Rapid Supply Chain Strategy Simulation Development for Enhanced Cross-Functional Collaboration in High Growth Environments

by

Clararose Faith Voigt

B.S.E Materials Science & Engineering, University of Pennsylvania, 2008

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

Master of Business Administration

and

Master of Science in Mechanical Engineering

In conjunction with the Leaders for Global Operations Program at the

Massachusetts Institute of Technology

June 2016

©2016 Clararose Faith Voigt. All rights reserved.
The author hereby grants MIT permission to reproduce and to distribute publicly copies of this thesis document in whole or in part in any medium now known or hereafter created.

Signature of Author

Department of Mechanical Engineering, MIT Sloan School of Management
6 May 2016

Certified by

Dr. Stephen Graves, Thesis Supervisor
Abraham J. Siegel Professor of Management Science

Certified by

Dr. Abbott Weiss, Thesis Supervisor
Senior Lecturer in Mechanical Engineering

Certified by

Dr. Henry Marcus, Thesis Reader
Professor Emeritus of Mechanical Engineering

Accepted by

Maura Herson, Director of MIT Sloan MBA Program
MIT Sloan School of Management

Accepted by

Rohan Abeyaratne, Chairman, Committee of Graduate Students
Department of Mechanical Engineering
Rapid Supply Chain Strategy Simulation Development for Enhanced Cross-Functional Collaboration in High Growth Environments
by
ClaraRose Faith Voigt

Submitted to the MIT Sloan School of Management and the Department of Mechanical Engineering on May 6, 2016 in Partial Fulfillment of the Requirements for the Degrees of Master of Business Administration and Master of Science in Mechanical Engineering

Abstract

Like companies from almost every industry, NIKE faces a marketplace that is transitioning toward e-commerce. Over the next five years, retail sales through NIKE.com are anticipated to grow meteorically. For NIKE specifically, this shift represents a change not only in where and how consumers shop, but also a significant transformation of NIKE's underlying business model. NIKE has historically derived the majority of its revenue from wholesale accounts, representing 76% of its revenue in FY15.1 The evolution from wholesale brick-and-mortar sales to online retail sales requires substantial changes across NIKE's supply chain and manufacturing strategies to better serve the online consumer's ever-increasing service, quality and product offering expectations and to capture the revenue and gross-margin upsides of vertically-integrated retail. Given the ripple effects of this business model shift that will affect every part of NIKE's business, NIKE Global Operations leadership seeks to identify data-driven solutions that support cross-channel, cross-function collaboration to capture end-to-end insight.

The key objective of this thesis is to identify simulation capabilities and development processes that will help supply chain leaders get to enhanced enterprise insight, faster. Thus, the goals of this research are two-fold: 1) Develop general end-to-end simulation capability and user needs assessments, and 2) Develop proof-of-concept simulators that integrate cross-functional metrics and business drivers, and enable rapid ‘what-if’ scenario generation and comparison.

After identifying user needs regarding both simulation capabilities and simulator content, two proof-of-concept simulations were developed from critical cross-functional business questions posed by a wide array of interviewed stakeholders. The first simulation presents a holistic framework for understanding liquidation supply and demand in the context of digital's forecasted growth. The second simulation concept presents a framework for selecting products with optimal characteristics for onshore/near-shore advanced manufacturing. Both concepts demonstrate that data and organizational integration is both feasible and desirable within the supply chain strategy planning process, and that simulation tools are valuable investments that can provide enriched insight above current processes.

Dr. Abbott Weiss, Thesis Supervisor
Senior Lecturer in Mechanical Engineering

Dr. Stephen Graves, Thesis Supervisor
Abraham J. Siegel Professor of Management Science
This page has been intentionally left blank.
Acknowledgements

I wish to acknowledge the Leaders for Global Operations Program for its support of this work. The encouragement and dedication of all of the involved professors and administrators has been remarkable. This is an experience that I shall never forget and has shaped me as a leader, contributor, and friend.

This project would not have been possible without the generosity of time and spirit exhibited by all of NIKE Inc.'s employees. From Global Supply Chain Innovation, I would like to specifically thank Jason Trusley for his mentorship and vision, Hugo Mora for sharing his wealth of academic and professional expertise and insight, and Ryan Sitter for his support in shaping the early phases of the project. All three of you provided not only valuable perspective about my project, but also valuable perspective about myself as a professional. Truly, there are so many individuals throughout NIKE that I would like to thank – without filling up the page, I will add Jon Frommelt (LGO '01) and Chris Drusnic who helped me through some of the most challenging aspects of the project, as well as the recent LGO and Sloan graduates that made my time at NIKE such a blast – Tatiana Mendoza (Sloan '14), Oliver Schrang (LGO '14), Erik Tautkus (Sloan '14), Ken Young (Sloan '14), and Matt Plitch (Sloan '13).

Thank you to my management and engineering advisors, Stephan Graves and Abbott Weiss, who pushed me to think critically throughout the internship and thesis writing process.

A heartfelt thanks also goes out to my lambdas – to the class of 2016, I am leaving this program a stronger, wiser and happier individual because of your influence on me. I am so grateful to have you in my life.

Finally – the best for last – I am forever thankful to my supportive husband, John Schott, who made this graduate education possible through endless smoothies, homemade sandwiches, healthy dinners, dry cleaning pick-ups, hugs, and perfectly executed vacations.

And to the future LGO who may someday be reading this thesis before internship, during internship, or as you’re in the midst of thesis writing – don’t worry. We’ve all been there. And we all got through it.
This page has been intentionally left blank.
# TABLE OF CONTENTS

1 **Introduction** ................................................................................................................................. 11
   1.1 *Project Introduction* .................................................................................................................. 11
   1.2 *Project Background* .................................................................................................................. 12
   1.3 *NIKE Overview* ........................................................................................................................ 13
      1.3.1 *Company History* ............................................................................................................. 13
      1.3.2 *Organizational Structure* ................................................................................................. 15
      1.3.3 *Manufacturing & Supply Chain Design* ............................................................................ 16
      1.3.4 *Business Channels* .......................................................................................................... 17
      1.3.5 *Business Models* ............................................................................................................. 18
   1.4 *NIKE's Evolution and Growth* .................................................................................................. 19
      1.4.1 *External Stimulus: Growth of the Consumer-Led Marketplace* ........................................ 20
      1.4.2 *Strategic Response: Supply Chain* .................................................................................... 21
      1.4.3 *Strategic Response: Manufacturing* .................................................................................. 23
2 **Problem Statement** .......................................................................................................................... 25
   2.1 *Current State* .......................................................................................................................... 25
   2.2 *Project Goals* ......................................................................................................................... 26
3 **Literature Review** .............................................................................................................................. 27
   3.1 *Strategic Simulations: Industry Case Studies* .......................................................................... 27
   3.2 *System Dynamics and Supply Chain Strategic Planning* ......................................................... 28
   3.3 *Valuing Lead Time* ................................................................................................................ 29
   3.4 *Supply Chain Impact of Advanced Manufacturing* .................................................................. 31
4 **Methodology** ..................................................................................................................................... 35
   4.1 *Conceptual Development* ....................................................................................................... 35
   4.2 *Analytical Construction* .......................................................................................................... 36
   4.3 *Results, Simulation Testing & Stakeholder Feedback* ............................................................. 37
5 **Supply Chain Simulation Conceptual Development** ......................................................................... 38
   5.1 *Simulation Characteristics* ....................................................................................................... 38
      5.1.1 *Collaboration* ................................................................................................................... 38
      5.1.2 *Accessibility* ..................................................................................................................... 39
      5.1.3 *Transparency* ................................................................................................................... 39
      5.1.4 *Agility* ................................................................................................................................ 40
   5.2 *Simulation Content* ................................................................................................................... 40
      5.2.1 Business Channel Liquidation and Value Channel Capacity ............................................. 41
      5.2.2 On-Shore/Near-Shore Advanced Manufacturing and Supply Chain Impact ...................... 41
6 **Supply Chain Simulation Analytical Construction** ........................................................................... 43
   6.1 *Liquidation Simulation* ............................................................................................................. 43
      6.1.1 Revenue and Inventory Ecosystem Background ..................................................................... 43
      6.1.2 Liquidation Supply Background ............................................................................................ 44
      6.1.3 Liquidation Demand Background .......................................................................................... 45
TABLE OF FIGURES

FIGURE 1: NIKE BRAND REVENUE (2007-2015) ................................................................. 14
FIGURE 2: NIKE BRAND REVENUE GROWTH (2011-2015) ........................................... 14
FIGURE 3: NIKE BRAND REVENUE PROJECT ENGINE BREAKDOWN FY15 .................... 14
FIGURE 4: SUPPLY CHAIN SCHEMATIC (COURTESY OF NIKE) ................................. 16
FIGURE 5: NIKE BUSINESS CHANNEL RELATIONSHIPS (ADAPTED FROM NIKE) ........... 17
FIGURE 6: NIKE BRAND REVENUE, BY CHANNEL (2010-2015) .............................. 20
FIGURE 7: NIKE BRAND REVENUE GROWTH, BY CHANNEL (2011-2015) ................. 20
FIGURE 8: PRIMARY DRIVERS IN RESHORING DECISION FOR US MANUFACTURERS (MIT SURVEY, 2012) ... 22
FIGURE 9: COMPARISON OF 'CLASSIC CRAFT' AND 'MODERN CRAFT' CONSTRUCTION (BLOOMBERG, 2012) .......................................................... 23
FIGURE 10: CURRENT STATE STRATEGY DEVELOPMENT PROCESS .......................... 25
FIGURE 11: FUTURE STATE STRATEGY DEVELOPMENT PROCESS ............................... 26
FIGURE 12: KIEVIET AND ALEXANDER’S DECISION MODEL FOR AM APPLICATIONS .............................................................. 32
FIGURE 13: TRADITIONAL SUPPLY CHAIN, LEFT, AND AM SUPPLY CHAIN, RIGHT (MASHHADI ET. AL, 2015) ................................................................................. 33
FIGURE 14: SD MODEL USED TO SIMULATION BOTH A TRADITIONAL AND AM SUPPLY CHAIN (MASHHADI ET. AL, 2015) ................................................................. 33
FIGURE 15: PRODUCT DESIGN AND DEVELOPMENT PROCESS AS PRESENTED BY EPPINGER AND ULRICH, 2012 ........................................................................... 35
FIGURE 16: EARLY SIMULATION UI PROTOTYPE ............................................................ 36
FIGURE 17: LIQUIDATION SIMULATION DASHBOARD FOR FASHION X WITH THREE PRODUCT ENGINES ... 53
FIGURE 18: BUSINESS PARAMETER TREND DASHBOARD USER INTERFACE DESIGN ......................................................................................... 54
FIGURE 19: PRODUCT TO SUPPLY CHAIN MATCHING (FISHER 1997) ............................ 56
FIGURE 20: ILLUSTRATIVE SD CASUAL LOOP DIAGRAM .............................................. 59
FIGURE 21: BASELINE LIQUIDATION SUPPLY PROFILE. LIQUIDATION SUPPLY .......... 62
FIGURE 22: 2015 AND 2020 REVENUE AND UNITS COMPARISON .............................. 63
FIGURE 23: BASELINE CO TAKE RATE % RESULTS ...................................................... 64
FIGURE 24: BASELINE DIGITAL CO UNIT DEMAND AND PERCENTAGE OF TOTAL FASHION X CO DEMAND 65
FIGURE 25: BASELINE INCREMENTAL B&M RETAIL MTO CONTRACT INCREASE REQUIRED DUE TO DIGITAL GROWTH ...................................................... 65
FIGURE 26: SCENARIO 1 - SELECT RESULTS ................................................................. 66
FIGURE 27: SCENARIO 2 - SELECT RESULTS ................................................................. 67
FIGURE 28: PLOTTED SCENARIO OUTCOMES ................................................................. 68
TABLE OF TABLES

TABLE 1: LIQUIDATION SIMULATION INPUTS ............................................................................................................................... 47
TABLE 2: EXAMPLE CHANNEL-SPECIFIC INPUT PARAMETERS FOR A FASHION COMPANY ......................................................... 48
TABLE 3: LIQUIDATION SIMULATION OUTPUTS .......................................................................................................................... 48
TABLE 4: MARKET MEDIATION AND PHYSICAL COST IMPLICATIONS OF LOCALIZED ADVANCED MANUFACTURING SUPPLY CHAIN INTEGRATION ........................................................................................................... 58
TABLE 5: RESPONSIVE SUPPLY CHAIN TECHNOLOGY AND PROCESS DEVELOPMENT AREAS ................................................. 70
1 Introduction

1.1 Project Introduction

This thesis research focuses on understanding the need for strategic simulation in response to the phenomenon of meteoric retail channel growth. The growth of online channels requires companies to enhance their supply chains, including integration of advanced manufacturing capabilities, to better respond to consumer demands in the digital space. Executed from within NIKE’s Global Supply Chain Innovation (Global SCI) team, the project demonstrates how supply chain simulations that integrate cross-functional data and metrics can be used to enhance strategic supply chain decisions. Both organizational process and analytical perspectives are explored with respect to simulation development.

From an organizational process perspective, the project successes include introduction of systematic approaches to develop simulations within a complex organizational structure that has separate simulation development teams (i.e. Global SCI) and user groups (i.e. business units), and introduction of user experience/user interface (UX/UI) prototyping tools to aid simulation storytelling and gain stakeholder support. From an analytical perspective, the project succeeds in illustrating the benefit of disparate dataset integration to provide enhanced strategic insight. This is accomplished through two proof-of-concept simulations - one that explores opportunities to further integrate supply chain strategy development processes in product liquidation planning, and a second that captures supply chain and marketplace impacts of localized advanced manufacturing strategies in a conceptual advanced manufacturing simulation framework. Project challenges include validation and calibration of the proof-of-concept liquidation planning model. These challenges point to the immense importance of established relationships and feedback devices between the simulation development team and user groups, and are used to support recommendations (Section 8).

The thesis begins by delving into the external marketplace forces and corresponding internal strategic responses that are part of digital’s expansion (1.2: Project Background, 1.3: NIKE Overview, 1.4: NIKE’s Evolution and Growth). Next, the problem statement regarding NIKE’s desire to enhance supply chain strategy development through integrated, cross-functional modeling is presented in Section 2: Problem Statement. Section 3: Literature Review describes existing research on salient topics such as successful strategic simulation efforts in industry and use of System
Dynamics modeling for strategic simulation, as well as the value of lead time and the ripple effects caused by advanced manufacturing adoption across the supply chain. Section 4: Methodology explains the three-step process (Conceptual Development, Analytical Construction, and Simulation Results and Refinement Opportunities) executed to develop user needs for strategic simulation at NIKE, the proof-of-concept Liquidation Planning simulation, and the advanced manufacturing simulation conceptual framework.

The findings from the applied methodology are presented in Sections 5 - 7. Section 5: Supply Chain Simulation Conceptual Development describes the key simulation characteristics identified by the user interviews as well as the simulation content identified as most critical for near-term development. Section 6: Supply Chain Simulation Analytical Construction begins with development of the Liquidation Planning simulation and continues on to describe the conceptual framework for the theoretical Advanced Manufacturing Product Selection model. Preliminary results and stakeholder feedback of the Liquidation Planning simulation are presented first in Section 7, followed by general results and suggested future work for the Advanced Manufacturing Product Selection modeling concept. Section 8: Organizational Process Recommendations describes three organizational process recommendations for future success in strategic simulation development across an enterprise. Finally, Section 9: Conclusion revisits the original impetus for this project – the increasing complexity of NIKE’s supply chain through NIKE retail’s rapid growth and integration of advanced manufacturing techniques – and looks toward the future.

1.2 Project Background

NIKE Inc. is the largest athletic apparel, footwear and equipment company in the world. NIKE’s mission is to bring inspiration and innovation to every athlete. This inspiration and innovation is largely derived from the cutting-edge products delivered by NIKE’s world-renowned design teams to enable active lifestyles. This project focuses on a different innovation concept for NIKE – the idea that innovation is not limited to product. The rise of e-commerce is transforming NIKE’s marketplace on myriad fronts – from brick and mortar to e-commerce, from 3rd-Party Wholesale accounts to NIKE.com, and from broad customer segmentation to catering to individual consumers – thereby provoking an expansion of the boundaries of NIKE’s innovation scope.

NIKE recognizes the need to respond to these evolutionary forces through widespread changes across its supply chain, from sourcing and manufacturing through delivery to consumers’ hands. Moreover, NIKE has recognized that these marketplace shifts bring the supply chain closer to the consumer than
ever, requiring input and corresponding strategic shifts across all functions, encompassing finance, merchandizing, and sales. These parallel changes across NIKE’s $30 billion enterprise call for enhanced coordination of supply chain strategy development to ensure global rather than local optimization and end-to-end goal alignment.

The focus of this thesis is the design of simulation tools required for rapid supply chain strategy development in order to facilitate cross-functional strategic optimization and collaboration. The key objective is to identify simulation capabilities that will help supply chain leaders get to enhanced enterprise insight, faster. Thus, the goals of this research are two-fold:

- Develop general end-to-end simulation capability and user needs assessments
- Develop proof-of-concept simulators that integrate cross-functional metrics and business drivers, and enable rapid scenario development

1.3 NIKE Overview

This section describes NIKE’s current business operations and structure to provide contrast to the widespread changes occurring as a result of the rise of e-commerce, as described in Section 1.4: NIKE’s Evolution and Growth.

1.3.1 Company History

NIKE was founded in 1964 as Blue Ribbon Sports by University of Oregon track coach Bill Bowerman and University of Oregon runner-turned-business man Phil Knight in Eugene, Oregon. The company transitioned to the NIKE name and internationally-recognized logo in 1971. The original business concept focused on developing cutting-edge running shoes – Bill Bowerman used his track team to test and iterate on his self-made designs, including the iconic waffle iron sole design that became the prototype for the modern running sneaker. Over the last five decades, NIKE’s products have expanded into apparel, equipment and footwear for a wide range of sports including baseball, American football, soccer, basketball, lacrosse as well as everyday fashion for men, women and youth. While NIKE has acquired other apparel, equipment and footwear companies (Bauer Hockey, Umbro, Cole Haan) to build out its product portfolio, today NIKE Inc. is comprised of NIKE Brand (inclusive of the NIKE Golf, Hurley and Jordan brands) and Converse only. In 2015, NIKE Inc.’s revenue totaled $30.6 billion, with NIKE Brand comprising 94% of net sales and Converse making up the 6% balance. NIKE Brand revenues have doubled since 2007 (Figure 1), and since rebounding from the 2008 recession NIKE Brand revenue growth rate has sustained double digital growth for all years but one (Figure 3). Throughout its growth and expansion, the majority of NIKE’s revenue is still derived from footwear sales – in 2015,
64% of NIKE's revenues were derived from footwear sales across all categories and geographies (Figure 2).
1.3.2 Organizational Structure

NIKE's organizational structure is a matrix with three primary dimensions: Geography, Product Engine and Category. The matrix has evolved over time to encourage collaborative decision-making throughout the enterprise.

NIKE's geographic dimension is split across six regions: North America, Western Europe, Central & Eastern Europe, Greater China, Japan and Emerging Markets. While each region has dedicated supply chain innovation, sales and operations planning (S&OP), inventory management and demand planning teams, manufacturing and procurement functions are pooled by product engine to serve globally. The three product engines - apparel, equipment and footwear - are dimensions that are critical to manufacturing and procurement; conversely, in supply chain, these dimensions are not used to provide additional organizational structure.

Category is a relatively new dimension, introduced to better compete in the marketplace through more targeted sales strategies; categories include Running, Basketball, Football (Soccer), Men's Training, Women's Training, Action Sports, Fashion and Golf. These dimensions are applied to most sales, supply chain and operations functions within the geographies, but not to manufacturing and procurement. Thus, functional teams execute specific tasks within the geography, product engine and category permutations; some functions, such as finance, global business planning, and corporate strategy, operate outside of the previously defined dimensions and operate at a global level.

Accordingly, the matrix generates a multifaceted structure that results in each employee having multiple peers at the same level (i.e. a North America Basketball Demand Planner will have a North America Soccer Demand Planner as well as a Western Europe Basketball Demand Planner as peers) as well as multiple managers (i.e. a North America Basketball Demand Planner must coordinate with both the North America and Basketball leadership team strategy). The matrix is further refined by secondary dimensions such as business channel, broadly represented by NIKE's Direct to Consumer and 3rd-Party Wholesale channels, and business model, such as NIKE's Always Available products. As will be discussed in Section 1.4, the teams defined by these secondary dimensions are becoming more and more critical as the business evolves.
1.3.3 Manufacturing & Supply Chain Design

Born out of a business strategy developed by Phil Knight while attending Stanford Graduate School of Business, NIKE has almost exclusively used offshore manufacturing partners to produce and assemble its products since its inception in 1964. Mr. Knight's paper, "Can Japanese Sports Shoes Do to German Sports Shoes What Japanese Cameras Did to German Cameras?" proposed that the substantially lower wages in Asia could be leveraged to compete against the then-popular German-made athletic shoes. This idea formed the basis of NIKE's supply chain strategy for the next 50 years.  

NIKE's supply chain begins with raw material suppliers and contract manufacturers in Asia for essentially all apparel, equipment and footwear products, serving all geographies and business channels. In 2015, NIKE utilized 146 contract manufacturers for footwear. The vast majority were concentrated in Vietnam, China and Indonesia, where approximately 43%, 32% and 20% of total footwear was derived and assembled respectively. In contrast, NIKE's apparel products are manufactured by over 400 factories primarily located in China, Vietnam, Sri Lanka, Thailand, Indonesia, Malaysia and Cambodia. With over 67% of 2015 revenue generated in North America and Western Europe, the off-shore production results in long inbound transit times. This physical distance also extends product development cycles, as footwear and apparel samples must be shuttled between NIKE's Beaverton, OR headquarters and offshore partners during the meticulous design process. After production, transit time is incurred to account for travel from the factory to the destination country distribution centers via ocean freight. Once at the destination country, units are either shipped directly to account distribution centers or shipped to a NIKE distribution center for later account allocation.
1.3.4 Business Channels

NIKE sells through two primary business channels – 3rd-Party Wholesale, and Direct to Consumer (DTC), which is NIKE’s retail designation. The DTC channel includes a digital platform, NIKE.com, premium brick-and-mortar Inline stores, such as NIKETOWN, and liquidation outlets, known as NIKE Factory Stores (NFS).

Using a wholesale business model framework, NIKE as a wholesale entity develops and oversees contract manufacturing and sale of the product to the 3rd-Party Wholesale and DTC accounts. Both 3rd-Party Wholesale and DTC accounts are treated identically from a broad operational perspective. Inventory remains on NIKE’s wholesale balance sheet until it is shipped to the designated account; receipt by the account, whether 3rd-Party Wholesale or DTC, initiates the transfer to the account. Transfer to a 3rd-Party Wholesale account removes the inventory from NIKE’s balance sheet; inventory transferred to a DTC account is still included on NIKE Inc.’s balance sheet but indicates a handoff of inventory management and oversight to the specific DTC account.

3rd-Party Wholesale accounts purchase NIKE products at wholesale prices and resell them in their brick and mortar and digital spaces. Value chain accounts that sell discounted liquidation product are included in this category. NIKE.com and Nike Stores sell in-season product, although NIKE.com sells discount (close out) items as well. With sale of products directly to consumers, these DTC channels achieve significantly higher gross margins for NIKE Inc. NIKE Factory Stores serve to clean the DTC and 3rd-Party Wholesale marketplaces of outdated product to maintain brand value and image, and largely sell liquidation products.
1.3.5 Business Models

Both 3rd-Party Wholesale and premium DTC accounts (i.e. Inline stores and NIKE.com) order in-season product through three primary business models. NIKE DTC accounts operate with the same characteristics and schedule as 3rd-Party Wholesale accounts with respect to inventory and shipment flow. These business models determine both inventory allocation as well as inventory risk distribution between NIKE and the account:

1. Futures Model – Make-To-Order (MTO)
2. Always Available (AA) Model – Non-Seasonal Items, hybrid Make-To-Order/Make-To-Stock (MTO/MTS)
3. At-Once (AO) Model – Quasi-MTS

The Futures model is the seasonal business model that made NIKE famous at its start: accounts place orders six months before delivery date, and units to fulfill MTO orders are shipped directly to the account, or shipped to a NIKE distribution center where they are held until they are 'called off' by one of the accounts that has placed a Futures order for that particular SKU. The majority of units sold are through this order type.

The AA Model represents a specific type of responsive business model that is available in the Western Europe and North America geographies as of the time of this research. This business model is primarily comprised of non-seasonal core apparel SKUs that have relatively high volume and low variability throughout the year (black/grey/white shorts, tees, pants, etc.). Safety stock is staged at NIKE DCs to maintain service to accounts. Currently, accounts can order AA product through a Futures contract to receive a large volume at once, or can manage their AA SKU inventory through the MTS replenishment model. Although the safety stock component of this business model requires NIKE to hold inventory without planned demand against it, AA product is lower risk due to the fact that its season-less nature lengthens the time before obsolescence significantly.

The AO Model represents a responsive order type available to all accounts. Products included in the AO inventory pool include new launch products, product ordered by NIKE to satisfy factory minimums, units previously on Futures MTO contracts that were canceled or returned and non-seasonal AA product safety stock (see description above). Accounts can place orders against this inventory pool – known as General Availability (GA) – and have it shipped immediately. Thus, some of the AO product can be classically defined as MTS (AA safety stock, launch product) whereas other products delivered in the AO business model are unplanned inventory types. Besides the AA safety
stock, inventory units held for AO orders represent high obsolescence risk for NIKE; as they are seasonal items with no planned demand against them, the likelihood of liquidation is increased.

Finally, Nike Factory Stores (NFS) use two business models:

1. Liquidation Product – sale of Close Out and Early Price Reduction inventory
2. Futures Model – Make-To-Order (MTO) of out-of-season product

Liquidation products are inventory units that are the result of unrealized demand either in-season or after the product’s active season. These are units that were either originally ordered by a 3rd-Party or DTC account via a MTO Futures contract but were canceled or returned, or were awaiting AO orders. Liquidation units fall into two distinct categories:

1. Close Out (CO) units: units that remain in inventory past their active season
2. Early Price Reduction (EPR) units: units that are not selling through in the market as anticipated, and early (in-season) liquidation is required to maintain marketplace health

CO units generally result from the cancelled and returned MTO Futures product from 3rd-Party Wholesale and DTC accounts. EPR units generally arise from products awaiting Non-AA (i.e. seasonal product) AO orders.

While NFS exists to clean the marketplace of aged inventory, the assortment that arises from EPR and CO units alone may not be appropriate for NIKE’s in-store merchandizing standards. Store assortments are improved through MTO Futures contracts of out-of-season product. These orders consist of past-season apparel, equipment and footwear SKUs that are no longer available to premium 3rd-Party Wholesale or DTC accounts. ‘Futures Minimums’ are utilized to maintain high product assortment quality within stores to attract consumers.

1.4 NIKE’s Evolution and Growth

The dramatic growth of e-commerce has touched every industry, including retail. Forrester Research forecasts over 40% growth of online retail sales in the US from 2014 to 2018, from $294 billion to $414 billion, while offline retail sales are forecasted to remain flat. ³

This digital revolution affects NIKE’s marketplace landscape dramatically, challenging the established organizational and operational structures described in Sections 1.3.2-1.3.3. External influences on NIKE’s fundamental enterprise building blocks have compelled NIKE to evolve in ways that change their resource needs and strategic decisions, and are the direct drivers of the development of this internship project to create rapid supply chain simulation capabilities. To highlight the importance of
end-to-end supply chain strategy coordination through new tools and processes, this section describes these major business model and marketplace shifts and the corresponding responses across NIKE's supply chain and manufacturing strategies.

1.4.1 External Stimulus: Growth of the Consumer-Led Marketplace

As discussed in Section 1.3.4, NIKE's revenue has historically been derived from its 3rd-Party Wholesale accounts. Thus, the rise of digital not only requires NIKE to change its commerce platform, but also to expand its operational focus to include its own retail operations. Since 2010, NIKE's 3rd-Party Wholesale has been declining as a percentage of NIKE's overall revenue and its growth rate has seen an overall decline as well, while DTC has been rising in significance (Figure 6, Figure 7).¹ NIKE revenue forecasts continue these growth patterns, fueled by sales through NIKE.com. Public projections of e-commerce revenue growth include a goal of $7 billion by FY20.⁴
The increased proportion of business through the digital channel implies changing consumer expectations. Native e-commerce companies like Amazon have redefined baseline consumer expectations, setting new standards for velocity and responsiveness. For NIKE, the speed of online shopping amplifies "fast fashion" dynamics. Consumers routinely demand products that reflect immediate trends, are always in-stock and customizable; seamless shopping and delivery experiences are also required in the e-commerce paradigm, replete with 1-2 day shipping and easy return policy. This has direct implications for NIKE's product development process, manufacturing processes and supply chain network described in Section 1.3.3, which currently operate with a product lead time of at least six months.

### 1.4.2 Strategic Response: Supply Chain

As described in Section 1.3.3, essentially all of NIKE's contract-manufacturing partners currently reside offshore, with 66% located in South, Southeast and East Asia and almost 30% of all factories located in Greater China. While this arrangement incurs long lead times to NIKE's traditional primary markets in North America and Western Europe, the trade-off between low labor wages and transportation lead time worked in NIKE's favor as it operated as a wholesaler in the pre-Internet marketplace.

The growth of DTC operations, specifically digital, has changed the cost/benefit equation for offshore manufacturing. Retail growth increases the inherent cost of the long lead times that NIKE has historically tolerated, as the penalties of high inventory levels and low forecast accuracy are borne directly by NIKE rather than third-party entities. Additionally, the rise of e-commerce has amplified the demand volatility intrinsic to the fashion industry due to high SKU volume, lack of historical data for new products and short selling seasons. Consumers' increased access to digital information has resulted in even shorter trend cycles and heightened consumer expectations for immediacy, putting additional pressure on lead time reduction. Finally, 39% of digital consumers express interest in customization, a product characteristic that demands radically different supply chain features. Although NIKE.com does offer customizable products through NIKE iD, the custom product lead time is 3 – 6 weeks and expedited shipping is not available at the time of this thesis. These pressures have contributed to NIKE's strategic decisions to reduce lead time through onshore or near-shore manufacturing. In 2015, NIKE voiced support for the Trans-Pacific Partnership (TPP), stating that its passage would further encourage development of onshore advanced manufacturing strategies to "deliver product faster to market, create innovative performance footwear, [and] provide customized solutions for consumers."
NIKE is not alone in facing a change in the value proposition of offshore manufacturing. Since 2010, companies such as Ford, Caterpillar, Apple and GE made announcements about upcoming repatriation of manufacturing activities. Even non-US companies are moving manufacturing to North America, such as Foxconn and Lenovo.\textsuperscript{8,9} This recent manufacturing trend is generically known as ‘reshoring,’ indicating a change in manufacturing location, and includes both ‘back-shoring,’ when manufacturing is relocated to a firm’s home country as well as ‘near-shoring,’ when manufacturing is relocated to a region near a firm’s home country.\textsuperscript{10} A multitude of forces have emerged that challenge the offshore paradigm. Existing literature identifies far-ranging forces that are shaping and accelerating this trend, including elevated international risks, increasing wages in China and South Asia, elevated Intellectual Property concerns and R&D innovation efficiency.\textsuperscript{9,11} A 2012 survey performed by MIT demonstrated that over a third of the 108 participating US manufacturing companies were considering reshoring, with 16% definitely reshoring. Among the large number of reshoring drivers, the number one driver for reshoring consideration reported by the participants was time-to-market reduction (Figure 8).\textsuperscript{9} Reshoring reduces time-to-market across the supply chain: it not only reduces the transportation time from the manufacturer to the retail outlet, but can also reduce design and product development duration as collaboration between supply chain entities is streamlined.

Supply chain impacts of e-commerce also arise in the realm of supply chain performance management. Supply chain performance success within a consumer-led, digital world is defined differently than supply chain success in a 3rd-Party Wholesale business. Although NIKE has always put the consumer at the center of all of its strategic decisions, digital’s growth brings NIKE’s supply chain in immediate contact with the consumer with much higher frequency. Thus, delivery and service level metrics have become even more critical as the consumer is directly aware of late shipments and stock-outs. Additionally, the supply chain must adjust physically – distribution centers and transit lanes must excel at individual unit deliveries rather than pallet-sized shipments.
An example of NIKE’s response in this area is the construction of the state-of-the-art 2.8 million square foot distribution center in Memphis, TN, opened in 2015. Beyond adding capacity in storage, shipping and receiving, this site was designed to enhance NIKE’s shipment processing time through automated conveyer belts and sortation. This facility enables shipment of all three product engines (footwear, apparel and equipment) from one site, and parallel processing of wholesale orders, brick-and-mortar NIKE retail orders, and individual digital orders.12

1.4.3 Strategic Response: Manufacturing

Given the high labor costs of primary Western markets like North America, the potential of onshore manufacturing opportunities have been unlocked through another key reshoring driver: advancement of manufacturing process automation technology. These advanced manufacturing strategies rely on automation rather than manual labor, thereby negating wage cost differentials between manufacturing locations. Additionally, the high capital cost of these strategies are decreasing – relative to the cost of labor, average robot prices since 1990 have fallen by 40-50% in many advanced economies.13 These technologies, such as additive manufacturing, also enable the rapid customization demanded by the marketplace.

NIKE’s use of advanced manufacturing technologies began in 2012 – the year that Flyknit technology was introduced. Flyknit is the world’s first mass-produced product utilizing computer-controlled weaving technology. Sensors in the system adjust speed and tension in real-time, and the entire system substantially reduces manual labor requirements by eliminating the need to cut any fabric and reducing the number of sewing steps.14 NIKE’s then-president, Charlie Denson, acknowledged that the reduction in manual labor is so steep with this technology, that it could truly enable manufacturing anywhere in the world.15 NIKE also utilizes additive manufacturing, also known as 3D printing, as a part of its advanced manufacturing strategy. While NIKE predominately utilizes additive manufacturing as a prototyping tool to shorten product development cycles currently, with plans to install the technology into the new Advanced Product Creation Center on its Beaverton, OR campus, NIKE has used 3D printed plates in three models of soccer cleats, combining Flyknit technology and 3D printed components in its Vapor Ultimate Cleat in 2014.16,17,18
In 2015, NIKE publically announced its partnership with Flex, a California-based international supply chain solutions company that offers design, manufacturing, distribution and aftermarket services. Flex is known for bringing disruptive technologies to manufacturing in other industries, such as the US automotive industry, as well as innovative 'sketch-to-scale' product development processes. NIKE hopes to capitalize on this experience to further its Manufacturing Revolution (ManRev) initiative. ManRev includes both manufacturing modernization and innovation, through development and integration of advanced manufacturing technologies, as well as enhanced product R&D through joint innovation efforts with Flex.
2 Problem Statement

The rise of NIKE's DTC channels translates to enormous revenue growth opportunities due to the channels' higher gross margins and ability to build stronger brand connections with consumers. NIKE's current supply chain strategy development process, however, must be enhanced to harness this opportunity given the simultaneous supply chain and manufacturing changes that are occurring to respond to the increasing complexity of consumer demands in the digital space. As a result, supply chain strategy development must encompass business unit insight from procurement, manufacturing, and supply chain. Moreover, supply chain's more direct connection with the consumer in an e-commerce environment requires additional input from teams outside of traditional operations units as well, including merchandizing, sales, and finance.

2.1 Current State

NIKE seeks to augment the existing strategy development process through increased enterprise-wide collaboration and design of 'what-if' simulation tools to test alternative scenarios as the business changes rapidly. Currently, analytical tools utilized to quantify the impact and qualitatively shape supply chain strategy are created in dedicated functional teams and are not specifically designed for cross-functional use. While functional teams share analytical outputs with one another to inform each other's strategic decisions, often the underlying assumptions and baseline conditions are not explicitly communicated (Figure 10). The current state results in missed opportunities to adjust functional teams' assumptions based on knowledge residing elsewhere within the organization, or to create a more optimal strategy through wider modeling scopes.

This research seeks to improve the current state of supply chain strategy development along three dimensions:
1) Cross-Functional Development
Strategic supply chain decisions will require enhanced cross-functional input as the growth of digital retail affects every aspect of NIKE's supply chain and operations. Tools must be comprehensible and accessible by many teams, with a common 'language' and user-friendly design.

2) Agile Model Design and Development
Models will need to integrate scenario-testing platforms for experimentation to enable faster strategic responses. The simulation development process between the modeling team and business units will need to be agile as well, to enable swift creation of effective analytical tools as varied competitive response needs arise.

3) Accessible Operational Data
Geo-based teams and functional teams will need greater access to business unit parameters outside of their domains to successfully leverage cross-functional analytical tools. Moreover, NIKE's global and geo-specific supply chain leadership will need expanded access to snapshots of current business parameters, as well as historical business parameter trends, for enriched insight on present operations and future trajectories.

2.2 Project Goals
The overarching project goal was to innovate on NIKE's supply chain strategy development process, demonstrating how supply chain strategy simulations can help supply chain leaders achieve enhanced enterprise insight, faster (Figure 11).

![Figure 11: Future state strategy development process](image)

In order to achieve the central goal, two objectives were achieved in series. The first objective was to determine user needs for cross-functional simulation capabilities and functionality. Attainment of this initial objective subsequently allowed for defining business problems to address in the second objective: development of proof-of-concept rapid supply chain strategy simulators that integrate metrics and key business drivers from different functional teams.
3 Literature Review

This section presents existing literature relevant to this thesis’ research on rapid supply chain strategy simulation at NIKE. The section begins with a review of successful cross-functional simulation efforts documented in industry as well as their challenges. Next, three sections provide background for the theoretical Advanced Manufacturing Product Selection simulation framework presented in Section 6.2. The first reviews the benefits of utilizing System Dynamics as a modeling methodology for supply chain simulations. Drawing on the lead time benefits of onshore manufacturing described in Sections 1.4.2 and 1.4.3, the next section explores the value of lead time in the context of both reduced inventory costs and enhanced forecast accuracy, as well as reduced product development cycle time. The last section presents qualitative and quantitative research on advanced manufacturing technologies’ supply chains impact.

3.1 Strategic Simulations: Industry Case Studies

The desire to cross-functionally integrate supply chain decision-making processes is not unique to NIKE. With increasing global competition, supply chain sophistication, and access to Big Data resources and methodologies, growing interest in enterprise-wide optimization that integrates supply chain design and supply chain operations is well documented. Existing literature includes case studies of successful simulations developed and implemented across large-scale supply chains that crystalize strategic-level insight from underlying operational forces. Examples from relevant consumer goods companies include Dell, a privately-owned multinational computer technology company that employs more than 103,000 people worldwide, and McKesson, a Fortune 100 company that distributes more than one-third of all pharmaceutical products in North America. Both companies published case studies regarding their application of Operations Research to supply chain management problems that span business units to develop ‘what-if’ tools.

Dell developed a Retail Margin Maximizer to increase gross margin and decrease end-of-season inventory for both its wholesale business and retail account partners, resulting in over $41 million in the first year of implementation. McKesson, in collaboration with IBM Research, developed supply chain scenario modeler (SCSM) to quantify the impact of strategic and tactical supply chain decisions across operational, financial and environmental performance metrics. Built through a bottoms-up approach utilizing the underlying supply chain network and transactional level data, the success of SCSM implementation was tangible through savings of over $1 billion in working capital after 2 years of use. While the approaches and scopes differed significantly between the two case studies, the organizational process challenges were the same – attaining buy-in from
critical stakeholders was difficult, and required rigorous trust-building through frequent meetings and close collaboration during the solution development process.

The literature also documents generalized strategic-level simulation approaches. Strategic-level simulation can be approached from a financial lens to align operational strategy with increased shareholder value – by connecting operational drivers to balance sheet components through operational KPI frameworks such as the SCOR model, ‘value trees’ can be used to develop strategy that is intelligible by both operations and finance managers. This common framework is useful in supporting cross-functional collaboration through a universal platform. These technical tools fall into the category of Value Based Management (VBM), such as the DuPont Model; they typically measure success based on Economic Value Added (EVA), Return on Assets (ROA) or Return on Equity (ROE). While value trees simply present causal relationships between operational and financial variables, they are limited due to the absence of feedback loops between variables and time delays related to decision-making.

3.2 System Dynamics and Supply Chain Strategic Planning

System Dynamics (SD) is a macro-level modeling approach that focuses on capturing the feedback loops and time delays that are missed in VBM and other quantitative tools, and are often the sources of complex system behavior. While SD can be applied to any system, MIT’s Jay Forrester established the indelible connection between system dynamics and supply chain management in his groundbreaking work in the late 1950s and early 1960s. Forrester’s proclaimed goals for Industrial Dynamics research are equally applicable to the problems facing supply chain managers, today:

1. To develop in the manager a better intuitive feel for the time-varying behavior of industrial and economic systems...[to improve] one's judgment about the factors influencing company successes.
2. To provide a background showing how the major aspects of a company are related to one another
3. To help predict the future course of an existing organization.
4. To improve the future prospects of a company. Beyond prediction lies the ability to redesign an organization and its policies so that it stands a better chance of success.

Forrester also aptly identified another strength of the approach – to build operational enterprise models from stakeholders’ mental models across the business, stating that “The results are beneficial even before one...has reached an accurate quantitative formulation of company behavior that will have reliable predictive value.”
The modern benefits of SD for supply chain management are well documented in the literature, particularly as technological advances simultaneously introduce more robust data and more complexity. In the context of the unprecedented rapid growth of NIKE's retail business and the accompanying radical changes its supply chain will undergo to meet the channel's new and ever-changing demands (i.e. increased customization, faster product introductions, enhanced shopping experiences), General Motors' (GM) case study regarding its use of SD to determine the right strategy for deploying OnStar in-car communication technology is particularly relevant. Like NIKE, GM was facing major strategic decisions regarding its products, supply chain and market position in an entirely new business model, and it used SD to determine whether to adopt a wait-and-see evolutionary strategy or a bold revolutionary strategy – ultimately choosing the latter for OnStar's launch. Their approach also exemplified the flexibility of SD and its ability to manage uncertainty and assumptions, stating, "To cope with the inherent uncertainty, we needed a modeling process that would allow integration of various methods and data sources. Our method had to be flexible enough to absorb a wide variety of inputs based on judgment, historical analogies, market research, and other sources."

Because of the time-varying behavior and feedback loops inherent to advanced manufacturing networks in general, as well as the abundance of uncertainty for NIKE specifically, a system dynamics framework is used in Section 6.2 to conceptualize a localized advanced manufacturing simulation.

3.3 Valuing Lead Time

NIKE's hypothetical decision to move a portion of its manufacturing base onshore/near-shore will have a major impact on supply chain lead time. The strategy would bring manufacturing close to both its product research and development efforts located in Beaverton, OR as will as its primary market, North America. Thus, two benefits arise from this arrangement: 1) drastically reduced inbound lead time and 2) faster, more productive product development and innovation cycles due to physical proximity of manufacturing and product R&D processes.

Increasing forecast accuracy within the fashion industry has been recognized as an exceedingly difficult task; accordingly, lead time reduction has often been considered as a means to sidestep forecast accuracy methodology challenges. Two key results exemplify the power of lead time on forecast accuracy:

- According to the investigation of Wal-Mart, in the apparel industry, if the retailer orders 26 weeks before selling season, the error of market demand forecasting will be about 40%. If
the retailer orders 16 weeks before selling season, then the prediction error will be about 20%, and the time of ordering is closer to selling season, the error of market demand forecasting will be only about 10%.

- Another prime example in the apparel industry supply chain is that if the order lead time is compressed from 8 months to 4 months, the prediction error will fall from 65% to 35%.

The benefits of lead time compression on forecast accuracy as well as supply chain management in terms of inventory holding requirements, stock outs and service levels are well documented in the literature. In order to achieve these results, however, lead time reduction generally requires significant financial investment. In NIKE's case, lead time reduction through reshoring initiatives would require substantial investments in high-tech manufacturing equipment and facilities and construction of a new raw material supply chains to serve the manufacturing sites. The positive side of the trade-off equation for these investments may include reduced stock-outs, reduced inventory obsolescence costs, and reduced logistics costs, but identifying the break-even point for investment requires analysis of the financial value of the lead time reduction compared to the current state. It has been demonstrated that the marginal value of time for innovative products such as NIKE's high fashion offerings is high due to the dominance of obsolescence and markdown costs. Thus, this section will focus on research that provides frameworks for placing a value on lead time, facilitating the determination of the appropriate level of financial investment in advanced manufacturing strategies to achieve desired lead time reductions.

A highly applicable example of lead time valuation is de Treville et al.'s expansion of their option-based model that develops cost-differential frontiers. A cost-differential frontier "compares production at a given non-zero lead time to make-to-order production, showing the cost reduction required to compensate for the resulting demand-volatility exposure." The greater the cost-differential, the less expensive the long lead time supply chain/manufacturing option must be to justify selection. de Treville et al. use industry data to explore this concept. For example, Nissan's current supply chain configuration is presented - Nissan freezes production with an 8-week lead time to save 1-2% in production costs. Without modeling the value of lead time, the 1-2% production cost savings seem worthwhile. Exploration of the demand volatility Nissan faces, however, proves otherwise; with current demand volatility of 20-30%, acceptance of the long 8-week lead time would required 5-7% savings, respectively, to rationalize the long lead time. Extensions for salvage value, service level, and stochastic demand variability are applicable to NIKE's questions regarding the value of shorter lead times offered by onshore manufacturing. High cost-differential frontiers are calculated for low salvage values, high service levels and stochastic
demand variability – these are all features of NIKE's marketplace and suggest that higher investments in lead time reduction may be warranted. 36

Back-shoring and near-shoring strategies not only reduce inbound transportation time to primary markets – they also reduce total time-to-market (TTM). As a fashion industry enterprise, this is of particular interest to NIKE as it desires rapid response to changes in trends and marketplace demographics in-season, and also seeks to revolutionize apparel and footwear manufacturing for new products (e.g. Flyknit) to gain competitive edge. With onshore partners such as Flex, it is conceivable that NIKE could greatly reduce its product design, development and launch cycle from its current duration of over a year, and accelerate the development of innovative manufacturing technologies and processes in parallel. Thus, increasing the proximity of R&D and manufacturing activities is another driver in the reshoring trend as innovation activities are affected by strong interdependencies and complementarities. According to Albertoni et al., "[T]he co-location of R&D and manufacturing is critical to foster innovation." 37 In response to globalization trends, a substantial volume of research exists exploring the impact of the proximity of supply chain participants and innovation cycles. Dankbaar (2006) presents case study-based evidence to support hypotheses that firms with in-house manufacturing have stronger research and development, and that firms without in-house manufacturing must ensure their research teams are fully equipped with manufacturing knowledge. 37 The importance of proximity is amplified in markets with fierce time-based competition, such as fashion. 38,39

3.4 Supply Chain Impact of Advanced Manufacturing

Advanced manufacturing technologies that leverage advancements in additive manufacturing (AM) and automation will be disruptive to existing supply chain designs. While modernization efforts that improve plant efficiency result in incremental changes, advanced manufacturing in this context will change product development timescales and capabilities, raw material supply chain, raw and finished good inventory profiles, skilled labor requirements, optimal manufacturing economies of scale, transportation requirements and distribution network design decisions. It is imperative to understand and quantify the second-order and third-order impacts of advanced manufacturing to develop comprehensive integration plans.

Because of the nascent nature of advanced manufacturing like AM, much of the existing literature focuses on conceptual frameworks to explore the potential supply chain trade-offs that AM will pose once adopted. 40,41 Mohr and Kahn provide a robust qualitative framework of 'Impact Areas' across the supply chain as a result of additive manufacturing integration. 42 In the context of supply
chain strategy simulation for NIKE, Impact Area 3 and 5 are the most relevant:

- Impact Area 3: Decentralization of manufacturing – 3D printing technology does not require the same skills as conventional manufacturing; manufacturing could be re-shored and take place closer to customers in their home markets, mitigating the risks of obsolescence.
- Impact Area 5: Rationalization of inventory and logistics – 3D printing will have an impact on the volume of the inventory and on the inventory mix, including a shift to inventory in the form of raw materials (e.g., powders or filament coils) rather than semi-finished parts and components.

Beyond skill requirement changes due to Impact Area 3, there are also technological changes – as explored by Bogers et al., advanced manufacturing such as additive manufacturing will enable decentralization due to the technology’s lack of tooling and auxiliary systems.  Delving further into these impact areas qualitatively, it is clear that quantitative simulation is required to robustly explore the full impact of advanced manufacturing. For example, regarding Impact Area 3, although labor hours are reduced overall, higher-skilled laborers are required. Simulation is required to determine the cost of manufacturing in areas where these skilled laborers reside and capacity limits resulting from worker scarcity, as well as the cost of training staff and total compensation.

Other qualitative approaches to additive manufacturing supply chain integration include Kieviet and Alexander's decision model for adoption of additive manufacturing (Figure 12). Measuring existing supply chain and product characteristics along three dimensions – Complexity Level, Supply Chain Performance, and Strategic Benefit Curve – enterprises can use a mix of qualitative and quantitative inputs to determine whether the benefits of AM outweigh the costs.

Examples of quantitative models representing advanced manufacturing impacts across supply chains are limited, but two are developed and presented by Mashhadi et al. for additive manufacturing. Both an Agent-Based Simulation (ABS) and System Dynamics (SD) models are generated.
Within the ABS model, two supply chains are compared – a traditional supply chain comprised to raw material suppliers, a manufacturer, retailers and customers, and a modified supply chain with the same agents but with customers ordering directly from the manufacturers, who supply the 3D printing design to the retailers to produce for the end-consumer (Figure 13).

Parameters such as processing time, consumer demand, and shipping time are included in the model; the differences between the two simulations reside in the agent behavior rather than the parameter values. Results demonstrate that the structure of the modified supply chain actually results in higher inventory levels overall as manufacturing is distributed among the five retailers, but lead time is reduced significantly, by approximately 50%.
Within the SD model, the same stock-and-flow diagram is used to model a traditional and modified supply chain (Figure 14). Only manufacturing set-up time is varied, with additive manufacturing having lower set-up time than traditional manufacturing in this construct. Because of the reduced product delay to the retailer, inventory oscillations are damped in the modified scenario - a representation of reduced 'bullwhip effect' noted by Jay Forrester in his original industrial dynamics work.27 As described in Section 3.2, the representation of the bullwhip effect in the SD model is a critical result that cannot be captured in a static model.

The models presented by Mashhadi et al. provide a starting point in quantifying the impact of advanced manufacturing technologies on supply chain metrics. Even the outputs of these simple models pose interesting questions for supply chain management in an advanced manufacturing paradigm. For example, regarding the results from the ABM simulation, will supply chain managers be willing to accept higher inventory levels to achieve shorter and shorter customer lead times as customer satisfaction increases in importance as a metric in an e-commerce-driven marketplace? Additionally, in the advanced manufacturing scenario, manufacturing becomes distributed rather than centralized and the traditional manufacturing/retailer supply chain echelons are completely redefined. This supports consideration of the entire supply chain during design and implementation of localized advanced manufacturing strategies. Only with wider context can trade-offs such as one manufacturing center versus multiple manufacturing locations be assessed, allowing for analysis of raw material and finished good inventory as well as labor costs versus service improvements.

Using these supply chain impact findings in the existing literature as well as the lead time value findings outlined in Section 3.3 above, Section 5.2 develops a conceptual simulation framework to quantify the benefits of a shift from offshore, labor-intensive manufacturing to onshore advanced manufacturing within the context of NIKE’s seasonal and non-seasonal product demand profiles.
4 Methodology

The two project objectives were achieved through a process executed in three stages: Conceptual Development, Analytical Construction, and Simulation Testing. In an effort to capture the innovative spirit of the product design process, the activities within these three broad stages were designed to encompass the first five of the six phases described in Steven Eppinger and Karl Ulrich’s textbook, Product Design and Development (Figure 15). The project methodology began with Eppinger and Ulrich’s recommended strategy to start with expansive exploration of user needs and wide-ranging concept generation, followed by concept down-selection, refinement and testing. The final recommended phase, Project Ramp-Up, was not conducted as the thesis work ended with proof-of-concept hand-off to internal simulation development teams.

![Diagram of product design and development process]

Figure 15: Product design and development process as presented by Eppinger and Ulrich, 2012

4.1 Conceptual Development

As depicted in Figure 15, the Conceptual Development stage for this project included phases one and two, Planning and Conceptual Development. The stage was exploratory in nature, covering a wide variety of topics through more than 30 user interviews from across NIKE’s functional teams from different geographies, product engines and categories. These efforts comprised of identifying user needs and establishing specifications for supply chain strategy simulators, as well as concept generation and concept selection for the proof-of-concept simulators.

The interviews were focused on two broad categories of content:

Simulation Characteristics (User Needs and Specifications):
• How would you like to interact with a simulation?
• Which user interface features are important to you?
• What would you need to make a simulation effective?
• What contextual information would you need to develop a strategic scenario?

Simulation Content (Concept Generation and Selection):

• What information gaps exist in your work today?
• Which data sets do you wish you had access to for strategy development?
• Which areas do you think would benefit most from simulation?
• What are the key strategy levers and business drivers in your area of focus?
• What are the critical metrics for your area of focus?

During this stage, initial User Interface (UI) prototypes were developed using UXPin (www.uxpin.com), a cloud-based wireframe application, to guide and enrich stakeholder interviews, and to test concepts before selection (Figure 16). The stage concluded with the selection of two simulator concepts to develop into proof-of-concept models.

![Early simulation UI prototype](image)

4.2 Analytical Construction

Analytical construction encompassed what Ulrich and Eppinger refer to as System Level Design and Detailed Design. This began with identification of critical drivers, strategic levers and key metrics, and ended with refinement of analytical frameworks for each model. This phase also included the
identification, acquisition and cleaning of data sets required for the simulations utilizing Alteryx Designer, a software application for data preparation, blending, and analysis in repeatable workflows.

For the Liquidation Simulation, the shipment and inventory ecosystem was constructed in partnership with geo-specific DTC, Global DTC Strategy, and Global Performance Management team members. The key drivers and strategy levers were integrated, as well as the key output metrics. Data identification, acquisition and cleaning were also performed in this stage of the project. The Liquidation Planning simulation was constructed in Excel, using VBA and Frontline Solver for the simulation logic.

For the Advanced Manufacturing Product Selection simulation, a theoretical approach was taken. An actual model was not constructed, but system dynamic concepts from MIT’s Dr. John Sterman’s text book, Business Dynamics: Systems Thinking and Modeling, were utilized to create a conceptual model that could be further developed to support supply chain strategy decisions related to advanced manufacturing design and integration.

4.3 Results, Simulation Testing & Stakeholder Feedback

In the final stage, the results of the simulations were explored the stakeholders, akin to phase five of the Eppinger and Ulrich diagram, Testing and Refinement. For the Liquidation Planning simulation, the analytical framework was applied to a specific geography dataset to validate the model. Parameters representing a generic fashion company were then used to generate a baseline, and different scenarios aligning with various strategic initiatives were tested as well. The Liquidation Simulation capabilities and results were socialized with key stakeholders to gather feedback on both the analytical formulation and preliminary output. Stakeholder feedback was not collected for the Advanced Manufacturing Product Selection concept as it was developed after the onsite portion of this research concluded.
5 Supply Chain Simulation Conceptual Development

This section describes the results of the user interviews: Simulation Characteristics (User Needs and Specifications) and Simulation Content (Concept Generation and Selection).

5.1 Simulation Characteristics

Through the user interviews conducted, identified conceptual and technical user needs are grouped into four overarching characteristics:

1. Collaboration
2. Accessibility
3. Transparency
4. Agility

5.1.1 Collaboration

In response to the accelerated rate of change across the enterprise related to the growth of digital operations, enhanced cross-functional collaboration was one of the primary user needs vocalized. Employees at senior leadership levels as well as in operational positions acknowledged that a deeper understanding of the inventory and sales ecosystem as a whole will improve the ability to build more complex supply chain strategy and to execute effectively.

In response to this need, the proof-of-concept simulation development focused on areas where different functional teams would benefit from platforms to share strategic ideas, assumptions and data. Benefits arise from not only the integration of data and dynamics, but also from the ability to use these simulations as conduits for cross-functional communication. Liquidation supply and demand planning is one area where a collaborative platform can enhance strategic design as distinct teams manage different aspects of each side of the supply/demand equation. A second area identified is localized advanced manufacturing planning. As highlighted in Section 3.3 and 3.4 of the Literature Review, advanced manufacturing technologies and physical proximity can be leveraged for faster product development cycles, enhanced forecast accuracy and lower inventory levels. A cross-functional simulation that includes demand planning, supply chain, manufacturing and procurement could capture these varied impacts. Both of these examples are translated to the proof-of-concept models detailed in Section 6.
5.1.2 Accessibility

From the very top of NIKE’s supply chain organization, there is motivation to put advanced analytics in the hands of team members across the supply chain and beyond. While the supply chain simulators are envisioned as long-term strategic simulation tools for a senior leadership audience, they are part of a larger vision to enable more sophisticated decision-making at every level. Encompassed within accessibility lies the concept of usability – for accessible tools to be effective, they must be usable by the target audience. One team that had developed a simulation tool for inventory management explained how after months of development, users could not use the tool outputs after launch. Instead, users copied the simulation outputs to Excel to perform the analysis they needed for operational tasks.

This set of user needs was the impetus for the development of user interfaces utilizing UX Pin in an effort to start testing the user experience for accessibility and usability (see Section 4.1 and Figure 16). Additionally, the analytical model logic was kept simple to align with mental models about the business. For the results of these efforts, see Section 7.1.4 where feedback from stakeholder socialization is discussed.

5.1.3 Transparency

Users saw an opportunity for greater transparency in analysis performed within different functional teams. The perceived lack of transparency arose from two factors. First, as described in the problem statement, while functional teams often receive outputs from parallel teams, they may not be an integral part of the model development or assumption selection processes that generate the shared outputs. For example, the liquidation planning group may receive forecasted liquidation units from demand planning teams, but may not have direct access to the underlying business parameter assumptions used to calculate the volume of liquidation units. Second, access to the underlying assumptions of a different functional team alone may not provide sufficient context to explain their selection. Accordingly, users expressed interest in the historical trends of critical business parameters that other functional teams may be aware of but are not readily available to related functional groups.

This user need was addressed by creation of a simulation dashboard – the assumptions in the scenario are displayed side-by-side with the baseline parameters. Comment boxes are provided on the dashboard for users to share why they selected particular parameters to guide reviewers through their scenario development process (see Section 6.1.5.3). The concept of a parameter trend
dashboard was developed to highlight annual and/or seasonal trends for a particular parameter as well as basic statistics over the last 12 months (minimum, maximum, average). The goal of the parameter trend dashboard is to provide relevant operational background information for users during scenario assumption development (see Section 6.1.7).

5.1.4 Agility

Users expressed the desire for rapid experimentation capabilities to test new ideas in response to the corresponding increase in the complexity of supply chain and organizational strategy. Users were interested in opportunities to expand current modeling practices that focus on the details of present-state business operations. In order to iterate strategically throughout and across fiscal years, models with repeatable, adjustable functionality to simulate hypothetical strategic shifts can be of significant value. Beyond the structure and function of the models, there was also an interest in overall faster model development — increasing the speed of simulation development could assist in strategic pivots by providing the right analytical tools at the right times.

To provide agility, the proof-of-concept model includes a simulation case for rapid scenario development that is displayed alongside the baseline results in the dashboard. Furthermore, the raw data gathered as inputs for the proof-of-concept liquidation model was processed in Alteryx, a data cleansing and integration tool, to enable future repeatability. Additionally, the need for agility through efficient simulation development procedures and team structure is explored in Stakeholder Feedback (Section 7.1.4) and Organizational Process recommendations (Section 8).

5.2 Simulation Content

During the user interviews, the stakeholders were asked not only about the process characteristics they sought during strategy development, but also about their current work processes to pinpoint areas that would benefit the most from simulation. They were asked about key strategy levers (parameters that they can control to change outcomes) and business drivers (exogenous parameters that influence decisions) that are critical to their operations, as well as the corresponding metrics, to home in on the content for the proof-of-concept simulations. This information was used to identify key business questions to drive simulation design, focusing on concepts that included metrics and parameters managed by disparate functional teams to highlight collaboration value.
Thus, the two concepts selected were drawn from the collaboration examples described in Section 5.1.1: Business channel liquidation and value channel capacity, and on-shore/near-shore advanced manufacturing and supply chain impact.

5.2.1 Business Channel Liquidation and Value Channel Capacity

A particular use case for strategic simulation would be to support cross-functional collaboration surrounding liquidation strategy development. For a fashion company with revenue historically driven by wholesale accounts, there would not be a strong use case for a model that encompasses the liquidation supply and demand dynamics from all channels collectively. The accelerated growth of digital sales, however, creates difficulties in forecasting the liquidation unit supply/demand match dynamic on both sides of the equation. First, the sheer growth rate of the channel will impact the volume of CO unit supply and demand in the liquidation system. Second, as the digital channel evolves its supply chain and marketing policies, they may change the rates of liquidation supply and demand. For example, increasing customer returns and more lenient return policies for the digital channel may increase returns to the parent enterprise. Alternatively, the digital channel may adjust the mix of close out and premium product sold as macroeconomic or customer preference factors change, potentially increasing CO unit demand. Thus, the business would benefit from a platform that provides improved visibility to the net impact of digital's rapid growth on CO unit supply and demand in context of the other channels' operations, and therefore its overall retail liquidation capacity requirements.

The fact that the liquidation supply and demand parameters and metrics are often managed by a disparate set of teams compounds the ambiguity of the net impact. Liquidation supply parameters and metrics are managed by demand planning teams, while retail liquidation account managers are accountable for liquidation demand parameters and performance metrics. Accordingly, the business drivers and metrics that determine the success of the overarching liquidation strategy are not comprehensively managed despite their interdependent nature. This disparity provides additional support for selecting this area of supply chain strategic development as the focus for the proof-of-concept simulation, to test the success of a collaborative platform and integration of cross-functional datasets and metrics.

5.2.2 On-Shore/Near-Shore Advanced Manufacturing and Supply Chain Impact

Another use case for strategic simulation is within the realm of advanced manufacturing strategy development. Technology, geographic location, and product selection decisions can be further refined by assessing success through a supply chain lens. This could include quantifying the
benefits of reduced inventory, stock-outs and markdowns as well as reduced product cancellations/returns through shorter lead times and enhanced forecast accuracy. Simultaneously, of equal importance is the opportunity to shape advanced manufacturing strategy through consideration of the supply chain constraints and marketplace behavior.

A specific area of advanced manufacturing strategy was selected to investigate the benefits of cross-functional insight and data integration: product selection. Considering seasonal and non-seasonal products offered by a generic fashion company, a repeatable simulation that can take inputs regarding consumer demand, supply chain costs, manufacturing costs, and procurement costs would be extremely valuable in selecting product types best suited for a particular localized advanced manufacturing capability. Given seasonal products with a short active season, relatively low volume, high demand variability, and high margin and non-seasonal products with a long active season, high volume, lower demand variability, and relatively lower margin this type of simulation can be leveraged to define which products will benefit the most from the new manufacturing processes and supply chain configuration by their intrinsic product characteristics.

While critical manufacturing factors such as volume, product costs and technical capabilities are considered in traditional manufacturing strategy, this type of simulation provides an opportunity to better integrate supply chain and marketplace performance factors such as gross margin, inventory holding costs, obsolescence risk and forecast accuracy. Beyond integration at a data level, this simulation can also be used as a communication platform for supply chain, manufacturing and procurement teams to explore what global optimums truly mean for the company, rather than focusing on local optimums within their functional silos. Ultimately, this type of simulation could be used to select products that will deliver the most value as well as identify which advanced manufacturing strategic decisions (such as geographic placement, variable cost drivers) should be, in turn, informed by product selection decisions.
6 Supply Chain Simulation Analytical Construction

This section describes the analytical frameworks and supporting components of the two proof-of-concept rapid supply chain simulators developed in response to the user needs expressed during Conceptual Development – Simulation Content (Section 5.2). The simulations are presented in generalized form, representing a generic fashion company (Fashion X) that has both wholesale and retail operations located in a generic geography.

6.1 Liquidation Simulation

The Liquidation Simulation is based on liquidation unit supply and liquidation unit demand dynamics for Fashion X. Using a five year revenue forecast, the simulation provides the company’s supply chain leaders from liquidation demand and supply planning teams a collaborative baseline platform to identify how current sales and liquidation parameters will influence future liquidation dynamics given different growth rates of each business channel. The simulation also provides a scenario planning platform, where users can adjust any of the parameters along business channel and product type dimensions to assess how strategic changes can influence future outcomes compared to the baseline output. A concise dashboard and visualization of sales and liquidation parameter trends are also presented in Sections 6.1.5.3 and 6.1.7, respectively. These auxiliary components of the simulation are examples of supporting tools that Fashion X may need for effective simulation integration into the strategy development process, aligning with expressed user needs regarding simulation characteristics as described in Section 5.1.

6.1.1 Revenue and Inventory Ecosystem Background

Fashion X has a single warehouse location serving both retail and wholesale accounts. There are three primary revenue channels: Brick and Mortar Retail, Digital Retail and Wholesale Accounts. Fashion X offers product via four business models to all three primary channels:

1. Make-To-Order (MTO) – channels may order seasonal product in advance of the season through MTO contracts.
2. Seasonal Make-To-Stock (MTS) – channels may order short life cycle, seasonal trend product during the season from a seasonal MTS inventory pool.
3. Non-Seasonal Make-To-Stock (MTS) – channels may order long life cycle, staple products during the season from a non-seasonal MTS inventory pool.
4. Close Out (CO) – channels also derive a portion of their annual revenue from CO sales by ordering CO items held at the fashion entity warehouse. Additional details on CO product are provided in Section 6.1.2 below.

The simulation features pooling of MTO products awaiting in-season sales – each primary revenue channel may also sell product in-season that was originally planned as part of a MTO contract for a different primary channel. For example, a percentage of the Digital Retail channel's sales in a given year may be from product that was originally ordered by the Wholesale Account.

To provide flexibility to each primary channel in exchange for the inventory risk of the MTO model, the simulated contracts include provisions for MTO product cancellation awaiting delivery at the fashion company's warehouse. These products are then made available as seasonal MTS items for a different channel to order. Return of MTO product is also an option for each primary channel. Similar to canceled products, returned products are also made available as seasonal MTS items for potential sale through other primary channels.

Fashion X owns and controls a Retail Liquidation channel. This channel serves to clear the market of as much liquidation product as possible, including remaining CO items not sold by the primary channels. The simulation also includes a New Product Sales Minimum to represent assortment requirements that exist to maintain merchandizing attractiveness within the Retail Liquidation stores. Any remaining liquidation product is sold through various external liquidation options that are bundled into a Value Chain channel for the purposes of this model. Value Chain channel revenue is, in turn, bundled into the Wholesale Account revenue stream.

6.1.2 Liquidation Supply Background

In this simulation, total annual liquidation supply for Fashion X is determined by the volume of two types of liquidation product units: Close Out (CO) and In-Season Reduction (ISR) units.

The volume of each business channel’s MTO contracts that are either cancelled or returned by the account correlates with the volume of CO units supplied. Cancellation and return rates vary by both business channel and by product type. The volume of cancellation and returns do not directly equal CO unit supply because cancelled and returned units become available to other accounts for in-season MTS order. Because of this dynamic, there is a conversion rate that measures the percentage of cancelled and returned units that eventually transition to CO status. This conversion rate may be a function of various factors, including cancellation/return timing, product type, original business
channel and general market conditions. For the purposes of this simulation, it is a factor of product type only.

Cancellations by Fashion X rather than the account are another factor that influence the volume of CO supply. These cancellations occur after MTO orders by specific accounts are placed and accepted by the company, but before production is initiated to fill the orders. MTO purchase orders may be preemptively canceled based on the account's previous season performance or if internal demand forecasts are below order volumes. Preemptive company-initiated cancellations therefore do not directly contribute to CO unit supply but are included in the simulation as they can be used as strategic levers to control total marketplace supply. Moreover, all other factors being equal, an increase in company-initiated cancellations will decrease CO unit supply due to overall MTO contract reductions.

In this simulation, ISR units arise from slow-moving seasonal MTS inventory. These units are removed from the MTS inventory pool through ISR designation at a constant rate that correlates with total orders from the seasonal MTS inventory pool.

6.1.3 Liquidation Demand Background

Fashion companies generally prefer to liquidate products through premium outlets to value chains to protect brand value, preferring their own liquidation retail stores to any other channel. This simulation represents this preference by requiring all ISR units to be sold through the Retail Liquidation channel, and maximizing remaining CO item sales through the Retail Liquidation channel rather than sending them to Value Chain.

Fashion X measures the success of CO unit distribution through a metric that represents the volume of CO inventory remaining in their ownership over time. A CO Inventory Mix % metric is used to measure the balance of CO units remaining in inventory compared to total inventory (Equation 1). A target CO Inventory Mix % therefore drives liquidation to Value Chains if preferred channels cannot absorb sufficient CO units to meet the target percentage.

Equation 1: CO Inventory Mix % (Units)

\[
CO \text{ Inventory Mix } \% = \frac{Ending \ CO \ Inventory}{Ending \ Total \ Inventory} \times 100\%
\]
Equation 2: Retail Liquidation Take-Rate % (Units)

\[
\text{Retail Liquidation Take Rate} \% = \frac{\text{Retail Liquidation CO Sales}}{\text{Sum of CO Sales (B&M Retail, Digital Retail, 3rd Party, Retail Liquidation, Value Chain)}}
\]

Fashion X is simultaneously interested in assessing the success of their CO liquidation strategy through a metric that measures sales through the preferred Retail Liquidation channel. The metric used in this simulation, Retail Liquidation Take Rate, represents CO sales through the preferred Retail Liquidation channel as a percentage of total CO sales through all available channels (Equation 2). A target Retail Liquidation Take Rate is strategically used to encourage CO supply to the Retail Liquidation channel. Attainment of this target may be limited, however, by annual ISR volume or new product ordering requirements to maintain in-store assortment quality. Additionally, the actual Retail Liquidation Take Rate may decrease below the target due to increased CO sales through the other channels. This may signal increases in CO sales in premium channels, which may have negative implications for average selling price and gross margin targets.

6.1.4 Key Business Questions

Fashion X is facing increased e-commerce growth like many fashion companies. The simulation is constructed to address the following types of business questions:

- Will the rapid growth of digital revenue significantly increase liquidation supply volume?
- Will digital demand for liquidation units significantly influence overall liquidation capacity, measured as a percentage of total liquidation demand?
- Will the retailer’s liquidation sales network be able to absorb liquidation supply through the next five fiscal years with projected channel growth rates, or will sale of CO units through external Value Chain outlets be required to maintain acceptable CO inventory levels?

6.1.5 Analytical Formulation

The following sections describe the analytical formulation of the Liquidation Simulation.
6.1.5.1 Input and Output Overview

The model's analytical formulation is built utilizing the following input parameters:

**Table 1: Liquidation Simulation Inputs**

<table>
<thead>
<tr>
<th>Input Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>i</strong></td>
<td>Business Channel, i = 1 (Brick and Mortar Retail), 2 (Digital Retail), 3 (Wholesale Accounts), 4 (Retail Liquidation)</td>
</tr>
<tr>
<td><strong>j</strong></td>
<td>Fiscal Year, j = t+1, t+1, ..., t+5</td>
</tr>
<tr>
<td><strong>k</strong></td>
<td>Product Type, k = 1, 2, 3, ..., n</td>
</tr>
<tr>
<td><strong>l</strong></td>
<td>Inventory Source, l = 1 (Brick and Mortar Retail), 2 (Digital Retail), 3 (Wholesale Accounts)</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Revenue, i = 1, 2, 3, 4</td>
</tr>
<tr>
<td><strong>G</strong></td>
<td>Five Year Compound Average Growth Rate (CAGR)</td>
</tr>
<tr>
<td><strong>r</strong></td>
<td>Price Inflation Rate</td>
</tr>
<tr>
<td><strong>ASP</strong></td>
<td>Average selling price, where ASP = ASP_t*(1+r)</td>
</tr>
<tr>
<td><strong>PTS</strong></td>
<td>Product type sales percentage (units)</td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>Close out sale percentage, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>O</strong></td>
<td>MTO sale percentage, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>SS</strong></td>
<td>Seasonal MTS sale percentage, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>NS</strong></td>
<td>Non-seasonal MTS sale percentage, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>OC</strong></td>
<td>MTO inventory from different channel sale percentage, i = 1, 2, 3 and l = 1, 2, 3, where i ≠ 1</td>
</tr>
<tr>
<td><strong>CC</strong></td>
<td>Company cancellation percentage of MTO contract, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>AC</strong></td>
<td>Account cancellation percentage of MTO contract, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>AR</strong></td>
<td>Account return percentage of MTO contract, i = 1, 2, 3</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>Average ISR percentage of inventory available for seasonal MTS orders</td>
</tr>
<tr>
<td><strong>CCC</strong></td>
<td>Close out conversion rate of canceled units</td>
</tr>
<tr>
<td><strong>CCR</strong></td>
<td>Close out conversion rate of returned units</td>
</tr>
<tr>
<td><strong>NPM</strong></td>
<td>New product minimum percentage of total Retail Liquidation sales</td>
</tr>
<tr>
<td><strong>TCIM</strong></td>
<td>Forecast Target Close Out Inventory Mix % (see definition, Equation 2)</td>
</tr>
<tr>
<td><strong>WDSI</strong></td>
<td>Total Wholesale Days Sale of Inventory (DSI) where DSI = Ending Inventory/Annual Sales * 365</td>
</tr>
</tbody>
</table>

The channel-specific input tables appear like Table 2 below. Note that the configuration of this sample input table displays the baseline condition, where future operations are characterized by current fiscal year parameters, FY = t. Historical values are included as well (t-1, t-2), which could be utilized to calibrate model assumptions.
Table 2: Example channel-specific input parameters for a fashion company with four product types, displaying product type parameters for one product only. Note that not all of the input parameters described in Table 1 are represented.

<table>
<thead>
<tr>
<th>Business Channel, 1</th>
<th>Historical Values</th>
<th>Forecast Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t-2</td>
<td>t-1</td>
</tr>
<tr>
<td>R_1</td>
<td>$10,000</td>
<td>$11,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Type Sales Breakdown</th>
<th>t-2</th>
<th>t-1</th>
<th>t</th>
<th>t+1</th>
<th>t+2</th>
<th>t+3</th>
<th>t+4</th>
<th>t+5</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTS_11</td>
<td>21%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
<td>23%</td>
</tr>
<tr>
<td>PTS_12</td>
<td>15%</td>
<td>27%</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
</tr>
<tr>
<td>PTS_13</td>
<td>50%</td>
<td>40%</td>
<td>46%</td>
<td>46%</td>
<td>46%</td>
<td>46%</td>
<td>46%</td>
<td>46%</td>
</tr>
<tr>
<td>PTS_14</td>
<td>14%</td>
<td>10%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
<td>12%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fiscal Year, k</th>
<th>t-2</th>
<th>t-1</th>
<th>t</th>
<th>t+1</th>
<th>t+2</th>
<th>t+3</th>
<th>t+4</th>
<th>t+5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Type Parameters</td>
<td>PTS_11</td>
<td>PTS_12</td>
<td>PTS_13</td>
<td>PTS_14</td>
<td>PTS_15</td>
<td>PTS_16</td>
<td>PTS_17</td>
<td>PTS_18</td>
</tr>
<tr>
<td>C_11</td>
<td>2.0%</td>
<td>3.0%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>O_11</td>
<td>65.0%</td>
<td>71.0%</td>
<td>68.0%</td>
<td>68.0%</td>
<td>68.0%</td>
<td>68.0%</td>
<td>68.0%</td>
<td>68.0%</td>
</tr>
<tr>
<td>SS_11</td>
<td>11.0%</td>
<td>8.0%</td>
<td>9.5%</td>
<td>9.5%</td>
<td>9.5%</td>
<td>9.5%</td>
<td>9.5%</td>
<td>9.5%</td>
</tr>
<tr>
<td>NS_11</td>
<td>8.0%</td>
<td>7.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>6.0%</td>
</tr>
<tr>
<td>OC_11</td>
<td>7.0%</td>
<td>6.0%</td>
<td>6.0%</td>
<td>6.1%</td>
<td>6.1%</td>
<td>6.1%</td>
<td>6.1%</td>
<td>6.1%</td>
</tr>
<tr>
<td>OC_12</td>
<td>7.0%</td>
<td>5.0%</td>
<td>8.0%</td>
<td>5.5%</td>
<td>5.5%</td>
<td>5.5%</td>
<td>5.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>CC_11</td>
<td>5.0%</td>
<td>4.0%</td>
<td>31.0%</td>
<td>31.0%</td>
<td>31.0%</td>
<td>31.0%</td>
<td>31.0%</td>
<td>31.0%</td>
</tr>
<tr>
<td>AC_11</td>
<td>4.0%</td>
<td>5.0%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>AR_11</td>
<td>3.0%</td>
<td>3.5%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>CCC_11</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
<td>70.0%</td>
</tr>
<tr>
<td>CCR_1</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
<td>65.0%</td>
</tr>
</tbody>
</table>

Table 3: Liquidation Simulation Outputs

<table>
<thead>
<tr>
<th>Output Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>U_{ij}</td>
<td>Total Units Sold, i = 1, 2, 3, 4</td>
</tr>
<tr>
<td>PTU_{ijk}</td>
<td>Product Type Units Sold, i = 1, 2, 3, 4</td>
</tr>
<tr>
<td>CU_{ijk}</td>
<td>Close Out units sold, i = 1, 2, 3, 4</td>
</tr>
<tr>
<td>OCU_{ijk}</td>
<td>MTO inventory from different channel sold, i = 1, 2, 3 and l = 1, 2, 3, where i \neq l</td>
</tr>
<tr>
<td>IU_{ijk}</td>
<td>Inline units sold (total units less Value Chain and CO), i = 1, 2, 3</td>
</tr>
<tr>
<td>MU_{ijk}</td>
<td>MTO units sold, i = 1, 2, 3</td>
</tr>
<tr>
<td>SSU_{ijk}</td>
<td>Seasonal MTS units sold, i = 1, 2, 3</td>
</tr>
<tr>
<td>NSU_{ijk}</td>
<td>Non-Seasonal MTS units sold, i = 1, 2, 3</td>
</tr>
<tr>
<td>MTO_{ijk}</td>
<td>MTO ordered, i = 1, 2, 3</td>
</tr>
<tr>
<td>CCU_{ijk}</td>
<td>Company cancelled units, i = 1, 2, 3</td>
</tr>
<tr>
<td>ACU_{ijk}</td>
<td>Account cancelled units, i = 1, 2, 3</td>
</tr>
<tr>
<td>ARU_{ijk}</td>
<td>Account returned units, i = 1, 2, 3</td>
</tr>
<tr>
<td>CO_{ij}</td>
<td>Close out units generated</td>
</tr>
<tr>
<td>ISR_{ijk}</td>
<td>ISR units generated</td>
</tr>
</tbody>
</table>
### Output Variables

<table>
<thead>
<tr>
<th>Output</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPMU$_{ijk}$</td>
<td>Minimum new product units required, $i = 4$</td>
</tr>
<tr>
<td>NPU$_{ijk}$</td>
<td>New product units, $i = 4$</td>
</tr>
<tr>
<td>COC$_{ijk}$</td>
<td>Close Out liquidation capacity</td>
</tr>
<tr>
<td>VCU$_{ijk}$</td>
<td>Value Chain units sold</td>
</tr>
<tr>
<td>TI$_{ik}$</td>
<td>Total Wholesale Inventory</td>
</tr>
<tr>
<td>COI$_{ik}$</td>
<td>Close Out Inventory</td>
</tr>
</tbody>
</table>

Outputs (Table 3) are generated by applying the inputs to the mathematical formulation, described below in Section 6.1.5.3.

#### 6.1.5.2 Assumptions

The following assumptions are used within the model:

1. Account inventory does not build year over year; i.e. all MTO units that are not canceled or returned are assumed to be sold in the given fiscal year.
2. The only sources of Close Out (CO) are channel customer cancellations and returns.
3. The Retail Liquidation channel must take all ISR generated in a given fiscal year.

#### 6.1.5.3 Equations

The logic for liquidation supply is developed using top-line business channel revenue to derive each business channel's unit sales using average channel unit prices (Equation (3), Equation (4)). Product Type sales are calculated by applying the Product Type sales percentage to total unit sales (Equation(5)):

For all business channels, $i = 1, 2, 3, 4$, for the five forecast years, $j = t+1, t+2, ..., t+5$:

$$ R_{ij} = R_{ij-1} \cdot G_i $$  \hspace{1cm} (3)  

$$ U_{ij} = \frac{R_{ij}}{P_{ij}} $$  \hspace{1cm} (4)

$$ P_T U_{ijk} = U_{ij} \cdot P_T S_{ijk} \text{ such that } U_{ij} = \sum_{k=1}^{n} P_T U_{ijk} $$  \hspace{1cm} (5)

Next, in order to derive the CO supply from MTO contracts and CO demand from the primary business channels ($i = 1, 2, 3$), each segment of Product Type sales for primary business channels are broken down into different order-types depending on the specific characteristics of each business channel (Equations (6) – (11)).
\[ CU_{ijk} = PTU_{ijk} \cdot C_{ijk}, \text{for } i = 1, 2, 3 \]  
(6)

\[ OCU_{ijkl} = PTU_{ijk} \cdot OC_{ijkl}, \text{for } i = 1, 2, 3 \text{ and } l = 1, 2, 3 \]  
(7)

\[ IU_{ijk} = PTU_{ijk} \cdot (CU_{ijk} + OC_{ijkl}), \text{for } i = 1, 2 \text{ and } j = 1, 2, 3 \]  
(8)

\[ IU_{ijk} = PTU_{ijk} \cdot (CU_{ijk} + OC_{ijkl} + VCU_{jk}), \text{for } i = 3 \]  

\[ MU_{ijk} = IU_{ijk} \cdot O_{ijk}, \text{for } i = 1, 2, 3 \]  
(9)

\[ NSU_{ijk} = IU_{ijk} \cdot NS_{ijk}, \text{for } i = 1, 2, 3 \]  
(10)

\[ SSU_{ijk} = IU_{ijk} \cdot SS_{ijk}, \text{for } i = 1, 2, 3 \]  
(11)

Subsequently, applying assumption #1, calculated MTO Unit Sales (Equation (9), Equation (12)) are utilized to back-out Account Cancellation Units and Account Return Units from total MTO ordered through application of cancellation rates and return rates (Equation (13), Equation (15), Equation (16)). Next, CO units generated by cancelled and returned items – the percentage of rejected items that are not sold as full-price seasonal MTS units – are derived by applying business channel and product type-specific conversion rates (Equation (17)). Calculated seasonal MTS unit sales in conjunction with full-price sales of canceled and returned units as well as the ISR rate are utilized to determine ISR units generated (Equation (18)).

For business channels, \( i = 1, 2, 3 \), for the five forecast years, \( j = t+1, t+2, \ldots, t+5 \):

\[ MU_{ijk} = MTO_{ijk} - MTO_{ijk} \cdot CC_{ijk} - MTO_{ijk} \cdot AC_{ijk} - MTO_{ijk} \cdot AR_{ijk} \]  
(12)

\[ MTO_{ijk} = \frac{MU_{ijk}}{1 - CC_{ijk} - AC_{ijk} - AR_{ijk}} \]  
(13)

\[ CCU_{ijk} = MTO_{ijk} \cdot CC_{ijk} \]  
(14)

\[ ACU_{ijk} = MTO_{ijk} \cdot AC_{ijk} \]  
(15)

\[ ARU_{ijk} = MTO_{ijk} \cdot AR_{ijk} \]  
(16)
Finally, the allocation of remaining CO units to the preferred liquidation channel versus Value Chain accounts is calculated based on the Retail Liquidation channel’s remaining capacity for CO unit sales after accounting for New Product Minimum requirements and ISR liquidation requirements (Equation (19), Equation (20)). The Target CO Inventory Mix (TCIM) percentage (Equation 1) is utilized to calculate CO unit allocation, whether or not Value Channel sales are necessary, using calculated Total Wholesale Inventory (TI) in the denominator of the equation (Equation (21)) and CO Inventory (COI) in the numerator (Equation (22)). In the Excel model, Excel Solver Macros are used to calculate CO sales required through the Retail Liquidation and Value Chain channels to maintain TCIM. Aligned with the equations below, the Solver logic assesses if the balance of CO available is greater than Retail Liquidation channel capacity (COC). If the condition is found to be true, Solver allocates the maximum CO possible to the Retail Liquidation Channel given the specified New Product Minimum percentage and annual ISR volume, and the balance of CO units is allocated to the Value Chain to maintain the TCIM (Equation (23)). If the condition proves to be false, then Solver allocates CO units to the Retail Liquidation channel while maintaining TCIM, and the volume of new product units is adjusted above the New Product Minimum requirement to make up additional Retail Liquidation demand, as needed (Equation (24)).

\[ CO_{jk} = CCC_{jk} \sum_{i} ACU_{ijk} + CCR_{jk} \sum_{i} ARU_{ijk} \]  

\[ ISR_{jk} = \frac{\left[ \sum_{i} SSU_{ijk} - \left( (1 - CCC_{jk}) \sum_{i} ACU_{ijk} + (1 - CCR_{jk}) \sum_{i} RTU_{ijk} \right) \right]}{1 - l} \]

\[ NPMU_{ijk} = PEU_{ijk} * NPM_{ijk}, \text{ for } i = 4 \]  

\[ COC_{jk} = PEU_{ijk} - (NPMU_{ijk} + I_{jk}), \text{ for } i = 4 \]  

\[ TL_{jk} = \frac{\sum_{i=1}^{4} PEU_{ijk}}{365} * WDSI_{jk} \]  

\[ COI_{jk} = CO_{jk} - \sum_{i} CU_{ijk} - VCU_{jk} + COI_{(j-1)k}, \text{ for } i = 1, 2, 3, 4 \]
If $CO_{jk} > COC_{jk}$

Then $\text{MIN}[VCU_{jk}]$

Such that $NPU_{ijk} = NPMU_{ijk}$ for $i = 4$, and

$CU_{4jk} = COC_{jk}$ and

$$\frac{COI_{jk}}{TL_{jk}} = TCIM$$

(23)

If $CO_{jk} - \sum_{i=1}^{3} CU_{ijk} \leq COC_{jk}$

Then $\text{MAX}[CU_{4jk}]$

Such that $VCU_{jk} = 0$ and

$NPU_{ijk} = PEU_{ijk} - l_{jk} - CU_{ijk} \geq NPMU_{ijk}$ for $i = 4$ and

$$\frac{COI_{jk}}{TL_{jk}} = TCIM$$

(24)
6.1.6 Simulation Dashboard and Scenario Planning

The Excel workbook for the Liquidation Simulation contains both baseline and scenario planning models. The baseline is static, applying actualized current fiscal year parameters to forecasted business channel revenue for the next five fiscal years, while the scenario planning model can be adjusted along any one of the strategic levers listed in Table 1.

In order to address the user needs for transparency, agility and collaboration, a concise simulation dashboard is used to display both baseline and scenario (current FY default, or user-adjusted) parameters (Figure 17). In order to adjust scenario parameters, users enter the percentage increase or decrease desired into the orange highlighted ‘Delta’ cell. White ‘Delta’ cells are calculated percent differences at aggregate channel levels. Three icons on the dashboard provide easy user control – one to execute the Solver macros for liquidation demand decisions (Simulate), one to reset the dashboard and re-run the Solver macros to the baseline conditions (Reset Dashboard), and one to quickly access any of the individual calculation sheets in the file (Browse Sheets). Comment sections encourage scenario developers to provide qualitative narratives to justify their quantitative parameter adjustments. This dashboard centralizes the model inputs and provides transparency to the underlying model assumptions.

Figure 17: Liquidation Simulation dashboard for Fashion X with three product engines
Below the parameter input area, the dashboard also contains five sections of graphs displaying baseline and scenario output:

1. **Revenue Output** – units and dollars broken down by business channel, product engine
2. **Order Type Breakdown** – MTO sold broken out by business channel, product engine; seasonal MTS and non-seasonal MTS order trends; Retail Liquidation unit trends
3. **Liquidation Supply Results** – CO Supply Source Trends; CO vs. ISR liquidation volume; MTO Gross-to-Net trends; % CO Supply of Total Marketplace Sales
4. **Liquidation Demand Results** – CO Demand Source Trends; % CO Inventory Mix without Value Chain Sales; Take Rate Trends and Averages broken out by Product Engine
5. **Digital Impact Results** – Sales Impact on Other Inventory Sources; Digital CO Demand % of Total CO Demand

Snapshots of these five output sections can be found in the Appendix. Displayed data reflects randomized inputs.

### 6.1.7 Input Parameter Trend Analysis

![Strategy Lever Trends](image)

**Figure 18: Business parameter trend dashboard user interface design**

To further address user needs of transparency and collaboration, regressions are run against critical strategic levers to provide information about both annual and seasonal trends. The intent of
This additional information is to provide historical context for users when making parameter adjustments, and to provide quantitative support for assumptions used in scenario development. This research performed similar analysis for NIKE, where regression analysis was conducted along the business channel and product engine dimensions using custom R code in Alteryx. Trends were detected at significance level $\alpha = .1$ for both the linear time-series and seasonal regressions. High and low deviations were detected and reported for the seasonal regressions as well to provide additional insight. For illustrative purposes, visualization of this analysis is integrated into the UXPin wireframe for the Liquidation Simulation. In the generic example depicted in Figure 18, the analysis was executed along different timespans – fiscal years 2013 – 2015, 2014 – 2015 and 2015 – to further demonstrate how these trends behave over time.

6.2 Advanced Manufacturing Product Selection Simulation

The Advanced Manufacturing Product Selection simulation concept is based on hypothetical development of onshore/near-shore advanced manufacturing for a generic fashion company. This simulation concept is speculative in nature; it is developed based on existing literature and does not reflect NIKE operations. Its purpose is to demonstrate the value of comprehensive simulations when designing manufacturing strategies.

6.2.1 Advanced Manufacturing Product Selection Simulation Background

Given the development of localized manufacturing capabilities, a simulation that aligns products with different supply chain configurations based on their specific product characteristics can minimize global supply chain costs and maximize global supply chain benefits. This model considers which broad category of products is best suited for a new onshore/near-shore advanced manufacturing supply chain: non-seasonal core products, or seasonal trend products. The simulation concept provides a framework to assess the benefits of the entire onshore advanced manufacturing supply chain compared to the current offshore manufacturing strategy, and aligns those benefits with seasonal or non-seasonal product characteristics. Finally, this framework is extended beyond product selection to support the idea that selected product characteristics can, in turn, be used to further refine manufacturing technology and strategy. Section 7.2 explores the latter point, identifying research opportunities to hone advanced manufacturing technology specifications to maximize responsive supply chain performance.
6.2.2 Assumptions

Advanced manufacturing is defined as a single disruptive technology or collection of disruptive technologies that exhibit responsive characteristics and integrate a high level of automation, akin to additive manufacturing.

6.2.3 Concept Background: Innovative vs. Functional Product Supply Chains

The concept of supply chain strategy optimization based on product characteristics segmentation was initially introduced in the early 1990s by Marshall Fisher's analysis of Sport Obermeyer's seasonal skiwear business. Like many fashion companies, Sport Obermeyer contended with short selling seasons and long lead times for overseas production in Asia; forecast accuracy and inventory risk were exacerbated as Sport Obermeyer had to place the majority of orders five months before its first product samples were shown to accounts due to manufacturing capacity constraints. Fisher developed 'risk-based production sequencing' to address this issue: produce the SKUs with the highest forecast accuracy early without demand signals, and postpone production of the most unpredictable SKUs until some demand signals were received from early account orders. This strategy allowed Sport Obermeyer to reduce stockouts and markdown costs significantly.

Fisher expanded and generalized this framework of supply chain and product matching in his pivotal article, “What is the Right Supply Chain for Your Product?” Fisher defined products as innovative or functional, distinguished by demand profile. Products with unpredictable demand are innovative, characterized by high gross margins. Products with predictable demand are functional,
characterized by lower product margins. Furthermore, Fisher’s model defines two different types of supply chain costs: physical costs such as production, transportation and inventory storage, and market mediation costs such as product markdowns, lost sales opportunities through stockouts and customer dissatisfaction. Since functional product demand is relatively easy to predict, physical costs dominate their supply chain operations and physically efficient supply chains are required to minimize those costs. Conversely, innovative product supply chain operations are dominated by market mediation costs due to their highly unpredictable demand. Responsive supply chains that aggressively minimize lead time and deliver with speed, flexibility and quality are required to minimize market mediation costs (Figure 19). This methodology continues to be supported by supply chain leaders such as David Simchi-Levi.

Fisher’s definitions of innovative and functional products align with a fashion company’s seasonal and non-seasonal product definitions. Thus, the model begins by reviewing each major stage of the theoretical onshore advanced manufacturing supply chain – Product Development, Manufacturing, Distribution, and Sales – and identifying cost component impacts, breaking them down into physical and market mediation costs. Dominance in physical cost reductions would support production of functional items like the core portfolio, while dominance in market mediation cost reductions would support production of innovative, seasonal items.

Next, a system dynamics (SD) model representing the company’s supply chain from manufacturing through sales needs to be developed to calculate the various costs. While development of the actual model is out of scope for this thesis, an instructive SD example is presented to highlight the methodology’s value.
6.2.4 Analytical Framework

Reviewing the first-order impacts identified in the literature (Sections 3.3 and 3.4) there are numerous physical cost reductions possible through onshore advanced manufacturing, but there are also significant market mediation cost reduction opportunities. Thus, it is critical to evaluate the actual order of magnitude of these cost reductions, inclusive of feedback loops and time delays, to support strategic product selection decisions. Like the GM case with OnStar, many of these effects are unknown since the technology or supply chain configuration does not yet exist. As discussed in Section 3.2, system dynamics simulations are well suited for estimation and sensitivity testing across a range of values.

Table 4: Market mediation and physical cost implications of localized advanced manufacturing supply chain integration

<table>
<thead>
<tr>
<th>Localized Advanced Manufacturing</th>
<th>Product Development</th>
<th>Manufacturing</th>
<th>Distribution</th>
<th>Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockout Opportunity Cost</td>
<td></td>
<td></td>
<td></td>
<td>Proximity to primary market and agile manufacturing system increases forecast accuracy, decreasing stockout opportunity costs</td>
</tr>
<tr>
<td>Markdown Costs</td>
<td></td>
<td></td>
<td></td>
<td>Proximity to primary market and agile manufacturing system increases forecast accuracy, decreasing markdown costs</td>
</tr>
<tr>
<td>Geographic proximity of manufacturing and product design teams decreases product development cycle time, increasing product attractiveness and market share</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Share Loss</td>
<td></td>
<td></td>
<td></td>
<td>Opportunity for mass and individual customization addresses growing consumer demand for individually tailored products, thus increasing market share</td>
</tr>
<tr>
<td>Stockout Opportunity Cost</td>
<td></td>
<td></td>
<td></td>
<td>Proximity of manufacturing site to primary market decreases lead time, reducing inventory requirements and thus obsolescence risk</td>
</tr>
<tr>
<td>Markdown Costs</td>
<td></td>
<td></td>
<td></td>
<td>Proximity to primary market and agile manufacturing system increases forecast accuracy, decreasing markdown costs</td>
</tr>
<tr>
<td>Inventory Holding Costs</td>
<td>申诉性制造技术的响应性</td>
<td></td>
<td></td>
<td>申诉性制造技术的响应性</td>
</tr>
<tr>
<td>Labor Costs</td>
<td>Increased automation inherent in advanced manufacturing decreases labor costs, but increases skilled labor requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material Costs</td>
<td>Increased automation and additive manufacturing technology decreases material waste compared to traditional reductive manufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production Costs</td>
<td>Closer coordination between manufacturing and product design team enables design for manufacturing, decreasing production costs</td>
<td>Variable production costs compared to traditional variable production costs may be higher or lower, depending on batch sizes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation Costs</td>
<td>Reduced physical distance decreases transportation requirements and costs, but responsive nature of advanced manufacturing may lead to smaller batch sizes, dampening transportation cost benefits</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 20 provides an example of a system dynamics simulation that could be used to evaluate the cost outcomes quantitatively. To demonstrate the sensitivity to inputs, two different scenarios are
described with the same SD model structure: one supporting core product manufacturing, and one supporting seasonal product manufacturing.

Figure 20 focuses on the reduction in physical distance between the primary market and manufacturing base, which affects the supply chain in a variety of ways. Lead time reduction, increased manufacturing and product design team coordination and decreased transportation costs are presented for illustrative purposes. The model features a balancing product attractiveness loop that arises from enhanced product development coordination and thus decreased time to market: products that better match current consumer preferences will increase demand and sales, allowing a fashion company to increase product prices to a point before product attractiveness declines due to price sensitivity and dampens demand. A delay is featured in this loop, reflecting consumers’ gradual reactions to price adjustments. Simultaneously, lead time reduction as a result of decreased distance between the manufacturing base and primary market results in increased forecast accuracy, thereby reducing stockouts and corresponding opportunity costs of stockouts. This pathway increases revenue growth, along with increased product attractiveness that results in decreased market share loss to competitors. Finally, a decrease in distance between the manufacturing base and primary market results in decreased transportation costs; this has a secondary impact of also decreasing price while maintain gross margin.

The magnitude and timing of these effects and responses are crucial to determine which costs – physical or market mediation – exhibit the greatest reductions. For example, consider a particular set of input values with a short delay between price/product attractiveness response and modest gains in forecast accuracy. Although the supply chain configuration produces more attractive products, the prices are too high to increase market share due to the high price sensitivity of
consumers, resulting in a net market share effect of zero. In parallel, the transportation efficiencies are more significant than forecasting gains, causing transportation cost reductions to outweigh the decreased opportunity cost of stock outs. This result would support production of functional, core products as the supply chain conditions minimize physical costs.

Conversely, suppose an alternative set of inputs is utilized with a long delay between price/product attractiveness response and significant gains in forecast accuracy. Here, the ability to produce the ‘right’ product may have an overwhelmingly positive effect on market share as the negative price impact on product attractiveness may be delayed until later in the season, or even after a season is over. Simultaneously, the significant gains in forecast accuracy result in far fewer stockouts, and the benefits of lower stockout opportunity costs surpass transportation cost reductions. In this case, the simulation outcomes support manufacturing innovative, seasonal products as the supply chain conditions minimize market mediation costs.
7 Simulation Results, Scenario Testing & Stakeholder Feedback

This section contains results for both proof-of-concept simulations. First, as data from one of NIKE's geographic regions was applied to the generic Liquidation Simulation presented in Section 6, calibration results are presented. Next, results derived from data representing the generic fashion company (Fashion X) described in Section 6 are discussed, both baseline output and scenario testing. The quantitative output is followed by stakeholder feedback on the model results. This section concludes with generalized results and recommendations for future work for the theoretical Advanced Manufacturing Product Selection simulation concept.

7.1 Liquidation Simulation Results

7.1.1 Baseline Calibration

Historical parameters and revenue from fiscal years 2013 - 2014 were used to test model calibration and validate the model's analytical formulation. While the research effort endeavored to develop model logic and assumptions to align with business operations through engagement of key stakeholders, +/- 10% calibration could not be achieved. Calibration issues likely arose from the fact that certain key parameters had to be estimated and some CO dynamics approximated due to data issues, resulting in an inability to validate these concepts beyond qualitative stakeholder input.
7.1.2 Select Baseline Results

Hypothetical parameters from fiscal year 2015 are used for fiscal year 2016 - 2020 revenue forecasts to assess the impact of Digital channel’s rapid growth on liquidation supply and demand. Channel-specific liquidation parameters for Fashion X are selected to model a Digital channel with double-digit cancellation and return rates, and a Wholesale channel with single-digit cancellation and return rates to see how this disparity would influence baseline outcomes.

Baseline Liquidation Supply Breakdown

<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wholesale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Returns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Returns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 21: Baseline liquidation supply profile. Liquidation Supply shows relative volume of CO generated by retail accounts (B&M and Digital) versus Wholesale accounts, as well as ISR product.

Review of the overall liquidation results demonstrate that through 2020, the Digital channel will not have a significant impact on CO supply despite the forecasted rapid growth compounded by higher liquidation operational parameters. Although Digital contribution to annual Liquidation Supply volume does increase as a percentage of the total through FY20, the volume of CO units is still dominated by Wholesale accounts (Figure 21).

This unintuitive result - why Digital’s extreme revenue growth rate above Wholesale’s stable growth rate would still result in an overwhelming proportion of CO supply from the latter – arises from the relationship between business channel revenue forecasts and corresponding unit sales forecasts. While Digital does become a more significant percentage of the geography’s revenue, its unit contribution is small because of its much higher retail average selling price (ASP) in the direct-to-consumer space compared to Wholesale, where ASP represents wholesale rates (Figure 22). For the parameters selected for this example, this translates to a Digital ASP that is 3.5 higher than the Wholesale ASP. Thus, the cancellation and return characteristics of the digital business channel are important, but do not significantly influence Retail Liquidation capacity or Value Chain volume over the next five years.
The simulation's ability to combine the financial effects of business channel ASP and revenue growth rates with operational parameters such as cancellations and return rates through cross-functional data integration provided this perspective that isolated analyses could not.

![Baseline Revenue - 2015 vs Baseline Revenue - 2020](image)

![Baseline Units - 2015 vs Baseline Units - 2020](image)

*Figure 22: 2015 and 2020 revenue and units comparison. Note higher growth of Digital as a percentage of annual revenue by 2020, but lower influence on overall units sold in 2020.*

The model’s formulation for ISR supply proves to be the more influential liquidation supply source. The Retail Liquidation channel's capacity to absorb CO units is decreased due to the growth of ISR units through FY20. This is reflected in the reduction in CO Take Rate (Figure 23) for the Retail Liquidation channel over the five-year forecast. The Value Take Rate undergoes a corresponding increase, reflecting the increase of CO units sold through the channel to liquidate CO inventory in excess of the CO Inventory Mix % target.
Beyond implications for Retail Liquidation capacity, the baseline model demonstrates that Digital's growth has a sizable impact on CO Demand and other inventory sources. Baseline results indicate that the Digital channel will become a more significant source of CO Demand through FY20 for Fashion X (Figure 24). Accordingly, in addition to forecasted Retail Liquidation capacity to absorb CO units as a function of revenue and New Product Minimum, this simulation demonstrates that supply chain strategy may consider incorporating Digital's capacity to sell CO units into overall liquidation capacity planning. This inclusion can support avoidable expansion of the Retail Liquidation network and provide a more accurate forecast of Fashion X's overall ability to maintain brand image while liquidating product. Additionally, the baseline results highlight Digital's influence on B&M Retail Store MTO contracts (Figure 25). Baseline results suggest that B&M Retail Store MTO contracts will need to increase to accommodate both B&M Retail Store channel demand as well as Digital demand through FY20. If inventory pooling continues to operate in this manner, B&M Retail Store buy-strategy should encompass Digital growth forecasts and order trends to ensure sufficient service levels through both direct-to-consumer channels. Implementation of either one of these strategic changes would require enhanced organizational linkages between functional teams, and the simulation itself can be used as an initial platform for execution planning.
Figure 24: Baseline Digital CO unit demand and percentage of total Fashion X CO demand

Figure 25: Baseline incremental B&M Retail MTO contract increase required due to Digital growth
7.1.3 Scenario Testing Results

Two scenarios are presented to demonstrate how quantitative simulation output can be utilized to support qualitative supply chain strategy at Fashion X: 1) Increase Digital revenue CAGR 15% while keeping total geography revenue constant, and 2) Increase seasonal MTS orders 10% across all business channels and all product engines and simultaneously decrease MTO orders 10%. Selected scenario results are presented in Figure 26 and Figure 27 below.

![Figure 26: Scenario 1 - select results](image)

An increase in Digital revenue CAGR decreases total marketplace units as well as liquidation units due to the much higher ASP of the Digital retail channel versus the Wholesale outlet, despite Digital’s high cancellation and return rates. The Digital channel becomes an even greater source of CO demand, and the CO Take Rate increases year over year compared to the baseline. This outcome supports supply chain investments in premium customer service rather than capacity enhancements in either the full-price or discount channels in a retail-driven marketplace. While fashion companies recognize that investments in customer service are key given rising consumer expectations in the digital space, strategic simulations such as this one can provide quantitative analysis to those support strategic investments.
Shifting Fashion X's business toward seasonal MTS in Scenario 2 increases liquidation units significantly due to the increased inventory risk compared to the MTO model. The scenario's increased ISR volume decreases the retail liquidation channel's ability to absorb CO units, thus decreasing the scenario's CO Take Rate below baseline forecast. This result suggests that if Fashion X aspires to provide rapid response shipments to accounts, the capability should be supported by supply chain investments that effectively mitigate liquidation risk. Supply chain lead time reduction and product development time-to-market reduction through onshore/near-shore manufacturing are examples of investments that would enable a true pull market supply chain configuration. Additionally, investments in human resources and technology that can realize the enhanced forecast accuracy potential of shortened lead time will further reduce inventory obsolescence risks.
7.1.4 Stakeholder Socialization Feedback

The analytical framework and baseline and scenario results were shared with a cross-functional set of key stakeholder groups. Stakeholders were generally pleased with the concept and general construction of the simulation, but lingering uncertainty regarding specific simulation aspects highlight overarching management challenges related to simulation development practices and their integration into strategic planning processes.

First, stakeholders were unfamiliar with the concept of a simulation baseline. While the baseline represented 'business-as-usual' by applying FY15 parameters to FY16-FY20 revenue forecasts to simulate operations over the next five years, in employees' minds baseline results should be equivalent to corporate strategy. The baseline demonstrates whether or not operational targets can be achieved with business-as-usual operations; a 'bad' baseline does not necessarily signify bad outcomes, merely the fact that business-as-usual will not suffice to meet target metrics. The purpose of the scenario-planning platform is to allow users to adjust the parameters to achieve the operations targets set in corporate strategy, and then adjust operations to achieve the new parameters. This exposes an opportunity for training on how to understand and utilize simulations in strategy development and execution.

Another area of uncertainty resided within the simulation’s inability to make managerial decisions. For example, the simulation allows ISR units to increase without maximum bounds even if high volume of ISR units is counter to typical operational level strategy. This points to an opportunity to
utilize more sophisticated simulation techniques in future iterations that incorporate managerial decision points, such as Agent-Based Modeling (ABM). ABM models systems are composed of interacting, autonomous agents. Agents can be people or objects, and their behavior is defined by simple rules that determine their interactions with other agents and the environment. Thus, actual supply chain ‘rules’ can be applied to these agents as the simulation evolves over time to obtain results that reflect internal policy.

Finally, stakeholder feedback was at times conflicting during the analytical construction phase, with some functions satisfied with the simulation formulations and other functions in disagreement about their validity. The dissonance between the model’s structure and the opposing stakeholders’ mental model of the business was challenging to counter despite support elsewhere in the organization. This experience illustrates the difficulties that can arise when the simulation team resides externally to the business units, particularly for cross-functional simulations where input from a large number of disparate teams is required. This disconnect can only be rectified through formalized relationships between the simulation development team and the critical business units to ensure there is robust requirement planning processes to support simulation development; this explored further in Section 8, Recommendations.

### 7.2 Advanced Manufacturing Product Selection General Results

While full system dynamics modeling is required for real-world strategic decisions, broad hypotheses regarding product type selection can be made from the theoretical framework developed in Section 6.2. It is possible that seasonal product manufacturing will realize the greatest potential of onshore advanced manufacturing. The forecast accuracy and product development improvements achieved by this new supply chain are largely irrelevant for long life cycle, low volatility core products. While physical cost reductions can be attained through incremental efficiencies in overseas conventional manufacturing, market mediation cost reductions can only be achieved through major investments such as onshore advanced manufacturing. Other authors have noted the alignment between onshore advanced manufacturing and Fisher’s market-responsive supply chain for innovative products as well.48

As discussed elsewhere in this thesis, the value proposition of a responsive and agile supply chain for seasonal products is growing as fashion companies expand revenue through digital retail. 3rd-Party Wholesale partners can no longer be relied upon to absorb the risk of long lead time, high-risk seasonal products. Furthermore, the higher inherent obsolescence risk of short life-cycle
seasonal products creates an even more compelling case for deploying seasonal products within the onshore advanced manufacturing supply chain to address inventory management issues.

Combining the theoretical analysis of end-to-end supply chain cost reductions in Section 6.2 and existing literature on advanced manufacturing technologies' impact on supply chains explored in Section 3.4, many areas for further research and development exist for mechanical and industrial engineers to truly enable responsive supply chains for innovative products in the realm of advanced manufacturing. Four examples are provided in Table 5 below:

Table 5: Responsive supply chain technology and process development areas

<table>
<thead>
<tr>
<th>Supply Chain Stage</th>
<th>Development Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Development</td>
<td>Develop systems to convey manufacturing process capabilities and constraints to non-technical users to realize product development cycle time improvement potential through manufacturing/design coordination</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Develop manufacturing technologies with modular capabilities for delayed differentiation as well as customization to increase responsiveness to market demands</td>
</tr>
<tr>
<td>Manufacturing/Distribution</td>
<td>Develop manufacturing technologies than can easily adapt to a decentralized manufacturing strategy to be closer to local markets for enhanced responsiveness and agility (i.e. low/no tooling requirements, and/or auxiliary systems, low labor requirements)</td>
</tr>
<tr>
<td>Distribution</td>
<td>Design responsive transportation lanes for small batch shipments for just-in-time supply of customized products</td>
</tr>
</tbody>
</table>

Additional details on two of the four examples above are presented for consideration.

- To enable faster product development cycles through tighter R&D coordination, product designers must understand the capabilities and constraints of the advanced manufacturing technology. These data must be available in a format and language that is accessible and comprehensible. Using footwear as an example, being able to convey information such as dimensional limits or material property requirements to a designer could reduce iterations required between the design and manufacturing teams.
• Responsiveness and customization can be further enhanced if advanced manufacturing
technologies have the ability to exist in a decentralized configuration to be as close to the
consumer as possible. This may translate to low/no tooling requirements and/or auxiliary
systems such as no molds, cooling systems, or complex pre- or post-processing systems,
allowing the system to be installed with a small footprint in a facility without industrial
features. To address cost competitiveness concerns, the technology system’s labor
requirements must also be controlled so the decentralized configuration does not increase
labor costs excessively. Technology that can be operated with low head-count, and/or low
skill requirements, could accomplish this objective.
8 Organizational Process Recommendations

This thesis research demonstrates that successful cross-functional supply chain strategy development requires more than in-house analytics expertise and robust simulation tools; it also requires carefully crafted organizational process and cultural initiatives. Thus, three organizational process recommendations arise from the completed research:

- Enhance cross-functional collaboration and communication processes,
- Formalize team structure and processes for future simulation development, and
- Create simulation adoption metrics.

While these apply to NIKE specifically, the recommendations apply to any company seeking to expand or enhance its business intelligence toolset.

The first recommendation responds to a single commonality across all stakeholder interviews during the Conceptual Development phase: individuals and teams are hungry for cross-functional input as soon as possible. The digital channel’s growth has already introduced more complexity into the daily operations of many functional teams, and there is widespread recognition that the complexity needs to be addressed, in part, by enhanced cross-functional collaboration. The development of production-quality cross-functional simulations like the proof-of-concept simulation presented in this research will take significant time and resources. Cross-functional collaboration via structured communication can be implemented sooner, before analytics are complete, and still add a tremendous amount of value. The first step of this recommendation could be a reassessment of organizational structure to identify areas that lack sufficient connections given evolving business strategies. Next, flexible working groups could be created in lieu of organizational structure adjustments to test out the best organizational linkages before formal organizational changes are enacted.

The second recommendation arises from both the successes and challenges of this research effort with respect to stakeholder engagement. Early success achieving buy-in from a large volume of cross-functional stakeholders can be attributed to the substantial amount of time spent on identifying user needs and generating concepts for product development; truly understanding the simulation capabilities and content requirements from the stakeholders’ perspective was essential. Aside from delivering a tool that answered pertinent business questions, it was absolutely critical to clearly address their needs in order to maintain their interest and willingness to participate. Without a formal process or defined team, however, stakeholder communication failures occurred
as the project progressed through the analytical development stage due to time constraints, resulting in dissatisfaction with certain elements of the Liquidation Planning simulation formulation as discussed in Section 6.1.5. It is possible that some of these issues could have been addressed through clearer team definition and stakeholder ownership that would have allowed for faster review and iterative development. The internal supply chain modeling teams responsible for delivering effective ‘on-demand’ strategic simulations must expend significant resources on identifying user needs for success, and this can only be achieved via sustained and well-defined collaboration with involved business units. This recommendation could be implemented through appointment of business unit champions who are also accountable for simulation development success, and defined development gates for both conceptual and analytical phases.

The final recommendation addresses the fact that as access to data increases at all enterprises in every industry, there is a tendency for models and dashboards to proliferate. More business intelligence does not equate to better business intelligence, especially if the intended users do not adopt the toolkit. Additionally, if internal supply chain modeling teams are accountable for owning and maintaining these types of strategic simulations, the volume of requests will need to be managed to sustain quality and speed. While the formal integration of team processes and structure as recommended above will help create the tools that teams need and want, the effectiveness of analytical solutions and engagement strategies cannot be measured on volume of tools launched. The adoption of these tools is the true indicator of analytics success, and can be measured by number of active users, tool access rates, or qualitative surveys.
9 Conclusion

The effects of the shift towards digital retail and integration of advanced manufacturing technologies are being felt across the enterprise. The user needs revealed through this research can be broadly applied to continued simulation development efforts, and the proof-of-concept simulations demonstrate the value of cross-functional supply chain simulations through enhanced strategic insight and communication. This thesis’ organizational process recommendations can be used to support rapid supply chain simulation development success, as well as development of other analytical tools.

Overall, the criticality of cross-functional collaboration will increase with the expanding significance of e-commerce and advanced manufacturing strategies. NIKE.com may evolve from a commerce platform to an all-encompassing athlete community, where the supply chain must deliver not only products but also user lifestyle experiences through connections to other consumers, businesses and organizations. Beyond using advanced manufacturing technologies for superior production of the current product portfolio, these technologies may eventually be used for customized, individually-tailored athletic performance pieces, requiring an even tighter connection between consumers and manufacturing and thus raising the bar on supply chain performance even further. Many future research opportunities exist for the LGO community and beyond to optimize the supply chain as its capabilities continue to grow, and to also enhance the speed of optimization through flexible simulation design processes and analytical methods.
11 References


Kremers, L. (2010). The link between supply chain and finance. *Supply Chain Asia*


