/overview/i-cut-vision-pro/overview/>

Ferguson, T. (2011). NCSU's textile eLearning Resource/Printing. Retrieved from <https://equella.wolfware.ncsu.edu/file/486857a6-83f0-48ec-8387-b1a0e2f9cd17/1/Printing/player.html>

Fralix, M. T. (2001). From mass production to mass customization. *Journal of Textile & Apparel Technology & Management: JTATM*, 1(2) Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=TDH0642804200102853&site=ehost-live&scope=site>

Free, M. (2012, June 27). Is the re-shoring of manufacturing A trend or A trickle. *Forbes*.

Furniture/Today staff. (2012). Patriotism drives demand for made-in-USA product. *Furniture/today*, 36(47), 36-37. Retrieved from <http://search.ebscohost.com.prox.lib.ncsu.edu/login.aspx?direct=true&db=bth&AN=78907940&site=bsi-live&scope=site>

- Ganesan, R. (2015). In SpringerLink (Online service) (Ed.), *The profitable supply chain electronic resource: A practitioner's guide*. Berkeley, CA: Apress : Imprint: Apress. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/NCSU3342177>; Get an online version (NCSU only) (<http://proxying.lib.ncsu.edu/index.php?url=http://link.springer.com/openurl?genre=book&isbn=978-1-4842-0527-3>)
- Glock, R. E. (2000). In Kunz G. I. (Ed.), *Apparel manufacturing : Sewn product analysis*. Upper Saddle River, NJ: Prentice. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/NCSU1086839>
- Goforth, K. A., Hodge, G., & Joines, J. A. (2011). Adapting lean manufacturing principles to the textile industry. *Production Planning & Control*, 22(3), 237-247. doi:10.1080/09537287.2010.498577
- Grant Thornton LLP. (2010). *Supply chain solutions part 1 of 3*. ().World Trade 100 Magazine.
- Gunn, T. G. (1992). *Using information system as a competitive weapon. 21st century manufacturing: Creating winning business performance*. (pp. 137). New York, N.Y: HarperCollins.
- Günther, O. (2008). In Kletti W., Kubach U. (Eds.), *RFID in manufacturing*. Berlin: Springer. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/DUKE003985603>

Handfield, R. (1994). US global sourcing: Patterns of development. *International Journal of Operations & Production Management*, 14(6), 40-51. doi:10.1108/01443579410062077

Hill, J. E. (2000). *APICS Series on Resource Management : Basics of Supply Chain Management*. Boca Raton, FL, USA: CRC Press. Retrieved from <http://www.ebrary.com>

Hewlett Packard. (2010). Understanding DPI.

Hodnett, C. W. (2014). Shoppers still buying american. *Furniture/today*, 38(26), 1-12.

Retrieved

from <http://search.ebscohost.com.prox.lib.ncsu.edu/login.aspx?direct=true&db=bth&AN=94776169&site=ehost-live&scope=site>

Huynh, M., Zhong, X., & Ghimire, P. (2014). Developing a QR Code/barcode processor with a user-defined database feature. *Business Studies Journal*, 6, 29-44. Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=100265511&site=bsi-live&scope=site>

Inala, K. (2007). Assessing product configurator capabilities for successful mass

customization. (481). Retrieved from http://uknowledge.uky.edu/gradschool_theses/481

International Trade Administration, Office of Textile and Apparel (OTEXA). (2014).

MAJOR SHIPPERS REPORT-top ten top ten U.S. general imports. International Trade Administration.

- Iyengar, S. S., & Lepper, M. R. (2000). When choice is demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology*, 79(6), 995-1006. doi:10.1037/0022-3514.79.6.995
- Jamieson, D., Hossain, E. & Bhasin, K. How bangladesh garment industry traded workplace safety for jobs. Retrieved from http://www.huffingtonpost.com/2013/05/23/bangladesh-garment-industry_n_3288266.html
- Jitpaiboon, T., Dobrzykowski, D. D., Ragu, N., T., & Vonderembse, M. A. (2013). Unpacking IT use and integration for mass customisation: A service-dominant logic view. *International Journal of Production Research*, 51(8), 2527-2547. doi:10.1080/00207543.2012.720727
- Kato, A., & Sato, T. (2014). The effect of corruption on the manufacturing sector in india. *Economics of Governance*, 15(2), 155-178. doi:10.1007/s10101-014-0140-y
- Kehoe, D. F., & Boughton, N. J. (2001). New paradigms in planning and control across manufacturing supply chains. *International Journal of Operations & Production Management*, 21(5), 582. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=7306903&site=bsi-live&scope=site>
- Kennedy, C. (2012). American-made, and proud of it? *Gifts & Decorative Accessories*, 113(8), 14-14. Retrieved

from <http://search.ebscohost.com.prox.lib.ncsu.edu/login.aspx?direct=true&db=bth&AN=83363743&site=bsi-live&scope=site>

Kenney, C. (2011). In Health Sector Management Collection. (Ed.), Transforming health care : Virginia mason medical center's pursuit of the perfect patient experience. Boca Raton: CRC Press. Retrieved from

<http://www2.lib.ncsu.edu/catalog/record/DUKE005315698>

Lampel, J., & Mintzberg, H. (1996). Customizing customization. Sloan Management Review, 38(1), 21-30. Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=9702180916&site=ehost-live&scope=site>

Lesser, R. B. (2014). Intelligent manufacturing: Reviving U.S. manufacturing including lessons learned from delphi packard electric and general motors. Boca Raton: CRC Press, Taylor & Francis Group. Retrieved from

<http://www2.lib.ncsu.edu/catalog/record/NCSU3042891>

Lim, H., Istook, C. L., & Cassill, N. L. (2009). Advanced mass customization in apparel. Journal of Textile & Apparel Technology & Management (JTATM), 6(1), 1-16.

Retrieved from

<http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=61228767&site=ehost-live&scope=site>

Moser, H., & Manivannan, S. M. (2010). Creating a low-cost model. *Supply Chain Europe*, 19(6), 44-45. Retrieved from

<http://search.proquest.com.prox.lib.ncsu.edu/docview/820882312?accountid=12725>

MS Printing Solutions. (2015a). JP5. Retrieved from <http://www.msitaly.com/machines/19-ms-jp5-evo>

MS Printing Solutions. (2015b). MS LARIO. Retrieved from

<http://www.msitaly.com/machines/23-ms-lario>

National Science Foundation. (2010). Global S&E labor force. Retrieved from

<http://www.nsf.gov/statistics/seind10/c3/c3s5.htm>

Nike.Nike ID. Retrieved from http://www.nike.com/us/en_us/c/nikeid

Obama, B. (2012). *Remarks by the president in state of the union address*. Presented at Congress

Oh, H., Yoon, S., & Shyu, C. (2008). How can virtual reality reshape furniture retailing? *Clothing and Textiles Research Journal*, 26(2), 143-163.

doi:<http://dx.doi.org.prox.lib.ncsu.edu/10.1177/0887302X08314789>

Pålsson, H., & Johansson, O. (2009). Supply chain integration obtained through uniquely labelled goods: A survey of swedish manufacturing industries. *International Journal of Physical Distribution & Logistics Management*, 39(1), 28-46.

doi:10.1108/09600030910029174

- Piller, F. T. (2004). Mass customization: Reflections on the state of the concept. *International Journal of Flexible Manufacturing Systems*, 16(4), 313-334.
- Piller, F. T., Moeslein, K., & Stotko, C. M. (2004). Does mass customization pay? An economic approach to evaluate customer integration. *Production Planning & Control*, 15(4), 435-444. doi:10.1080/0953728042000238773
- Pine II, B. J., & Victor, B. (1993). Making mass customization work. *Harvard Business Review*, 71(5), 108-117.
- Plumer, B. (2013, September 5). The U.S. may have more manufacturing jobs than we think. *The Washington Post*
- Pope, C. (2008). Lean's last hand. *Industrial Engineer*, 40(7), 35-39. Retrieved from <http://search.proquest.com/prox.lib.ncsu.edu/docview/231518012?accountid=12725>
- PrestoPhoto. Understanding color. Retrieved from <http://www.prestophoto.com/help/Understanding+Color>
- Purina. (2015). New just right by purina makes personalized dog food a reality. Retrieved from <https://www.purina.com/dogs/understanding-dog-food/new-just-right-by-purina-makes-personalized-dog-food-a-reality>
- Reichhart, A., & Holweg, M. (2007). Creating the customer- responsive supply chain: A reconciliation of concepts. *International Journal of Operations & Production Management*, 27(11), 1144-1172. doi:10.1108/01443570710830575

Republican National Committee. (2014). Restoring the American dream: Economy & jobs.

Retrieved from <https://www.gop.com/platform/restoring-the-american-dream/>

Reshoring Initiative. (2015). Bringing manufacturing back home. Retrieved from

<http://www.reshorennow.org/>

Rother, M. (1999). In Lean Enterprise Institute., Shook J. (Eds.), *Learning to see: Value*

stream mapping to create value and eliminate muda. Cambridge, MA: Lean Enterprise

Institute, 2009. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/NCSU2700642>

Ru, K. (2002). Adoption of new technology for higher productivity unavoidable. *Textile*

Magazine-Madras-, 43, 65-68.

Ruamsook, K., Russell, D., & Thomchick, E. (2009). Sourcing from low- cost countries.

International Journal of Logistics Management, 20(1), 79-96.

doi:10.1108/09574090910954855

Saporito, B. (2013). How Walmart plans to bring back ‘Made in America’. Retrieved from

<http://business.time.com/2013/04/12/how-walmart-plans-to-bring-back-made-in-america/>

Satam, D., Liu, Y., & Hoon, J. L. (2011). Intelligent design systems for apparel mass

customization. *Journal of the Textile Institute*, 102 (4), 353-365.

doi:10.1080/00405000.2010.482351

Select USA. (2014). The textile industry in the United States. Retrieved from

<http://selectusa.commerce.gov/industry-snapshots/textile-industry-united-states>

- Senanayake, M. (2004). Mixed mass production and mass customization: Best practices for apparel.
- Serrano, I., Ochoa, C., & Castro, R. D. (2008). Evaluation of value stream mapping in manufacturing system redesign. *International Journal of Production Research*, 46(16), 4409-4430. doi:10.1080/00207540601182302
- Shelton, R. K., & Wachter, K. (2005). Effects of global sourcing on textiles and apparel. *Journal of Fashion Marketing & Management*, 9(3), 318-329. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=20132796&site=ehost-live&scope=site>
- Shima Seki.Sip-160f3. Retrieved from <http://www.shimaseiki.com/product/print/sip160f3/>
- SoftWear Automation Inc. (2014). SoftWear automation inc. Retrieved from <http://www.softwearautomation.com/>
- Summa. (2015). Summa DC4 thermal transfer printer. Retrieved from http://www.summa.be/html_en/products/dc4.php
- Sung, M. W. (2013). Reshoring textiles? *Textile Asia*, 44(2), 3-3. Retrieved from <http://search.ebscohost.com/login.aspx?direct=true&db=tdh&AN=86234614&site=ehost-live&scope=site>
- Taj, S. (2008). Lean manufacturing performance in china: Assessment of 65 manufacturing plants. *Jnl of Manu Tech Mnagmnt*, 19(2), 217-234. doi:10.1108/17410380810847927

The Economist Print Edition. (2002, Sep 19th). Spitting image. *The Economist Print Edition, Technology Quarterly: Q3 2002*

The Recycler. (2013). Epson reveals secrets behind development of micro piezo technology. Retrieved from <http://www.therecycler.com/posts/epson-reveals-secrets-behind-development-of-micro-piezo-technology/>

Timbuk2. Build your own. Retrieved from http://www.timbuk2.com/customizer?gclid=Cj0KEQiAreilBRDzrNfb6uqX4fwBEiQAk-MRYzy_YWya4IW5Mcdguxrt3udnqQnDsgWv6AMPhe4rNpAaAu5i8P8HAQ

Transparency International. (2014). Corruption perception index 2014: Results. Retrieved from <http://www.transparency.org/cpi2014/results>

U.S. Department of Commerce, Select USA. (2014). The textile industry in the united states. Retrieved from <http://selectusa.commerce.gov/industry-snapshots/textile-industry-united-states>

U.S. Department of Labor, Bureau of Labor Statistics. (2015). Manufacturing employment, all employees 1960-2015. Retrieved from <http://www.bls.gov/iag/tgs/iag31-33.htm>

Walmart. (2013). Walmart to boost sourcing of U.S. products by \$50 billion over the next 10 years. Retrieved from <http://news.walmart.com/news-archive/2013/01/15/walmart-to-boost-sourcing-of-us-products-by-50-billion-over-the-next-10-years>

Wankel, C. (2008). Ethical manufacturing. *21st century management: A reference handbook*. (pp. 461) SAGE Publications, Inc. doi:<http://dx.doi.org/10.4135/9781412954006>

Wikipedia. (2014). Printing registration. Retrieved from http://en.wikipedia.org/w/index.php?title=Printing_registration&oldid=627943586

Womack, J. P. and Jones D. T. (2003). *Lean thinking: Banish waste and create wealth in your corporation*. New York: Free Press. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/NCSU1979833>

Womack, J. P., Jones D. T. and Roos D. (1991) *The machine that changed the world : How Japan's secret weapon in the global auto wars will revolutionize western industry*. New York, NY: Harper Perennial. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/DUKE004147386; Publisher description> (<http://proxy.lib.duke.edu/login?url=http://www.loc.gov/catdir/description/hc044/91055106.html>)

Womack, J. P. (2003). In Jones D. T. (Ed.), *Lean thinking : Banish waste and create wealth in your corporation*. New York: Free Press. Retrieved from <http://www2.lib.ncsu.edu/catalog/record/NCSU1979833>

WTO. (2015). Understanding the WTO: The agreements. Retrieved from http://www.wto.org/english/thewto_e/whatis_e/tif_e/agrm5_e.htm

WWD staff. (2014). Production playing field leveling out worldwide. *WWD: Women's Wear Daily*, 208(20), 8-1. Retrieved

from <http://search.ebscohost.com.prox.lib.ncsu.edu/login.aspx?direct=true&db=bth&AN=97402796&site=bsi-live&scope=site>

Yardley, J. (2013, May 22). Report on deadly factory collapse in Bangladesh finds widespread blame. *New York Times*, pp. A5.

Zhang, Q., & Hathcote, J. (2008). Factors influencing apparel imports from china. *Clothing and Textiles Research Journal*, 26(23), 23-40. doi:10.1177/0887302X07305922

Zund. (2015). Pneumatic oscillating tool. Retrieved from <http://www.zund.com/en/pneumatic-oscillating-tool>

Zund Cutting Systems. (2012, November, 15th). Cutting Textile Material. Retrieved from https://www.youtube.com/watch?v=lw_pdnOKgOc

APPENDICES

Appendix A- Company C Observation Data

JP5 operator Activities

0:07:02 Starts 'RIPing' 5 yrd print
0:09:21 Starts printing 4 yrd print
0:15:58 Finished printing 4 yrd print
0:16:14 Print done 'RIPing'/Starts printing 5 yrd print
0:21:55 Loads 2 yrd print
0:23:33 Finished with 5 yrd print/ begins previously loaded 1 yrd print
0:25:25 Finished with 1 yard print/ starts row of swatches
0:27:43 Finished with row of swatches/starts 2 yrd print
0:31:10 Finished with 2 yrd print

Total time

24:08 Total printing process with RIP, loading, and printing 7.5 yrds

Time per yard 3:10 min

Heat setting Activities

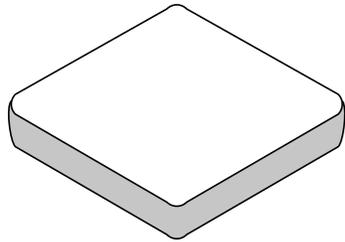
0:02:47 Begin the heatset process of 1 yrd print
0:04:18 Finish the heatset process of 1 yrd print

Total time

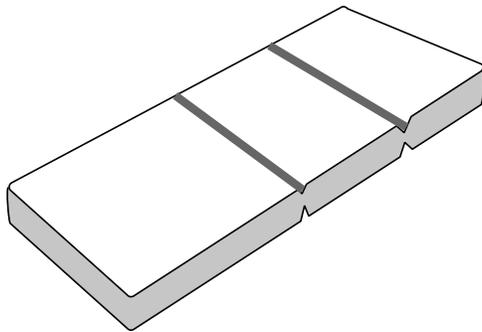
0:01:31 Total heat set time of 1 yrd of fabric

Time per piece 1:31 min

Appendix B- *Cushion Manufacturer's Most Common Cushions*



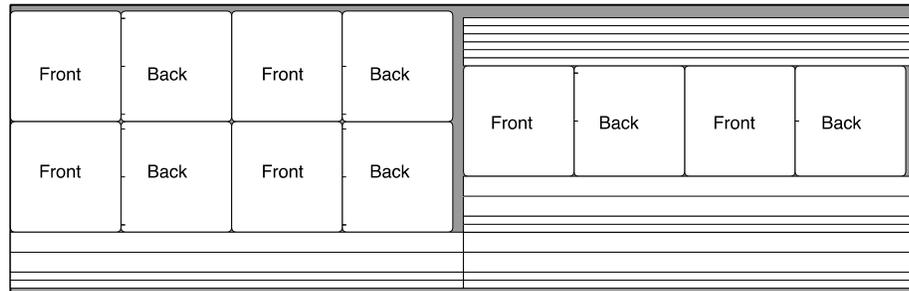
Small Cushion



Large Cushion

Appendix B- *Cushion Manufacturer's Most Common Cushions Cont.*

6 Small cushions

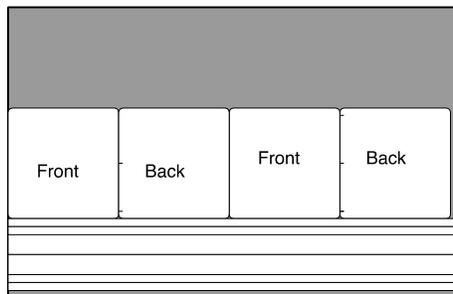


Fabric Length: 170"

Efficiency: 94%

Average fabric length/Cushion: 28.3"

2 Small cushions

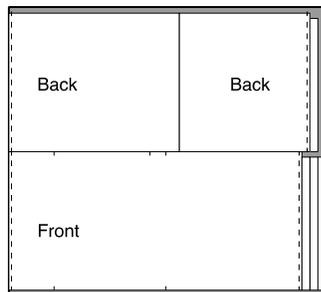


Fabric Length: 85"

Efficiency: 62%

Average fabric length/Cushion: 42.5"

1 Large cushion



Fabric Length: 59"

Efficiency: 95%

Average fabric length/Cushion: 59.0"

Appendix C-Printer Data

MS	High Quality	High Speed	Resolution	Grey levels	Drop size	Max Width
LaRio	2100 lin met/hr	4,500 lin met/hr				
MS JPKevo	350 Lin. m/hr	640 lin m/hr				
MS JP7	180 lin. m/hr	335 lin. m/hr	600 dpi x 600 dpi	16		
MS JP6	90 lin. m/hr	210 lin. m/hr				
MS JP5evo	50 lin. m/hr	100 lin. m/hr				
Leopard	Kyocera KJ4B					
QualiJet	80 lin. m/hr	210 lin. m/hr	600 dpi x 600 dpi	16	Variable 4-72 pl	180 cm / 71"
CET Color	Ricoh Gen5					
Q5-1000 h		61 Lin. m/hr	600 dpi x 600 dpi		5, 10, 15 pl	240cm / 94.5"
Q5-1000 hl		73 Lin. m/hr	600 dpi x 600 dpi		5, 10, 15 pl	320cm / 126"
Longier	Ricoh Gen5					
RU 3200		55 Lin. m/hr	600 dpi x 1200 dpi		variable 7- 35pl	320cm / 126"
Gandy	Ricoh Gen5					
softjet 3304		106 Lin. m/hr	1200 dpi x 1200 dpi		variable 7- 35pl	180, 250, 330cm / 71, 98, 130"

Appendix D-Cutting Data

The cut times used here rely on the following assumptions.

- The Zund S3 can cut at 40"/sec when cutting a straight line settings (National Sales Manager, personal communication, March 5, 2015).
- The video recommended by the Zund Director of Marketing and Communications, accurately reflects file and material loading times (personal communication, March 3, 2015; Zund Cutting System, 2012).
- Although max speed is quoted it is unlikely that the machine will run at max speed during most cutting operations.

Cutter Speed Data

Gerber			
Z1'2.54,	1.1 ,m/s	372	Lin.,m/hr
Aristomat			
GL,2032' 8	2.3 ,m/s	855	Lin.,m/hr
Impact			
Breeze	1.2 ,m/s	446	Lin.,m/hr
Shima			
P' CAM	0.66 ,m/s	248	Lin.,m/hr
Lectra			
P' CAM	0.01 ,m/s	41.5	Lin.,m/hr

Appendix D-Cutting Data cont.

Cutter 1	Activities	
	0:0:0 Started Pulling fabric from roll	Zund Cutting Systems. (2012, November, 15th). Cutting Textile Material. Retrieved from https://www.youtube.com/watch?v=lw_pdnOKgOc
	0:00:33 Loaded tool, and file, pressed start	
	0:00:08 1 second per registration mark	(Director of Marketing and Communications, personal communication, March 3, 2015)
	658.37 average cut length (appendix D)	
	0:00:07 If cutter max speed = 90"/sec (Aristomat, Appendix E)	
	0:00:15 If cutter max speed = 45"/sec (Impact, Appendix E)	
	Total time	
	0:00:48-56	
	Time per piece	0:00:48-56

Appendix D-Cutting Data cont.

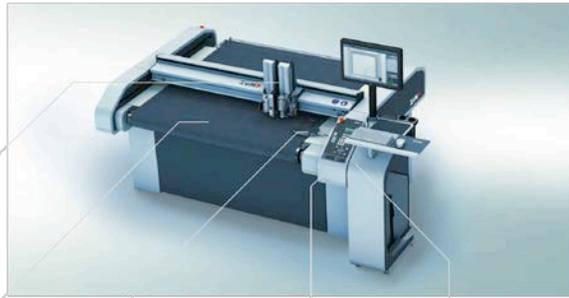
is, mod. design and focus on our customers.

Your first choice in digital cutting.



S3 Cutter Intelligent, efficient, flexible

Modular tooling
Define the functions your S3 cutter needs to perform, and select the Zund tools that will make up the perfect configuration for you.



Cutting surface and material hold-down
The S3 features an active cutting table. The vacuum holds down the material and is digitally adjustable across the width of the machine. An energy-efficient vacuum generator process (active hold-down).



Automatic tool installation
An automatic installation system is used for tool setup. It helps the cutter determine the proper cutting depth, accuracy and efficiency.



Intelligent performance
The intelligent control technology behind the S3 is particularly impressive. It delivers exceptional performance by combining digitally advanced cutting technology with a precise, maintenance-free drive system.



Ergonomics and operation
The construction and design of the S3 is tailored to the needs of our customers. Ergonomic, user-friendly operation and simple handling are the result.



The Zünd building-block design Investing in the future



Technology with a purpose
The basic functions are the core of the Zünd modular design. Control and system is designed for the user and user efficiency. Addressed or applied any time. From the earliest stages of development, the innovations are continually integrated according to the same modular concept. No matter how you decide to configure your Zünd cutting system today, you are making a safe investment for tomorrow.



System operation
In this type of system or "plug-and-play" production, loading, unloading and production occur at the same time, while the operator stays focused on one side, the other continues processing on the other. This setup increases workflow efficiency, saves set time to a minimum and maximizes profitability.



Fully automated sheet board handling
With the sheet board you can run your S3 cutter into a fully automated production system. Sheets of any and larger different materials are picked up with vacuum grippers and transferred from the loading table to the cutting surface. After processing, the machine advances the cut material and stacks into an off-line zone. Operative for single jobs, this fully automated workflow gives you the necessary tools for reliable, efficient production.



Roll-off units
Zünd offers a variety of roll-off systems for different types of materials. Each has its own design and is optimized for specific material characteristics. For some applications, for example, we recommend a digital roll-off system. In combination with the guide roll, even sticky materials such as foil can be advanced without wrinkles or breaks.