ABSTRACT

LOU, XINGQIU. Fashion Design and Development Deciphered. (Under the direction of Dr. Trevor J. Little).

Reducing speed-to-market has been identified as the top priority by the textile and apparel industry. Companies struggled to make timely decisions and to meet deadlines to keep up with rapidly moving consumer behavior and to survive in this extremely competitive market. The concern about speed is a constant topic throughout the industry.

Technology is dramatically changing the way consumers shop, spot trends and share ideas. Consumers today expect rapid trend turnover and a greater number of choices regarding materials, colors and sizes, which adds pressure to companies to reduce time-to-market.

The objective of this research is to explore the current activities and timeline of apparel design and development, as well as to determine the key factors that affect its speed. A deciphered model was built and validated, aiming to manage better the time involved in the process. Opportunities for blockchain technology are also discussed.

This study used a collective case study and the Delphi method to address the research objectives. Five cases with different lengths of the design and development calendar were selected. Qualitative inputs were gathered through a series of semi-structured interviews. Based on the conclusions from the five case studies, an initial deciphered model was built to manage the calendar time. Once the initial deciphered model was created, the Delphi method was adopted to validate and refine the model. Five experts with more than five years' experience in the field of apparel design and development were invited to participate in this study. Experts' inputs were gathered through a rubric, containing yes/no statements or questions and open-ended questions. The feedback from the experts were analyzed and incorporated to finalize the model.

The results of this study find that the design and development cycle ranges from one month to 14 months. A longer design and development cycle has more gates involved in the process; whereas, a shorter cycle has fewer gates, suggesting that the decision-making meetings (gates) add more time to the process. The type of organization and its interface with customers and consumers affect the speed of design and development. Apparel brands have the longest calendar; mass customization companies have the shortest calendar; and vertically integrated retail is in the middle. Within design and development, producing salesman samples was found to be the most time-consuming process, taking from one month up to six months.

This research provides insights into refining companies' go-to-market processes and on reaching milestones more quickly and effectively. Reducing the time from the beginning of product development to the product's market launch lowers the risk of incorrectly anticipating trends, seasonality and demand patterns and increases a company's ability to respond quickly. Bringing new products to market in a timely manner not only helps companies outpace competitors and capture consumer demands better, but also ensures a company's long-term loyal customers.

Fashion Design and Development Deciphered

by
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APPROVED BY:

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DEDICATION

To my parents

Guiling Chen and Yan Lou

for their love and support.

BIOGRAPHY

Xingqiu Lou was born in 1992 in Beijing, China. She went to Beijing Institute of Fashion Technology in 2010 to obtain her bachelor's degree in Fashion Design and Engineering with a dual degree in International Economics and Trade. She realized her passion for the textile and apparel industry and decided to pursue her graduate degree. She came to the United States in 2014 and received a Master of Science Degree in Fashion and Apparel Studies from the University of Delaware. In 2016, she moved to Raleigh, North Carolina to get her Ph.D. degree in Textile Technology Management from North Carolina State University, Wilson College of Textiles. While completing her Ph.D. degree, she also received a Master of Science Degree in Statistics from North Carolina State University. Her current research interest includes new product development, emerging apparel and textile technologies, product lifecycle management, mass customization, and sustainable development in the apparel and textile industry.

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Many thanks to the four companies for their participation and their contributions to this study. I would also like to thank the five experts who contributed with their expert knowledge.

Finally, I would like to thank my beloved family. Their endless love and support is my greatest motivation of my study and life here in the United States. Last but not the least, a very special thanks to my boyfriend, Yudong Zhang. Thank you for always being by my side during the ups and downs of my academic career.

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CHAPTER 1. Introduction

1.1 Background

In today's fast-paced environment, speed-to-market lies at the center of the discussion throughout the fashion industry. As indicated in a survey from McKinsey in 2018, 98% of apparel executives rated improving go-to-market processes as their priority. Among 16 different aspects of the apparel go-to-market processes, reducing speed-to-market was identified as the top priority. The survey found that the majority of the respondents were too slow in introducing new products to market and 92% of the respondents struggled to meet deadlines and make timely responses.

Generally, the fashion cycle includes three phases: planning, design and product development; sell-in; and production and delivery. The length of the fashion cycle depends on a number of factors and varies among companies. Of these three phases, the planning, design and product development phase is typically the longest and has the widest variability among companies; therefore, it has the greatest potential to accelerate speed-to-market.

Apparel design and development is a dynamic process in which several lines of new products are produced each season, and multiple seasons are developed each year. Furthermore, apparel design and development is an iterative process. Multiple activities require several rounds of review and revision prior to approval. Specifically, creating a design concept needs to pass through many sketches and internal reviews, which could take from three to six weeks. Then, another one to two weeks are needed for technical designers to create, revise, and finalize the computer-aided designs (CADs). After the first prototype is made and fitted on either a live model or a three-dimensional (3D) virtual model, samples are requested. This process is repeated until the latest sample is approved, and then the production process can begin. Typically, multiple iterations are needed before the design goes into production, and each round of the sampling process takes several weeks to several months. The calendar time varies among companies, taking three to 15 months to finalize a product, from concept to the final garment, and even longer if the production is sourced offshore or if the materials are distant from the production site (Bandinelli, Rinaldi, Rossi & Terzi, 2013; Shih, Agrafiotes & Sinha, 2014; Donaldson, 2015).

Since the fashion industry is an extremely competitive and global market, companies must produce products that meet the rapidly changing environment and dynamic consumer demands. Currently, technology is dramatically changing the way consumers shop, spot trends and share ideas. Consumers today expect rapid trend turnover and a greater number of choices regarding materials, colors and sizes, which adds pressure to companies to reduce time-to-market.

The objective of this research is to explore the current activities and timeline of apparel design and development, as well as to determine the key factors that affect its speed. A deciphered model was built and validated to manage the time involved in the process. Opportunities for blockchain technology are also discussed. A shorter product development calendar reduces the time from the beginning of product development to the product's market launch, which lowers the risk of incorrectly anticipating trends, seasonality, and demand patterns and increases a company's ability to respond quickly. The results of this study provide insights into refining companies' go-to-market processes and achieving milestones more quickly and effectively. Getting new designs into stores more quickly and building a more rapid and flexible supply chain not only help companies outpace competitors and better capture consumer demands, but also ensure a company's long-term loyal customers. More importantly, as technologies are transforming the industry, such as automation and artificial intelligence, ever more textile and apparel companies are considering bringing business back to the United States (US). Accelerating speed-to-market will improve US companies' competitive advantage over countries offering low wages and labor-intensive practices.

1.2 Research Objectives

The research objectives of this study are as follows:

Research Objective 1: Perform a collective case study to explore current activities and the timeline of apparel design and development.

Research Objective 2: Identify the key factors that affect the speed.

Research Objective 3: Build an initial model that manages the time involved in design and development.

Research Objective 4: Validate the model using the Delphi method and refine the model.

1.3 Dissertation Structure

This dissertation consists of six chapters. Chapter 2 presents a review of the literature on product development models and selected factors that have the potential to speed up the process, including technologies such as two-dimensional (2D) CAD, 3D virtual prototyping, body scanning technology, 3D printing (3DP) technology, digital printing technology and digital thread dyeing technology, and business strategies, such as lean product development, product lifecycle management and blockchain. The product development calendar and measures for apparel product development are also discussed. Chapter 3 presents the research objectives, research methods, data collection and data analytics methods. A collective case study is used to analyze the current design and development process from five companies, and the Delphi method is used to validate and refine the deciphered model. Chapter 4 analyzes each case study individually, and Chapter 5 discusses the findings and presents the model. Finally, in Chapter 6, the conclusions of this research as well as limitations and recommendations for future studies are presented.

CHAPTER 2. Literature Review

2.1 Apparel Design and Development Process

The apparel design and development process is different from the processes in other industries since apparel products are developed in seasonal lines rather than as an individual product (May-Plumlee & Little, 1998). A seasonal line includes many groups of new products produced simultaneously in one season. Some decisions made during the product development process apply to all products in the line, while others apply only to a few products (May-Plumlee & Little, 1998).

Several revisions and modifications occur during the design and development process. During any given stages of the design and development process, some products in the line may move forward, some may recycle through previous stages and some may be dropped from the line (May-Plumlee & Little, 1998). Even when the final product is selling at stores, revisions still occur through interactions between designers, developers and merchandisers to align with consumer demands (Bandinelli, Rinaldi, Rossi & Terzi, 2013).

Typically, several lines of new products are produced each season in a company and multiple seasons are created each year. Some stages of the process in one line overlap with that of another line, increasing the complexity of the development process. For example, when one line of product is being developed, a second line might be in production, and a third line might be selling at retail stores (Burns & Bryant, 1997).

In practice, a calendar is used to schedule the development process. The length of the calendar varies, according to the literature. Bandinelli, Rinaldi, Rossi and Terzi (2013) indicated that 15 months are needed for the apparel industry, and 12 months are needed for the leather industry. Shih, Agrafiotes and Sinha (2014) suggested that three to six months are required for textile product development, followed by another three to nine months for apparel product development. Donaldson (2015) revealed that the average total cycle time for product design and development is 190 days, including 95 days for design, 64 days for production and 31 days for transportation.

2.2 Product Development Models

Product development is the process of designing, developing and marketing a new product to market (Glock & Kunz, 1993). The development of the new technologies, as well as the continuously changing consumer behaviors and market environment, have updated the models over time. Reviewing existing product development models provides a detailed understanding of the stages and activities in the product development process. In this research, different theoretical models and conceptual frameworks are classified into four categories based on their structures: sequential model, concurrent model, stage-gate model and spiral model.

2.2.1 Sequential model

The sequential model, also known as the waterfall model, identifies the list of activities that are involved in the product development process. In this type of model, a product moves sequentially through a series of steps. Each step of the process must be completed in one department before moving forward to the next step without overlap (Hatcher, 2004).

Urban and Hauser (1980) first designed the five-step decision process: opportunity identification, design, testing, introduction and profit management, as shown in Figure 1. Each step moves forward sequentially by passing through a Go/No decision point. These decision points have a similar function as the gates in Cooper's Stage-gate model, which is explained in detail in Section 2.2.2.

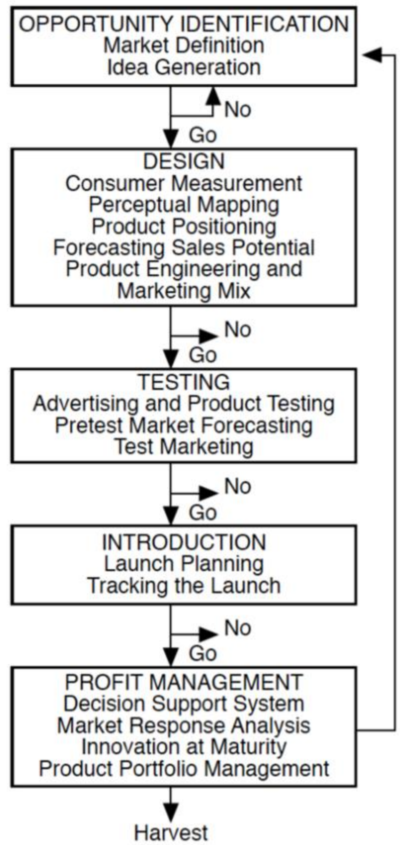


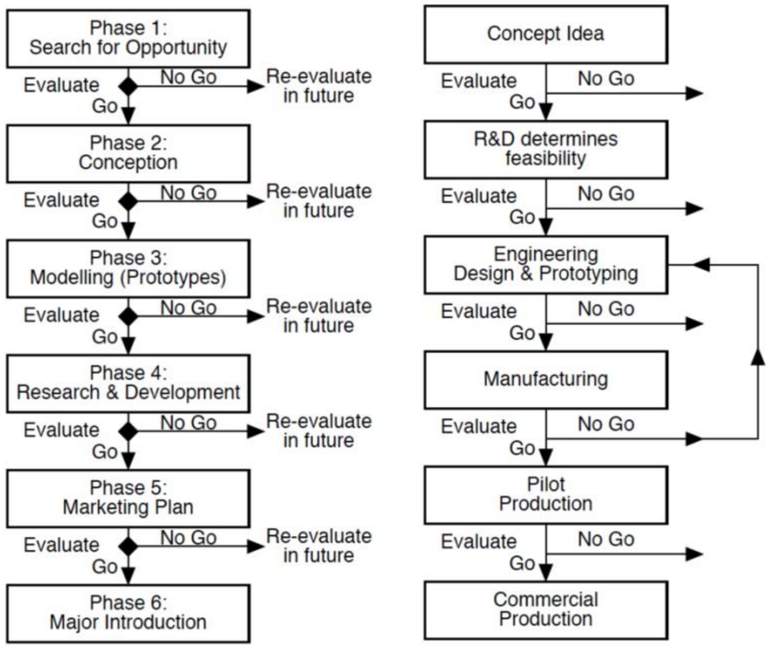
Figure 1. Design and development process (Urban & Hauser, 1980).

Cooper (1983) proposed a product development process model consisting of seven stages and 16 activities. Each stage is independent and moves to the next stage by a Go/Kill decision point. In 1986, Cooper and Kleinschmidt identified a set of 13 activities after reviewing 203 new products at 123 firms, as shown in Figure 2. However, they found that only 1.9% of the companies performed all 13 activities, while most companies included 8 or 9 activities in their product development process.

Activities	Description
1. Initial screening	The initial go/no go decision where it was first decided to allocate funds to be proposed new product idea.
2. Preliminary market assessment	An initial preliminary, but nonscientific, market assessment; a first and quick look at the market.
3. Preliminary technical assessment	An initial, preliminary appraisal of technical merits and difficulties of the project.
4. Detailed market study/market research	Marketing research, involving a reasonable sample of respondents, a formal design and a consistent data collection procedure.
5. Business/financial analysis	A financial or business analysis leading to a go/no go decision prior to product development
6. Product development	The actual design and development of the product, resulting in, e.g., a prototype or sample product.
7. In-house product testing	Testing the product in-house: in the lab or under controlled conditions (as opposed to in the field or with customers).
8. Customer tests of product	Testing the product under real-life conditions, e.g., with customers and/or in the field.
9. Test market/trial sell	A test market or trial sell of product – trying to sell the product but to a limited or test set of customers.
10. Trial production	A trial production run to test the production facilities.
11. Precommercialization business analysis	A financial or business analysis, following product development but prior to full-scale launch.
12. Production start-up	The start-up of full-scale or commercial production.
13. Market Launch	The launch of the product on a full-scale and/or commercial basis: an identifiable set of marketing activities specific to this product.

Figure 2. New product process activities (Cooper & Kleinschmidt, 1986).

Other similar sequential models in the literature include Gruenwald (1992) and Himmelfarb (1992), as shown in Figure 3. In particular, Gruenwald (1992) found that the three most common factors that influence new product ideas are customers, marketing, and research and development. Himmelfarb (1992) incorporated consumer inputs into design objectives in the product development process.



(a) (b)

Figure 3. (a) Sequential models by Gruenwald (1992). (b) Sequential models Himmelfarb (1992).

Carr and Pomeroy (1992) developed a theoretical model specifically for the apparel design and development process, as shown in Figure 4. The process begins with market research and ends at pre-production. Each process in the sequence must be completed before sending to the next one for further processing. Burns and Bryant (1997) listed eight ordered steps in the apparel development process: research, design, design development and style selection, marketing the line, pre-production, sourcing, and apparel production and distribution. Kincade, Regan and Gibson (2007) summarized four common stages in the apparel design and development process: ideas and research, line conceptualization, preparation for production, and market preparation. As depicted in Figure 5, it takes six to 12 months ahead of the selling season if all design and development activities within the four stages are performed in a sequential manner.

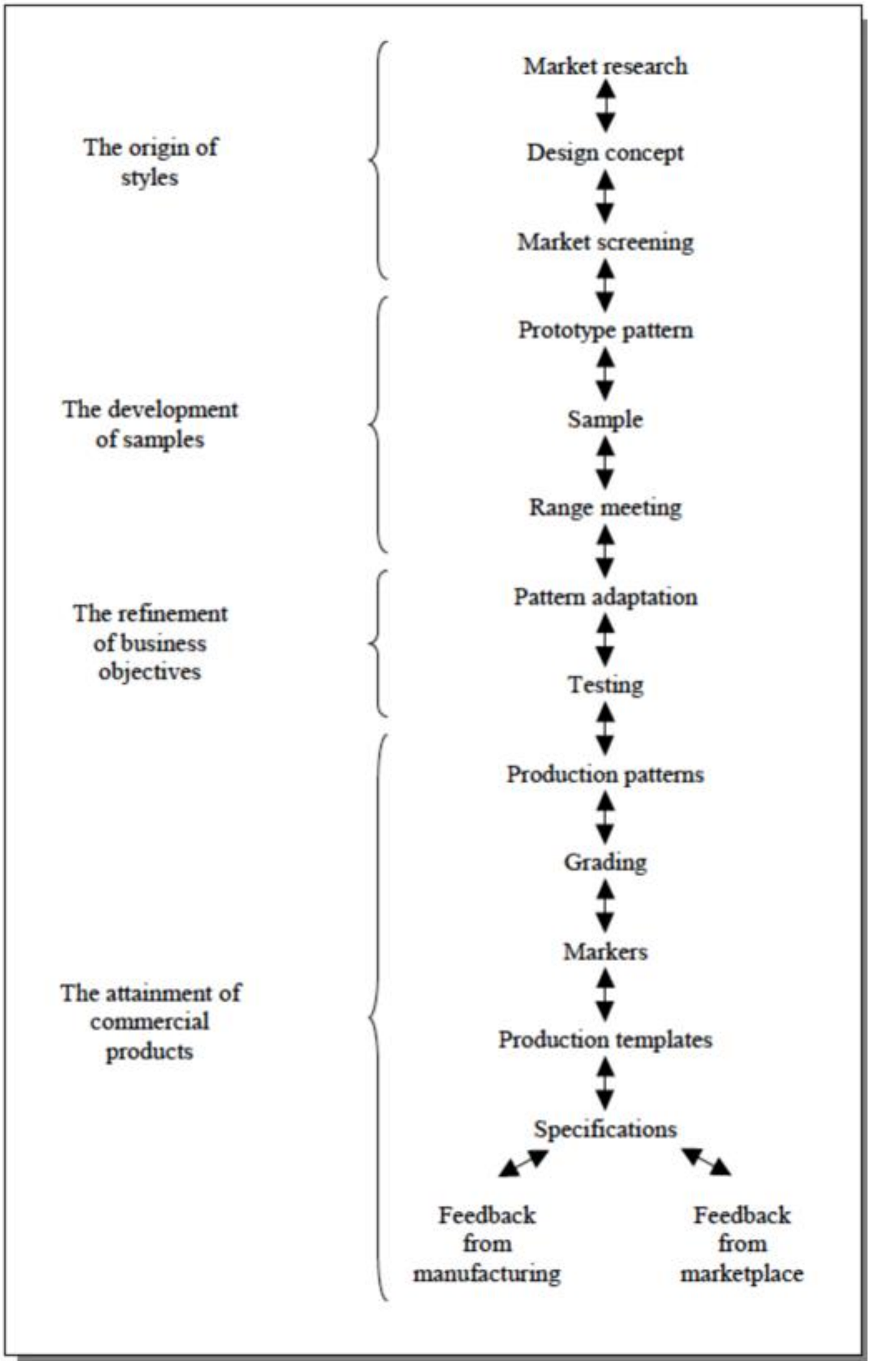


Figure 4. The process of apparel design and product development (Carr & Pomeroy, 1992).

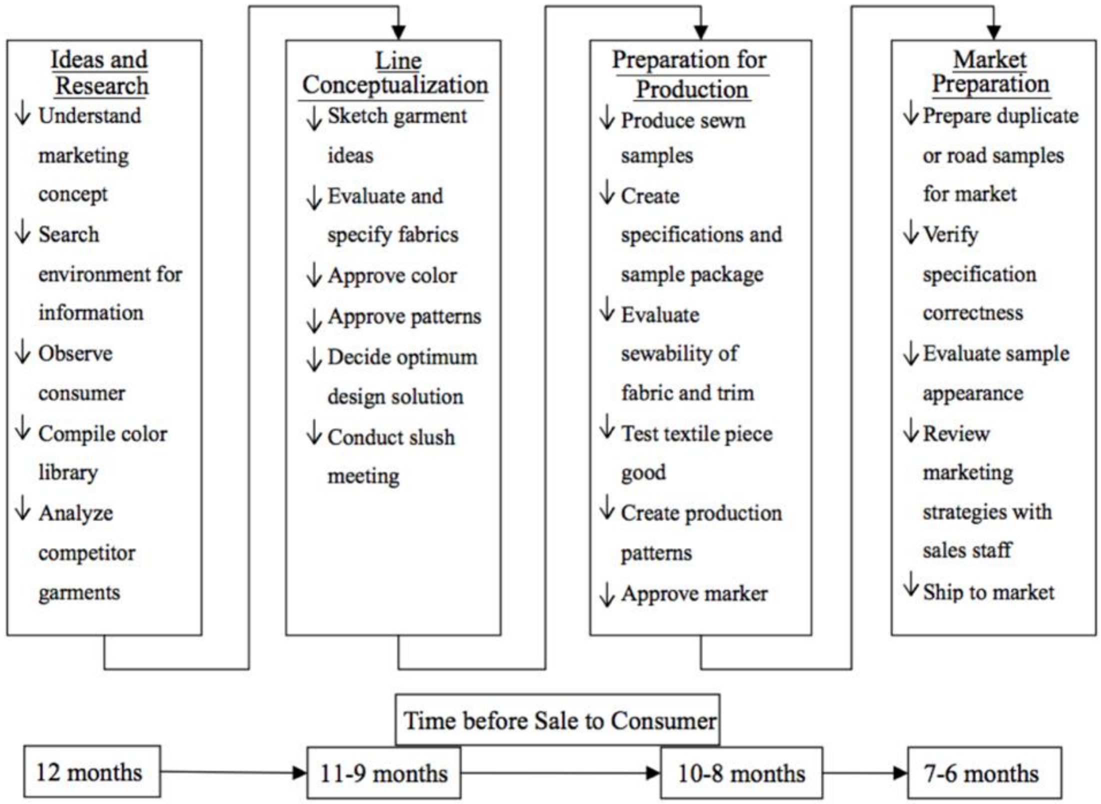


Figure 5. Traditional order and timing for apparel product development activities (Kincade, Regan & Gibson, 2007).

The sequential models describe a segmented and slow approach, since the work must proceed sequentially step-by-step, as well as the minimized communication between departments. Each department is functionally independent and contributes to the process sequentially. One department completes all the work and then forwards it to the next department, resulting in long development cycle time (May-Plumlee & Little, 1998). Flexibility is also limited in a sequential process due to its linear structure. Specifically, in a sequential model, activities cannot move backward or forward freely to capture the continuously changing market, which causes potential consumer dissatisfaction. Additionally, market inputs and contact with consumers are often integrated in the late stages of the overall development process to test the performance of the product. The market opportunities identified at the beginning of the process may not exist after going through a series of activities and several rounds of revisions (May-Plumlee & Little, 1998). Therefore, sequential models are too restrictive for apparel products and are inappropriate for the rapidly changing and highly competitive apparel market (May-Plumlee & Little, 1998; Hatcher, 2004).

2.2.2 Concurrent model

Due to the limitations in sequential model, the concurrent model, also known as a parallel model, was developed. In the concurrent model, sequential stages are still used to capture the overall process. However, within each stage, several activities proceed simultaneously in multiple departments (Hatcher, 2004).

Gaskill (1992) used a fashion retail product development model when investigating the product development activities of an international specialty apparel retailer. As illustrated in Figure 6, the model begins with a comprehensive trend analysis. Once the concept is established, the processes of fabrication selection, palette selection and fabric design take place at the same time. These concurrent activities not only speed up the product development process, but also enhance the communication between different departments. However, Gaskill's (1992) model stops at line presentation.

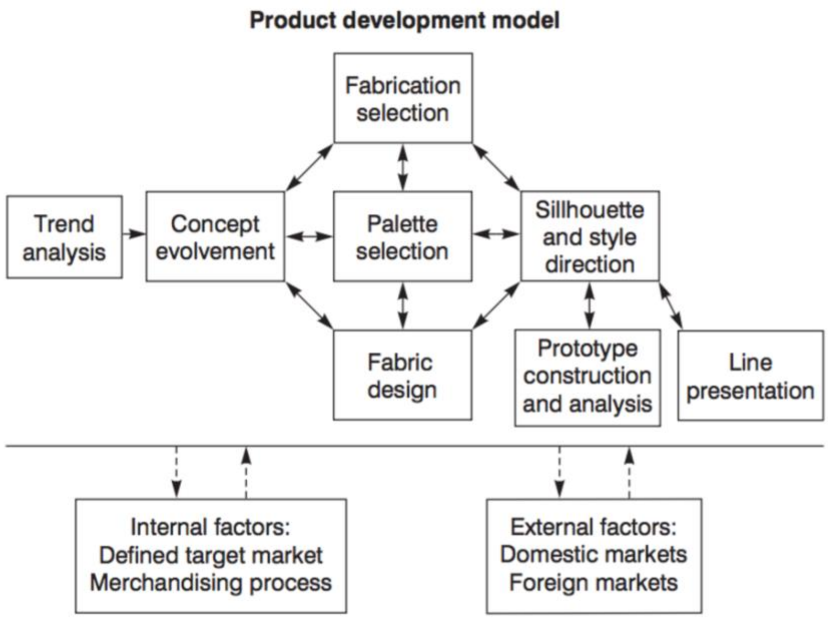


Figure 6. Fashion retail product development model (Gaskill, 1992).

In 1999, Wickett, Gaskill and Damhorst refined and extended Gaskill's (1992) retail product development model, naming the new model the revised apparel retail product development model. As illustrated in Figure 7, this model captures the entire development process by adding an inspirational search for trends, line adoption and a post-adoption stage. The post-adoption stage includes fit and style-perfecting, production pattern marking, and materials and garment specifications. Similar to Gaskill's (1992) model, several activities are carried out in parallel in multiple departments in the new model. Moreover, according to the authors, both internal factors (sales trends, target consumer base, employee input and marketplace research) and external factors (global market trends, competition, media, government regulations and producer capabilities) affect the overall development process.

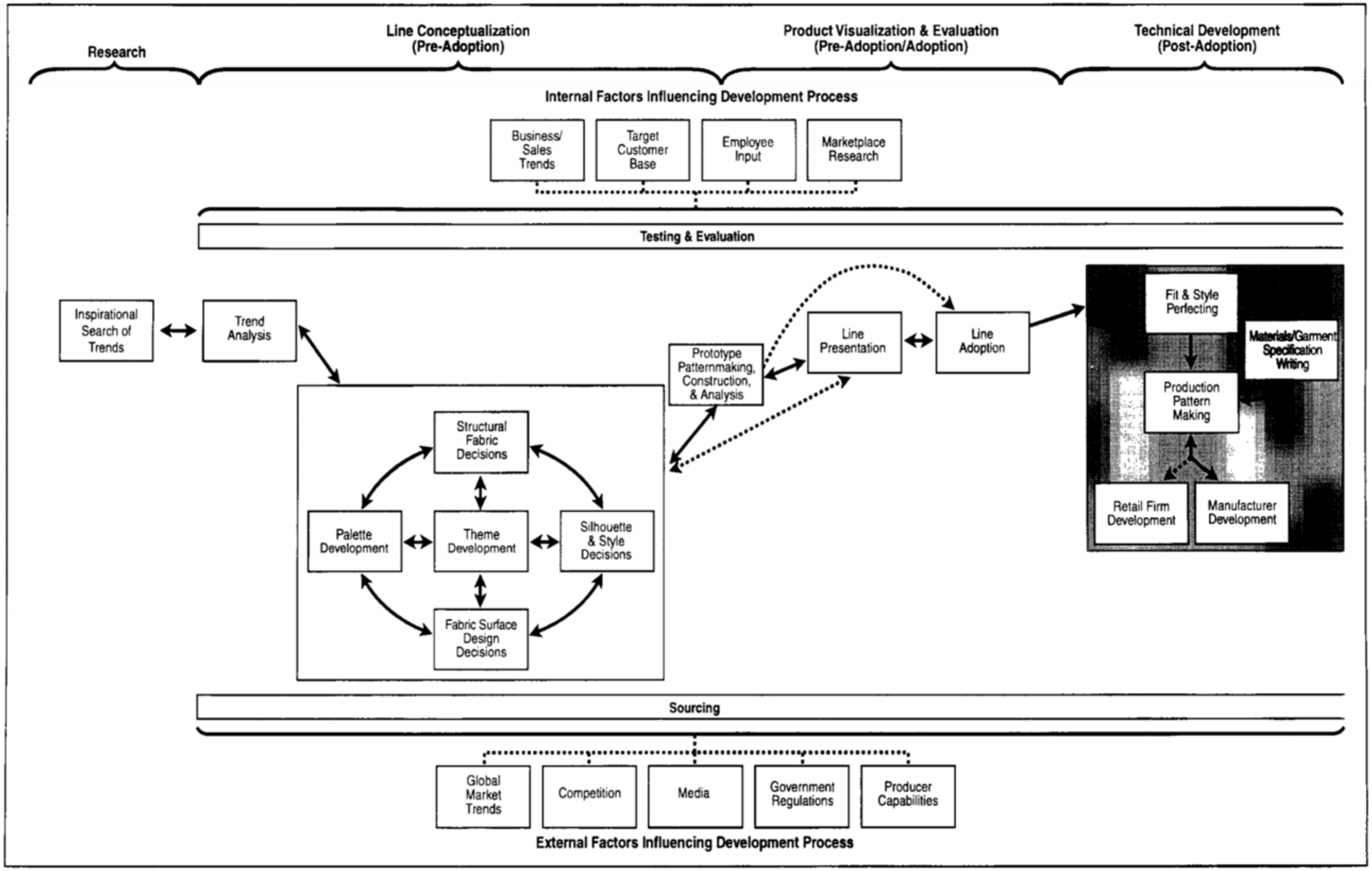


Figure 7. Retail apparel product development model (Wickett, Gaskill & Damhorst, 1999)

May-Plumlee and Little (1998) developed a no-interval coherently phased product development (NICPPD) model for apparel products. This NICPPD model includes six phases: line planning and research; design/concept development; design development and style selection; marketing the line; pre-production and line optimization. Figure 8 illustrates the design/concept development phase of this model as an example. May-Plumlee and Little (1998) further identified four functional divisions: marketing, merchandising, design and development and production. They assigned each activity to the corresponding division. In this model, multiple activities can be performed concurrently within each division, and multiple divisions work in parallel to advance the process. Overlapping stages and fuzzy gates are integrated in this model, indicating that different departments make decisions collaboratively regarding whether a style should proceed to the next stage or recycle to the previous stages (Hatcher, 2004). If a style is recycled, it either goes backward for revisions and reevaluation or is dropped from the line.

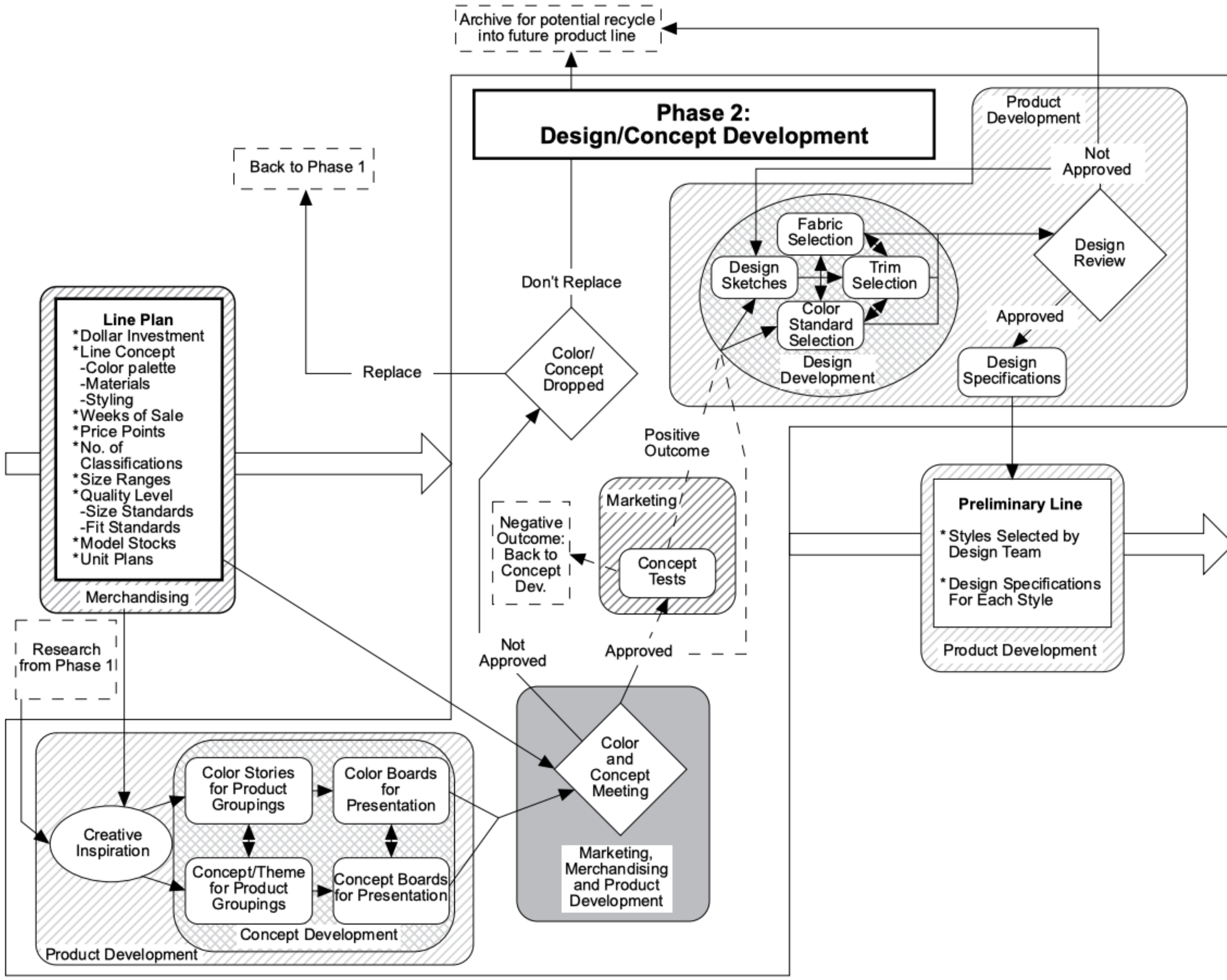


Figure 8. No-interval coherently phased product development (NICPPD) model (May-Plumlee & Little, 1998).

In contrast to the sequential model, the concurrent model converts the linear process into a more integrated and simultaneous process; thus, reducing time-to-market. Figure 9 illustrates the difference between the concurrent and sequential product development processes. The concurrent model is more efficient and has a shorter development time. Manufacturers could target more accurately and react more quickly to consumer demands by reducing the time between product development and a product's launch (Kincade, Regan & Gibson, 2007). Moreover, the concurrent approach allows the continuous exchange of information and communication between different departments, which leads to better products and improved consumer satisfaction. However, most interactions are only among companies' inter-departments, and consumers and suppliers are not involved in the process (Kincade, Regan & Gibson, 2007). Another drawback of this model is that it does not specify the time when multiple departments converge to take decisions and then move on to the next stage (Hart & Baker, 1994).

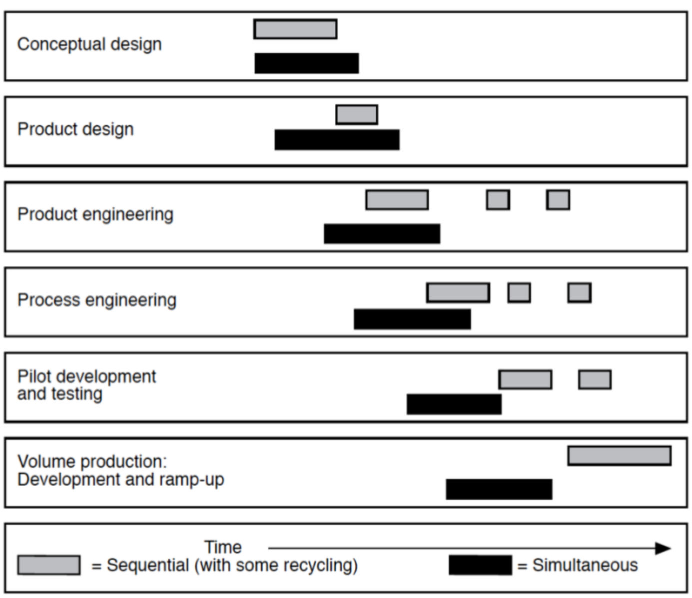


Figure 9. Difference in product development time between sequential and concurrent models (Rosenthal, 1992).

2.2.3 Stage-gate model

The Stage-gate model was introduced by Cooper (1990) and is one of the most often cited models in the product development literature. Cooper (1990) designed the Stage-gate system for developing a new product from idea to launch. As illustrated in Figure 10, the product development process is divided into several stages and gates. Within each stage, multiple activities are conducted in parallel by cross-functional teams from different departments of a company. At the end of each stage, there is a gate that serves as a quality control checkpoint or a decision point. At the gates, a set of deliverables are reviewed and must be approved by senior managers before moving forward (Cooper, 1990). The outputs of the gates are typically Go/Kill/Hold/Recycle decisions. In other words, the stage is when the work is done, and the gate is the point at which the decision is made. However, products can only move to the next stage when the current stage is completed.

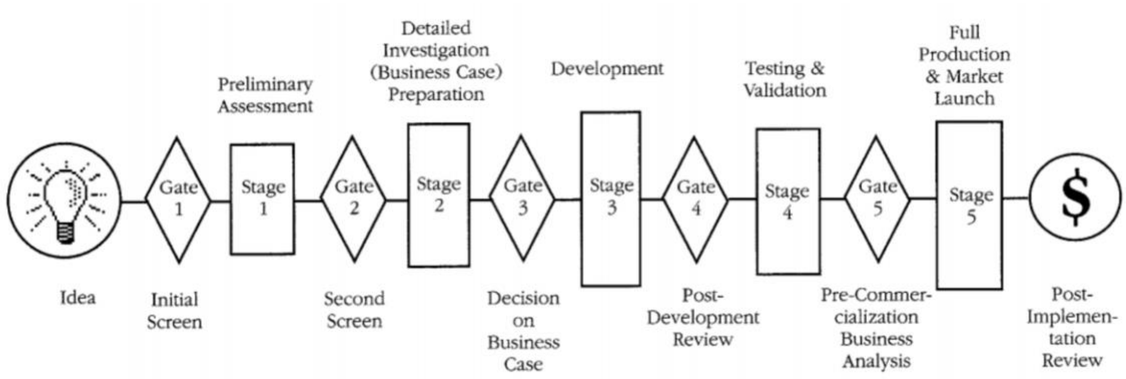


Figure 10. Stage-gate system (Cooper, 1990).

In 1994, Cooper optimized the initial Stage-gate model into the third-generation process model, as presented in Figure 11. This system increases flexibility by allowing skip stages, gates and activities based on the uniqueness of each individual product. Furthermore, implementing the third-generation Stage-gate facilitates the effectiveness of product development and compresses product development time by overlapping stages and incorporating fuzzy gates. Products can move ahead to the next stage conditional on completing the current stage at a specified time in the future (Cooper, 1994). Although Cooper's model provides some insights, it was not designed specifically for apparel products.

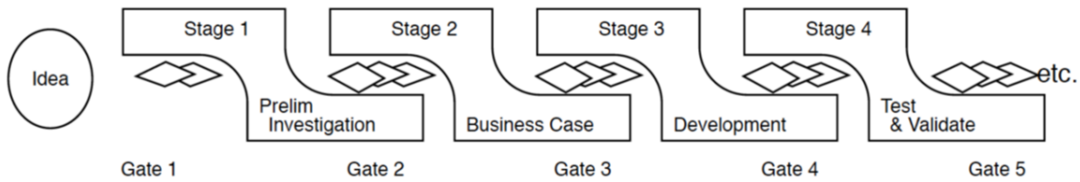


Figure 11. The third-generation Stage-gate (Cooper, 1994).

2.2.4 Spiral model

Boehm (1986) first presented the spiral model within software development, and it can be defined as multiple iterations of the development process. As illustrated in Figure 12, in each iteration, one prototype is made. Once the first prototype is evaluated, the second prototype is made and further revised based on the feedback from consumers. The preceding processes keep being repeated until the final product is desired. In general, three prototypes are made before reaching to the final one. The spiral model tends to engage consumers through the spirals and considers consumer feedback during the product development process.

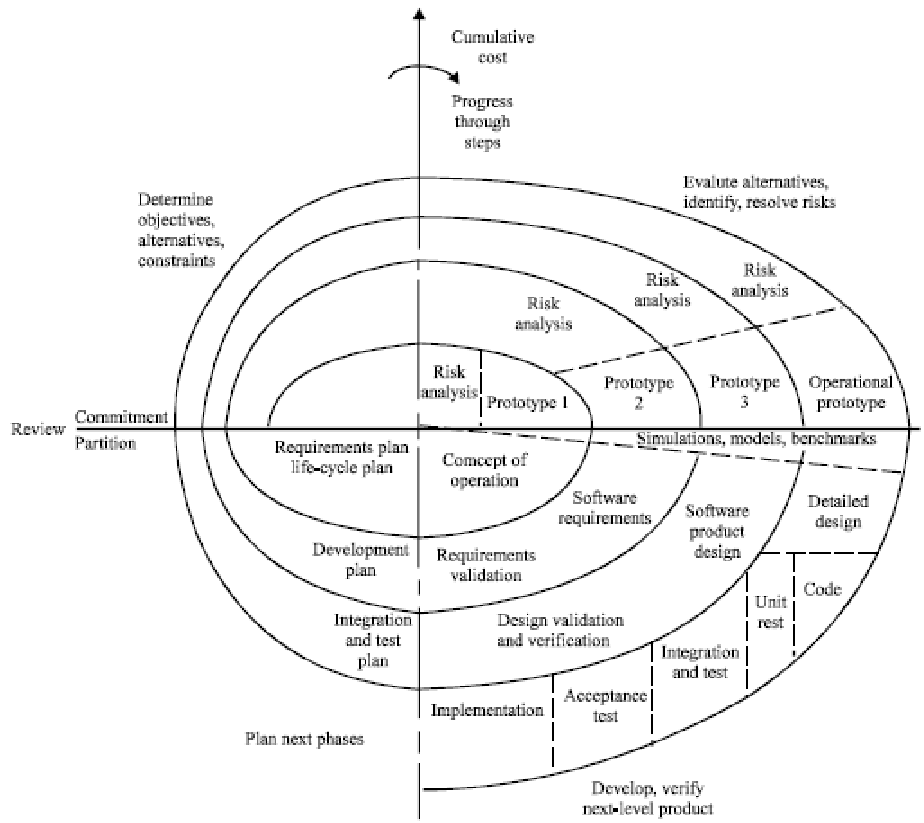


Figure 12. Spiral development model (Boehm, 1986).

Cooper (2008) introduced an updated version of the Stage-gate model, which is more flexible and adaptable than its predecessor, by integrating spiral development. As illustrated in Figure 13, six spirals are built into the model, which allows companies to continuously incorporate valuable consumer feedback. In the first spiral, the product development team approaches consumers to understand their needs and wants. In the second spiral, the team presents the proposed products to the consumer, either via a computer-based virtual prototype or a hand-made prototype. The next four spirals are a series of prototypes. Products are finalized through the process of “build-test-feedback-revise” iterations (Cooper, 2008).

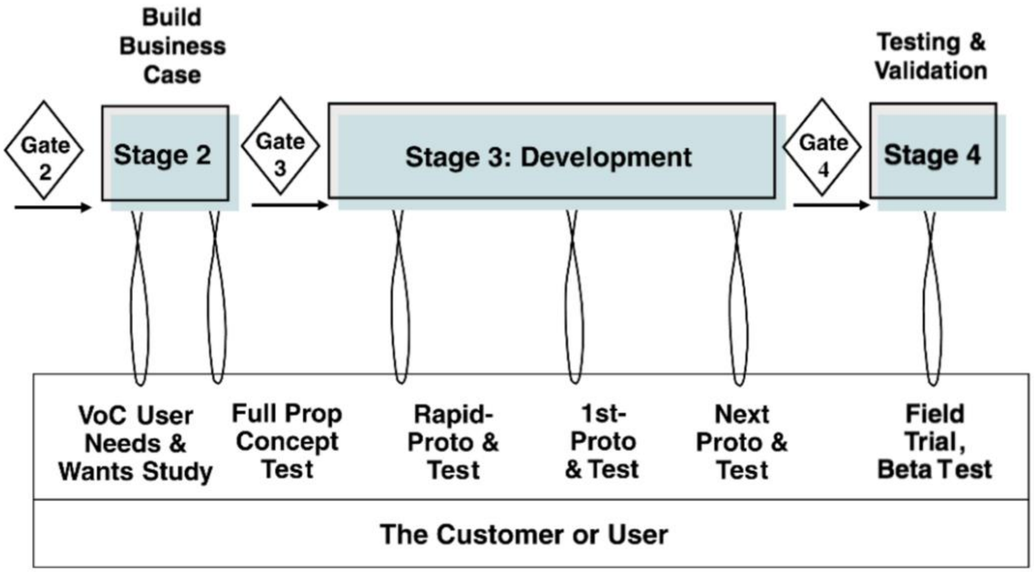


Figure 13. The next-generation version of Stage-gate (Cooper, 2008).

In 2014, Cooper developed a new generation of the Stage-gate model to meet the fast-paced environment. Due to consumers being unclear regarding what they want or need at the beginning of the development process, a product must be continuously changed along its path to launch. Figure 14 illustrates how the spirals are incorporated at each stage of the process to adapt new information and feedback. Each spiral consists of the process of "build-test-feedback-revise" iterations, and each iteration moves the product closer to the final product. Instead of developing a single model, Cooper (2014) broke the model down into different scales based on the difficulty and complexity of the new product: a full five-stage version for major and high-risk developments; a light version for moderate risk projects, such as significant modifications, improvements, and extensions; and an express version for minor product change, as shown in Figure 15.

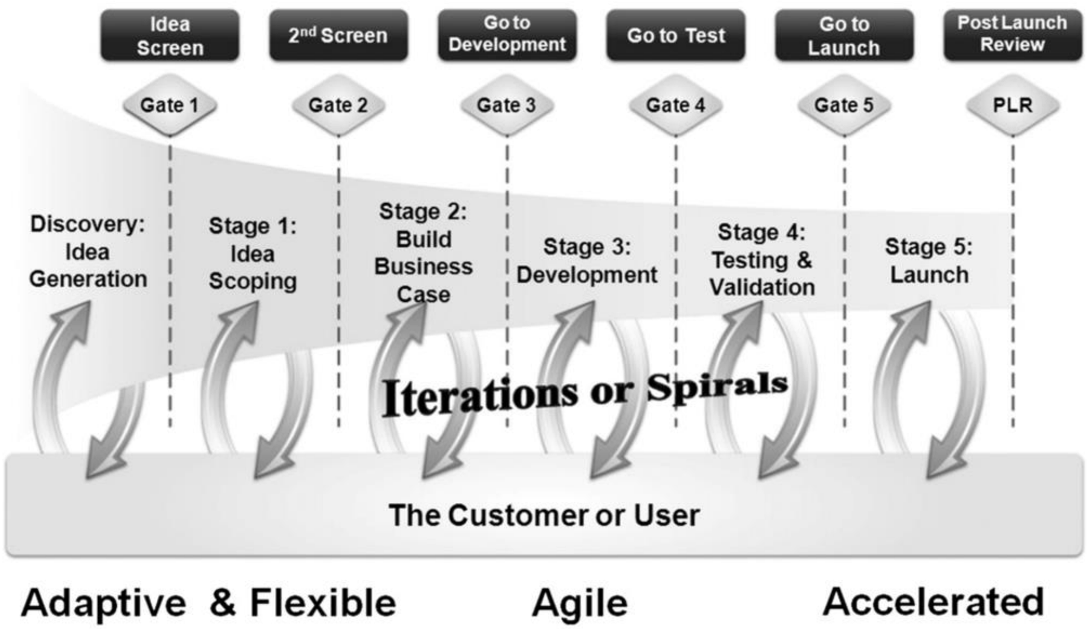


Figure 14. The next-generation idea-to-launch system (Cooper, 2014).

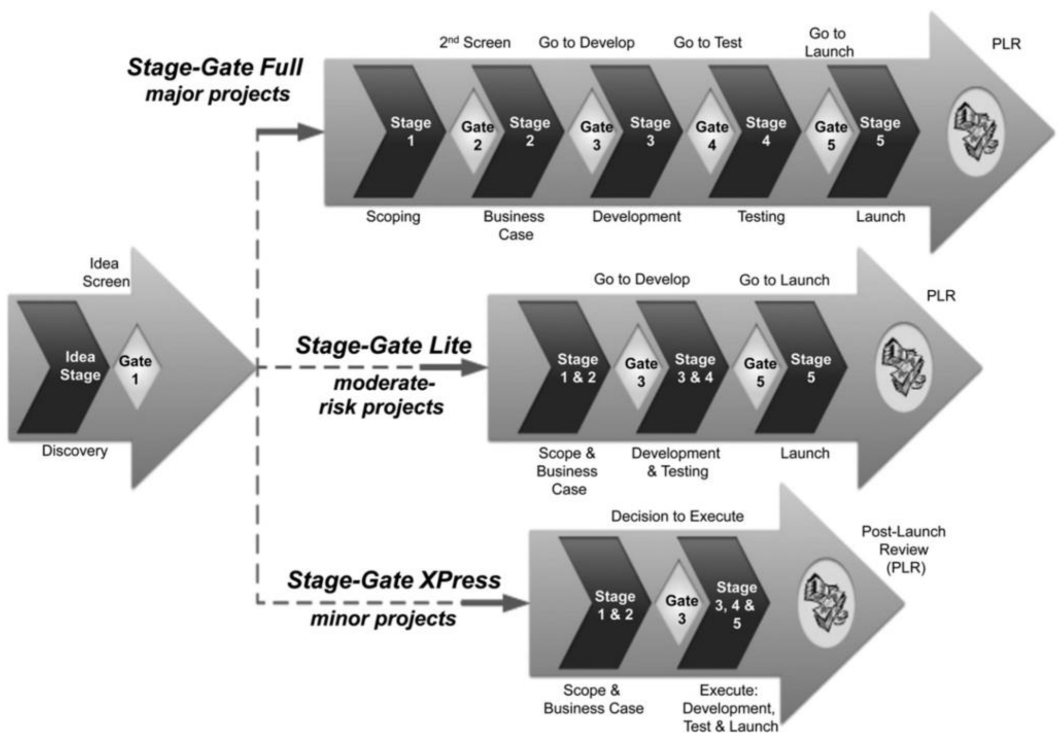


Figure 15. Scalable Stage-gate systems (Cooper, 2014).

In this new version, key activities, or even the entire stage, can be overlapped, accelerating the product development process and reducing time-to-market, as shown in Figure 16. However, even the shortest product development cycle still requires 13.8 months from idea generation to product launch, which is too long for apparel products.

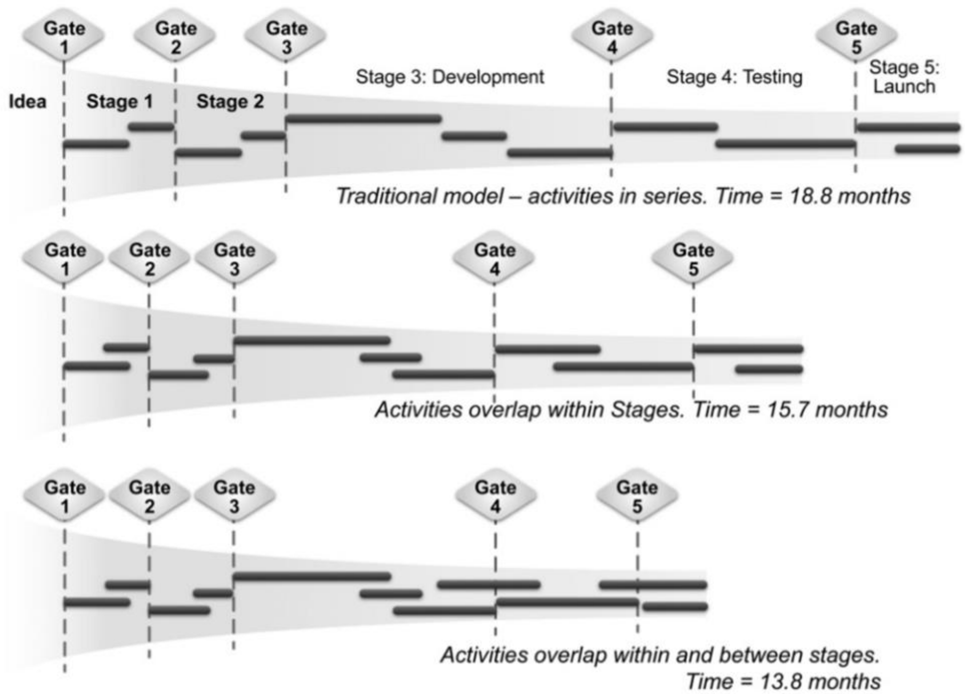


Figure 16. Overlapping activities and stages (Cooper, 2014).

2.2.5 Summary

Four types of product development models were reviewed in this section: the sequential model, the concurrent model, the Stage-gate model and the spiral model. In addition to the previously identified limitations, most existing models are considered dated and lack discussion on the issue of speed. Considering the current rapidly changing market and dynamic consumer demands, a model is needed that provides details regarding activities and timeline, and further reveals the factors that are known to determine apparel design and development time.

2.3 Lean Product Development

In the early 2000s, the research interests of product development shifted from product development models to lean product development. The concept of lean was not new. It was first introduced in the Toyota Production System (Ohno, 1988) and became popular through the book *The Machine That Changed the World* (Womack, Jones & Roos, 1990). The concept of lean has been widely used in the manufacturing process, and its core idea is to eliminate waste and streamline the process (Liker, 1996). Waste is defined as non-value-added activities, such as overproduction, waiting, transportation, incorrect processing, excess inventory, unnecessary movement, defects and unutilized employee creativity (Womack, Jones & Roos, 1990). Due to the success of lean in manufacturing, there has been an increasing number of researchers trying to apply its principles, tools and techniques to other processes, such as new product development (Salgado & Dekkers, 2018).

Compared with lean production, lean product development is a relatively new area of research. The first detailed and systematic view of lean product development was proposed by Morgan and Liker (2006) through the description of the Toyota Product Development System. Following a two-and-half-year in-depth study of the Toyota product development system and more than 1000 hours of interviews with Toyota representatives, Morgan and Liker (2006) developed 13 principles of lean product development, which can be further categorized into three elements: skilled people, process, and tool and techniques. The model built in Chapter 5 follows the lean product development approach.

Lean product development is one of the approaches that are being considered by different industries to maximize value, increase quality, shorten lead times, and lower costs (León & Farris, 2011). Previous research has focused on determining different types of non-value-added activities (wastes) in product development process. Liker and Morgan (2006) re-interpreted the eight types of waste during the manufacturing phase in a new product development optic. Bauch (2004) suggests three different wastes: reinvention, lack of discipline and IT resource limitations. Oehmen and Rebentich (2010) identified eight categories of waste specifically for lean product development: waiting of people; overproduction of information; over-processing of information; miscommunication of information; stockpiling of information; generating defective information; correcting information; and unnecessary movement of people. However, some research has pointed out that waste in product development should be interpreted as the wrong input rather than unnecessary activities since product development involves the extensive use of information and data, which can only be assessed in hindsight (Gudem & Welo, 2010; Salgado & Dekkers, 2018).

Set-based concurrent engineering is a central concept in lean product development. This concept is discussed often in the previous literature. Set-based concurrent engineering refers to the consideration of all concepts of each product at the front-end of the product development process. After testing and analyzing, the set of alternatives is gradually narrowed down to the final design (Morgan and Liker, 2006; Ward, 2007). This approach reduces uncertainties and iterations by exploring all alternatives at the beginning, instead of throughout the process. In addition, since revisions and modifications in the later stages of the product development process cause reworks and delays, set-based concurrent engineering helps reduce the overall cost and speed up the process (Hoppmann, Rebentisch, Dombrowski & Zahn; 2011; Liker, 1996).

There is a number of challenges and questions when applying the lean concept and principles from manufacturing to product development. First, manufacturing deals with physical products, while product development involves flows of data, information and knowledge, which make the process much more complex, uncertain and unpredictable than manufacturing (Rossi, Cattaneo, Le Duigou, Fugier-Garrel, Terzi & Eynard, 2016). Second, there are no empirical studies concerning the implementation of lean product development in the literature, except Toyota and limited industrial application in the literature (Hoppmann, Rebentisch, Dombrowski & Zahn, 2011).

2.4 Product Lifecycle Management

Product lifecycle management (PLM) emerged in the early 2000s. Rooted in CAD and product data management (PDM) systems, PLM is a business approach that manages a product throughout the entire lifecycle by integrating people, process and technology (Garetti, Terzi, Bertacci & Brianza, 2005). The concept of PDM was developed in the 1980s (Ameri & Dutta, 2005). The core concept involves having access to valid data during the product development process, and further tracking and managing all product-related information, such as electronic documents, digital files or database records (Philpotts, 1996). Unlike the PDM system, which focuses on managing data in design and manufacturing, PLM aims to streamline the flow of information through the entire lifecycle of a product, from concept through design, production, consumer purchasing, to final disposal (Ameri & Dutta, 2005; D'Avolio, Bandinelli & Rinaldi, 2015). As a technology solution, PLM integrates a set of tools and technologies, including CAD, computer-aided manufacturing (CAM), computer-aided engineering (CAE), enterprise resource planning (ERP), and PDM (Srinivasan, 2011).

The PLM tools have been successfully implemented in the aerospace and automotive industries for years and have been recently adopted by the fashion industry. The fashion PLM system seeks to connect everyone in the supply chain. By working together on a shared platform, everyone is aware of what is happening and follows the same schedule. Various tools have been developed for companies to collaborate and communicate on a real-time basis (D'Avolio, Bandinelli & Rinaldi, 2015), in particular, in the cloud-based PLM systems. Some fashion PLM software companies include Lectra Systems Inc., Gerber Technology, Centric Software, Tukatech Inc., Infor Global Solutions, PTC Inc., Siemens AG, Backbone, and Visual Next.

As illustrated in Figure 17, the PLM software Infor Global Solutions developed a fashion PLM planned process scope. This process involves four stages: plan, design, develop and approve. The different elements involved in the process are color-coded, including merchandising planning, assortment store planning, external sources, PLM basic data, component development, product development, supplier and customer collaboration, supplier management and general features.

One of the primary benefits of PLM is shortening the cycle time from concept to production. Less paperwork and fewer meetings can be achieved since designers, developers and manufacturers can communicate and work together without necessarily being in the same location. However, the way PLM is being used in practice has only compressed the cycle time through the documentation process but not reduced much of time-to-market.

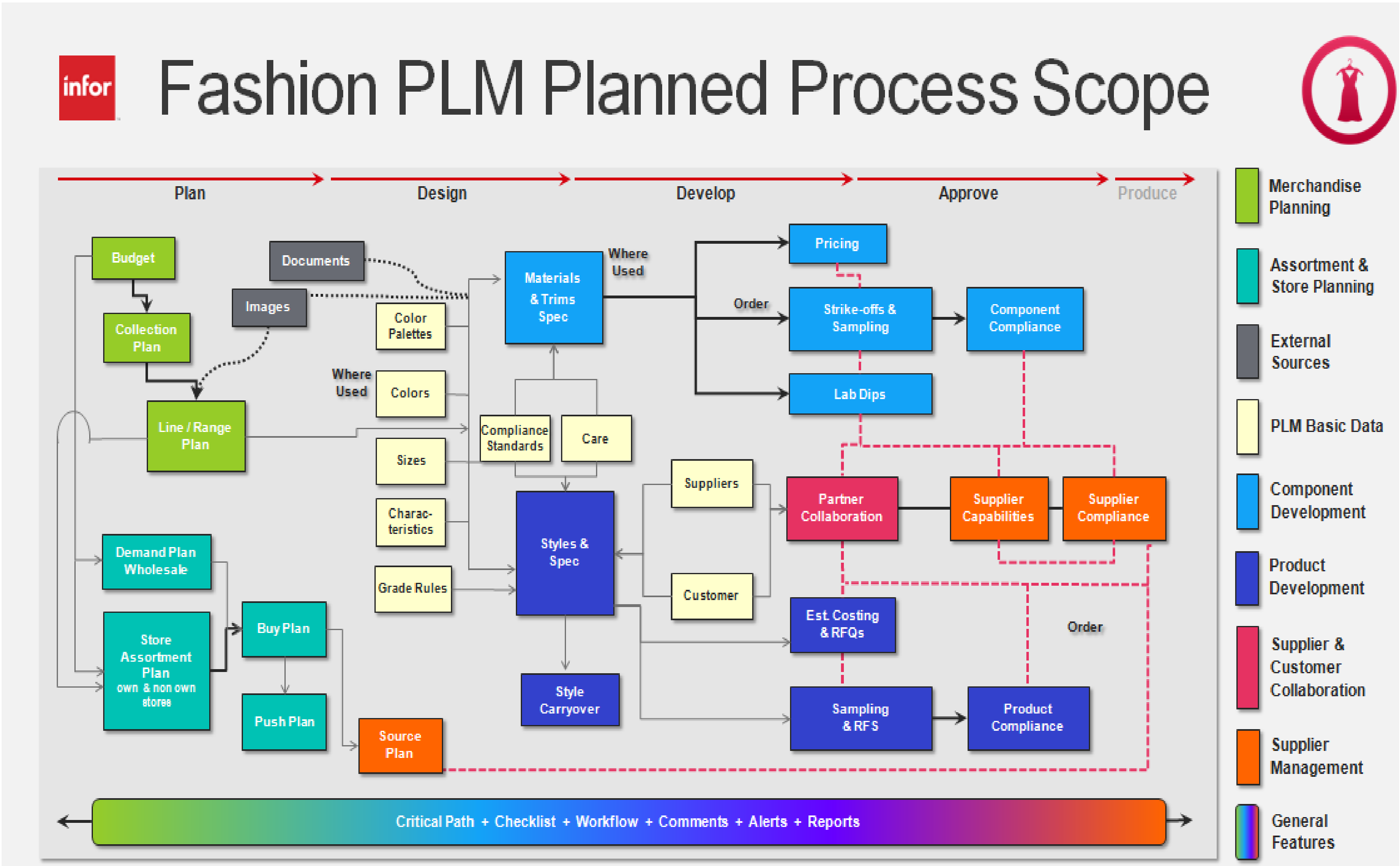


Figure 17. Fashion PLM planned process scope (Infor Global Solutions).

2.5 Blockchain Technology

Blockchain is a relatively new and emerging technology that can be considered a digital, decentralized and distributed public ledger that records data, tracks transactions, and updates information (Greene & Longobucco, 2018). Blockchain was first successfully implemented in 2009 through Bitcoin, a cryptocurrency and digital payment system. Since then, blockchain has been growing in popularity and opened a wide range of new possibilities in various industries, such as banking, financial services, healthcare and automotive (Chakrabarti & Chaudhuri, 2017). Figure 18 displays the different structures between centralized and decentralized systems. Compared with the centralized structure, in which a third party is in control of the transactions and data, the decentralized structure ensures that all information is shared and visible to all nodes in the network (Casino, Dasaklis & Patsakis, 2019). This unique attribute makes the process more transparent and secure, and further reduces the possibility that the system crashes or can be hacked.

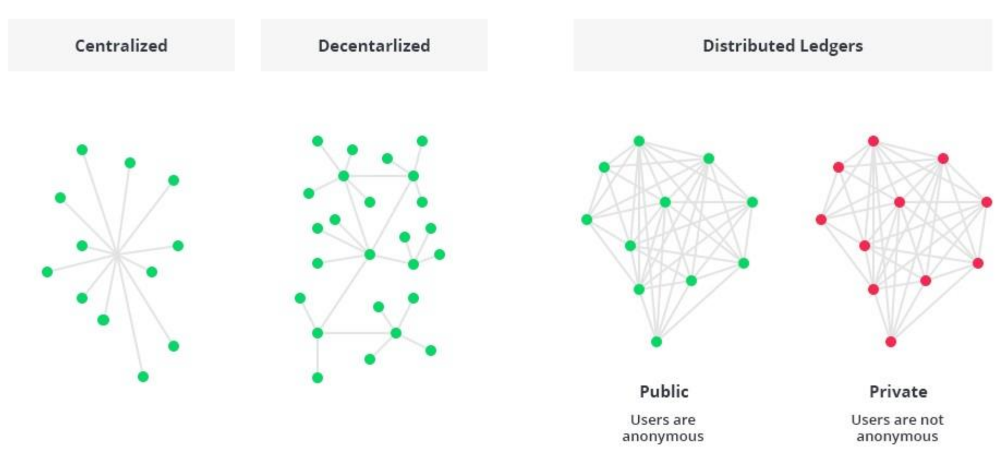


Figure 18. Difference between centralized, decentralized and distributed system.

The blocks represent a collection of valid transactions. Each block contains a record of data and a cryptographic hash of the previous block, as shown in Figure 19 (Crosby, Pattanayak, Verma & Kalyanaraman, 2016). Each transaction must be validated independently and signed digitally by the majority of nodes in the network. Then, the verified transactions are grouped and saved in a block. Each subsequent block is linked to the previous block by incorporating the cryptographic hashing algorithm. If a block is successfully confirmed, it is aligned with the previous blocks and, thus, forms a blockchain. By design, the transaction data saved in any given block cannot be modified or removed after approval by all the nodes. Modifying a single block would have to alter all subsequent blocks in the chain due to the interconnected structure of the blocks.

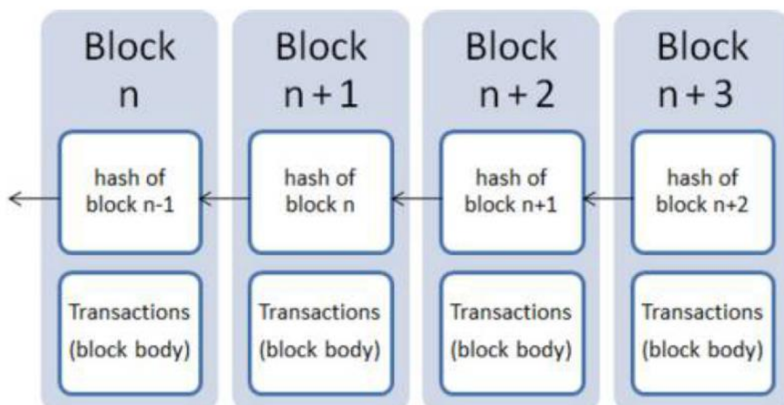


Figure 19. Components inside a block.

The literature reveals that the majority of blockchain research has been conducted on bitcoin or other cryptocurrency environments. Recently, researchers have recognized blockchain's potential in other areas, including supply chain, smart contract, healthcare, Internet of Things (IoT), education, privacy and security and data management (Chakrabarti &

Chaudhuri, 2017). However, most literature has focused on a conceptual- or theory-based research frameworks, and limited empirical data have been collected. Therefore, the overall state of blockchain research is still at an early and exploratory stage. In practice, companies such as IBM, Walmart and Apple are currently applying blockchain to logistics and the supply chain. However, most of these companies are still in the early proof-of-concept stage.

One of the major applications of blockchain in the fashion industry is supply chain management. Outside the fashion industry, blockchain technology has already been adopted in the food supply chain and the diamond supply chain. The literature has found that the food industry benefits from blockchain technology by improving transparency, efficiency and security and safety (Galvez, Mejuto & Simal-Gandara, 2018). IBM launched the Food Trust platform in Oct 2018, which is a blockchain-based cloud network of growers, processors, wholesalers, distributors, manufacturers, retailers and others aiming to improve transparency, traceability and efficiency across the food supply chain. Major retailers such as Walmart and Kroger are currently using this technology to track their food products. Instead of taking days and weeks, food can be traced to its original in a few seconds. Moreover, the unique structure of blockchain enables all network members (stakeholders) to gain a high level of trusted information. Similarly, blockchain technology has been adopted by the diamond industry to trace each gem to its source to eliminate the diversion of conflict minerals and to provide consumer assurance (Crosby, Pattanayak, Verma & Kalyanaraman, 2016).

However, the fashion supply chain is a complex process. Consumers lack information regarding how garments are produced and their content. Sometimes, even brands themselves do not have full visibility of their own supply chains. As consumer demands for transparency grow, fashion brands are taking steps to confirm the transparency and authenticity of their products, and blockchain technology has the potential to contribute to these areas. Currently, there are three main applications of blockchain in the fashion industry: supply chain transparency, product authentication and inventory management (Greene & Longobucco; 2018; Hanson, 2018; Jordan & Rasmussen, 2018). Combined with radio frequency identification technology (RFID), which has already been used in many companies, such as Walmart, blockchain technology helps track the finished product from the beginning of product lifecycle all the way through the distribution chain until the product reaches the consumer (Hanson, 2018). This tracking information includes location, date and time, shipment handling details, temperature, condition of the package/product, etc. (Chakrabarti & Chaudhuri, 2017). Blockchain technology not only tracks whether the shipment has been properly handled or arrived on time, but can also help retailers find any lost or damaged products during shipping (Chakrabarti & Chaudhuri, 2017). Due to the structure of blockchain, these shipment records cannot be altered, lost or destroyed (Greene & Longobucco; 2018; Hanson, 2018). The information saved in blockchain is visible to all involved stakeholders, including consumers, retailers and suppliers. These stakeholders can see the product source and product process, which reduces the possibilities of product counterfeits (Chakrabarti & Chaudhuri, 2017).

Some early adopters in the fashion industry have started using blockchain to manage their supply chains better. Designer Martine Jarlgaard collaborated with Provenance, a supply chain transparency company, and presented her blockchain-tracked garments at the Copenhagen Fashion Summit in 2017 as the first garment using blockchain technology (Beckwith, 2018). Her garments came with a tag with a QR code that could be scanned with a mobile phone to access a full history of the supply chain behind each garment, as shown in Figure 20 (Beckwith, 2018).

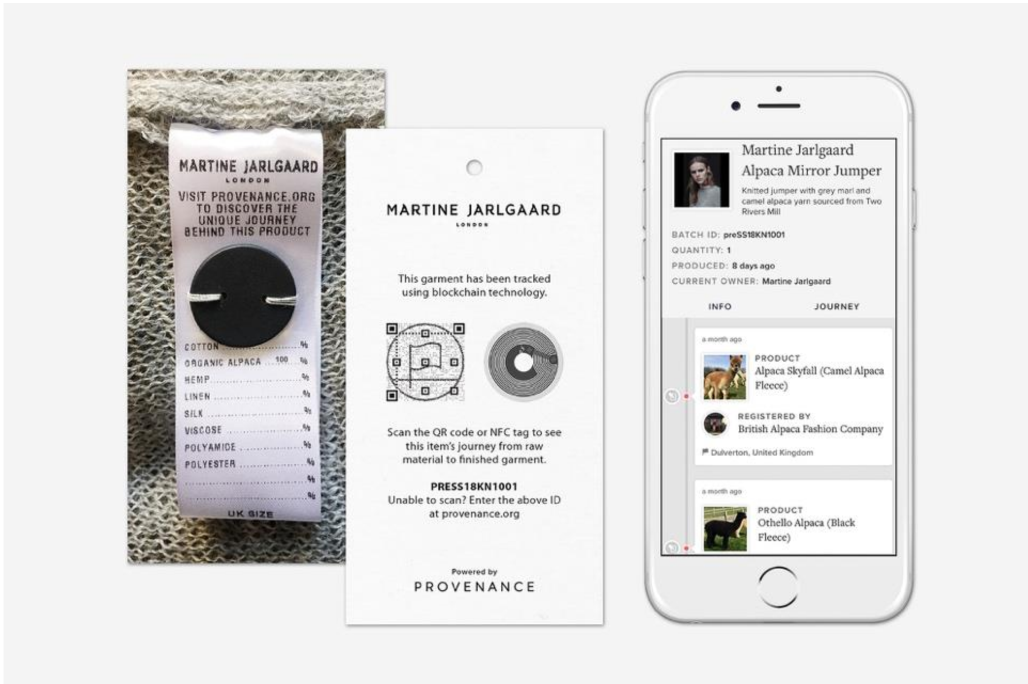


Figure 20. Martine Jarlgaard’s garment using Blockchain technology (Beckwith, 2018).

However, the implementation of blockchain in the fashion industry is still at the early stage. Very few companies have adopted this technology. Hanson (2018) found that blockchain has the potential to speed up the shipping process, save costs and improve efficiency. Limited research has been conducted on investigating the potential of blockchain in the design and development process. Furthermore, no research has investigated whether this innovative technology could revolutionize the future of the apparel product development process and shorten the product development cycle accordingly.

2.6 Product Development Calendar

The product development calendar, also known as the merchandising calendar or time and action calendar, is one of the most important planning and control tools for managing seasonal apparel products. The calendar helps companies coordinate all the design, development and production activities, assign responsibility to the corresponding departments, and plan the start and stop dates for each activity throughout the entire process (Senanayake & Little, 2001). The product development calendar is typically displayed in the form of the Gantt chart (Senanayake, 2015). Each task is assigned a set amount of time and must be completed in this time frame.

Figure 21 is an example of the multi-season product development calendar, which includes 40 product development activities and four seasons: spring, summer, fall, and resort. Each season is color-coded. For example, spring begins in the last week of February and does not finish until the fourth week of December. In Figure 21, the right column of the calendar highlights the involved department responsible for one or multiple activities.

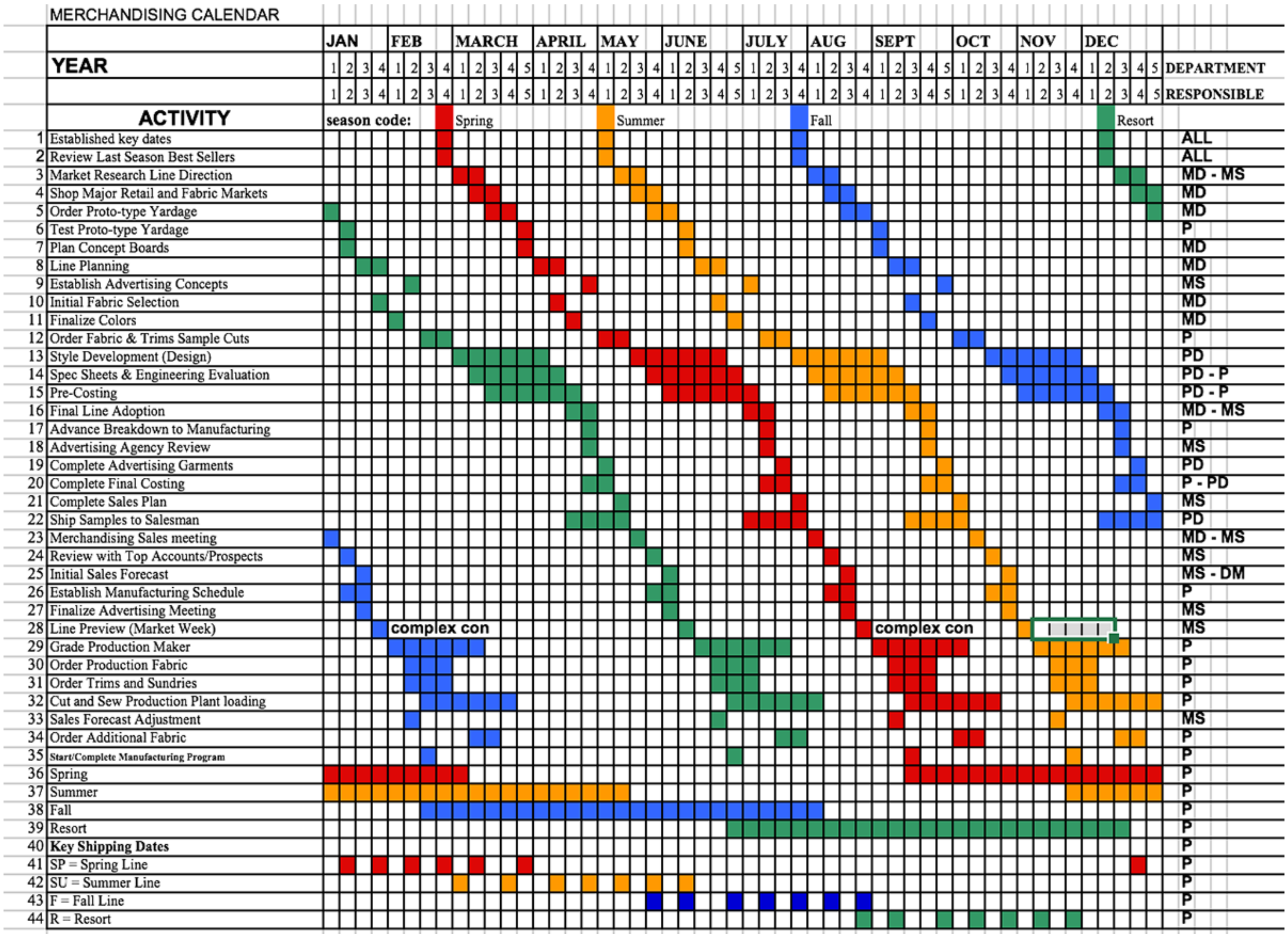


Figure 21. Multi-season product development calendar (Carlson, 2015).

The product development calendar can be viewed as a combination of sequential and concurrent model activities. While most activities are ordered and must be completed before moving forward, some activities can proceed concurrently. The merchandiser needs to track and monitor the progress of each activity. When a single activity is delayed, it may cause all subsequent activities to be delayed, which, consequently, then miss production and shipment deadlines (Rosenau & Wilson, 2014). Even if the work is accomplished ahead of time, it will impact the following activities. Therefore, the product development process has to be well planned and scheduled. Additionally, every calendar needs to be reevaluated after each season and adjusted if necessary.

The timeline and activities in the product development calendar may vary from company to company depending on various factors, such as product type: fashion versus basic, original versus knock-off, or the company's business model: wholesale, retail private label, fast fashion, or mass customization (Senanayake, 2015). A traditional calendar begins one year in advance of the spring/summer and fall/winter seasons. Typically, four to six months is required to complete the product development cycle. The process might take even longer if the production is sourced offshore or if the materials are distant from the production site (Keiser, Garner & Vandermar, 2017).

Today, many companies spend a great deal of money and time trying to reduce product development time by effectively managing the calendar and incorporating advanced technology and management systems. However, in practice, most companies continue to use spreadsheets or stand-alone software solutions to manage the process, instead of integrating the calendar into the company wide PDM or PLM solutions.

2.7 Measures for Apparel Design and Development

The concept of measuring the success or failure of an individual product or overall development process can be traced to 1964 in the National Industrial Conference when Cochran and Thompson (1964) published the paper *"Why New Products Fail."*. Since then, researchers have defined measures of product development success or failure in different ways. Measures can be varied depending on different products and business strategies (Griffin & Page, 1993).

Cooper and Kleinschmidt (1987) studied 203 new products and identified 11 measures of new product success. Of these measures, most are related to a company's financial performance, such as profitability level, payback period, domestic and foreign market share, sales and profits. Griffin and Page (1993) analyzed 77 related pieces of literature and organized 46 different measures into five categories: measures of firm benefits, program-level measures, product-level measures, measures of financial performance and measures of consumer acceptance. In addition, Griffin and Page (1993) found that academics and industry emphasize different sets of measures. Companies focus more on consumer-related measures, such as consumer acceptance and satisfaction, and financial measures such as margin level; whereas, researchers are more interested in product-level measures such as speed-to-market, and firm-level measures, such as success/failure rate.

Since apparel products are produced in seasonal lines and have a relatively short product development cycle, it is inappropriate to generalize the measures of other product categories into apparel. A few studies have focused specifically on the measures for apparel product development (Mattila, 1999; Senanayake & Little, 2001; Mattila & Ojala, 2002; Jang, Dickerson & Hawley, 2005). Mattila (1999) first identified seven retail performances associated with the seasonal fashion products: service level, lost sales, product substitute percentage, gross margin, stock-turn, gross margin return on inventory, and sell-through percentage. Senanayake and Little (2001) benchmarked the apparel product development process using measures such as sample adoption ratio, product development cycle time, manufacturing cycle time, sell-through, pick and ship time, return on net assets, investment per sales, forecast accuracy and gross margin return on inventory. Moreover, considering the development of new technologies, additional measures such as the performance of virtual samples and the quality of virtual samples should also be included (Senanayake & Little, 2001).

Mattila and Ojala (2002) defined retail success as receiving high gross margins and consumer service levels while having fewer inventories. When dealing with the seasonal fashion products, forecast accuracy, lead-time, offshore/local sourcing mix and up-front/replenishment buying mix become the key success factors. Jang, Dickerson and Hawley (2005) investigated 27 participants from 12 apparel and textile companies in the US with different business types, product specifications and company size. The researchers proposed four major measures: customer acceptance, financial performance, product-level and firm-level. Each major measure has several sub-measures, and some have third-order measures. Specifically, in the measure of consumer acceptance, sales, consumer satisfaction and market share are identified as the sub-measures. Sell-through, longevity and growth are the third-order measures of sales. In the financial performance measures, retail profitability is the only sub-measure. Five sub-measures emerge within the product-level measure: product value to consumer, adaptability, excitement, style mixes of line and cost efficiency. In the firm-level measure, contribution to the firm’s business and brand building are included. Among all the measures, sales and retail profitability are considered to be the dominant performance measures for apparel product development.

There is an increasing number of measures in apparel product development, meaning that the industry focuses more on monitoring the product development process. Additionally, the measures for delivering new products to the consumers have also increased remarkably over time (Senanayake & Little, 2001).

2.8 Advanced Technologies in Apparel Design and Development

Advanced technologies have been widely used in every aspect of the textile and apparel industry, from design and development, to manufacturing and retail. In this research, advanced technologies that have the potential to reduce time in the design and development process are been reviewed. Different technologies include 2D CAD, 3D virtual prototyping, body scanning technology, 3D printing technology, digital printing technology and digital thread dyeing technology.

2.8.1 Two-dimensional computer-aided design technology

Computer-aided design has been widely used by designers and developers in the textile and apparel industry. The history of CAD can be traced to 1957, when Dr. Patrick J. Hanratty developed the first commercial numerical control programming system, PRONTO. Three years later, Ivan Sutherland created SKETCHPAD, which allowed designers to interact with the computer graphically (Zhang, 2015). The early commercial applications of CAD were adopted in the automotive, aerospace and electronics industries, and were further introduced into the textile and apparel industry in the 1970s (Zhang, Zhang & Li, 2008).

Early applications of the 2D CAD technologies were in textile and apparel design and pattern creation. As illustrated in Figure 22, the traditional design and pattern making processes begin with a designer sketching ideas on paper and working with the pattern technologist to produce the paper patterns. A large number of samples is created and evaluated by the buyer. If the sample is rejected, the process begins from the design again and repeats until the sample is accepted (McCartney, Hinds, Seow & Gong, 2000). This process depends significantly on the pattern technologist's personal skill and is very time-consuming.

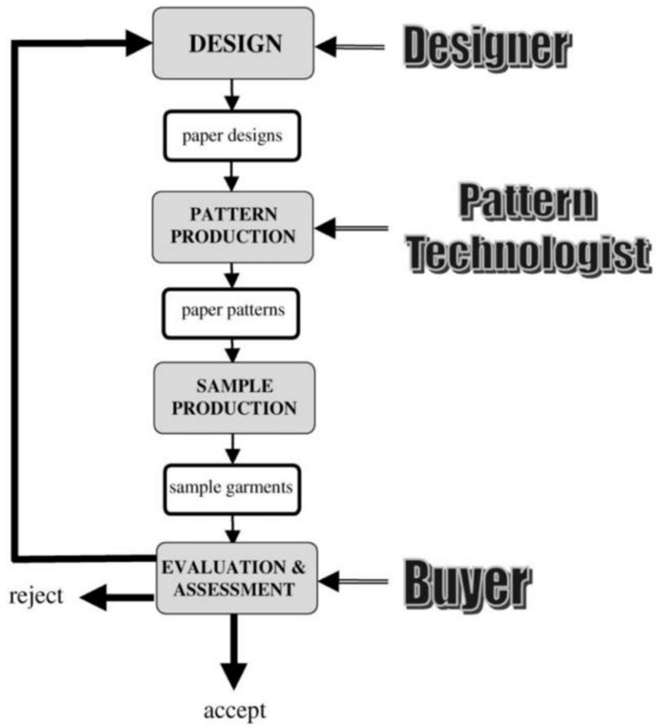
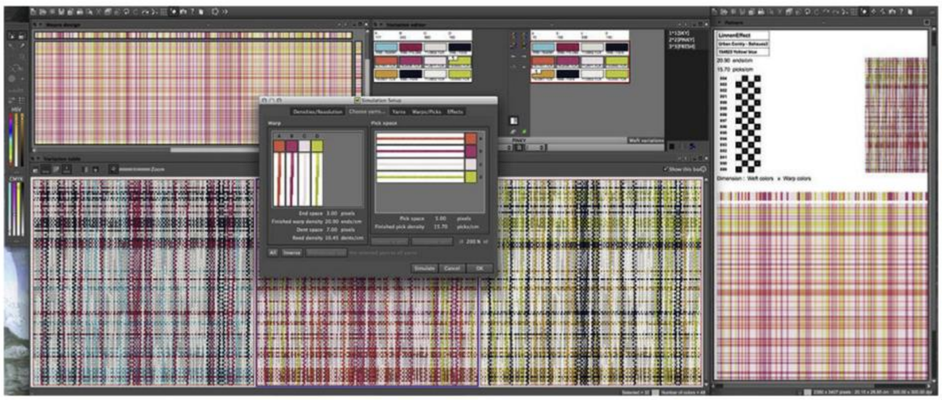


Figure 22. The traditional design and pattern making method (McCartney, Hinds, Seow & Gong, 2000).

Two-dimensional CAD significantly impacts textile and apparel design. Both woven and knitted fabric designs can be achieved using CAD systems, as shown in Figure 23. Textile design software allows designers to select a number of textures, colors and patterns, and to visualize the pattern in various fabrics.

(a)



(b)

Figure 23. Computer-aided design technology for textile design. (a) knit fabric, (b) woven fabric (Jhanji, 2018).

As displayed in Figure 24, designers create artworks and illustrate design ideas more quickly and more precisely by using the multiple tools available in apparel design software, such as draw and erase or do and redo. The 2D apparel design software enables designers to modify their existing designs easily to create new pieces or to apply a single design to different materials, patterns or colors (Jhanji, 2018). In addition, a variety of color and fabric prints can be easily applied to different designs. This practice speeds up the traditional design process and shortens the time between initial concepts and final design.

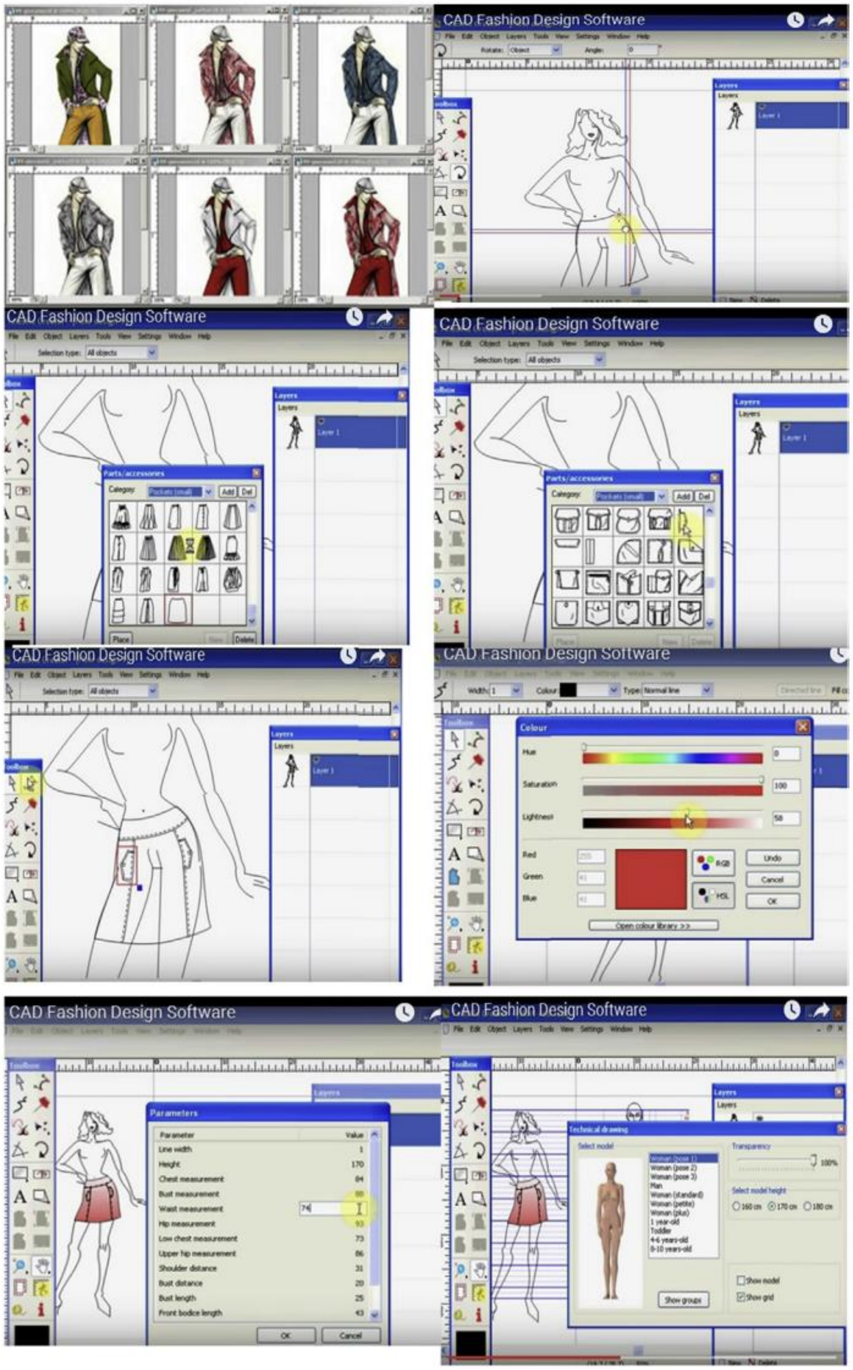
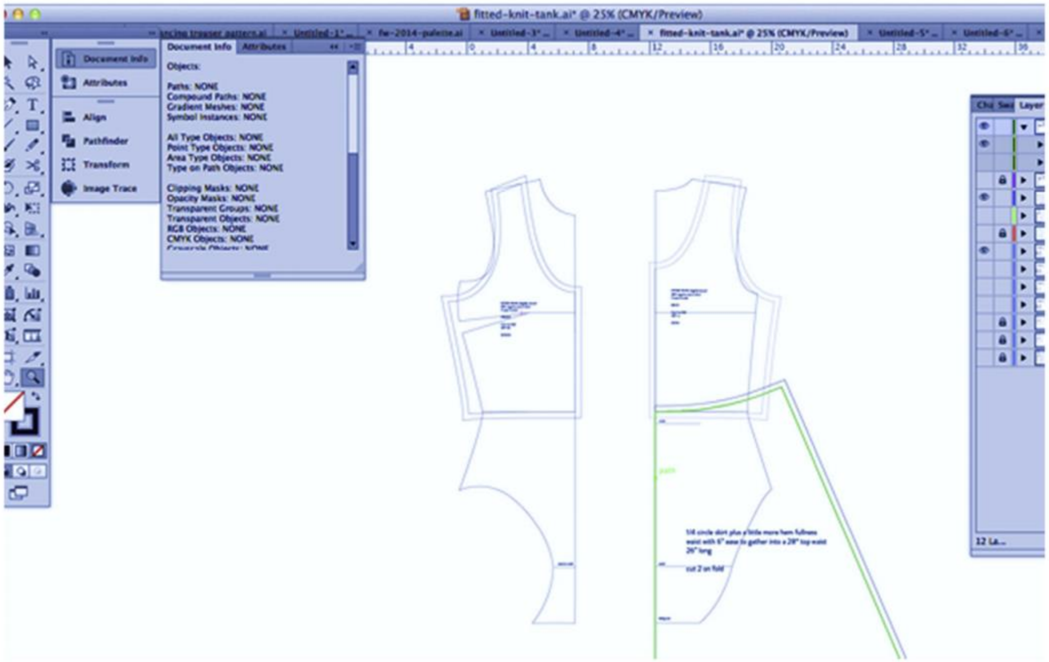
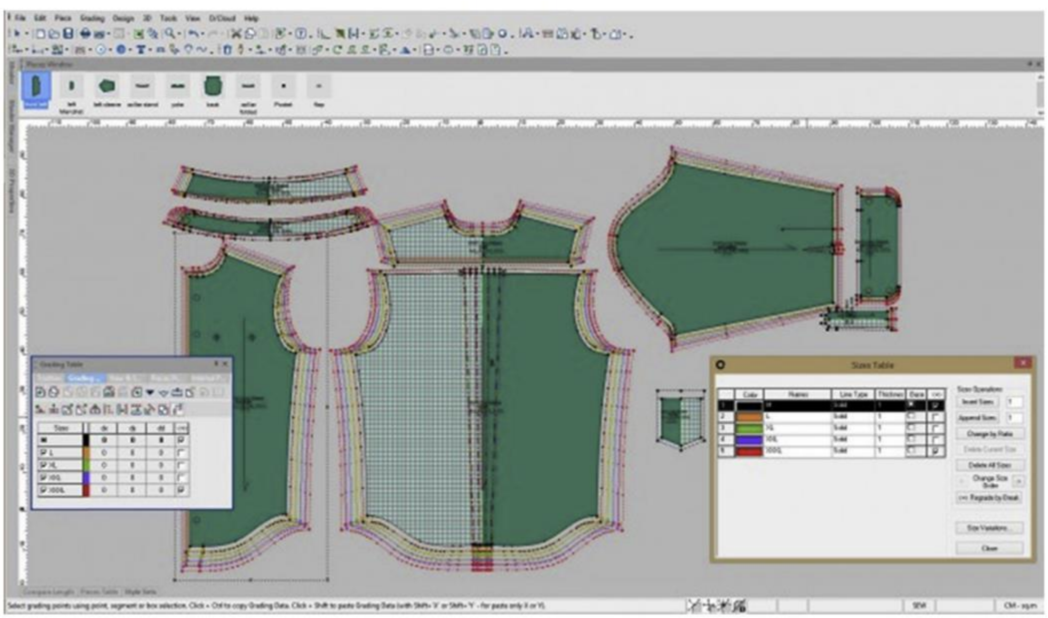


Figure 24. Computer-aided design technology for apparel design (Jhanji, 2018).

Two-dimensional pattern creation software is mainly used for pattern digitizing/scanning, pattern drafting, grading and marker making. Designers can manipulate pattern pieces more easily and quickly than with the traditional manual pattern making method (Collier & Collier, 1990). Basic flat pattern templates are stored in the database and can be retrieved by designers to generate the new desired style. Figure 25 illustrates how patterns can be graded into different sizes easily by either using standardized grading rules or by inserting a customized grading table. This process eliminates complicated calculations and laborious work, which facilitates the process and reduces errors and cost (Jhanji, 2018). Once the patterns are graded and further nested, the pieces can be quickly laid out in a marker making system, which automatically places the pattern pieces to minimize fabric use (Collier & Collier, 1990). Some examples of the 2D pattern creation software are Modaris (Lectra), Accumark (Gerber), TUKAcad (Tukatech), Master Pattern Design (PAD System), cad.assyst (Human Solutions), GRAFIS (Software Dr K. Friedrich), Audaces Apparel (Audaces), COAT (COAT- EDV-Systeme) and Fashion CAD (CAD/CAM Solutions) (Sayem, Kennon & Clarke, 2010).



(a)



(b)

Figure 25. Computer-aided design technology for pattern creation. (a) pattern making, (b)pattern grading (Jhanji, 2018).

2.8.2 Three-dimensional virtual prototyping technology

The early development of the 3D virtual prototyping technology was at the beginning of the 1990s when Hinds and McCartney (1992) included a virtual mannequin in their system to visualize garments. Later, research focused on converting 2D to 3D by draping digital 2D patterns onto a 3D mannequin; and 3D to 2D, which flattens the 3D design into 2D patterns (Sayem, Kennon & Clarke, 2010). Three-dimensional virtual prototyping technology has been widely used in the textile and apparel industry in the 21st century, and it has opened up a new method for fit evaluation (Park & DeLong, 2009). Some examples of 3D prototyping software include Vstitcher (Browzwear), Accumark Vstistcher (Gerber), Modaris 3D Fit (Lectra), e-fit Simulator (Tukatech), CLO3D (CLO), Pattern Design Software 3D (EFI Optitex), Haute Couture 3D (PAD system) and Vidya (AssystBullmer).

The traditional prototyping process is very iterative. Pattern makers create 2D patterns by manipulating a set of basic blocks. Once a prototype is made and put on a mannequin or a live model to evaluate fit, necessary changes must be made and another prototype has to be prepared. This process is repeated until the desired product is achieved (Meng, Mok & Jin, 2010). Multiple prototypes are usually needed to compare design alternatives or to achieve a final product with good fit and high quality. Due to different time zones and languages, communication between designers and factories is often delayed and problematic.

Three-dimensional virtual prototyping technology converts 2D patterns into a finished sewn garment and place the garment on a virtual fit model, as shown in Figure 26. The model contains different variations of body shape and sizes (Lee & Park, 2017). This technology is typically linked with the 2D pattern creation software. Prior to making actual samples, designers check the fit of the garment in a 3D environment and adjust the fit and fix the patterns by using

2D pattern creation software. In addition, designers can visualize garments and fabric drape on the 3D virtual mannequin and make quick decisions regarding selecting different colors, sizes and fabrics (Lee & Park, 2017). The 3D virtual prototyping technology saves time and cost by reducing the number of physical samples. According to Salmon (2014), on average, the number of physical samples reduces from three or five to two for each garment. In addition, this technology improves communication between different departments, including merchandising, design and product development, meaning decisions can be made more quickly and products can be presented to consumers much more rapidly (Salmon, 2014).

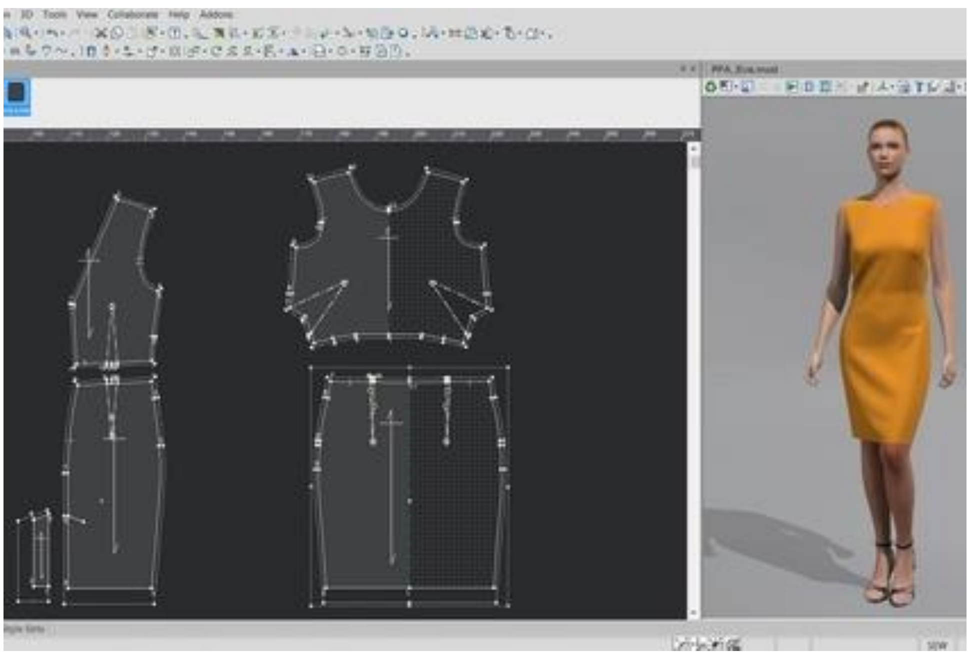


Figure 26. 3D Virtual prototyping (Barrie, 2015).

The literature has focused on investigating the accuracy of 3D virtual prototyping technology by comparing virtual and actual garments. Fabric simulation has been mentioned as an important factor that negatively impacts fit. According to Porterfield and Lamar (2017), the same fabric will drape differently depending on the cut of the garment due to the nature of fabric, which is anisotropic and differs from area to area. Ease is another concern. Essentially, there are four types of ease: fitting ease, which provides basic physiological movement comfort; fashion ease, which is the additional amount of ease for a specific style; dynamic ease, which adds to extreme postures; and negative ease, which concerns fabrics that have tensile properties (Zhang, 2015; Ling, 2013; Petrova & Ashdown, 2008; Ng, Cheung & Yu, 2008). Proper ease should be added to obtain an accurately fitted garment. As indicated by Porterfield and Lamar (2017), designers are not confident about making fitting decisions based only on the 3D virtual mannequin. Instead, designers prefer to interact with fabric on the physical body and to manipulate physical samples. Other factors that may negatively affect the accuracy of fit include garment complexity and the selection of a virtual mannequin.

In summary, 3D virtual prototyping technology has been in use in the industry for a long time. However, in practice, 2D CAD technology continues to dominate the design and development process. There are at least two main challenges: the first relates to using the fabric in an optimum utilization approach; the second is offering the consumer a visualization of how they would appear in that style. In particular, fashion still needs to produce physical samples before achieving the final design, which adds extra time and money. The following section discusses the time difference between different methods.

2.8.3 Discussion regarding speed

In the literature, three studies have compared the time difference of different methods. Ondogan and Erdogan (2006) compared the time between manual and CAD methods for pattern making, grading and marker making processes. They designed four models from the simplest, which consists of five pieces, to the most complex, which consists of 11 pieces, in five sizes, from XS to XL. Ondogan and Erdogan (2006) categorized pattern and marker making processes into eight stages and found that the CAD method is more efficient in three out of the eight stages, namely grading, size set patterns check and correction, and marker making preparation. The manual method is more efficient in one stage: main size pattern preparation. There is no significant speed difference between the two methods in the remaining four stages, namely main pattern check and correction, adding seam allowances, marker making and correction, and marker plotting.

Similarly, Puri (2013) compared the time spent using manual and CAD methods for three styles: bottom (three pieces), top (five pieces), and dress (13 pieces). In addition to pattern making, grading and marker making processes, Puri also compared the time involved in physical and virtual prototyping making processes. It was found that the CAD method is more favorable in grading, sample making and marker making preparation procedures. No significant difference was found in creating main size pattern and marking making procedures. The findings revealed that the CAD system is more beneficial regarding speed when the complexity and the number of the patterns increase. Kılıç (2019) further mapped out the detailed steps in pattern making, grading and marker making processes and compared the efficiency between the two methods for each step: specifically, 18 steps in pattern making, 10 steps in grading and two steps in marker making. The findings are in line with the literature in that the largest time difference between the manual and the CAD methods was in the grading and marker making processes.

In summary, CAD technology shortens the design and development time. especially for the grading, prototyping and marker making processes. However, the time spent in developing main size pattern remains the same between the two methods. In addition, the literature has compared the time difference based on the same number of manual patternmakers and digital patternmakers. However, in reality, it is difficult to quantify the improvement of speed since companies might reduce the number of manual patternmakers when implementing the CAD system, resulting in fewer digital patternmakers and less time difference accordingly.

2.8.4 Body scanning technology

Three-dimensional body scanning technology has been used in the textile and apparel industry since the 1990s. The process captures information about the human body by measuring the surface of the body and generating a 3D image using hundreds of measurements (Ashdown & Dunne, 2006). The traditional anthropometric measurement, which uses tape or calipers, is very time-consuming. The 3D scanning process takes five to 15 seconds, and an additional one to two minutes are needed to generate measurements (Han, Nam & Choi, 2010).

The body scanning technology consists of multiple light sources, one or more vision or capturing devices, software, computer systems and monitor screens (Istook & Hwang, 2001). Whole body scanners are widely used in the textile and apparel industry to capture whole body measurements. The first body scanner was developed in the 1990s and was bulky, expensive and had low resolution (Daanen & Ter Haar, 2013). Since then, the technology has improved greatly. Examples of 3D whole-body scanner companies are Cyberware, Vitronic, Human Solutions GmbH, 3dMD, Size Stream, The Textile Clothing Technology Corporation [TC]2 and The Wicks and Wilson Limited, and Intellifit.

There are two primary types of body scanning systems: laser-based and light-based, as shown in Figure 27. Other systems exist but are not widely used for measuring human bodies (Istook & Hwang, 2001). In a laser-based scanning system, a strip of laser light is projected onto the human body from different sides and the laser lines are reflected into cameras located in each scan heads. Cyberware and Vitronic were the early leading manufacturers of laser-based systems

(Daanen & Ter Haar, 2013). The laser-based scanning system provides accurate measurements with high resolution and a low level of noise. However, the disadvantages include high cost and a longer time to digitize large surfaces (D'Apuzzo, 2007). A light-based scanning system employs white light sources to project a contour pattern onto the human body surface. Two types of white light sources are commonly used: The Textile Clothing Technology Corporation [TC]2 uses the phase measuring profilometry technique (PMP). And The Wicks and Wilson Limited employs the Moiré light projection techniques (Istook & Hwang, 2001). The scanning time of the light-based scanning system is short, mostly within one second. However, multiple devices are required to be in use serially to measure large surfaces such as the whole human body, which adds additional time and cost (D'Apuzzo, 2007).

(a) (b)

Figure 27. Whole body scanners. (a) Vitronic, (b) Sizestream.

Other systems include the millimeter waves system, which is currently used at airports for security checks. This system has the advantage regarding time and effort but may cause ethical problems. since the full body is revealed (Daanen & Ter Haar, 2013).

Recent developments in body scanning technology include a 4D body scanner, handheld scanners and phone scanners. Four-dimensional scanning technology offers the opportunity to document dynamic natural poses and activities. One example of such a scanner is the 3dMDbody.u System developed by the company 3dMD, as shown in Figure 28. Their first generation was developed and commercially available in 2005 and captured an ordered sequence of 3dMD images over time. Later, the company developed a variety of the 3dMD temporal-based system, such as the 3dMDhead.u System, the 3dMDface.u System and the 3dMDfoot.u System. In addition to the textile and apparel industry, the 3dMD temporal-based systems have many applications in the healthcare industry (3dMD, 2016).

Figure 28. 3dMDbody.u system developed by 3dMD (3dMD, 2016).

Handheld scanners are usually controlled by the user's hand or robotic arms to obtain images from different angles, as shown in Figure 29. These scanners are more flexible than whole body scanners since they can be carried around. However, they are mostly used to capture some body parts or static objects instead of the full human body since it is difficult for the scanned subject to remain completely still during the entire scanning process (Motley, 2017). The scanning time varies depending on the speed of the scanner and the size of the scanned object/subject. Typically, handheld scanners take longer time than a whole body scanner. Handheld scanners outperform whole body scanners when capturing shadow areas, such as armpits and the crotch. However, no current software can automatically extract body measurements from commercial handheld scanners. Some examples of the handheld scanners available on the market are Artec Leo, Artec Eva and Artec Space Spider (Artec Europe), GO!SCAN 50, handyscan 700, Metrascan 750 (Creaform), Einscan pro+ and freescan X5 (SHINING 3D), Sense (3D Systems Inc.) and DRAKE (THOR3D) (Lansard, 2018),

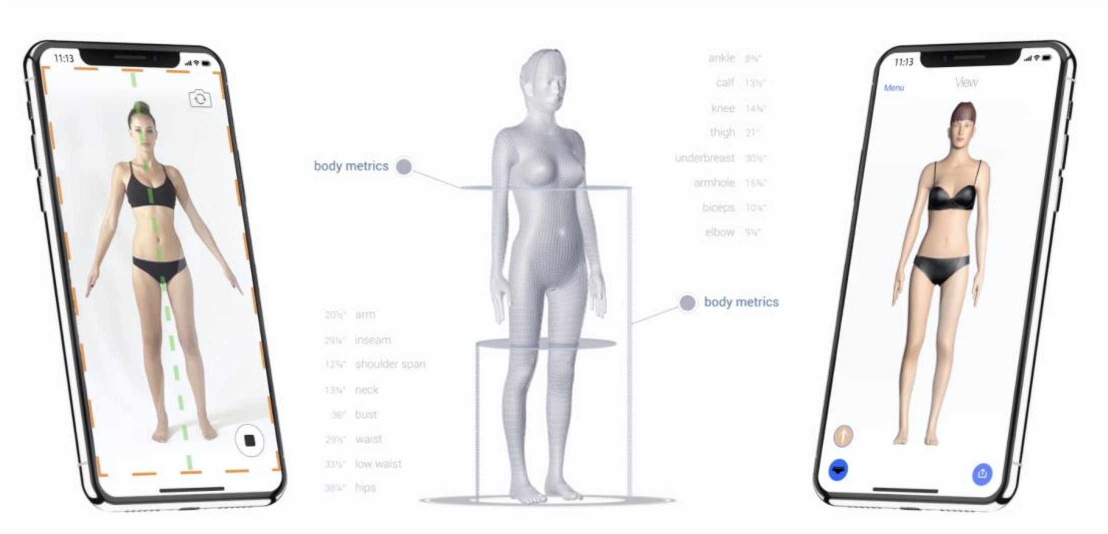
(a) (b)

Figure 29. Handheld scanners. (a) Artec Eva by Artec Europe, (b) Sense by 3D Systems Inc.

Phone scanners are also gaining popularity these days. The occipital structure sensor was launched in 2013 and can be added to a smart phone or touchpad, as shown in Figure 30. This structure sensor has been used in garment fitting, health and fitness, as well as in the entertainment industry (Structure by Occipital; 2018a). In 2018, the company launched a new, advanced depth sensor with improved resolution, precision and accuracy, and a global shutter to handle fast moving objects and scenes (Structure by Occipital; 2018b).

Figure 30. Occipital structure sensor.

Recently, companies such as Nettelo and 3DLook have introduced mobile 3D body scanning technology, as shown in Figure 31, which processes and measures the human body from mobile devices such as smartphones (Scarano, 2017). Consumers can easily obtain their body measurement using a body scanning mobile app.



(a)

(b)

Figure 31. Mobile 3D body scanning. (a) Nettelo, (b) 3DLook.

Although body scanning technology provides measurements within a short time, it has several concerns. A large set of measurement data is generated during the scanning process, but not all the data are useful in the following pattern making or draping processes. However, it takes additional time to extract and manage these data. Accuracy is another problem. During the scanning process, movements or different postures of the scanned subject influence the measurement accuracy (Zong & Lee, 2011). Shaded areas, such as armpits and the crotch, or dark outfits may cause the problem of missing data, which requires extra time and effort to process additional data, extending the overall time (Zong & Lee, 2011).

2.8.5 Three-dimensional printing technology

Three-dimensional printing (3DP) technology was first introduced in the 1980s. In 2010, designer Iris van Herpen released her concept of 3DP for the first time during the Amsterdam fashion week in the Netherlands. Since then, the 3DP technology has entered the fashion industry and led to a rapidly growing and discussion. In 2011, Continuum Fashion Company produced the world's first 3DP bikini swimwear, which enabled 3DP technology to enter the ready-to-wear market (Wang & Chen, 2014). In recent years, 3DP technology has been explored in different markets, including footwear, accessories and haute couture.

The 3DP process begins with designing products using the CAD software, typically a 3D modeling program. Once modeling is completed, the software divides the products into multiple horizontal layers and develops products by each divided layer (Mellor, Hao & Zhang, 2014). After printing, sanding and polishing processes are needed to improve the surface finish. Color can also be altered through painting or a dyeing process (Yap & Yeong, 2014).

There are three 3DP methods that are most applicable to the fashion industry: stereolithography (SLA), selective laser sintering (SLS) and fused deposition modeling (FDM) (Vanderploeg, Lee & Mamp, 2017). The SLA method is the earliest and is still being used today. This method converts liquid photopolymers into solid 3D objects, one layer at a time. The printing time depends on the size and complexity of the printed products. Smaller products can be printed in six to eight hours, while larger products can take up to several days (Sclater, 2011).

An example of using SLA in the fashion industry is Dutch designer Iris van Herpen, who created her Wilderness Embodied Collection in 2013, as shown in Figure 32.

Figure 32. Wilderness embodied collection by Iris van Herpen.

The SLS method uses powdered material and does not need support structures. Since SLS has a wide printing material selection, ranging from nylon, glass and ceramics to metals such as aluminum, silver and steel, it allows designers to create delicate but also highly functional and durable products (Sclater, 2011). As shown in Figure 33, Designer Iris van Herpen used SLS to develop a dress in her haute couture collection in 2013.

Figure 33. VOLTAGE by Iris Van Herpen.

The FDM method is commonly used in different industries since it is relatively affordable and offers a variety of low-cost desktop printers (Vanderploeg & Mamp, 2017). Materials generally consist of wax, metals and ceramics. Previous studies have found that FDM is capable of printing flexible, glossy, lace-like fabrics with soft PLA polymers (Melnikova, Ehrmann, & Finsterbusch, 2014).

The 3DP technology provides the fashion industry with an alternative method for design, product development and production. Due to the nature of this technology, only 3D data files and raw materials are needed to develop products, which reduces time-consuming processes such as pattern making and garment construction (Sun & Zhao, 2017). However, several challenges remain. Current 3DP materials do not have the same properties as real fabrics, which results in less comfort. Other limitations include fewer selections of materials and colors, as well as the high cost in industrial production (Wang & Chen, 2014).

2.8.6 Digital printing technology

Inkjet digital textiles printing technology has been rapidly developed since the 1990s and has revolutionized the textile printing process (Ujiie, 2006). Inkjet printing is a non-contact printing technology in which colorants are dropped or sprayed through the print-head nozzles onto various textile substrates (Ujiie, 2006). Compared with the conventional screen-printing processes, which require large minimum order quantities, digital printing technology enables shorter print runs and a quick response to consumer demand. This technology significantly reduces time-to-market by eliminating time-consuming processes such as screen engraving, printing past making, washing, and color matching (Kan & Yuen, 2012). Since designs can be made digitally and adjusted on the spot, samples can be produced rapidly as required and short-term delivery can be achieved (Dehghani, Jahanshah, Borman, Dennis & Wang, 2004). All costs, downtime and wastage associated with screen engraving, past making and strike-offs are eliminated. In addition, there is no restriction on the number of colors or size of repeat. Other advantages of digital printing technology include excellent print fastness, less energy, water and chemicals consumed, and less or no stock (Kan & Yuen, 2012). This advanced technology is ideal for just-in-time delivery and mass customization products. as well as for short-run niche market products such as silk ties (Tyler, 2005).

2.8.7 Digital thread dyeing technology

In 2019, Twine Solution, which is a technology startup, developed a digital on-demand thread system. This system is able to dye raw and off-the-shelf white thread to a variety of desired colors and lengths that are ready for immediate use. This system is linked to the company's color matching application, which can match colors accurately in seconds (Crawford, 2019). Compared with the conventional bulk dyeing of thread, this new technology shortens lead time by obtaining dye thread immediately for sewing, knitting or embroidery products and eliminates the time needed for color samples. In addition, since it dyes exactly the amount needed, this technology reduces the large inventory of colored thread and reduces costs accordingly.

CHAPTER 3. Methodology

This chapter presents the research objectives, research methods, data collection and data analytics methods.

3.1 Research Objectives

The reviewed literature revealed that attentions and opportunities are now turned into the design and development process to compress the product development calendar. The objective of this research is to explore the current activities and timeline of the apparel design and development process, as well as to determine the key factors that affect its speed. A deciphered model was built and validated for apparel companies to manage the time involved in the process. The model built from the research presents different lengths of the product development cycles, ranging from the longest to the shortest. For each cycle, the sequence of detailed activities and the timeframe for each activity are mapped out. As the literature in Chapter 2 indicated, no such model has previously been developed and the published models in the literature are considered dated and lacking a discussion on speed. Therefore, this research can be considered pioneering in this field.

In summary, the research objectives are listed as follows:

Research Objective 1: Perform a collective case study to explore current activities and the timeline of apparel design and development.

Research Objective 2: Identify the key factors that affect the speed.

Research Objective 3: Build an initial model that manages the time involved in design and development.

Research Objective 4: Validate the model using the Delphi method and refine the model.

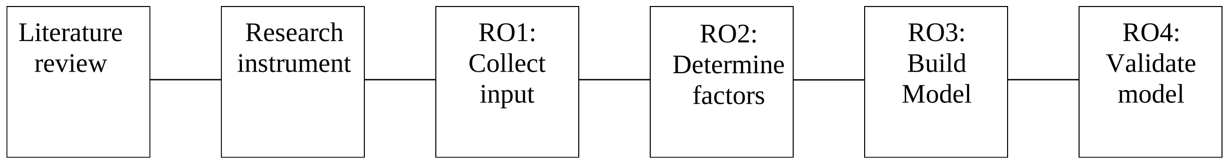


Figure 34. Research Map.

This study used a collective case study and the Delphi method to address the research objectives. Specifically, a collective case study was used to achieve Research Objectives 1 to 3, and the Delphi method was used to achieve Research Objective 4. The following sections of this chapter outlines the detailed characteristics of the research methods and the data collection and data analysis.

3.2 Collective Case Studies

Case studies, as a qualitative research design, have been widely used in social and applied sciences to understand complex issues (Yin, 1984). This method is especially useful when exploring a single individual, group or event in-depth in a real-life context (Yin, 1994). The approach is also useful when investigating problems that are difficult to explore using a quantitative research method (Mills, Durepos, & Wiebe, 2009).

This study used a collective case study design to obtain a detailed understanding of the current activities and timeline of the design and development process. A collective case study involves collecting and analyzing inputs from multiple cases rather than studying just a single case. This multiple approach gathers a greater amount of information and provides an in-depth understanding of the subject (Merriam, 1998). Multiple cases can be used to achieve the replication of a single case study in different settings or to compare and contrast different cases.

In a case study design, data are sourced from documentation, archival records, interviews, direct observations, participant observation and physical artifacts (Yin, 1994). The data collection may include a combination of document analysis, in-depth interviews, participant observation, oral histories, multimedia, situation analysis, or be a clinical case study (Mills, Durepos, & Wiebe, 2009).

3.2.1 Sample selection and description

Sample selection is one of the critical steps in a case study. Samples should be selected strategically and align with the research objectives. Four to 15 samples are recommended to perform multiple case studies (Mills, Durepos, & Wiebe, 2009). This study conducted five cases. There are two methods used to select multiple cases. The first method is a parallel design in which all the cases are selected in advance and are conducted at the same time. The second method is a sequential design in which each selection of cases follows the other. In particular, the selection of each case is informed by the outcome of the previous completed case (Mills, Durepos, & Wiebe, 2009). This current study used the second approach since the selected company should have different lengths of the design and development calendar. All five selected cases are located within the US and their descriptions are presented as follows:

Case I. Case I is an apparel brand with a nearly 100-year history. The company has around 100 employees and is well-known for athleticwear, including T-shirts, shorts, fleeces, sweatshirts, sports bras and basics. The Case I company has an 11-month design and development calendar.

Case II. Case II is an apparel brand that has more than 20 years' history with over 15,000 employees. The Case II company produces performance apparel, footwear and accessories for men, women and youth and has a 14-month design and development calendar.

Case III. Case III is an apparel brand that has roughly 20 years' history of producing luxury performance sportswear, seasonal resort apparel, refined tailored clothing, and sartorial accessories for men and women. The Case III company has relatively a small group of in-house employees located in their headquarters and has a nine-month design and development calendar.

Cases IV& V. Cases IV and V are from the same apparel company, but from different product types with different lengths of the design and development calendar. The company has roughly 50 years' history and has between 201 and 500 employees. Case IV focuses on the company's ready-to-wear products, including menswear shirts, neckwear, trousers, formalwear, and accessories, and has a six-month calendar. Case V focuses on the company's mass customization products, including menswear shirts, neckwear and trousers, and has a one-month calendar.

3.2.2 Data collection

Qualitative inputs were gathered through a series of semi-structured interviews. Interviewing is one of the most critical sources of data in the case study, providing a breadth and depth of information (Yin, 1994). The interviews were conducted either via the telephone or face to face. The interviewees were asked to describe their product development calendar and explained each activity and the timeline. Three tables were created and sent to the interviewee to assist the process, including a list of design and development activities, a list of technologies and a list of business practices. Each interview contained a set of open-ended questions developed prior to the interview process. These questions were used to set the theme and guide the process. Additional questions were asked during the interview to clarify or further expand certain points.

Some examples of the interview questions are presented in Table 1, and the full interview questions and the three tables are in Appendix A.

Five companies were invited through a formal email requesting participation and including a letter of informed consent. Prior to collecting the inputs, the Industrial Review Board (IRB) approved the use of human subjects (Appendix B). Interviews were conducted during summer 2019 and fall 2019, and normally took one to four hours. Follow-up calls and visits were made to verify the information whenever necessary.

Table 1. Examples of the interview questions.

#	Interview Questions
1	How many seasons are designed and developed per year and how many lines are designed and developed in each season?
2	How long is your company's current design and development cycle per line per season?
3	Please check the activities that are included in your design and development process.
4	Please indicate the time needed for each activity.
5	Please indicate which activities can be done concurrently and code the concurrent activities as the same number.
6	Which five activities are more time consuming in your design and development process?

3.2.3 Data analysis

In qualitative research, data are mainly unstructured text-based data that come from interview transcripts, field notes, audio or video clips, photographs or other documents. In contrast to quantitative research, which uses statistical methods, qualitative research relies on the interpretation and explanation of the subject under investigation. Data analysis in qualitative research usually begins by reading a large number of transcripts, followed by identifying patterns, themes and relationships, and finally interpreting the meaning of the data (Patton. 2002).

In this study, data come from five interview notes. During the interview, companies' representatives were asked to check the list of activities included in their design and development process and to measure quantitatively the time needed for each activity. They were asked also to indicate the technologies and business approaches used to help reduce the cycle time. Each case was first analyzed individually and then compared to identify the key factors that affect the speed. In each case, the company's background and its current design and development process were described. A process model was created for each case using sequential, concurrent and Stage-gate approaches. Based on the conclusions drawn from these five case studies, an integrated initial model was built.

3.3 The Delphi Method

This study used the Delphi method to validate the initial model. The Delphi method originated in a series of studies that researchers at the RAND Corporation conducted at the end of the 1940s (Kaplan, Skogstad & Girshick, 1949). The method is a research technique that aims to obtain the most reliable consensus of opinion from a group of experts who are knowledgeable about a particular subject or who can provide valuable contributions to resolve a complex problem (Dalkey & Helmer, 1963). In the Delphi method, experts are selected according to the predefined guideline and are asked to participate in the structured survey. Most questions in the survey are numeric estimates, either rating on a scale or yes/no (Kauko & Palmroos, 2014). The experts also have the opportunity to add comments on the issues raised in the questionnaire.

3.3.1 Sample selection and description

The number of experts in the Delphi method varies from 3 to 98 (Rowe & Wright, 1999). This study invited five experts. By definition, an expert has spent 10,000 hours or five years in the discipline. In this research, all the selected experts had more than five years' experience in the field of apparel design and development, but with different backgrounds and expertise. The information about the expert panel is presented as follows:

Expert I. Expert I is a CMO from a technology software company and has more than 20 years' experience in fashion and technology and who has worked for different companies in marketing, communications, product development, and sales.

Expert II. Expert II is a CEO of a digital magazine dedicated to the fashion industry. The expert has over 45 years' experience in design and digital solutions for the retail, footwear and apparel industries.

Expert III. Expert III is a CEO with over 30 years' experience in the apparel and fashion industry. The expert is skilled in trend analysis, negotiation, luxury goods, operations management and business development.

Expert IV. Expert IV has over 15 years' experience in product development, production, supply chain management, apparel mass customization, apparel process analysis and improvement and apparel technology management. The expert is currently a department chair in a fashion department and has published numerous research articles in different journals and professional conferences.

Expert V. Expert V is a CEO of a creation-driven fashion brands and has 30 years' experience in business process optimization and enterprise performance management.

3.3.2 Data collection and analysis

Five experts were invited via a formal email requesting their participation and asked individually to evaluate the model. In addition to a copy of the model itself, the experts received a model description document (Appendix C) that briefly explains the model and the research objectives. A rubric (Appendix D) was developed and sent to the experts to validate the model. The rubric contains 13 yes/no questions and four open-ended questions. Some sample questions in the rubric are presented in Table 2.

Table 2. Sample questions in the rubric.

#	Rubric Questions
1	A Gate is a major decision point for design and development for some types of companies. Do you recognize the value of Gates in this model depiction? (Yes/No)
2	Typically, Gates take time in the Design and Development Calendar. Do you think organizations with more gates have longer time? (Yes/No)
3	Concurrent activities are coded as "C" in the model. Are concurrent activities valid for Design and Development? (Yes/No)
4	In your opinion, whether technology be used to alter the calendar time?
5	Do you have a perspective on an optimum calendar?

The inputs were gathered via email. Follow-up calls and visits were made to clarify the information whenever necessary. Prior to collecting the inputs, the IRB approved the use of human subjects (Appendix E). The Delphi method was conducted in spring 2020, and normally took one to two hours. After collecting the feedback from all five experts, the initial model was refined, and a final model was built.

CHAPTER 4. Case Studies

4.1 Case Study I

4.1.1 Background information

Case I is an apparel brand from a diverse and global company. The parent company is a socially responsible leading marketer of everyday basic apparel in the Americas, Europe, Australia and Asia-Pacific. The parent company's products are sold everywhere that consumers shop, including mass-merchandise, mid-tier department-stores, college bookstores, dollar-stores, food and drug stores, and club-store retailers, as well as directly to consumers via the Internet. Approximately 80% of the parent company's apparel is produced in company-owned manufacturing facilities. The parent company has nearly 70,000 employees in more than 40 countries, including in the US. Net sales are around $6 billion. Most of the total net sales are from third-party brick-and-mortar customers. About 34% of the parent company's total net sales come from international markets, and its international sales have continuously grown in the past three years. The company's largest international markets are Australia, Europe, Japan, Canada, Mexico, China and Brazil.

The brand itself has a 100-year history and is well-known for athletic wear, including T-shirts, shorts, fleece, sweatshirts, sports bras and basics. In addition to active wear for men and women, the brand provides uniforms for athletic programs. The products are distributed through sporting goods retailers, e-commerce sites, department stores, college bookstores and specialty retailers, including Urban Outfitters, Zumiez and PacSun. The brand has been collaborating with designers and other brands worldwide and actively partnering with university businesses as well. Significant growth has occurred for this brand in sales outside US, primarily in Europe and Asia.

4.1.2 Design and development calendar

The brand has different design and development calendars for different product lines. Since all other calendars are derived from a main calendar, in this case study, the main calendar is used for further analysis. The Case I calendar has 382 activities, which takes 46 weeks to sales meeting and 83 weeks to start shipping. The calendar is in the form of an Excel table, which specifies each activity name, how long each activity takes, the deadline of each activity, the predecessor of each activity and the person responsible for the activity. The Case I calendar can be separated into five components: key milestones, garment development, prints/pattern development, color development and graphics development. Key milestones consist of 11 cross-functional team meetings, beginning with the seasonal strategy meeting and ending with the sales meeting. The other four components contain a list of activities related to prototype, print, color and graphics development.

The Case I calendar can be considered a combination model of sequential, concurrent and Stage-gate. As illustrated in Figure 35, the Stage-gate model is used to capture the entire process. Specifically, four stages and three gates are included in the calendar. Five components (i.e., key milestones, garment development, prints/pattern development, color development and graphics development) are independent and parallel to each other. From Stage 1 to Gate 2, activities in key milestones, garment development, prints/pattern development, and graphics development are carried out concurrently. From Gate 2 to Gate 3, activities in all five components proceed in parallel. After Gate 3, activities in all components except for proto/garment development are continued to develop until the sales meeting. However, within each component, activities move sequentially and must be completed before moving to the next one.

Among all the meetings in the key milestones, three meetings are considered to be the gates by the brand. During the gates, multiple departments review major decisions in person or via video conference. As illustrated in Figure 35, the first stage takes 13 weeks, during which the performance of the previous season is recapped and the resources are planned for the upcoming season. Specifically, seasonal strategies are outlined, and all details are reviewed to align with the brand concepts, including styles, colors, graphics, prints/patterns and fabrics/trims. Meanwhile, target cost and volume are decided, prototype yardage is ordered, and sketches and graphics are refined.

The first gate takes place after the design team finishes all black and white CADs for new styles. Then, multiple teams meet to verify that all CADs follow the brand seasonal strategies and brand concepts. Adjustments are made as needed. This first decision-making meeting takes approximately two days.

The second stage takes two weeks to complete. During stage two, the initial tech pack is created, and initial color CADs are developed. Color CADs are reviewed and finalized during the second decision-making meeting, which takes roughly one week. After the meeting, all CADs are updated by adding color codes, attribute codes and style numbers.

Eight more weeks are required in the third stage. During this stage, the tech pack is delivered to vendors and the first prototype order is placed. Moreover, the brand shares the assortment plan with key retail partners in order to align with the brand concepts and to obtain insights into product placement and segmentation. If any common themes that need to be added to the product line are mentioned by most of the retailers, the brand will make decisions on whether to make changes. Additionally, appliques are created in all colorways, and lab dips are initiated. Before moving to the third gate, the first prototype is reviewed for fabric/draping, aesthetics and fit, and the first cost is estimated.

At the third gate, the brand identifies the drops from the line and finalizes the line, which normally takes one week. To have the same brand stories across all products, other types of calendar start at the third decision-making meeting (Gate 3) when the line is finalized. Additionally, novelty fabric, patches, graphic and printing strike offs are reviewed during this meeting and further prepared to be shown to buyers.

After the third gate, a full set of CADs is finalized within one week, followed by ordering samples within two weeks. Twenty-three weeks are required in the fourth stage before presenting the line to the sales team. During Stage 4, retail and wholesale pricing are reviewed, costs and volumes are finalized, and margin roll-up is approved.

When reviewing more closely the remaining four components in the Case 1 calendar, during the first stage, both proto/garment development and print/pattern development are carried out. Specifically, proto/garment development starts with ordering prototyping yardage, which is scheduled five weeks prior to sending tech packs to vendors. From Gate 2 to Gate 3, the pattern team creates patterns and makes and ships the first prototype. After the first prototype is reviewed, the second prototype is made and delivered, followed by the second review. Some special products require a third prototype, but normally the activities in garment development ends at the third gate, when the line is closed.

Print/pattern development also starts in the first stage. The digitals first develop in one colorway and then in all colorways through Stage 1 to 4. The final digitals are approved before the sales meeting.

Graphics/applique development starts after reviewing the black and white CADs during the first gate. After Gate 1, the graphic team works on appliques for different sizes in one colorway. Once all color CADs are reviewed and finalized in the second gate, all colorways appliques are created, and the graphic team begins to print the graphic artworks. Final appliques and prints are received and approved during Stage 4.

Color development begins after reviewing the color CADs at the second gate. Color CADs are continued to be updated through Gate 3 to stage 4 and are finalized before the sales meeting.

In summary, the company in Case I developed different calendars for different product lines, which can all be spawned from one main calendar. All other calendars start at the third decision-making meeting (Gate 3) of the main calendar, during which the line is finalized, to align the brand story across all products. This main calendar is a combination model of sequential, concurrent and Stage-gate, making Case I's calendar both unique and powerful.

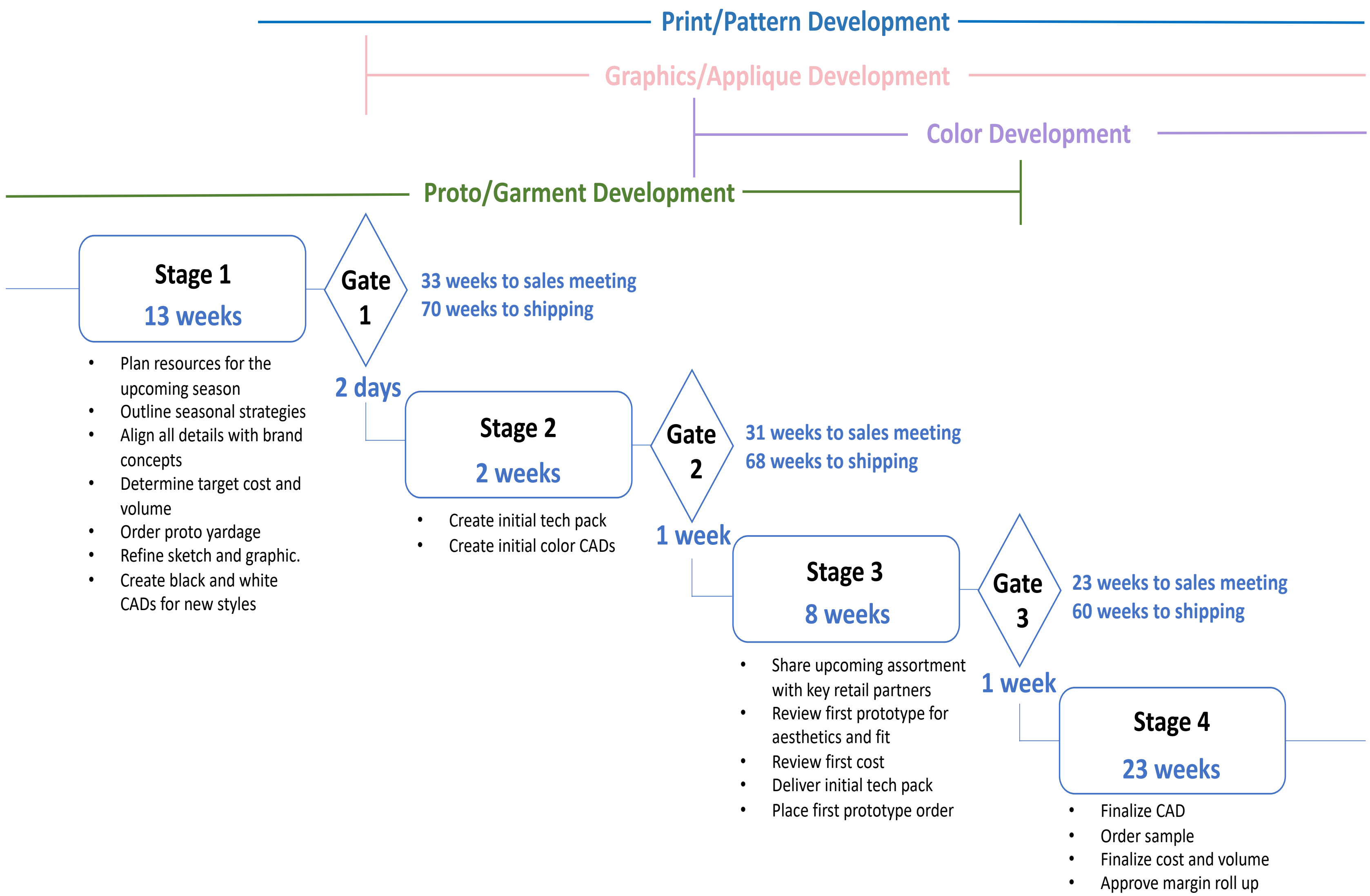


Figure 35. Schema of the Case I calendar deciphered.

4.2 Case Study II

4.2.1 Background information

Case II is a global apparel brand that has over 20-years history and approximately 15,000 employees. The product offerings include apparel, footwear and accessories for men, women and youth. More than half the company's net revenue comes from apparel, followed by footwear and accessories. In addition, a small portion of the net revenue comes from their digital fitness subscriptions and digital advertising through different platforms. The brands' products are sold worldwide. Specifically, a large majority of the products are sold in North America. Other international markets include Europe, Asia-Pacific and Latin America. More than half the sales are generated through wholesale channels, including national and regional sporting goods chains, independent and specialty retailers, department store chains, institutional athletic departments and leagues and teams. The brand also sells products directly to consumers through its brand and factory house stores and through websites globally. Most of the brand's factory house stores are located in outlet centers in North America.

All Case II products are developed in collaboration with the brands' own product development teams and manufactured with technical fabrications produced by third parties. The product development teams work closely with the marketing and sales teams, as well as with professional athletes to identify trends and determine consumer needs. Most of the specialty fabrics and other raw materials used in the apparel products are sourced by contracted manufacturers from a limited number of suppliers. All the products are manufactured by unaffiliated manufacturers. Most of the products are manufactured in Jordan, Vietnam, China and Malaysia.

4.2.2 Design and development calendar

Case II has two calendars, one for apparel and one for footwear. This case study focuses on the apparel calendar. Case II has a 14-month design and development calendar, which can also be considered a combination model of sequential, concurrent and Stage-gate. As illustrated in Figure 36, five stages and four gates are included in this calendar.

The first stage begins with market research and trend forecasting for the upcoming season. Meanwhile, design teams start to design initial sketches. The first gate takes one week, during which initial sketches and initial costing are reviewed.

The second stage takes eight weeks. During the second stage, the brand sets up a three-year lifecycle plan for all their products, including apparel, footwear and accessories. Materials are also reviewed and updated into the PLM software before moving to the next stage. The second gate is the brand's internal global meeting, which takes two weeks. During the meeting, seasonal strategies are outlined, and all product categories are reviewed.

In the third stage, four activities are carried out concurrently: material development, black and white all-over print design, artwork design and apparel advanced design. Nine weeks are required for this stage. The third gate is the brand's regional meeting, which takes three weeks. Different region's representatives meet with their corresponding key buyers to obtain feedback and further refine the product line regarding color, print and sizes.

Twelve more weeks are needed in the next stage. In this stage, styles and color are finalized, the first prototype is produced, and all colorway all-over prints are designed. The fourth gate takes one week. The first prototype is reviewed and commented on during the meeting.

In the final stage, the second prototype is produced and further reviewed. All-over print development is finalized before the sales meeting.

In summary, Case II has two calendars, one for apparel and one for footwear products. The calendar is a combination model of sequential, concurrent and stage-gate. Since Case II is a global apparel brand, multiple meetings are required to make global and regional decisions.

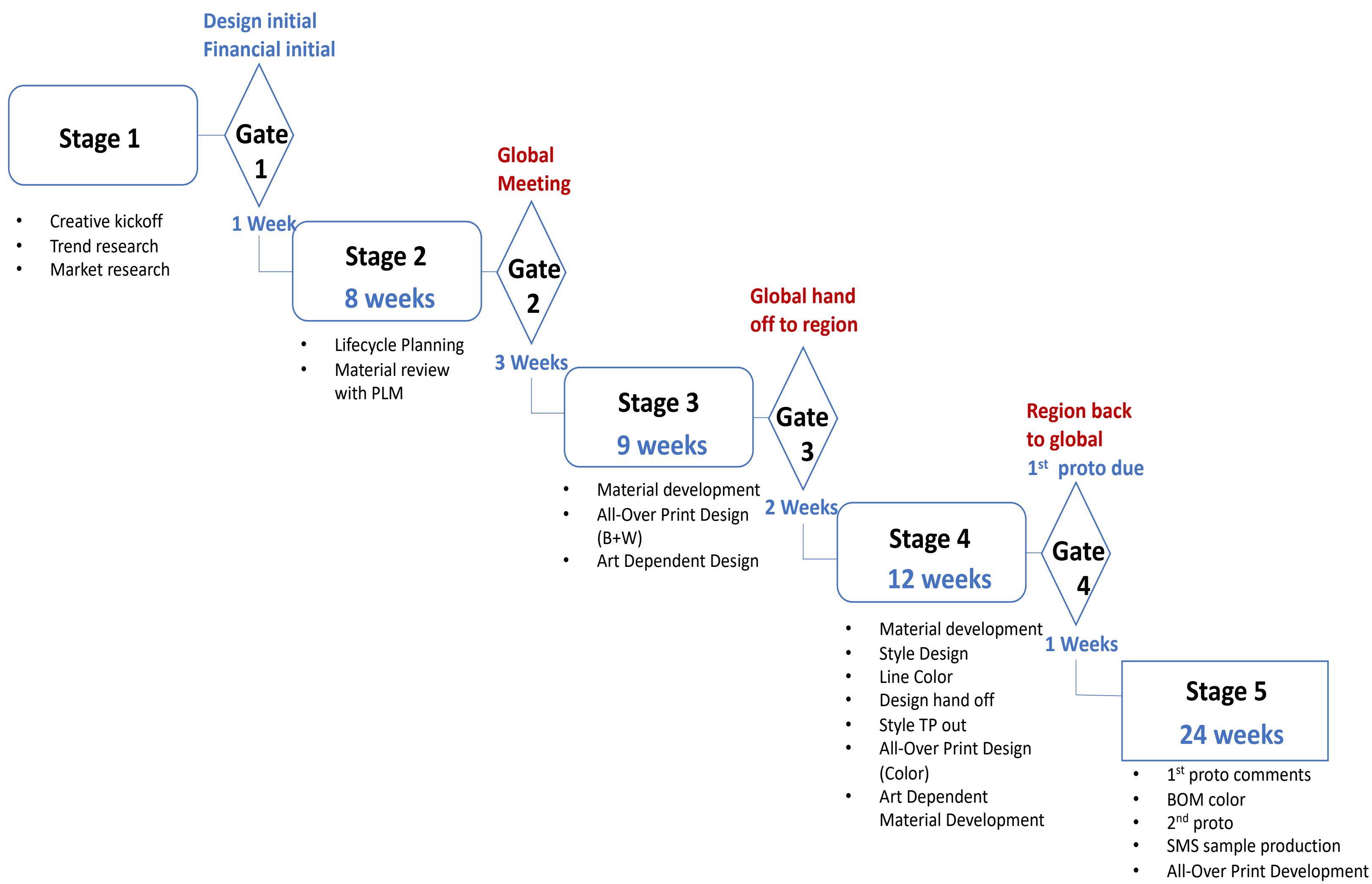


Figure 36. Schema of the Case II calendar deciphered.

4.3 Case Study III

4.3.1 Background information

Case III is a premium American lifestyle brand from one of the world's leading luxury goods company. The business includes jewelry, watches, leather goods, clothing and accessories. The parent company has roughly 30 years' history and over 28,000 employees. Compared with 2018, sales increase by nearly 30 % in 2019 at both actual and constant exchange rates. The growth is across all business areas and distribution channels. The jewelry business contributes roughly half the company's total sales, followed by the watch business. More than half the sales come from retail stores, followed by wholesale and online retail. Most of the company's markets have experienced growth, with double-digit increases in Asia-Pacific and the Americas.

The Case III has roughly 20 years' history of producing luxury performance sportswear, seasonal resort apparel, refined tailored clothing, and sartorial accessories for men and women. More specifically in the US, the company's products are distributed through the finest specialty retail stores, prestigious resorts, and the most exclusive country clubs in the world, as well as through its own branded boutiques and online stores. Currently, the brand has nearly 20 retail stores in the US and their global distribution includes North America, Europe, Asia, Australia and the South Pacific.

The brand has three product lines for menswear and one product line for womenswear, which have all achieved significant growth over the past year. Case III has a relatively small group of in-house employees located at its headquarters. Specifically, eight employees are responsible for menswear product lines and one employee is responsible for womenswear.

4.3.2 Design and development calendar

Case III has one calendar for all product lines. The calendar consists of 27 activities, which takes eight months to the sales meeting and nine months to bulk production. The Case III design and development calendar can be viewed as a combination model of sequential, concurrent and Stage-gate. Since Case III does not have sourcing, costing or production teams, most of their employees are in charge of multiple roles (e.g. design, product development, color, fabric, etc.). As a result, there are fewer cross-departments decision-making meetings involved in the calendar. As illustrated in Figure 37, there is only one decision-making meeting (gate). During the meeting, costing is reviewed. However, activities related to costing are not built into the calendar. Following the meeting, 19 more weeks are needed to the sales meeting, and 26 more weeks to bulk production.

The first stage has 10 activities, which takes three months. During this stage, activities within each month take place concurrently. However, activities in the previous month must be completed before passing through the next month. After establishing color pallet and creating styles and colors in the first month, the activities in the second month begin, including fabric selection, planning the product line, beginning lab dips and CAD artwork, and generating new ideas. These activities all work concurrently during the second month. Then, the activities in the third month begin, including developing fabric and color, prototypes, and new trims.

The second stage has 17 activities, which take six months. Similarly, activities within each month of Stage 2 are carried out in parallel. However, activities in the previous month must be completed before moving forward to the next month without overlap. During the first month, sample purchases are ordered to the garment factories, in addition to ordering sample fabric and trims. Meanwhile, lab dips, hand looms and print strike offs are continued to be developed and, eventually, finalized by this month. At the same time, styles are continuously developed and revised. After all these activities are completed, the activities in the second month start, including producing sample yardage and finalizing style development and costing. Then, in the third month, both sample fabric and trims are delivered to factories. Photo samples are due in the fourth month. Additionally, salesman samples are finalized, and samples are prepared for the sales meeting. In the next month, the sales meeting takes place, during which fit is reviewed. After one month of sample production, samples are commented on in the last month of the Stage 2 and styles are finalized for bulk production.

Moreover, there is a three-month season overlap in the Case III calendar. As illustrated in Figure 37, the fourth month to the sixth month of Stage 2 in the previous season overlap with the first month to the third month of Stage 1 in the current season.

Case III embraces high quality and superior craftsmanship. During the design and development process, the brand has three different types of samples: photo samples, approval samples and pre-production samples. Since the brand makes samples for every color of their products and each product normally requires two physical prototypes, six months are required for making salesman samples.

In summary, Case III has one single design and development calendar for all product lines in both menswear and womenswear. The calendar is a combination model of sequential, concurrent and Stage-gate. Due to the small number of in-house employees, only one decision-making meeting is needed to review costing and samples related decisions. Samples are made for every color of each individual product, resulting in six months for sample production.

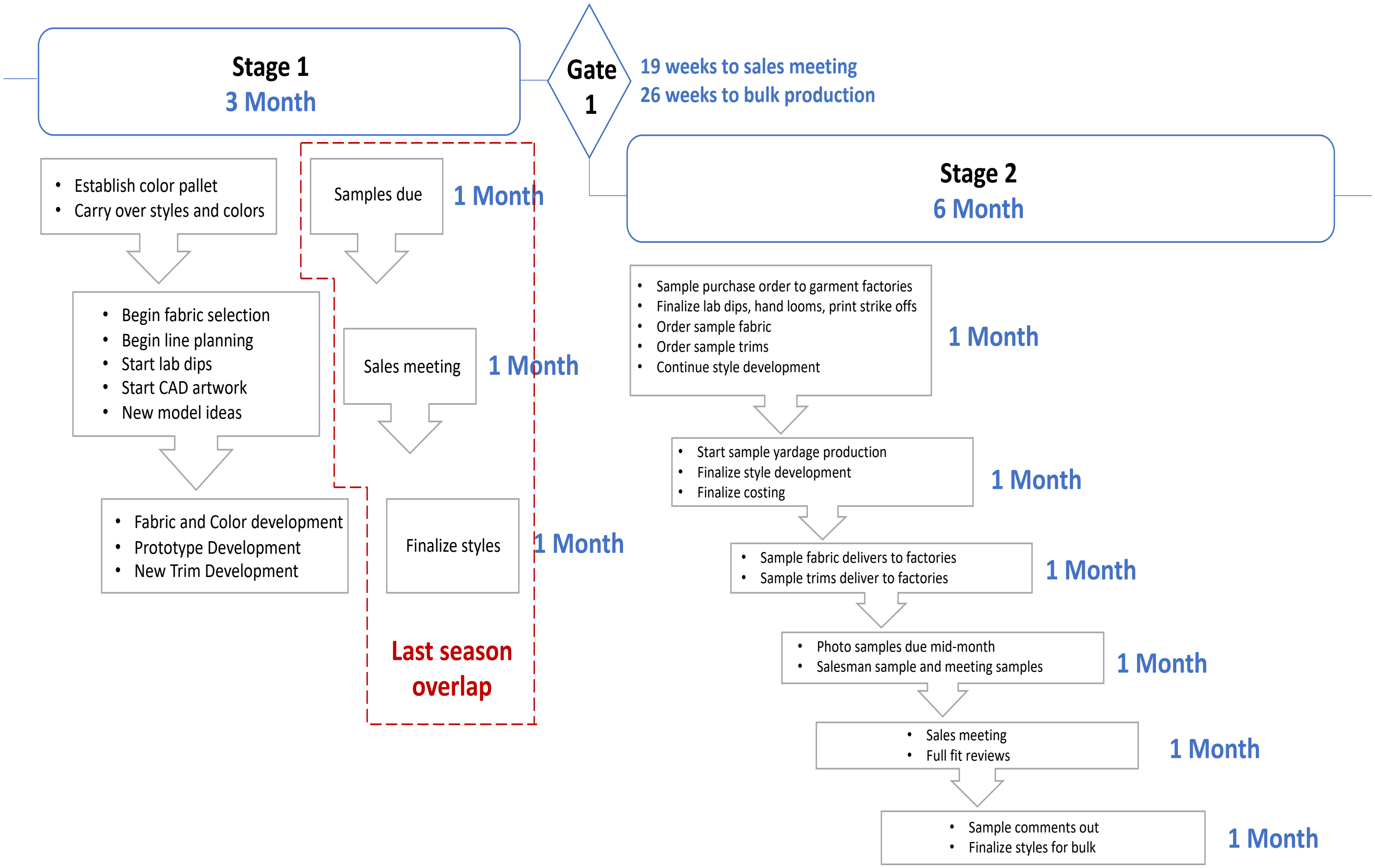


Figure 37. Schema of the Case III calendar deciphered.

4.4 Case Study IV

4.4.1 Background information

The following two cases are from the same apparel brand, which has two different business models with different lengths of the design and development calendar. Case IV focuses on the brand's ready-to wear products, which has a six-month calendar, and Case V focuses on the brand's mass customization products, which has a one-month calendar. The brand is privately held and was established in the late 1970s, with roots that stretch back to the early 1930s. The brand has between 201 and 500 employees, producing menswear shirts, neckwear, trousers, formalwear, and accessories. All the brand's products are manufactured in the US, with the exception of a small selection of neckwear and accessories that are made in Italy. The products have a reputation for quality, craftsmanship and originality, and have been distributed through many of the world's most highly regarded independent retailers and department stores, such as Nordstrom and Barneys. In addition to the in-house brands, the brand has also worked as a private-label manufacturer and partner for more than 800 clients. Mostly of their clients are family-owned businesses across America, Japan, Europe and all over the world.

4.4.2 Design and development calendar

Case IV focuses on the brand's ready-to wear products, which has a six-month design and development calendar. The brand has two selling seasons: spring season and fall season. For the fall season, the design process starts in December and products go to market in July. As illustrated in Figure 38, the calendar can be described as a sequential model, in which activities must be completed before moving to the next one. There are no decision-making meetings (gates) involved in the process.

In December, the preliminary process begins by reviewing the performance during the past season and trend forecasting for the upcoming season. Then, the fabric team begins designing, selecting and testing fabrics. The textile design is accomplished using an out-source textile design CAD called NedGraphics. Typically, 60-70 fabrics are tested and approved per season. After the pattern designer creates CADs for new styles and the manager approves costing and specifications, the mills begin weaving. It takes six to eight weeks for the mills to weave sample yardage. After the sample yardage is received, the design team finalizes the menswear collection by the end of February or early March. After this, samples are requested, and it takes three to four weeks to produce samples. Samples are received in late April or early May to present in the trade show.

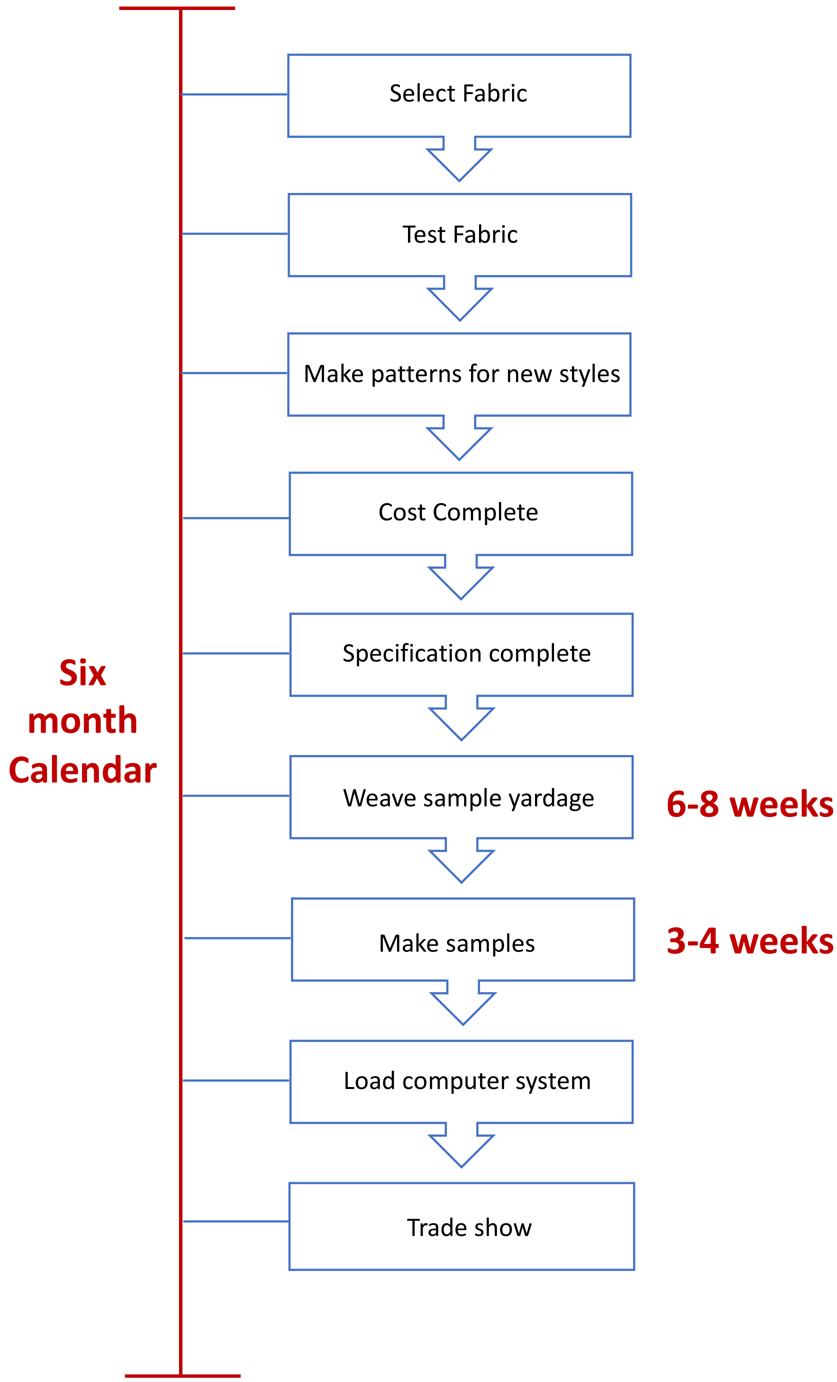


Figure 38. Schema of the Case IV Calendar deciphered.

4.5 Case Study V

4.5.1 Design and development calendar

Case V focuses on the brand's mass customization products, which has a one-month calendar. Mass customization products allow customers to choose from pre-selected fabrics and to customize the style with a range of features and fit options. It takes four to five weeks from the date that the customer places the order to the date that the customer receives the finished product. Mass customization requires a mass-production system by definition.

As illustrated in Figure 39, the calendar consists of three stages. During Stage 1, the brand pre-loads six pre-determined bodies and pre-determined components into the software. Additionally, all fabrics are selected and tested and ready to print. In the next stage, consumers place the order either online or in a retail store by choosing from these pre-determined components. Ultimately, consumers can choose over 0.4 billion design combinations for a customized product. For example, the design combinations that consumers can choose for a customized shirt include fabrics, collar styles, cuff styles, front styles, button and buttonhole colors, pockets options and monogram options. After consumers place their order, the brand designs the customized product by combining the different pre-determined components, followed by printing the marker and making the finished product. This one-month calendar can also be viewed as a sequential model. There are no decision-making meetings (gates) during the process. However, pattern makers, factory managers, and fabric and sales teams meet once a year to review both design and financial performance.

Notably, design can be split into two steps for customized products. The brand first separates all design components and pre-loads them into the software. Most of the fabrics and designs are chosen at the early stage of the product development cycle, which means the brand has the potential to design and develop more quickly. Then, the brand reassembles different design components based on the consumer's selections.

Unlike the traditional mass production process, companies do not need to design and invest at the early stage for mass customized products. Instead of designers designing a large quantity of the final products and contacting with consumers at the final sale stage, different components are designed during the mass customization process. Then, consumers combine these components based on their needs and wants and pay for the product before it is produced. This new design method is more efficient because it integrates consumers in the process and accelerates speed-to-market accordingly.

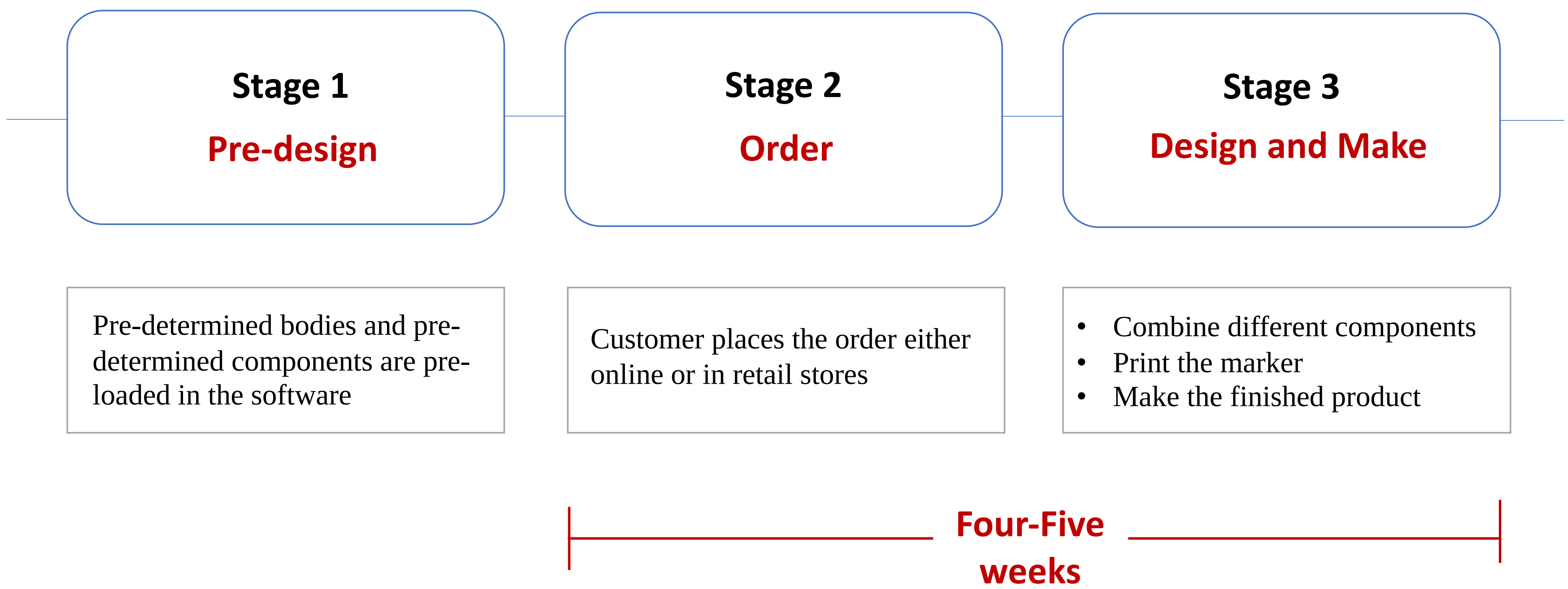


Figure 39. Schema of the Case V Calendar deciphered.

CHAPTER 5. Findings and Discussion

5.1 Initial Deciphered Model

As illustrated in Figure 40, a model was built to manage the time involved in the process based on the five case studies combined with the literature review. The model especially reveals the factors that are known to determine apparel design and development time. Six different cycles are included in the model, ranging from the longest to the shortest. This deciphered model can be viewed as a scalable Stage-gate system, see Figure 15 in Chapter 2. Detailed activities are mapped out using sequential, concurrent and stage-gate approaches. The stage-gate model is used to capture the entire process. Within each stage, detailed activities are color-coded are mapped out using either a sequential or a concurrent approach. Each cycle represents one season of the products based on the case study, although most companies produce two or three seasons each year.

The results indicate that the length of the apparel design and development calendar ranges from one month to 14 months. However, there is no relationship between the speed of the design and development process and the success of the business. The model reveals that mass customization companies have the shortest calendar; whereas, traditional apparel brands have the longest calendar; and vertically integrated retail is in the middle. This finding indicates that the type of organization affects design and development time. Within design and development, producing salesman samples was found to be the most time-consuming activity. Moreover, the deciphered model demonstrated that a longer design and development cycle has more gates involved in the process; whereas, a shorter cycle has fewer gates, suggesting that gates add more time to the process. However, no relationship was found between the number of concurrent/sequential processes and the speed of design and development. A more detailed discussion of these findings is presented in the following sections.

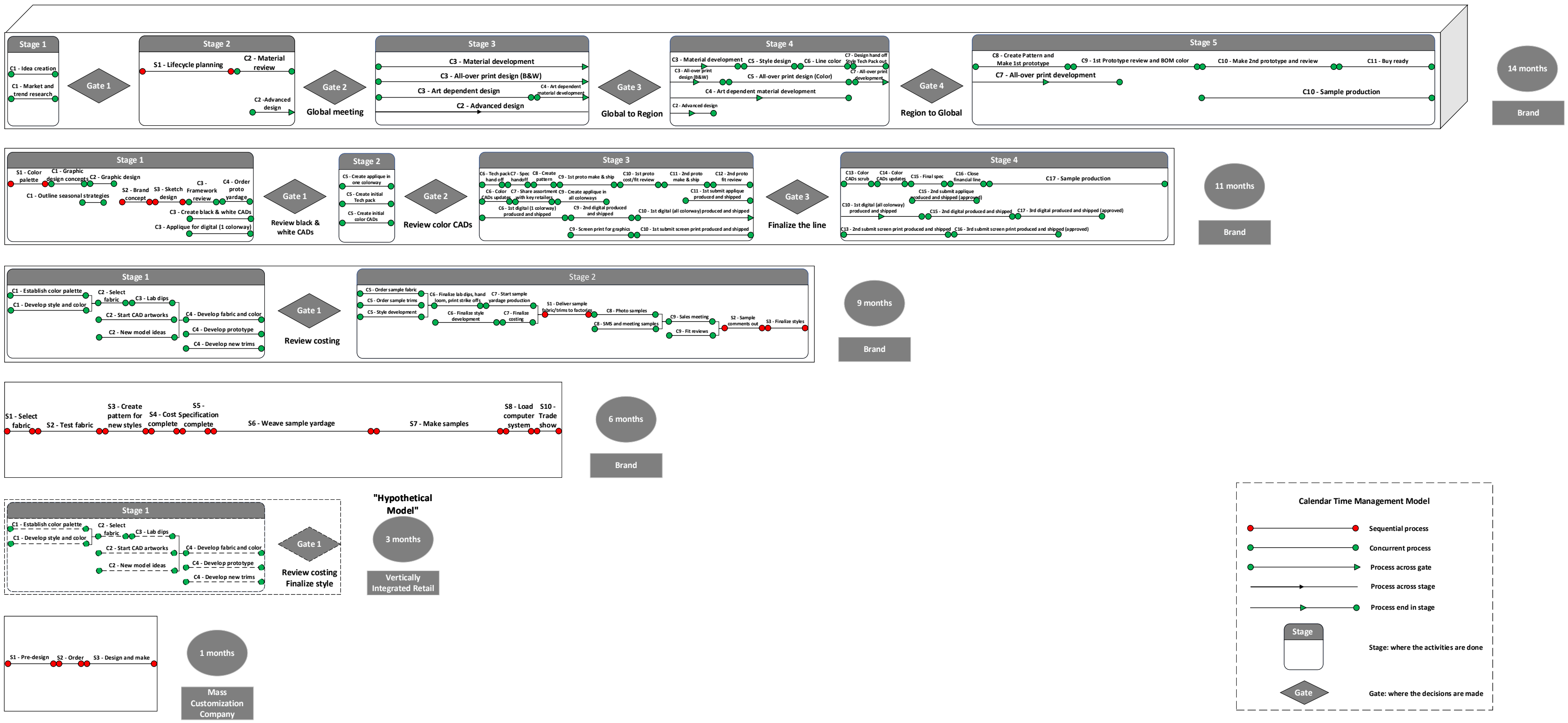


Figure 40. Initial deciphered model.

5.2 Organizational Structure

This study finds that the type of organization and its interface with customers and consumers affect the speed of design and development. As illustrated in Figure 41, mass customization companies have the shortest calendar; traditional apparel brands have the longest calendar; and vertically integrated retail is in the middle. It was found that the main difference among different types of organization is the value network.

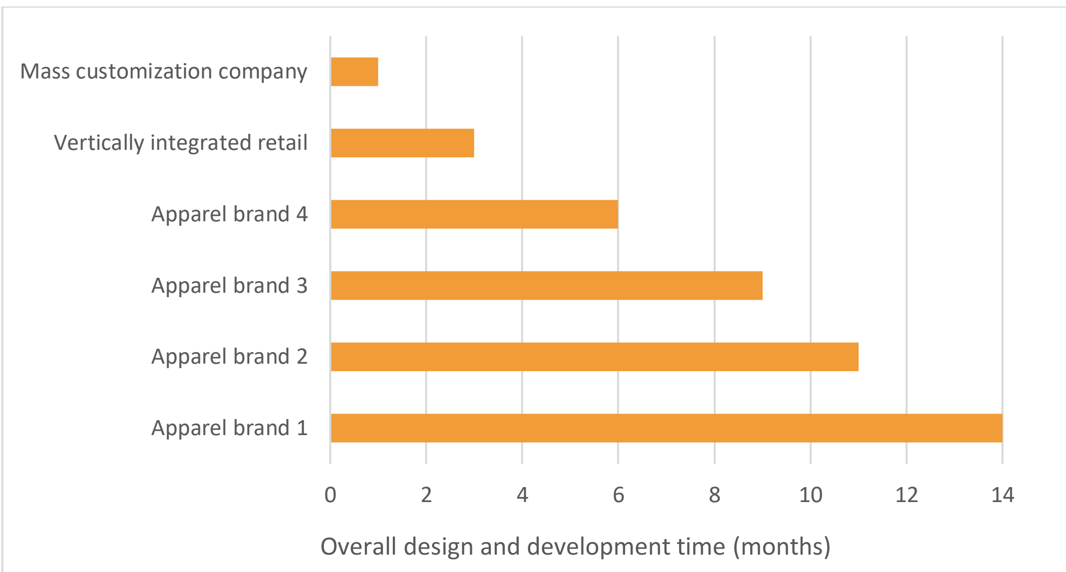


Figure 41. Design and development time based on different types of organization.

Value network is the organizational reflection of how the company is networked to compete within a business model and mirrors the complete network of relationships that need to be maintained (Romanelli and Tushman, 1994). Relationships that were established in value networks are valuable. Value networks are composed of complementary nodes and links (Peppard & Rylander, 2006). Internal value networks include activity-focused sets of relationship within work groups (Smith & Allee, 2009). In the apparel industry, these relationships refer to different departments within an organization, such as design, product development, material and marketing. Usually, a task delivered over a network requires two or more network nodes. Regarding apparel products, different departments collaborate and work concurrently to create a product line. An external value network includes its upstream suppliers, its downstream customers, retailers and distributors, and its partners and ancillary industry players (Christensen, Anthony & Roth, 2004). In the apparel industry, the downstream network of traditional apparel brands is retailers; whereas, the downstream network of retail and mass customization companies is consumers. Two types of organizations – apparel mass customization companies and vertically integrated retail – are discussed in detail in the following sections.

5.2.1 Apparel mass customization process

As revealed in the initial model, mass customized products have the shortest design and development time. In this section, the concept of customization and different types of apparel customized products are first reviewed, followed by a discussion of the findings.

The concept of customization was anticipated in 1970 by Toffler in *Future Shock*, then defined by Davis (1989) in *Future Perfect*, and then further explored in the 1990s. Customization can be defined either in a broader or narrower approach. The broad concept describes customization as the ability to provide individually designed products to consumers through high process agility, flexibility and integration (Silveira, Borenstein & Fogliatto, 2001). Other researchers have proposed a narrower and more practical concept. They define customization as a system that uses information technology, flexible processes and organizational structures to deliver a wide range of products and services that meet the specific needs of individual customers at a cost close to that of mass production products (Silveira, Borenstein & Fogliatto, 2001).

In the apparel industry, customized products can be classified in different ways based on the level of direct consumer involvement in the process. “True customized” apparel, also known as personalization or totally custom, allows the consumer to design the garment, fabric, and colors and have the garment made to their measurements and fit preferences (Anderson-Connell, Ulrich & Brannon, 2002). This approach is the highest level of customization, which provides consumers with full control over the design and allows them to design the product without limits (Senanayake & Little, 2001). Usually, consumers are provided with professional assistance, such as a design manager in the process to create their products.

“Made to order” or “Design options” (Anderson-Connell, Ulrich & Brannon, 2002) provides consumers with a variety of options to select in the form of a menu (e.g. fit, color, fabric, construction, accessories, thread, etc.). Some research has cited this approach as modular customization, in which products are customized by assembling preset pieces (i.e., modules) of varying combinations (Anderson & Pine, 1996). However, this approach does not necessarily limit the range of choices nor decreases the variety of final customized garments. In Case V, consumers can choose from different combinations of pre-selected fabrics and predesign components either online or in-store, with the ability to choose from over 0.4 billion options for a customized product.

Another two types of customization are “Clothes clones,” which duplicates a product that consumers currently have in their closet (Anderson-Connell, Ulrich & Brannon, 2002), and “Postproduction customization,” which has existed in the market for a long time due to it having less complexity. Examples of “Postproduction customization” include customizing products with a monogram, such as uniforms with a name and number, or customized labels, hangtags and boxes.

The apparel customization process in this research focuses on the “Made to order” or “Design options” approach since it contains similar design and development activities to the traditional mass production method. Figure 42 displays the workflow of the Case V mass customization process.

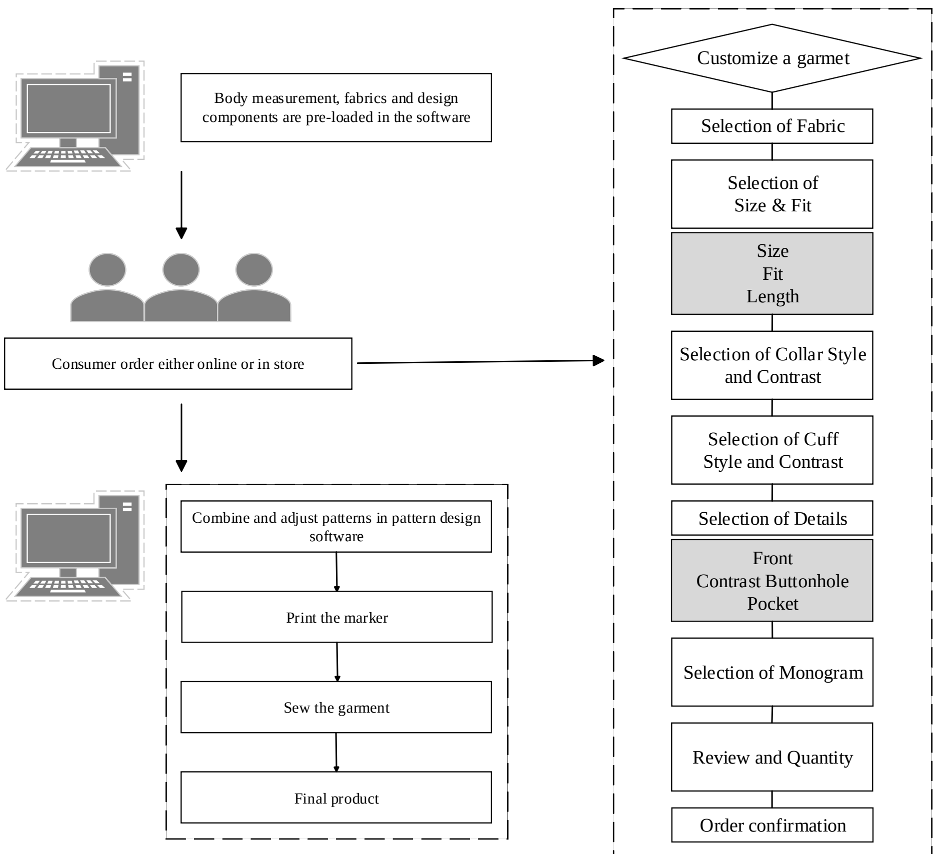


Figure 42. Workflow of mass customization process.

The results of this study point out that the value chain of mass customization system is different from that of mass production system. In particular, the sequence of activities in design, product development, production and distribution need to be changed when producing mass customized products (Anderson, 1996). The traditional mass production system is based on a forecast-driven strategy in which information on consumers' preferences and demands are anticipated based on market research and previous sales data. As illustrated in Figure 43, information was first gathered by retail stores and flowed back via distribution channels to production and product development departments (Ngniatedema, 2012). Consumers are only directly linked with retailers at the end of the value chain, choosing products from the assortments that companies place in the market. This structure results in disadvantages such as poor fit, low customer satisfaction, overstocking and long lead time.

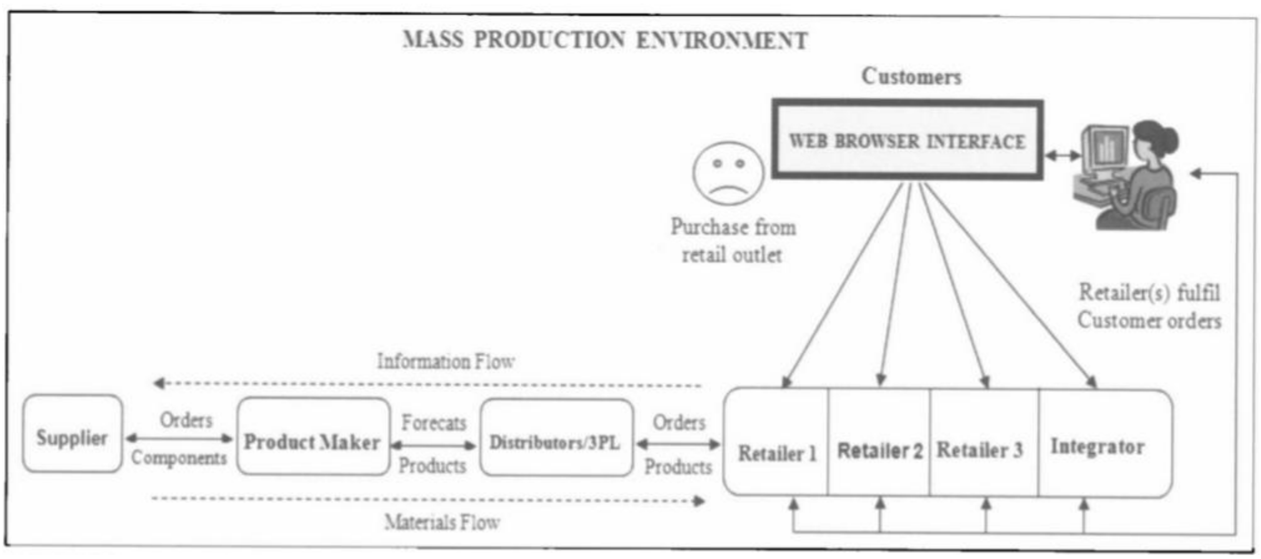


Figure 43. Mass Production Environment (Ngniatedema, 2012).

In contrast, the mass customization process follows a different structure and is based on a demand driven strategy, as shown in Figure 44. In mass customization, consumers are placed at the beginning of the value chain. Hence, the final sale to the consumer becomes the first step in the process instead of the last step. Consumers select from pre-determined combinations of design features and options and pay for the finished garment before it is produced. In addition, it was found that the degree of organizational transformation is determined by the initial point that consumers become involved in the process (Lampel & Mintzberg,1996; Duray, Ward, Milligan & Berry, 2000). The earlier consumers are first involved in the value chain (e.g. design, fabrication, assembly, postproduction), the higher the effect on the finished products and a higher level of organizational transformation required (Duray, 2002).

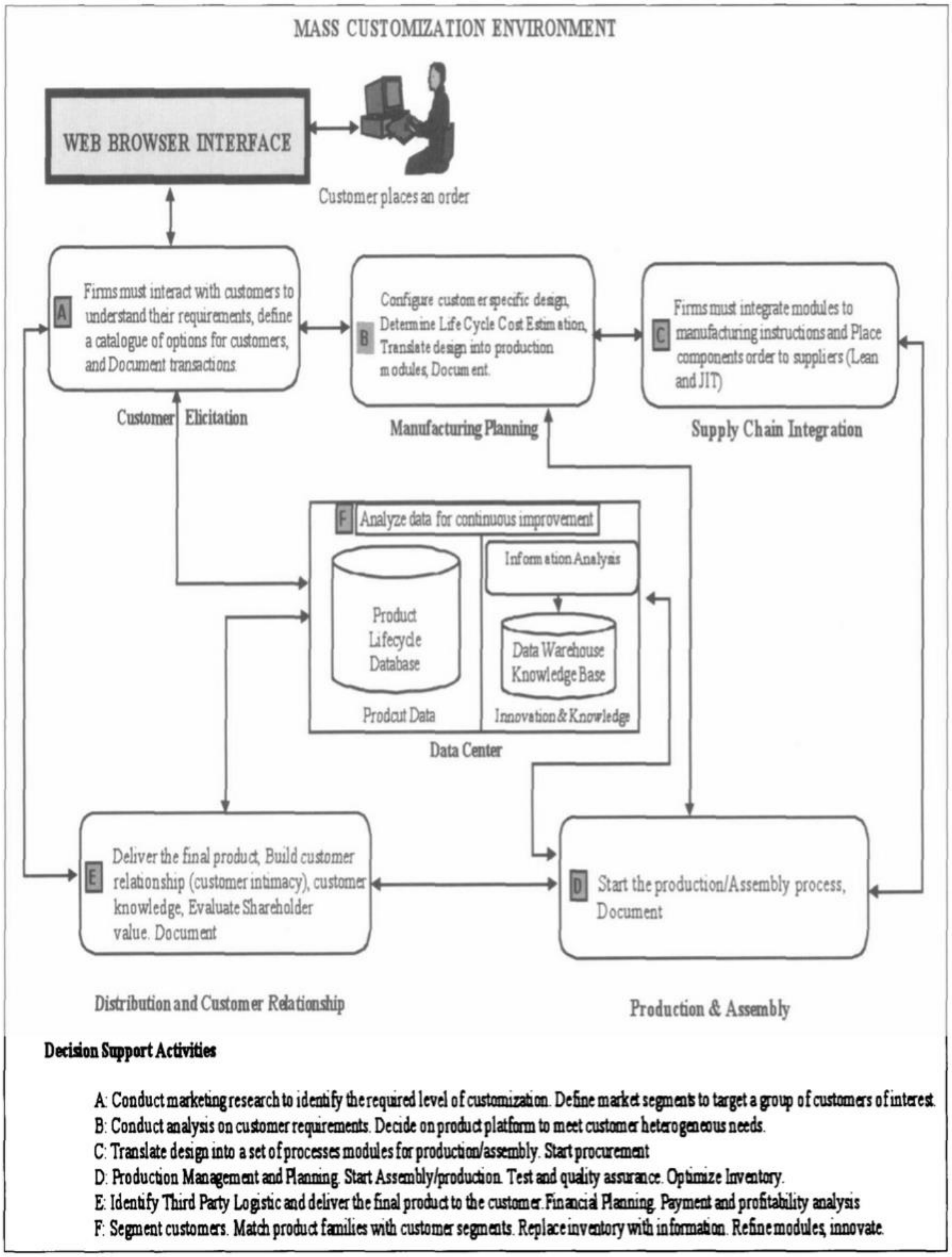


Figure 44. Mass Customization Environment (Ngniatedema, 2012).

The findings indicate that the design and development process in mass customization is different from that of mass production. In mass production, a design begins with an idea and the forecasted fabric or color, and then undergoes a lengthy process of creating patterns and making prototypes (Kincade, Regan & Gibson, 2007).

In contrast, in mass customization, the design and development process can be viewed as a two-step process: predesign and reassemble. First, the final garments are separated into different components regarding fabric, color, style and size, and these components are pre-loaded into the pattern making software. Then, the combination of these pre-determined components is reassembled based on the consumer's selections, followed by printing the marker and making the finished garment. This two-step process reduces product time-to-market and fulfills the consumer's specific needs. Notably, the number of combinations that consumers can choose from is relatively large. In Case V, consumers can select from over 0.4 billion combinations of design features and options and receive their finished products in one month. However, it would require much more time to design and make the same quantity of garments by using the traditional mass production approach.

The findings reveal that apparel customized products have the shortest design and development time in the industry. This finding supports the literature, suggesting that the customization process can quickly translate consumer orders into the design, production and delivery of final product (Ngniatedema, 2012). One of the main reasons for this speed is because the mass customization process interfaces with the consumer directly and eliminates time-consuming processes such as creating specifications and producing salesman samples. Furthermore, fabrics are tested at an early stage of the value chain. In addition to speeding up time-to-market, the mass customization approach allows a company to target consumer demands more accurately, to reduce inventory and returns, to improve cash flows, to increase consumer satisfaction and to build strong customer relationships.

5.2.2 Vertically integrated retail

Vertical integration is another type of organization structure. A firm is vertically integrated if it owns assets, organizes activities or controls activities in different stages of the value chain (Lafontaine & Slade, 2007). In the apparel industry, this integration refers to the degree to which an organization owns its upstream suppliers and its downstream buyers. The literature has found that a high degree of vertical integration offers apparel companies a clear advantage in implementing quick responses (Manuel & Herrero 2014).

The findings of this research indicated that retail has a relatively short design and development calendar. In addition to vertical integration, retail must have its own stores that interface with consumers directly. To gain speed, retail needs also to have its own design and development entity to take advantage of this type of organization. The three-month "hypothetical" design and development time in this study is in line with Donaldson's (2015) research, which suggests that the average total cycle time is 190 days including 95 days for design and development.

5.3 Calendar Activity

Within design and development, producing salesman samples was found to be the most time-consuming process. Apparel brands need to produce samples to display to retail stores buyers to make final buying decisions and place orders. As indicated in the case studies in Chapter 4, the time for producing salesman samples ranges from one month up to six months, resulting in a longer calendar since samples are considered a design and development activity.

Figure 45 displays the overall design and development time versus the time for producing samples based on the case studies. Once retailers make initial purchases, an additional three to six months is needed for production and transportation before consumers can buy garments in-store. In contrast, since vertically integrated retail and mass customization companies interface with consumers directly, both can eliminate the salesman sample production process, shortening the process accordingly.

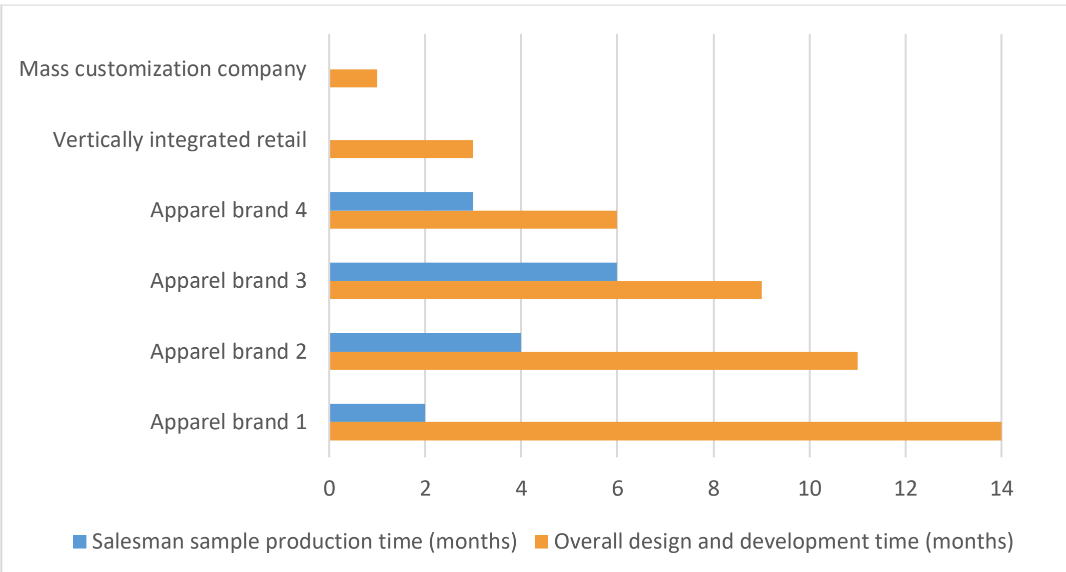


Figure 45. Salesman sample production time.

5.4 Product Development Models

The initial model used a Stage-gate model to capture the entire design and development process. In each stage, activities are color-coded based on their type and either proceed sequentially or concurrently. Between each stage, some companies use gates to represent a major decision point.

The results of this study find that a longer design and development cycle has more gates involved in the process, with a shorter cycle having fewer gates. As illustrated in Figure 46, the 14-month cycle has four gates; the 11-month cycle has three gates; the nine-month and three-month cycles have one gate; and the one-month cycle has no gates.

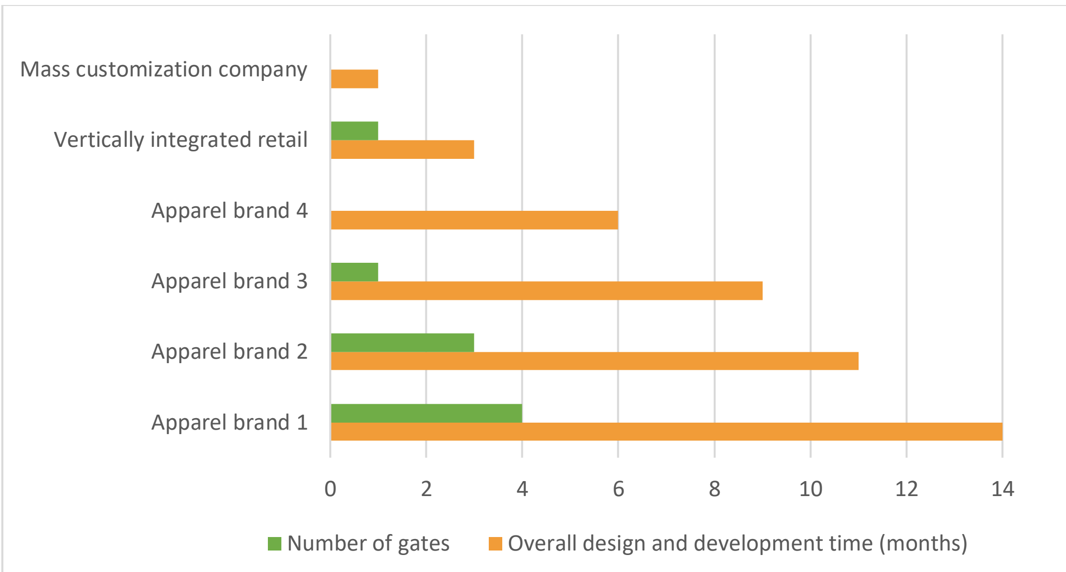


Figure 46. The number of gates in design and development.

As mentioned in Chapter 2, gates refer to the quality control checkpoints or decisional meetings. At gates, a set of deliverables is reviewed and must be approved by senior managers before moving to the next stage (Cooper, 1990). The outputs of the gates are typically Go/Kill/Hold/Recycle decisions. This finding suggests that gates tend to add more time to the process and delay product launches, which is consistent with the previous research. A survey by McKinsey highlighted that 61% of the 1200 respondents stated that more than half the time spent in decision-making meetings is ineffective (Smet, Jost & Weiss, 2019). Additionally, previous studies on lean product development have identified excessive meetings and waiting for decisions as potential wastes in the product development process. Rossi, Kerga, Taisch and Terzi (2011) identified motion and waiting as two out of the eight wastes. Specifically, motion means excess motion or activity such as unneeded and un-useful meetings during the process and waiting refers to waiting for materials, information or decisions. Oehmen and Rebentisch (2010) categorized miscommunication of information as one type of wastes, including large and long meetings, excessive email distribution lists and unnecessary hand-offs.

This present research finds that most of the activities proceed concurrently instead of sequentially in design and development. However, no relationship was found between the number of concurrent or sequential processes and the time involved in design and development.

5.5 Model Validation

In the model validation phase, a rubric consisting of 13 yes/no statements or questions and four open-ended questions was sent to the five experts. All the yes/no statements or questions were used to validate whether sequential, concurrent or Stage-gate are appropriate to represent the apparel design and development process. Based on the experts' feedback, as shown in Table 3, only two experts selected "no" to two statements or questions. One expert suggested that sequential activities are not valid for the design and development process. One possible reason for this answer might be that, in the proposed model, most activities proceed concurrently, and only a few activities move sequentially. Another expert indicated that retail does not have to have its own private-label design and development group to obtain a shorter calendar. One possible reason for this answer is a different understanding of the private-label entity.

Table 3. Expert feedback on yes/no questions.

#	Questions	# of Yes	# of No
1	A Gate is a major decision point for design and development for some types of companies. Do you recognize the value of Gates in this model depiction?	5	0
2	Gates occur between stages. Do you see how stage are represented?	5	0
3	Typically, Gates take time in the Design and Development Calendar. Do you think organizations with more gates have longer time?	5	0
4	Activities that are sequential follow one another. Do you note where sequential activities are included in the model?	5	0
5	Sequential activities are coded as “S” in the model. Are sequential activities valid for Design and Development?	4	1
6	Activities that are concurrent proceed at the same time. Do you note where concurrent activities are included in the model?	5	0
7	Concurrent activities are coded as “C” in the model. Are concurrent activities valid for Design and Development?	5	0
8	Do concurrent activities take time out of the Design and Development calendar?	5	0
9	Some concurrent activities cross stages and therefore are not decided in the Gate. Do you recognize that not all activities are decided in the Gate?	5	0
10	The type of organization can affect design and development time? Also, the product is known to affect the time for Design and Development. The model shows that Brands take longer than Retail and longer than Customization?	5	0
11	In particular, Retail must have its own Private Label Design and Development group to take advantage of this type of organization?	4	1
12	The Model shows that longer calendars relate to brands while shorter calendars relate to consumer direct and retail owned interface with consumers?	5	0
13	The Model shows that the shortest calendar was found for customized products?	5	0

Regarding the open-ended questions, the researcher first explored what types of technology can be used to alter the calendar time and the design and development activities. All the experts agreed that technology can streamline the process and shorten the cycle time accordingly. Three-dimensional technology was mentioned the most by experts. Other technologies include digital printing, digital dyeing, virtual inventory and digital supply chain technology. One expert emphasized on-demand manufacturing, which supports the findings in this study that mass customization companies have the shortest calendar. The comments from the experts are presented as follows:

> "*3D product development technology and visualization can be used to minimize the number of samples that need to be produced."*
>
> *"A totally digital supply chain combined with on-demand manufacturing can make the design and development process more efficient and streamlined."*
>
> *"There are new up and coming technologies that will dramatically effect to the total time e.g. digital printing of materials, going from 3 months on average to 3 days based on WIP. Then you might have digital dyeing of thread currently taking 2 months, now this time can be reduced to a matter of hours for samples and small runs. Just two examples of the new digital technologies that will help transform the industry and with the added benefit that these new solutions are sustainable."*
>
> *"Technology will alter the calendar time favorably. A reduction in errors, duplicate efforts combined with an increase in communication across a single unified platform drives efficiency and saves time."*

"Technology is used to alter design and development. 3D tools and vendor portals allow for streamlined, real-time communication and virtualization of product designs to speed things such as sampling."

"Yes, through virtual inventory and digital supply chain allowing gates within stages and mixing S and C."

"Yes, one example is fabric coloration and surface design through digital technologies."

Then, the researcher further investigated the experts' perspective regarding an optimum calendar. All the experts agreed that the current design and development cycle is too long, and that retailers and brands need to reduce their time-to-market. Most of the experts mentioned that the business model affects the calendar time and needs to be transformed considering the changing market. The comments from the experts are presented as follows:

"Allow consumers to create designs based on standard choices."

"People won't wait for yearlong workflows/calendars, retailers and brands will need to reduce their time to market. The entire business model as we know it needs to be transformed, we need to connect all supply chain partners via technology (PLM others) to allow a smarter workflow, using automation and triggers to push/pull data from each of the stage gates and sub-tasks. We should also consider using A.I. & M.L. to support the process experts in helping to create the product templates and workflows dynamically."

"There are too many factors to suggest a single "optimum calendar". A company's breadth of assortment, selling model (stores, ecommerce, wholesale, etc.), materials development strategy (internal versus vendor sourced) and most importantly the roles and complexity of the organization all affect the development calendar. I have worked

with companies whose development calendars range from 16 weeks to 52 weeks. Most customers with whom I've consulted have been able to leverage PLM technology to remove 2-4 weeks from an offline disparate product development process."

"Optimum calendar is subjective and depend on business model and customer or consumer expectations. "

Finally, the researcher asked for comments and suggestions about the model. One expert recommended that the apparel brand needs to be further distinguished. The comments from the experts are presented as follows:

"The biggest issue is convincing companies to change their business models."

"We need to be aware of the changing market, moving away from "stack it high sell it cheap" to smaller personalized products and small runs (mass customization) linked to constant change of design that can be enabled by new digital technologies."

"I would provide a little more information about the companies studied as it may be relevant to the types of activities and gates referenced."

5.6 Final Deciphered Model

The final model was refined and presented in Figure 47. As suggested by the experts, the apparel brand is further distinguished by global apparel brands and apparel brands. This is the only change suggested by the experts regarding the model; therefore, it was the only change made compared with the initial deciphered model.

In summary, global apparel brands have the longest calendar, including a 14-month cycle and a 11-month cycle, followed by the apparel brands, which have a nine-month cycle and a six-month cycle. Mass customization companies have a one-month design and development calendar, which was the shortest one found in this research. Retail is in the middle, with a 3-month calendar.

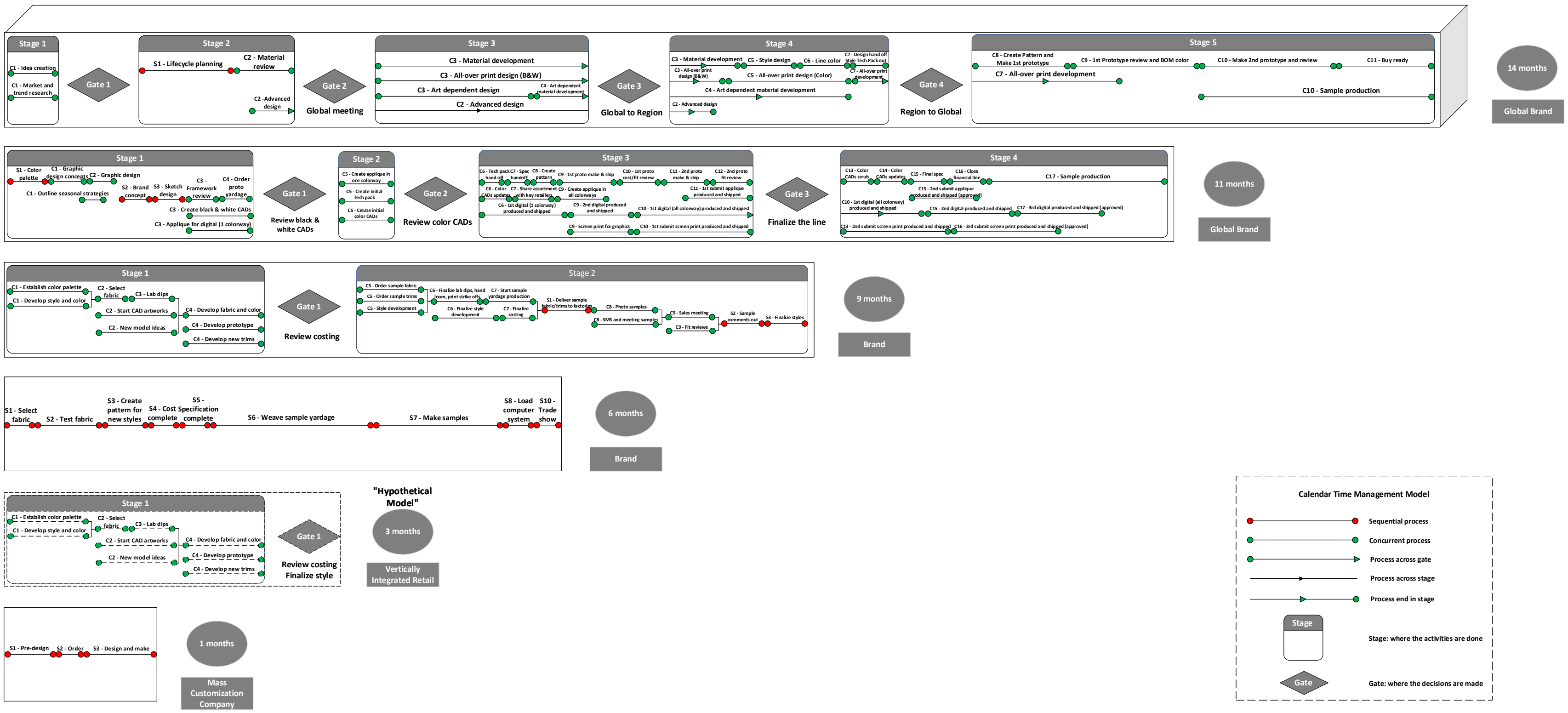


Figure 47. Final Deciphered Model.

CHAPTER 6. Conclusions and Future Study

6.1 Conclusion

The textile and apparel companies struggled to make timely decisions and to meet deadlines to keep up with rapidly moving consumer behavior and to survive in this extremely competitive market. The concern about speed is a constant topic throughout the industry. Fashion designers, private label retailers and apparel and footwear brands all focus on improving their ability to deliver new products to the market as quickly as possible.

Technology is changing consumers activities dramatically. With the development of smartphones and mobile apps, consumers can find what they want, whenever they want it, at the best possible price. Consumers today expect rapid trend turnover and greater choices of materials, colors and sizes, which adds pressure to reduce time-to-market.

The purpose of this study was to investigate the current activities and timeline of the apparel design and development process and to determine the key factors that affect its speed. A deciphered model was built and further validated, aiming to manage the time involved in the process. The objectives of this study were as follows:

1. Perform collective case studies to explore current activities and the timeline of fashion design and development.
2. Identify the key factors that affect the speed.
3. Build an initial deciphered model that manages design and development time.
4. Validate the model using the Delphi method and refine the model.

This study used a collective case study and the Delphi method to address the research objectives. Specifically, to achieve Research Objective 1 to 3, five companies with different lengths of the design and development calendar were selected. Qualitative inputs were gathered through a series of semi-structured interviews. The interviews were conducted either via the telephone or face to face. During the interviews, the representatives from each company discussed their current design and development process, including the time needed for each activity and the technologies or business practices they have adopted to help reduce the cycle time. Based on the five case studies, an initial deciphered model was built to manage the calendar time.

Once the initial model was created, the Delphi method was adopted to validate and refine the model. Five experts were invited to participate in this study. All the selected experts have more than five years' experience in the field of apparel design and development, but with different backgrounds and expertise. The experts were provided with a rubric containing yes/no questions and open-ended questions. The feedback from the experts was analyzed and incorporated to finalize the model.

The deciphered model consists of six different cycles, with each cycle representing one season of the products. The design and development cycle ranges from one month to 14 months. The Stage-gate model was used to capture the entire process. Within each stage, detailed activities are mapped out using either a sequential or a concurrent approach.

This study found that the type of organization and its interface with customers and consumers affect the speed of design and development. Apparel brands have the longest calendar; mass customization companies have the shortest calendar; and vertically integrated retail is in the middle. Different organizations have distinct value network that reflect how the organization is networked internally and externally. The internal value network for all three types of organization (i.e. apparel brand, retail, and mass customization company) are the same, which refers to the different departments inside an organization such as design, product development, material and marketing. The external value networks are different, however. The downstream network of the apparel brands is buyers from different stores; whereas, the downstream network of retail and mass customization companies is consumers.

Second, within design and development, producing salesman samples was found to be the most time-consuming process, taking from one month up to six months. Since samples are considered a design and development activity, they add additional design and development time. Samples are required for apparel brands to display to buyers to enable them to make final buying decisions and to place orders. Typically, samples are produced outside the US and need to be sent back and forth to review and revise, resulting in a longer cycle time. Since the other two types of organization, namely mass customization companies and vertically integrated retail, interface with consumers directly, specifications and sample production processes can be eliminated and, thus, have shorter cycle times.

Third, this study revealed that a longer design and development cycle has more gates involved in the process; whereas, a shorter cycle has fewer gates, suggesting that gates, which are the decision-making meetings, add more time to the process. Additionally, the research found that most of the activities proceed concurrently instead of sequentially within each stage. However, no relationship was found between the number of concurrent/sequential processes and the speed of design and development.

Finally, although no companies have adopted blockchain technology in design and development in practice, a blockchain model should be considered for mapping out the future of design and development. As mentioned in Chapter 2, due to the unique structure of blockchain, any information saved in a block cannot be modified or removed following approval. When this technique is applied to design and development in the apparel industry, any standard activity or activities that have been approved can be saved in a block, as shown in Figure 48. In mass customization, different design components such as different materials, colors, collar styles, cuff styles, can be saved in a block.

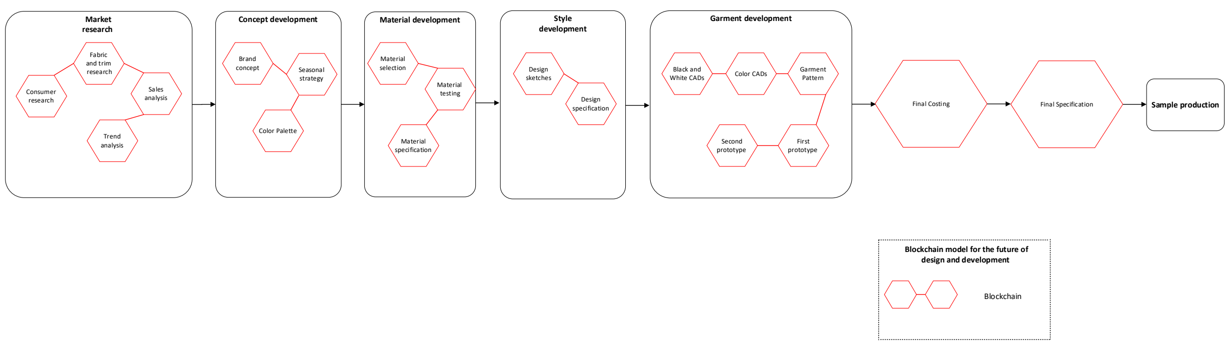


Figure 48. Blockchain model for the future of design and development.

6.2 Implications

This research has several implications. First, it contributes to the limited body of new product development knowledge. Most existing product development models are considered dated and lacking a discussion on speed. This research studied different lengths of the design and development process and mapped out each activity and the corresponding timeframe in detail. The developed model revealed the factors that are known to determine the time involved in the design and development process.

Second, this research provides insights into refining companies' go-to-market processes and on reaching milestones in a timely manner. One approach is to adopt advanced technologies to digitalize fully each step of the supply chain. Specifically, 3D design and visualization tools can be used to reduce the time needed for the early rounds of prototypes. However, fashion still needs to produce at least one physical sample before reaching the final design. Artificial intelligence and machine learning techniques should also be considered to predict accurately consumer demands, forecast trends and seasonality, and to create the product templates and workflows dynamically. Additionally, adopting technologies that connect all supply chain partners and allow for a streamlined, real-time communication is also suggested.

Another more disruptive approach is to transform the current business model or to employ an entirely new business model. To gain speed, one could adopt a model that links the product more closely to the point of demand, such as the mass customization model. This approach is recommended. In this type of model, fashion is driven by demand. Only the products consumers want and have paid for are produced. To achieve mass-customization, a mass-production system is required. A digital supply chain combined with on-demand manufacturing will dramatically compress the calendar. However, it is difficult to convince companies to change their business models.

Third, the findings present a new way of thinking about design and development at both the education level and the practice level. Instead of creating and producing a large quantity of garments ahead of time and then contacting consumers at the final sale stage, different design components (i.e. material, collar, cuff, pocket, button) and on-demand production should be considered. Consumers are integrated into the process by combining different components based on their selections and paying for the product before it is produced. This new method of on-demand design and development reduces time-to-market, reduces waste by producing the right product the first time, fulfills consumers' specific needs and builds a strong customer relationship. This also means that the design and development processes will change to an "interchangeable components" approach.

Reducing the time from the beginning of product development to the product's market launch lowers the risk of incorrectly anticipating trends, seasonality and demand patterns and increases a company's ability to respond quickly. Bringing new products onto the market in a timely manner not only helps companies outpace competitors and capture consumer demands better, but also ensures a company's long-term loyal customers. More importantly, as the industry is transformed by technologies such as automation and artificial intelligence, ever more apparel and textile companies are considering moving their business back to the US. Accelerating speed-to-market will improve US companies' competitive advantage over countries offering low wages and labor-intensive practices.

6.3 Limitations and Future Studies

A number of limitations are apparent in this study. First, the calendar for retail is based on a "hypothetical" model because retail in the textile and apparel industry is experiencing a revolution. It is suggested that future studies use a case study approach to explore retail's design and development process. Second, due to the limitations in resource and time, the sample size is at the lower limit for a collective case study and the Delphi method. Five companies were selected to perform a collective case study and five experts were invited to validate the model. A large sample size is recommended in the future to generalize the results of this study.

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APPENDICES

Appendix A

Case Study Interview

1. Please state your role in the product development process briefly.

2. How many seasons are designed and developed per year? How many lines are designed and developed in each season?

3. How long is your company's current design and development cycle by line by season? Please specify.

4. Please check the activities that are included in your design and development process in Table 3.1. Add or remove activities as needed.
5. Please indicate the time and the resource loading needed for each activity in your revised Table 3.1.
6. Please indicate which activities can be done concurrently in your revised Table 3.1. Please code the concurrent activities as the same number.

Table 3.1. Product development activities

Activities		Have this activity	Time taken	Resource loading	Done concurrently
Market research	Market research firms				

	Trade literature				
	Trade associations				
Sales data from previous lines					
Target consumer research					
Sales forecasts					
Fabric and trim research					
Color research					
Trend research					
Line planning and meetings					
Creative inspiration					
Concept development	Color stories for product groupings				
	Concept/Theme for product groupings				
	Color boards for presentation				
	Concept boards for presentation				
Color and concept meetings					
Concept tests					
Design development	Fabric selection				
	Trim Selection				
	Color standard selection				
	Design sketches				
Design review meetings					
Design specifications					
Preliminary line meetings					
Raw material development	Co-develop fabrics with vendors				
	Development internally produced fabrics				
	Materials tests				
Garment development	Sample Yardage, Trim and Findings order				
	First Pattern				
	First samples (prototype)				

	Fit and style evaluation meetings				
	Wear testing				
	Revised prototypes				
	Primary costing				
	Sample specifications				
Sales/Merchandising meetings					
Revised sizes/color/styles					
Add sizes/color/styles					
Final line adoption and meetings					
Order fabrics for sales samples					
Order duplicates					
Duplicates					
Promotional materials for sales representatives					
Market display					
Sales Reps show line markets					
Review retail orders and meetings					
Add styles/colors/sizes					
Sales forecast					
Modified the line meetings					
Detail costing					
Production specification					
Production pattern					
Final garment specification					
Graded pattern					
Verify grading and fit					
Size specification sheets					
Production marker					
Source production					
Production fabric, trim and findings orders					
Final line review and meetings					
Add styles/colors/sizes					
Production					

7. Which five activities are more time consuming in your design and development process?

1.	
2.	
3.	
4.	
5.	

8. Do you have cyclic activities repeated within design and development process? Please specify.

1.	
2.	
3.	
4.	
5.	

9. Please check the technologies that are used in your design and development process in Table 3.2. Add or remove as needed.
10. Which technologies helped your company speed up time to market? Please indicate the improvement obtained in product development speed in your revised Table 3.2. Define the units when indicating the improvement.

Table 3.2. Technologies in design and development process

Technologies	Have this technology	Improvement (define units)
2D design (art works, flat, line plans)		
2D pattern making		
Computerized Grading		
Computerized Marker making		
Automatic marker making		
Marker Plotter		
Automated cutting		
Automated spreading		
Automated sewing/seaming		
Threadless joining		
3D design		
3D virtual prototyping		
3D visualization		
Body scanning		
Phone scanning		
Digital printing		
3D printing		
Fabric property measuring		
Sewing thread measuring		
Stripe/plaid matching technology		

11. Please check the business approaches that are implemented in your design and development process in Table 3.3. Add or remove as needed.
12. Which business approaches helped your company speed up time to market? Please indicate the improvement obtained in product development speed in your revised Table 3.3. Please define the units when indicating the improvement.

Table 3.3 Business approaches in design and development

	Have this approach	Improvement (define units)
PDM		
PLM		
Lean product development		

Blockchain		
Merchandising calendars		
Daily point of sale data		
ERP		

Appendix B

IRB Form for Case Study

North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study: <Fashion Design and Development Deciphered, IRB PROTOCOL - 15498>
Principal Investigator: <Xingqiu Lou xlou3@ncsu.edu 3026908079>

Faculty Point of Contact: <Dr. Trevor Little tlittle@ncsu.edu 9195156646 >

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate and to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of the apparel design and development process. We will do this through case studies.

You are not guaranteed any personal benefits from being in this study. Research studies also may pose risks to those who participate. You may want to participate in this research because you will be able to manage your design and development process. You may not want to participate in this research because you don't want to discuss your design and development process.

In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above or the NC State IRB office (contact information is noted below).

What is the purpose of this study?
The purpose of the study is to explore current activities and timeline of apparel design and development and to determine the key factors that affect the speed.

Am I eligible to be a participant in this study?
There will be approximately 6 number of participants in this study.

In order to be a participant in this study you must be responsible for design and development process in your company.

You cannot participate in this study if you are not either responsible for design and development or have no knowledge of design and development.

What will happen if you take part in the study?
If you agree to participate in this study, you will be asked to do all of the following:
1. You will receive three excel forms and some open-ended questions along with the informed consent form.
2. You will review the forms and make changes and return the forms to the researcher.
3. The researcher will review the forms and set up a follow up meeting to further discuss the case study information if needed.

The total amount of time that you will be participating in this study is up to 1 day depending on the complexity of your design and development process.

Risks and benefits

There are minimal risks associated with participation in this research. There are no direct benefits to your participation in the research. The indirect benefits are better understanding design and development process.

Right to withdraw your participation

You can stop participating in this study at any time for any reason. In order to stop your participation, please stop completing the forms. If you choose to withdraw your consent and stop participating you will not expect any penalty.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely on an NC State managed computer. Individual data with identifiable details removed may be made available to the public as required by a professional association, journal, or funding agency.

Compensation

For participating in this study, you will not receive anything for participating.

What if you are an employee?

Participation in this study is not a requirement of your employment, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher, < Xingqiu Lou xlou3@ncsu.edu 3026908079>

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (institutional Review Board) Office via email at irb-director@ncsu.edu or via phone at 1.919.515.8754. An IRB office helps participants if they have any issues regarding research activities.

You can also find out more information about research, why you would or would not want to be a research participant, questions to ask as a research participant, and more information about your rights by going to this website: http://go.ncsu.edu/research-participant

Consent To Participate

“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.”

Participant’s printed name ___________________________________

Participant's signature ______________________________________ **Date**

Investigator's signature _____________________________________ **Date**

Appendix C

Model Description

This model was built to manage the time involved in the apparel design and development process based on the five proprietary case studies combined with the literature review. The model especially reveals the factors that are known to determine apparel design and development time. Six different cycles are included in the model, ranging from the longest to the shortest. Detailed activities are mapped out using sequential, concurrent and stage-gate approaches. Specifically, the stage-gate model is used to capture the entire process. In each stage, activities are color-coded based on their type, either sequential or concurrent. Each cycle represents one season of the products based on the case study, although most companies produce two or three seasons each year.

The results indicate that the length of the apparel design and development calendar ranges from one month to 14 months. However, there is no relationship between the speed of the design and development process and the success of the business [external to the model]. This model finds that the type of organization affect the speed of design and development. Apparel brands have the longest calendar; mass-customization companies have the shortest calendar; and vertically integrated retail is in the middle.

Within design and development, producing salesman samples was found to be the most time-consuming process, taking from one month up to six months. Since samples are considered a design and development activity, they add additional design and development time.

Furthermore, this model reveals that a longer design and development cycle has more gates involved in the process; whereas, a shorter cycle has fewer gates, suggesting that gates, which are the decision-making meetings, add more time to the process. As shown in the model, the 14-month cycle has four gates; the 11-month cycle has three gates; the nine-month and three-month cycles have one gate; and the one-month cycle has no gates. However, no relationship was found between the number of concurrent or sequential processes and the time involved in design and development.

Third, customization has a different design and development process compared with other cycles. A traditional design and development process begins with an idea and the forecasted fabric or color, and then undergoes a lengthy process of creating patterns and making prototypes. In customization, the design and development process can be viewed as a two-step process: Pre-design (component design) and reassemble. First, the final garments are separated into different components regarding fabric, color, style and size, and these components are pre-loaded into the pattern-making software. Then, the combination of these pre-determined components is reassembled based on the consumer's selections, followed by printing the marker and making the finished garment. Notably, the number of combinations that consumers can choose from is relatively large. In case V, consumers can select from over 0.4 billion combinations of features and options. However, it would require much more time to design and make the same quantity of garments by using the traditional mass-production approach.

In summary, this model presents different lengths of the design and development process and mapped out each activity and the corresponding timeframe in detail. Since the concern about speed is a constant topic throughout the industry, this study provides insights into refining companies' go-to-market processes and on reaching milestones in a timely manner.

Appendix D

Rubric

1. A Gate is a major decision point for design and development for some types of companies. Do you recognize the value of Gates in this model depiction?

   (a)Yes (b) No

2. Gates occur between stages. Do you see how stage are represented?

   (a)Yes (b) No

3. Typically, Gates take time in the Design and Development Calendar. Do you think organizations with more gates have longer time?

   (a)Yes (b) No

4. Activities that are sequential follow one another. Do you note where sequential activities are included in the model?

   (a)Yes (b) No

5. Sequential activities are coded as “S” in the model. Are sequential activities valid for Design and Development?

   (a)Yes (b) No

6. Activities that are concurrent proceed at the same time. Do you note where concurrent activities are included in the model?

   (a)Yes (b) No

7. Concurrent activities are coded as “C” in the model. Are concurrent activities valid for Design and Development?

   (a)Yes (b) No

8. Do concurrent activities take time out of the Design and Development calendar?

   (a)Yes (b) No

9. Some concurrent activities cross stages and therefore are not decided in the Gate. Do you recognize that not all activities are decided in the Gate?

   (a)Yes (b) No

10. The type of organization can affect design and development time? Also, the product is known to affect the time for Design and Development. The model shows that Brands take longer than Retail and longer than Customization?

    (a)Yes (b) No

11. In particular, Retail must have its own Private Label Design and Development group to take advantage of this type of organization?

    (a)Yes (b) No

12. The Model shows that longer calendars relate to brands while shorter calendars relate to consumer direct and retail owned interface with consumers?

    (a)Yes (b) No

13. The Model shows that the shortest calendar was found for customized products?

    (a)Yes (b) No

14. In your opinion, whether technology be used to alter the calendar time? If yes, how? If no, please explain the reason.

15. In your opinion, whether technology be used to alter Design and Development activities? If yes, how? If no, please explain the reason.

16. Do you have a perspective on an optimum calendar?

17. Do you have any other comments or suggestions for this model?

Thank you for your participation. We appreciate your help.

Appendix E

IRB Form for the Delphi Method

North Carolina State University

INFORMED CONSENT FORM for RESEARCH

Title of Study: <Fashion Design and Development Deciphered, IRB PROTOCOL - 15498>
Principal Investigator: <Xingqiu Lou xlou3@ncsu.edu 3026908079>

Faculty Point of Contact: <Dr. Trevor Little tlittle@ncsu.edu 9195156646 >

What are some general things you should know about research studies?
You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate and to stop participating at any time without penalty. The purpose of this research study is to gain a better understanding of the apparel design and development process. We will do this through the Delphi method.

You are not guaranteed any personal benefits from being in this study. Research studies also may pose risks to those who participate. You may want to participate in this research because you will provide guidance regarding managing the speed of design and development process. You may not want to participate in this research because you cannot complete the assignment on time.

In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above or the NC State IRB office (contact information is noted below).

What is the purpose of this study?

The purpose of the study is to explore current activities and timeline of apparel design and development and to determine the key factors that affect the speed.

Am I eligible to be a participant in this study?

There will be approximately 6 number of participants in this study.

In order to be a participant in this study you must have extensive knowledge of design and development - usually at least 5 years working experience in the field.

You cannot participate in this study if you have no knowledge of this field.

What will happen if you take part in the study?

If you agree to participate in this study, you will be asked to do all of the following:
1. You will receive the proposed model and model description along with the informed consent form via email.
2. You will review the model and provides comments and suggestions.
3. You will send back the model with comments back to researcher via email.

The total amount of time that you will be participating in this study is up to 1 hour.

Risks and benefits
There are minimal risks associated with participation in this research. There are no direct benefits to your participation in the research. The indirect benefits are better understanding design and development process.

Right to withdraw your participation

You can stop participating in this study at any time for any reason. In order to stop your participation, please stop reviewing the model. If you choose to withdraw your consent and stop participating you will not expect any penalty.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Data will be stored securely on an NC State managed computer. Individual data with identifiable details removed may be made available to the public as required by a professional association, journal, or funding agency.

Compensation

For participating in this study, you will not receive anything for participating.

What if you are an employee?

Participation in this study is not a requirement of your employment, and your participation will not affect your job.

What if you have questions about this study?

If you have questions at any time about the study itself or the procedures implemented in this study, you may contact the researcher, < Xingqiu Lou xlou3@ncsu.edu 3026908079>

What if you have questions about your rights as a research participant?

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the NC State IRB (institutional Review Board) Office via email at irb-director@ncsu.edu or via phone at 1.919.515.8754. An IRB office helps participants if they have any issues regarding research activities.

You can also find out more information about research, why you would or would not want to be a research participant, questions to ask as a research participant, and more information about your rights by going to this website: http://go.ncsu.edu/research-participant

Consent To Participate

"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled."

Participant's printed name ____

Participant's signature ____ **Date**

Investigator's signature ____ **Date**