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Multi-Echelon Inventory Strategies for a Retail Replenishment Business Model
by
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Abstract

The mission of the Always Available retail replenishment business at NIKE is to ensure consumer-essential products are in-stock at retailers at all times. To achieve this goal, NIKE has developed a forecast-driven, make-to-stock supply chain model which allows retailers to place weekly orders to an on-hand inventory position in a distribution center. The challenge facing the business is how to design an inventory strategy that achieves a high level of service to its customers while minimizing inventory holding cost. Specifically, safety stock holding cost is targeted as it accounts for the majority of on-hand inventory and can be reduced without significantly impacting the underlying supply chain architecture.

This thesis outlines the application of multi-echelon inventory optimization in a retail replenishment business model. This technique is used to determine where and how much safety stock should be staged throughout the supply chain in order to minimize safety stock holding cost for a fixed service level. Provided a static supply chain network, the ideal safety stock locations and quantities which result in minimal total safety stock holding cost is determined. For this business, the optimal solution is to stage lower-cost component materials with long supplier lead times and high commonality across multiple finished goods at the manufacturer in addition to finished goods at the distribution centers. Safety stock holding cost reduction from component staging increases significantly when the distance between manufacturers and the distribution center decreases and for those factories producing a variety of finished goods made from the same component materials due to inventory pooling. Forecast accuracy drives the quantity of safety stock in the network. The removal of low volume, highly unpredictable products from the portfolio yields significant inventory holding cost savings without a detrimental impact to revenue. By deploying the optimal safety stock staging solution and by removing unpredictable products, this analysis shows that finish goods safety stock inventory would be reduced by 35% for the modeling period (calendar year 2012) while only decreasing topline revenue by 5%.

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1 Introduction

The purpose of this thesis is to describe the application of multi-echelon inventory optimization methodologies to a global apparel retail replenishment business. This research was conducted in conjunction with NIKE, Inc. (NIKE), a world leader in athletic apparel, footwear, equipment and accessories. This introductory chapter provides the necessary context for the reader to understand subsequent analysis, findings and recommendations. A synopsis of NIKE and the specific challenge addressed by this research, an overview of the goals and approach used, and a summary of the subsequent chapters of the thesis are presented.

1.1 Overview of NIKE, Inc.

Founded originally as Blue Ribbon Sports in January, 1964, NIKE has grown to be largest seller of athletic footwear and athletic apparel in the world. The firm's principle business is the design, development and worldwide marketing and sales of athletic footwear, apparel, equipment, accessories and services.¹ Headquartered in Beaverton, Oregon, NIKE's products are sold in nearly every country in the world through a combination of NIKE-owned retail stores and websites, third party retailers and independent distributors. The chart in Figure 1 plots NIKE's topline revenue from fiscal year 2008 to 2013, segmented by geography. Revenue has grown at a compounded annual growth rate of 6.3% over the past five years. Recent annual growth is approximately 10% and is expected to continue at that rate for the next few years.²

NIKE, like many of its peers in the footwear and apparel industries, relies nearly exclusively on contract manufacturers for the production of its products. As of

¹ NIKE, Inc. SEC Form 10-K filling, May 31st, 2013
² NIKE, Inc. SEC Form 10-K fillings and S&P CapitalIQ Estimates Consensus
August, 2013, NIKE contracted with 369 factories in 35 countries for apparel manufacturing and 107 factories in 12 countries for footwear. In total, NIKE's contract manufacturers employ nearly 900,000 workers on six continents.\(^3\)

**Figure 1: NIKE Inc.'s Total Revenue by Geography**

![Revenue by Geography Graph](image)

*NIKE separates its subsidiary brands, Converse and Hurley, from its geographic segmentation*

NIKE follows the traditional retail cycle of four selling seasons – spring, summer, fall and winter. Major new product introductions generally occur in the spring and fall seasons. The lifecycle of a product, as defined by both its style and color, varies from a single, three-month season up to 24 to 36 months.

### 1.2 Problem Statement

NIKE primarily offers its products to retailers and consumers using four distinct business models: Futures, Always Available, Quick-Turn, and Custom. Each of these

models is explained in detail in Section 2.1. This thesis focuses on the Always Available retail replenishment business model. Always Available allows retailers to order products weekly from NIKE. Enabling this replenishment capability is a forecast-driven, make-to-stock supply chain model where demand is fulfilled from an on-hand inventory position. The target replenishment lead time is one week from order receipt to delivery. Due to NIKE’s primarily off-shore manufacturing supply base, the company must take an inventory position of its products in a local distribution center (DC) to facilitate the one-week replenishment lead time. The target order fill rate service level, set by management, is 95%.

Currently, NIKE faces three key challenges with the Always Available program:

1. The target service level of 95% is not being achieved for all products due to stock outs.
2. On-hand inventory levels are high for certain products, leading to capacity constraints in the DCs and decreased profit margins due to product discounts during seasonal closeouts.
3. NIKE is able to stage inventory at different nodes in the supply chain, which creates the opportunity to reduce the total inventory cost required to achieve the target service level. However, the optimal staging strategy is unclear.

To summarize, the problem facing the Always Available business is how best to design its supply chain and inventory strategy to achieve a high level of service to its customers while minimizing the inventory holding cost required to do so.

### 1.3 Project Goals

The purpose of this research is to develop an inventory strategy that ensures a target level of service is met while minimizing the requisite inventory holding costs. There are three primary classifications of inventory – cycle stock, pipeline inventory
and safety stock. Cycle stock results from batch ordering and depends directly on how frequently orders are placed. Pipeline or in-transit stock is goods in-transit between echelons in the supply chain. Safety stock is inventory held to protect against uncertainty in supply and demand over the short run [1]. Thus, the goal is to develop an inventory strategy which prescribes at which nodes and with what quantity safety stock should be staged to reduce the total cost of inventory required to achieve a target service level.

This thesis targets the minimization of safety stock for two reasons. First, safety stock constitutes the majority of on-hand inventory for NIKE, which is a result of the immense challenges in accurately predicting consumer demand behavior for athletic footwear and apparel and long lead times from off-shore manufacturing. Second, cycle and pipeline stock are an artifact of the reordering policies and physical supply chain network, which are both fixed. Safety stock, on the other hand, can be reduced without modifying these core supply chain attributes.

Safety stock minimization necessarily assumes a static supply chain network and set of products to assess inventory tradeoffs in the current state. A secondary goal of this research is to quantify the potential reduction in inventory by relaxing these constraints. Specifically, what is the benefit, in terms of safety stock reduction, of improved forecast accuracy through better forecasting techniques or the removal of difficult-to-predict products from the Always Available portfolio? How could the underlying supply chain network be modified to reduce the total safety stock cost?

1.4 Project Approach

The scope of the project is Always Available apparel products sold in the North American and European geographies in calendar year 2012. Apparel products and these two geographies constitute the majority of the Always Available business. The first step is to determine the demand-side characteristics needed to develop
inventory optimization models, including the specific products, demand forecasts and actual customer orders. The second step is to define the current-state supply-side attributes, which include the component material and finished goods source base, product bill of materials, lead times between nodes and component cost at each stage in the supply chain. Using these inputs, multi-echelon inventory optimization models are constructed in the Llamasoft Supply Chain Guru\(^4\) software environment, a tool used by NIKE for supply chain modeling and optimization. These models and their outputs result in the development of inventory staging recommendations. Further scenario analysis is performed to quantify the benefit of relaxing the current-state assumptions surrounding product set, forecast accuracy and the sourcing network.

1.5 Thesis Overview

This document is divided into nine chapters. Chapter 2 provides a detailed description of supply chain operations at NIKE, focused specifically on the Always Available business. Chapter 3 reviews relevant academic literature and analytical tools utilized during this project. Chapter 4 presents the thesis hypothesis. In Chapter 5, a concept model is used to explore the fundamental behaviors of multi-echelon inventory optimization. The model is then scaled to include all products in Chapter 6. Chapter 7 outlines the key results and recommendations based on these models and subsequent analyses. Chapter 8 provides recommendations for implementation and areas for additional analysis. And finally, the conclusion of this thesis is presented in Chapter 9.

2 Supply Chain Operations at NIKE

To understand the supply chain structure of NIKE requires a foundational knowledge of NIKE's broader organizational structure. The company is organized into a three-dimensional matrix structure. The primary layer of the matrix is the geographies. The general managers of these business units have profit and loss responsibilities and oversee all activities within the region, including supply chain and distribution operations. The second layer of the matrix is the product engines, which are divided into footwear, apparel and equipment. These organizations are responsible for product design and creation, material sourcing, and finished goods manufacturing. The division into footwear, apparel and equipment is an artifact of the unique design and manufacturing characteristics of their specific product types. Figure 2 provides the fiscal year 2013 revenue split between the product engines, which has held stable at 64% for footwear, 30% for apparel and 6% for equipment.\(^5\) For the purpose of this thesis, only footwear and apparel will be explored further.

Historically, the geographies and product engines were the only dimensions of the matrix. However, in the 2000s, NIKE sought to better tailor its offerings to the holistic needs of their end consumer. A male runner, for example, will purchase a pair of running shoes from NIKE but may struggle to find apparel that adequately compliments the color scheme and overall look of his shoes. Consumers would shop across brands to assort their wardrobe even though NIKE offered a complete line of products. Further, the company recognized that, while few firms compete directly with the full breadth of the NIKE brand, many firms compete for specific consumer segments such as runners and basketball players. These competitors had gained market share by focusing their marketing and product creation efforts to the specific needs of the consumer in their target segment. The third layer of the matrix, dubbed the categories, was created in response. The purpose of the category structure is to align the product design, creation and marketing functions within a

\(^5\) NIKE, Inc. SEC Form 10-K filing, May 31\(^{st}\), 2013
particular consumer segment. The major categories, which span geographies and product engines, are Running, Basketball, Football (Soccer), Men's Training, Women's Training, Action Sports, and Sportswear. Figure 3 provides a breakdown of revenue by category for fiscal year 2013.6

Figure 2: Percent of NIKE Brand Revenue by Product Engine

The architecture of NIKE's organizational structure has a significant impact on inventory decisions and supply chain operations. Each decision from product creation through delivery to the end consumer affects each organizational entity and, as a result, requires alignment. For example, if a product engine wants to move a product from one factory in a given country to another factory in a different country, the geography is impacted by changes in lead times, inventory levels and potentially product cost. Further, the category is keen to ensure the new factory will not impact the ability of NIKE to deliver to the consumer for this specific segment, which could risk the competitive position of the firm.

6 Ibid.
In the following sections, NIKE's four business models are explained and the general structure of the supply chain is introduced. Then, the Always Available model is presented in detail, including a key modification of the supply chain architecture.

### 2.1 Overview of NIKE Business Models

NIKE utilizes four business models to supply retailers and consumers with product: Futures, Always Available, Quick Turn and Custom. The vast majority of revenue comes through the Futures and Always Available models. Quick Turn and Custom are a small but strategically significant source of growth for the firm.

#### 2.1.1 Futures Business Model

The Futures model at NIKE is a classic retail make-to-order business model. Its origin stems from the off-shored nature of the footwear and apparel manufacturing,
which inherently results in long product lead times. In the Futures model, NIKE solicits firm orders from retailers four to six months prior to delivery. NIKE aggregates these orders and transmits them to its contract manufacturing supply base. The contract manufacturers then procure raw materials, manufacture the finished goods and ship the products either to a NIKE DC or directly to retail customers. The benefits of the Futures model for NIKE and its suppliers are immense: NIKE has limited inventory risk as orders are firm, it has clear visibility into its near-term revenue and growth, and its suppliers have sufficient lead times to optimally procure, produce and deliver the products. Considering these benefits it is unsurprising that the majority of revenue for NIKE comes from Futures orders. In fiscal year 2013, 87% of wholesale footwear and 67% of wholesale apparel revenue came from Futures orders. These percentages have remained fairly stable over the past three years.7

Despite these benefits, the Futures model has shortcomings. Most notably, nearly all inventory risk is pushed to the retailer and demand for products must be predicted well in advance. If actual demand falls below expectations, the retailer is forced to close out the product at a discount, sacrificing profit margin. In some cases, NIKE will accept returns for certain types of products. On the other hand, if a product is selling well, the retailer may stock out, thereby disappointing consumers and sacrificing upside profit from lost sales. Both instances have a negative impact on NIKE. High discounts tarnish the brand’s image in the marketplace and hurt the profitability of NIKE’s retail partners whom the firm needs for market access. Stock outs lead to negative consumer sentiments towards the brand and, through lost sales, limit the revenue and profitability potential of the firm. To respond to these limitations, NIKE developed the Always Available replenishment model.

7 Ibid.
2.1.2 Always Available Business Model

The strategic imperative behind the Always Available business model is to ensure consumers have the product they want in their desired color and size when and where they shop. Accomplishing this goal requires a departure from the long lead-time, make-to-order Futures model. Rather, for the select category essential products offered in the Always Available portfolio, retailers place weekly orders to NIKE that are fulfilled from an on-hand inventory position in a DC. These products are typically long lifecycle, meaning the product design remains unchanged across multiple seasons, and ideally have low seasonality of demand. The term “category essential” means these are core, foundational products to a category. Put differently, in the case of a stock out of a “category essential” product, consumers are likely to substitute a competitor’s product. The Always Available business currently represents approximately 8-10% of NIKE’s total revenue. Figure 4 provides examples of typical Always Available products.

Figure 4: Representative Always Available Products

The Always Available business model provides a variety of benefits for retail partners. By shifting the inventory risk back to NIKE, retailers hold less inventory and can respond to fluctuations in demand more quickly. This results in fewer

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8 Author’s estimate.
markdowns and closeouts, leading to higher profit margins. Further, retailers are able to restock products that are selling quickly reducing lost sales. For NIKE, this replenishment model ensures its products remain in stock, thereby capturing higher revenue and serving as a competitor blocking mechanism.

2.1.3 Quick Turn and Custom Business Models

Though the Quick Turn and Custom business models are out of the scope of this thesis, they represent a strategically important portion of the business. Quick Turn is NIKE’s model for rapid response to marketplace demand, typically driven by key “sports moments” such as major sports championships, a significant achievement by a professional athlete, or other unexpected sports culture events. Most of the products in this business are tee shirts and professional or collegiate jerseys. For example, consumer demand will spike for a given NFL player’s jersey immediately after he has an outstanding game performance. NIKE would like to capitalize on this demand and ensure the appropriate product offerings are available in the marketplace. To enable this rapid response to major spikes in demand, NIKE has developed various near- and on-shore finishing processes to screen-print tee shirts or jerseys as a means for delayed differentiation.

The Custom business model allows consumers to design their own footwear and apparel based on a library of designs, materials, colors and patterns. Dubbed Nike iD in the marketplace, consumers use a web interface⁹ to select the base style and execute the customization, which NIKE will then manufacture and deliver to the consumer in a few weeks. This model capitalizes on the growing trend of individuality and customization in the retail space.

2.2 Overview of NIKE Supply Chain

As referenced in Section 1.1, nearly all of NIKE’s products are manufactured by contract manufacturers located throughout the world. Though the footwear and apparel supply chains are different in many regards, a single model can be used to understand the basic supply chain architecture at a macroscopic level. To illustrate the supply chain design, a pair of athletic training shorts will be used. Figure 5 captures the basic supply chain architecture for these shorts, including processes ownership within NIKE and inventory ownership for both NIKE and its retail partners.

Figure 5: NIKE Supply Chain Macro-level Structure for Athletic Training Shorts
In general, there are five echelons or layers in the supply chain – the supplier, manufacturer, distribution center (DC), retailer and consumer. Returning to the example of the athletic shorts, the supplied components include yarn and/or fabric, elastic for the waistband, drawstrings, decals, and tag materials. The transit lead times between nodes and production lead times at each node vary and depend on the geographic location of each node, the degree of vertical integration of the manufacturer, process technologies, transportation methods and capacity constraints. For the Futures business, a planning lead time of four to six months is used for the complete, end-to-end process.

NIKE divides the organizational responsibility for supply chain operations into two internal groups. The product engines are responsible for the sourcing of raw materials through the manufacturing of finished goods. Once the finished good is made and delivered to a third-party freight consolidator in the origin country for shipping, the supply chain organization within the geography takes ownership and is responsible for the product through to delivery to the end customer.

Inventory ownership is a crucial feature of this supply chain and factors heavily into the development of the multi-echelon inventory strategy. NIKE takes financial ownership of their products once the finished good is manufactured and sent to the consolidator. In the short run, the third-party suppliers are financially responsible for the product in all prior process steps. However, NIKE will take ownership of raw materials and finished goods work in process (WIP), either through formal transfer of products or payments made to suppliers, if these materials are not consumed within a negotiated period of time. For example, if demand falls below expectation after a season and the supplier has purchased excess raw material, NIKE will compensate the supplier directly.

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10 Not all of NIKE’s products flow through a DC or a third-party retailer. However, the bulk of NIKE’s wholesale business follows this general supply chain structure.
Within the finished goods manufacturing node for apparel, there are additional process steps that could be considered distinct echelons. However, these intermediary nodes are not crucial for the purpose of understanding the subsequent analysis in this thesis.11

2.3 Distinct Features of the Always Available Supply Chain

Recall from Section 2.1.2, the purpose of the Always Available business model is to ensure core, category essential products are available to consumers in their size, style, and color preference whenever they shop. To ensure product availability, NIKE replenishes retailer orders from an on-hand inventory position in a DC. Retailers can place orders throughout the season and NIKE targets a retailer replenishment lead time of one week.

NIKE uses the same physical supply chain network for its products, regardless of whether the product is offered through the Futures or Always Available business models. Indeed, all Always Available products are also offered through Futures. Only certain retail accounts have the need and technical sophistication required to utilize the replenishment benefits of Always Available. In practice, many Always Available retailers will use Futures orders at the start of a selling season to “load-in” their retail floors and will use the replenishment offering to “fill-in” products that are selling well throughout the season.

To enable rapid replenishment, NIKE has modified its standard, five-echelon structure to include inventory stocking nodes. These inventory positions in the supply chain reduce the effective replenishment lead time for their respective downstream echelons. This is the key difference between the Futures and Always Available supply chains. Figure 6 provides a diagram of a typical Always Available supply chains. Figure 6 provides a diagram of a typical Always Available supply chains. Figure 6 provides a diagram of a typical Always Available supply chains. Figure 6 provides a diagram of a typical Always Available supply chains.

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11 For a more thorough treatment of the intermediary manufacturing nodes in NIKE’s apparel supply chain, see Sections 2.3-2.4 of the MIT LGO thesis by Robert Giacomantonio, *Multi-Echelon Inventory Optimization in a Rapid-Response Supply Chain*, 2013.
supply chain network. The network structure is the same as presented in Figure 5 but now explicitly highlights the inventory stocking locations for raw materials and finished goods. The component material inventory position at the finished goods factory, called Material Staging in NIKE lexicon, consists of staged input components. The finished goods inventory position at the factory, dubbed Demand Pull, are completed products held at the factory. The third inventory node is the finished goods held at the DCs located in each geography – Memphis, TN for North America and Laakdal, Belgium for Europe.

Figure 6: NIKE Always Available Supply Chain Macro-level Structure
3 Literature Review

A significant body of research has been performed to study this problem of how best to achieve a target service level in a make-to-stock business model while minimizing the requisite amount of safety stock, and inventory holding cost, through staging inventory in the supply chain. This chapter is divided into two sections. The first explains the item fill rate safety stock formula and highlights the key drivers of safety stock. The second section summarizes techniques for minimizing total safety stock through multi-echelon staging.

3.1 Safety Stock

As described in Section 1.3, there are three main classifications of inventory:

1. Cycle Stock: on-hand inventory that results from batch ordering. Cycle stock is driven by the governing inventory policy set by the company, which in turn dictates the reordering frequency. NIKE uses a modified base-stock policy with a one-week review period. Each week, the total inventory position (on-hand in the DC plus in-transit) is compared to forecasted demand. The magnitude of the order placed is the forecasted demand for the week following lead time, less any forecasted excess inventory for demand during lead time. For example, if lead time is three weeks, the order placed would be expected demand for week four less expected excess inventory during the prior three weeks. For reasonably stable demand, average cycle stock is 3.5 days of sales.

2. Pipeline Stock: inventory in-transit between supply chain echelons. For NIKE, this consists of finished goods inventory between the finished goods factory and the DC. Components in-transit between suppliers and the finished goods manufacturer are generally not included in inventory calculations. In steady state, pipeline inventory will be equal to the expected
demand during lead time. In terms of days of sales, a lead time of 30 days results in 30 days of pipeline inventory.

3. Safety Stock: inventory held to account for uncertainty in supply and demand in the short run.

To determine the required safety stock to achieve a target service level for a periodic review inventory policy, the following equation can be used

\[
\text{Safety Stock} = k \times \sigma_L
\]

where \( k \) is the safety factor and \( \sigma_L \) is the standard deviation of demand during the sum of the lead time and review period. Assuming normalcy in forecast error, \( k \) can be derived using the unit normal loss function \( G[k] \),

\[
G[k] = \frac{E[D_{\text{LeadTime}}]}{\sigma_L} (1 - IFR)
\]

where \( E[D_{\text{LeadTime}}] \) is the forecasted demand during the lead time and \( IFR \) is the target item fill rate. The standard deviation of demand over lead time, \( \sigma_L \), takes the form [2]:

\[
\sigma_L = \sqrt{E(L)(\sigma_D)^2 + (E(D))^2\sigma_{\text{LeadTime}}^2}
\]

where\(^{12}\)

\( E(L) \) = expectation, or mean, lead time
\( \sigma_D \) = root mean square error (RMSE) of forecasted demand over a unit time period (e.g., one week)
\( E(D) \) = expectation of demand over a unit time period (e.g., one week)
\( \sigma_{\text{LeadTime}} \) = standard deviation of lead time.

\(^{12}\) This formula assumes demand and lead time are independent random variables.
As evident from these equations, the required inputs for safety stock calculations are:

- Demand forecast
- RMSE of demand forecast
- Expected supply lead time
- Standard deviation of supply lead time
- Target item fill rate (IFR)

### 3.2 Multi-Echelon Inventory Optimization Techniques

The question of where to stage safety stock to minimize total inventory cost while maintaining a fixed service level has been studied at length. Simpson [3] proposes a methodology for determining where to stage in-process inventory for a serial supply chain utilizing a base-stock manufacturing processes. In the decades since, a variety of research has expanded on this foundation. Graves [4] offers a comprehensive review of the subsequent literature on safety stock in a manufacturing environment and proposes a new modeling paradigm that removes the rigid constraints on production flexibility. Masse [5] provides an additional summary of relevant, more recent literature on the specific question addressed by this thesis.

Graves and Willems [6] introduce a method for modeling safety stock in a supply chain that is subject to forecast uncertainty. This framework and related optimization algorithm are used by a variety of commercially available safety stock optimization software and form the analytical basis for this thesis. Subsequent research, including Graves and Willems [7] and Schoenmeyr and Graves [8], expand this approach to include non-stationary demand and evolving forecasts.
4 Hypothesis

The preceding sections provide an overview of NIKE’s corporate structure and supply chain operations and introduce the key literature related to the question being addressed by this thesis. With this background, a series of hypotheses can be made.

As introduced in Section 1.3, three key questions drive this research:

1. Given the extant NIKE supply chain architecture and portfolio of products offered through the Always Available model, what is the best multi-echelon inventory staging strategy that achieves a target item fill rate while minimizing total system safety stock cost?
2. What is the value, in terms of safety stock reduction, of reducing systemic forecast error, either by improving forecast accuracy or removing difficult-to-predict products from the portfolio?
3. How can the underlying physical supply chain network be modified to reduce total system safety stock cost?

Based on these questions, three hypotheses will be explored:

1. Multi-echelon safety stock staging will reduce the total finished goods safety stock in the distribution center and will decrease the total system safety stock cost. However, the value of staging will depend heavily on the relative lead times between nodes and component material commonality across products sourced from the same factory.
2. Decreasing total portfolio forecast error through improved forecast accuracy or the removal of difficult-to-predict products will significantly reduce safety stock requirements and, ultimately, decrease total inventory in the system.
3. Regardless of staging strategy, producing finished goods closer to the final destination will reduce total system safety stock. Implementing component staging at these near-shore factories will amplify the reduction in total system safety stock cost.

5 Multi-Echelon Inventory Optimization – Concept Model

A simplified supply chain architecture illustrates the core dynamics of multi-echelon inventory optimization. Specifically, the supply chain model for a pair of athletic training shorts introduced in Section 2.2 can be used. In this chapter, a mathematical framework to minimize overall safety stock value given a specific target item fill rate, based on Graves and Willems [6], is introduced and applied to this representative supply chain architecture. An Excel implementation is detailed. The results of this model, including the optimal solution of staging components at the finished goods manufacturer, are explored. Finally, limitations to this modeling approach are addressed.

5.1 Inventory Modeling

Graves and Willems [6] propose a methodology that models a supply chain as a network of nodes. Each node represents a distinct step in the manufacturing and distribution process. For NIKE, these nodes are stages in the supply chain. The purpose of the algorithm is to determine the quantity of safety stock to stage at each node which minimizes total system safety stock cost while achieving a target service level. The detailed explanation and application of the algorithm in the subsequent sections is based on their original paper and Masse [5].
5.1.1 Inputs and Assumptions

To translate a complex supply chain into a series of mathematical equations necessary for modeling, a number of key assumptions about supply chain inputs and dynamics must be made.

**Lead time**
Both transit lead times between nodes and process lead times within a process step are assumed to be known and deterministic. In reality, this is rarely the case as there is variability in shipping, receiving, order processing, and manufacturing. However, data on lead time variability was unavailable at the time of this research. For the purpose of this concept model and subsequent full-scale models, the planned lead times set in the MRP systems at NIKE are used. While these values are likely to be an upper-bound of true transit and processing lead times, they are consistent with NIKE's overall planning paradigm and will be leveraged in any large scale implementation of multi-echelon inventory optimization.

**Customer Demand Variability**
In the apparel retail industry, customer demand is notoriously difficult to predict. Both consumer preferences and product designs change frequently. Further, for the Always Available business, demand manifests as orders placed by retailers to NIKE's DCs. As is the case in supply chains lacking perfect coordination, these orders are batched based on the retailers' internal processes and do not necessarily reflect true consumer demand over time.

NIKE uses a commercially available statistical forecasting and planning software, Logility's Voyager\(^{13}\), to develop monthly demand forecasts. This software uses a variation of the Holt-Winters exponential smoothing method to predict future demand based on past actual and forecasted demand. The tool then generates seven

forecasted monthly demand values, one for each of the six months leading up to the
target business month and a forecast during the actual business month.

To generate a forecast error value used for safety stock calculations, the six-month-
ahead forecast is selected based on administrative lead times required for securing
materials and factory capacities. The root mean square error (RMSE) based on 12
months of forecast and actual sales data is used. The RMSE has the form

\[
\sigma_{\text{Forecast}} = \sqrt{\frac{1}{n} \sum_{t=1}^{n} (x_t - f_{t-y,t})^2}
\]

where

\( \sigma_{\text{forecast}} = \) forecast standard deviation
\( n = \) number of forecasted periods (\( n = 12 \))
\( x_t = \) observed demand for period \( t \)
\( f_{t-y,t} = \) forecasted demand for period \( t \) made in period \( t-y \) (\( y = 6 \))

This calculation is performed at the SKU level, meaning product style and color but
not size. Forecasts are not generated for specific sizes; rather, a size curve is
applied.

**Unconstrained Stocking Nodes and Processing Characteristics**
The model makes the broad assumptions that each stocking node has unconstrained
capacity for holding inventory and that processing and transit times are invariant to
the quantity of product in each process step. It also does not account for loss, either
through inventory shrinkage or yield loss in the manufacturing processing. These
assumptions are reasonable for the purpose of the research questions being
addressed.
5.1.2 Methodology

The model treats each process step as a distinct process node. The nodes are then arranged into a tree system, representing the entire bill of materials (BOM) for a product. Figure 7 presents a tree representation of the original supply chain structure for the athletic shorts.

Demand is fulfilled from the DC node (right side of diagram) with an assigned service time, which is the time the customer is quoted from order placement to receipt. Working upstream from the DC node (right to left), each successive node is assigned a guaranteed service time to its downstream node and an inbound service time from its upstream node. Demand for the downstream node must be completely fulfilled within the guaranteed service time. The inbound service time is the time allowed for the supplier(s) to obtain and deliver the necessary input components. Safety stock is located at each node to account for the peak demand likely to occur over the net lead time of that node. The process is repeated until all nodes are assigned the required safety stock to cover peak demand. The optimal solution is the lowest cost assignment of safety stock across the entire supply chain that satisfies the peak demand requirement. Not all nodes necessarily require safety stock, as will be explained in more detail.
Formally, the objective function for the optimization is:

\[
\min \sum_{j=1}^{N} h_j \left( D_j (S_{I_j} + T_j - S_j) - (S_{I_j} + T_j - S_j) \mu_j \right)
\]

Subject to

1. \( S_j - S_{I_j} \leq T_j \) for \( j = 1, 2, \ldots, N \)
2. \( S_{I_j} - S_{I_i} \geq 0 \) for each pair \( (i,j) \), where node \( i \) directly supplies node \( j \)
3. \( S_j \leq s_j \) for all demand nodes \( j \)
4. \( S_{I_j} \geq 0 \) and integer for \( j = 1, 2, \ldots, N \)

Where

- \( h_j \) = unit inventory value at node \( j \)
- \( S_{I_j} \) = inbound service time to node \( j \)
- \( S_j \) = guaranteed service time of node \( j \)
- \( D_j(t) \) = is a function representing the maximum or peak demand over an interval of length \( t \) experienced by node \( j \)
\( T_j \) = the planned lead time or processing time of node \( j \)
\( \mu_j \) = average demand per time period experienced by node \( j \)
\( s_j \) = maximum service time for demand node \( j \)

At each node \( j \) in the supply chain, the assigned safety stock is the difference between peak demand, \( D_j \), and average demand, \( \mu_j \) over the net replenishment time for the node. The net replenishment time for the node is given by \( SI + T - S \). The optimization minimizes this safety stock quantity multiplied by the holding cost, \( h_j \), across all nodes in the supply chain.

The four constraints restrict the optimization to the feasible solution space given the design of the supply chain. The first constraint ensures that the net replenishment time (the summation inside of the parentheses in the objective function) for each node is non-negative. The second constraint requires node \( j \) to wait until all supply nodes \( i \) have delivered materials. The third constraint ensures the guaranteed service time for each node is less than the quoted service time for the end customer. The fourth simply ensures that all times are positive and integer units.

This formulation is a nonlinear optimization problem. Graves and Willems [6] provide a dynamic programming approach for solving it on a larger scale, which is the algorithm used by commercially available software such as Llamasoft’s Supply Chain Guru. However, for simple supply chain architectures, this algorithm can be implemented in Excel.
5.2 Model Implementation

To demonstrate the dynamics of multi-echelon inventory optimization, the athletic running shorts presented previously will be used. Figure 8 summarizes the supply and demand attributes of this product.\textsuperscript{14}

Figure 8: Demand and Supply Attributes of Athletic Shorts

<table>
<thead>
<tr>
<th>Demand-side Attributes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Monthly Demand</td>
<td>37,000 units</td>
</tr>
<tr>
<td>Monthly Forecast RMSE</td>
<td>7,800 units</td>
</tr>
<tr>
<td>Monthly Demand CoV</td>
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</tr>
<tr>
<td>Target Service Level</td>
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</tr>
<tr>
<td>Annual Inventory Holding Cost</td>
<td>20%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supply-side Attributes</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product and Staging Node</strong></td>
<td><strong>Product Value at Node</strong></td>
<td><strong>Monthly Inventory Holding Cost</strong></td>
<td><strong>Transit / Process Lead Time of Prior Node</strong></td>
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<td>Component A at Material Staging</td>
<td>$1.02</td>
<td>$0.01</td>
<td>2 days</td>
</tr>
<tr>
<td>Component B at Material Staging</td>
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<td>$0.00</td>
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<tr>
<td>Component C at Material Staging</td>
<td>$0.26</td>
<td>$0.00</td>
<td>28 days</td>
</tr>
<tr>
<td>Component D at Material Staging</td>
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<td>$0.00</td>
<td>46 days</td>
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<td>$0.03</td>
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<tr>
<td>Finished Good at DC</td>
<td>$5.80</td>
<td>$0.04</td>
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</tbody>
</table>

\textsuperscript{14} The bill of materials, product value, demand data and lead times have been changed to preserve confidentiality. However, they are representative of a typical Always Available product.
Two additional inputs are required to complete the model. First, the guaranteed demand service time, $s_j$, for customers is set to zero. NIKE targets an order to receipt lead time from its DC of one week. Because there generally is not enough time to receive an inbound shipment, process the order and ship to the consumer within the one-week window, the DC must fill all orders from an on-hand position. Second, the formula for peak demand per time period, $D_j$, is the average demand per time period plus safety stock. Section 3.1 provides an overview of the safety stock calculation using a target service level. Using this information and the formulation of the optimization model from Section 5.1.2, an Excel model can be built to determine the lowest-cost safety stock. This model, including formulas, is provided in Appendix A.

The Solver optimization engine in Microsoft Excel utilizes the General Reduced Gradient (GRG2) algorithm for solving non-linear optimization problems. This algorithm identifies the locally optimal solution for well-scaled, non-convex models. However, because it only guarantees local optimality, testing multiple initial conditions is required to ensure the solution space is adequately explored. This is a limitation of formulating this problem in Excel and large-scale implementation requires a more sophisticated optimization engine. However, for this simple concept model, the solution space is easily explored through manual manipulation of decision variables. This approach is described at length in Section 5.3.

5.3 Model Results

In effect, the optimization algorithm iterates through all possible staging scenarios to determine the lowest inventory holding cost solution. For this example with four component materials and finished goods staging at the factory, there are five

\[ 15 \text{ For the purpose of the Excel concept model, safety stock is calculated using the Type I service level methodology, where } k \text{ is simply the safety factor based on the unit normal distribution function rather than unit loss function. This simplification is purely for ease of implementation in Excel. Type II (or fill rate) service level is used in the Supply Chain Guru implementation.} \]
possible staging conditions resulting in 32 combinations of staging scenarios. The table in Appendix B displays the output of these 32 combinations.

Toggling between staging and not staging a given material at a given node impacts the net replenishment lead time. When a node stages safety stock, its guaranteed outbound service time goes to zero as it has enough inventory to cover peak demand. This translates to a zero inbound service time for that component at its downstream node. The net replenishment time for the downstream node will be the lead time between the upstream node and the downstream node. If the upstream node does not stage inventory, the net replenishment time for the downstream node is the sum of the service time between the downstream node and the upstream node (as before) and the upstream node's inbound lead time. The amount of safety stock held at a node is the $k$ safety factor multiplied by the standard deviation of demand over the net replenishment lead time.

Five specific inventory tradeoff scenarios are worth exploring in more detail to elicit deeper insights into the optimal staging strategy for NIKE's supply chain. The model results for these five scenarios – No Upstream Staging, Finished Goods Staging, Complete Material Staging, Staging at All Nodes, and the Optimal Staging Solution – are presented in Figure 9.
### Scenario 1: No Upstream Staging

<table>
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### Scenario 2: Finished Goods Staging

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### Scenario 3: Complete Material Staging

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### Scenario 4: Staging at All Nodes

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<td>$ 16.95</td>
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<td>****</td>
<td><strong>63470</strong></td>
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### Scenario 5: Optimal Staging Solution

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Under the No Upstream Staging scenario, all safety stock inventories are held at the customer-facing DC. The safety stock quantity at this node must buffer against expected peak demand over a net replenishment time of 82 days, which is the critical path lead time for the entire sourcing and production process. The critical path lead time is the sum of 46 days for the longest lead time component material, 25 days for finished goods production and 11 days of transit to the DC.

In the Finished Goods Staging scenario, the factory must hold sufficient safety stock to cover expected peak demand across a net replenishment lead time of 71 days,
which is the sum of the longest lead time component material (46 days) and production time (25 days). The DC now only holds enough safety stock to cover the transit time from the finished goods inventory position at the factory (11 days). Notably, while the quantity of finished goods safety stock in the DC decreases nearly 63% under this scenario due to the significant decrease in net replenishment time, the total quantity of finished goods safety stock in the system increases almost 30% and the total system safety stock cost increases 8.2%. Because safety stock is proportional to the square root of the lead time, separating the replenishment lead time across two serial nodes actually increases the total safety stock required in the system.16

Under the Complete Material Staging scenario, safety stock for all four component materials is held. This reduces the net replenishment lead time for the DC to the sum of finished good production lead time and transit lead time, or 36 days. The inventory holding cost of the safety stock staged in component form is significantly less than the finished good, as the value of the components is less than the value of the finished good. Therefore, the total safety stock quantity in the system, in terms of finished goods equivalent units, increases by nearly 270% compared to the No Upstream Staging scenario, but the total safety stock holding cost decreases by nearly 22%. In the Staging at All Nodes scenario, safety stock is held for all products at all locations. The net replenishment time to the DC is the same as Finished Goods Staging scenario whereas the time to replenish the finished goods position at the factory decreases to 25 days, which is the production lead time. The buffer of component stock staged at the start of production eliminates all additional component lead times. Again, because there is a net increase in finished goods safety stock in the system, due to the finished goods staged at the factory, the total safety stock cost is higher.

16 To clarify this mathematical relationship, consider a simple example: the square of 2 plus the square root 2 equals 2.83 which is greater than the square root of 4.
The Optimal Staging Solution stages three of the four component materials but no finished goods at the factory. In this scenario, cost is minimized to $633.23 per month, a 22.7% decrease from the No Upstream Staging scenario. The net replenishment time for the DC node is 38 days, which is the sum of the upstream transit time from the factory (11 days), the production lead time (25 days) and the lead time for the unstaged component material, Component A (2 days). The key difference between the Optimal Staging Solution and the Complete Material Staging solution is that Component A is not being staged. This results in a small difference of 1.2% in total safety stock cost. In effect, the incremental cost of staging safety stock for Component A, which results in a decline in the net replenishment lead time for the DC of two days, is equivalent to the difference in total cost between the two scenarios. Note that the value of Component A is significantly higher than the other constituent inputs. This results in a higher inventory holding cost per unit. The cost savings from the decreased quantity of safety stock at the DC, due to the reduction in the DC's net replenishment lead time by two days, is less than the increased cost of holding safety stock for Component A.

This fundamental tradeoff between the incremental cost of staging a component material and incremental savings from decreasing the quantity of finished goods safety stock held at the DC that results from this staging is at the core of multi-echelon inventory optimization. The algorithm determines where this tradeoff is minimized. Further, in the specific case of NIKE, staging finished goods at the factory always increases the total system safety stock cost. Splitting the inventory across two serial nodes increases the total quantity of finished goods safety stock in the system. The inventory holding cost difference between a finished good at the factory versus at the DC, assuming a constant percentage of product value, is not significant and does not justify staging more finished goods at an upstream node.
5.4 Model Limitations

Though this concept model of the athletic training shorts is useful for illustrating the fundamental tradeoff in multi-echelon inventory optimization, it has its shortcomings. Principally, this model is for a single style-color SKU. A typical factory will produce a variety of colors of a single product, as well as other products which share common BOM components. Therefore, the inventory pooling advantage of staging components used across SKUs is not being captured. Additionally, most products are made of significantly more than four components. The example athletic training shorts are actually made from 14 components sourced from nine different factories around the world. The BOM was simplified to four components purely for illustrative purposes.

6 Scaled Multi-echelon Inventory Optimization

Commercially available inventory optimization software packages provide a scalable environment for analysis and allow for more complex supply chain architectures to be modeled. NIKE has a relationship with the supply chain software firm, Llamasoft, and utilizes their supply chain network and inventory optimization software, Supply Chain Guru, to support strategic supply chain decision making. This chapter provides a brief overview of the software, explains the large-scale implementation performed for the Always Available business and presents the key model results.

6.1 Supply Chain Guru Overview

Llamasoft’s Supply Chain Guru is an integrated software platform that combines supply chain network and safety stock optimization. It also offers simulation
functionality. The tool has three components that make it attractive for enterprise-
level supply chain modeling. First, it has an intuitive user interface based on the
Microsoft Office environment. Input and output files are can be viewed and
manipulated in Microsoft Excel and Access formats. Second, the software includes a
large supply chain intelligence database, which includes a spectrum of reference
data, including geospatial mapping, transit costs, and emission data. Third, the
solver engine itself contains multiple integrated solvers, operations research
algorithms and simulation engines. The tool also includes a variety of graphical
outputs and easily allows for scenario analyses. For this research, the inventory
optimization package of Supply Chain Guru was used for large scale modeling and
analysis of the Always Available business. This package first solves the network
optimization algorithm to establish the underlying network architecture and
product flows and then uses a variant of the multi-echelon inventory optimization
algorithm developed by Graves and Willems [6] to determine the lowest-cost
staging scenario. The solver algorithm uses dynamic programming approach, which
alleviates the concern surrounding the GRG2 algorithm’s ability to find global
maxima and minima presented in Section 5.2.

6.2 Supply Chain Guru Implementation

To assess the opportunity of multi-echelon inventory optimization for the Always
Available business, the entire calendar year 2012 product line for the North
American and European geographies is modeled. Models are built at the finished
goods factory level of aggregation. In NIKE’s current supply chain structure,
component material is held at the finished good factory and is not shared across
factories. Further, purchase orders for each geography are administratively
distinct; therefore, though Europe and North America may source an identical
product from the same factory, the orders are treated separately and must be
modeled as unique products. For the North American geography, 27 finished-goods
factories in 12 countries are modeled with 289 finished good products (style-color).
For Europe, 19 factories in 8 countries, which supplied 131 finished good products, are modeled. The time period for the models is one month, meaning the output is safety stock quantity per month.

*Supply Chain Guru* uses a series of database tables, which can be constructed in Microsoft Access or Excel, as input files. For each factory, the following tables are created:¹⁷

- **Products table:** defines all the products in the system, including finished goods and components.
- **Bill of Materials (BOM) table:** establishes the relationship between finished goods and component products. If, in a single factory, a particular component is used in multiple finished goods, the BOM table contains a row for each component-finished good relationship.
- **Sites table:** contains the name and physical locations of the physical nodes in the supply chain (e.g., Supplier A, FG Factory B, DC).
- **Sourcing Policies table:** establishes linkages between the sites in the model and products that flow between the sites. For example, the DC must source finished goods from Factory A, which in turn sources component materials from Suppliers A-E. This table also contains the finished goods production lead time, which is set to 25 days based on internal planning data.
- **Inventory Policies table:** determines which products can be held in inventory at which site. Suppliers cannot hold inventory, Factories can hold components and finished goods, and DCs can only hold finished goods. This table also defines the product value at the specific site used in the inventory holding cost calculation and establishes the inventory reordering policy, which is seven days for the DC and 30 days for Factories. Suppliers are assumed to have infinite inventory.

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¹⁷ For a much more thorough explanation of the attributes of the input tables, see Giacomantonio, *Multi-Echelon Inventory Optimization in a Rapid-Response Supply Chain*, 2013 or the step-by-step manual for building models in the *Supply Chain Guru* environment provided to NIKE at the culmination of this research.
Transportation Policies table: defines the transit time and days between replenishment for a given product between nodes. For this implementation, transit times are static and based on internal planning times. Days between replenishment are based on NIKE’s general inventory policy (seven days for the DC and 30 days for Factories).

User-defined Demand table: provides mean quantity demanded and forecast error for each product for each month. The mean quantity demanded is the forecasted quantity for that month. The forecast error is the forecast RMSE described previously.18

Once these input tables are complete, the optimization algorithm is executed and the following output tables are generated:

Inventory table: an output of network optimization, this captures two of the three types of inventory in the system – cycle stock and in-transit inventory. When lead time variability is present a third field called the safety inventory is populated to capture the additional safety stock required. Lead time variability is not used in this research.

Safety Stock Details table: the key output from safety stock optimization. This table provides the safety stock quantity, cost and days of sales by scenario, month, site, and product type. It also provides safety stock cost, which is simply the inventory holding cost at each node (20% of the value of inventory at that node).

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18 More formally, the forecast RMSE is scaled by the Variance Law to better approximate the value used in Logility Voyager software. The Variance Law is an empirical relationship that accounts for variation in error as a function of volume. A full discussion of the Variance Law is outside the scope of this thesis.
6.3 Model Results

Based on the findings from the concept model in Section 5.3, the expected lowest-cost multi-echelon staging solution is to stage some components at the factory but no finished goods. Figure 10 plots the total monthly safety stock holding cost for all 289 products in North America during 2012 across three scenarios – No Upstream Staging, Finished Goods Staging (in the factory and at the DC) and the Optimal Solution. Staging finished goods at the factory is the most expensive solution due to the net increase in total quantity of finished goods in the system. This is the same result found in the concept model. The Optimal Solution results in staging some, but not all, component materials at the factory and finished goods in the DC. On average, Finished Goods Staging is 44.8% more expensive than the No Upstream Staging scenario while the Optimal Solution is 23.9% less expensive. Similarly, Figure 11 plots the analogous data for the European geography. The average cost increase for Finished Goods Staging is 46.4% while the savings in the Optimal Solution is 18.2% compared to the No Upstream Staging solution.

The Optimal Solution minimizes safety stock holding cost across the entire supply chain network. However, from a NIKE-centric view staging component materials but not finished goods at the factory is not necessarily optimal in the short-run. As described in the inventory ownership diagram presented at the bottom of Figure 5, NIKE does not take immediate financial ownership of inventory held on-site at the contract manufacturers. Therefore, in the short-run, the optimal solution for NIKE may be the solution which minimizes the amount of safety stock in the DC.
Figure 10: Monthly Safety Stock Holding Cost for North America by Staging Scenario

![Total System Safety Stock Holding Cost for the North American Geography](image)

Figure 11: Monthly Safety Stock Holding Cost for Europe by Staging Scenario

![Total System Safety Stock Holding Cost for the European Geography](image)
In Figure 12 and Figure 13, safety stock days of supply held in the DC is plotted over the same time scale by scenario for North America and Europe, respectively. Days of supply (DOS) is a metric where the safety stock quantity is divided by the forward forecasted demand. In effect, it conveys the number of days of projected demand that would be satisfied by the safety stock position. For both geographies, Finished Goods Staging minimizes this measure of inventory held in the DC. This same result was found in the prior analysis of the concept model. When finished goods are staged at the factory, the effective net replenishment time for the DC is decreased to the transit time between the nodes. Expected demand over this shortened lead time is lower and, therefore, the safety stock quantity decreases.

Figure 12: DC Safety Stock Days of Supply for North America by Staging Scenario
While the Finished Goods Staging solution may be ideal in the short-term, this strategy has significant flaws over the long term. First, the prior analysis has illustrated how staging finished goods at the factory actually increases the total quantity of finished goods in the system and the total holding cost for the system. Though NIKE does not have immediate financial ownership of this increased inventory at the factory, it must eventually accept this inventory at the end of the product’s lifecycle. This represents a significant inventory liability for NIKE. Absent perfect coordination and purchase order tapering, this will result in an increased quantity of product that must be cleared through retail channels, likely at a discount. This process erodes profit margin and has other negative impact on the brand. Second, many factories are not able to commit significant working capital to hold NIKE’s inventory. Third, these factories are not operationally equipped to warehouse significant inventories and the risk of shrinkage is high. Therefore, the Optimal Solution, which is the lowest cost across the entire supply chain, should be considered ideal.
Similar criticisms could be made for staging component materials at the factory. However, in practice, the relationship in this region of the supply chain is different. NIKE already takes an active role in the procurement of component materials on behalf of finished goods factories and generally is more financially invested in these materials earlier in the process. Further, these components have much longer lifecycles than the finished good products and the risk of needing to closeout components at the end of a season is lower.

6.4 Model Validation

To validate the outputs of the model, comparisons between inventory levels predicted by the model and actual performance should be made. However, this posed a unique challenge for a few reasons. First, about one half of the products offered through the Always Available replenishment program were staged upstream from the DC. Second, in the year prior and during this research effort, the Always Available supply chain did not use a forecast-driven safety stock inventory methodology for setting inventory positions in the upstream nodes when products were staged. Third, component staging at the finished goods factory is a relatively new capability for NIKE and, as such, only a handful of products were being staged.

Instead, a quasi-qualitative approach for validation was made. Comparisons between the No Upstream Staging scenario and the unstaged actual historical inventory quantities, the only directly analogous scenarios, were made. The model output predicted lower finished goods inventory at the DC for most of the products but much higher inventory positions for others. This discrepancy is primarily attributable to human interaction with the inventory planning system. Inventory planners at NIKE have the capability to manually adjust the safety stock positions and frequently do this based on additional information they receive from other parts of the business that is not captured in the forecasts. The resulting inventory position is thus decoupled from the calculated position driven from historical
forecast error. This conclusion was validated with a number of subject matter experts at NIKE and further explains why, in general, the total inventory positions were believed to be too high while stock outs were still frequent.

7 Key Results and Recommendations

The optimization models presented in the prior section lead to a number of findings related to the original hypotheses presented in Section 4. In this chapter, staging component materials is explored in depth to better understand which components should be staged and why. The role of the underlying supply chain network and the impact of reducing forecast error are explained. Finally, near- and long-term recommendations for improving the overall supply chain are made.

7.1 Staging Component Materials

From a total system perspective, staging component materials at the factory and finished goods at the DC is the lowest-cost multi-echelon solution. However, certain factories and products receive a greater benefit from component staging than others. There are three variables which drive the magnitude of the reduction in safety stock cost from staging component materials – distance from factory to DC, input component commonality across product families, and component cost.

Figure 14 is a scatter plot of the percent reduction in total system safety stock cost as a function of finished goods factory distance from the DC for North America in the Optimal Solution scenario. The general trend is negative, implying factories which are closer to the DCs have a more significant reduction in system safety stock cost as compared to those further away. A simple thought experiment illustrates this

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19 For this specific dataset, nearly all suppliers for Europe were located in Asia, which led to less differentiation between factory to DC lead times. A similar, though less pronounced relationship does exist in that geography.
Consider a factory in Mexico that has a seven-day transit to the North American DC and a factory in Indonesia with a 23 day transit time. Assume the input components are both coming from Southeast Asia, where the transit time from the component supplier to the factory in Mexico is about 20 days versus seven days for the Indonesian factory. Production time for both is 25 days. Recall that safety stock at a node is proportional to the square root of the net replenishment lead time for the node. Staging components at the factory in Mexico reduces the net replenishment time for the DC from 52 days to 32 days. Staging components at the Indonesian factory only reduces the net replenishment time from 55 days to 48 days. Eliminating the long component lead times for the near-shore factory yields a much greater reduction in DC replenishment time and, as a result, finished goods safety stock quantity and total safety stock cost as compared to off-shore factories. The value of multi-echelon inventory optimization, or staging components in NIKE’s supply chain, increases significantly as the distance between the DC and finished goods factory decreases.

**Figure 14: Safety Stock Reduction as a Function of Lead Time for North America**

![Safety Stock Reduction vs. Factory Distance](image)
A second driver of value for component staging results from the net inventory reduction due to pooling of common components. Most components for apparel products are shared across a variety of finished goods. At a minimum, there is typically more than one color of a given style, which means all components except the dyed fabric are common. Assuming independent forecast error for multiple products, the aggregated pooled safety stock components will be less than the sum of the individual safety stock quantities for a fixed service level. All else equal, a factory which supplies a large variety of finished goods composed of the same input components, such as fleece sweatshirts and sweatpants, will have a greater benefit from component staging than a factory which produces a more differentiated selection of products.

The third variable is simply the holding cost, which is a percentage of the product value at the node. All else equal, low cost components should be staged instead of high cost components. This is best illustrated by Component A in the concept model, where the high inventory holding cost negated the benefit of staging the material and reducing the net replenishment time by two days.

In summary, staging the right components at the finished goods factory minimizes the total system safety stock holding cost. Factories with shorter finished goods lead times compared to component lead times will receive the greatest benefit from staging. Further, large factories producing finished goods from common components yield even greater benefits. These two results have significant implications for how to modify the underlying supply chain architecture to take full advantage of component staging.

### 7.2 Reduction in Forecast Error

The *Supply Chain Guru* inventory models provide an environment for a variety of additional scenario analysis and hypothesis testing. One particular question relates
the impact of forecast accuracy on safety stock. At the time of this research, NIKE was undertaking an initiative to improve the statistical forecasting process in the Always Available business.

Figure 15 is a histogram of the monthly forecast error coefficient of variation (CoV)\(^{20}\) for the products in the North America Always Available business. The majority of products have a forecast error CoV that is less than or equal to one. However, approximately 14% of products (by product type) have error CoVs higher than one. A CoV greater than one indicates an error term that is larger, in magnitude, than the forecasted demand. These are incredibly difficult to predict products. As a result of this large error, a significant quantity of safety stock must be held to achieve the target service level.

The output from the inventory models can be used to determine the value of eliminating these highly unpredictable products from the Always Available portfolio and, instead, offering them only as Futures products. Figure 16 plots the revenue and safety stock impact of removing products with a CoV greater than one from the North America portfolio. The y-axis displays the percent of total Calendar Year 2012 revenue. The x-axis displays the percent of total safety stock held in the DC node. Under the No Upstream Staging scenario, where all safety stock is held at the DC, removing the 14% of products with a CoV greater than one leads to a decrease in total revenue for the Always Available business of 4.7% and a reduction in DC-held safety stock of 10.4%. Eliminating these products and implementing the optimal solution of component staging at the finished goods factory magnifies the reduction in safety stock to 34.4%. The value of excluding products with high forecast error, achieved either through removing them from the portfolio or improving statistical forecasting techniques for these products, is significant.

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\(^{20}\) Coefficient of Variation (CoV) is normalization metric defined as the forecast error divided by the mean forecasted quantity. For this analysis, monthly forecast error and quantities is used.
Figure 15: Histogram of Forecast Error CoV for Products in North America

Figure 16: Impact on Revenue and North America DC Safety Stock by Excluding Products with CoV > 1.0

Reduction in North America DC Safety Stock Inventory from Removing High CoV Products
7.3 Recommendations

The findings detailed in the prior two sections result in recommendations for how best to design a supply chain and inventory strategy for the Always Available business. These recommendations can be divided into near-term, current state actions that will yield immediate results and long-term, future state strategic maneuvers that will significantly improve the entire supply chain system.

7.3.1 Current State Recommendations

The lowest-cost multi-echelon inventory staging solution is to stage select long lead time, highly common component materials at the finished goods factory in addition to the necessarily safety stock inventory at the DC to cover customer demand fluctuations. Initially, component staging should be focused on near-shore factories or those factories which have the greatest discrepancy between finished goods transit time and component transit time. Further, these factories should be of large scale to take advantage of the pooling benefits that result from staging common components. The specific materials to be staged should be those of comparably low cost, highly common and with long supplier lead times. Finally, products that are difficult to forecast, or otherwise have high forecast errors, should be considered for removal from the portfolio of Always Available products.

7.3.2 Future State Recommendations

In the long-run, a number of actions can be taken which will meaningfully reduce the total inventory in the Always Available supply chain and improve the financial performance of the business.
**Forecast Error**

The relatively high forecast error for Always Available products is a key driver of high safety stock inventory, regardless of staging scenario. A number of actions can be taken to address this issue. Statistical forecasts should be generated for at least two seasons prior to adding a product to the Always Available offering. This allows planners to understand the demand dynamics of the product and adjust their forecasts accordingly. Based on this “pre-forecast” and the resulting error, a decision can be made whether the product should be added. For example, a new forecast error metric based on the forecast CoV could be created. If a product has an error higher than certain threshold, such as greater than one, during the “pre-forecast” period, additional management scrutiny would be triggered prior to its addition to the portfolio. Further, products should be monitored on a continuous basis. Those that exhibit high forecast errors would be candidates for removal. Finally, forecasting methodology should be continuously reviewed and improved. Best in class forecasting is a collaborative exercise which combines analytical insights and individual expertise from organizations across the business. Not only should the algorithms be continually refined based on performance, mechanisms that incentivize collaboration, information sharing, and after-action review within the business and with retail and supply partners should be created.

**“Core” Factory Approach**

A second area for significant improvement surrounds the assortment of the product portfolio and the manufacturing source base. The key differentiator for the Always Available program is the opportunity for retailers to more flexibly, and more profitably, react to consumer demand for a set of core product types. The supply chain design is the primary enabler of this offering. One recommendation would be to target a core set of finished goods factories which are prime candidates for component staging – operationally mature, relatively near shore, and high volume, supplying products with a highly common bill of materials. These factories can be focused on a specific apparel segment, such as base layer, fleece, t-shirts, or socks. NIKE would develop a partnership with these factories to establish their operational
capabilities for component staging and inventory control. In return for the factory’s investment in these skills, NIKE would enter longer-term contracts to ensure production is not moved season to season. Committing to a factory for multiple seasons is also necessary to gain the benefit of component staging, as the value of material staging is lost if products are moved season to season. Finally, as products are added and removed from the Always Available portfolio, preference should be made towards producing these products in the core finished good factory partners. Once the organizational processes are established and a track record of successful execution is in place, the model can be replicated at additional factories.

**Product Design**

The supplier lead time of component materials drives the safety stock quantity to be staged. Further, component commonality amplifies the cost reduction from component staging. Both of these factors should be considered during the product design process for products which may be offered through the Always Available model. This idea, design with the supply chain in mind, can take many forms. In the most extreme case, designers could be limited to a pre-set pallet of components and materials which are ideal for inventory staging. At the other end of the spectrum, designers could simply be informed of the supply chain impacts of their design decisions and persuaded to consider alternative components or materials which may have shorter lead times or are more commonly used in other products. NIKE provides similar information to designers about the environmental impact of their material selections through the NIKE MAKING smartphone application.21

Product design and innovation are at the core of NIKE and any action to constrain the designer’s creativity should be heavily scrutinized. However, in the case of Always Available products, the successful execution of the supply chain is as critical as the design of the offering. Allowing the supply chain to influence the design

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process without placing detrimental limitations on the creativity and innovation core to the company should be explored.

Integration with the Futures Business

An implicit assumption to the modeling and analysis performed in this research is that the Always Available business exists in isolation. In reality, every product in the Always Available portfolio is also offered to retail partners through the traditional future business. Additional colors of the exact same product offered in Always Available are through Futures, as well. The majority of components which would be staged under the ideal multi-echelon solution are used in these more seasonal products. Integration of component staging with the Futures business achieves significant benefits for both business models. Inventory pooling, and the reduction in aggregated safety stock that results, is amplified as more products are produced from the same set of common components. Lead times for the Futures business would be reduced, thereby creating the opportunity to respond to spikes in demand for seasonal products apart from the specific Always Available offerings. While the execution of this integration is challenging, the potential benefits are substantial and worth exploring further.

8 Implementation Methodology

This research identifies the lowest-cost inventory staging strategy for achieving a target service level for the Always Available business. Organizational alignment is crucial for realizing the benefits of this strategy. Once the benefits are proven in a pilot setting, the strategy can be expanded to more factories and product types, ultimately netting benefits across the Always Available and potentially Futures businesses. This chapter provides a discussion of the critical organizational aspects required to implement the component staging strategy and an example pilot
implementation. Broader applications of the findings from this research are also explored. Finally, additional areas of analysis are introduced.

8.1 Align Product Selection and Sourcing Strategies

Successful implementation of the inventory strategy outlined in this research relies on the coordination and alignment of disparate groups within NIKE. Supply chains are inherently integrated systems which cut across the entire firm. At NIKE, all stakeholders must have the transparency to quantify tradeoffs, understand the impact of their decisions, and share information with their partners, both internal and external. The strategy developed through this research highlights areas that require specific attention.

Each organizational element – product design, the product engines, and geography supply chain / demand planning groups – should recognize how their function impacts the rest of the supply chain. The materials selected by the product designers directly impact the ability to profitably stage components. The lead time to the DCs, dictated by the factory selection made by the product engines, has a huge influence on the quantity of safety stock which must be held. Further, moving products season to season to minimize FOB cost eliminates the benefits of component staging and may increase the total inventory in the system, both of which may ultimately raise the total landed cost of the product for the company. Demand planning, and the ability to forecast demand accurately, significantly impacts the quantity of safety stock required. Each piece of the value chain must be aligned to obtain material benefits from a multi-echelon inventory strategy.

Inherently, models such as the ones developed as part of this research are simplified approximations of reality. To best test the results of this research, a pilot implementation is recommended. NIKE should identify a class of products, such as base layer apparel, which is a strong candidate for component staging. Based on the models, a factory partner should be identified who has the financial stability and
operational maturity to build a robust component staging program. NIKE should commit to this program with this factory for multiple seasons. Some of the key lessons to be learned include how best to propagate demand forecasts and safety stock information to each node in the supply chain, which components can actually be staged effectively compared to the model's recommendations, and how the component staging for Always Available impacts the Futures business. Once the processes have been established and the benefits of staging quantified, the program can be expanded to other classes of products. The optimization models are useful for identify which factory and products will yield the greatest benefits from component staging. However, they do not capture the sourcing organization's business sense and experience, which is required for successful execution of the strategy.

8.2 Broader Applications

The findings of this research and the dynamics of multi-echelon inventory optimization that have been presented are not unique to NIKE's Always Available business. Rather, the core findings are universally true. Relative lead times between each echelon and the value of the product at that echelon are the key drivers for staging decisions. Due to the long transit lead times for off-shored manufacturing, staging products at the factory will always increase the net quantity of inventory in the supply chain, despite reducing the quantity held in the local distribution centers. In the optimal solution, inventory is held upstream from the major value-added step in the manufacturing process. For textiles and footwear, this is at the component level immediately prior to finished goods manufacturing. Finally, the value of multi-echelon inventory staging improves significantly when the final factory to DC transit time is reduced and multiple products can be made from the same pool of components.
The high markups typical of apparel and footwear products result in a skewed tradeoff between lost sales and inventory costs. The cost of inventory is significantly smaller than the lost profit from a stock out. From a theoretical viewpoint, this implies that the target service level should be close to 100%, meaning the amount of safety stock and total inventory in the system should be nearly unconstrained. For other business reasons, NIKE has selected 95% as the target service level (fill rate) for all products. However, regardless of the methods used for defining the service level, staging components at the factory will help reduce the total inventory cost.

8.3 Additional Areas of Analysis

A variety of assumptions were made throughout the modeling of NIKE’s supply chain due to data availability constraints. To develop more accurate models and implement multi-echelon inventory optimization at an operational level, additional data and analysis is required:

- Transit lead times: collect and analyze historical data of actual transit times between all nodes to determine mean and variability.
- Product lead times: collect and analyze historical data of actual production time and assign the specific mean and variability of production time to each unique factory.
- Forecasted and actual demand at a more granular aggregation: the current models use monthly forecasts and actual sales to develop forecast error values for modeling. For more operationally-focused efforts, forecasts should be made at the weekly level and actual sales should be based on specific sales order and purchase order data.
- Temporal impacts on forecasting: the current models assume the six-month-ahead forecast is the best metric for measuring error and setting safety stock throughout the supply chain. However, forecast accuracy should improve
over time and the error for setting safety stock at each node should capture this improvement. The analysis should look at forecast evolution over time and determine which error value should be used for each node.

- Inventory holding costs: more accurate values of inventory holding costs at each node will improve the accuracy of the inventory versus lead time reduction tradeoff.

Beyond improving the optimization models, this data will also allow for robust simulation of the potential solutions, allowing for further comparisons and sensitivity analysis. Under the assumptions used in this inventory optimization, all possible solutions will achieve a 95% service level when demand is approximately normal. However, the true demand NIKE experiences is often erratic compared to the forecast. Some staging solutions, which may not be optimal under the normal demand assumptions, will react better to erratic demand signals. Moreover, certain staging solutions such as Finished Goods staging may recover much more quickly in the instance of a stock out. A model which uses supply-side dynamics with historical demand forecasts to set an inventory staging policy and then uses actual demand history to simulate the supply chain performance should result in additional insights into cost and service tradeoffs between inventory staging scenarios.

In addition to further data analysis and simulation of supply chain models to determine the ideal inventory staging solution, exploring the potential value of flexible production capacity would be useful. Ultimately, the Always Available business is seeking the lowest-cost method to fulfill stochastic demand for NIKE’s products. The approach used in this research focused on inventory reduction through multi-echelone staging and implicitly assumed static, pre-planned production capacity. A complementary means for meeting demand while reducing cost and inventory would be flexible production capacity. To truly react to changes in demand requires both staged inventory as well as flexible, unassigned capacity at the factory to produce the products as they are needed. Additional analysis could be
performed to quantify the benefit for reserving capacity early and then deploying that capacity as needed throughout the year, thereby reducing the production lead time substantially.

9 Summary and Conclusion

The Always Available business model offers retailers the opportunity to capture increased revenue and profit by better reacting to customer demand. To achieve this outcome, NIKE allows retailers to replenish their offerings throughout the selling season, thereby netting demand upside and reducing the product discounts needed to clear excess inventory. NIKE uses a forecast-driven, make-to-stock model to enable this offering. The purpose of this research was to determine the ideal multi-echelon inventory staging strategy which achieves a target service level while minimizing the total system safety stock holding costs.

Based on the inventory modeling and optimization techniques outlined in this thesis, the ideal inventory strategy of staging select component materials at the finished goods factories is established. By removing the long supplier component lead times, the total system safety stock holding cost is minimized. The ideal candidate factories for component staging have relatively short finished goods to DC lead times compared to supplier lead times and supply a large quantity of finished goods composed of the same components. The ideal candidate components are lower-cost and used by a large number of finished goods. Forecast error has a significant impact on the total quantity of safety stock and efforts to reduce the error in the portfolio, either by improving forecasting techniques or eliminating unpredictable products, will result in significant reductions in safety stock.

Implementation of this strategy requires coordination across the entire value chain, including product design, sourcing and manufacturing, distribution and demand
planning. A pilot implementation focused on key factory and product family will highlight additional challenges and opportunities for cost savings that may be extended to other parts of the business. Additional data collection and analysis is necessary to fully operationalize the strategy outlined in this research. However, the benefits of multi-echelon inventory staging are immense.
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<th>Monthly Inventory Holding Cost at Node (20%)</th>
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<th>Outbound Guaranteed Service Time (Sj)</th>
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| Total Safety Stock         | $55116                          | $633.94                          | 45                                           |
|-------------|----------------------------------|-----------------------------|---------------------------------------------|-----------------------|--------------------------|--------------------------------------|------------------------------------|----------------------|--------------------|------------------|
| A           | 2                                | 1.022                       | =D11*(0.2/30)                               | 0                     | =F11+C11-H11             | =G11+C11-H11                        | =F11*NORM.S.INV($C$2)*$C$6*SQRT(11) | =J11*E11             | =111/SC5           |
| B           | 28                               | 0.45                        | =D12*(0.2/30)                               | 1                     | =F12+C12-H12             | =G12+C12-H12                        | =F12*NORM.S.INV($C$2)*$C$6*SQRT(12) | =J12*E12             | =12/SC5            |
| C           | 28                               | 0.26                        | =D13*(0.2/30)                               | 1                     | =F13+C13-H13             | =G13+C13-H13                        | =F13*NORM.S.INV($C$2)*$C$6*SQRT(13) | =J13*E13             | =13/SC5            |
| D           | 46                               | 0.16                        | =D14*(0.2/30)                               | 1                     | =F14+C14-H14             | =G14+C14-H14                        | =F14*NORM.S.INV($C$2)*$C$6*SQRT(14) | =J14*E14             | =14/SC5            |
| Finished Good at DC  | 11                              | 5.8                         | =D16*(0.2/30)                               | 1                     | =H15                     | =H15                                | =H15*F16                | =G16+C16-H16         | =16/SC5            |

Total Safety Stock = SUM(J11:J16) = SUM(K11:K16) = SUM(L11:L16)
## 10.2 Appendix B: Iterations of Multi-echelon Inventory Optimization Model

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11 References


